Proceedings of
a Symposium
at the J. Paul
Getty Museum,
April 1995

PROCEEDINGS

The Structural Conservation of Panel Paintings

The Getty Conservation Institute

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J. Paul Getty Museum

24–28 April 1995

Edited by Kathleen Dardes and Andrea Rothe

The Getty Conservation Institute
Los Angeles

Front cover: Alessandro Allori, *The Abduction of Proserpine,* 1570. Detail. Oil on panel, 228.5 × 348 cm. The J. Paul Getty Museum (73.PB.73), Los Angeles.

Back cover and page 305: Girolamo di Benvenuto, *Nativity,* ca. 1500, reverse. Tempera on panel, 204 × 161 cm. The J. Paul Getty Museum (54.PB.10), Los Angeles. The panel bears witness to the history of its conservation: This light, modern cradle was installed in 1987, after the removal of heavy, traditional crossbars (see page 187), traces of which are still evident. Strips of aged poplar, inserted to repair cracks caused by earlier restorations, can also be seen.

Page 1: Transverse surfaces of chestnut (*Castanea* sp.) (left) and poplar (*Populus* sp.) (right), showing pore structures.

Page 109: Illustration showing sawyers producing veneers; from J. A. Roubo, *L'art du menuisier* (Paris: Académie Royale des Sciences, 1769).

Page 187: Girolamo di Benvenuto, *Nativity,* reverse. A cumbersome, traditional cradle, installed around 1900 and removed in 1987, is shown.

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Foreword

In april 1995 the Getty Conservation Institute and the J. Paul Getty Museum sponsored an international symposium, "The Structural Conservation of Panel Paintings," at the J. Paul Getty Museum in Malibu, California. Initially the idea of Andrea Rothe, head of Paintings Conservation at the Museum, and enthusiastically supported by Kathleen Dardes, senior coordinator in the Institute's Training Program, the conference was attended by more than two hundred participants from some twenty countries, who gathered for five days of papers and discussions.

During pauses, participants were able to meet informally with old and new colleagues in the galleries and gardens of the Museum. This combination of formal and informal exchanges greatly encouraged the flow of ideas and contributed significantly to the success of the symposium.

The purpose of the symposium was to document the techniques, both traditional and contemporary, of panel stabilization. This book encompasses the wide range of topics covered by the speakers. After an introductory examination of wood characteristics, the papers go on to consider the technological aspects of wood, the history of panel-making techniques, and the various methods of panel stabilization that have been developed and refined over the course of many centuries. Indeed, as the reader will discover, many of the techniques described are the products of a long and venerable tradition developed by generations of master artisans, who then passed along an understanding of and sensitivity to the properties of wood. Other articles focus on the modern scientific and technical advances that conservation has made in the second half of the twentieth century—advances that have helped conservators solve, often by innovative methods, the most challenging structural problems.

In sponsoring this symposium, the Museum and the Conservation Institute hoped to contribute to a wider understanding of the historical, practical, and scientific aspects of panel stabilization. We are grateful to Andrea Rothe and Kathleen Dardes for the dedication they have shown in the organization of the symposium and in the publication of these proceedings.

Miguel Angel Corzo
DIRECTOR
The Getty Conservation Institute

John Walsh
DIRECTOR
The J. Paul Getty Museum

Preface

In addition to representing the aesthetic and intellectual sensibilities of their creators, the world's great paintings serve as rich historical documents. The close contact with these works of art that conservators and curators have long enjoyed allows access to their most hidden parts and, consequently, to a better understanding of the materials and working practices that are the underpinnings of artistic expression. For paintings are more than the manifestation of an idea or a creative impulse; they are also a composite of ordinary materials, such as wood, glue, canvas, metal, and pigments of various sorts, that have been put to a wonderful purpose.

Wood has served for centuries as a support for painting, largely because of its strength and availability. Paralleling the long history of wood as a painting substrate is an almost equally long history of attempts to control its behavior. An early recognition of the tendency of all wood species to deform under certain conditions has led generations of woodworkers to devise techniques, both varied and ingenious, to control the movement of wooden supports and its consequent damage to the paint layer.

However, even the most ingenious efforts on the part of panel makers to create strong painting supports were often overcome by the inherent properties of wood. In response to such problems, time has witnessed the development of various approaches—some now considered quite radical and intrusive—to the treatment of structural problems in panel paintings. Nowadays a more restrained approach is taken, informed by the ethical principles that guide the conservation profession, as well as by both the scientific knowledge and the tradition of craftsmanship that continue to nourish it.

It is important to understand the changes in thinking and practice that mark the evolution in the structural conservation of panel paintings. Many people skilled in the craft and traditions of panel repair and stabilization, however, have encountered few opportunities to pass their methods on to others beyond their immediate circle. Without a serious effort to document and present these methods to a wide professional audience, many of these approaches to the structural conservation of panels, and the rationales behind them, would be lost forever.

One of the editors of this publication, Andrea Rothe, recognized the need to make this type of information more accessible. This realization led to a series of discussions by staff of the J. Paul Getty Museum and the Getty Conservation Institute on how to bring to the attention of a wider audience the various working philosophies and methods, both traditional and contemporary, that have been used for the stabilization of painted panels. Working with an advisory group of experienced panel painting conservators from institutions in the United States and Europe, the Museum and the Institute developed the idea of an international meeting that would address a number of key topic areas of importance to a comprehensive treatment of this subject. These areas included aspects of wood science and technology relevant to wooden painting supports, historical methods of panel fabrication, and both historical and present-day approaches to the structural stabilization of panel paintings. The advisory group then identified the specialists best qualified to address these areas, including a number of craftspeople with long experience in panel conservation. Since many of these people had but infrequent opportunities to publish the results of their work or to participate in international conferences, their methods and techniques were not always known beyond their own workshops. It was the skills and accomplishments of these professionals that the symposium particularly wanted to document. We also wanted to afford these experts an opportunity for professional exchange with colleagues who had similar backgrounds and interests.

This symposium, therefore, was the first international gathering devoted specifically to the structural stabilization of panel paintings. Throughout the five days of the meeting, many different perspectives were presented and discussed. Some reflected the traditional, time-honored aspects of the panel conservation craft, while others were indicative of the scientific and technical strides panel conservation has made in recent years. It became clear to those attending the symposium that the modern conservator of panel paintings has at his or her disposal an expanding body of information and experience that melds traditional techniques, art-historical research, and scientific discovery.

The symposium set out to present the state of the art of the structural conservation of panel paintings. This volume, containing the contributions of the symposium's speakers, achieves our aim of making this information available to a wide audience of professional colleagues. We hope that it will also inspire further research and practical innovation in this area.

In addition to thanking the authors for their efforts with respect to both the symposium and this volume, the editors also would like to thank their colleagues at the J. Paul Getty Museum and the Getty Conservation Institute, most especially John Walsh, director of the Museum, and Miguel Angel Corzo, director of the Institute, both of whom have enthusiastically supported the goals of this project. Marta de la Torre, director of the Institute's Training Program, committed the program to the development of this project throughout its many phases, while Deborah Gribbon, associate director and chief curator at the Museum, supported the participation of the Museum's conservation and logistical staff. In addition, we would like to acknowledge the special contributions of Brian Considine, Valerie Dorge, Gordon Hanlon, and Mark Leonard. Sheri Saperstein assisted in the coordination of both the symposium and this volume with her customary flair, charm, and good humor.

The advice and guidance offered throughout the planning stages of the symposium by George Bisacca of the Metropolitan Museum of Art, New York; David Bomford of the National Gallery, London; and Ian McClure of the Hamilton Kerr Institute, Cambridge, are also reflected in these proceedings. For their assistance, we are very grateful.

In addition to the above, a number of other people lent their expertise as reviewers. These include Joseph Fronek, Los Angeles County Museum of Art; David Grattan and Gregory Young, Canadian Conservation Institute; Bruce Hoadley, Department of Forestry and Wildlife Management, University of Massachusetts, Amherst; Robert Krahmer, College of Forestry, Oregon State University; Paolo Mora, former chief restorer at the Istituto Centrale del Restauro, Rome; James T. Rice, Daniel B. Warnell School of Forest Resources, University of Georgia; Wayne Wilcox, Forest Products Laboratory, University of California.

Finally, we would like to thank Neville Agnew, associate director, programs, at the Getty Conservation Institute, for overseeing the various stages of the publication of this volume. Very special thanks are extended to the volume's managing editor, Tevvy Ball, whose fine eye and sure touch succeeded in taming a sometimes unruly manuscript. In this he was assisted by Sylvia Tidwell, who skillfully and scrupulously copyedited the manuscript; Elizabeth Maggio, Barbara Harshav, and Michelle Buchholtz, who assisted with translations from Italian and French; and Joy Hartnett, Scott Patrick Wagner, and Kimberly Kostas, who helped attend to the myriad details involved in preparing these proceedings for publication.

Kathleen Dardes
The Getty Conservation Institute

Andrea Rothe
The J. Paul Getty Museum

Introduction: Keynote Address

David Bomford

This symposium on the conservation of panel paintings, organized by the J. Paul Getty Museum and the Getty Conservation Institute, has created the conditions for one of those rare, defining moments in paintings conservation that are not always apparent at the time they occur. With a meeting and publication such as this, our disparate and far-flung profession has stopped for a moment, reflected on its contexts, its motives, and its actions, and then stepped forward with more unity and a better collective understanding.

At the last major conference to consider the treatment of panel paintings—the 1978 International Institute for Conservation congress "The Conservation of Wood in Painting and the Decorative Arts," held in Oxford—about one-third of the papers presented were on the theme of panel paintings. For the record, four of the speakers at that conference also have articles in the present volume.

Although the Oxford conference is often cited as the natural predecessor of this symposium, I have been reflecting more on a different week, in 1974, when the Conference on Comparative Lining Techniques took place in Greenwich, England. This was, without doubt, a key moment for our profession, as agreed by all who attended. For the first time, the history, ethics, and practice of the structural treatment of easel paintings (albeit on canvas) were debated in a straightforward and scholarly manner. After Greenwich, treatments could no longer be mysterious, unfathomable rituals rooted in the past. Traditional methods and craft-based skills still served as the basis of much good practice, but now these methods and skills had to be rational, explicable, and accountable. More important, the old automatism—the repeated major treatment of paintings for no other reason than habit—was no longer acceptable. In a brilliant keynote paper—still one of the wisest ever written about paintings conservation—Westby Percival-Prescott, the organizer of the Greenwich conference, spoke of the lining cycle—the relentless spiral of ever-increasing treatment and deterioration into which paintings can all too easily fall. He pointed out something so daringly radical, so threatening to all our livelihoods, that it produced a palpable sense of shock: *to do nothing* is often the best form of treatment. Today, when the notion of preventive conservation is taken for granted and advocating minimal intervention is common, when unlined paintings and untouched panels are prized beyond measure, it is difficult to recall just how often we intervened, even in the early 1970s.

The Greenwich conference was a landmark. It changed attitudes and set in motion a whole new rationalization for the treatment of paintings, establishing the policy that minimal treatment is best. It is also interesting to note that although a few of the authors in the present volume attended the Greenwich conference, only one actually presented a paper: this author is Andrea Rothe, who also delivered a paper at Oxford and whose original idea for a panel-conservation workshop resulted in this symposium and this proceedings volume.

Let us try to contextualize our theme of the structural conservation of panel paintings. During this symposium we shall be asking questions, considering choices, and describing actions. I shall begin by posing a simple puzzle to you: Let us say I have two groups of world-famous paintings. In the first is Titian's *Assunta* in the Frari, Botticelli's *Primavera* in the Uffizi, and Rubens's *Samson and Delilah* in the National Gallery, London. In the second group is Titian's *Pesaro Altarpiece,* also in the Frari; Botticelli's *Birth of Venus,* also in the Uffizi; and Rubens's *Garden of Love* in the Prado. What is the difference between these two groups?

Given the context of this symposium, the answer appears fairly obvious: the first group are all on panel, the second on canvas. But if we had asked the question at random of art historians or conservators not necessarily preoccupied with our subject, I imagine they might struggle for an answer and even then not be certain of all the facts. If we then produce another group of famous paintings—Raphael's *Foligno Madonna* in the Vatican, Leonardo's *Virgin of the Rocks* in the Louvre, and Pontormo's *Cosimo de' Medici* in the J. Paul Getty Museum—and ask what distinguishes them from the other two groups, the art historians and conservators might well be further confused—for these are all paintings originally on panel, now transferred to canvas.

Few individuals think about or are even aware of the structural basis of paintings. This lack of awareness of physical structure has serious implications for the few of us who take responsibility for these matters. A disregard for the nature of painting supports leads inevitably to a disregard for their importance or condition. Because practically no one monitors the versos of paintings, the responsibility for establishing guidelines for sound practice and observing those guidelines falls to us. It is inconceivable that the excesses of the early nineteenth century could ever be repeated—we only have to think of some four hundred Renaissance panels pointlessly transferred to canvas in St. Petersburg to realize the scale of it all—but it is incumbent on us to reach the same conclusions as those who met in Greenwich in 1974: our actions, great or small, must be logical, accountable, and ethical, bequeathing an honorable and defensible legacy to those who will care for paintings in the future.

I have mentioned that we are going to consider choices during this symposium. The papers at this symposium are loosely arranged in historical progression, beginning with the nature of materials and the making of panel paintings. Therefore, the first choices that we must consider are those facing the painters themselves. In general, the earlier panel painters operated within traditions that almost totally circumscribed their methods and materials. Perhaps because they were not aware of choice in the way that we now interpret the concept, they left few remarks to guide us. Nevertheless, there is much that can be learned from documentary sources and from examination of the works themselves that can inform us about the manner of their making.

Wood is, of course, an ideal material for movable paintings and altarpieces. It is strong, relatively light, and self-supporting. It can be planed smooth or carved in relief, and it is equally appropriate for the simplest of panels or the most fantastic of carved structures. Its resilience and autonomous strength can also be considered a long-term *disadvantage,* however, since both strengths allowed later predatory collectors to dismember great works into smaller, freestanding parts, beginning the process by which panel paintings have been scattered randomly and out of context in collections around the world.

Much recent technical research on early Italian altarpieces and other panel paintings has concentrated on reassembling (on paper, at least) the original sequences of now-separated fragments, such as those of Ugolino di Nerio's Santa Croce altarpiece, which are dispersed among collections in Berlin, London, and Los Angeles. The very nature of wood can be vital in this quest, as horizontal predelle and vertical registers of the great altarpieces were often painted on single, massive planks. To anyone who has bothered to look at the backs of such altarpieces in situ, this is a simple and obvious fact. However, only in relatively recent years have X rays been used to clarify the original structure of dismembered altarpieces by following wood-grain patterns through rows or columns of separated sections. X rays make it possible to reconstruct the widely scattered fragments of Ugolino's altarpiece into seven separate vertical units, each based on a massive poplar plank. The wood grain in these reassembled planks runs continuously from the tops of the pinnacle panels to the bases of the three-quarter-length saints. The predella, now separated into seven separate panel paintings, consisted of an enormous plank more than 4 m long.

X rays and visual examination also reveal the presence of irregularly spaced dowel holes down the sides of the seven vertical tiers; the holes—which only match up if the panels are correctly arranged—were clearly used to link adjacent planks. Faint batten marks on the backs of many of the panels indicate an original structural framework that supported the entire altarpiece. A stepped, or half-lap, shape at the side of each vertical plank suggests that the makers created the altarpiece so that it could be executed in separate sections and assembled in situ by pegging the planks and overlapping battens together. Remaining pieces of metal fixings on each vertical tier indicate the previous use of an overall metal strut to support the whole structure.

Deductions such as these, which bring to life the working methods of late medieval artisans, are vital if we are to understand works of art in context. These lines of research demand from each conservator of panel paintings that each join, hole, notch, nail, or mark on the backs and sides of panels, whatever its period or origin, be scrupulously preserved and recorded for the sake of future scholarship. As part of this symposium, conservators discuss the ethics of thinning panels and applying secondary supports—procedures that have, in the past, concealed or destroyed important evidence. Let us be sure in the future that not a single clue to the original structures of panel paintings is lost or concealed without adequate documentation.

Documentary evidence from the great ages of European panel painting—from medieval times to the Baroque—is somewhat sketchy. Some documentation is marvelously complete, such as the contract for a polyptych painted in 1320 by Pietro Lorenzetti for Santa Maria della Pieve in Arezzo, in which everything, from the subject to the materials and the structure, is precisely detailed. Other documents give us a brilliant, anecdotal immediacy, such as the financial accounts for Jacopo di Cione's San Pier Maggiore altarpiece (National Gallery, London) of 1370–71, in which the prices for the nails, eggs, pots, pigments, and gold are listed individually. This documentation even includes an entry that notes the charge for "taking and fetching the altarpiece to and from Santa Maria Nuova when it has been varnished." This record provides one of the few references in early Italian sources to the varnishing of painted altarpieces.

One of the most evocative of all documentary discoveries occurred in 1968, when some accounts were found in the state archive in Florence that provided information about the arrival in Florence of Hugo van der Goes's Portinari Altarpiece, the date of which had never been known for certain. These accounts detail the transport of the triptych by sea from Bruges via Sicily to Pisa, and then along the Arno to Florence, where it arrived at the San Frediano Gate on 28 May 1483. The documentation provides a vivid impression of the sheer size of the triptych and the physical difficulty of handling it: sixteen men were required to move it to its destination on the high altar of the Church of Sant'Egidio in the hospital of Santa Maria Nuova, where it was regarded as a marvel by all who saw it (it is now in the Uffizi). There is, incidentally, a technical curiosity about the portrait of the donor Tommaso Portinari on the left wing of the altarpiece. X rays reveal that it was painted separately on a sheet of tinfoil or parchment, which was then glued to the panel. Portinari left the Netherlands for Italy in 1477, before van der Goes had begun the wings of the triptych; apparently van der Goes insisted on painting a live study of his patron before Portinari's departure for Italy—and then incorporated the portrait into the triptych later.

Most documents are either of a legalistic or financial nature, or consist of practical treatises on the procedures of painting. Painting on wood at this period was the norm; there was little choice available. When wood as a material is mentioned at all, it is simply in terms of how to prepare it for painting. These documents occasionally mention the problems of wood—such as moisture, knots, and protruding nails—but the character of wood is seldom mentioned. Cennino Cennini is almost unique in referring specifically to different woods for different purposes. He recorded the use of poplar, linden, and willow for ancone or panels; boxwood for little drawing panels; maple or chestnut for brush handles; birch for drawing styluses; and nut, pear, or plum wood for boards on which to cut metal foil.

In general, though, available documentation provides meager information about painters' views of the wide variety of woods used for painting supports, or their attitudes toward the material qualities they exploited in making their art. Clearly, wood fulfilled many of the painters' requirements through its versatility as a medium—but was it the servant or the master of those who used it?

Such documentation does little to solve one of the recurring paradoxes of the history of painting materials: Did painters simply choose materials that fitted their perceived objectives, or did the nature of the materials themselves dictate the directions in which works of art developed? The safe answer suggests that the two notions are inextricably interdependent, although there are certainly moments in the history of art when the emergence or reassessment of materials seems to have determined subsequent aesthetic directions. Two such cases are the refined use of drying oils for painting in early-fifteenth-century Flanders, exploited by the predecessors of van der Goes, and the dependence of Impressionism on the new nineteenth-century pigments.

Perhaps the most famous myth of the whole technical history of painting involves the first of these two examples and a panel painting. Vasari wrote in his biography of Antonello da Messina of an occasion on which Giovanni da Bruggia (now known as Jan van Eyck) devoted the utmost pains to painting a picture and finished it with great care: "He varnished it and put it in the sun to dry, as was then customary. Whether the heat was excessive or the wood badly joined or ill-seasoned, the picture unfortunately split at the joints." Following this experience, van Eyck set about finding a paint medium that would dry in the shade, without the need of the sun, and that would be lustrous without any varnish. Hence he invented oil painting. "Enchanted with this discovery, as well he might be," Vasari continues, "Giovanni began a large number of works, filling the whole country with them, to the infinite delight of the people and immense profit to himself." The fact that this highly improbable legend is demonstrably untrue does not make it any less enjoyable, nor does it invalidate the premise that the material history of art and the connoisseur's history of art are closely intertwined.

The history of painting contains specific examples where the nature and limitations of painting on panel have affected the arrangement of a composition or, conversely, where the composition has dictated the structure of the panel. It is well known that painters avoided painting key components (such as faces) over panel joins, which risked coming apart. It is surely no coincidence that the faces of Holbein's two *Ambassadors* (National Gallery, London), recently restored, are carefully placed more or less centrally on two of the ten oak planks that compose the panel.

The artist's decision to paint on a panel becomes significant when there is a genuine choice to be made. From the later fifteenth century onward—and more rapidly in Italy than in northern Europe—convention increasingly allowed canvas paintings to have equal status with panel paintings. Consequently, convenience and lower cost led to greater use of canvas, especially for larger works. Many painters, however, used both canvas and wood. One of the great questions of the history of painting techniques is this: Why does a painter choose one support over another for a particular work? Why, for example, did Botticelli paint the *Primavera* on panel and the *Birth of Venus* on canvas? The works were probably both part of the same decorative scheme. Before the top of the *Birth of Venus* was cut, the works would have been the same size as each other—and also the same size as another work on canvas, *Pallas and the Centaur* (Uffizi Gallery, Florence). Botticelli painted the *Primavera* just before he left for Rome in 1481 or 1482, and he painted the two canvases just after he returned to Florence. Had he somehow been influenced in favor of canvas while he was away working in the Sistine Chapel? If so, he certainly reverted to panel after these two pieces, and continued to use panel for the great majority of his work.

We can ask the same question with regard to many painters over the next two centuries. While the answers would vary, the majority of choices would be, undoubtedly, pragmatic. We must never overlook practical or commonsense explanations for the ways in which painters worked or for the constraints of tradition within which they learned their craft.

Rubens and Rembrandt, for example, were equally versatile on wood and canvas, although they operated within a tradition that had hitherto favored wood for painting supports. In his Leiden and early Amsterdam periods, Rembrandt worked almost exclusively on wood, producing those beautifully wrought, surprisingly colorful small panels that established his reputation as a *fijnschilder* (fine painter). He continued to use panels throughout his career, but with the production of larger portraits and history pieces in the early 1630s, he increasingly chose canvas. This choice can be easily explained by practical or financial considerations. Apart from the existing tradition of using panels, they were easily available ready-made in a range of standard sizes from specialist panel makers. They were also much preferred for smaller-format pictures because they were self-supporting and needed only simple preparation. Since panels were more expensive than canvas, however, there came a point at which it was worthwhile to go to the greater trouble of stretching and priming canvas. In his down-to-earth discussion of the advantages of canvas in his *Inleyding tot de Hooge Schoole der Schilderkonst (Introduction to the High School of Painting),* Rembrandt's pupil Samuel van Hoogstraten wrote that canvas was "suited most for large paintings and, when well primed, easiest to transport."

Incidentally, while on the subject of seventeenth-century Dutch panels and of Rembrandt in particular, we must note the extraordinary success of dendrochronology (up through the seventeenth century) in clarifying dating problems. Tree ring analysis can also give spectacular confirmation that certain panels have come from the same tree. For example, *The Woman Taken in Adultery* of 1644 (National Gallery, London) and the *Portrait of Herman Doomer* of 1640 (Metropolitan Museum of Art, New York) have the same structure, as does the panel to which the 1634 canvas painting *Saint John the Baptist Preaching* (Staatliche Museen zu Berlin, Preussischer Kulturbesitz, Gemäldegalerie) has been affixed—proof that the third painting was also done in Rembrandt's studio. Nor can the dendrochronologist ignore wider aspects of European history. Peter Klein recently reminded me of a long-forgotten war between Sweden and Poland in the late 1640s, which stopped forever the supply of Baltic oak to western Europe and established one of those key dates that every student of painting techniques should know.

Rubens's restless genius resulted in many extraordinary experimentations with his painting supports. He frequently enlarged his panels as he went along, in some cases doubling or tripling the original size with a bewildering patchwork of added pieces. In the *Watering Place* (National Gallery, London), composed of eleven pieces of wood, Rubens successively moved the position of the sun to the left as he extended the composition. The result is there are now three suns: two painted and one drawn. In other cases, the complexity of the structure is not the result of enlargement, since Rubens seems deliberately to have constructed composite panels that were then painted in a single campaign of working. The exquisite companion paintings of the *Château de Steen* (National Gallery, London) and *The Rainbow Landscape* (Wallace Collection, London), on twenty planks and nineteen planks, respectively, are examples of this method. Beyond simple enlargement, did Rubens have a purpose in constructing such elaborate panels? Did he believe that such construction might somehow make the work more stable? Was he simply using up scraps of wood? About half of Rubens's entire output of oil paintings, including his oil sketches, was on wood panel. He seems to have liked the smooth surfaces of panels prepared with white grounds. Only once in surviving documents do we read of this preference; in a letter to Sir Dudley Carleton in 1618, he wrote, "It is done on panel because small things are more successful on wood." In fact, the appeal of panel painting was so great for Rubens that he was quite undeterred by the considerable difficulties of constructing and painting on large panels. Rubens's remark anticipates the only other quote I have been able to find to explain a painter's preference for wood over canvas. Philippe de la Hyre, son of the more famous Laurent, said in a lecture in 1709, "Wood prepared for working is much smoother than canvases; that is why it is greatly to be preferred for smaller works which require great refinement."

Panel painting continued, of course, through the nineteenth century. Wood was still the most convenient material for smaller works. Countless oil sketches exist on little panels, of which the plein air paintings of the Barbizon school and Seurat's celebrated studies for the *Baignade* and the *Grande Jatte* are obvious examples.

In the nineteenth century—no doubt inspired by the increasing expertise of picture restorers in thinning and backing old panel paintings—painters continued to experiment with wooden panels. For example, many of the small genre pictures of Meissonier (a fascinating character who was Manet's commander in the Franco-Prussian War and also the sworn enemy of Courbet) were assembled from small, thin strips of either sycamore or oak, in arrangements reminiscent of Rubens's panels. So thin they are almost veneers, they are mounted on thin oak backboards. Is this simple enlargement a curious technical idiosyncrasy of Meissonier? In the case of the *Halt at an Inn,* now in the Wallace Collection, London, the evidence provides a satisfying proof of enlargement: The panel consists of nine members, the central part being sycamore; the rest of the members are oak mounted on an oak veneer backing. The original composition, comprising the center panel and the first four additions, was engraved by Flameng and signed and dated 1862. Meissonier then enlarged the composition to its present size, probably in 1863. He signed it at both stages—above the left-hand doorway in the central part, and at the bottom left on the final addition. Valuable documentary evidence of various types has elucidated the creation of this particular painting.

Once a panel painting left the artist's studio, it began its precarious existence in a world of unpredictability and danger. The misfortunes of paintings in the last half millennium are well known; it is miraculous that so many have survived. Wooden panel paintings are, of course, especially vulnerable, since their main structural element exists in a condition of predictable instability that is under control if the surroundings are benign but easily out of control should the surrounding environment change.

Wood is such a familiar material that it is easy to underestimate its abilities to behave unexpectedly. The simple fact is that we still do not fully understand the behavior of partially restrained, or even unrestrained, centuries-old wooden panels. While we understand the general idea of expansion and contraction in humid and dry conditions, the stresses and strains of a composite structure can be very complex. We cannot predict how a painted panel will behave if, for example, it is held for years in steady conditions and then exposed to slow or rapid cycles of change. What actually happens when a panel is moved from a dry climate, where it has been for centuries, to an air-conditioned museum? What is the impact on the painting? What limits of tolerance have already been breached? A great mistake of past generations of restorers was to assume they could ignore or override the natural tendency of wood to warp, twist, split, and rot. Many past treatments have tried to impose structural restrictions on panels without imposing corresponding control of the environment. The long-term results of cradling, cross-grain battens, and rigid frame fitting are clearly demonstrated—so, too, are the innumerable cases in which restorers have regarded the wood as a simple nuisance and have thinned panels to a wafer (a process that actually made them *more* troublesome) or jettisoned them altogether by transferring the paint to a new support.

As conservators we see examples of these attitudes each day of our working lives, and we must deal with the consequences. It is no use, however, to say, "Well, *I* wouldn't have started from here." All of the horrors, misjudgments, and merely careless acts have already occurred; we must start from what has resulted. Conservators of panel paintings must be empiricists above all else. Our starting point is a situation in which centuries of aging, neglect, and malpractice have transformed the condition of many panel paintings into something far removed from their original states. Our conservation options are limited by the situation, but there are still choices to be made in terms of prevention and intervention. These choices are explored in all their variety during this symposium.

In this volume we learn about the pros and cons of balsa backing, attached and unattached auxiliary supports, retention or cutting out of deteriorated areas, and reinforcement with battens and V-shaped wedges. We see traditional hand tools, used with consummate skill; ingenious clamping jigs; and state-of-the-art low-pressure systems. We also learn something of old regional practices that may cause us to reexamine our own understandings of the properties of wood. One such example is the so-called Munich treatment, in which shellac in alcohol is copiously brushed onto the backs of warped panels to reduce their curvature. Clearly the shellac must be acting as more than a simple moisture barrier. The question raised by the Munich treatment opens up a whole realm of study of the effects of solvents other than water on wood.

We are privileged to be witnesses as the world's leading practitioners of the conservation of panel paintings question one another, debate choices, and describe actions. Here we learn in detail about the mistakes of the past, directions of the present, and speculations about the future.

We also explore unfamiliar corners of art history and the history of conservation, and touch, in passing, on the methodologies of historical inquiry. On this historiographical note, I must mention another famous legend concerning a panel painting ascribed to Michelangelo, the *Entombment* in the National Gallery, London. One of the abiding myths about this picture recounts that the painting was discovered in the nineteenth century doing duty as a market stall in Rome "for the sale of fish, frogs, etc. and old pans, gridirons etc. etc." The myth grew when, based on this story, Helmut Ruhemann, who cleaned the painting in 1968, explained the hundreds of little, raised, discolored spots on the surface of the picture as the excreta of flies attracted by the fish.

Recent scholarship has blown the legend apart. The brown spots are not flyspecks at all, but straightforward mold. And the story about the panel being used as a stall or tabletop becomes distinctly shaky when we trace it back to the Roman dealer who had the painting and discover that he used exactly the *same* story about at least one other panel by

Palmezzano that passed through his hands. My colleague Jill Dunkerton, who uncovered this diverting little piece of misinformation, commented in a lecture on the *Entombment*: "This recycling of battered old panel paintings as furniture was a little joke—frequently repeated, I fear—of the dealer, and yet another reminder of how careful we need to be in our assessment and interpretation of any piece of evidence about a painting, be it anecdotal, documentary, or scientific."

No mythology is necessary for my last example. Its bizarre history is apparent with even the most casual examination. It is the Trinity Altarpiece, begun by Pesellino and finished by Filippo Lippi, who delivered it in 1460 after Pesellino's death in 1457. A set of fascinating documents describes the commissioning of the altarpiece and what happened to it when it was left uncompleted on Pesellino's death. Having been assessed by Lippi and Domenico Veneziano as just half finished, it was taken from Florence to Prato for Lippi to complete. Meanwhile, a financial dispute was in progress between Pesellino's widow and his business partner, which complicated the final payments made to her for her husband's work on the painting. Which parts were by Pesellino and which by Lippi has been the subject of intense debate ever since the altarpiece was removed from the Church of the Compagnia dei Preti in Pistoia in the eighteenth century. At that time, the main panel was sawn into five fragments that, apart from the two angels, one might imagine to be so irregular in shape as to make them unsalable. Nevertheless, they were dispersed and sold. The *Crucifixion* fragment was purchased in 1863 by the National Gallery, London, which initiated a search for the other pieces. Three other fragments were found over the next sixty-five years. The fourth (the two saints on the left) was discovered in the British Royal Collection, which would not part with the piece but instead released it on loan in 1919 to be joined to the other parts. (In theory, if the altarpiece is ever moved or treated, the queen's restorer should be in attendance.) The bottom part of the right-hand pair of saints, who were found in 1929, never did surface, so a restorer was commissioned to paint their lower robes and feet.

The predella panels, also sawn apart in the eighteenth century, were bequeathed in 1937, seventy-four years after the reassembly of the jigsaw began. This complicated and generally unsatisfactory story has a recent and upbeat postscript. The predella—now assumed to be entirely by Filippo Lippi and his workshop rather than by Pesellino—has always been obviously too short for the main panel and original frame. Now the missing cental part of the predella has been identified as a panel by Filippo Lippi of the *Vision of Saint Augustine* in the Hermitage, St. Petersburg. Everybody knew the painting existed; some even remarked on its affinities with the Trinity Altarpiece; but until now, no one had suggested that it had been part of the same plank as the other predella panels.

This story represents the whole checkered history of panel painting in one example. It begins with a complicated genesis, documented with an extraordinary clarity that conjures up the immediacy of life and death, the stop and start of the painting process, and the realities of financial transactions and legal disputes. Next the painting enjoys an undisturbed existence for three centuries in Pistoia, followed by butchery and dispersal. Finally the artwork is painstakingly reassembled during the last two centuries (concurrent with current research on its original format), and it finally comes to rest in the relative tranquillity of a modern museum environment.

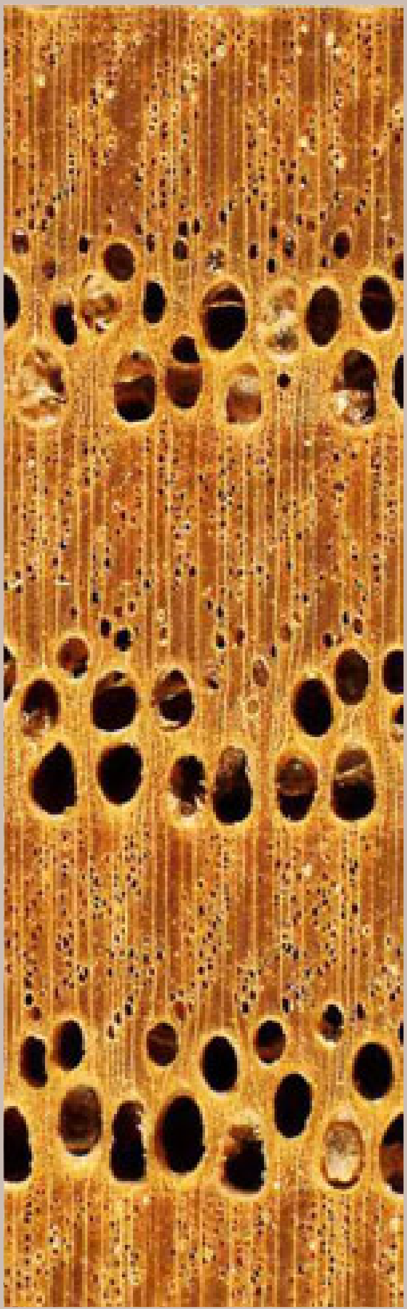
Panels are not simply the convenient carriers of the painter's invention. Panels *matter* in themselves, in the same way that canvases began to matter to us in Greenwich in 1974, and in the same way that documents, preparatory drawings, underdrawings, paint layers, inventories, and archives matter to us today. All of these materials contribute to a complete account of a work of art—from its commission, planning, preparation, execution, and delivery, to its ownership as a cherished possession, to its precarious survival, and, finally, to a present-day existence as cultural artifact, social record, and signifier of individual genius.

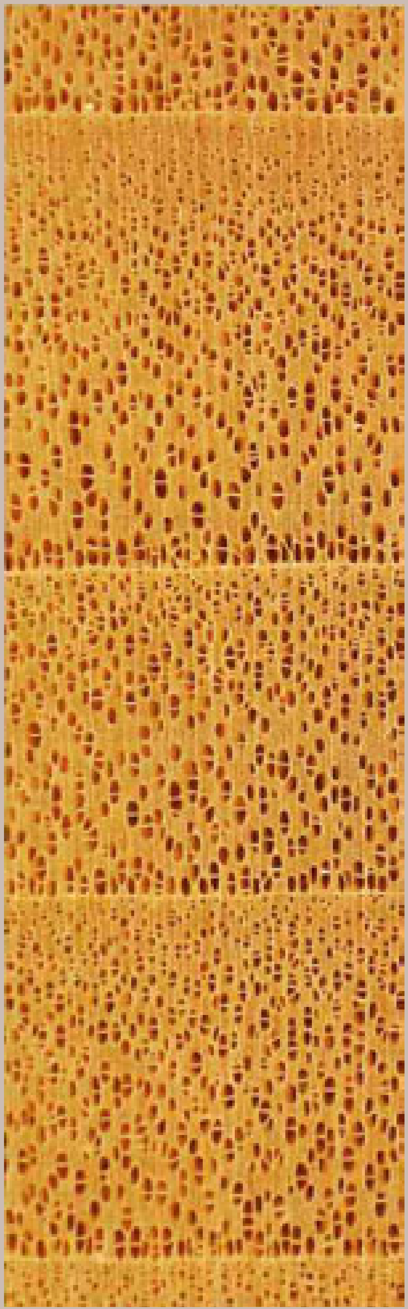
It is important to emphasize the totality of the work of art. While a painting may be a sublime creation of its maker's aesthetic sensibility, it is also a material document with a unique character given by the method of its making and the circumstances of its survival. When an artwork's history permits, its continuity over time can be thrilling. If we are lucky, we can appreciate a structure essentially unaltered since it left the artist's hand. It is our function as conservators to preserve, stabilize, consolidate, and repair where necessary—and it is also our responsibility to interrupt that continuity from the artist's hand as little as we possibly can.

The conservation of panel paintings must begin and end with the integrity of the historical object and the work of art. If we criticize, often justifiably, the failures of the past to address this requirement—as well as criticize the excessive interventions of our predecessors—then we must be accountable ourselves to the judgments of those who follow us. If we inform ourselves of all the historical contexts surrounding these works, if we ask the right questions, consider the best choices, and justify our actions, then the future of the panel paintings in our care should be assured.

PART ONE

Wood Science and Technology





Chemical and Physical Properties of Wood

R. Bruce Hoadley

From the beginning of civilization, wood has played an indispensable role in human survival. It is therefore not surprising that wood retains a prominent place in our cultural heritage. In the decorative arts wood has routinely been utilized because of its aesthetic virtues. In contrast, when wood is used for painting panels, where the surface appearance is obscured, the choice of wood reflects the universal availability of the resource as well as the working and performance properties of the timber. As an engineering material wood is strong and stiff for its weight and has density and hardness in the range suitable for conversion with hand tools. Wood is chemically stable when dry, and its surfaces offer a compatible substrate for paint application. The use of wood is not without its pitfalls, however, and requires the understanding that it is anisotropic—that is, it exhibits properties with different values when measured in different directions—as well as hygroscopic—adsorbing and releasing moisture readily. It is also dimensionally unstable and subject to deterioration by fungi and insects.

It is fundamental when exploring the complex nature of wood to remember that wood comes from trees and that usable timber is found in tens of thousands of tree species the world over. Pieces of wood large enough for painting panels are normally from the trunks or stems of mature trees. While many features of wood structure are common to all tree stems without regard to type of wood, it is not surprising that among such a diverse resource deriving from so many different species, a wide array of characteristics can be expected—such as the twelvefold variation in density from the lightest to the heaviest woods.

Trees are living plants, and wood is cellular tissue. Understanding wood therefore begins at the cellular level, and it is both appropriate and important to think of wood as a mass of cells. Woody cells evolved to satisfy the needs of trees—on the one hand to serve as good structural beams and columns, on the other hand to provide systems for conduction of sap and storage of food materials. The cells specialized for these mechanical and physiological functions are primarily elongated and fiberlike and parallel to the tree-stem axis. The alignment of these longitudinal cells in wood determines its grain direction. The stem of a tree "grows" in diameter by adding cylindrical layers of cells, which we recognize as growth rings. The combination of the axial direction of longitudinal cells and cell arrangement in growth rings gives wood tissue its anisotropy: its properties are significantly different in its three structural directions.

All timber species have common attributes of stem form and structure, and the fundamentals of wood properties can be discussed in general terms. Consideration of particular woods, however, reveals that certain groups or individual species require qualification. As a first level of investigation, for example, we recognize the broad differences between the hardwoods and the softwoods; more specifically, we recognize that one species of pine may be strikingly different from another. The systematic study of anatomy goes hand in hand with wood identification, and familiarity with anatomical structure is fundamental to the understanding of wood properties in general, as well as to the understanding of the important similarities and differences among woods.

Of the problems arising in painting conservation, those involving moisture-related dimensional change are certainly among the most challenging. Therefore, along with a brief review of pertinent chemical and mechanical properties of wood, this article will emphasize wood-moisture relationships, with particular reference to dimensional change.

Specific Gravity of Wood

Specific gravity—that is, relative density—is perhaps the single most meaningful indicator of other properties of wood. It is closely related to strength and surface hardness, as well as to resistance to tool action and fasteners. Woods of higher specific gravity generally shrink and swell more than woods of lower specific gravity, and they present greater problems in seasoning.

Specific gravity is the ratio of the density of a substance to the density of a standard (usually water). In reference to wood, it is customary to measure density on the basis of oven-dry weight and current volume. Because of shrinkage and swelling, the volume of wood may vary slightly with its moisture content. Density is expressed as weight per unit volume: as grams per cubic centimeter or as pounds per cubic foot. Water has a density of 1 g cm^{-3} (62.4 lb ft^{-3}). A sample of wood having a density of 0.5 g cm^{-3} (31.2 lb ft^{-3}) is half as heavy as water and has a specific gravity of 0.5. (Note that specific gravity is a unitless quantity.)

Among woods the world over, specific gravity ranges from less than 0.1 to greater than 1.0. Among the more familiar woods, balsa (*Ochroma* spp.) has an average specific gravity of 0.15; snakewood (*Piratinera guianensis*) averages 1.28. Figure 1 shows a comparison of specific gravity values for a number of woods, including those commonly found in painting panels. The chart shows that the terms *hardwood* and *softwood* are misleading with regard to literal hardness and softness. It is valuable to understand these contrasting terms as indicating botanical classification with reference to different anatomical structure rather than to disparate physical and mechanical properties.

Physical Structure of Wood

Many of the physical and mechanical properties of wood are inherently tied to its anatomical structure. Gross features of wood—that is, visual features or those apparent with low-power magnification such as a 10× hand lens—provide important indications of its properties. It is therefore appropriate to begin by highlighting the gross structure of wood.

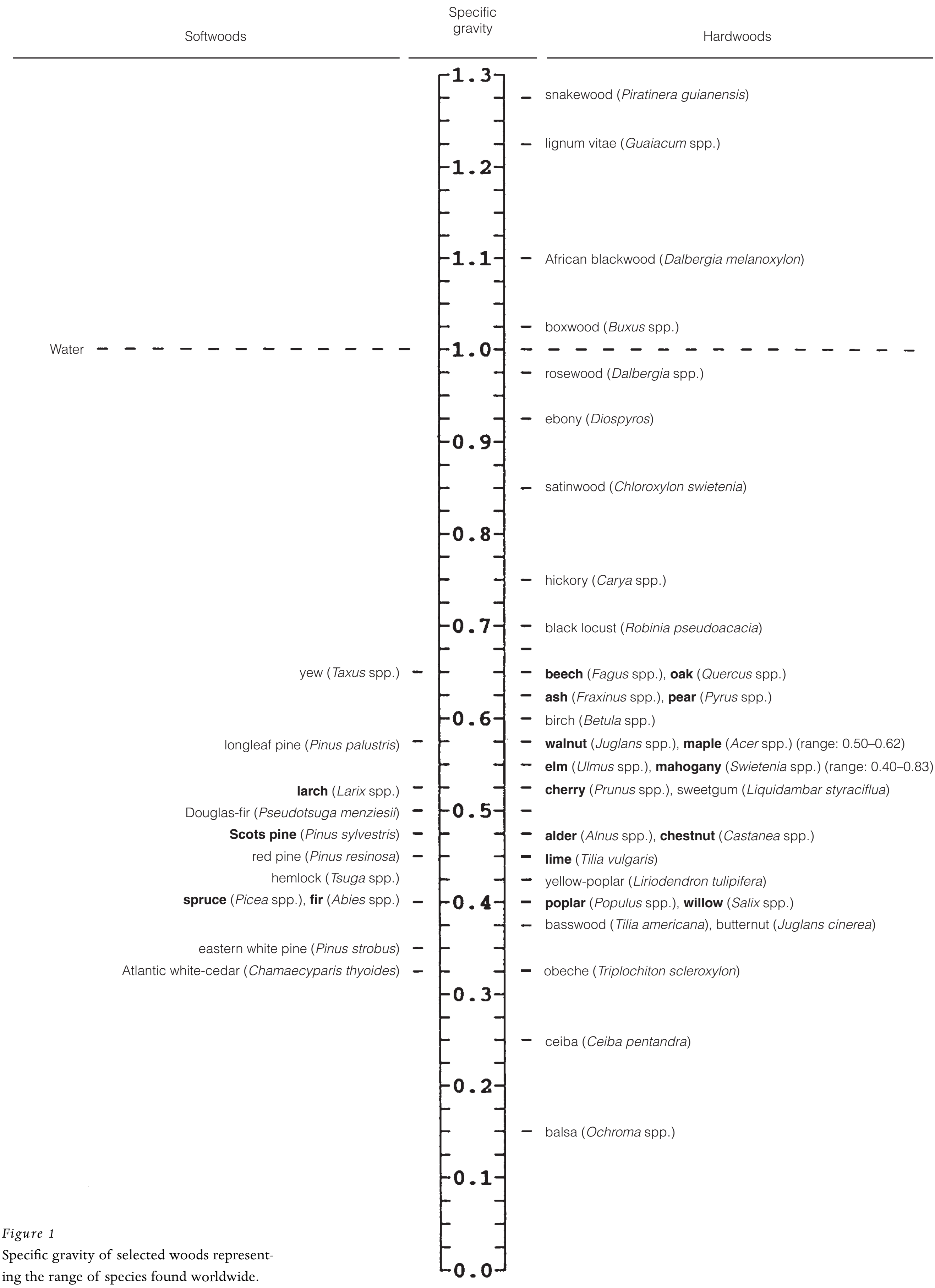


Figure 1
Specific gravity of selected woods representing the range of species found worldwide. Woods shown in boldfaced type are among those commonly found in painting panels.

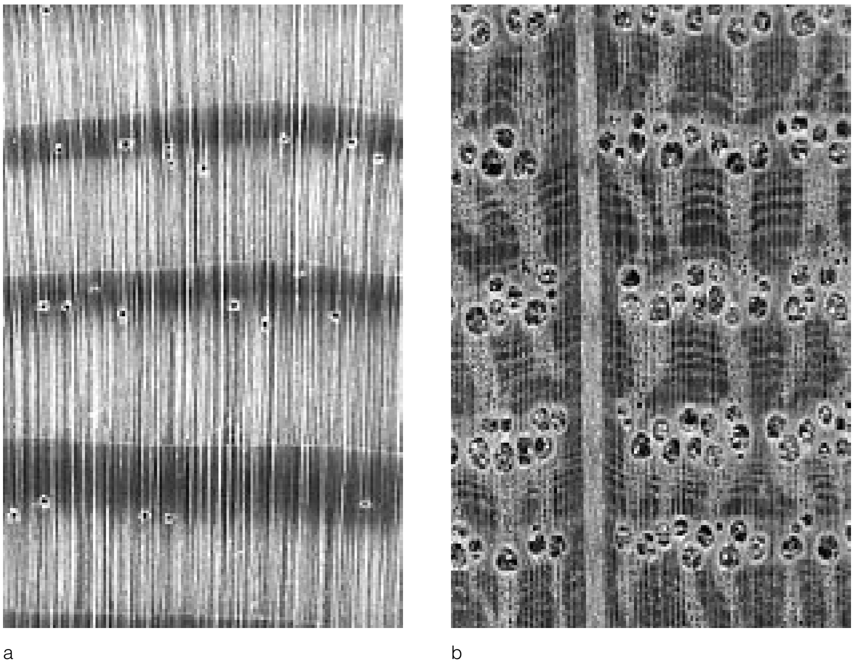


Figure 2a, b
Cross-sectional (end-grain) surfaces of (a) an uneven-grained softwood, Scots pine, and (b) a ring-porous hardwood, white oak, showing features visible with a hand lens (10× magnification).

Gross features

In viewing end-grain surfaces (Fig. 2a, b), individual wood cells usually cannot be seen without magnification. (In certain hardwood species, the largest cells, vessel elements, may be evident as visible pores on cleanly cut surfaces.) However, the familiar pattern of circular growth rings is apparent, concentrically arranged around the central pith. Within each ring, depending on the species, a first-formed earlywood layer may be distinct from an outer latewood layer. The visual pattern, or *figure,* on longitudinal board surfaces is most commonly the result of this earlywood-latewood variation. Distinct earlywood-latewood contrast usually indicates variation in cell characteristics, with latewood having greater density than earlywood. In some woods, however, there may be no significant difference in properties within growth rings.

Individual wood cells usually have an elongated shape, although they vary in proportions, from short and barrel shaped to long and needlelike. Most cells are longitudinal; that is, they are elongated vertically in the standing tree, parallel to the stem axis. On an end-grain surface we therefore see these cells in cross section. Scattered through the longitudinal wood cells are horizontally oriented ray cells, grouped to form flattened bands of tissue called *rays*. These ribbonlike rays (with their flattened sides oriented vertically) radiate horizontally outward from the pith, crossing perpendicularly through the growth rings. Individual ray cells are always too small to be seen without magnification, and therefore narrow rays are not apparent. However, some hardwood species have rays of up to tens of cells in width, which are therefore visible as distinct radial lines on cross sections. Collectively, the ray cells in most species account for less than 10% of the volume of the wood. It is important to understand that rays are present in every species and, whether visible or not, have an important role in many properties of wood.

The cylindrical form and arrangement of the growth rings in the tree stem, along with the vertical and horizontal arrangement of cells,

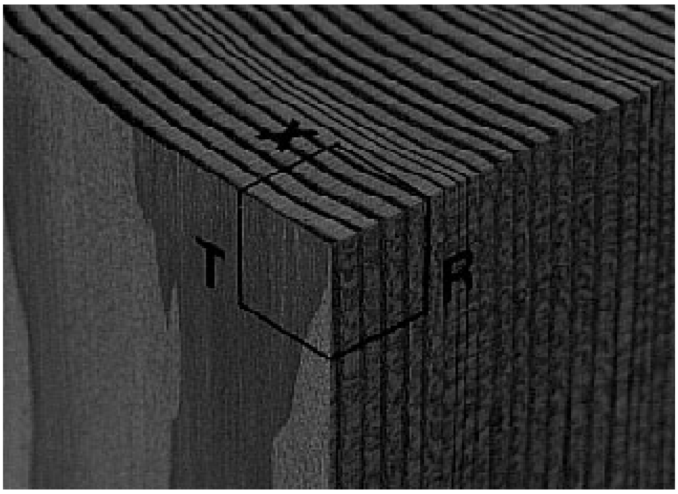


Figure 3
Block of coniferous wood, Douglas-fir, cut into a cube along the principal structural planes: transverse or cross-sectional (*X*), radial (*R*), and tangential (*T*).

establishes a three-dimensional orientation to the wood tissue (Fig. 3). A plane perpendicular to the stem axis is termed the *transverse plane,* or *cross-sectional plane,* also appropriately called the *end-grain surface,* as represented by the end of a log or board. The tree cross section is analogous to a circle, and a longitudinal plane passing through the pith of the stem (as would a radius of the circle) is a *radial plane* or surface. A plane parallel to the pith but not passing through it forms a tangent to the circular growth-ring structure at some point and is termed a *tangential plane* or surface, at least at that point. Relative to the anatomical structure of the wood, the tangential "plane" would take on the curvature of the growth ring. However, any slabbed log surface or "flat-sawn" board is accepted as a tangential cut, even if the board surface is truly tangential only in a limited central area. In a small cube of wood, as used for anatomical study, the curvature of the rings is insignificant, allowing the cube to be oriented to contain quite accurate transverse, radial, and tangential faces (Fig. 3).

Thin slices or sections of wood tissue, as commonly removed from the surfaces for study, are termed transverse, radial, and tangential sections. These tissue sections, as well as the planes they represent, are often designated simply by the letters *X, R,* and *T,* respectively.

In a further exploration of the anatomical nature of wood, generalities must give way to more specific detail according to the type of wood considered. A systematic approach is to follow the standard botanical classification of wood.

Within the plant kingdom, timber-producing trees are found in the division spermatophytes, the seed plants. Within this division are two classes, the gymnosperms and the angiosperms. Trees belonging to the gymnosperms (principally in the order Coniferales) are called *softwoods*. In the angiosperms, a subclass known as dicots (dicotyledonous plants) includes *hardwoods*.

Anatomical characteristics: Softwoods

The cell structure of softwoods is relatively simple compared to that of the hardwoods (Fig. 4a–c). Most of the cells found in coniferous woods are tracheids, which account for 90–95% of the volume of the wood. Tracheids are fiberlike cells with lengths of approximately one hundred times their diameters. Average tracheid lengths range from 2 mm to 6 mm among coniferous species, with a corresponding diameter range of approximately 20–60 µm. The relative diameter of tracheids is a basis for classifying texture among conifers. Tracheid size is important to the porosity and to the performance of coatings applied to wood.

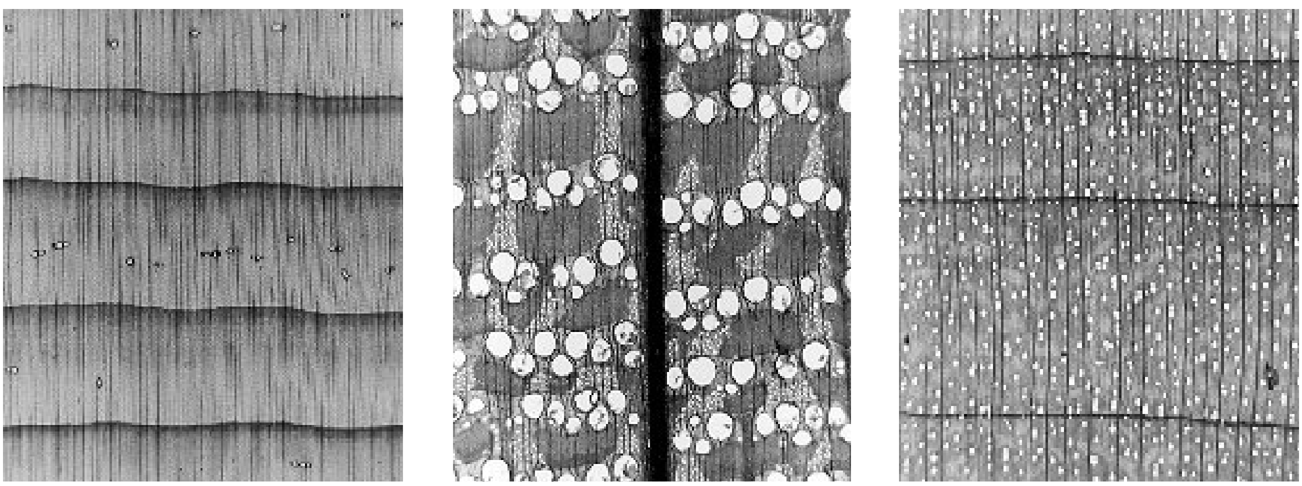
Across a softwood growth ring, latewood is distinguished from earlywood by decreased radial diameter and increased cell-wall thickness. The transition may be gradual in some woods, abrupt in others. The earlywood-latewood contrast may be slight in some woods ("even-grained" woods) or may be pronounced in others ("uneven-grained" woods). In uneven-grained woods such as hard pines or larches, there may be as much as a threefold difference in specific gravity (0.3–0.9) from earlywood to latewood.

Some coniferous species have resin canals, tubular passageways lined with epithelial cells that exude resin, or pitch, into the canals. Resin canals are a constant feature of some genera in the family Pinaceae (the pine family), including *Pinus* (pine), *Picea* (spruce), and *Larix* (larch). Resin canals are largest and most numerous in the pines—they are usually distinct to the naked eye. In other species, magnification may be required to locate them. The resin from canals may bleed through paint films and result in yellowish speckling of finished surfaces. The rays in softwood are narrow, usually one cell wide (except occasional rays with horizontal resin canals in some species), and therefore cannot be seen without magnification. With a hand lens they are barely visible—appearing as light streaks across radial surfaces.

Anatomical characteristics: Hardwoods

In comparing the anatomy of the hardwoods with that of the softwoods, several general differences are apparent. There are many more cell types present in hardwoods, and there is more variation in their arrangement. Rays in hardwoods vary widely in size, from invisibly small to conspicuous to the eye. Temperate hardwoods lack normal resin canals.

Hardwoods have evolved specialized conductive cells called vessel elements, which are distinct in having relatively large diameters and thin cell walls. They occur in the wood in end-to-end series, and their end walls



a b c

Figure 4a–c
Transverse sections of (a) a typical softwood, spruce; (b) a ring-porous hardwood, oak; and (c) a diffuse-porous hardwood, maple.

have disappeared; thus they form continuous vessels ideal for sap conduction. When vessels are cut transversely, the exposed open ends are referred to as *pores*. Pores vary in size among and within species. In certain woods such as chestnut and oak, the largest pores are up to 300 μm in diameter and can be easily seen without magnification, whereas in some species, such as holly, the pores are no larger than 40 μm in diameter and are barely perceptible even with a hand lens. Among hardwoods, pore size serves as a measure of texture. Oak has large pores and is coarse textured; pear has very small-diameter pores and is fine textured.

In some species (e.g., oaks, ashes, elms) the largest pores are concentrated in the earlywood. Such woods are said to be *ring porous;* they are inherently uneven grained and therefore have distinct growth-ring-related figure. Ring-porous structure results in uneven density and affects woodworking behavior with characteristics such as uneven resistance to abrasive paper or uneven retention of pigmented stains. In certain other woods (e.g., maple, birch, lime, poplar) pores are more uniform in size and evenly distributed across the growth ring; these are said to be *diffuse porous*. Such woods may show inconspicuous figure, or figure may be associated with uneven pigmentation or density of fiber mass in the outer latewood. Most diffuse-porous woods of the temperate regions have relatively small-diameter pores, but among tropical woods, some diffuse-porous woods (e.g., mahogany) have rather large pores. A third classification, *semi-ring-porous* (also called *semi-diffuse-porous*), refers to woods in which the first-formed pores in a growth ring are large, but the pores decrease in size gradually to small pores in the latewood, without clear delineation between earlywood and latewood.

Hardwoods have three other types of longitudinal cells: fibers, tracheids, and parenchyma cells. All are uniformly small in diameter (mostly in the range of 15–30 μm) and therefore can be seen individually only with microscopic magnification. Fibers are present in all woods and are characteristically long and needlelike, with tapering, pointed ends and relatively thick walls. On transverse surfaces, masses of fibers appear as the darkest areas of the tissue. Thick-walled fibers are characteristic of high-density woods such as oak and ash. Low-density hardwoods such as poplar have thin-walled fibers. Tracheids and parenchyma cells range from absent or sparse to fairly abundant. They are thinner-walled cells than are fibers, and when they are present in sufficient numbers, the resulting areas of tissue usually appear lighter in color than adjacent fiber masses.

Rays are quite variable among hardwood species. The size of rays is expressed by cell count as viewed microscopically on tangential sections, particularly ray width, or *seriation,* of the largest rays present. In woods such as chestnut and willow, the rays are *uniseriate* (that is, only one cell wide) and therefore visible only with a microscope. At the other extreme, such as oak, the largest rays are up to 40 seriate and up to several inches in height. Rays in oak are conspicuous to the unaided eye.

Rays influence physical and mechanical behavior as well. Rays, especially larger ones, represent planes of weakness in the wood. Shrinkage stresses associated with the seasoning of wood may develop separations, or checks, through the ray tissue. Also, the restraining effect of the rays results in differential radial and tangential shrinkage, a common cause of cupping in flat-sawn boards and of radial cracking in timbers.

Chemical Properties of Wood

Wood, as the biological product of higher-order plants, has a chemical composition that is understandably complex, and a thorough discussion of wood chemistry is quite beyond the scope of this article. However, even a brief summary of the more important fundamentals of cell-wall chemistry provides a basis of understanding of the anisotropic physical and mechanical properties of wood—especially its hygroscopic nature and dimensional behavior—and of chemical reactions involved in such practical conservation procedures as finishing, gluing, stabilization, and preservative treatment.

Chemical composition

The bulk of cell-wall substance is a composite of three major types of organic molecules: cellulose, hemicelluloses, and lignin. These constituents can be thought of as skeletal, matrix, and encrusting substances, respectively. Only minor amounts of inorganic (ash) content are present in wood. In various amounts, depending on species, additional substances called extractives, or extraneous materials, may also be present, mainly as additives to the heartwood.

The major chemical constituents of wood are typically present in the following approximate percentages:

Cellulose	40–50%
Hemicelluloses	20–30%
Lignin	25–30%
Ash	0.1–0.5%
Extractives	1–5%

Of the major constituents, cellulose is the most easily described and is in many respects the most important. Wood cellulose is chemically defined as $(C_6H_{10}O_5)_n$, the basic monomer of which is called glucose anhydride. As shown in Figure 5, glucose anhydride units are alternately linked in pairs to form bimers (cellobiose), which in turn are repetitively end linked to form the long-chain linear polymer cellulose. The average degree of polymerization (DP) of cellulose is in the range of 10,000. The hemicelluloses found in wood are polysaccharides of moderate size (DP averaging 150–200 or greater) of the types that are invariably associated with cellulose and lignin in plant-cell walls. Predominant types include xylan (the principal hemicellulose in hardwoods), glucomannan, and galactoglucomannan (the major hemicellulose of softwoods). Many other forms of

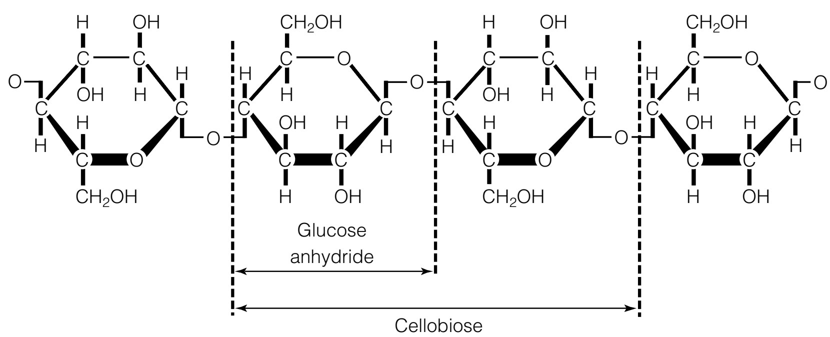


Figure 5
Representative portion of a molecule of cellulose, the major chemical constituent of wood.

hemicellulose are also present. Lignin has complex three-dimensional polymeric structure comprising various phenylpropane units. Lignin apparently infiltrates and encrusts the cell-wall structure after the polysaccharides are in place. Although lignin contributes to the compressive strength of wood, cellulose provides the major contribution to tensile strength.

Cellulose, hemicelluloses, and lignin are essentially permanent products synthesized by the developing wood cells soon after division in the cambium. Extractives are principally associated with heartwood formation and are located as much outside the cell wall as within. These extraneous materials are called extractives because they can be extracted from wood with the appropriate solvent with little change to the basic wood structure. Extractives are typically low-molecular-weight compounds that, among the various species of wood, fall within classifications such as tannins, terpenes, polyphenols, lignins, resin acids, fats, waxes, and carbohydrates. In addition to influencing the appearance of the wood, mainly as color, extractives may contribute to other properties of the wood, such as significant decay resistance in some species.

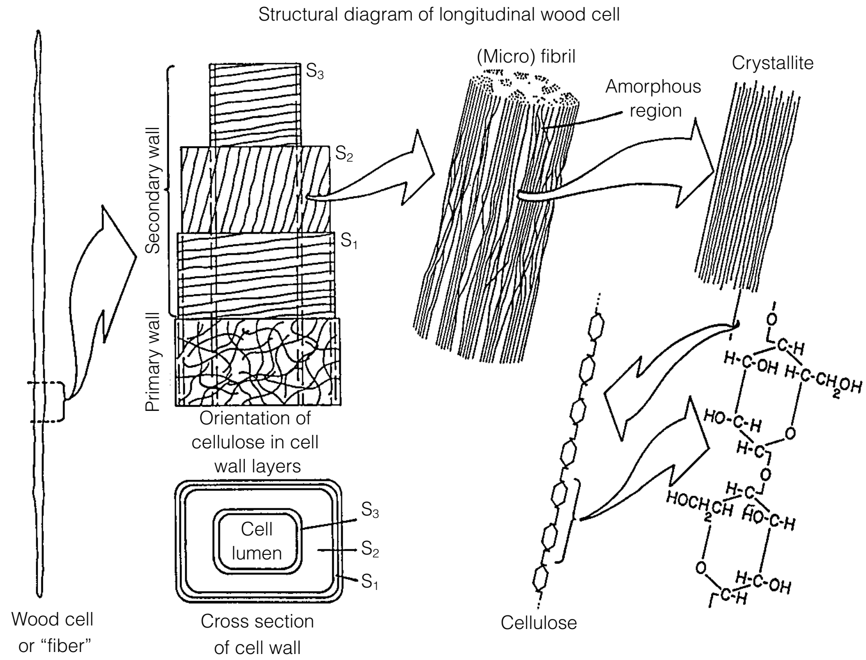
Cellulose within the cell wall

The nature and orientation of cellulose determine the architecture of the cells. Insight into the configuration of the cellulose within cell walls provides the important key to understanding and anticipating many of the properties and resulting behavior of wood.

Figure 6 presents a conceptual model representing a typical longitudinal wood cell, such as a hardwood fiber or a softwood tracheid. The cell wall has layered structure. The outer layer, the primary wall, was the functional cell wall during cell division in the cambium and during subsequent enlargement or elongation of the developing daughter cell. Immediately after enlargement the secondary wall formed within, giving permanence to the cell's dimensions and shape. The primary wall is very thin and lacks any apparent structural orientation; in contrast, the secondary wall occupies the dominant portion of the cell wall and has three layers, designated as S_1, S_2, and S_3, each with orientation revealed by striations visible under the electron microscope. The direction of these striations, as diagrammed in Figure 6, indicates the general orientation of aligned cellulose. The apparent groupings, as suggested by ridges seen in micrographs, are referred to as *fibrils* (subgroupings are sometimes termed *microfibrils*).

Within the thinner S_1 and S_3 layers, the fibril orientation is nearly perpendicular to the cell axis, whereas fibrils within the dominant S_2 layer are oriented more nearly parallel with the cell axis. Experimental evidence provides a theoretical explanation for the arrangement of cellulose within fibrils. In random areas, called crystallites, cellulose molecules (or, more likely, portions of cellulose molecules) are aligned into a compact crystalline arrangement. Adjacent areas in which cellulose is nonparallel are called amorphous regions. The hemicelluloses and lignin are also dispersed between crystallites and through the amorphous regions. Within the fibrils, water molecules cannot penetrate or disarrange the crystallites. Water molecules can, however, be absorbed by hydrogen bonding, in one or more layers, to the exposed surfaces of crystallites and components of amorphous regions—namely, at the sites of available hydroxyl groups. Such polar groups of the polysaccharide fractions on exposed wall surfaces

Figure 6
Diagrammatic model of a longitudinal wood cell, showing the orientation of fibrils within layers of the cell wall and the arrangement of cellulose within fibrils.



provide the principal active sites for bonding of adhesives and finishes and for other chemical reactions with wood. Because the average length of cellulose molecules is far greater than the apparent length of the crystallites, it is concluded that an individual cellulose molecule may extend through more than one crystalline region, being incorporated in crystal arrangement at various points along its total length. Therefore, within the fibrillar network, the random endwise connection of crystallites would appear to offer linear strength to the fibril. Since crystallites would be more readily displaced laterally from one another due to the intrusion or loss of water molecules (or other chemicals capable of entering the fibrils), dimensional response would occur perpendicular to the fibril direction.

In summary, knowledge of the linear organization of cellulose within the fibrils, the dominance of the S_2 layer, and the near-axial orientation of fibrils within the S_2 layer provides a foundation for understanding the greater strength and dimensional stability of the cell in its longitudinal, as compared to transverse, direction. It follows that wood itself—as the composite of its countless cells—has oriented properties.

Wood-Moisture Relationships

Virtually every property or response of wood, from its strength to its decay susceptibility, is related to its moisture condition—but probably no property is of greater concern than its dimensional behavior in response to moisture. We recognize that such problems as warping and checking of panels and flaking of paint are among the most challenging conservation issues. If there is to be a hope of preventing or correcting such problems, the fundamental relationships involving wood, moisture, and the atmosphere must be recognized.

Before exploring interrelated details, we can easily summarize underlying principles. First, the wood in trees is wet, containing large amounts of moisture in the form of sap, which is mostly water. It is appropriate to think of wood at this stage as being fully swollen. Second, when wood is taken from trees and dried to a condition appropriate for common uses, it loses most (but not all) of its moisture. Third, the loss of moisture affects many properties: for example, it increases strength but decreases dimension (i.e., causes shrinkage). Fourth, after initial drying to an equilibrium with its environment, wood remains hygroscopic and will continue to adsorb or desorb moisture, and consequently change dimension or other properties, in response to changes in relative humidity (RH). Fifth, wood can remain dimensionally responsive to humidity-related moisture changes indefinitely.

Moisture content

The amount of moisture in wood is usually expressed quantitatively as moisture content (MC). The MC of wood is defined as the ratio of the weight of water in a given piece of wood to the weight of the wood when it is completely dry. The water-free weight of wood is also referred to as its oven-dry weight, determined by drying a specimen at 100–105 °C until it ceases to lose weight (loss in weight is taken as moisture loss). MC is expressed as a percentage and is calculated as follows:

$$MC = \frac{W_i - W_{od}}{W_{od}} \times 100$$

where: MC = moisture content, in percent; W_i = original weight; and W_{od} = oven-dry weight.

Forms of water in wood

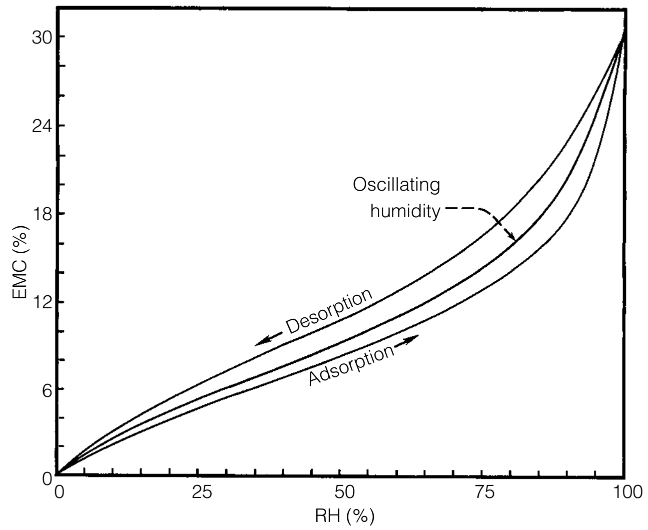
Water exists in wood in two forms: bound and free. Water adsorbed and held within the cell walls by hydrogen bonding is called *bound water*. Any available moisture will be adsorbed by the cell walls until they reach saturation. Water in wood in excess of cell-wall saturation exists as liquid water in the cell cavities; it is called *free water*. The hypothetical moisture condition of wood wherein the cell walls are completely saturated with bound water but the cell cavities are devoid of free water is called the fiber saturation point (FSP). The FSP is usually expressed as a numerical value of moisture content. For common species of wood, the FSP is approximately 28–30% moisture content.

The sap contained in living trees is primarily water, with small amounts of dissolved minerals and nutrients. In living trees, the moisture content of the wood is always above the FSP, but it can vary from as low as 35–40% in some woods to 200–300% in others. When trees are harvested and the timber is seasoned for use, all the free water and some of the bound water is dried from the wood. As drying progresses, the FSP has special significance to wood properties. For example, loss of free water has no effect on strength or dimension of wood. In any portion of the wood tissue, bound water is not lost until all free water is dissipated. Only when wood is dried below the FSP does the loss of bound water effect an increase of strength and a reduction of dimension.

Hygroscopicity

Cell-wall substance is hygroscopic—that is, wood has the capability of exchanging bound water in the cell walls by adsorption or desorption directly with the atmosphere. When wood is seasoned, the amount of bound water that is lost, as well as the amount that remains in the wood, is determined by the RH of the atmosphere in which the drying is com-

Figure 7
Relationship between environmental RH and EMC for wood, with white spruce as an example. The hysteresis effect is indicated by the different curves for desorption and adsorption in thin specimens under carefully controlled conditions. In the natural environment, with its fluctuating humidity, wood of lumber thickness attains average MCs as indicated by the oscillating humidity curve.



pleted. After initial drying, wood remains hygroscopic. It responds to changes in atmospheric humidity and loses bound water as RH decreases, or regains bound water as RH increases.

The moisture condition established when the amount of bound water is in balance with the ambient RH is called the equilibrium moisture content (EMC). The extremely important relationship between EMC and RH is shown in Figure 7. The figure contains average data for white spruce, a typical species, shown as having an FSP of about 30% of the moisture content. The FSP varies somewhat among different species: for woods having a high extractive content, such as rosewood or mahogany, the FSP can be as low as 22–24%; for those low in extractives, such as beech or birch, the FSP might be as high as 32–34%. Temperature also has an effect on EMC. The curves shown are for 21 °C, but at intermediate humidities the EMC would be about one percentage point lower for every 14–16 °C elevation in temperature. The EMC curves always converge at 0% RH and 0% EMC, so variation due to extractives and temperature will therefore be most pronounced toward the FSP end of the relationship.

Under conditions in which the RH is closely controlled, as in laboratory treatments or experiments, the curve for wood that is losing moisture (a desorption curve) is significantly higher than the curve for wood that is gaining moisture (an adsorption curve), as illustrated in Figure 7. This effect is called hysteresis. During the conditioning of wooden objects under precisely controlled laboratory conditions, the hysteresis effect may be apparent. Under normal room or outdoor conditions of fluctuating RH, an averaging effect results, usually referred to as the oscillating curve.

Moisture-Related Dimensional Change

As with most physical solids, wood responds dimensionally to thermal changes—expanding when heated, contracting when cooled. However, the coefficient of thermal linear expansion for wood is relatively quite small—about a third of the value for steel. For most uses of wood, such minute dimensional change is insignificant to an object's performance and is usually ignored; therefore, thermal expansion or contraction of wood will not be covered here. Moisture-related shrinkage and swelling of wood, however, is of critical importance and is the major contributor to warping and cracking of painting panels. The following discussion addresses the dimensional change in wood due to changes in MC below the FSP.

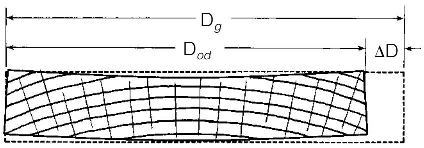
Shrinkage percentage

The traditional approach to expressing the relative dimensional instability of wood is to measure the total amount of linear shrinkage that takes place in a given direction from its green[1] condition to its oven-dry condition, expressed as a percentage of the green dimension. Linear dimensional change in wood is usually measured separately in the three principal directions: longitudinal (S_l), radial (S_r), and tangential (S_t). Quantitatively, the total shrinkage percentage is calculated as follows:

$$S = \frac{D_g - D_{od}}{D_g} \times 100$$

where: S = shrinkage, in percent, for a given direction (S_l, S_r, or S_t); D_g = green dimension; and D_{od} = oven-dry dimension.

Figure 8 illustrates the application of the formula in the determination of tangential shrinkage (S_t) based on green and oven-dry measurements of a tangentially sawn strip of wood.



$$S_t = \frac{\Delta D}{D_g} \times 100$$

Figure 8
Determination of the total shrinkage percentage for wood. Tangential shrinkage percentage (S_t) is calculated as the change in dimension after oven drying ($\Delta D = D_g - D_{od}$), divided by the original green dimension (D_g).

Total longitudinal shrinkage of wood (S_l) is normally in the range of 0.1–0.2%. In practical situations involving typical moisture-content changes over a moderate range, only a portion of this small quantity would be affected, and the resulting dimensional change becomes insignificant. It is therefore reasonable to assume that wood is stable along its grain direction, and for most purposes longitudinal shrinkage and swelling can be ignored—in fact, longitudinal shrinkage data are not commonly available. It should be cautioned, however, that abnormal wood tissue, such as juvenile wood, reaction wood, or cross-grain pieces may exhibit longitudinal shrinkage of up to ten to twenty times that of normal. In addition, it should be expected that abnormal wood will occur unevenly in severity and in distribution, and the resulting uneven longitudinal shrinkage will cause warp.

Radial shrinkage is quite significant, and tangential shrinkage is always greater than radial. Tangential shrinkage varies among species over the range of about 4–12%, with an overall average of about 8%. Average radial shrinkage values range from about 2% to 8%, averaging slightly over 4%. Values of average tangential and radial shrinkage are given for woods commonly found in painting panels in Table 1.

Over the range of bound-water loss, shrinkage of wood is roughly proportional to MC change, as shown by solid-line curves in Figure 9. Careful measurement of changing dimension as wood is slowly dried will show nonproportional behavior, especially at MCs near the FSP, because of the moisture gradient inherent in drying. However, in theory, the effect of MC on shrinkage is essentially proportional, and the relationship is assumed to be linear (see dashed-line curves, Fig. 9).

Estimating dimensional change

Based upon published percentages of shrinkage for individual species and upon the assumption that shrinkage bears a linear relationship to moisture content, the anticipated dimensional change in a given piece of wood can be estimated. Because shrinkage percentages are averages and exact

Table 1 Total (green to oven-dry) tangential and radial shrinkage percentages for selected woods typically found in painting panels. For most woods, the values listed are estimates averaged from various sources for the more common species of the genus. (For more extensive listing of shrinkage values for individual species, consult the following references: Chudnoff 1984; Princes Risborough Laboratory 1972, 1977; U.S. Department of Agriculture 1987.)

		Shrinkage (%)	
Common name	Scientific name	Tangential	Radial
SOFTWOODS			
Spruce	*Picea* spp.	7.4	3.6
Fir	*Abies* spp.	7.6	3.8
Pine, Scots	*Pinus sylvestris*	7.7	4.0
Larch	*Larix* spp.	7.8	3.3
HARDWOODS			
Mahogany	*Swietenia* spp.	5.1	3.2
Walnut, European	*Juglans regia*	6.4	4.3
Chestnut	*Castanea* spp.	6.8	4.0
Willow	*Salix* spp.	7.2	4.2
Alder	*Alnus* spp.	7.3	4.4
Cherry	*Prunus* spp.	7.8	4.2
Ash	*Fraxinus* spp.	8.3	5.2
Poplar	*Populus* spp.	8.5	3.4
Maple	*Acer* spp.	8.8	4.2
Elm	*Ulmus* spp.	9.1	5.2
Lime	*Tilia* spp.	9.5	6.8
Oak, white	*Quercus* spp.	10.2	5.2
Beech	*Fagus* spp.	11.8	5.8

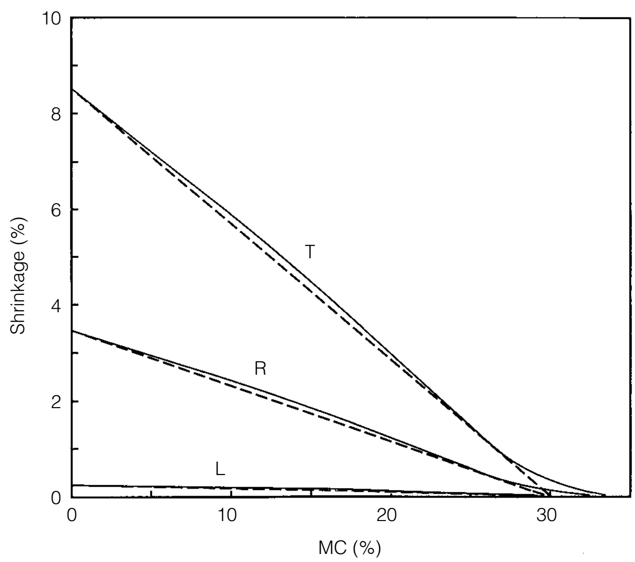


Figure 9
Relationship between MC and shrinkage in the tangential (*T*), radial (*R*), and longitudinal (*L*) directions. Plotted data represent a typical wood such as poplar. Experimental results of carefully dried wood are shown as solid curves. As indicated by dashed lines, a linear relationship is assumed for calculations of approximate shrinkage behavior.

moisture content cannot be predicted, expected dimensional change cannot be calculated with precision. The theoretical dimensional change for a given piece of wood can be calculated using the following formula:

$$\Delta D = \frac{D_i(MC_i - MC_f)}{\frac{FSP}{S} - FSP + MC_i}$$

where: ΔD = dimensional change, in linear units; D_i = initial dimension, in linear units; MC_i = initial moisture content, in percent; MC_f = final moisture content, in percent; FSP = fiber saturation point, in percent (if not known for species, use 30%); and S = published value for shrinkage, in percent (S_l, S_r, or S_t).

In calculating dimensional change for pieces of wood with intermediate or variable growth-ring placement, a modified shrinkage percentage would have to be estimated by rough interpolation between the radial and tangential values. It should be noted that because shrinkage takes place only below the FSP, neither MC_i nor MC_f can be greater than the FSP. Positive values of dimensional change indicate shrinkage; negative values indicate swelling.

As an example, suppose a painting panel is assembled by the edge-gluing of flat-sawn boards that have been identified as poplar (*Populus* spp.); the finished panel measures 76 cm in width. The panel is placed in a building where records have shown a seasonal variation from a high of 60% RH in the summer to a low of 25% during the winter heating season. What dimensional changes in width can be expected?

From the oscillating curve of Figure 7, one can assume EMC extremes of a high moisture content (MC_i) of 10.9%, a low moisture content (MC_f) of 5.4%, and an FSP of 30%. From Table 1, S_t for poplar is given as 8.5%.

The estimated change in the width of the panel from its summer to its winter condition is calculated as

$$\Delta D = \frac{76 \text{ cm } (10.9\% - 5.4\%)}{\frac{30\%}{8.5\%} - 30\% + 10.9\%}$$

$$= \frac{76 \text{ cm } (0.109 - 0.054)}{\frac{0.30}{0.085} - 0.30 + 0.109}$$

$$= \frac{76 \text{ cm } (0.055)}{3.338} = 1.25 \text{ cm}$$

The panel would be assumed capable of shrinking by approximately 1.25 cm. It is important to realize that this calculation would predict the behavior of normal wood free to move, whereas a painting panel may be subject to restraint by its frame and cradling or mounting hardware and by the applied layers of gesso and paint.

Careful evaluation of the formula presented above leads to some important general conclusions. It is apparent that the overall dimensional change, ΔD, is directly influenced by the magnitude of each of the three factors D_i, S, and ΔMC (i.e., $MC_i - MC_f$), which should be considered separately. In the conservation of painting panels, the overall dimensions and species of the panel wood are already determined; the change in MC is the variable within our control.

It must be emphasized that the calculations given above are of theoretical value in understanding potential dimensional change; however, in practical terms they are approximations at best. The formula for predicting dimensional change in unrestrained wood has been found to be no more accurate than ±25%. It would therefore seem fitting to consider a simple graphic method of approximating dimensional change.

Combining the oscillating curve of Figure 7 with the principle of Figure 9, a composite working graph might be devised as shown in Figure 10. For the right-hand portion of the graph, the appropriate shrinkage percentage (S_t, S_r, or interpolated estimate) is taken from published data according to the panel at hand. Users of the graph may translate estimates of changes in RH into percentage dimensional change by following initial and final RH values up and over to corresponding EMC values, then over and down to corresponding S values.

The graphic solution can be applied to the problem discussed above. In the example already proposed, charted graphically as example 1 in Figure 10, a change in RH from 60% to 25% would result in a shrinkage of approximately 1.6% for tangentially cut poplar.

As a numerical check for the calculation of dimensional change in the poplar panel discussed above, if D_i were considered simply as one unit of dimension, the value of ΔD would have been calculated as:

$$\frac{1\,(0.109 - 0.054)}{\frac{0.30}{0.085} - 0.30 + 0.109} = \frac{0.055}{3.338} = 0.0165, \text{ or } 1.65\%$$

Therefore, (76 cm)(1.65%) = (76 cm)(0.0165) = 1.25 cm.

The graphic relationship among RH, MC, and shrinkage draws attention to the point that RH is the important controlling parameter, and dimensional change is the eventual consequence. Too often RH is not given the serious attention it deserves. Although weight of wood is usually not of direct concern, it can be important indirectly if we remember that it reflects the MC. A painting probably loses or gains weight primarily as a response to changes in the MC of its wooden panel. Therefore, the simple monitoring of the weight of a painting, especially when it is being

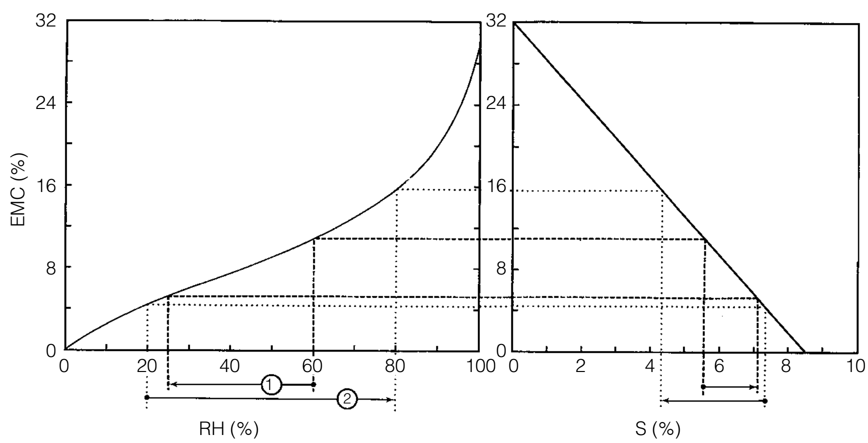


Figure 10
Relationship between RH and EMC, and between EMC and shrinkage *(S)*, shown for tangentially cut poplar (S_t = 8.5%). As shown by dashed and dotted lines, the two examples discussed in the text illustrate the effect of RH change on potential shrinkage and swelling (negative shrinkage).

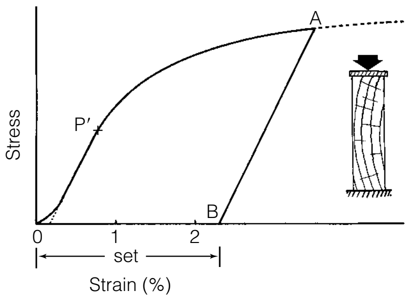


Figure 11
Diagrammatic stress/strain relationship plotted for a wooden element compressed tangentially beyond its proportional/elastic limit (P′) to point A. When unloaded, strain recovers only to point B, resulting in permanent set.

transported or relocated to a new environment, would be an excellent way to detect changing conditions that might eventually result in dimensional-change problems. The relative amount and rate of weight gain or loss could signal developing problems.

With time, the dimensional response of wood may lessen slightly, in part because hygroscopicity of the wood may decrease or because of the mechanical effects of repeated shrinkage/swelling cycles or stress setting of the wood. Nevertheless, experiments with wood taken from artifacts thousands of years old have shown that the wood has retained its hygroscopicity and its capacity to dimensionally respond to changes in MC. The assumption should therefore prevail that wooden objects, regardless of age, can move dimensionally when subjected to variable RH conditions.

Restrained swelling and compression shrinkage

An important consequence of dimensional behavior occurs when wood is mechanically restrained from the swelling that would normally be associated with increased MC. If transverse swelling of wood is restrained, the effect is that of compression by the amount of the restraint. The consequence is therefore best understood in terms of the mechanical properties of wood in compression perpendicular to the grain.

As shown in Figure 11, the elastic limit of transverse compressibility of wood is typically between 0.5 and 1%, and compression beyond this elastic limit results in permanent strain, or *set*. The importance of the low elastic limit is evident when it is compared quantitatively to typical values of free swelling of wood subject to common variation in RH, with its resultant MC change. For example, consider a panel prepared from tangentially cut boards of poplar with an average tangential shrinkage percentage (from Table 1) of 8.5%. Suppose further that the panel had been prepared from wood in equilibrium at 20% RH and mounted into a frame that would confine it from swelling along its edges, and that the panel were later subjected to a humidity of 80% until EMC was reached. As shown in Figure 10, example 2, a change from 20% to 80% RH would be expected to produce a swelling (negative shrinkage) of approximately 3% in an unrestrained panel. However, given our restrained panel with an elastic limit of less than 1%, at least two-thirds of its restrained swelling is manifested as compression set. If the panel is eventually reconditioned to the original 20% humidity, it would recover only its elastic strain and would shrink to a dimension some 2% or more smaller than its dimension at the original MC. This loss of dimension from cyclic moisture variation under restraint is called *compression shrinkage*. This mechanism is a very common cause—and perhaps the one most often incorrectly diagnosed—of dimensional problems in wooden objects. Too often any loss of dimension of a wooden component is interpreted simply as "shrinkage," with the assumption that MC must be lower than it was originally.

Cracks and open gaps in painting panels that are attributed to simple drying and shrinkage may in fact be traceable to compression shrinkage induced by restrained swelling. The elastic limit in tension perpendicular to the grain is of similar magnitude to that in compression—0.5–1%.

However, the compression set accumulated by excessive restrained swelling cannot simply be reversed by continuing the restraint of the panel during the drying/shrinkage phase of the cycle, because the amount of tensile strain is limited to about 1.5%, whereupon failure occurs. Therefore, if

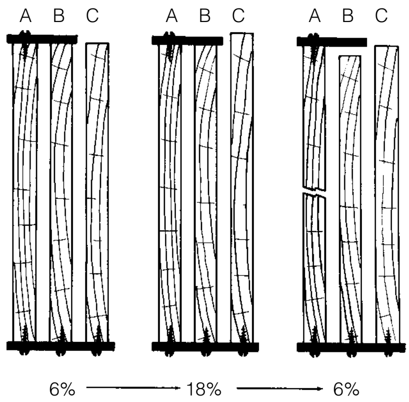


Figure 12
Classic experimental demonstration of the effects of restrained swelling and compression shrinkage on elements of wood representing panels. At an initially low MC, three matched specimens are machined to equal tangential dimension. Element A is restrained and fastened to rigid restraining surfaces at both edges, element B is restrained but fastened only at one edge, and element C is unrestrained and fastened only at one edge. All elements are slowly conditioned to a high MC and then brought back to the original low MC. The restrained specimens, A and B, show typical consequences of compression shrinkage.

a panel has its edges fastened in place rather than being simply confined, it may show no ill effects during the humid/swelling phase of the cycle but may crack open when redried to its original moisture condition.

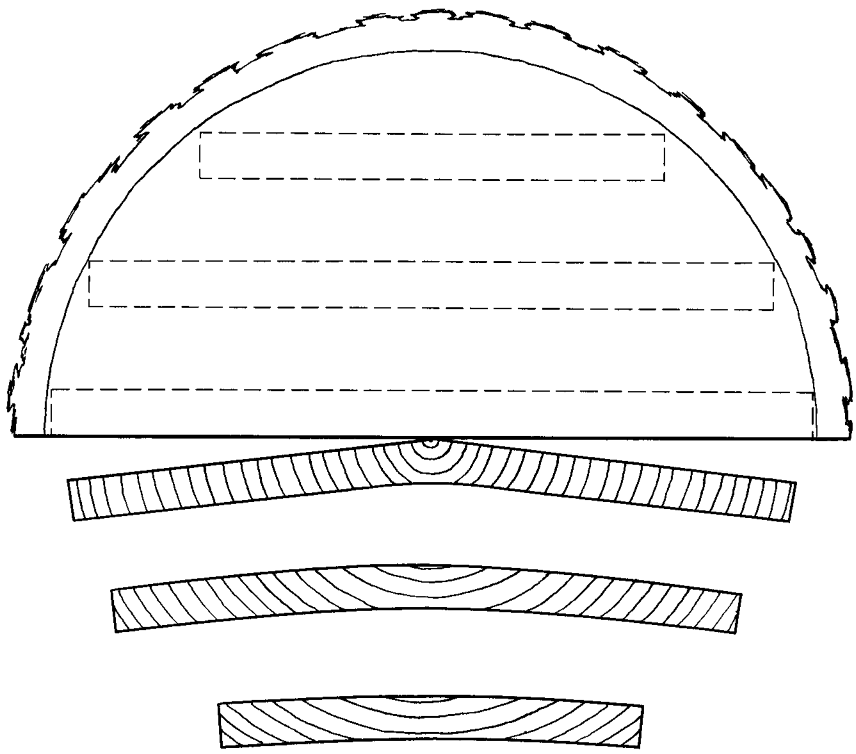
The classic experiment shown diagrammatically in Figure 12 demonstrates the typical extreme consequences of restrained swelling and compression shrinkage in panels.

Warp

Although dimensional change alone may be a serious consequence of moisture variation, even minor amounts of uneven shrinkage or swelling can cause warp, defined broadly as the distortion of a piece from its desired or intended shape. Various forms of warp include *cup* (deviation from flatness across the width of a board), *bow* (deviation from lengthwise flatness of a board), *crook* (departure from end-to-end straightness along the edge of a board), and *twist* (in which four corners of a flat face do not lie in the same plane).

In painting panels, cupping is perhaps the most commonly encountered form of warp and can result from a variety of causes, singly or in combination. Uneven moisture change in opposite faces of a panel may cause a slight, and usually temporary, cupping concave to the drier face, which may disappear as moisture equalizes through the thickness of the panel. Growth-ring placement within a board is an important factor in the determination of cupping potential. Quarter-sawn (radially cut) boards tend to remain flat as MC changes. Flat-sawn (tangentially cut) boards, however, routinely cup, or attempt to cup, as they season (Fig. 13). Cupping results from the different components of tangential and radial grain orientation across opposite faces of the boards. Panels fashioned from flat-sawn boards will tend to cup additionally as MC varies. If

Figure 13
Warp in flat-sawn (tangentially cut) boards during seasoning. The severity and distribution of cupping is related to the location in the log and the resulting curvature of growth rings, as well as to the tangential/radial ratio of shrinkage percentages. Note that flat-sawn boards located closest to the pith have the most severe cup, concentrated near the center. Panels that are held flat may crack if the normal cupping is prevented.



flat-sawn boards or panels are held flat and restrained from attempted cupping, cracking may result along the grain into the concave face.

A less obvious source of cupping in painting panels is compression shrinkage. The causal mechanism is typified by a panel painted only on the face side, its unpainted back therefore exposed to much more rapid moisture sorption. In the case of such a panel originally coated with gesso and painted when the wood was at a fairly low MC, subsequent exposure to high humidity causes the wood at the back surface to adsorb moisture and go into compression set. If the panel were mounted by fastening at its edges, the expected cupping concave to the painted surface would be largely restrained. Upon restoration of a normally low humidity condition, the rear of the panel now manifests its compression shrinkage and shortens; the panel then cups concave to the unpainted surface. This mechanism is commonly the real source of cupping that has been attributed to tangential/radial shrinkage and "drying out." Uneven compression shrinkage can overshadow the effects of tangential/radial shrinkage and can also produce cupping in radially cut panels that would otherwise remain flat under simple moisture cycling.

Note

1 The term *green* as applied to wood suggests the moisture condition in the living tree or in freshly cut timber. However, because many important properties, such as dimension and strength, are unchanged by loss of free water, green wood is taken as any condition of MC above the FSP.

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Identification of Wood in Painting Panels

R. Bruce Hoadley

THROUGH MANY CENTURIES wooden panels were a standard surface for artistic painting. In such works of art, the rendering itself typically receives intensive examination, whereas the panel supporting the painting is sometimes evaluated simply as wood, with little concern as to its species or characteristics. In modern conservation and curatorial investigation, however, there is increasing appreciation for the potential importance of identifying the wood of panels. Considering the natural range of an identified species of wood may have important implications as to the geographic origin of a painting. It may become evident that individual artists or regions preferred certain woods or that some woods were chosen over others because of properties such as dimensional stability or ease of seasoning without defects. Finally, proper identification of wood is fundamental to conservation treatment when repair or replacement is involved or when it is important to anticipate the properties or behavior of a panel.

Simply stated, the process of wood identification usually involves the visual recognition of anatomical features of the wood that singly or in combination are known to be unique to a particular species or group of species. Physical properties such as color, odor, specific gravity, relative hardness, or reaction to chemical reagents may sometimes be helpful, but the most important diagnostic features of the wood relate to its cellular structure. Therefore, an understanding of the basics of wood anatomy is fundamental to wood identification.

Visual features—that is, those apparent without magnification—are the obvious starting point of the identification process and may provide at least an indication of the wood's identity. In most cases, however, portions of the wood must be examined under magnification. An initial classification of an unknown wood is routinely made by observing features evident with a hand lens on end-grain surfaces prepared with a razor blade or sharp knife. Final determination, or verification of tentative visual or hand-lens results, is best made on the basis of minute detail observed in razor-cut thin sections of wood tissue examined with a microscope.

For the more common woods, the necessary features for identification are soon learned and memorized, and thorough examination of macroscopic and microscopic detail gives an immediate identification. Otherwise, the compiled characteristics can be compared directly with samples of known wood, with photographs or descriptive reference material, or with information in computer databases. Expertise in wood identification therefore requires at least a general familiarity with the anatomical characteristics and nomenclature of wood as well as the availability of suitable reference material for the woods being considered.

It is beyond the scope of this article to present a complete treatise on wood anatomy and the identification of all woods that might be encountered in painted panels. Instead, an attempt will be made to provide a primer of the basics of wood anatomy along with routine approaches and techniques for wood identification. In addition, a summary of pertinent features and the identification process is presented for a selection of woods—a sampler of sorts—most commonly found in painting panels.

Woods and Their Names

Taxonomy, the science of classifying living things, provides a systematic approach to the study of wood tissue, as closely related trees can be expected to have similarities of anatomical features. Wood identification therefore finds its foundation in taxonomy, and narrowing the identity of an unknown piece of wood to its tree species follows closely the taxonomic network. In taxonomic classification, woody plants of tree sizes in temperate regions of the world are found principally in either of two classes, the gymnosperms, which include the conifers, or *softwoods,* and the angiosperms, wherein the *hardwoods* occur. In turn, classes are divided into orders, families, genera (singular: genus), and, finally, species (Table 1).

Each species is designated by a scientific name, a Latinized, italicized binomial term comprising its genus name followed by its species name, or *epithet*. For example, the species we know by the common name of black poplar has the scientific name of *Populus nigra—Populus* indicating the generic name for all poplars and *nigra* the epithet for the black poplar species. Botanical names are universally accepted among scientific disciplines, and their usage is therefore preferred in order to prevent the confusion that may result when a species has a number of common or local names in a particular language. For example, Norway spruce, *Picea abies,* is also known in English as European spruce or simply as whitewood.

The ultimate objective in wood identification is to determine the species of tree from which a particular piece of wood originated, and it is therefore always proper and desirable to use the species name to designate a piece of its wood. Unfortunately, the woods of species within a genus (such as, for example, the poplars) are commonly so similar that they lack distinguishing features and cannot be separated. In this situation the scientific name of the genus is given, followed by the designation "sp." (plural: spp.), printed in roman (not italic) script. As an example, a painting panel might, in fact, be black poplar but can perhaps only be identified as poplar; it is therefore designated *Populus* sp.

Wood Anatomy: The Basis for Identification

Wood identification is based primarily on anatomical structure and should proceed with the awareness that wood is a composite mass of countless numbers of cells. These cells were produced by cell division of the cambium, the layer of reproductive tissue beneath the tree's bark, and the cyclic variations of this growth process are recognizable in most woods as growth rings. Each wood cell has an outer wall that surrounds an internal cavity. In the living tree, a cell cavity may contain a living protoplast, or at least some liquid sap, whereas in the wood found in painted panels, the now-dried cells are defined by their walls, their central cavities apparently empty in most cases.

Wood cells are typically elongated, varying from short barrel shapes (sometimes large enough in diameter to be individually visible) to extremely long fibers that are too small in diameter to be seen individually without considerable magnification. Most of the cells—usually more than 90%—are elongated in the direction of the tree stem or branch. These cells are termed *longitudinal* cells in relation to the stem axis. The remainder of the cells are *ray* cells, elongated horizontally in the tree and therefore perpendicular to the longitudinal cells. Ray cells, arranged to form flat, ribbonlike groups, radiate outward from the central pith of the stem. If just the longitudinal cells could be removed without disturbance to the ray cells, the rays in a tree stem would appear somewhat like bristles in a giant bottlebrush.

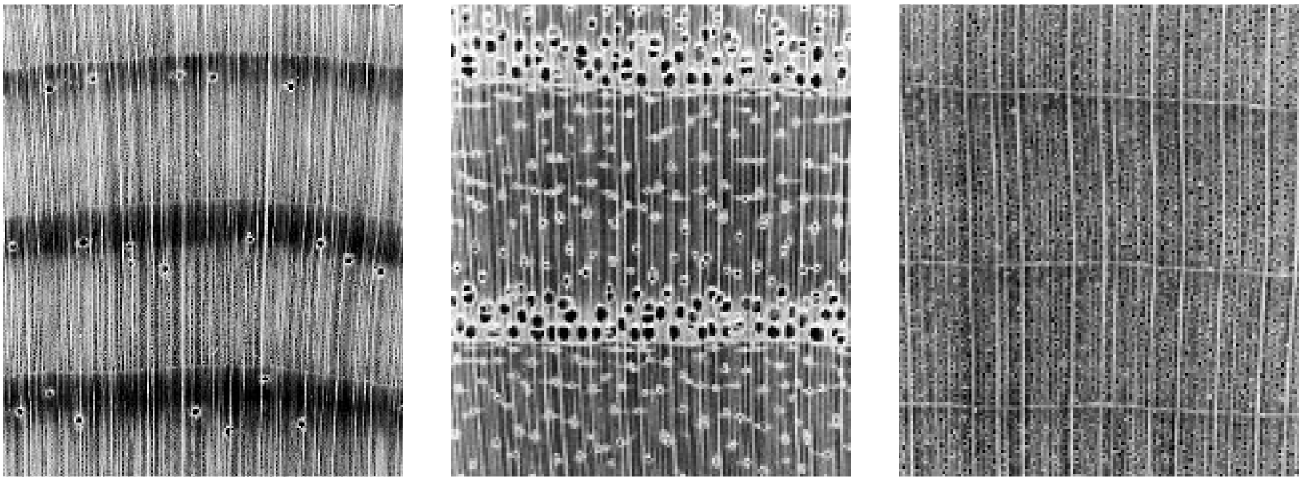
Wood Identification Techniques

There is no single technique or method of wood identification best for every situation or for every species. Surely the investigator begins the process by taking advantage of any obvious features that may immediately suggest an answer. Only a few woods, however, such as oak (*Quercus* spp.) and beech (*Fagus* spp.), have unique visual features that enable fairly reliable identification. Among the other woods, visual features such as distinctive heartwood color, as in walnut (*Juglans* spp.) and cherry (*Prunus* spp.), or physical properties, such as the greater density and hardness of maple (*Acer* spp.) as compared to the lightness and softness of poplar (*Populus* spp.), are occasionally helpful. However, colors may fade or deepen with age, density may be difficult to assess in panels that are framed or cradled, and overall visual features may be obscured by gesso or by the painting itself. Further examination requires magnification.

Hand-lens examination

Beyond the casual observation of visual features discussed above, the next step is to determine the orientation of the grain in the wood and then to find a location where the wood can be cut across the grain, such that the longitudinal cells will be exposed in cross section. In painting panels these locations will be along two opposite edges of the panel. An area of approximately 5–10 mm square will usually reveal important information. The final surfacing cuts should be made with a razor-sharp instrument to ensure that the wood tissue is cleanly severed so that cellular detail will be visible. A surface so exposed is called a transverse surface, a cross-sectional surface, or an end-grain surface.

The width and placement of the growth layers (growth rings) are usually immediately apparent. In a few species of hardwoods, such as oak, chestnut (*Castanea* spp.), ash (*Fraxinus* spp.), and mahogany (*Swietenia* spp.), the cells forming vessels (called *pores* when exposed on transverse surface) are large enough to be individually visible without magnification. And, with magnification, even the smallest pores can also be seen. A 10× magnifier, referred to simply as a hand lens, is most commonly used. Hand-lens examination also serves to separate the hardwoods, in which all longitudinal cells appear uniformly small. Figure 1a–c demonstrates the appearance of typical softwood and hardwood end-grain surfaces as seen under low-power magnification.



a b c

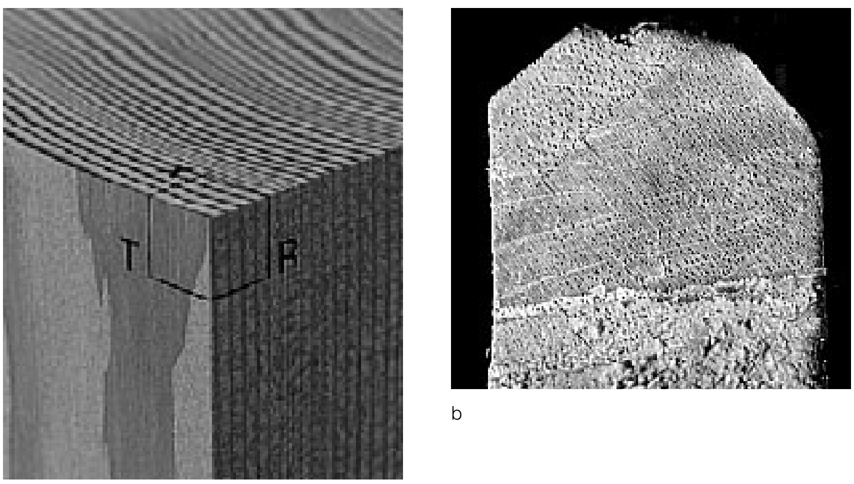
Figure 1a–c
Woods can be initially classified into general types by examination of transverse surfaces with a 10× hand lens. Examples shown are (a) a softwood, pine (*Pinus sylvestris*), (b) a ring-porous hardwood, ash (*Fraxinus* sp.), and (c) a diffuse-porous hardwood, maple (*Acer* sp.).

Microscopic examination

For microscopic examination of wood, thin sections taken from the transverse surface are sometimes useful, but the most valuable information is usually found in radial and tangential sections. Examination of a cleanly cut end-grain surface with a hand lens reveals the orientation of radial and tangential directions in the area of the wood sample under scrutiny, and accessible surfaces can be split or shaved down along the radial and tangential planes in the grain direction. The tangential plane is formed parallel to the growth rings, the radial plane perpendicular to the growth rings. Figure 2 illustrates the principal planes of wood structure and the preparation of small areas of radial and tangential surfaces with respect to the transverse surface.

During work on painting panels, it is often possible to cut sections directly from a corner edge of the panel. In other cases it may be more expedient to use material removed in conservation work or simply to remove a small piece for identification. A piece 3 × 3 × 10 mm will typically be sufficient.

From the surface of any of the principal planes of the panel or wood sample, a tiny slice of tissue is carefully sliced off with a razor blade.



a b

Figure 2a, b
Block of softwood (*Pseudotsuga menziesii,* Douglas-fir) (a) machined to expose principal planes: X = transverse (cross-sectional or end-grain); R = radial; T = tangential. A small portion of the end-grain edge of this panel of poplar (*Populus* sp.) was surfaced with a razor blade (b). On this exposed transverse surface, the anatomical orientation is revealed on the basis of the growth ring and ray placement. The upper right corner was beveled parallel to the rays to produce a radial plane. The upper left corner was then beveled parallel to the growth ring to produce a tangential plane. From the surfaces of any of these principal planes, thin tissue sections can be taken for microscopic examination.

The section is placed on a glass microscope slide and covered with a thin cover glass; enough water is added with an eyedropper to surround the tissue section without excessively flooding the area under the cover glass. When placed on the stage of a standard compound light microscope, the translucent section is illuminated with transmitted light, and the cellular detail can be examined at magnifications up to 500× (Fig. 3).

Slicing of the section is most critical to success. Initial surfacing cuts might be made with a sharp knife, a replaceable scalpel blade, or an industrial-type razor blade, but sectioning of tissue is best done with a double-edged or equivalent-quality razor blade, although these blades may be too fragile for higher-density woods, especially on transverse surfaces. It helps to moisten surfaces with water prior to sectioning. For small pieces removed from the panel, sectioning will be much easier if the sample is boiled or soaked in hot water for a few minutes. Sections should be removed with a smooth, sliding, slicing action, rather than by pushing or forcing the cutting edge directly forward.

Sections should be sliced as thinly as possible, ideally not more than one or two cell diameters thick. Skimming off several tiny, thin bits (1–2 mm across) will usually yield better results than attempting to take a larger single section, which will be mostly too thick to show detail. With hand sectioning, the sections will not be uniformly thin, but if they are well cut, they will have appropriately thin areas near their edges where detail will be visible.

Survey of Panel Woods

Table 1 lists woods common to painting panels. This selection will probably account for the species found in well over 95% of painting panels. Species within most genera cannot be separated on the basis of wood tissue alone. Nevertheless, in cases in which different species are found in distinctly different geographic localities, the known origin of a painting may suggest a probable identification. This section presents key diagnostic features of the woods listed in Table 1 and provides the reader with a foundation for identifying them in painting panels. It is highly recommended, however, that the reader examine known samples of woods and consult

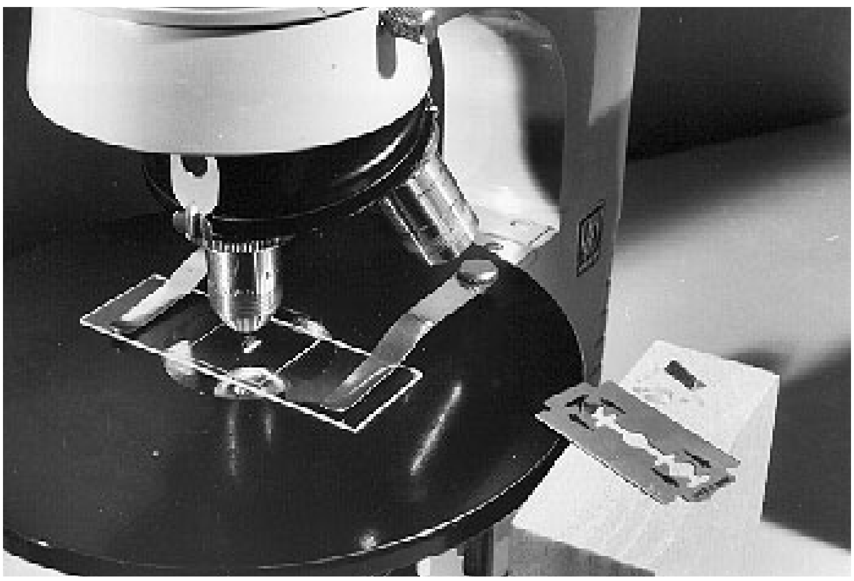


Figure 3
The small specimen of wood near the razor blade is sufficient for identification. A clean cut of a transverse surface reveals the orientation of the rays and growth rings, enabling accurate radial and tangential surfaces to be prepared. From any of the three principal surfaces, a tiny, thin section can be removed with a razor blade and mounted on a slide with a drop of water for microscopic examination, as shown.

Table 1 Selected woods found in painted panels. Generic designations of woods are followed by examples of the more common European species.

Common name	Scientific name	Figures
SOFTWOODS (CONIFERS)		
Fir	*Abies* spp.	7, 9c
silver fir	*A. alba*	
Larch	*Larix* spp.	6, 10b
European larch	*L. decidua*	
Spruce	*Picea* spp.	5, 8, 9b, 10a
Norway spruce, European spruce, whitewood	*P. abies*	
Pine	*Pinus* spp.	
Scots pine	*P. sylvestris*	1a, 4, 9a
HARDWOODS		
Maple	*Acer* spp.	1c, 19, 26b, 27d, 27e
field maple	*A. campestre*	
Norway maple	*A. platanoides*	
sycamore, great maple	*A. pseudoplatanus*	
Alder	*Alnus* spp.	18, 24a, 25b
common alder, black alder, European alder	*A. glutinosa*	
gray alder	*A. incana*	
Chestnut	*Castanea* spp.	12
sweet chestnut, European chestnut	*C. sativa*	
Beech	*Fagus* spp.	17, 27f
European beech	*F. sylvatica*	
Ash	*Fraxinus* spp.	1b, 13
European ash	*F. excelsior*	
Walnut	*Juglans* spp.	15
European walnut	*J. regia*	
Poplar	*Populus* spp.	2b, 23, 24b, 25a, 27a, 28a
white poplar	*P. alba*	
black Italian poplar	*P. canadensis* var. *serotina*	
black poplar	*P. nigra*	
European aspen	*P. tremula*	
Cherry	*Prunus* spp.	20, 26c
European cherry, wild cherry	*P. avium*	
Pear	*Pyrus* spp.	21
common pear	*P. communis*	
Oak	*Quercus* spp.	11
Turkey oak	*Q. cerris*	
holly oak, holm oak	*Q. ilex*	
sessile oak, durmast oak	*Q. petraea*	
pubescent oak, white oak	*Q. pubescens*	
common oak, pedunculate oak	*Q. robur*	
Willow	*Salix* spp.	28b
white willow	*S. alba*	
Mahogany	*Swietenia* spp.	16, 25c, 27b, 29
Central American mahogany	*S. macrophylla*	
Lime	*Tilia* spp.	22, 26a, 27c
small-leaved lime	*T. cordata*	
large-leaved lime	*T. platyphyllos*	
European lime	*T. vulgaris*	
Elm	*Ulmus* spp.	14
smooth-leaved elm	*U. carpinifolia*	
wych elm	*U. glabra*	
Dutch elm	*U. hollandica* var. *hollandica*	
English elm	*U. procera*	

references of wood anatomy to see how variable or how consistent different specimens of a species can be.

The equipment necessary for a wood identification procedure includes a sharp knife or other woodworking tool for exposing fresh wood surfaces or for removing small specimens, razor blades (single- and double-edged types) for final surfacing and sectioning, a 10× hand lens, a transmission light microscope (capable of magnification up to 400–500×), glass slides, cover glasses, and an eyedropper. It is preferable that the investigator have reference samples of the species under consideration so that he or she can compare key features to those seen in the reference samples rather than relying on the written material and photographs alone.

As an initial step, a transverse surface of the unknown wood should be examined with a hand lens to determine whether the wood is a hardwood or a softwood. If there is any difficulty in establishing this distinction, a transverse section quickly examined under the microscope will show the radial rows of tracheids that characterize softwoods or the varied cell types with larger pores characteristic of all hardwoods.

Softwoods

With the hand lens alone, identification of the conifers is tentative at best, but it is usually worthwhile to evaluate any noteworthy macroscopic features. Coniferous wood tissue consists mainly of small and indistinct tracheids, and in transverse view the overall cellular appearance is confusingly similar among all conifers, as shown among the examples presented in Figures 4–7. Within a growth ring the contrast between earlywood and latewood may be characteristic. For example, in Scots pine (*Pinus sylvestris*) and larch (*Larix* spp.) there is a rather abrupt transition from the lighter mass of earlywood tracheids to the darker, denser latewood; in spruce (*Picea* spp.) and fir (*Abies* spp.) there is less contrast between earlywood and latewood, and the transition from earlywood to latewood is more gradual than abrupt.

One important feature seen under the hand lens is resin canals, which are tubular passageways formed by a cylindrical sheath of cells called epithelial cells. During the sapwood stage, the epithelial cells are living and exude resin into the resin canals. The resin canals, being three to five times the diameter of the surrounding tracheids, are visible on transverse surfaces under a hand lens. Among the conifers covered in this article, resin canals are present in pine (*Pinus* spp.), spruce, and larch (Figs. 4–6). Fir, however, does not contain resin canals (Fig. 7).

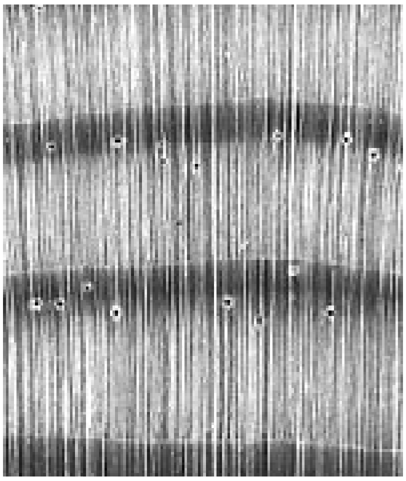
In pines the resin canals are large, solitary, and usually conspicuous, relatively numerous, and uniformly distributed in virtually every growth ring. In spruce and larch the resin canals are smaller and less numerous, and they tend to occur unevenly. They are apparently absent in some growth rings but may occur in tangential groups of two or more.

For coniferous woods, observations such as those discussed above will suggest possible answers, but minute features evident through microscopic examination of tangential and radial thin sections provide the most reliable basis for identification.

Routinely useful microscopic features include the height and width of the rays (as determined by cell count) viewed tangentially; in radial view, diagnostic features include the types of ray cells present, the shape and number of cell-wall pits (voids in the cell walls connecting to

Figure 4, right
Pine (*Pinus sylvestris*), transverse surface.

Figure 5, far right
Spruce (*Picea* sp.), transverse surface.



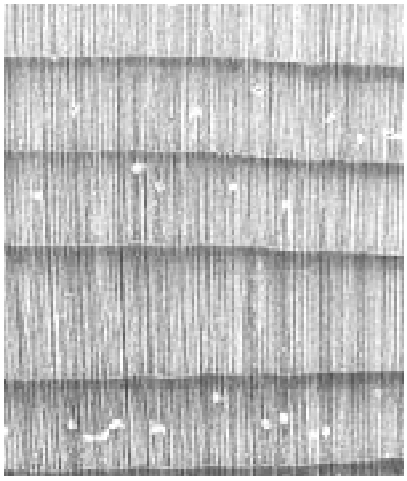
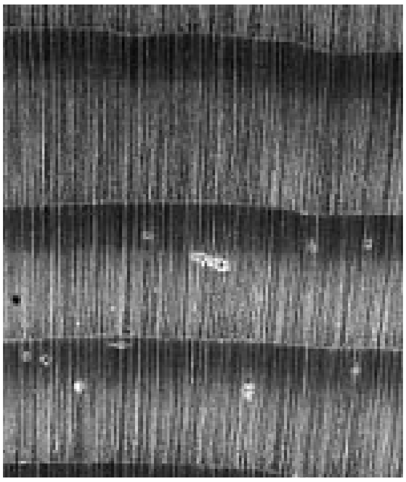
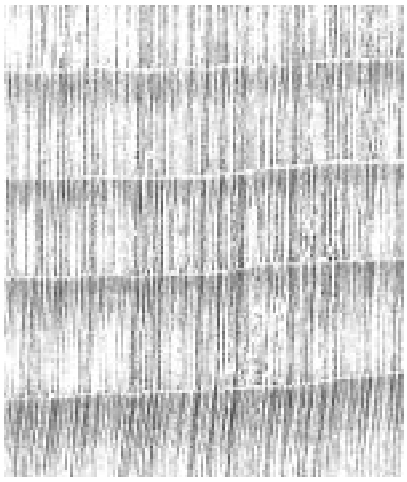


Figure 6, right
Larch (*Larix* sp.), transverse surface.

Figure 7, far right
Fir (*Abies* sp.), transverse surface.





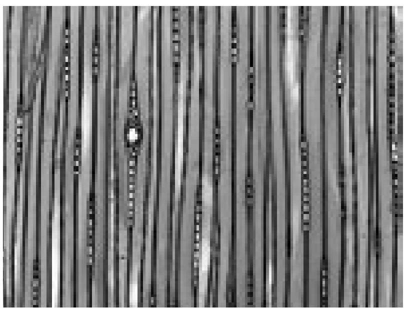
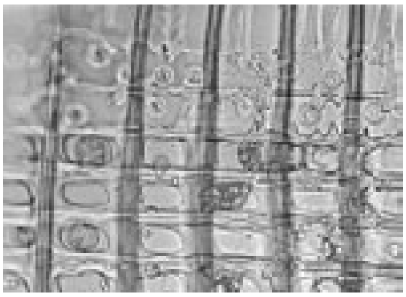


Figure 8
Tangential section of spruce (*Picea* sp.) showing several uniseriate rays and one fusiform ray with a centrally located transverse resin canal.

matching pits in adjacent cells), the smoothness of the cell walls, and the presence and color of the cell contents. Conifers that contain vertical resin canals, evident on transverse surfaces, also contain horizontal resin canals located within special rays called *fusiform* rays (Fig. 8). Therefore, the presence of resin canals can be confirmed by locating fusiform rays on tangential sections examined microscopically. Scots pine and fir are separated from one another and from spruce and larch by microscopic examination of radial sections (Figs. 9a–c). On such sections, groups of smaller (horizontal) ray cells will be evident crossing perpendicular to the larger (vertical) longitudinal tracheids. Of special significance are the *cross fields*—the rectangular areas formed where individual ray cells contact individual longitudinal tracheids. The pits occurring on these cross fields are classified in terms of size and shape. Scots pine, the principal pine of Europe and Asia, is distinct in having dentate ray tracheids (tracheids with jagged or toothed walls) and large cross-field pits (called windowlike pits) in the ray parenchyma cells (Fig. 9a). European larch (*Larix decidua*) and Norway spruce (*Picea abies*) have more or less smooth-walled ray tracheids and small multiple cross-field pits (called piceoid pits, each typically a rounded pit with a diagonal slash, similar in appearance to the Greek letter *phi*) in the ray parenchyma cells (Fig. 9b). Larch and spruce are separated by examination (in radial sections) of the first-formed longitudinal tracheids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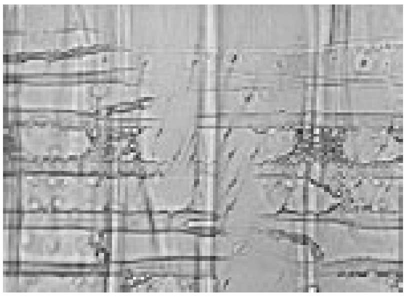

b

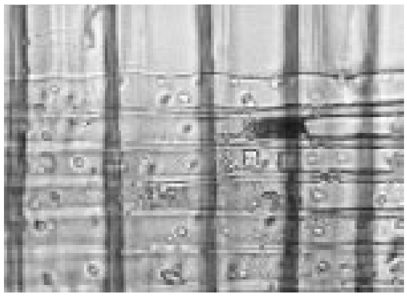

c

Figure 9a–c
Radial sections of (a) Scots pine *(Pinus sylvestris)* showing a portion of a ray: the upper two rows of ray cells are dentate ray tracheids, and the lower four rows of cells are ray parenchyma with large windowlike cross-field pitting; (b) spruce (*Picea* sp.) showing a portion of a ray; the upper and lower two rows of ray cells are ray tracheids, and the central two rows of cells are ray parenchyma with piceoid cross-field pitting; and (c) fir (*Abies* sp.) showing a portion of a ray: all ray cells are ray parenchyma with taxodioid cross-field pitting, and crystals are present in the third row (counted from the top) of ray parenchyma.

in the earlywood. In spruce, along a given earlywood tracheid, the large bordered pit pairs on the radial walls occur singly and only occasionally are paired; in larch, tracheids with many consecutive paired pits will be commonly found (Fig. 10a, b).

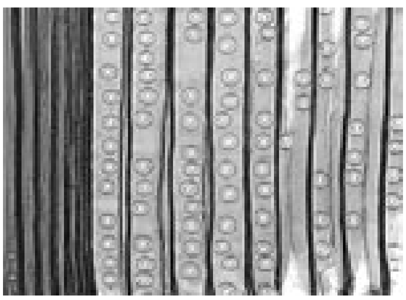
If no resin canals are seen on the transverse surface with the hand lens or if a tangential section reveals no fusiform rays, the wood may be fir. Microscopic examination of a radial section will reveal that ray tracheids are absent and that all rows of ray cells are of the same type of cells—ray parenchyma. The cross fields have multiple small pits called taxodioid pits, rounded pits with narrow borders appearing like the capital letter O (Fig. 9c).

It is always possible that the unknown wood under consideration is none of those described here. If the features of an unknown do not seem to agree closely with any of the woods described here, it is necessary to consult the literature to pursue a more thorough investigation. For example, there are numerous other pines that also have large resin canals but non-dentate ray tracheids or other types of cross-field pitting. For example, other softwoods that have been found in painting panels include the true cedars, *Cedrus* spp. (cedars may also contain resin canals and fusiform rays), and Mediterranean cypress, *Cupressus sempervirens* (containing longitudinal parenchyma, vertically oriented cells occurring among the longitudinal tracheids; they have dark contents, conspicuous when observed microscopically).

Hardwoods

The hardwoods can be roughly classified by examination of transverse surfaces with a hand lens and evaluation of the size and arrangement of pores. If the wood has relatively large pores grouped into the first-formed portion of the growth ring, forming a conspicuous zone, the wood is

Figure 10a, b
Radial sections showing bordered pits on radial walls of longitudinal tracheids in earlywood. In (a) spruce (*Picea* spp.), bordered pits are usually unpaired; and in (b) larch (*Larix* spp.), bordered pits are commonly paired.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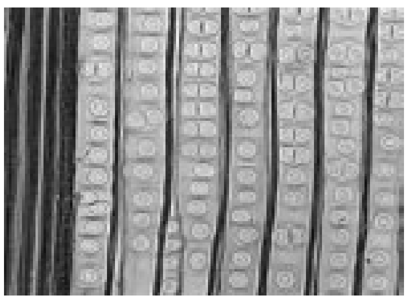
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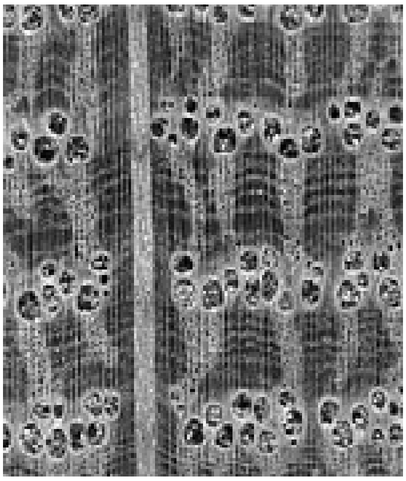
Figure 11, right
Oak (*Quercus* sp.), transverse surface.

Figure 12, far right
Chestnut (*Castanea* sp.), transverse surface.



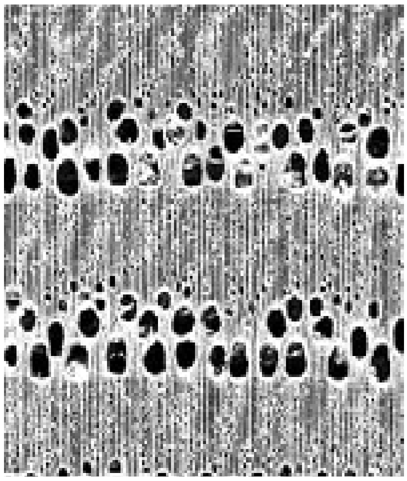
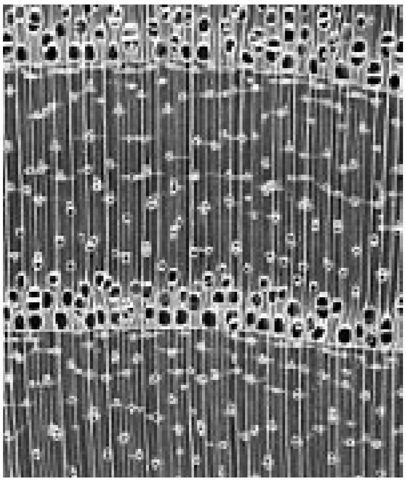
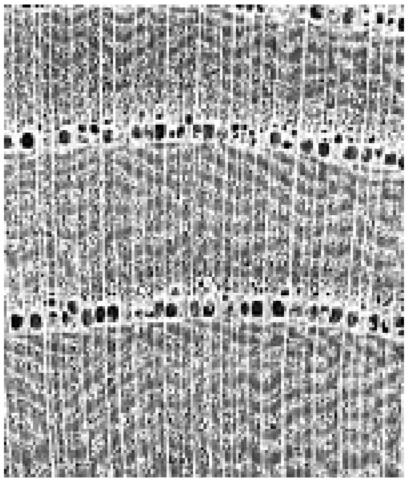


Figure 13, right
Ash (*Fraxinus* sp.), transverse surface.

Figure 14, far right
Elm (*Ulmus* sp.), transverse surface.





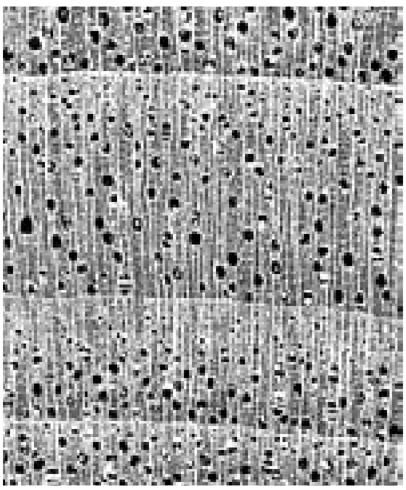


Figure 15
Walnut (*Juglans* sp.), transverse surface.

classified as ring porous. Examples of woods in this category include oak, chestnut, ash, and elm (*Ulmus* spp.) (Figs. 11–14). If large earlywood pores do not form a distinct zone, the wood may be considered semi-ring-porous, as walnut (Fig. 15). If the pores appear uniform in size and are evenly distributed throughout the growth ring, the wood is diffuse porous (Figs. 16–23). Tropical hardwoods are commonly diffuse porous, and in many tropical species the pores are relatively large, as in mahogany. Most diffuse-porous hardwoods of the temperate regions are fine textured: that is, the pores are relatively small in diameter, as in maple or poplar.

Although pores are visible with a hand lens, all other cells are too small in diameter to be seen individually on transverse surfaces. Groups or masses of cells may, however, be recognized. Masses of denser, thick-walled fiber cells usually form a darker background mass against which groups of thinner-walled parenchyma cells produce lighter-colored zones, lines, or patterns that may be characteristic of a species. For example, the tangential lines of parenchyma are distinctly visible in mahogany (Fig. 16). Perpendicular to the growth rings, the rather straight lines of the rays are also apparent. Rays range in size among hardwoods, from large and conspicuous in oak and beech to fine and barely perceptible with a hand lens on transverse surfaces in poplar and pear.

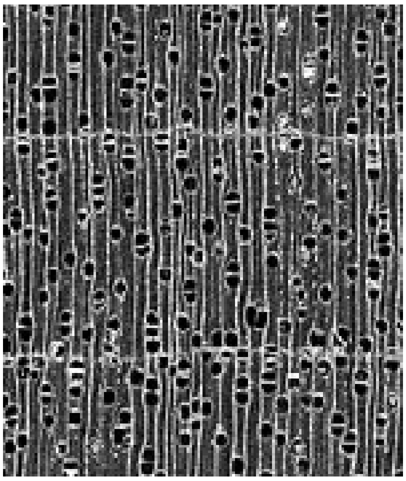


Figure 16
Mahogany (*Swietenia* sp.), transverse surface.

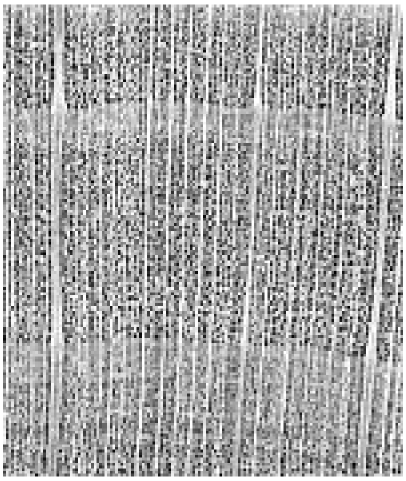


Figure 17
Beech (*Fagus* sp.), transverse surface.

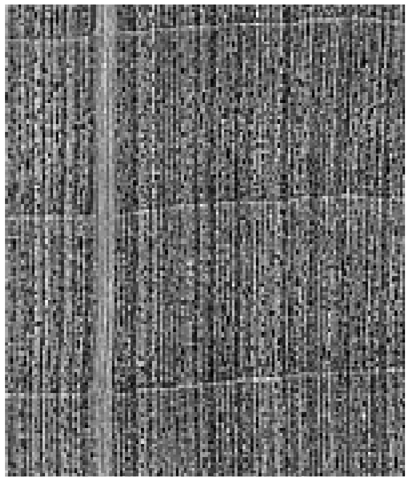


Figure 18
Alder (*Alnus* sp.), transverse surface.

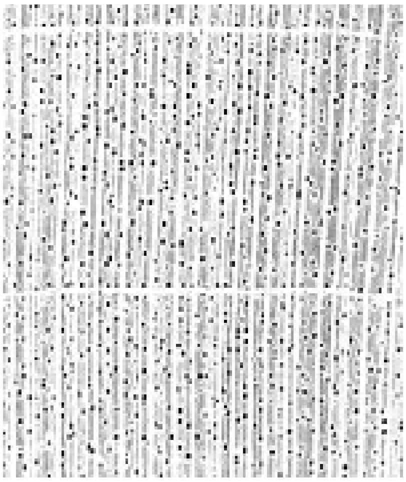


Figure 19
Maple (*Acer* sp.), transverse surface.

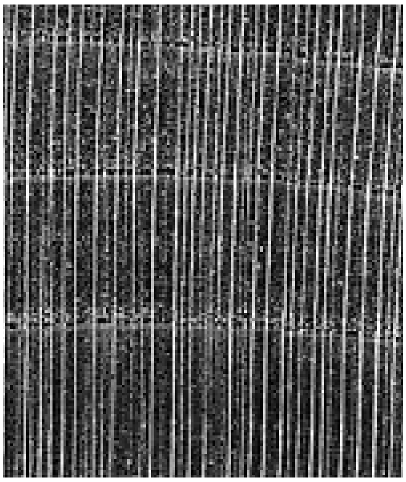


Figure 20
Cherry (*Prunus* sp.), transverse surface.

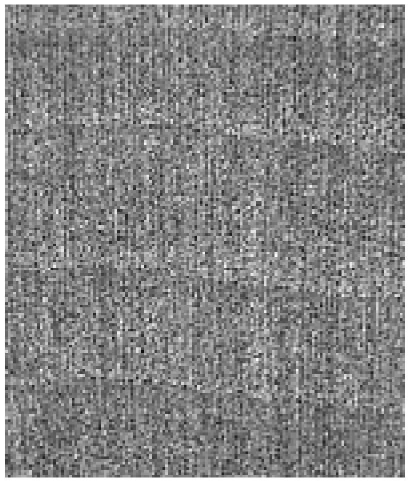


Figure 21
Pear (*Pyrus* sp.), transverse surface.

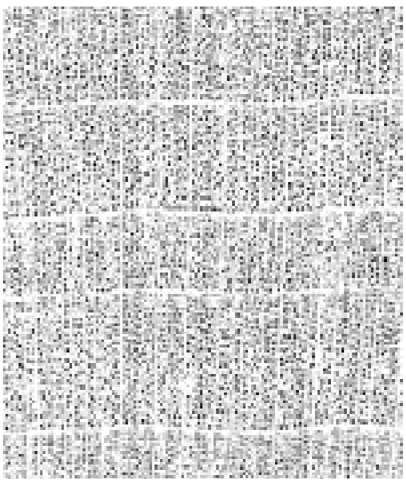


Figure 22
Lime (*Tilia* sp.), transverse surface.

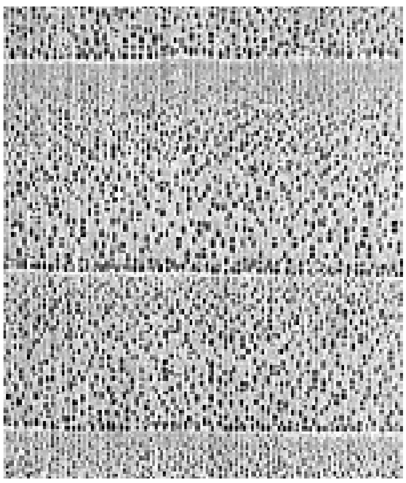


Figure 23
Poplar (*Populus* sp.), transverse surface.

In summary, with nothing more than a hand lens, some hardwoods can be identified at least to the level of their genus by the size and distribution of the pores, the size and distinctiveness of rays, and characteristic patterns of parenchyma cells.

Among the hardwoods, especially the diffuse-porous hardwoods, microscopic analysis also provides the best means of confirming many genera and sometimes provides a means of separating species within a genus. Useful features include ray seriation (the width of a ray determined by a count of the number of cells across the ray as viewed in tangential section), the type of perforations (openings of the end walls of vessel cells), the type of intervessel pitting (distinctive patterns of multiple pits in cell walls connecting vessels laterally), and the presence or absence of spiral thickenings on the walls of vessels.

Ring-porous and semi-ring-porous hardwoods

When end-grain surfaces are examined with a hand lens, four of the hardwoods presented here stand out as ring-porous woods by virtue of the conspicuously larger pores forming a distinct row or zone of earlywood in each growth ring, as is clearly seen in Figures 11–14. Woods with pores varying gradually in size, from larger earlywood pores to smaller latewood pores, and without clearly defined earlywood and latewood zones are classified as semi-ring-porous (synonymous with semi-diffuse-porous) woods. An example is walnut (Fig. 15). Ring-porous and semi-ring-porous woods can usually be reliably identified by careful consideration of features seen under a hand lens, although it is good practice to verify the identification by a check of appropriate microscopic features.

In *oak* (Fig. 11), the regular occurrence of very large rays is the key feature; they are visible on virtually any surface, forming conspicuous radial lines across transverse surfaces and visible as distinct lines up to several inches long along tangential surfaces. On radial cuts the rays emerge as irregular but conspicuous patches of contrasting tissue referred to as *ray fleck*. Microscopic examination of a tangential section reveals that the large conspicuous rays are up to thirty to forty cells wide and thus are *multiseriate*. Among these are the countless narrow rays that are only one cell, called *uniseriate*.

In *chestnut* (Fig. 12), as in oak, the latewood pores occur in irregular patches that wander radially across the latewood, and these latewood pores are distinguishable with a hand lens near the earlywood but diminish to invisibly small and numerous in the outer latewood. But unlike oak, chestnut lacks any large multiseriate rays, and a microscopic check of a tangential section reveals that the rays in chestnut are exclusively uniseriate, a feature unique among ring-porous timber of the temperate regions.

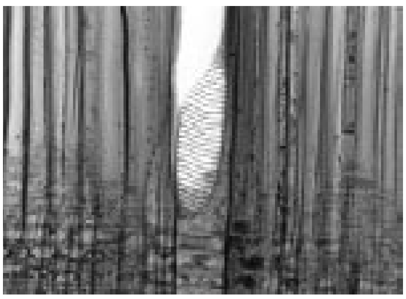
Ash (Fig. 13) exhibits a distinct zone of large earlywood pores. The mass of tissue surrounding the earlywood pores appears lighter than the denser fiber mass of the latewood. Pores in the first-formed latewood are solitary or in radial multiples of two or three, with each pore or multiple surrounded by a narrow band of lighter-colored parenchyma cells. In the outer latewood, pairs or short strings of pores often appear to be connected by lighter parenchyma, forming short irregular tangential lines. As a microscopic check, note that the latewood pores (vessels) are thick walled, and in European ash (*Fraximus excelsior*) the rays are commonly 3 and 4 seriate.

Elm (Fig. 14) has an easily recognized feature of wavy bands of pores dominating the latewood portion of the growth rings. These undulating, more or less tangential bands are up to several pores wide and give the latewood portion of growth rings a distinctive jagged appearance on tangential board surfaces. A microscopic check of tangential sections will show rays to be mostly 4–6 seriate.

Walnut (Fig. 15) is a typical semi-ring-porous wood. The larger pores are usually visible without magnification, but pore size diminishes across the growth ring, and the smallest latewood pores can be seen only with a hand lens. Pores are solitary or in radial multiples of two to four. Rays are distinct but not conspicuous when viewed on transverse surfaces with a hand lens; on tangential surfaces examined microscopically, rays of European walnut *(Juglans regia)* are mostly 2–4 (occasionally 5) seriate. The milk-chocolate color of the heartwood is also an important identification characteristic.

Diffuse-porous hardwoods

Woods in this group lack a distinct earlywood zone of larger pores when examined in transverse surface with a hand lens. The term *diffuse porous* implies that pores of more or less uniform size are distributed evenly across the growth ring. Pores may be relatively large, as in many coarse-textured tropical woods such as mahogany (Fig. 16); the largest pores of coarse-textured hardwoods are visible without magnification, and the large-diameter vessels exposed lengthwise along tangential or radial surfaces appear as distinct lines (called vessel lines). Diffuse-porous hardwoods of the temperate regions, however, are typically fine textured; the relatively small pores cannot be seen without magnification, and vessel lines are indistinct to invisible. In a few woods, such as mahogany and cherry, heartwood color may be useful. But most diffuse-porous woods are nondistinctive pale shades of light brown and, especially after centuries of aging, some darken while others lighten. Ray size is helpful in identifying some; pore size and arrangements are helpful in identifying others. A few woods have characteristic patterns of parenchyma cells. With most diffuse-porous woods, however, reliable identification requires the determination of microscopic features.



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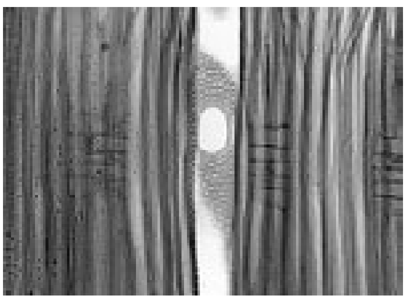
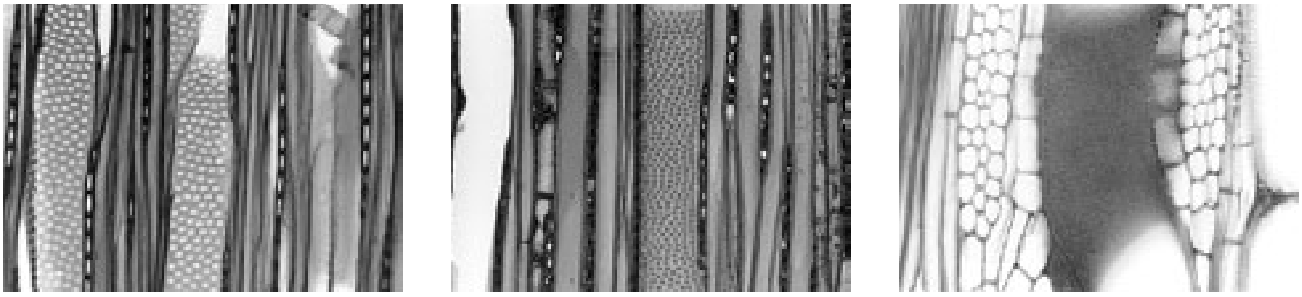


b

Figure 24a, b
Radial sections showing examples of perforations, the openings in the end walls of adjoining vessel cells in hardwoods: (a) scalariform perforations in alder (*Alnus* sp.); and (b) a simple perforation in poplar (*Populus* sp.).

Vessel cells have several important microscopic features. The distinctive characteristic of vessel cells is that their end walls have openings where they are joined end to end. These openings, called perforations, enable the aligned vessel cells to form continuous conductive pipelines—i.e., vessels. In most species the perforations are single large openings called *simple perforations;* in other species, the vessel end walls have a series of elongated openings separated by thin bars and forming ladderlike or gratelike openings called *scalariform perforations*. A few species have both types of perforations. They are best viewed in radial sections (Fig. 24a, b). Another important microscopic feature is intervessel pitting (pits are small voids in the cell walls). Where two vessels are in contact side by side (as where a pore multiple is seen on a transverse surface), the common wall joining the two vessels is relatively wide and has numerous pits. Because pore multiples are more commonly radial, the shared tangential vessel walls with intervessel pitting are most easily found by scanning tangential sections. The appearance of these intervessel pits (size, shape, and arrangement) may be an important identification characteristic for a



a b c

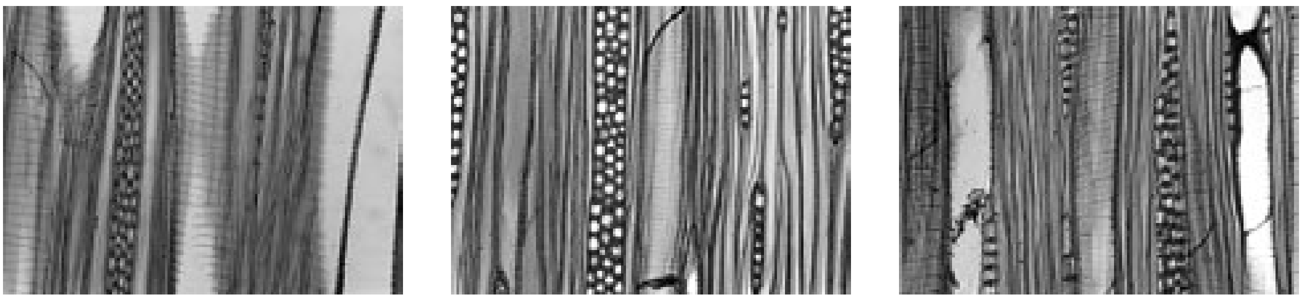
Figure 25a–c
Tangential sections showing examples of intervessel pitting in hardwoods: (a) large intervessel pits in poplar (*Populus* sp.); (b) medium-sized intervessel pits in alder (*Alnus* sp.); and (c) very small and numerous intervessel pits in mahogany (*Swietenia* sp.).

species (Fig. 25a–c). In some species the vessels have spiral thickenings. In longitudinal sections, they appear somewhat like coiled springs within the vessels (Fig. 26a–c).

As previously mentioned, ray seriation is a valuable microscopic feature (Fig. 27a–f). Also, pitting where ray cells contact the radial walls of vessels, called ray-vessel pitting, may have a characteristic appearance (Fig. 28a, b).

Mahogany from the tropical Americas and the West Indies found its way to Europe through the earliest trade routes. Mahogany is an extremely variable wood in both color and density and defies simple description. Heartwood color varies from medium to deep reddish brown. Some wood is straight grained, but interlocked grain is common, resulting in a ribbon or stripe figure on radially cut panels. The coarse-textured wood displays vessel lines on longitudinal surfaces. Growth rings are commonly delineated by terminal parenchyma, visible as fine, creamy light tangential lines on cross-sectional surfaces and visible among the figured patterns on longitudinal panel surfaces. Seen with a hand lens, the rays are usually conspicuous on transverse surfaces (Fig. 16). A few pores appear to contain chalk-white inclusions; others have dark contents. The rays of mahogany are often storied (occurring in a tiered arrangement as viewed on tangential surfaces), so that ripple marks are produced (Fig. 29). In tangential sections examined microscopically, the reddish or amber contents of the vessels are often conspicuous; rays are 1–6 (mostly 3–4) seriate, with relatively large-diameter cells (Fig. 27b). An important microscopic feature of mahogany is the extremely minute and numerous intervessel pitting, the individual pits measuring only 2–3 μm in diameter. This feature serves to separate mahogany from many other woods that resemble it—Spanish-cedar (*Cedrela* spp.), for example—in which the intervessel pits average 6–8 μm in diameter.

Figure 26a–c
Tangential sections showing examples of spiral thickenings in the vessel elements of hardwoods: (a) large-diameter spiral thickenings in lime (*Tilia* sp.); (b) fine, evenly spaced spiral thickenings in maple (*Acer* sp.); and (c) variable diameter and uneven spacing of spiral thickenings in cherry (*Prunus* sp.).



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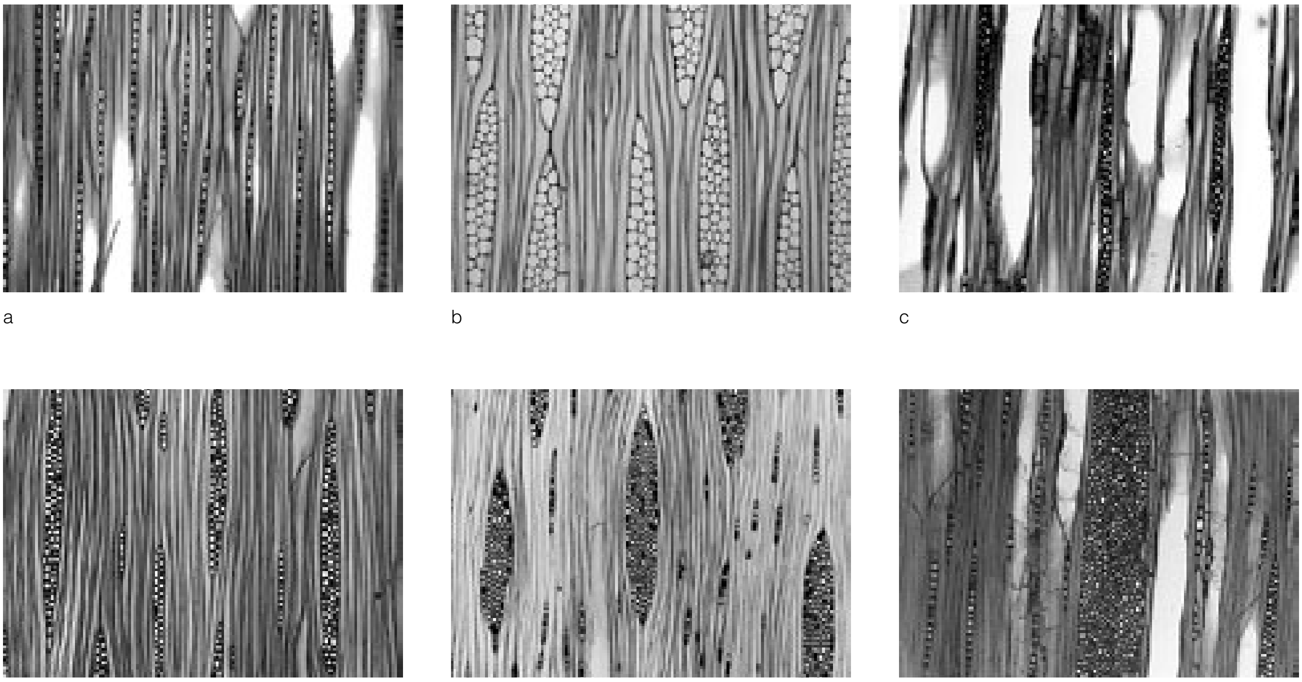


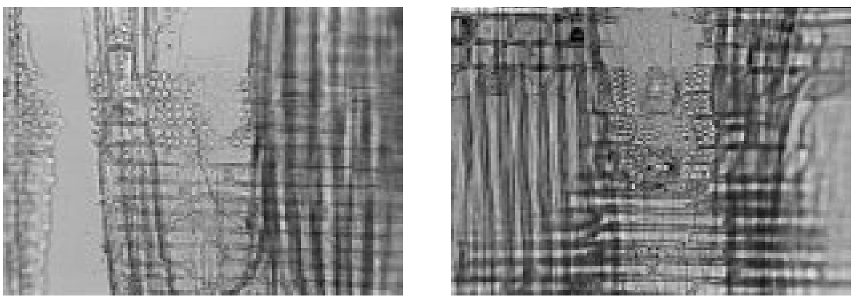
a b c d e f

Figure 27a–f
Tangential sections showing examples of ray-cell size and shape as well as ray seriation in various hardwoods: (a) uniseriate rays with flattened cells in poplar (*Populus* sp.); (b) multiseriate rays in mahogany (*Swietenia* sp.); (c) multiseriate rays with flattened to oval cells in lime (*Tilia* sp.); (d) multiseriate rays (up to 4–5 seriate) with rounded cells in soft maple (*Acer* sp.); (e) multiseriate rays (up to 8–9 seriate) with rounded cells in hard maple (*Acer* sp.); and (f) a portion of a large multiseriate ray with variable-sized cells in beech (*Fagus* sp.).

Beech can usually be identified on sight by its easily visible rays. On transverse surfaces, the largest of the rays form conspicuous light radial lines recognized quickly, especially with a hand lens (Fig. 17). On tangential panel surfaces the uniformly scattered larger rays are characteristic; on radial surfaces the rays produce a striking ray fleck of darker ray tissue against lighter background tissue. Beech is properly classified as a diffuse-porous wood, with uniformly small pores evenly distributed across most of the growth ring, although an apparent latewood zone of fewer pores terminates each growth ring. Beech may be confused with plane (*Platanus* spp.), which also has large rays. In plane, however, the rays are uniformly large and appear more crowded on tangential surfaces. Confusion is easily resolved by microscopic examination of a tangential section: in plane the rays rarely exceed 15 seriate; in beech the widest rays are up to 20–25 seriate, with many cells of very small diameter (Fig. 27f).

Alder (*Alnus* spp.) is light reddish brown, diffuse porous, and fine textured. It may be recognized on sight, however, by the occasional presence of large, conspicuous, oak-sized rays (Fig. 18). These rays are relatively few in number and may be inches apart—thus, small samples of the

Figure 28a, b
Radial sections of (a) poplar (*Populus* sp.) showing the large ray-vessel pits in the marginal rows of procumbent ray cells in contact with a vessel element; and (b) willow (*Salix* sp.) showing the large ray-vessel pits in the marginal rows of upright ray cells.



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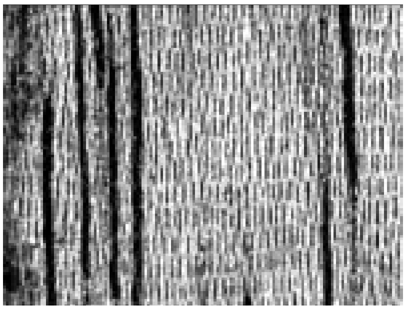


Figure 29
Tangential surface of mahogany (*Swietenia* sp.) showing storied rays resulting in ripple marks.

wood may contain no rays. In any case, the identification of alder is best confirmed by microscopic examination of longitudinal tissue sections. In tangential view, the large rays, if found, are discovered to be aggregate rays consisting of numerous closely spaced smaller rays (mostly biseriate), apparently separated by longitudinal cells. The countless other rays through most of the wood tissue are exclusively uniseriate. Intervessel pits are relatively small (4–8 µm in diameter), horizontally oval, and spaced slightly apart from one another (Fig. 25b). Radial sections show ray-vessel pitting similar to intervessel pitting, and perforation plates are scalariform with numerous fine bars (Fig. 24a).

The remaining diffuse-porous woods do not have visible features that faithfully indicate their identity. Hand-lens examination suggests possibilities at best, but final analysis should automatically proceed on the basis of microscopic features.

Maple is perhaps the paradigm of diffuse-porous structure. Hand-lens examination of end-grain surfaces shows solitary pores or short radial multiples of pores with very uniform size and distribution. Growth rings are delineated by a subtle, narrow line of slightly darker tissue, hardly sufficient to be designated as latewood. Rays appear sharply defined, appearing approximately as wide as the diameter of the larger pores (Fig. 19). On tangential panel surfaces, the rays are sometimes not evident, but on some pieces they may appear as tiny, fine, crowded but distinct lines; on radial surfaces, a conspicuous ray fleck of darker rays against the lighter background may be evident, suggesting a beech or plane ray fleck in miniature. Radial sections show simple perforations in the vessels. In tangential sections, intervessel pits appear rather large and distinct, and rounded or angular through crowding. The vessels show fine, evenly spaced spiral thickenings (Fig. 26b). In tangential sections the ray cells appear round. Rays are up to 4 to 5 seriate in the "soft maple" group (e.g., *Acer campestre* and *A. platanoides*) but up to 8 or more seriate in the "hard-maple" group (e.g., *A. pseudoplatanus*).

Cherry heartwood is distinctive in its medium cinnamon-brown to reddish brown color, which may age to a rather dark brown or reddish brown. Cherry is relatively fine textured and basically diffuse porous, although examination of a transverse surface reveals a concentration of pores, in some cases suggesting ring-porous arrangement, along the early-wood edge of the growth ring (Fig. 20). This concentration of earlywood pores contributes significantly to the figure of the wood as seen on tangential panel surfaces. Compared to maple, the pores are less evenly distributed, with multiples grouped into small clusters, the pores commonly joined tangentially as well as radially. The rays appear bright and distinct on cross-sectional surfaces and produce a characteristic light-on-dark ray fleck on radial panel surfaces of heartwood. In thin sections examined microscopically, the simple perforation plates and large, distinct intervessel pitting are similar to those of maple. An important difference, however, is in the spiral thickenings of the vessels: in cherry (Fig. 26c) the spirals appear uneven in thickness and more widely and irregularly spaced than in maple (Fig. 26b). The widest rays are up to 4 to 5 seriate with rounded cells, as in maple, but more commonly the rays show uniseriate extensions at either or both ends. There are many indistinguishably similar species of *Prunus*.

Pear (*Pyrus* spp.) has rather nondistinct visual features, the wood being very fine textured and uniformly diffuse porous (Fig. 21). In a transverse surface viewed with a hand lens, the pores are barely seen, and solitary pores appear more common than multiples. The rays are fine and inconspicuous. The wood is best identified on the basis of microscopic features: the rays are narrow, 1–3 (mostly 1 or 2) seriate. Vessels have very small (3–4 μm diameter) intervessel pits and simple (only occasionally scalariform) perforation plates. Spiral thickenings are commonly absent, although sparse spiral thickenings are occasionally present.

There are several other woods of the Rosaceae family that have anatomical features very similar to those of pear. These include apple (*Malus* spp.), hawthorn (*Crataegus* spp.), and mountain-ash (*Sorbus* spp.). Woods of this group usually cannot be separated with certainty and are summarily identified simply as fruitwood.

Lime (*Tilia* spp.) has neither characteristic visual features nor distinctive heartwood color. Hand-lens examination of transverse surfaces shows evidence of growth rings by slightly denser latewood fiber mass, the growth-ring boundary often delineated by a lighter line of latewood parenchyma (Fig. 22). Rays are fairly distinct and appear to flare (widen) as they cross the growth-ring boundary. Sections examined microscopically show vessels with simple perforations and fairly large intervessel pits. A key feature is the very thick spiral thickenings, which are conspicuous in the vessels (Fig. 26a). Tangential sections show that the rays are mostly 1–4 seriate, the ray cells appearing flattened or oval rather than rounded (Fig. 27c).

Poplar also lacks distinctive color and visual features. On cross sections viewed with a hand lens, the appearance of the pores may suggest a semi-ring-porous arrangement. Pores appear numerous, and multiples are common; the rays appear extremely narrow and are barely visible (Fig. 23). Under a microscope, tangential sections show that the rays are exclusively uniseriate (Fig. 27a). Intervessel pits are large and distinct and rounded or angular through crowding (Fig. 25a); intervessel pitting is easily found on tangential sections because of the numerous radial multiples. Vessels lack spiral thickenings, and the perforation plates are simple (Fig. 24b). Radial sections show distinctive large ray-vessel pitting in marginal rows of ray cells (Fig. 28a).

Willow appears confusingly similar to poplar and has many of the same anatomical features: diffuse-porous to semi-diffuse-porous structure with moderately fine texture, exclusively uniseriate rays, and vessels lacking spiral thickenings but with large intervessel pitting and simple perforations. The only consistent distinguishing feature is that poplar has exclusively homocellular rays, consisting entirely of radially elongated procumbent cells, whereas willow has heterocellular rays, which include both procumbent ray cells and upright ray cells (Fig. 28b). Viewed radially, upright ray cells appear more or less square or may be elongated in the longitudinal direction; they occur mostly in one or more rows along the upper and lower margins of the rays (compare Fig. 28a and Fig. 28b). The upright ray cells in willow also have distinctively large ray-vessel pits.

Summary

Among the woods commonly used in panel paintings, only a few, such as oak and beech, have visual features that suggest an immediate identification. For some, such as ash, elm, and chestnut, hand-lens examination of end-grain surfaces may suffice. For most, however, identification is best accomplished through microscopic examination of thin sections of tissue. Because the relatively short list of woods reviewed in this article covers most woods encountered in European painting panels, one can quickly learn to recognize and match the basic diagnostic anatomical features of this group.

Before any attempt is made to prepare slides for microscopic examination, the novice to wood identification should be especially apprised of two points. First, the orientation of the longitudinal direction (grain direction), as well as the placement of growth rings and rays, must be clearly understood, because sections, to be useful, must be taken along accurate transverse, radial, and tangential planes. Second, it is imperative that sections be smoothly sliced with minimum cellular damage and that they be sufficiently thin. Sections need not be large (2–3 mm is plenty), but they must be thin (ideally one to two cell diameters thick). Developing the skill of hand-slicing thin and undamaged sections with a razor blade is perhaps the greatest challenge, and mastery requires practice. Without reasonably well-made slides, attempts to identify a wood will likely be futile.

In the evaluation of the anatomical features of an unknown wood in order to match a particular species and thereby to identify it, a number of resources are recommended, including macro- and micrographs, written descriptions, and, especially, documented wood samples, from which comparison slides are prepared. Every conservation laboratory is likely to have samples of at least the more common woods. Adding samples of species that are confusing look-alikes is highly recommended.

As a final precaution, it is important to guard against the inclination to force a match of features of an unknown with those of one of the woods listed in Table 1: the conservator should always be alert to the possibility that the unknown wood is not one of the familiar or common woods.

Dendrochronological Analyses of Panel Paintings

Peter Klein

Dendrochronology is a discipline of the biological sciences that serves to determine the age of wooden objects. The method, while employed primarily for dating archaeological and architectural artifacts, is also used to solve art-historical problems (Baillie 1982; Fletcher 1978; Eckstein, Wrobel, and Aniol 1983; Eckstein, Baillie, and Egger 1984; Schweingruber 1988; Klein and Eckstein 1988). As such, it is the discipline's principal goal to give at least a terminus post quem for the creation of a painting by determining the felling date of the tree that provided the wood for the panel.

This article presents the current state of the application of dendrochronology as an aid for solving art-historical problems; also discussed are tree growth patterns and the dendrochronological methods employed.

Biological Base of Dendrochronology

A tree grows by both elongation and radial increments. The elongation takes place at the terminal portions of the shoot, branches, and roots. The radial increment is added within a particular zone of living cells between the wood and the bark. This layer, called the cambium, envelopes the woody portion of the stem, branches, and roots.

Dendrochronology focuses primarily on the annual periodicity of growth that is controlled by the climate (e.g., temperature and rainfall). In the cool and temperate climatic belt, a dormant season occurs from autumn to spring, and a growth season occurs during the summer. When the vegetative period begins in May, new cells form to conduct water from the roots to the treetop. These large cells are the earlywood cells. During the summer, around the end of June, the latewood formation starts; around the middle of September, the radial growth of the tree stops for seven months. The result is the gradual accumulation of growth during one growing season, forming an annual ring, or tree ring.

Conifers and hardwood species have different tree ring structures. In conifers—such as pine, fir, and spruce (Fig. 1a)—the wood is more or less uniformly composed of one cell type, the tracheids, and the growth ring is distinguished by differences in both cell size and cell-wall thickness between elements produced during the early and late parts of the growing season. The hardwood trees can be divided into two groups. In one, tree rings are evident because of the formation of a band of large earlywood vessels for water conduction, followed by the formation of a more compact latewood with smaller vessels and an increase in fibers, the cell

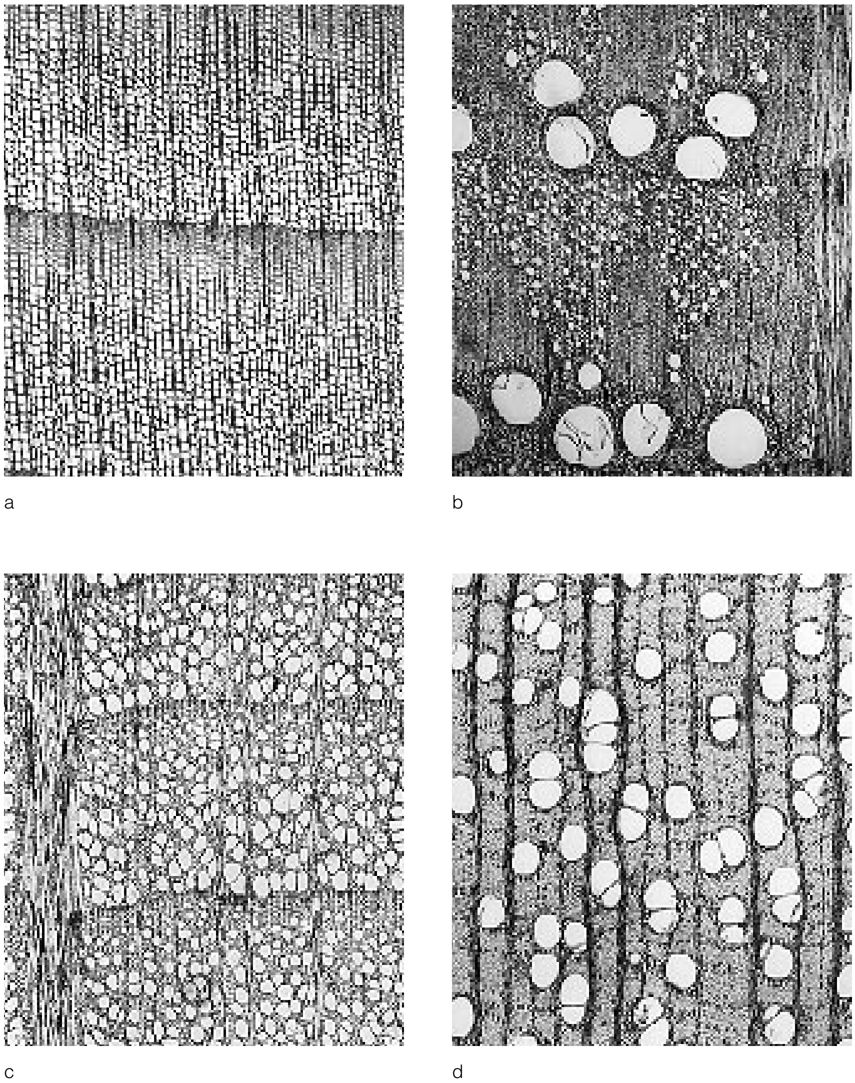


Figure 1a–d
Photomicrographs (cross sections) of (a) spruce wood (*Picea abies*); (b) oak wood (*Quercus petraea*); (c) beech wood (*Fagus sylvatica*); and (d) tropical wood (*Hopea brachyptera*). Magnification ×25.

elements that support the stem. This group—which includes oak, ash, and elm—is called *ring porous* (Fig. 1b). In the other group of hardwood trees, the growth rings are more difficult to recognize because the vessels are uniformly distributed throughout the tree ring, and the only demarcation between successive layers is either a radial flattening of the last few elements formed or an increase in fibers near the end of the growth period. This group of trees is called *diffuse porous* and includes poplar, lime, and beech (Fig. 1c). In the subtropics and tropics, there are no distinct growth-ring zones (Fig. 1d), but trees sometimes form zonal layers, which are not identical with real growth rings.

In addition to the differences in structure, the three groups differ physiologically. In ring-porous wood, the latest growth ring fulfills the major task of water conduction, and consequently a new ring must be formed every year. In diffuse-porous woods and in conifer wood, previously formed growth rings participate in the water conduction. Hence, under adverse climatic conditions, the trees do not need to form a growth ring every year and may be characterized by absent or partially missing rings. Conversely, it is possible that two growth increments may be formed in a single year. These occurrences make the determination of growth

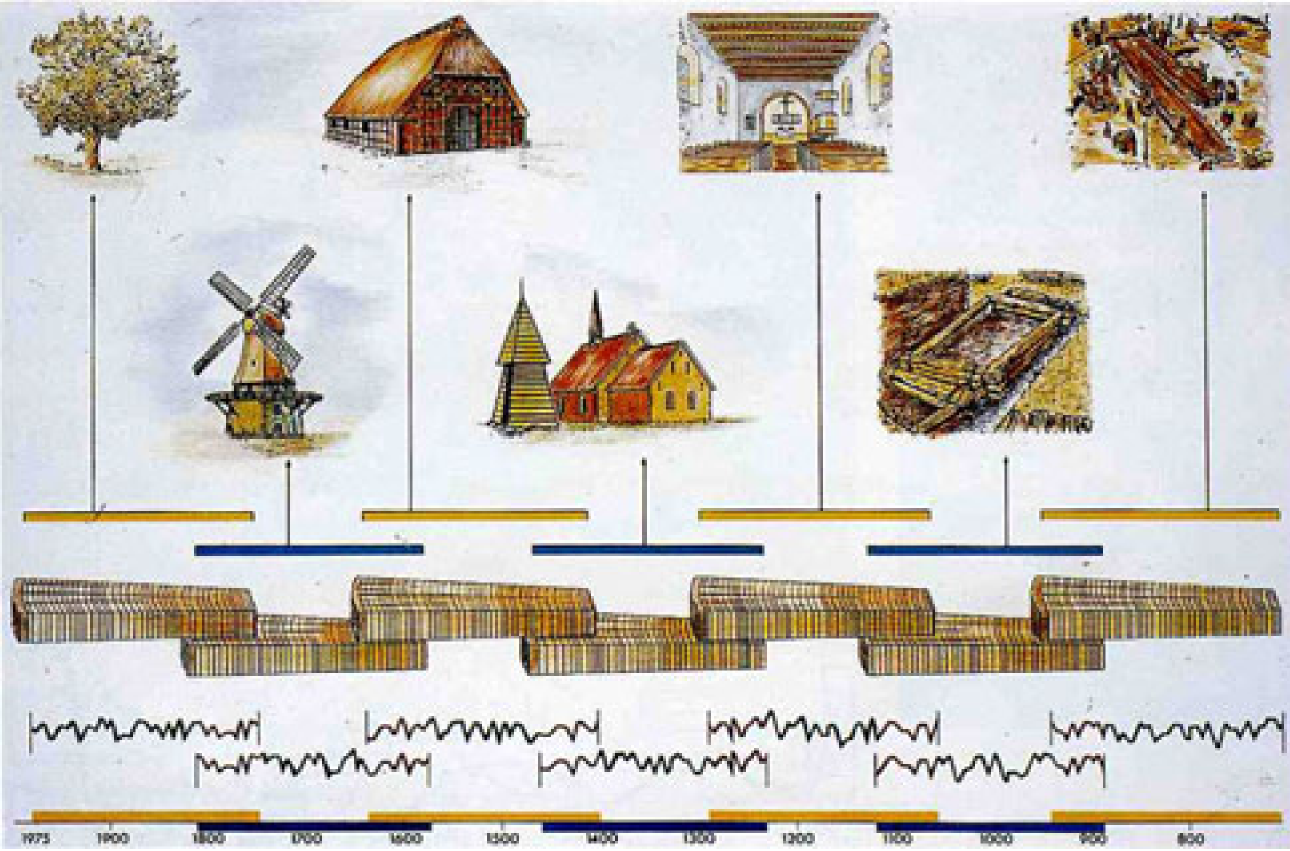


Figure 2
Overlapping system for the establishment of master chronologies.

rings and other dendrochronological work with diffuse-porous species more difficult than is work with ring-porous species such as oak.

The biological regularity of the ring series in trees of temperate zones makes it possible to date wood by comparing the sequences of undated wood with those of wood of known age. To establish comprehensive continuous growth-ring curves for periods longer than a tree's lifetime, it is necessary to use an overlapping system of individual curves (Fig. 2). An overlapping system is necessary for the establishment of these master chronologies, because trees in Europe do not normally live more than two or three centuries. Such standard curves exist, among others, for south and west Germany, several regions of north Germany, several areas in the Netherlands (partial), and the Baltic area, from which the wood for most Flemish and Dutch paintings was obtained (Fig. 3) (Eckstein et al. 1986).

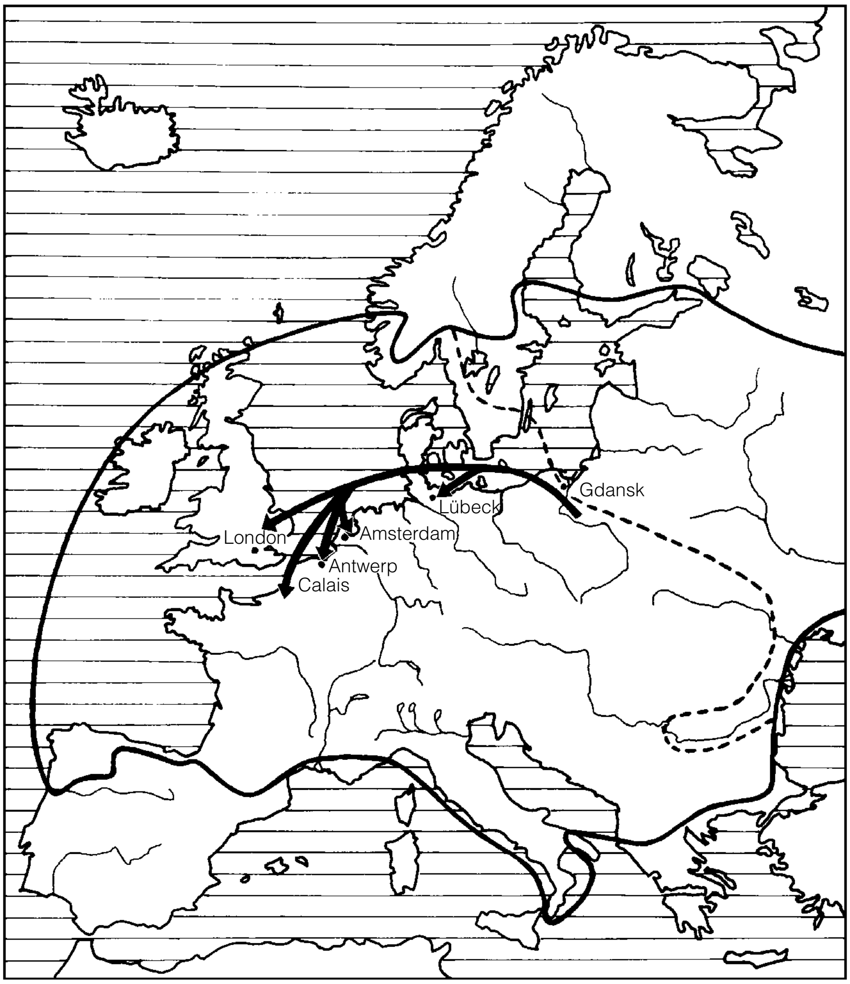
Measurement and Cross Dating

To determine the ring widths in wood, a magnifying glass with an integrated scale may be used (Fig. 4a). This method is used if measurements have to be taken without laboratory equipment at the site. It is more convenient and faster to take measurements in the laboratory using a stationary binocular and a traveling stage on which the sample is mounted. These devices can be connected to a computer to record the data for immediate use in subsequent steps of the analysis (Fig. 4b).

Cross dating in its simplest form is the comparison of two tree ring sequences to determine if and to what degree they match, as well as to determine their placement in time to each other (Fig. 5). If one of the curves is attributed to a definite stretch of time, the positioning of the

Figure 3

Areas of the natural distribution of oak. The distribution of *Quercus robur* L. (European oak) is shown as a heavy line; the distribution of *Quercus petraea* Liebl. (sessile oak) is shown as a broken line. European oak originates farther northeast than does sessile oak. The sources of oak timbers and the places of their use as panels are indicated by arrows.



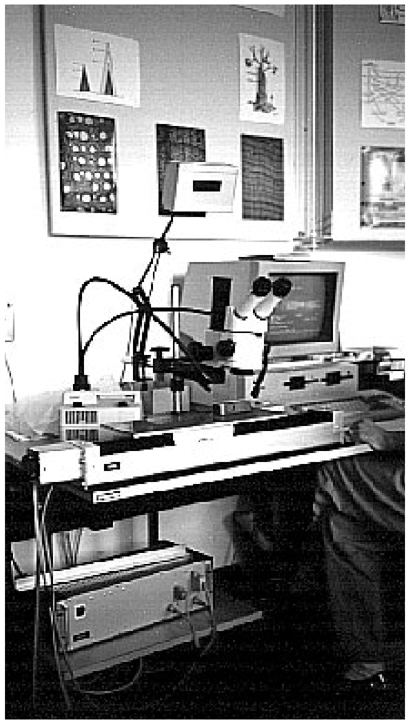
second curve by maximum coincidence leads to absolute dating. For each kind of wood, a master chronology must be established for different geographical regions.

Problems

In the course of dendrochronological work, a number of problems involving the biological material and the methodology are encountered:

1. Conifers (such as spruce) or diffuse-porous broad-leaved trees (such as lime) may not even produce a ring in some years, thus preventing accurate dating because of the missing data.
2. Sometimes the state of conservation of a sample does not permit determination of the ring widths, as in the case of sapwood that collapses from excessive drying or that is destroyed by insects, bacteria, or fungi. In some cases, not even the number of rings can be determined.
3. For the cross dating of curves, one needs a minimum number of rings to obtain reliable results. Unfortunately, it is not possible to give a definite figure as the minimum. Even curves considered quite "long" sometimes do not provide the characteristic pattern necessary to date the curve. There are so many variables that sometimes dating is possible with as few as 50

a



b

Figure 4a, b
Measurement of growth rings: (a) using a lens in the museum, and (b) using equipment for tree ring measurements in the laboratory.

tree rings, but in other cases even 200 rings may not be enough. The number needed, of course, depends mainly on the quality of the sample.

Sapwood Estimation and Seasoning

The final—and essential—result the art historian seeks is the identification of the year of tree felling. The last ring under the bark gives the exact date and even the season of tree cut, if it has been conserved. In preparing oak panels for paintings, panel makers usually cut the planks radially with regard to the cross section of the tree (Fig. 6). The bark and the light, perishable sapwood were removed, thereby eliminating evidence of the latest growth rings and making a determination of the exact felling year impossible, as only the latest measured growth ring of the panel can be determined to the exact year.

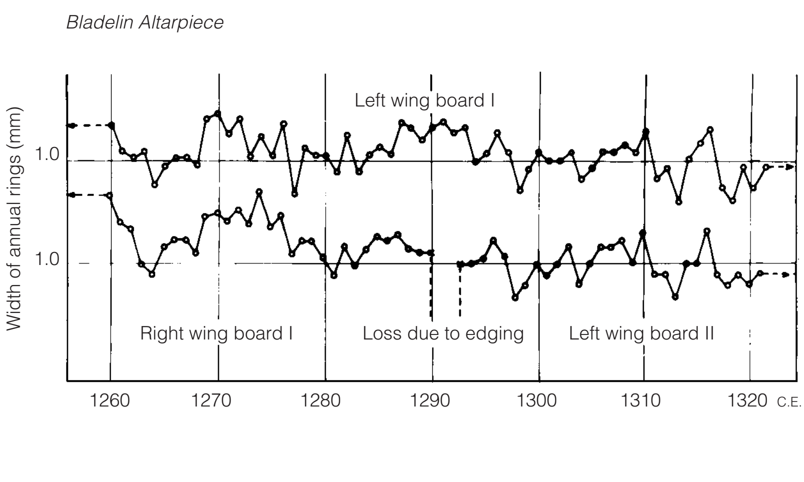


Figure 5
Comparison of growth rings derived from different boards of the Rogier van der Weyden *Bladelin Altarpiece*. Staatliche Museen zu Berlin, Preussischer Kulturbesitz, Gemäldegalerie (inv. 535).

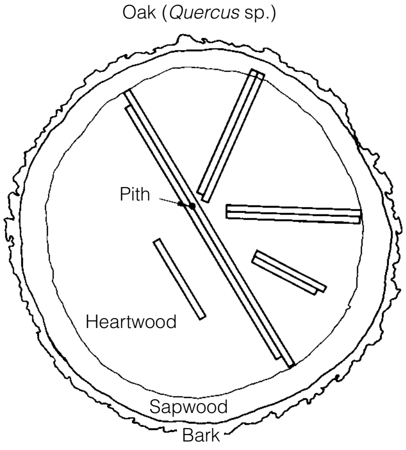


Figure 6
Various methods of extracting boards from an oak tree.

Furthermore, the statements below regarding the number of sapwood rings to be added are derived from statistical evaluation; each case must be considered individually. In addition to the dependence of the number of sapwood rings on the tree's age, the provenance of oak wood is also significant. In Europe, the number of sapwood rings varies from western regions to eastern regions (Hollstein 1980; Baillie et al. 1985; Eckstein et al. 1986; Kuniholm and Striker 1987; Lavier and Lambert 1996; Wazny 1990). With the elaboration of the new data (eastern provenance) for oak panels, new evidence for the sapwood allowance has to be accounted for. The number of sapwood rings found in trees from northern Poland was analyzed; all trees in the central 50% had 13–19 sapwood rings; the median value was 15, the minimum 9, and the maximum 36 (Fig. 7). For wood originating from Germany or the Netherlands, the median value was 17, with 50% of all values lying between 13 and 23.

To determine the earliest possible felling date, at least 7 or 9 sapwood rings (depending on whether the wood is of eastern or western origin) must be added to the latest growth ring found on the panel. Using the median, the felling date of the oak tree can be estimated with a span of −2 to +4 or +4 to +6. If a panel is made exclusively of heartwood, the felling date of the tree cannot be determined as precisely because there is always the possibility that an unknown number of heartwood rings were removed.

For beech (an all-sapwood species), however, the last growth ring available for measurement corresponds in many cases to the last ring formed in the living tree (and thus to the felling year). Usually, when panels were made of beech, the entire tree was used, except for the bark, which was removed. The same procedure can be verified for panels made from conifer wood.

The determination of the felling date also provides information as to the time the wood was seasoned before use in paintings. For oak panels of the sixteenth and seventeenth centuries, in most cases the interval between the felling of the tree and the creation of the painting has been determined to be approximately two to eight years (Bauch, Eckstein, and Brauner 1978). The few investigations carried out with signed and dated panels of the fifteenth century do not yet permit such an accurate estimate (Klein 1991). Instead, present studies regarding this period indicate a seasoning time of ten to fifteen years (Tables 1, 2), a finding that corresponds to the results of analyses obtained from fifteenth-century panels of the School of Cologne (Bauch, Eckstein, and Klein 1990). Similar investiga-

Figure 7
Distribution of the number of sapwood rings in oak trees from northern Poland.

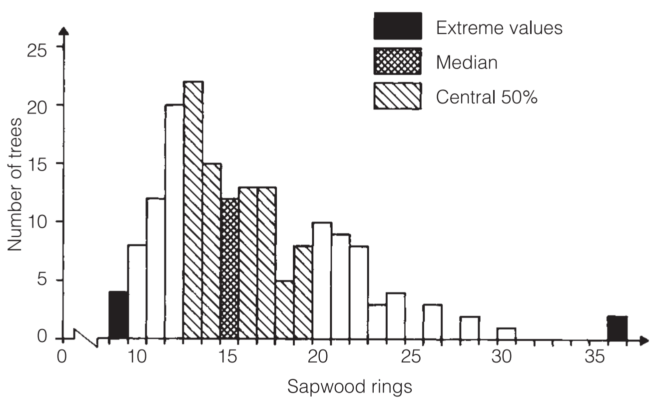


Table 1 Data relating to the determination of storage time for D. Bouts, *The Last Supper,* 1464. Oil on panel. Saint Pieter's Church, Louvain, Belgium.

	Minimum	Median	Maximum
Sapwood rings	9	15	36
Felling date	1445	1451	1472
Storage time (years)	19	13	—

Table 2 Data relating to the determination of storage time for J. Daret, *Adoration and Visitation,* 1434–35. Oil on panel. Staatliche Museen zu Berlin, Preussischer Kulturbesitz, Gemäldegalerie (inv. 527, 542).

	Minimum	Median	Maximum
Sapwood rings	9	15	36
Felling date	1418	1424	1445
Storage time (years)	16	10	—

tions with sixteenth-century beech wood resulted in an estimated seasoning time of two to seven years, corresponding well to what holds true for oak wood from the same period (Klein and Bauch 1983).

Dendrochronological Dating

Notwithstanding the problems related to the determination of the tree's felling date and the seasoning time of the wood, dendrochronological analysis can be helpful for art-historical attribution. Dendrochronological analysis, however, can contribute definitive information only when the felling date is later than the art-historical attribution. When the felling date is earlier, either the board was cut from the center of the tree, or it had been stored for a long time, or the art-historical attribution is too recent. In all these cases, dendrochronological determination cannot give a precise solution.

Above all, it is more helpful for the attribution to analyze a group of panels, rather than a single panel, of a particular workshop. To that end, the dendrochronological department of the University of Hamburg has collected more than two thousand analyses of panel paintings since 1968.

The following sections examine the justification for the use of the dendrochronological method on oak, beech, and conifer panels from the fifteenth to the seventeenth century.

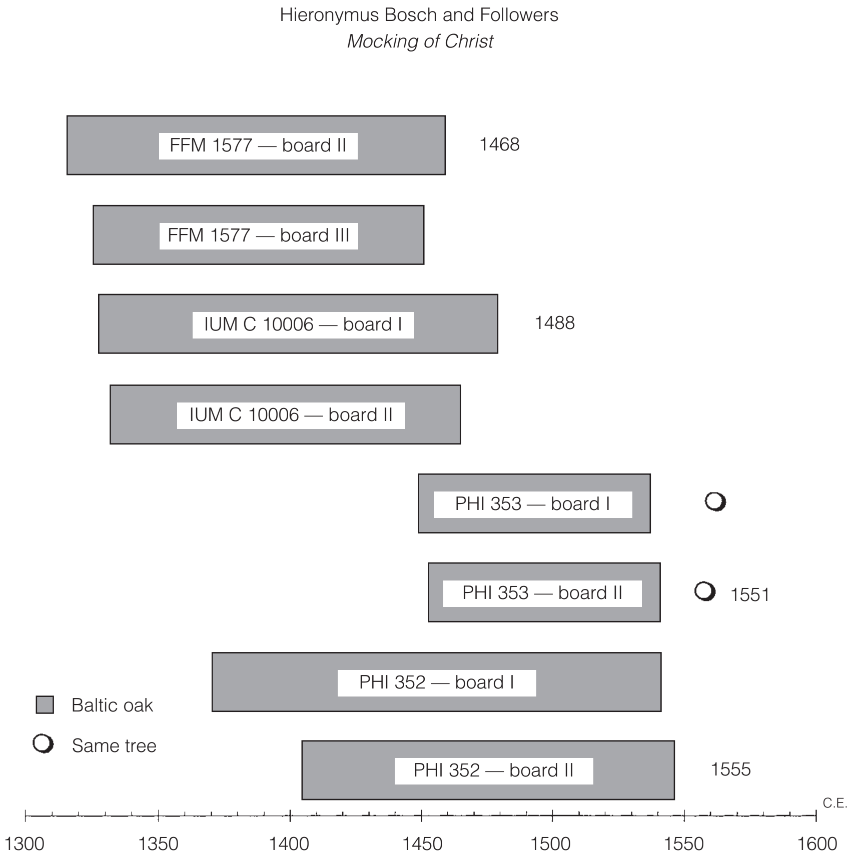
Table 3 Survey of fifteenth- and sixteenth-century panel paintings of Netherlandish painters and workshops

Attribution	Number of panels
J. van Eyck	23
R. Campin	32
R. van der Weyden	61
P. Christus	19
D. Bouts	35
H. Memling	25
G. David	39
H. Bosch	39

Oak wood

Oak wood was used nearly exclusively as a painting support from the fifteenth to the seventeenth century in the northern parts of middle Europe. Table 3 shows a survey of fifteenth- and sixteenth-century Netherlandish panel paintings; the results are reported elsewhere (Klein 1991, 1993, 1994a, 1994b). The wood was imported exclusively from the Baltic region by the panel makers.

Figure 8
Dendrochronological analyses of oak panels of Hieronymus Bosch (Frankfurt and Indianapolis) and followers (Philadelphia), with the same subject, the Mocking of Christ. (FFM = Städelsches Kunstinstitut und Städtische Galerie, Frankfurt; IUM = Indianapolis Museum of Art; PHI = Philadelphia Museum of Art.)



Regarding the paintings of Hieronymus Bosch, it is obvious that the dendrochronological analysis can differ between the original by Bosch and the later copies by his followers. The analysis of paintings with the same subject, the Mocking of Christ (Fig. 8), shows clearly that the two paintings in Philadelphia (inv. nos. 352, 353) were created in the 1560s. The felling dates of the painting panels in Frankfurt and Indianapolis lead to attributions in the lifetime of Bosch; nevertheless, a decision about an original can be finalized only by a critique of style.

Another example, shown in Figure 9, demonstrates that the copy of the *Garden of Earthly Delights* was painted in the middle of the sixteenth century, while the felling date for the original in Madrid corresponds with the art-historical attribution.

In the first half of the seventeenth century, the Dutch and Flemish painters used Baltic oak wood, but the Second Swedish-Polish War (1655–60) caused the total breakdown of the Hansa trade. Thus, Baltic timber is never found in panels made after 1650; oak boards from the forests in western Germany and the Netherlands were used instead. Tropical wood was seldom used in the seventeenth century; only in Rembrandt's workshop have different tropical wood species been identified (Table 4).

Dendrochronological analysis can prove that some boards originated from the same tree. Figure 10 shows, for example, five boards with an identical growth-ring structure. Furthermore, these boards have specific characteristics because they were cut off through the center of the tree

Figure 9
Dendrochronological analyses of oak panels of Hieronymus Bosch (Prado, Madrid) and a follower (private collection, Paris), both with the subject the Garden of Earthly Delights. (MA = Museo Nacional del Prado, Madrid.)

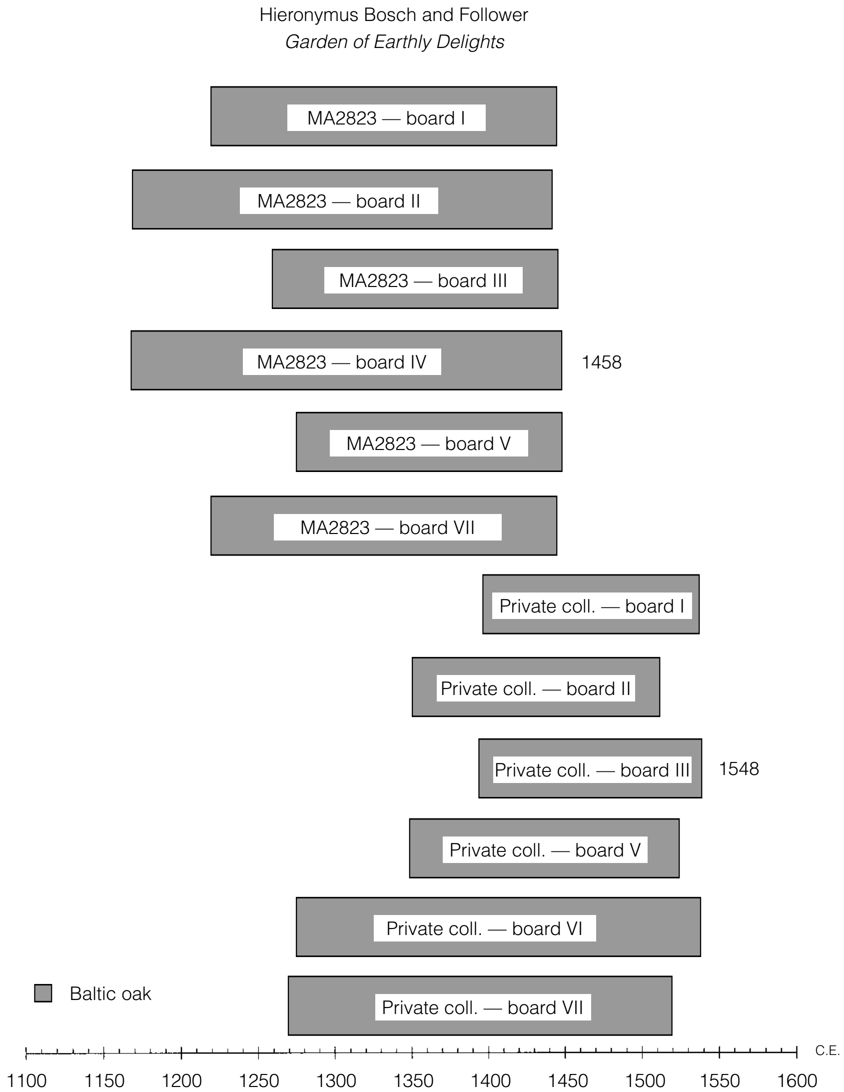


Table 4 Paintings of Rembrandt, with supports of tropical timber. (A = Rijksmuseum, Amsterdam; B = Staatliche Museen zu Berlin, Preussischer Kulturbesitz, Gemäldegalerie; DET = Detroit Institute of Arts; DRD = Gemäldegalerie, Dresden; KSK = Staatliche Kunstsammlungen, Kassel; MP = Alte Pinakothek, Munich; NY = Metropolitan Museum of Art, New York; PET = Hermitage Museum, St. Petersburg; PL = Louvre Museum, Paris.)

Painting/Location	Art-historical attribution/Signature	Wood species
Raising of the Cross (MP, 395)	attr. 1633	*Cedrela odorata*
Man Holding a Glove (NY 14.40.620)	sign. 164. [*sic*]	*Cedrela odorata*
The Holy Family (A, 4119)	attr. 1644	*Cedrela odorata*
The Visitation (DET, 27200)	attr. 1640	*Cedrela odorata*
Self-Portrait (KSK, 237)	sign. 1634	*Swietenia mahagoni*
Saskia (B, 812)	sign. 1643	*Swietenia mahagoni*
Susanna Bathing (B, 828E)	sign. 1647	*Swietenia mahagoni*
Christ at Emmaus (PL)	sign. 1648	*Swietenia mahagoni*
Young Woman (PET)	sign. 165(4)	*Swietenia mahagoni*
Old Man in a Fanciful Costume (DRD, 1567)	sign. 1654	*Swietenia mahagoni*
Anna Accused by Tobit (B, 805)	sign. 1645	*Cariniana legalis* or *C. estrellensis*
Joseph's Dream (B, 806)	sign. 1645	*Cariniana legalis* or *C. estrellensis*

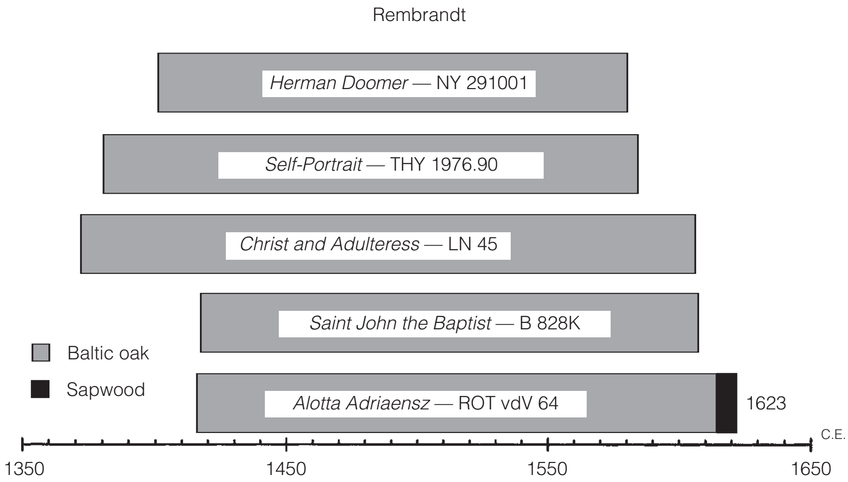


Figure 10
Dendrochronological analyses of five oak panels of Rembrandt (all boards are from the same tree). (B = Staatliche Museen zu Berlin, Preussischer Kulturbesitz, Gemäldegalerie; LN = National Gallery, London; NY = Metropolitan Museum of Art, New York; ROT = Museum Boymans–Van Beuningen, Rotterdam; THY = Coll. Thyssen, Madrid.)

and exhibit sapwood on both sides (see Fig. 6). These characteristics were found only in Rembrandt panels.

For Rubens and his workshop, it was proved that twelve boards from different paintings were fabricated from the same tree (Fig. 11). Most of the boards were used for the Medici cycle, which was ordered in 1621. By comparing the earliest felling date, 1618, with the order date, it can be surmised that the boards were seasoned only for a short time.

Beech wood

In central Europe, however, other woods—such as beech, lime, and poplar—and conifers were also employed for art objects. With reference to the experience gathered with oak, panels made of lime and beech wood from early German painters were also studied; dendrochronological dating was determined to be successful with the beech panels, while a chronology for limewood could not be established.

In historical times, beech was rarely used in construction; thus it has been impossible to establish a continuous chronology for dating beech panels up to the present. Such dating has been achieved in approximation, however, by comparative analysis based on oak chronologies. The positive results permit the absolute dating of the mean chronological sequence established from panels used by Lucas Cranach the Elder (1472–1553) and his associates. From the analysis of Cranach's signed and dated panels, it is clear that only a few years had elapsed between the youngest annual ring of each panel and its time signature. The determination of any given year, however, is limited to the last growth ring available for measurement. As has been discussed previously with regard to oak, it can be shown that boards from the same tree were used for entire panels or as parts of different panels (Figs. 12, 13). In comparison with oak panels, the number of boards extant from the same tree is extremely high for beech wood. This finding can be explained by the fact that beech wood panels were used only for a short time (1520–35) in the Cranach workshop and, furthermore, that beech wood was used (with some exceptions) only in the atelier of Cranach (Klein 1994c).

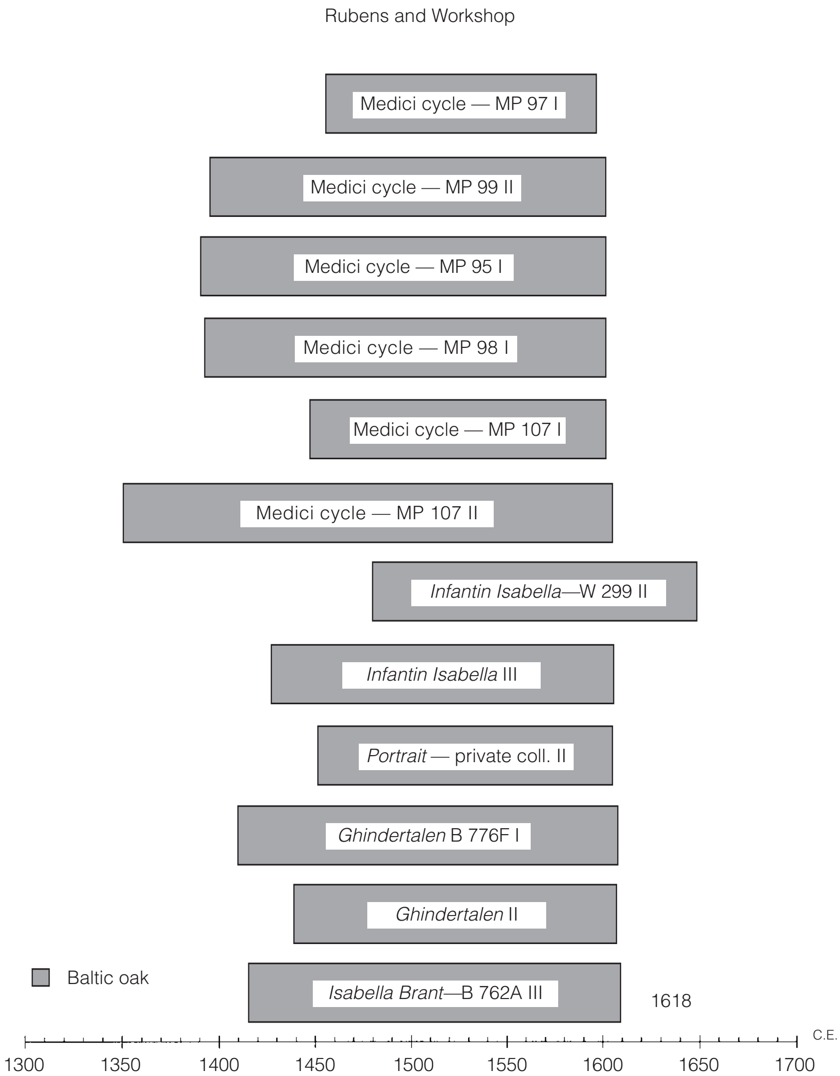


Figure 11
Dendrochronological analyses of twelve oak panels of Rubens and his workshop (all boards are from the same tree). (B = Staatliche Museen zu Berlin, Preussischer Kulturbesitz, Gemäldegalerie; MP = Alte Pinakothek, Munich; W = Kunsthistorisches Museum Wien, Vienna.)

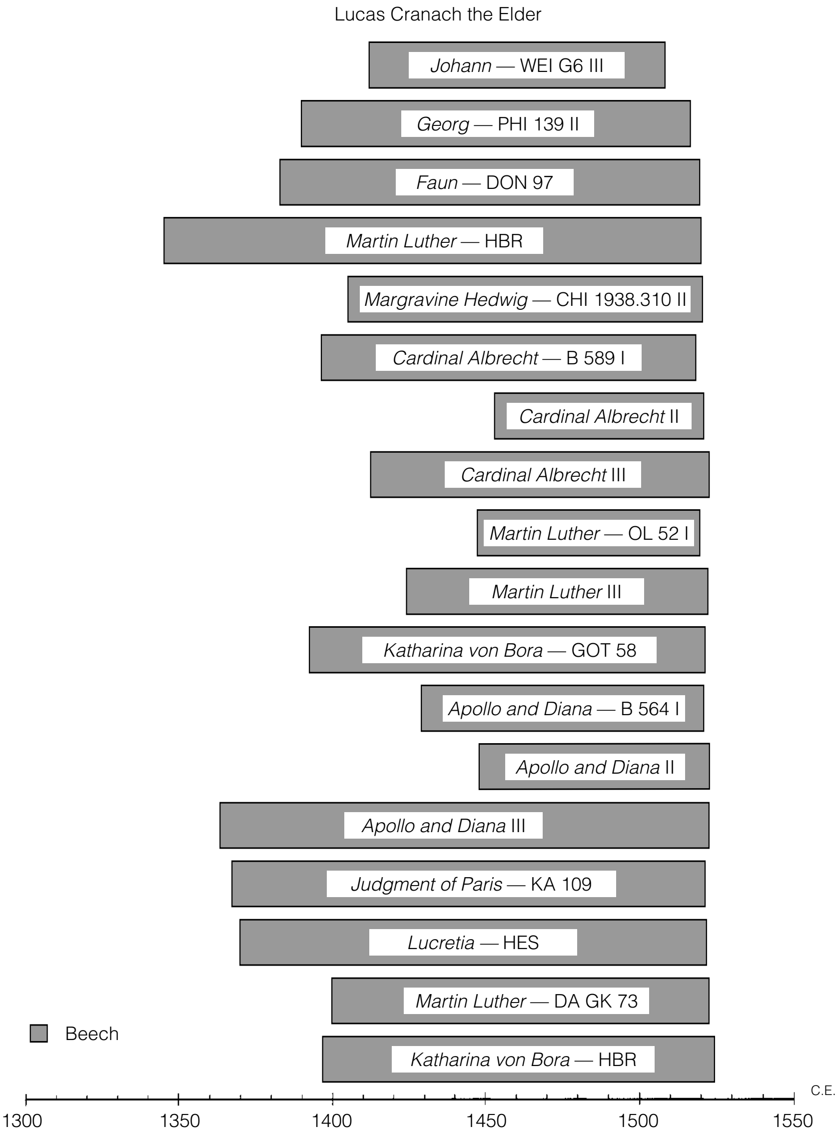
Conifer wood

To establish a chronology for fir, spruce, and pinewood, statistical measurements of chronological compatibility of recent trees within and between different regions were carried out, particularly for the forests in the northernmost and southernmost parts of Germany. In addition, panels of various conifer woods and the wood of stringed instruments were investigated at various museums in Europe and the United States (Klein 1990). For spruce wood, new chronologies were established and other existing chronologies used. For pinewood, a new chronology was established for northern Germany (Eckstein, Schubert, and Klein 1987). For fir wood, the establishment of a new chronology was unnecessary, because the chronology of Becker and Gierts-Siebenlist (1970) allows the dating of panels.

Spruce wood

The chronologies of spruce wood—originally established for dating stringed instruments—can also be used for dating panels. A chronology for the Alpine region, for example, has been successfully used to date several

Figure 12
Dendrochronological analyses of beech panels of Lucas Cranach the Elder (all panels are made from the same tree). (B = Staatliche Museen zu Berlin, Preussischer Kulturbesitz, Gemäldegalerie; CHI = Art Institute of Chicago; DA = Hessisches Landesmuseum, Darmstadt; DON = Coll. Fürstenberg, Donaueschingen; GOT = Schlossmuseum, Gotha; HBR = Roseliushaus, Bremen; HES = Sinebrychoffin Taidekokoelmat, Helsinki; KA = Staatliche Kunsthalle, Karlsruhe; OL = Landesmuseum für Kunst und Kulturgeschichte, Oldenburg; PHI = Philadelphia Museum of Art; WEI = Schlossmuseum, Weimar.)



panels of the cycle *Gray Passion* (Coll. Fürstenberg, Donaueschingen) created by Hans Holbein the Elder, as well as some boards from some altarpieces created by Hungarian masters (Fig. 14).

Fir wood

The fir chronology was used to date the following samples (Fig. 15). The panel *Maria Gravida* by the Master from Vienna contains six boards; the last ring indicates the year 1420. The art-historical attribution places the work between 1410 and 1430. When the seasoning time of the wood is considered, dendrochronology makes possible a more precise attribution of the panel to the mid-1420s. For the painting by a Hungarian master with an art-historical attribution of about 1490, the dendrochronological dating confirms the attribution, since the last growth ring is determined to be from 1472.

Conclusion

A large number of chronologies are available for several regions and time periods for the analysis of oak wood used for panels and carvings. Even so,

Figure 13
Dendrochronological analyses of beech panels of Lucas Cranach the Elder (all panels are made from the same tree). (B = Staatliche Museen zu Berlin, Preussischer Kulturbesitz, Gemäldegalerie; DON = Coll. Fürstenberg, Donaueschingen; HHK = Hamburger Kunsthalle, Hamburg.)

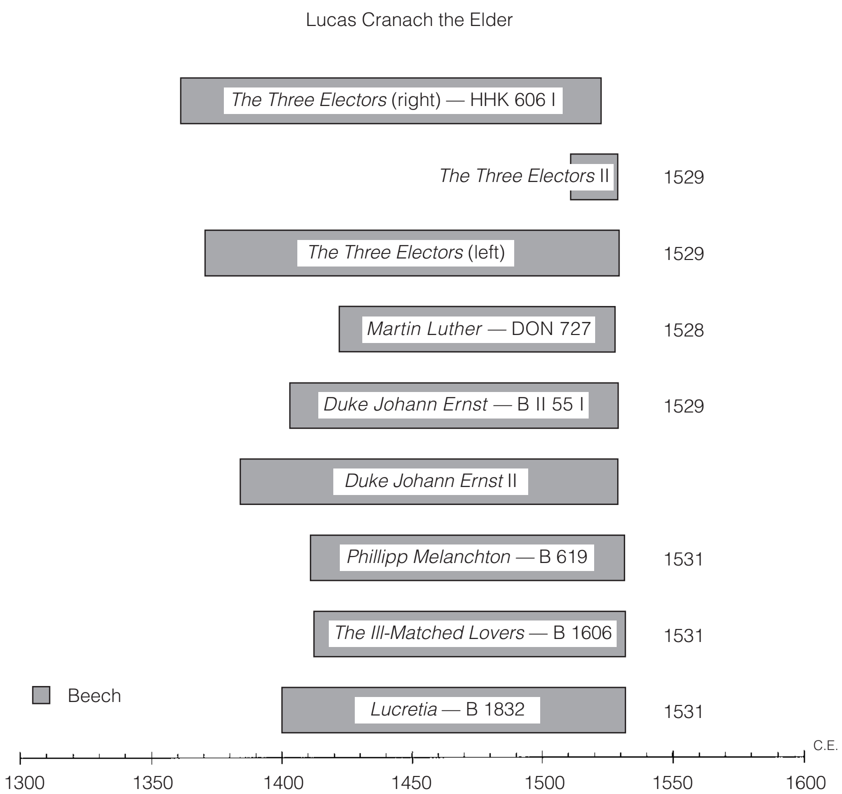
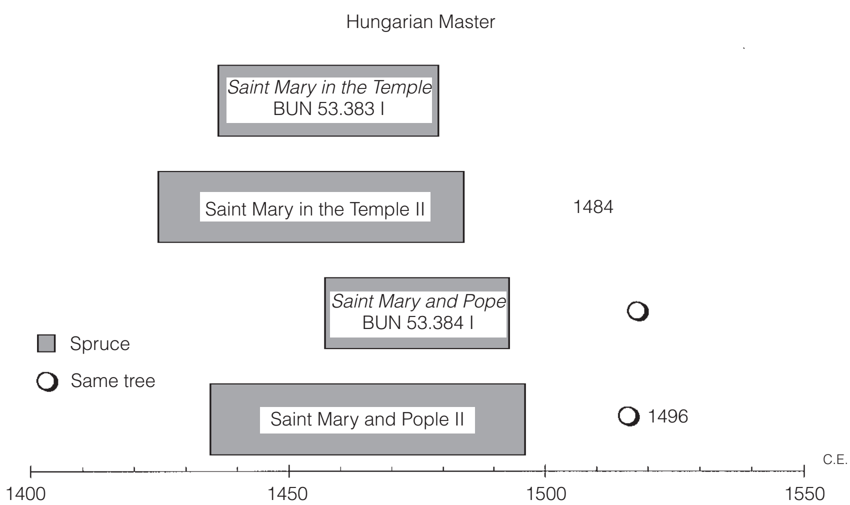


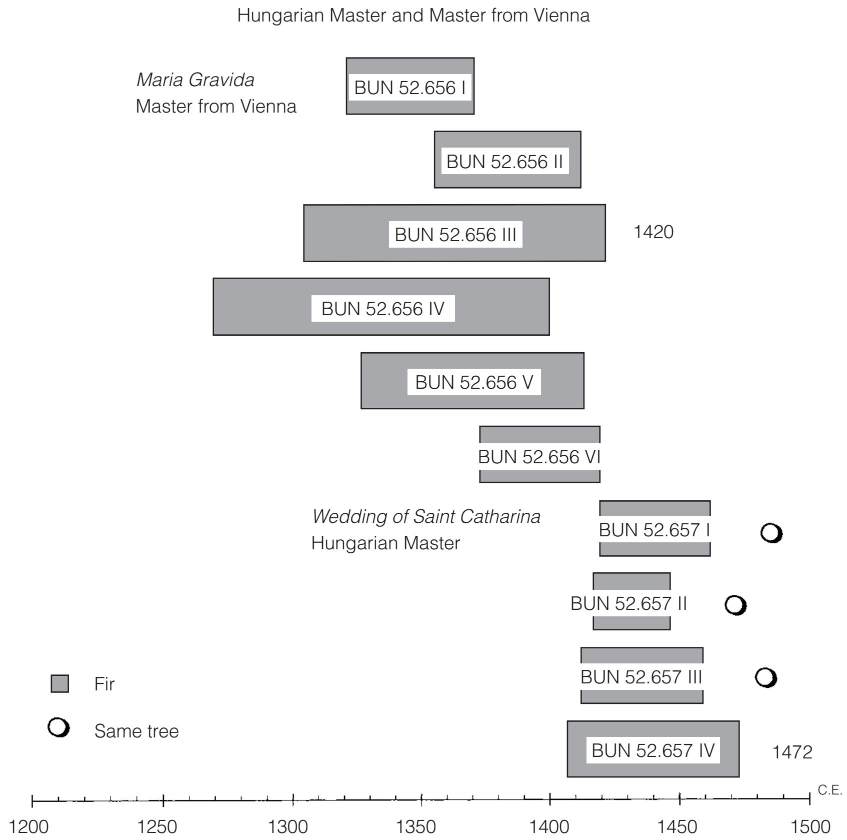
Figure 14
Dendrochronological analyses of spruce panels of a Hungarian master. (BUN = Magyar Nemzeti Galéria, Budapest.)



it is evident that the overall climatic conditions are often shrouded by local or regional influences, thus impeding the use of such general chronologies for dating particular objects.

The successful dating of beech wood widens the scope of tree ring dating in its application to wooden art objects and, at the same time, demonstrates the possibility that the use of dendrochronology may be extended to other diffuse-porous woods used for panels and carvings. Investigations into dendrochronological dating of poplar and linden wood are currently under way. Absolute dating of poplar is not yet possible because of the insufficient number of growth rings; in a few cases,

Figure 15
Dendrochronological analyses of fir panels of a Hungarian master and a master of Vienna. (BUN = Magyar Nemzeti Galéria, Budapest.)



however, a correlation between different boards originating from the oeuvre of one artist could at least be established. Analyses of linden wood initially showed more promising results, but at present, the irregularity of the growth-ring structure in individual trees impedes a successful establishment of master chronologies.

The biological investigations of panels and wood carvings can be helpful to the art historian, but they should always be interpreted along with results obtained by other methods. With regard to future research, the existing master chronologies must be completed. Furthermore, additional dendrochronological analyses with several kinds of wood from different centuries and regions are yet to be accomplished.

Acknowledgments

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Oldenburg; Hermitage Museum, St. Petersburg; Philadelphia Museum of Art; Louvre Museum, Paris; Museum Boymans–Van Beuningen, Rotterdam; Coll. Thyssen, Madrid; Kunsthistorisches Museum Wien, Vienna; Schlossmuseum, Weimar; as well as some private owners.

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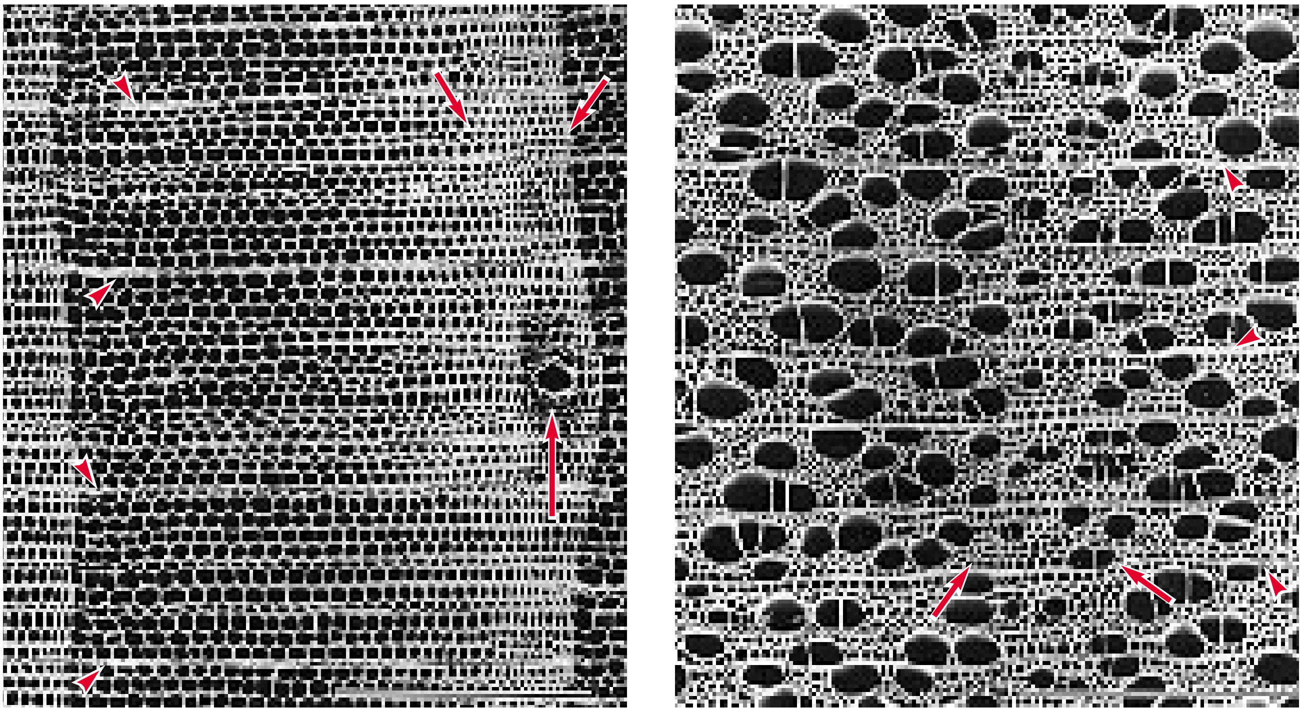
A Guide to Wood Deterioration Caused by Microorganisms and Insects

Robert A. Blanchette

Deterioration inevitably occurs in all woods if environmental conditions are conducive to biotic or abiotic degradation processes. Environmental factors, especially moisture levels, are of paramount importance to the type and rate of decomposition. In terrestrial environments, a complex association of biological and chemical processes may cause extensive biomass loss within a very short time. A variety of biotic agents, including insects, fungi, and bacteria, work together to decompose wood. If decay-limiting conditions are imposed that exclude microorganisms and insects, wood can survive for exceedingly long periods of time.

Old panel paintings are subject to deterioration. Many forms of deterioration may affect painted wooden objects, depending on the environments where the artworks have been found or stored. The extent of damage is related to how well these objects have been protected from moisture, insects, microorganisms, and extraneous compounds. This article provides basic information about biological deterioration processes of wood, as well as a guide to the microorganisms and insects that attack wood, their mode of action, and the effect on chemical and physical properties of wood.

Wood is composed of cells that consist of cellulose, lignin, and hemicellulose. Mono- and disaccharides, aromatic compounds, inorganic substances, and other compounds are also present in varying amounts. The chemical as well as anatomical nature of wood varies greatly among tree species. Differences are seen in various cell types, amounts of extractive material, wood densities, and so on (see Hoadley, "Chemical and Physical Properties of Wood," herein). Sapwood, the outermost part of the tree's wood, which contained living cells while growing, may have high concentrations of free sugars, starch, amino acids, and proteins that make it highly susceptible to attack by some fungi and insects. In contrast, heartwood, the innermost region of the tree, often contains cells with accumulated substances that resist degradation. The heartwood of some trees—such as oak, walnut, cypress, redwood, and cedar—contains compounds that provide some degree of natural durability. Most of these compounds are phenols synthesized by parenchyma cells from carbohydrate precursors at the sapwood-heartwood transition zone (Hillis 1987; Fengel and Wegener 1984). These substances may diffuse into cell walls and fill cell lumina. Although some heartwood is very resistant to attack, prolonged exposure to adverse environments or the presence of aggressive



a b

Figure 1a, b
Transverse sections of sound wood: (a) Spruce (*Picea*) showing earlywood and latewood (small arrows) tracheids, ray parenchyma cells (arrowheads), and resin canal (large arrow); (b) aspen (*Populus*) with large vessel elements distributed throughout earlywood and latewood regions (small arrows) surrounded by fibers and ray parenchyma cells (arrowheads). Scanning electron micrographs; bar = 500 µm.

heartwood-degrading microorganisms can result in substantial degradation (Blanchette et al. 1990; Blanchette 1992).

Anatomical characteristics of sound wood reveal great variation among tree species (Fig. 1a, b). Wood from coniferous trees (commonly referred to as softwood) is composed primarily of tracheids (90–95%). These cells have tapering ends that are closed. Transport of water and minerals is facilitated from one tracheid to another via pit apertures. Other cells include parenchyma cells and, in some species, resin canals. Wood from angiosperms (called hardwood) contains vessel elements, fibers, and parenchyma cells. Vessel elements have large lumina and cell-wall layers that differ from fibers. The middle lamella region of woody cells, found between cells, is highly lignified. The secondary wall layers are cellulose-rich regions, but they do contain some lignin. In general, softwoods have more lignin and less cellulose than do hardwoods. Additional and more detailed information on wood anatomy and chemistry can be found in writings by Fengel and Wegener (1984), Hoadley (1990), Miles (1978), Panshin and de Zeeuw (1980), and Shigo (1994).

Microbial Degradation of Wood

Fungi

Wood deterioration by fungi may occur from several sources. These include the following: surface molds that cause localized discoloration; stain fungi that penetrate deep into the sapwood causing blue, gray, green, red, or other dark coloration; and wood-destroying fungi that decompose cell-wall polymers (Table 1). In all situations, moisture is an important factor for spore (or other fungal propagulum) germination and for successful colonization of the substrate by the fungus. If the moisture content of the wood is below the fiber saturation point of approximately 28% (based on the oven-dry weight of the wood), there will not be

Table 1 Changes in wood due to degradation by fungi

Decay	Wood characteristics	Strength loss	Cell-wall components	Morphology
Brown rot (dry rot)[1]	Brown. Cracks and checks when dry, producing cubical fragments.	Large losses of strength in early stages of decay.	Cellulose depolymerization and loss.	Porous and shrunken cell walls, skeleton of altered lignified wall material.
Soft rot	Brown. Often localized to wood surfaces. Cracks and checks when dry.	Loss of strength in late stages of decay.	Cellulose degraded.	Cavities present in secondary walls, or secondary walls eroded, leaving only the middle lamellae.
White rot	Bleached appearance. Retains shape and composition until decay is advanced.	Major strength losses in intermediate to late stages of decay.	Lignin, cellulose, and hemicellulose degraded.	All secondary cell-wall layers and middle lamellae are eroded.
Fungal stain	Various discolorations in sapwood.	No strength losses.	Free sugars, nutrients, and wood extractives utilized; increase in melanin-like compounds and pigmented substances.	Preferential colonization of ray parenchyma cells; no cell-wall degradation.
Surface molds	Discolorations on wood surfaces only.	No strength losses.	Readily assimilated substances are removed.	Preferential colonization of parenchyma cells; no cell-wall degradation.

[1]*Dry rot* is a common term used to describe brown rot in some wood products.

sufficient free water available for fungal growth and development. The ideal environment for protecting wood from attack is often considered to be a relative humidity (RH) of less than 60%. In some modern museums, humidity can be well regulated; however, over past decades or centuries, many painted wooden objects have been subjected to environments conducive to fungal growth. The duration of this exposure and amount of moisture accumulation govern the type of fungus that may be established, as well as the extent of attack.

With current knowledge of wood-destroying fungi and their patterns of deterioration, it is possible to examine wooden cultural properties, determine the type of fungus that caused the damage, and identify typical characteristics for these forms of decay, such as microstructural damage to cells and loss of strength properties.

Three categories of wood decay are most commonly associated with wood that has been buried, entombed, or exposed to decay-promoting environments for a considerable length of time: brown rot, soft rot, and white rot (Table 1). For example, Fayum portrait paintings may have serious decay problems in parts of the wood, depending on the tomb environment and exposure to moisture (Martin and Reisman 1978). Panel paintings may show decay even if they have not been exposed to burial environments or are not thousands of years old. Painted wooden cultural objects from more recent times may be affected by poor storage conditions in damp cellars, churches, castles, country houses, or other highly humid environments. Since conservators may encounter a wide range of materials from different environments, all major forms of degradation by wood-decay fungi are presented below.

Distinct forms of decay are found in wooden materials because the enzymes and degradative mechanisms of different groups of fungi attack cell-wall components in different ways. As decay progresses, gross differences in color and physical characteristics are readily observed. Microscopic observations are required, however, to identify correctly the decay patterns in incipient to moderate stages of decay.

Brown rot

Brown-rot fungi cause a diffuse depolymerization of cellulose early in the decay process, resulting in significant losses in wood strength properties (Blanchette et al. 1990; Eriksson, Blanchette, and Ander 1990). In more advanced stages, wood polysaccharides are removed, leaving lignin chemically modified but undegraded. The resulting wood is a brown, lignin-rich substrate that cracks and checks into cubical fragments. Hyphae of the fungus colonize cell lumina and produce extracellular enzymes that diffuse throughout adjacent cell walls. Morphological characteristics show wood-cell walls consisting of a fragile network of residual lignin (Fig. 2a–d). These cells have little integrity and easily shatter into minute particles. Optimum wood-moisture content for brown-rot fungi ranges from 40% to 80% based on the oven-dry weight of the wood (Scheffer 1973; Zabel and Morrell 1992).

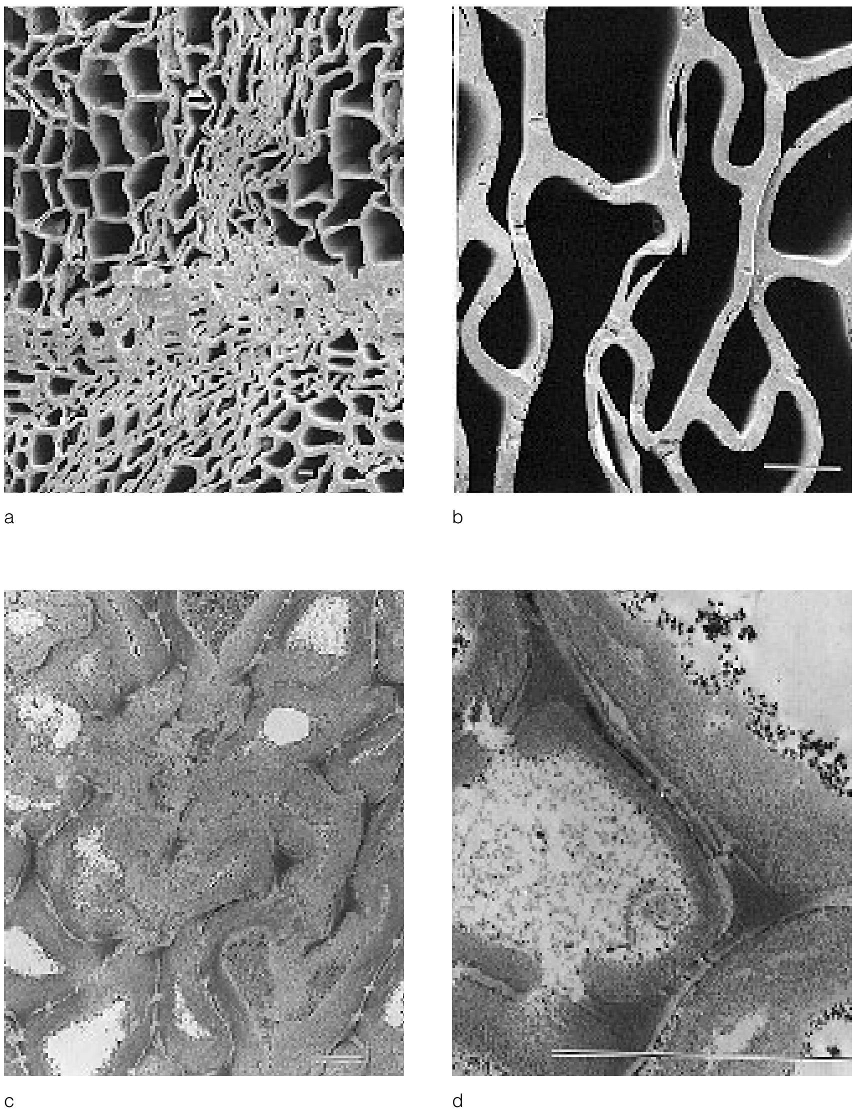


Figure 2a–d
Transverse sections of brown rot: (a) Collapsed and distorted tracheids are evident in spruce with advanced decay. The removal of cellulose has left a degraded cell wall that consists of residual lignin (scanning electron micrograph); (b) brown-rotted tracheids appear porous and have little strength and structural integrity left (scanning electron micrograph); (c) and (d) brown-rotted wood from the Statue of the Scribe of Mitry, V Dynasty (2340 B.C.E.), from Saqqara (Metropolitan Museum of Art, New York, MMA 26.2.4). Brown rot has caused the cells to disrupt into a fine mass of degraded cell-wall material. The residual lignin may fragment into dustlike brown particles. Transmission electron micrographs; bar = 15 μm.

Brown rot frequently occurs in buildings in which wood products are in contact with a source of moisture. One of the most destructive fungi causing timber decay is *Serpula lacrymans*. This brown-rot fungus has the capacity to spread rapidly through wood and across nonnutritional surfaces (Jennings and Bravery 1991). Fungi that cause brown rot are a significant threat to the conservation of ancient and historic buildings. Brown-rot fungi are also responsible for the decay of wooden objects, such as those from ancient Egyptian tombs along the Nile Valley that were apparently affected by intermittent flooding or from other sources of moisture that migrated into the tombs (Fig. 2c, d). The severe compromise of wood integrity after an attack of brown rot presents difficult conservation problems (Blanchette et al. 1991; Blanchette et al. 1994). The extensive degradation of cellulose caused by these fungi leaves such an extremely weak framework of residual wall material that fragmentation occurs with only slight pressure or agitation (Fig. 2a–d). *Dry rot* is a common but inappropriate term that has been used instead of *brown rot*. Although the wood is often dry when found, moisture was needed for the decay to be initiated. The surfaces of older decayed wood usually crack and check when brown rot has been the degradative agent; the result is dried, cubical zones of brown wood.

Soft rot

Soft rot in wood often resembles brown rot macroscopically but differs remarkably in its microscopic characteristics. Soft rot may be localized to a shallow zone on wood surfaces or be more diffuse, depending on environmental conditions and the length of time over which decay has occurred. It may be associated with water-saturated environments or with relatively dry environments where lack of moisture or interacting alkaline conditions appear to inhibit other, more aggressive brown- and white-rot fungi (Blanchette et al. 1990; Blanchette and Simpson 1992). Microscopic observations of soft rot in many wood species reveal cavities within the secondary wall (Fig. 3a–d). Fungal hyphae colonize cell lumina and produce fine hyphae that penetrate into the cell wall. Once inside the wall, the hypha aligns its growth along the same axis as the microfibrils and initiates a localized degradation of the cell wall. In transverse sections, holes are observed within the S_2 region of the secondary wall (Fig. 3a, b). These degraded zones are actually chains of cavities with conical ends formed by oscillatory growth patterns from the soft-rot fungus (Fig. 3c, d). Cellulose and hemicellulose are extensively degraded, and some lignin is lost, but substantial amounts of modified lignin remain in the degraded wood. In some woods, particularly low-density hardwoods, another form of soft-rot attack may occur. The fungus enters cell lumina and progressively erodes all secondary wall layers from the lumen toward the middle lamella region (Blanchette et al. 1990; Nilsson et al. 1989). The middle lamella is not degraded, leaving a highly lignified framework of lamellae between cells. Significant strength losses are associated with advanced stages of soft rot, but reductions in strength during incipient to intermediate stages of decay are not well documented (Kirk and Cowling 1984; Zabel and Morrell 1992).

White rot

White-rot fungi have the capacity to degrade all cell-wall components (Fig. 4a–d). Preferential degradation of phenolic extractives, as well as of lignin, often results in a mottled or overall bleached-white appearance.

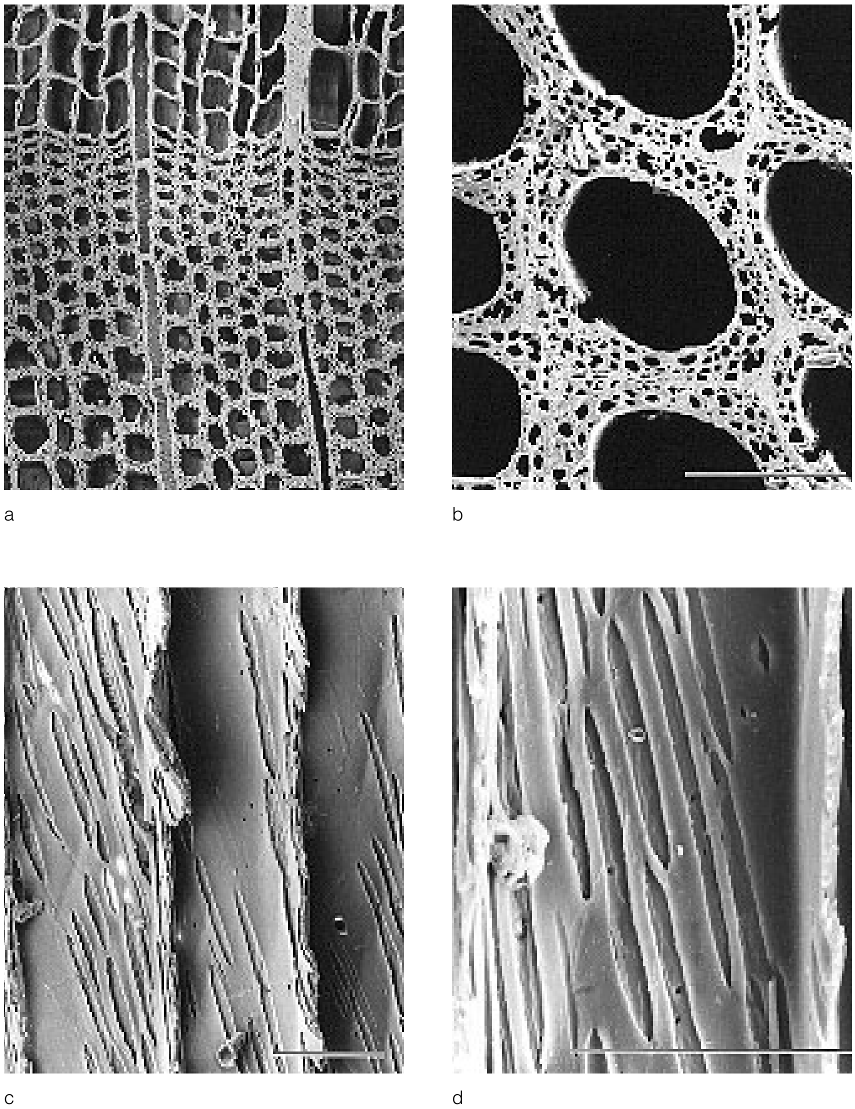


Figure 3a–d
Decay by soft-rot fungi of pine (*Pinus*) from Tumulus MM, Gordion, Turkey (700 B.C.E.): (a) and (b) Transverse sections showing numerous cavities, characteristic of soft-rot attack, within the secondary walls of tracheids; (c) and (d) radial sections of tracheids exhibiting chains of cavities with conical ends formed within the cell walls. These cavities are not visible from the cell lumina until the very advanced stages of decay. Scanning electron micrographs; bar = 30 μm.

The fungus colonizes wood at an optimum moisture content of 40–100% (similar to conditions favorable for brown rot) and progressively erodes the woody cell wall. All cell-wall layers are eroded in the vicinity of the hyphae located in cell lumina (Fig. 4a). More advanced stages of decay show completely degraded cell walls adjacent to cells that are not extensively decayed (Fig. 4b, c). This localized degradation of some cells results in relatively small reductions in wood strength properties until moderate to advanced stages of decay occur. Some species of white-rot fungi have the capacity to remove lignin selectively from wood. The removal of lignin in the cell walls and middle lamella causes cells to detach and separate from one another (Fig. 4d). The remaining cells consist primarily of cellulose (Blanchette 1990).

Mold and stain fungi

Many opportunistic nonwood-destroying fungi colonize freshly cut wood by utilizing simple sugars and other readily available substances. Surface molds may discolor the wood with aggregates of pigmented hyphae and spores or extracellular fungal compounds that stain the wood cell walls (Table 1). Fungi commonly referred to as stain fungi may penetrate deep into the sapwood, preferentially colonizing ray parenchyma cells

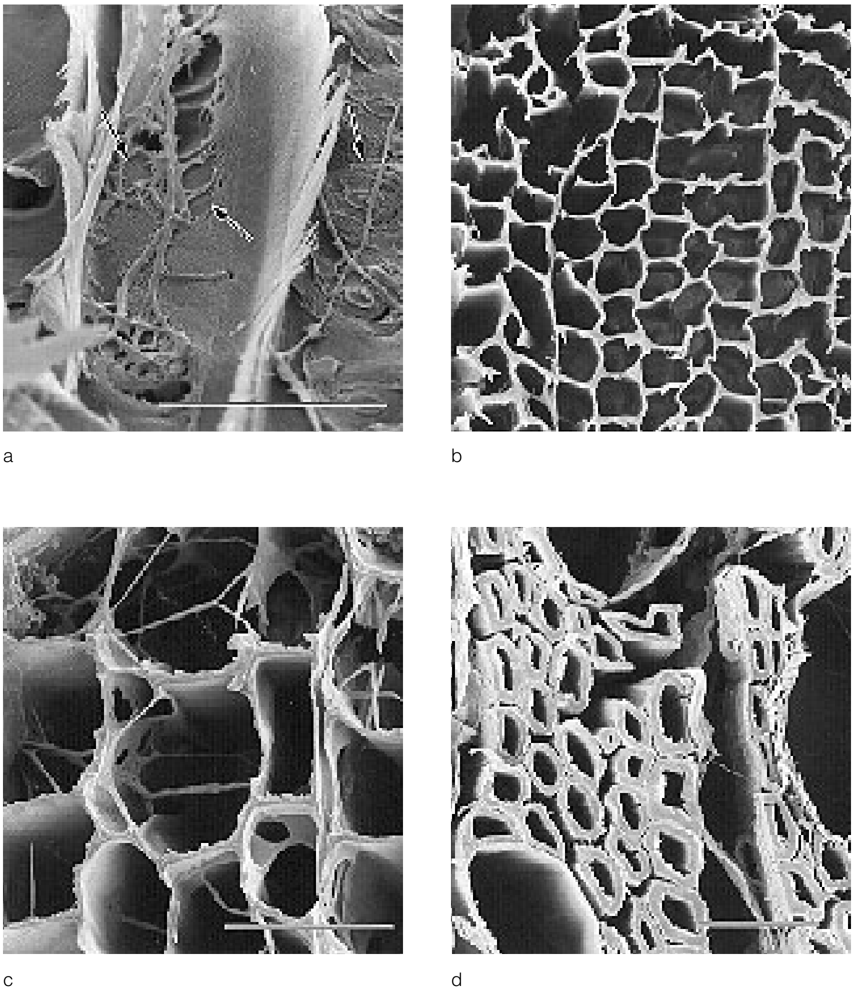


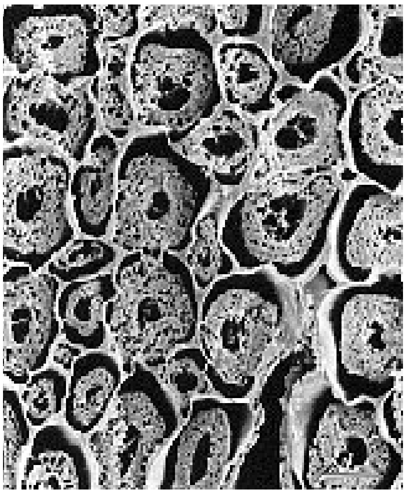
Figure 4a–d
Degradation of wood by white-rot fungi: (a) Tangential section showing fungal hyphae within tracheids causing a localized degradation of the cell walls around the hyphae (arrows); (b) and (c) transverse sections of eroded cell walls. The fungus degrades all wall components, resulting in localized erosion troughs and an overall thinning of cell walls; (d) delignification of birch (*Betula*) wood by a different species of white-rot fungus. Preferential degradation of lignin results in loss of the middle lamella between cells. The fibers and vessels, consisting of cellulose, readily detach and separate. Scanning electron micrographs; bar = 40 μm.

where stored nutrients are located. Since fungal growth follows the ray parenchyma cells, wedge-shaped staining patterns are evident when cross sections of the wood are examined. Stain fungi do not usually colonize heartwood.

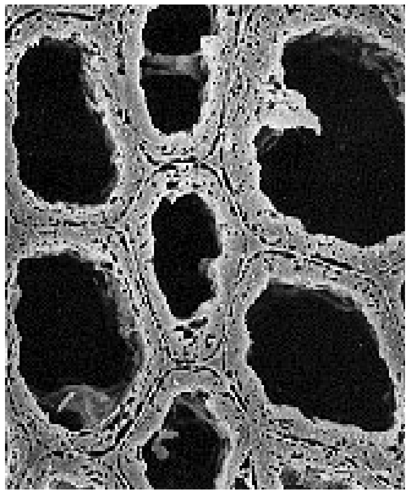
Melanin-like compounds within hyphae or pigmented substances produced extracellularly cause blue, gray-black, red, brown, green, or other stains within the wood. Fungi that cause stains do not directly degrade wood cell walls, nor do they cause significant reductions in wood strength. Stains are usually considered detrimental to wood quality but have also been valued for their unique coloration. Green-stained wood, created by the fungus *Chlorociboria,* was selected by numerous artists in the fifteenth and sixteenth centuries for intarsia panels; the green-colored wood was used for rendering natural scenery with trees and floral leaves or for depicting book covers, fabric, or porphyry (Blanchette, Wilmering, and Baumeister 1992). The stain is not light sensitive and has survived many centuries without loss of color. Interestingly, remnants of fungal hyphae are still present in green-stained wood from several intarsia panels examined during recent restoration and conservation work (Blanchette, Wilmering, and Baumeister 1992).

Bacterial degradation of wood

Bacteria that cause deterioration in wood are most often associated with waterlogged conditions. Buried wood from wet terrestrial sites or from



a



b

Figure 5a, b
Transverse sections of wood with bacterial degradation from the hull of the Uluburun, a late Bronze Age (1400 B.C.E.) shipwreck off the coast of Turkey: (a) and (b) Minute cavities caused by tunneling bacteria are present within the secondary cell walls. The residual wall matrix is porous and lacks integrity. The degraded wall material is disrupted during drying and is often pulled away from the middle lamella. Scanning electron micrographs; bar = 10 μm.

sunken ships in fresh or saline waters is usually severely affected by bacteria that erode cell walls or produce cavities or tunnels within the secondary walls (Fig. 5a, b). Other forms of bacterial attack include species that degrade membranes covering pit apertures but do not affect the cell wall. All of these bacterial degradation patterns are distinct from those produced by fungi and can be readily identified by examination with ultrastructural techniques (Fig. 5a, b). The exceedingly high moisture content and long exposure necessary for bacterial degradation suggest that this type of degradation would not typically be found in wooden panel paintings. Conservators who encounter waterlogged cultural properties may obtain additional information from writings by Blanchette and coworkers (1990), Blanchette and Hoffmann (1994), and Singh and Butcher (1991).

Insect Damage to Wood

General life cycle of insects

Damage to wood by wood-boring beetles (Fig. 6) results from the feeding stage of larvae (commonly referred to as woodworms) that bore circular tunnels ranging in size from 1 mm to 10 mm in diameter. The larvae feed on the wood, leaving fecal pellets and fine particles of wood in the frass. The common furniture beetle (*Anobium* spp.) adult lays numerous ellipsoidal eggs in surface cracks or along the rough end grain of wood (Fig. 7). After three to five weeks, larvae emerge from the eggs and eat their way into the wood with their strong mandibles. As the larvae tunnel through the wood, frass is often tightly packed into the gallery behind them. The larval period may last years, and a number of instar stages and molts occur before the larvae reach the pupal stage (Bravery et al. 1987; Creffield 1991; Hickin 1975). The size of the tunnels reflects the size of the growing larvae (Fig. 8a–c). Before pupation occurs, the larvae tunnel to the surface of the wood and form a chamber free of wood fragments and fecal pellets. Adults emerge after several weeks of pupation by boring an emergence hole out to the wood surface. The size of the tunnels, orientation within wood, and characteristics of the frass vary among the different beetle species (Table 2). The type of wood also may govern which wood-boring insect may attack. Some wood-boring beetles, such as powderpost beetles, require sapwood for successful larval development and do not infest heartwood. The *Lyctus* powderpost beetles have even stricter requirements that

Figure 6
Common adult wood-boring beetles that can damage wood. The actual size of each insect is represented by the bar next to the beetle. See Table 2 for a summary of the woods affected and the distinguishing characteristics of the damage.

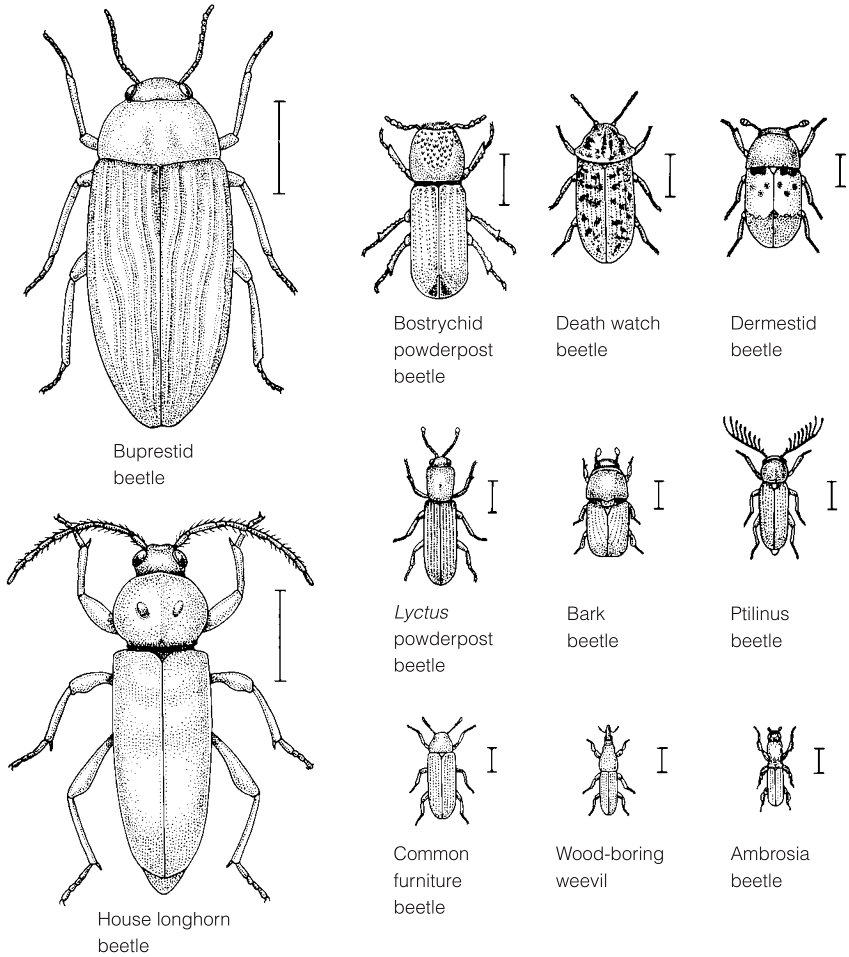
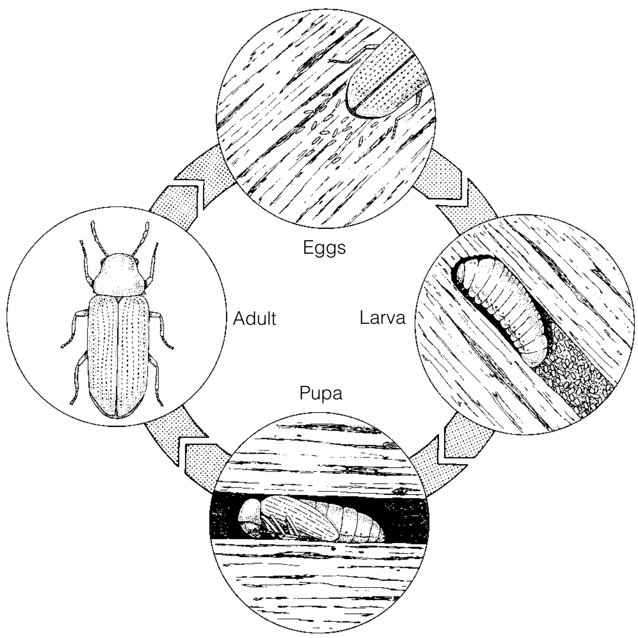


Figure 7
Life cycle of the common furniture beetle, *Anobium*. Eggs are laid on exposed wood. Larvae (woodworms) develop from eggs and bore into the wood, leaving pellets of frass and particles of wood behind. Larvae grow as they tunnel and feed on the wood. Larvae pupate before emerging as adults. Damage to the wood is due to the wood-boring larval stage of the beetle.



include wood with large vessel elements, such as oak and elm, and a high starch content (Hickin 1963, 1975). *Lyctus* beetles lay their eggs directly into vessel elements using a long ovipositor. The size of the ovipositor requires larger cells, such as the earlywood vessels of ring-porous woods, for successful penetration. Since eggs can be laid only in wood with vessels

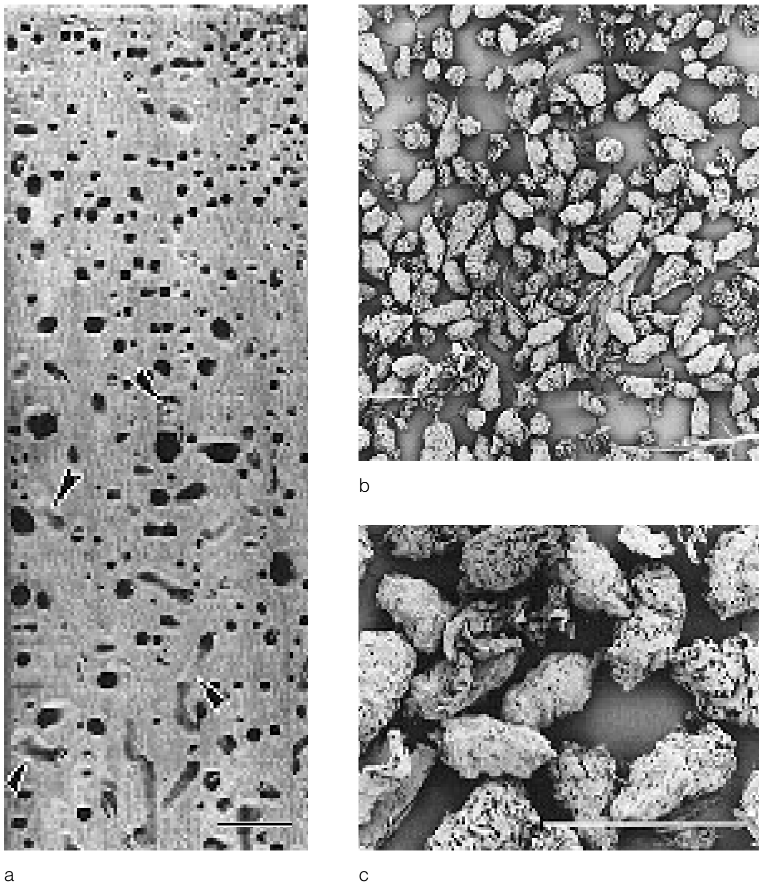


Figure 8a–c
Insect tunnels and frass of the common furniture beetle, *Anobium:* (a) Cut wood from a stretcher (seventeenth century, Italy) with boreholes caused by the larval stage of *Anobium*. The size of the tunnel reflects the size of the growing larva as it feeds on the wood. Insect frass (arrows) is usually held within the tunnels (in this sample, however, it has fallen out during cutting); radially sawed wood, bar = 1 cm; (b) and (c) *Anobium* frass consists of pellets and fragments of wood. These small frass pellets are characteristic of *Anobium* attack. Scanning electron micrographs; bar = 250 μm.

of sufficient size to accommodate the insect's ovipositor, damage by this beetle is restricted to hardwoods with large vessel elements (Bravery et al. 1987), as well as bamboo and rattan, which have large vascular elements.

Moisture content is also an important factor for wood-boring insects. The *Lyctus* and *Anobium* beetles require relatively low wood-moisture levels of 8–20% for continued activity (Creffield 1991). However, damage can also occur and is often most severe in woods exposed to damp conditions. Other wood-boring insects, such as ambrosia and bostrychid beetles (Fig. 6), require a wood moisture of greater than 30%. Many wood-boring insects attack only wood that has been previously altered by decay fungi (Table 2).

Termite damage

Termite damage has been found to affect some panel paintings that were in direct contact with the walls of infested buildings in tropical regions (Boustead 1968), but otherwise this type of damage is not frequently encountered by museum conservators. Termites eat the interior portions of the wood, leaving a thin shell of exposed wood. Damage can be extensive and is easily recognized by the broad feeding galleries in the wood. Dampwood termites and some subterranean termites have a preference for moist wood and are often associated with wood in an early stage of decay by wood-rotting fungi. Galleries follow earlywood regions, leaving thin zones of latewood behind. Dry-wood termites also require moist wood but do not need an external source of water. A diagnostic feature of drywood-termite attack is fecal pellets that accumulate in excavated galleries of the wood. Galleries also lack orientation with the wood grain. A great deal of

Table 2 Summary of wood-boring-insect damage to wood

Insect	Wood	Distinguishing characteristics
Common furniture beetle, *Anobium*	Sapwood of softwoods and hardwoods; may attack heartwood if fungal decay is present.	Meandering tunnels 1–2 mm in diameter, often in direction of grain, filled with frass consisting of oval pellets and wood powder.
Lyctus powderpost beetle	Sapwood of hardwoods with large vessels, such as oak and elm.	Damage in sapwood with high starch content. Circular tunnels 1–2 mm in diameter, usually parallel to grain, filled with fine powder.
Bostrychid powderpost beetle	Sapwood of tropical timbers.	Convoluted tunnels 3–6 mm in diameter, packed with fine powder.
Wood-boring weevil	Decayed softwoods and hardwoods.	Tunnels 1 mm in diameter, oriented in direction of grain, with fine, granular powder.
Ptilinus beetle	Sapwood of hardwoods.	Meandering tunnels 1–2 mm in diameter, packed with fine bore dust.
Death watch beetle	Sapwood and heartwood of decayed hardwoods.	Tunnels variable in diameter from 0.5–3 mm, randomly oriented but common in direction of grain; bore dust consists of fine, disk-shaped pellets.
Ambrosia beetle, pinhole borer	Standing trees or cut green timber; does not infest timber that has been dried.	Main tunnel 1–2 mm in diameter at right angles to grain with short lateral tunnels originating from it; wood is darkly stained by fungi around tunnels; no bore dust in tunnels.
Bark beetle	Bark of hardwoods and softwoods.	Insects tunnel through bark and cause scoring of wood surfaces beneath bark and phloem; only found on fresh wood with bark.
Dermestid beetle	Damage to dry animal material (leather, fur, etc.); wood damaged only when in contact with a food source.	Short tunnels free from bore dust in wood adjacent to animal material; circular holes 3–4 mm in diameter and up to 10 mm long.
Buprestid beetle, jewel beetle	Standing dead or recently cut logs; rare in dry timbers.	Large tunnels 7–8 mm in diameter, with oval emergence holes; large cylindrical frass pellets make up bore dust. Larvae have large flat heads.
House longhorn beetle, cerambycid beetle	Sapwood of softwoods.	Tunnels 6–10 mm in diameter with similar-sized oval emergence holes; bore dust contains cylindrical pellets with fragments of wood; most of the sapwood may be consumed, with just a thin veneer of surface wood left.

information has been published concerning these wood-destroying insects in buildings and other wood products. For discussions of termite biology and attack, see Creffield (1991), Hickin (1975), and Moore (1979).

Control of Fungi and Insects

Successful control of fungi and insects requires knowledge of the biological agents that can cause deterioration, as well as the ability to diagnose the existing damage adequately. Once this information is available, much can be gleaned from existing literature about the nature of the attack and its effects on the wood.

A clean, pest-free environment with RH control of less than 60% is essential to prevent damage by fungi and insects. Reducing wood moisture halts decay activities by fungi but does not eradicate the fungus or the reproductive structures that produced it. A change in moisture and return to more favorable conditions for fungal growth can result in renewed growth of the dormant fungus or facilitate new infestations. An inspection program and the eradication of established insect infestations from wooden objects are necessary to prevent future damage. Although effective control procedures for insects are available that utilize fumigants, heat, freezing temperatures, or insecticides (Edwards, Bell, and King 1981; Hickin 1978; Nesheim 1984; Robinson 1988), these methods may not be ideally suited for use by museum conservators because of the side effects that may damage the object or because of safety concerns regarding the use of highly toxic substances and reactions (chemical or physical) that can affect the painted wood surface or other associated materials. Alternative strategies that include changes in atmospheric gases, such as high CO_2 or N_2 environments and oxygen scavengers, are being used for controlling insect pests (Daniel, Hanlon, and Maekawa 1993; Gilberg 1989, 1990; Hanlon et al. 1992; Pinniger 1991; Valentin 1993). Additional information on the use of modified atmospheres to eradicate insect infestations is presented by Hanlon and Daniel ("Modified Atmosphere Treatments," herein). Further testing of various control strategies in different substrates and deterioration situations is important in determining the most appropriate compounds, methods, and procedures to use. It is hoped that this review of the causal agents involved in the biological degradation in wood will serve as a diagnostic guide and source of information about the effects that different fungi and insects have on wooden cultural properties.

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Modified Atmosphere Treatments of Insect Infestations

Gordon Hanlon and Vinod Daniel

The traditional approach to treating panel paintings infested with insect species has been to employ a range of toxic gases or chemical treatments to control or eradicate the infestation. However, over the last decade there has been a growing awareness of the environmental and health implications of using toxic gases or chemical treatments for pest eradication (Zycherman and Schrock 1988; Child and Pinniger 1987). Increased legislation in a number of European countries and in the United States has resulted in the restriction or outright banning of many toxic treatments. In addition, research has shown that toxic treatments can cause chemical change and damage to artifacts (Dawson 1988).

Insect damage to panel paintings is caused by several wood-boring species that lay their eggs on unpainted areas of the wood panel. During the life cycle of the insect, the larvae bore into the wood, forming tunnels or channels; the adults ultimately emerge through the characteristic round flight holes. This excavation of the wood ultimately undermines the structural stability of the panel, which, in turn, can undermine the surface paint layers. The wood-boring insects that commonly attack wood panels include the common furniture beetle or woodworm (*Anobium punctatum*), death watch beetle (*Xestobium rufovillosum*), powderpost beetle (*Lyctus* spp.), house longhorn beetle (*Hylotrupes bajulus*), and termite (*Cryptermes* spp.) (Schrock 1988). While a wide range of woods has been employed for the supports for panel paintings, the woods most commonly used in European panel paintings of the fourteenth to sixteenth centuries are poplar, oak, and walnut, which are all susceptible to insect attack.

To counteract insect infestation and the structural instability it causes, panel paintings have been treated with a wide range of toxic gases such as Vikane, ethylene oxide, and methyl bromide. Many chemical treatments have also been used and recommended in the past (Schiessl 1984; Serck-Dewaide 1978; *Museum* 1955). The liquid chemicals, applied by brush or injection, aim to kill any present infestation and have been recommended because they leave a residue that can prevent reinfestation. These chemicals include chloronaphthalene, mercuric chloride, Xylamon CombiClear, and arsenic salts. All of these chemicals are highly toxic, and in many cases, treatments with them will alter or affect the appearance of a painted surface. The residual effects of these chemicals may have health implications. There is even some doubt as to the effectiveness of some of these treatments (Hayward 1992).

Theory of Modified Atmospheres

As a direct result of concerns about the possible health risks, environmental impact, and damage to objects posed by toxic gases and other chemical treatments for controlling insect infestation, a growing number of research studies have investigated alternative treatments employing low oxygen environments. The stored products industry has used and published information on modified atmospheres to control insect pests in stored grains and food for several years (Bailey and Banks 1980). These studies, however, center on insect species that are not directly relevant to museum objects, and the aim of the studies is to control rather than to eradicate the insect infestation. More recent studies, which have focused on insect species that are known to be a problem for the museum community, discuss the effects of low-oxygen atmospheres on the mortality of several insect species (Valentin and Preusser 1990; Gilberg 1989, 1991; Rust et al. 1996; Valentin 1990). These investigations have shown the efficacy of low-oxygen environments—which use inert gases such as nitrogen, argon, and helium—to kill all life stages of the insect species studied and have quantified the relationship of temperature and relative humidity (RH) conditions to the mortality rate. A study sponsored by the Getty Conservation Institute was performed at the University of California, Riverside, where Rust and coworkers (1996) evaluated the mortality of all life stages of ten commonly found insect species at 55% RH and 25.5 °C in a nitrogen atmosphere having less than 0.1% oxygen. The time required for 100% kill varied from 3 hours for the adult firebrat (*Thermobia domestica*) to 192 hours for the eggs of the cigarette beetle (*Lasioderma serricorne*). Several independent studies have examined the mortality rates at low oxygen concentrations of wood-boring species, including the furniture beetle (*Anobium punctatum*), the powderpost beetle (*Lyctus brunneum*), the western drywood termite (*Incisitermes minor*), and the house longhorn beetle (*Hylotrupes bajulus*). All of these studies prove the efficacy of low-oxygen environments in killing the life stages of these species.

Based on this research, the Getty Conservation Institute and the J. Paul Getty Museum have perfected a number of methods for creating and maintaining a low-oxygen environment for the treatment of insect infestations. These methods are especially applicable to panel paintings and can also be used to treat infested picture frames and stretchers of canvas paintings. This article describes how these methods are applied to maintain an oxygen concentration of less than 0.1% and the desired RH for the duration of the treatment.

Practical Application

The two basic requirements for insect eradication using low-oxygen atmospheres are to create a method of encapsulating the object to be treated and to reduce the oxygen concentration within this enclosure to 0.1% or less.

Encapsulation of the infested object: Bag construction

The simplest method of encapsulating an object is to use plastic sheeting, which is heat-sealed to form a bag or pouch that encloses the panel to be treated. However, the oxygen permeability of various plastic sheeting varies considerably, and it is critical to select a plastic film with the lowest possible oxygen permeability to maintain the low-oxygen concentration within the bag for the duration of the treatment (Burke 1992). The authors selected Aclar (polychlorotrifluoroethylene) composite film with a permeability, or transmission rate, of 50 $cm^3 m^{-2}$ per day per atmosphere. Aclar is a plastic laminate sandwiched between layers of Mylar and polyethylene. Other plastic composite films are available with a lower oxygen permeability (such as Marvelseal), but these are either very expensive, unavailable in suitable sizes, or coated with an aluminized layer that prevents visual inspection of the object inside the bag.

Bags are fabricated by heat-sealing sheets of the Aclar plastic film (which has a heat-sealable inner coating of polyethylene) to create a bag or pouch that conforms to the shape of the object (Fig. 1). The seals can be made with a heated, handheld spatula or a clamping heat sealer. When the painting is placed into the bag, it is recommended that some form of spacer be used so that the bag does not rest on the painting's surface.

As a panel painting is essentially a two-dimensional object, even if the panel is enclosed in an integral frame, it is easy enough to construct a simple bag or pouch that closely conforms to the shape of the painting and is of a volume comparable to the panel painting. This results in an efficient enclosure for the subsequent reduction of the oxygen contained within the bag, whereas bags constructed for three-dimensional objects, such as furniture, are often much larger than an object's total volume.

Creating a low-oxygen environment

After the object has been encapsulated in an Aclar bag, the oxygen concentration in the bag must be reduced to less than 0.1%. As air is composed of approximately 20.9% oxygen, with the bulk of the remaining gases being nitrogen, the amount of oxygen to be removed or replaced is approximately 20% of the total volume of the bag. To produce and maintain the low-oxygen atmosphere, the bag is continuously purged with an inert gas such as nitrogen or with an oxygen scavenger, such as Ageless. Based on the studies by Rust and coworkers (1996), the authors recommend a treatment time of fourteen days at an oxygen concentration of 0.1%. This provides a safety margin, as the study found seven days to be the maximum time required to kill the most resistant species.

Figure 1
Heat-sealing of the Aclar plastic film to create a bag to encapsulate a panel painting for treatment.

To test the oxygen concentration within the encapsulating bag, the authors used the battery-powered Teledyne oxygen monitor (Model 320P). The monitor can be placed inside the transparent plastic bag, permitting the oxygen level to be read from the outside.

There are three methods for creating a low-oxygen environment:

1. *The static system*. This method is ideal for treating small objects, especially paintings. No purging of air in the bag is necessary. An estimated amount of an oxygen scavenger is inserted to absorb the oxygen in the bag initially and then to maintain the oxygen concentration at 0.1% for the fumigation period.
2. *The dynamic system*. An inert gas is used to flush all air out of the bag by an initial high flow rate. When an oxygen level of less than 0.1% is reached, the flow is reduced to the level required to maintain the low-oxygen atmosphere during the treatment period.
3. *The dynamic-static system*. The bag is purged with an inert gas (as with the dynamic system), but when the oxygen concentration has been reduced to 0.1%, the flow of nitrogen is turned off, and a predetermined quantity of an oxygen scavenger is inserted. The small opening in the bag for the insertion of the oxygen scavenger is sealed for the duration of the treatment.

Figure 2
Package of twenty-five sachets of Ageless oxygen scavenger.

The static system

The oxygen contained in the encapsulating bag is reduced to a low concentration by the use of an oxygen scavenger (Gilberg 1990; Daniel and Lambert 1993). The commercially available oxygen scavenger Ageless, which was used in this study, is described by the manufacturer as a mixture of finely divided moist iron (ferrous) oxide and potassium chloride (Fig. 2). Ageless is marketed in several different compositions that are used for a range of applications. The type used in this study was Ageless-Z, which is formulated to react rapidly and thoroughly with oxygen at an RH of 50% (Lambert, Daniel, and Preusser 1992; Grattan and Gilberg 1994). Ageless-Z is packaged in small, flat, paper packets and labeled as Z-100, Z-1000, and so on, to indicate the milliliters of oxygen that a single packet can scavenge. In most situations reported here, Ageless-Z-2000 was used. Because it can scavenge 2 l of oxygen, this size of packet minimizes the number of packets that need to be placed inside the bag.

When bags of Ageless are initially placed inside an Aclar bag, they scavenge the oxygen component of the air in the bag. Any oxygen that subsequently leaks into the bag must immediately react with the Ageless to maintain the low oxygen concentration in the sealed bag—that is, the leak rate cannot be greater than the rate of reaction of Ageless with oxygen. The leak rate refers to the amount of oxygen that permeates through the plastic into the bag.

This static system is ideal for panel paintings.

To treat an infected panel using Ageless, a bag is made out of Aclar plastic film, leaving an unsealed opening for the insertion of the Ageless packets. The Aclar bag should be constructed to be slightly larger than the object, to allow for the decrease in volume caused by the oxygen scavenging and to prevent any pressure from being placed on the painting by the bag. Once the bag is constructed, its approximate volume in liters

Figure 3
Placing oxygen-scavenger sachets into the encapsulating bag through the unsealed opening at the end of the bag.

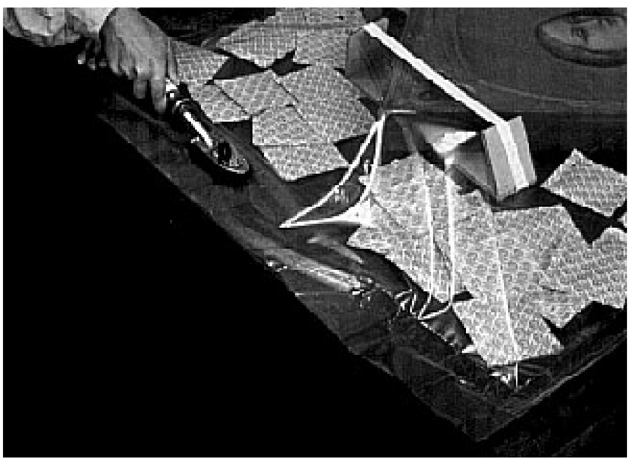
is calculated. Approximately 20% of this volume is oxygen that can be scavenged by the insertion of an appropriate number of Ageless packets; however, it is recommended that double the calculated number of Ageless packets be inserted into the bag to provide a large margin of safety (Fig. 3). The unsealed opening is then heat-sealed and left for fourteen days (Figs. 4, 5). As the reaction of Ageless with oxygen is exothermic, the Ageless packets can become hot. It is, therefore, important that the packets not be placed on the painting's surface. The heat generated by the reaction is localized; in experiments, the temperature and RH within the bag remained constant.

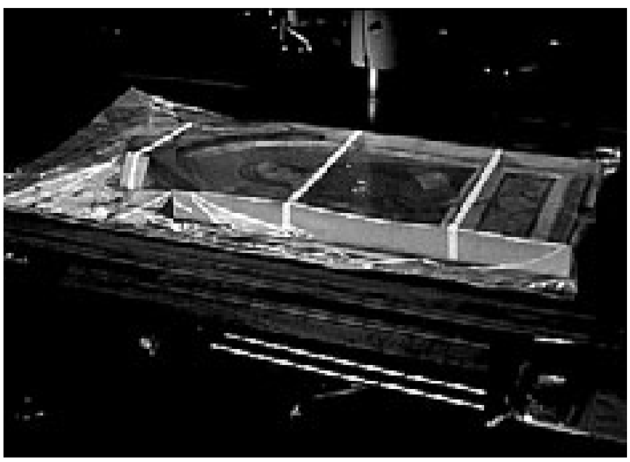
Dynamic and dynamic-static systems

Both the dynamic and the dynamic-static systems use nitrogen gas supplied by a pressurized tank or nitrogen cylinder. The nitrogen gas is passed through a series of polypropylene tubes and delivered to the encapsulating bag, where it replaces the oxygen in the bag (Fig. 6). In this way the oxygen concentration in the bag is reduced to 0.1%. These two methods were developed for the treatment of larger objects (Hanlon et al. 1992; Daniel et al. 1993; Daniel, Hanlon, and Maekawa 1993). Both methods initially use the same procedure of flushing the bag with a high flow of nitrogen gas. As nitrogen gas that comes directly from a gas cylinder has a very low RH, it is essential to introduce a humidification system between the nitrogen

Figure 4, below
Final heat-sealing of the opening used to insert the oxygen-scavenger sachets into the bag.

Figure 5, below right
Finished bag enclosing the panel painting to be treated and the number of oxygen-scavenger sachets calculated to reduce the oxygen concentration to 0.1%.





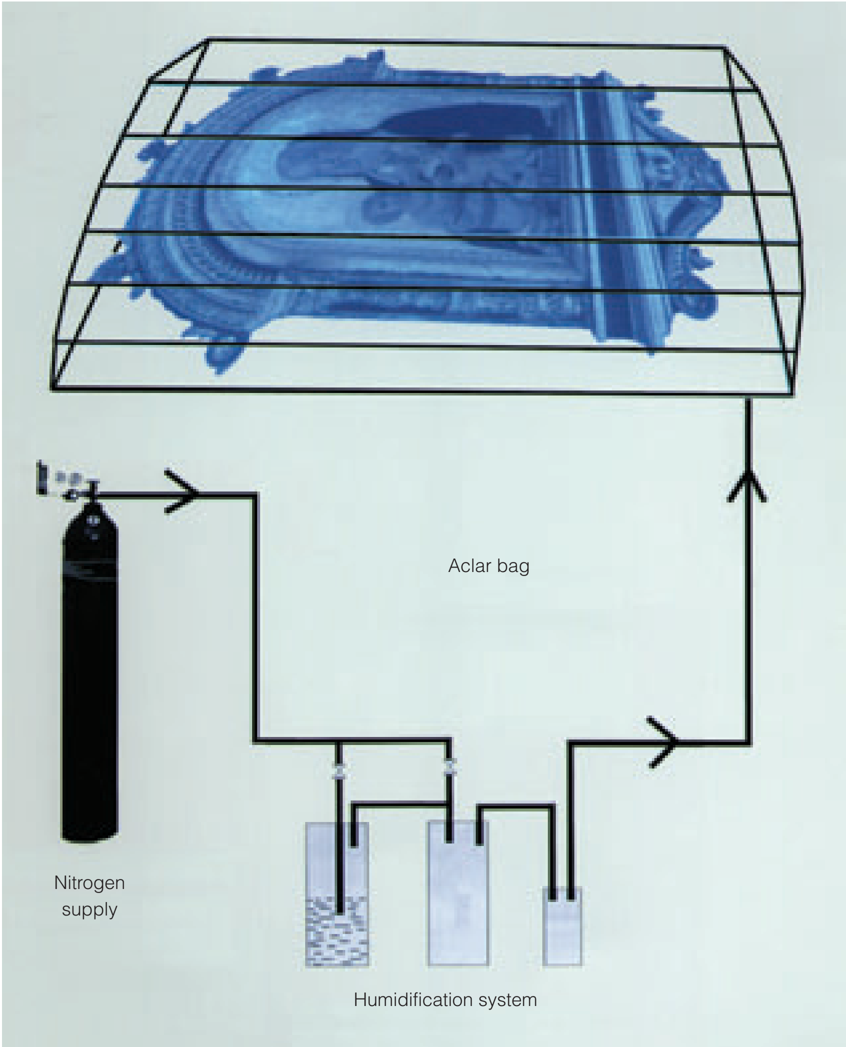


Figure 6
Schematic of the dynamic system for creating a low-oxygen environment.

supply and the bag containing the object. This allows the "dry" nitrogen from the cylinder to be humidified to the object's optimal RH before the gas flows into the bag. The humidification system functions by dividing the gas flow from the nitrogen cylinder into two valve-controlled lines. One stream of nitrogen is bubbled through water contained in a stout polypropylene bottle. The second stream flows directly to a second (dry) bottle, which is also connected to the water-filled bottle. The mixing of the dry and humidified gases is controlled by valves, which regulate the flow rate into each bottle. To monitor the RH of the resulting combined gas stream, a third bottle is used that contains an RH sensor and that also acts as a final mixing chamber before the humidified gas passes into the plastic bag containing the object (Fig. 7).

An important aspect of the design of the nitrogen-supply-and-humidification system is the use of leakproof fittings that minimize the influx of oxygen into the system. All fittings from the nitrogen cylinder to the entrance of the bag use ¼-in. (approx. 6 mm) brass O-ring-sealed Swagelok fittings. These fittings connect the polypropylene tubing, which is used to pipe the nitrogen gas from the gas cylinder, through the humidification system, and into the bag. Swagelok O-ring-sealed fittings are inserted into holes that are precisely drilled in the lids of the humidifica-

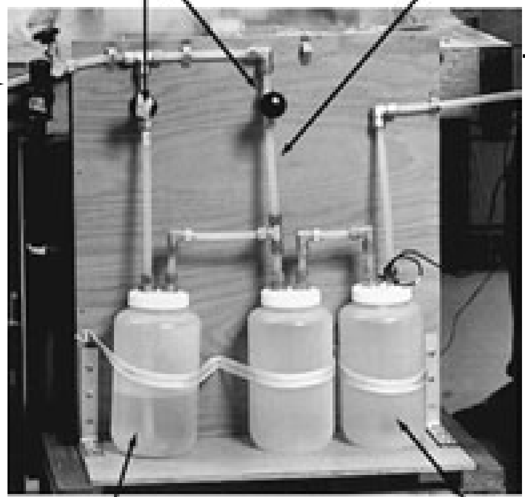


Figure 7
Humidification system for the nitrogen gas.

tion bottles and also connect the polypropylene piping joining the three bottles. A Swagelok fitting is also inserted into a precisely cut hole in the Aclar bag to allow the pipe to form a leakproof connection into the bag. A T fitting with an on/off valve is attached between the third bottle of the humidification system (which houses the RH sensor) and the bag. This allows the release of the nitrogen gas into the room atmosphere during the balancing of the humidification system, to produce the desired level of humidification of the nitrogen flow.

During the initial flushing at a high flow rate, the RH inside the bag should be constantly monitored. An opening of 15–30 cm is left unsealed and open on the corner of the bag opposite the nitrogen inlet to allow efficient mixing and flushing of the interior atmosphere without pressurizing the bag (Fig. 8). This opening is heat-sealed after the desired stable oxygen concentration is achieved.

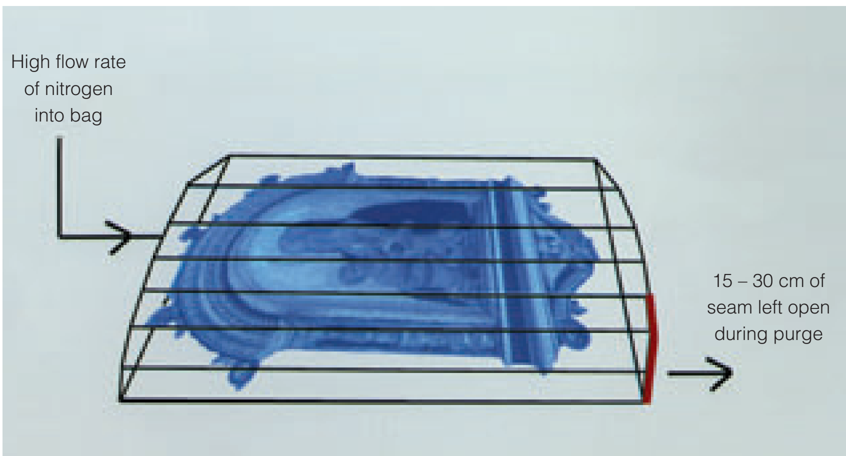


Figure 8
System for purging the encapsulating bag with nitrogen gas to reduce the oxygen concentration to 0.1%.

In the dynamic system, once an oxygen concentration of 0.1% is reached, the nitrogen flow is decreased to a very low rate to maintain the low oxygen concentration. In contrast, in the dynamic-static system, while the nitrogen flow is still running at a high rate, the calculated number of Ageless oxygen-scavenger packets is placed inside the bag, the opening is heat-sealed, and the nitrogen flow is turned off. The Ageless maintains the low oxygen concentration by scavenging any oxygen that may leak into the bag.

Alternative Encapsulation Systems

Many museums own fumigation chambers purchased many years ago, designed for the use of toxic fumigants such as methyl bromide and ethylene oxide fluoride. In many cases these chambers can no longer be used because of environmental regulations against the use of these fumigants. Recently the Getty Conservation Institute converted the Los Angeles County Museum of Art's Vacudyne 36-ft^3 (approx. 1000 l) fumigation chamber (designed for ethylene oxide fumigation) to the dynamic nitrogen system described above. Several modifications were made to the existing mechanical and electrical controls to allow oxygen, temperature, and RH sensors to be installed inside the chamber. To operate the chamber, it is flushed with humidified nitrogen. Once the oxygen concentration drops to 0.1%, the inlet valve and the nitrogen flow are closed, and the oxygen concentration inside the chamber is monitored. With this particular chamber the leak rate was determined to be 50 ppm per day (0.005%). The chamber needs to be refreshed every eight to ten days to maintain the oxygen concentration below 0.1%.

Conclusion

The Getty Conservation Institute has sponsored an extended mortality study at higher oxygen concentrations (0.3%, 0.6%, and 1.0%) which is being conducted by Michael Rust at the University of California, Riverside. Results from this study so far suggest that an oxygen concentration of 0.3% is also effective in producing 100% mortality for the cigarette beetle (*Lasioderma serricorne*) and furniture carpet beetle (*Anthrenus flavipes*). This new research promises much easier implementation of low-oxygen atmosphere fumigation for insect eradication in the future.

The use of low-oxygen atmospheres for eradicating insect infestation is a viable alternative to toxic gas and chemical treatments. All commonly found museum pests can be eradicated by using a 0.1% oxygen atmosphere. The methods described in this article produce and maintain the RH and oxygen concentration at the required level. These methods are advantageous because they are nontoxic and low in cost and can be used in a variety of settings, such as galleries, storerooms, or conservation laboratories.

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Materials and Suppliers

Aclar (polychlorotrifluoroethylene) composite film, Bell Fibre Products, P.O. Box 1158, Columbus, GA 31993; distributed by Sealpak, 13826 Prairie Avenue, Hawthorne, CA 90250.

Ageless, Ageless-Z, and Ageless-Z-2000, Mitsubishi Gas Chemical Co., Mitsubishi Building, 5-2 Marunouchi 2-chrome, Chiyoda-ku, Tokyo, Japan; distributed by Conservation Materials Ltd., 100 Standing Rock Circle, Reno, NV 89511.

Marvelseal, Ludlow Corp., Lamination and Coating Division, 1 Minden Road, Homer, LA 71040; distributed by Sealpak.

Swagelok fittings (1/4-in. brass O-ring-sealed), Swagelok, 31400 Aurora Road, Solon, OH 44139.

Teledyne oxygen monitor Model 320P (battery-powered), Teledyne Analytical Instruments, 2049 Century Park East, Los Angeles, CA 90067.

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A Survey of Adhesives for Wood Conservation

Donald C. Williams

This article will provide a brief review of the types of adhesives used for wooden objects; the conservation treatment of wooden objects whose elements have undergone structural damage; and the selection and use of adhesives during conservation treatments. Whereas some of the adhesives discussed may not be suitable for panel paintings, it is important for conservators to be familiar with them because they are likely to be encountered in previous ill-advised conservation attempts on panels.

When reviewing the properties, selection, and use of adhesives for wood conservation, it is first necessary to answer the question What is the adhesive supposed to do? Equally important is the converse question, What should the adhesive *not* do? Naturally, this inquiry is part of the strategy of any particular conservation treatment and, in turn, involves the evaluation of any ethical issues facing the conservator.

Adhesives and Their Properties

Natural protein adhesives

Prior to the development of synthetic resin adhesives in the early twentieth century, the most common adhesive for wood—indeed, the glue dominant almost to the exclusion of all others—was protein glue. There are a number of glues that fall into this category of proteinaceous animal by-products, such as casein, albumin, fish glue, and animal-hide glue.

Casein glue, a powder derived from the curds of acidified skim milk, forms a water-resistant and heat-resistant adhesive when mixed with water. Exceedingly strong, casein continues to be used for architectural laminae and was used in the past to butt-join panels during the original fabrication of panel paintings. Albumin glue, derived from blood proteins, is a water-resistant glue used since antiquity. For the ancients, the coagulating process, which drove the adhesion, required the use of fresh blood. However, when the process for making dried-blood glue was discovered in the early twentieth century, use of this adhesive became more widespread. Its primary utility was as a water-resistant, heat-activated adhesive for industrially produced plywood used especially in the fabrication of early wooden airplanes. Because of its prominence as a plywood adhesive, this thermoset glue is very often present as the binder in early plywood panels used as substrates for paintings. Fish glue, another traditional wood adhesive, is also a protein glue derived from the skins, bladders, and other by-products of the processing of fish for consumption. While the collagen derived from fish is very similar to that obtained from horses and other mammals, it tends to have a lower molecular weight and is therefore weaker and more easily soluble (Rose and von Endt 1984).

The protein glue used in the great majority of wooden artifacts encountered by the author is animal-hide glue. Through a heated aqueous extraction process, the protein collagen is removed from the hides, hooves, and sinews of mammals, primarily horses and cows, and purified to form gelatin or glue (Cummins 1986; Fernbach 1907; Perry 1944; Rose and von Endt 1984; Rosser 1939). Because protein molecules are broken down by heat, the temperature at which the collagen is extracted plays an important role in the characteristics of the adhesive. Collagen extracted at lower temperatures has a higher molecular weight and is stronger than collagen obtained from processing at higher temperatures. This characteristic is referred to as the gram-weight strength and is assigned by determining the weight necessary to depress the surface of a "glue jelly" by a specific amount according to a rigorously controlled protocol (DeBeaukelaer 1930; Fernbach 1907; Rosser 1939). In general, the gram-weight strength of glues normally used for woodworking is in the range of 200–300, although the range available is much broader (<100–>400). The procedure for preparing and using gelatin glues is based on the thermal and solubility properties of collagen, which is thermoplastic and water soluble.

Modifications of animal glue include the addition of plasticizers (usually glycerin or sorbitol up to 50% by dry weight), for flexibility and increased tack, and the addition of formaldehyde to yield a water-resistant, thermoset adhesive.

Probably the most important reason that hide glues are so widely used in the conservation of wooden artifacts is that they are almost completely reversible due to their water-soluble, thermoplastic nature. For many fabricators of wooden objects, this reversibility is not a factor, and the glue is used for other benefits, such as strength, ease of use, and availability. For the conservator, reversibility is a key consideration that becomes manifest in two principal areas. The first is the treatment of damaged or disassembled glue lines originally formed by hide glue. Manipulating, reforming, or removing the original material may be possible, as it was thermoplastic when applied and may remain so. The second benefit of this characteristic is retreatability, which is discussed elsewhere in this article. The structure of animal glues suggests a true chemical affinity for wood (von Endt 1986). Thus, their adhesion to a wooden substrate is excellent.

Animal-hide glue is hygroscopic, and its stability and properties are highly sensitive to environmental moisture. If the moisture level is too low, the glue becomes extremely brittle and can be fractured with very little applied stress, a circumstance that leads to failure of the bond line. If the humidity is too high, the glue softens and is susceptible to plastic deformation. In addition, an extremely high moisture level can result in an attack of fungi on the surface of the glue. For panel paintings that remain in—or are returned to—uncontrolled environments, this characteristic of animal glues must be weighed carefully when their use in conservation treatments of such panels is considered.

Natural resins

The use of natural resins as adhesives is not prevalent today; they are, however, encountered in historic objects.[1] Probably the most extensively used resin was shellac, a thermoplastic exudate of the bug *Laccifer lacca,* indigenous to India and Indochina. The resinous exudate is refined by a number of processes, including heat, solvent, and aqueous extraction, resulting in an amber-orange material of varying purity and composition, depending on the specifics of the refining process. From the experience of the author, shellac was primarily used to glue nonwood veneers to a wooden substrate.

Shellac is normally used in solution with alcohol and dries by solvent evaporation, although it can be used as a pure material liquefied by heat only. It is relatively incapable of resisting thermal or chemical attack, but under the proper conditions, it can remain stable indefinitely.

Contact adhesives

Contact adhesives form an immediate strong bond and therefore are also called *contact cements*. Contact adhesives include both natural and synthetic rubber in solution. They are thermoplastic and can be softened with heat and/or organic solvents.

Due to their primary function as laminae adhesives, the most common application of these adhesives is to glue wood or other veneers to a substrate. They may also be encountered in an earlier, inept repair to structural elements. These adhesives do not appear to be exceptionally stable over a long period of time (Feller and Encke 1982). Deterioration of the adhesive results in the delamination of the fabricated structure.

Synthetic resin adhesives

Emulsions

The most widely used general-purpose glues in the wood crafts today are those based on aqueous emulsions of polyvinyl acetate (PVA) and are commonly called "white" glues. Some closely related adhesives generically called "yellow," "aliphatic," or "carpenter's" glues may also be used. These water-based emulsions are opaque white or yellow liquids that become translucent when dry. Depending on their formulation and environmental influences, these adhesives can remain stable for long periods of time, as well as remain soluble and reversible to some degree.

PVA emulsion is the most common adhesive used for fabrication in contemporary woodworking. It is also used with moderate frequency in conservation. When the need arises, PVA and other emulsions bond well to hide glues.

In many respects, acrylic emulsion adhesives are much like PVA emulsion in appearance, use, and hardening mechanisms. While not widely used in the nonindustrial fabrication of objects, acrylic emulsions are used in conservation for the same applications as PVA emulsion. The advantage of acrylic emulsions is that they can be obtained in a wide variety of formulations with specific properties, such as molecular weight ranges and solubility characteristics for a hardened film.

Solutions

Synthetic resin solution adhesives are not widely used for fabrication in woodworking, but they remain a vital tool for the conservator.

A wide range of synthetic resins is available, and individual acrylic resins (or blends) possess particular characteristics. Of these properties, the two most important are solvent specificity and long-term stability. Resin solutions are themoplastic solutions that dry through solvent evaporation and, depending on the formulation, can remain resoluble for a longer period of time. The stability of certain acrylics has been well documented in conservation literature.

Two synthetic resin adhesives—cellulose nitrate and cyanoacrylate—are not used today for conservation but may be encountered in earlier, inept repairs. Cellulose nitrate adhesive is a solution of nitrocellulose and other film-forming materials in a mixture of organic solvents. This adhesive dries solely through solvent evaporation. Cellulose nitrate is not very effective as a bond-forming material with wood and therefore is almost never used as a primary adhesive in wooden objects. It is an unstable material unsuitable for use in the conservation treatment of any wooden artifact (Koob 1982; Selwitz 1988). Cyanoacrylate hardens quickly through an anaerobic chemical reaction with nitrogen in the atmosphere. Brief working time, poor adhesion to wood, and long-term instability render it unsuitable for use by the wood conservator.

Hot melts

While most thermoplastic materials could be broadly classified as hot-melt adhesives (e.g., hide glue, which begins to harden by cooling, and shellac and acrylics, which can be used as melted resins), this section will touch on those materials specifically designed to be used in a molten state and that harden solely by cooling. Hot-melt adhesives, as defined in this section, come in a wide variety of compositions the formulations of which can be very specific regarding the properties of the adhesive, not only in a solid but also in a liquid state (Gutcho 1983). Because these adhesives must often be heated to well above room temperature for them to flow, and because they solidify by cooling, their use is limited to the penetration possible in a very brief period of time.

Hot-melt adhesives are becoming increasingly important in the industrial fabrication of wooden objects and are beginning to be used in the conservation of historic wooden artifacts. However, knowledge of hot-melt adhesives within the conservation field is limited, and little critical study has been made of their long-term stability and other properties.

Multiple-component reactive adhesives

Thermosetting, multiple-component adhesives are likely to be encountered by the conservator only in previous, ill-advised repairs. These materials, which harden by the chemical reaction of the various components, include urea-formaldehyde resin, epoxies, and phenolics.

Multiple-component reactive adhesives possess great strength under a wide variety of conditions and can be virtually impervious to thermal, physical, or chemical attack. Because of their hardening mechanism, there are varying amounts of dimensional change from class to class—that is, epoxies shrink very little, whereas ureas shrink considerably more. As such, they may be good gap fillers, either in their raw state or when modified with bulking agents.

Despite these qualities, the use of these adhesives in conservation is discouraged. By their very nature as cross-linking polymers, they are intractable and, therefore, not easily reversible.

Selection and Use of Adhesives in Wood Conservation

The most widely used adhesives at the Smithsonian Institution's Conservation Analytical Laboratory are hot and cold hide glues; there is only minor use of synthetic resin emulsions or solvent-borne adhesives. Cross-linking and multipart adhesives are almost never used as replacement adhesives when joint failure is treated.

Knowledge of an object's use and of the structural stresses that will be placed on the object during that use is particularly important when the choice of an adhesive treatment is made. A panel painting on a display easel will experience different stresses from those of a painting that is hanging, and the grain direction of a panel (and therefore its natural potential for either strength or damage) could affect its exhibition or storage orientation. In addition, the object may serve its function indefinitely in controlled circumstances, but only briefly under adverse environmental conditions. It is against this backdrop that an assessment of the object's condition must take place.

Treating wood fractures

Because this article is especially pertinent to wood panels, extremely rare cross-grain breaks will not be discussed. Instead, the focus will be on breaks that are essentially along the grain, or longitudinal with respect to the wood orientation of the panel.

Simple fractures

A simple fracture, whether partial or complete, requires only the introduction of an appropriate adhesive, alignment, and modest compression to complete the reassembly. To speak of an "appropriate" adhesive, however, is to be intentionally ambiguous, as there is a variety of possibilities. Selection depends on such factors as the stresses the object must withstand and the sensitivity of any decorative surfaces (no small consideration when dealing with polychrome panels).

A partial fracture of an object that is still in one piece (sometimes tenuously) does not always leave easy access to the gluing area. The glue must be applied either by allowing it to flow into the void under gravity or capillary action or by forcing it in under pressure by use of a hydraulic device, such as a syringe.

A complete fracture presents immediately accessible gluing surfaces, and adhesive can be applied directly with a brush, spatula, or other appropriate tool.

For both complete and partial simple fractures, the conclusion of the gluing process is to align the parts to be unified and to apply only enough restraint to hold them in place until the glue dries.

Complex fractures

Complex fractures are particularly challenging when the gluing surfaces are no longer adequate for the reassembly of the artifact, either because the panel is distorted, leaving a void in the alignment, or because the gluing surface itself is damaged by displacement or splintering of the wood fibers. As with a damaged gluing surface, decisions must be reached as to how vigorously the conservator is to intrude in order to make the artifact whole. These decisions must, by nature, be ad hoc, but there are some general guidelines for treatment strategies.

The existence of substrate voids, either in the fracture region as a whole or at the glue line in particular, may contribute to the overall structural instability of the object. (Whether or not the voids contribute to further deterioration depends on numerous construction, usage, and environmental factors outside the scope of this article.) The degree of instability, along with the anticipated future circumstances of the artifact, usually determines whether the voids are to be filled or left empty.

In the case of panel paintings, the fill must be made to fit the void exactly. This can be accomplished by either cutting a wood piece to fit the void precisely, casting flexible thermoset material into the void, filling the void with an inflexible thermoset material, or using a combination of these methods. Unless the fill is a tight wood-to-wood system, the gluing surface should be isolated from the fill with an easily reversible barrier film, such as animal glue or synthetic resin solution. The author has found the use of hide glue to be the most convenient and utilitarian material for this purpose.

Treating degraded or failed adhesives

Reactivation of adhesives

Although it is the least intrusive intervention, reactivation unfortunately is usually among the least successful. Because it involves the use of solvents or heat, reactivation is limited to cradles or other backing supports of panel paintings and is not suitable for the panels themselves. By definition this technique can be applied only to adhesive materials that are thermoplastic and not so degraded as to prevent any useful re-formation of an adhering film. Even when successful, this approach rarely yields a strong bond, and the object may be incapable of fulfilling its normal use.

Reactivation is most commonly applied to aged hide glue, but it can also be applied to synthetic solvent-based adhesives, which, as mentioned above, are frequently present in artifacts as part of a previous attempt to rectify damage. Reactivation is usually done when other methods are not possible, but the resulting bond may not be strong enough to allow normal use of the object. With respect to panel paintings, there is also the very real possibility of damaging the decorative surface of the object; solvents that dissolve polymeric adhesives will also act as paint removers for many coatings.

Introduction of a new adhesive

A more intrusive repair method, but one with a greater chance of success than reactivation, involves adding new adhesive to the glue line to augment failing adhesives. The usual objective is to fill any voids completely, thereby providing the necessary degree of strength and the greatest possible stability and durability. The primary constraint on this technique is that the newly introduced adhesive must be compatible with and bond to the existing adhesive.

In general, this method of stabilizing the structure is used only for adhesives that are readily soluble in the same solvent and thus can meld together to form a cohesive bond. Hide glue is most commonly used for this type of repair. Water-based emulsion glues can be added to existing hide glues, as they will bond reasonably well. However, adding a glue such as PVA emulsion, with different mechanical properties that would make it react differently to environmental changes, can lead to failure of the glue line. This consequence, as well as concern over the long-term stability of PVA emulsion, discourages its use in wood conservation.

There is growing interest in synthetic hot-melt adhesives for this type of treatment. Although further investigation of hot-melt adhesives is needed, there is no theoretical reason why this treatment option should not be developed.

Replacing failed adhesives

The option of completely removing the aged adhesive materials is available, but it should be undertaken only in cases in which the object can be completely disassembled and the conservator has access to all gluing surfaces. For panel paintings, this treatment would be limited to backing supports. There is frequently a need to remove all of the existing glue because of the number of factors that contribute to adhesive failure, from environmental fluctuations to inept previous repairs with inappropriate adhesives. The continued presence of a failed glue on an object contributes to its accelerated deterioration.

Any adhesive material that can easily be removed mechanically with a tool without damage to the substrate is treated first. If mechanical removal cannot be done easily and cleanly, solvents are added to the procedure. The adhesive will swell and/or soften so it can be removed with wooden scrapers or cotton swabs.

Conclusion

The nature of the adhesive materials used on artifacts often reveals vital information about their historical/material technology that can provide useful clues and direction to the caretakers of the objects. The wise conservator will base conservation treatments requiring adhesive processes on a sound understanding of these processes.

Note

1 Most sources discussing the technology of natural resins refer to their widespread utility as coatings, sealants, and adhesives. See Koob 1984 and Mantell 1942.

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Consolidation of Wooden Panels

Arno P. Schniewind

Wooden panels for paintings were traditionally made of solid wood and consisted of either a single board or, for larger panels, a series of boards edge-glued to form the required size. Today a variety of wood-based panel materials are available as painting supports, including plywood, fiberboard, hardboard, and particleboard. Among these types, plywood (in the sense of wood with decorative face veneers) has been known since ancient times, but machine-made commercial plywood is of more recent origin. It appears to have found use as a support for paintings in the latter half of the nineteenth century (Muller 1992). The other wood-based materials are largely developments of the twentieth century, with particleboard coming into general use only after World War II.

In the general sense, the term *consolidation* refers to merging or joining separate parts or to making something strong and stable or to making it solid and compact. As used by conservators, the term refers to remedial treatments of materials that have lost cohesion as a result of deterioration, in order to stabilize an object and make it safe for its intended use (Wermuth 1990). It is thereby understood that a material to be consolidated has some degree of porosity, so that another substance can be introduced into the pore space to achieve a particular objective, such as strengthening of deteriorated wood. Consolidation can therefore be thought of as a kind of internal gluing. It is no accident that the theme of the Tenth International Congress of the International Institute for Conservation was "Adhesives and Consolidants," as the difference between the consolidation of a porous material and the use of adhesives to join together something like the shards of a broken ceramic vessel is largely one of scale (Brommelle et al. 1984).

The basic objective of consolidation is to assure the stability and safety of an object. In addition, specific objectives will vary with the intended use. The most demanding of these is when consolidation is required to reestablish full functionality of an object. Usually this will be the case when the object serves a significant structural function, as, for instance, structural wood members in a building or the legs of a chair that people will sit on. A less demanding level would be when stabilization is required through all or most of the interior of an object. Finally, in some cases, only a consolidation of surface layers may be required to prevent damage by abrasion. Objects in museum collections would rarely require reestablishment of full functionality but must be able to withstand some handling and perhaps the rigors of shipping.

Consolidation is a major intervention that is not to be undertaken lightly. In particular cases of advanced deterioration, however, it may become a necessary treatment. Once the necessity for consolidation is determined, a number of decisions must be made regarding materials and methodology. These decisions include choice of a consolidant, solvent (and level of solution concentration), and suitable method of application. Much will depend on the nature of the object to be treated, the type and condition of the material, and the functional requirements of the object. Usually structural function, as well as visual aspects, will be addressed. The present discussion will be directed to a comprehensive examination of various aspects of the consolidation of deteriorated wood, proceeding from consideration of the general to the more specific problems that might be encountered in the consolidation of wooden panels that support paintings. Hereafter, all references to wooden panels refer to painting supports. No attempt will be made to consider the consolidation of waterlogged wood, because that process presents problems and requires approaches not applicable to panel paintings.

Permeability of Wood

Consolidation of deteriorated wood entails the introduction of another substance into its porous structure, a process requiring that the substance be in fluid—liquid or gaseous—form. The ease with which a fluid can be introduced is governed by the permeability of the wood. The transport (movement) of fluids through wood can be represented by Darcy's law (Siau 1984):

$$\text{flux} = \text{permeability} * \text{gradient} \qquad (1a)$$

where flux is the volume of flow per unit time and unit area perpendicular to the flow direction, and gradient is the change in pressure over the flow path. Permeability depends both on the nature of the material and on the viscosity of the fluid that flows through it. Hence we get:

$$Q/A = (K/\eta)\,(\Delta P/L) \qquad (1b)$$

where: Q = rate of flow (volume per unit time); A = cross section perpendicular to the flow path (area); K = specific material permeability (volume per unit length); η = viscosity of the fluid (force per unit area times time); ΔP = pressure differential across the flow path (force per unit area); and L = length of flow path (length).

Inspection of Equation 1b reveals that fluid viscosity and pressure differential are the only variables available for manipulation, because for a given object, the cross-sectional area, the specific material permeability, and the flow path are fixed. A high viscosity results in a low rate of flow, while a high pressure differential produces a high rate of flow.

Alternatively, flow through wood can be modeled as capillary flow, in which case Poiseuille's law applies (Siau 1984). This is given by:

$$Q = (N\pi r^4 \Delta P)/(8\eta L) \qquad (2)$$

where: N = number of capillaries (no.); r = capillary radius (length); and all other variables are as previously defined. Here radius and number of capillaries take the place of the cross-sectional area and specific material permeability. It should be pointed out, however, that while the term $N\pi r^2$ defines an area, this is the area of the capillary openings and not the same as the cross-sectional area in Equation 1b. Again, a high flow rate can be achieved by either a low viscosity or a high pressure differential and, in this sense, Poiseuille's law is the same as Darcy's law.

Equations 1a, 1b, and 2 are for steady state flow, where the fluid enters on one surface and exits on an opposite surface. In consolidation treatments, a more realistic model is given by unsteady state conditions, where the fluid enters from opposing surfaces. For a parallel-sided body, the fractional volumetric retention of fluid—that is to say, the volume of fluid retained in the body expressed as a fraction of its total volume—is given by (Siau 1984):

$$F_{VL} = 2/L\,[(2K\Delta Pt)/(V_a\eta)]^{1/2} \qquad (3)$$

where: F_{VL} = fractional volumetric retention (volume per volume); L = distance between the opposing surfaces (length); K = specific permeability of wood (volume per length); t = elapsed time from beginning of treatment (time); V_a = porosity of the wood (pore volume per total volume); and other values are as previously defined.

Examination of Equation 3 shows that here also, all variables except viscosity and pressure differential are fixed for a given object and that high retention requires high pressure differential or low viscosity.

Pressure impregnation is ordinarily not a realistic choice in conservation work, but vacuum impregnation is effective and relatively easy to do (Schaffer 1974; Barclay 1981; Payton 1984; Simpson, Spirydowicz, and Dorge 1992). For any other application methods, one must simply substitute an alternate driving force for pressure differential (i.e., gravitational forces or the surface tension involved in wetting and capillary action). Thus, the viscosity of the fluid chosen for consolidation is the key factor in successful consolidation treatments (Schaffer 1971).

The permeability of sound wood is an extremely variable property. Permeability may vary from one species to another by as much as a factor of 1 million. Longitudinal permeability is greater than transverse (radial or tangential) permeability, with ratios varying from 500 to 80,000 in softwoods and from 30,000 to over 100 million in hardwoods (Siau 1984). Biological deterioration can cause dramatic increases in permeability, particularly if the organisms destroy the pit membranes (Ellwood and Ecklund 1959). Thus, the ease of treatment tends to increase with the degree of deterioration.

Criteria for Selection of Consolidants

A number of authors have discussed desirable characteristics of consolidants (Grattan 1980; Unger 1988; Rosenqvist 1963; Werner 1977). Grattan lists as many as eleven "ideal characteristics" (Grattan 1980). The major concerns of conservators are included in the following list of requirements of consolidants:

1. Long-term stability is necessary so that the consolidant does not deteriorate at a faster rate than the object itself.
2. The treatment should not change the appearance of the object. Undesirable changes include darkening, color changes, and glossy surface films where no gloss was extant or intended.

3. No internal stresses should be imparted to the object by shrinkage of the consolidant upon solidification. In extreme cases, such stresses could cause internal ruptures and distortions of the object.
4. The consolidant should be compatible with other materials, such as paint, that are either already present or might be added later during additional treatments.
5. The treatment should be reversible. Grattan felt that reversibility was necessary at least in the short term, if for no other reason than to allow correction of any mishaps that might occur during treatment (Grattan 1980).
6. The consolidant should be an effective strengthener.
7. The treatment should be capable of good penetration and result in ample deposition of consolidant.

The order of this list is somewhat arbitrary, because priorities vary with each case. For panel paintings, compatibility with other materials is of major importance because any interference with the ground or the paint layers will not be tolerated. It should also be noted that even though some of the first five items are couched in positive terms, they all refer to characteristics that consolidants should not have. They should not deteriorate, change appearance, cause stresses, interfere with associated materials, or be permanently fixed. Only the last two refer to positive effects, and in a sense, the sixth item implies the seventh. Thus, this review of the requirements of consolidants stresses the importance of making sure that a consolidation treatment will not harm the object.

Types of Consolidants

Types of consolidants may be divided into two categories: natural and synthetic materials. Comprehensive and detailed overviews of various types of consolidants for deteriorated wood are given in the literature (Unger and Unger 1987; Unger 1988).

Natural materials

Natural materials include hide glues, waxes, resins, and cellulose derivatives. Except for cellulose derivatives, which did not become available until the end of the nineteenth century, natural materials are also the traditionally used materials.

Hide glues have several significant disadvantages as consolidants: they do not penetrate well into the wood structure; they will shrink and swell in response to humidity fluctuations; they are not moisture resistant; and they will become brittle over time.

Waxes, specifically beeswax and paraffin, have been used as consolidants in the past either alone or as wax-resin mixtures. Using wax is a disadvantage because treated objects look greasy, attract dust, and darken with age. Furthermore, the strengthening that can be achieved is minimal. Unger refers to several examples of wooden panels treated with wax or wax-resin mixtures. Once applied, the wax is nearly impossible to remove entirely; therefore, residues may interfere with later treatments (Unger 1988).

Natural resins such as damar, shellac, and rosin have been used extensively in the past. However, these resins produce only moderate strengthening, and they embrittle with age. Unger cites a large-scale project in Austria, in which an altar was consolidated in the 1950s using 1500 l of shellac in ethanol (Unger 1988).

Drying oils, especially linseed oil, have also been used as consolidants in the past, but they provide very little effective strengthening.

Cellulose derivatives (acetate or nitrate) did find use as consolidants during the first half of the twentieth century, but today their application has virtually ceased. It is difficult to achieve much penetration with the cellulose derivatives, and the materials discolor and embrittle with age.

Natural materials are thus seen to have significant disadvantages. Therefore, further discussion focuses primarily on synthetic polymers.

Synthetic polymers

Synthetic polymers can be divided into thermosetting and thermoplastic types. This division is important in conservation, because thermosetting resins that might find use in consolidation generally are not soluble in organic solvents. Therefore, their use results in irreversible treatments. Thermoplastic resins are generally soluble in organic solvents, although they can become cross-linked, which leads to a loss of solubility (Ciabach 1983; Bockhoff et al. 1984).

Thermosetting resins

One class of thermosetting resins that might be considered for use as consolidants consists of the formaldehyde resins: phenol, resorcinol, urea, and melamine. These are widely used as adhesives in the production of wood-based materials, because they are excellent adhesives for wood. Phenolic and resorcinol resins are also waterproof and very resistant to weathering. Unger cites some past uses of these resins in conservation; however, there appears to be little, if any, such use at present (Unger 1988). A particular drawback of these resin systems is poor penetration, and all but the melamine formaldehyde resins either are initially dark or darken with age.

Epoxy resins have found wide application in the rehabilitation and repair of wood and concrete structures, and they are successfully used in stone consolidation because of their excellent durability, adhesion, and strength (Phillips and Selwyn 1978; Stumes 1979; Selwitz 1992). Unlike the formaldehyde resins, which shrink upon hardening, epoxy resins in their neat formulation do not change volume as they harden; consequently, shrinkage stresses are avoided. However, the neat resins have relatively high viscosity and therefore penetrate poorly. Penetration can be improved by the addition of solvents to reduce viscosity. Unger gives a number of examples where epoxy resins have been used in wood conservation projects, including some treatments of wooden panels. Their main application lies in strengthening structural members in wooden buildings or in strengthening museum objects that are exposed to the weather. According to Unger, epoxy resins are suitable for consolidation of wooden panels only if the wood is very severely deteriorated, because application into wood that is only moderately deteriorated results in insufficient penetration (Unger 1988). This may not apply if the small-molecule epoxies advocated by Munnikendam are used, however, because in their neat formulation they have about the same viscosity as 15% Acryloid B72 in acetone (Munnikendam 1973).

Thermoplastic resins

Thermoplastic resin consolidants can be introduced into wood as monomers or prepolymers and polymerized in situ, using either irradiation or a combination of heat and a catalyst to initiate the polymerization reaction. Commercial production of wood-polymer composites uses vinyl-type monomers such as styrene, methyl methacrylate, vinyl acetate, or acrylonitrile, but methyl methacrylate is considered to be best suited for industrial products (Meyer 1989). Unless cross-linking agents were introduced, the resin may still be soluble after polymerization, but in practical terms very little chance of removal remains. Unger and coworkers found that surface films and crusts remaining after they treated old pistol grips with mixtures of methyl methacrylate, styrene, and polyester could only be removed with considerable difficulty (Unger, Reichelt, and Nissel 1981). Schaudy has made extensive studies of a wide variety of consolidants that can be cured by irradiation. Some of these findings have been summarized recently: only certain resins tested were found suitable, but many types of objects, including polychrome wood, have been treated successfully (Schaudy 1990). The advantage of curing in situ lies in the low viscosity of monomers or prepolymers, which assures good penetration and good resulting strength. However, it is not likely to be the method of choice for use on panel paintings because of difficulties in ensuring that the ground and paint layers will remain unaffected by the treatment.

Alternatively, thermoplastic polymers can be introduced into deteriorated wood in solution form. Commonly used polymers for this purpose are polyvinyl acetate (PVA), polyvinyl butyral, acrylics, and soluble nylon (Grattan 1980; Unger 1988). Of these, soluble nylon is no longer used because it has poor durability and loses its solubility very quickly due to cross-linking (Bockhoff et al. 1984). The advantages of the other three types of resins are that they are reversible at least in principle; they can be applied by a variety of methods; and, in the case of PVA and acrylics, they have a record of stability extending over a period of more than sixty years. Disadvantages are that some solvents may cause the wood to swell during treatment, and that the strengthening effect is not as great as that which can be achieved with epoxy resins and other materials. With regard to PVA and acrylics, of particular interest is their use in picture varnishes: should these resins be used as consolidants for wooden supports of paintings varnished with such products, a degree of compatibility could be assured.

Application of Consolidants

Consolidants must be in either gaseous or liquid form if they are to be applied to deteriorated wood. There is one method of applying gas-phase consolidant that uses Union Carbide Corporation's Parylene polymers (Humphrey 1986). However, this process does not appear to penetrate sufficiently for effective wood consolidation, and the consequent thin films achieved would provide very little strengthening. In liquid form the consolidants may be in the molten state (e.g., waxes); they may be liquid monomers that are then polymerized in situ (e.g., methyl methacrylate); or they may be thermoplastic polymers in solution (e.g., PVA in acetone).

Choice of solvent and concentration for consolidant solutions

Since each synthetic resin has its own particular requirements, the choice of solvent is immediately limited to those that can provide solutions of compatible concentration and viscosity for the chosen resin. In wood consolidation, the choice between polar and nonpolar solvents is significant. Although polar solvents have an affinity for wood, they tend to penetrate poorly compared to nonpolar solvents, because polar molecules may be adsorbed on the internal wood surfaces, and such adsorption would reduce their mobility (Nicholas 1972).

As an organic solvent's degree of polarity increases, so does its tendency to swell wood. For example, among commonly used solvents, the virtually nonpolar toluene swells wood a mere 1.6% as compared to the swelling by water. Meanwhile, the polar acetone, ethanol, and methanol produce swellings of 63%, 83%, and 95%, respectively (Stamm and Harris 1953). In deteriorated Douglas-fir samples, vacuum impregnation with 15% solutions (weight basis) of consolidants produced values of swelling in the tangential direction measured immediately after treatment as shown in Table 1. When the nonpolar toluene was the solvent, swelling was less than 0.1% with two different resins, whereas Butvar B98 in methanol produced a swelling of 3.31%. This swelling was not permanent, though, and after four weeks most of the swelling had been recovered (Schniewind 1990b). With panel paintings, however, even temporary swelling could prove objectionable, as this might lead to undesirable stresses in the paint layers.

Table 1 Swelling of wood samples immediately after consolidation treatment

Solvent and consolidant	Swelling (%)
Acryloid B72 in toluene	0.06
AYAT in toluene	0.07
Acryloid B72 in acetone	1.03
AYAT in acetone	2.17
Butvar B98 in methanol	3.31

Another point to consider is that solvents with low boiling points are usually preferred over those with high ones, so that residual vapors persisting after treatment can be avoided. Residual solvents have other effects that will be discussed later.

When solution concentrations are chosen, it is necessary to balance the desire for good penetration—which can be achieved by keeping the concentration and hence the viscosity low—against the need to obtain a reasonable level of resin loading (the resin content after treatment). Given equal penetration, loading can be increased by increasing consolidant concentration. Thus, low concentration tends to yield good penetration but poor loading, whereas high concentration conversely results in poor penetration but good loading. Resin loading is important because the effectiveness of consolidation treatments largely depends on the amount of resin that can be added. The maximum possible loading can be calculated from the porosity of the wood. This is given by (Kellogg 1989):

$$V = 1 - \rho_1 \, (1/\rho_w + M_b/\rho_b + M_f/\rho_f) \quad (4)$$

where: V = fractional pore volume; ρ_1 = relative density (specific gravity) of (porous) wood, based on oven-dry weight and current moisture content; ρ_w = relative density of cell-wall substance; M_b = content of bound water; ρ_b = relative density of bound (adsorbed) water; M_f = content of free water; and ρ_f = relative density of free water.

For instance, let us take wood with a relative density of 0.5 and a total moisture content of 12% and treat this to saturation (i.e., filling all pore volume completely) with a solution that contains 10% Butvar B98 by volume. With a relative density of cell-wall substance of 1.5 and a relative density of the bound water of 1.014 (note that 12% is less than the fiber saturation point in wood so that no free water will be present), the fractional pore volume can be calculated as: $V = 1 - 0.5\ (1/1.5 + 0.12/1.014) = 0.61$ (Kellogg 1989). Butvar B98 has a relative density of 1.1. Of the total pore volume, 10%, or 0.061, is occupied by resin. Since a relative density of 1.1 corresponds to a density of 1100 kg m^{-3}, this converts to 67 kg m^{-3}; and when this is added to the wood density of 500 kg m^{-3}, it represents an increase, or resin loading, of 13.4%. The relative density of 0.5 corresponds to the high end of the range for typical softwoods in their original state. As the wood deteriorates, the relative density decreases and the porosity increases, making higher loading possible. In impregnation of wood with monomers, with subsequent curing in situ, much higher loading is possible—even when the polymer shrinkage during curing and the loss of monomer due to evaporation are taken into account (Simunkovà, Smejkalovà, and Zelinger 1983; Schneider 1994).

Methods of application

The most simple and straightforward way to apply consolidant is by brushing. In most cases it is quite difficult to get substantial penetration by brushing, but an adequate treatment can result if only the surface layers need to be strengthened. For catalyzed systems (i.e., thermosetting resins or resins polymerized in situ), brushing is probably the least effective method because the treatment is limited to a single application. Consolidant solutions, however, offer a somewhat better prospect, since it is possible to make more than one application. Grattan found that better results could be obtained by applying many coats of consolidant solution of low resin concentration, whereas solutions of high concentration can lead to the early development of an objectionable gloss on the artifact surface (Grattan 1980). Barclay was able to use a brush treatment of 5% solution of Butvar B98 in ethanol on portions of an English fire engine with good results (Barclay 1981).

To improve on the penetration achieved by brushing, some form of treatment that keeps the object in contact with consolidant solution over a period of time without allowing any intermediate drying can be very effective. This procedure can take the form of soaking in consolidant solution, as with two canoes treated with PVA in toluene in Japan (Chemical Section and Section for Repairing Technique 1968). However, considerations of cost, safety, and eventual disposal problems may speak against the use of the large quantities of solution that would be required for large objects. The alternative approach is to use a continuous or intermittent recirculating spray system within an enclosed space. A California Native American dugout canoe was treated in this manner. The treatment used a 13% solution (weight basis) of AYAT, a PVA, in methanol within a temporary enclosure, and achieved complete penetration of the wood (Schniewind and Kronkright 1984). A somewhat different approach was used by Nakhla (1986): consolidant solution was applied in drops onto the objects being treated. As long as the rate of application is consistent enough to keep the object wet with solution, this can also be a very effective method. Consolidant may also be injected selectively (Wermuth 1990).

The most effective method of achieving maximum penetration is to use vacuum impregnation, which can be a practical method, except in the case of very large objects (Schaffer 1974). The easiest method is to draw a vacuum while the object is submerged in consolidant solution within the vacuum chamber; the vacuum is continued until most of the air has been drawn from the porous wood structure. The vacuum is then released, causing atmospheric pressure to push the consolidant solution into the wood. For maximum results, the vacuum should be drawn first and the consolidant solution subsequently introduced to cover the object while under vacuum, so that the solution does not impede the removal of air from within the wood. However, this approach would require elaborate equipment, which would probably not be justified in most cases. Some parts of the fire engine previously mentioned were treated by vacuum impregnation, using a solution of 20% Butvar B90 in ethanol. The relatively high concentration was chosen to maximize loading, and the vacuum impregnation method was relied upon to achieve sufficient penetration (Barclay 1981).

While most of the examples given above are of consolidation treatments with soluble resins, the methods of application described can be executed with any type of liquid used for consolidation. For panel paintings it is difficult to visualize much other than brush treatments from the back. A possible exception would be soaking the panel face up in a shallow pan containing a small amount of consolidant. In any case, care must be taken that the consolidant does not reach either the ground or the paint layers—or at least, if it should reach the ground, that it does not change the ground's characteristics.

When solvents are used to introduce consolidants into deteriorated wood, there is potential concern that during solvent removal, evaporation from the surface will result in reverse migration of consolidant from the interior toward the object's surface (Payton 1984). When solvents are used solely to improve penetration of thermosetting resins, reverse migration can be reduced or eliminated by the prevention of solvent evaporation until the resin has been cured and fixed within the object (Selwitz 1992). Migration of water-soluble wood extractives to the wood surface can be observed in the course of normal lumber drying (Anderson et al. 1960). Reverse migration of soluble resins during solvent removal in stone consolidation can be mitigated by reduction of the rate of drying (Domaslowski 1988). Terziev and coworkers found that water-soluble sugars present in the sap of freshly cut wood would undergo significant redistribution during drying and that much more sugar migrates toward the surface during fast, as compared to slow, drying schedules (Terziev, Boutelje, and Söderström 1993). Samples of deteriorated Douglas-fir treated with Acryloid B72, Butvar B98, or Butvar B90 had lower bending strengths when dried very slowly, as compared to samples dried more rapidly in the open air (Wang and Schniewind 1985). The samples of B98 and B72 dried in the open air were examined by scanning electron microscopy to determine consolidant distribution. The results showed that the consolidant was more heavily concentrated near the surface than in the core. Since the samples had originally been completely saturated with consolidant solution, this was definite evidence of reverse migration (Schniewind and Eastman 1994). While the slowly dried samples were not examined for consolidant distribution, the observation of lower bending strength is consistent with less reverse migration, due to the slow rate of drying. The strength of beams depends more on the upper and lower surface layers than on the core; therefore, a greater concentration of consolidant in the surface layers would tend to increase bending strength of the samples.

Consolidant Effectiveness

Among the seven criteria for selection of consolidants discussed above, the most important positive characteristic is that the consolidant serve as an effective strengthener. This characteristic depends on a number of factors, including the amount and distribution of the consolidant, as well as the properties of the solidified consolidant itself.

Properties of wood and consolidant composites

The addition of consolidant to deteriorated wood produces a composite with resultant properties that depend on the relative amounts and properties of both components involved. One method for predicting the mechanical properties of composites is the so-called rule of mixtures, which can be stated as follows for the modulus of elasticity (Siau et al. 1968):

$$E = E_w V_w + E_p V_p + E_a V_a \qquad (5a)$$

where: E = modulus of elasticity of the composite; E_w, E_p, E_a = modulus of elasticity of wood substance, consolidant, and air, respectively; and V_w, V_p, V_a = volume fraction of wood substance, consolidant, and air, respectively.

If we remove the term for the consolidant from the right-hand side of Equation 5a, we get the modulus of elasticity of gross wood, E_g, as a composite of wood substance and air. Since the consolidant is simply contained in the air space of the porous wood, Equation 5a can therefore also be given as (Wang and Schniewind 1985):

$$E = E_p V_p + E_g \qquad (5b)$$

This equation can also be used for estimating other mechanical properties of wood and consolidant composites. Wang and Schniewind used Equation 5b to estimate both strength and stiffness in bending of treated Douglas-fir samples, and they obtained reasonably good agreement with actual test results. However, estimates tended to be on the low side—the probable reason being a greater concentration of consolidant in the surface layers, which would tend to improve the bending strength of the composite more than a uniform distribution (Schniewind and Eastman 1994).

Since the volume fraction of consolidant, V_p, is one of the factors in Equation 5b, it follows that the strengthening effect of consolidation should be positively related to the amount of loading achieved. This is not only intuitively obvious but also shown to be true by experimental results for monomers polymerized in situ (Simunkovà, Smejkalovà, and Zelinger 1983) and for polymers introduced in solution (Wang and Schniewind 1985). The value of V_p in Equation 5b will always be less than 1. The contribution of the consolidant to the properties of the composite will therefore depend highly on the strength of the consolidant in relation to the strength of the wood. As an extreme example, a polymer that has 10% of the strength of normal wood, if impregnated to a volume fraction of 10%, would only increase the strength of the composite by 1% over that of the wood alone.

Conversely, the more severely deteriorated the wood, the greater the strengthening effect of a given consolidation treatment. This idea is illustrated in Figure 1, which shows improvement factors for different levels of deterioration (Schniewind 1990a). In this example the strength of the most severely deteriorated wood was increased by 47%, while that of the least damaged wood improved by only 10%.

Epoxy resins can be formulated with excellent strength properties, which is an important justification for their potential application in the repair and consolidation of engineered structures. Accordingly, epoxy resins will result in probably the best possible strengthening in the consolidation of deteriorated wood if their use can be justified. Similarly, vinyl monomers polymerized in situ in normal wood at a loading of approximately 50% produced increases in bending strength on the order of 70–80% (Siau et al. 1968) and from 100% to more than 600% increases in compression strength perpendicular to grain (Meyer 1989). Consistent with Equation 5b, the greater increases in compression strength perpendicular to grain are possible because wood is weaker perpendicular to grain than parallel to grain, and strength parallel to grain is the determining factor in bending strength.

The strengthening effect of soluble thermoplastic polymers tends to be significantly less, because it is rarely possible to achieve levels of loading as high as 50% and because of the lower strength of the resins themselves. Physical data for several commonly used soluble resin consolidants and their improvement factors are shown in Table 2. Deteriorated Douglas-fir was used, with the loading between 20% and 23% (Schniewind and Kronkright 1984; Wang and Schniewind 1985). Butvar B98 is seen to give the greatest strengthening, followed by Acryloid B72. All but the three PVA resins with the lowest molecular weights gave statistically significant levels of improvement. Considering that the tensile strength of normal Douglas-fir is on the order of 125 MPa, it can be seen that the tensile strengths of all resins for which data are available are less than that of the wood. This is particularly true for the PVA resins, which also have glass-transition temperatures, T_g, either below or not much above room temperature—bringing them close to or into a rubbery, rather than glassy, rigid state. Of course, in some circumstances such flexibility may be

Figure 1
Improvement factor: ratio of bending-strength values of wood treated with Butvar B98 to bending-strength values of untreated wood, for deteriorated Douglas-fir at various levels of residual bending strength (degrees of deterioration).

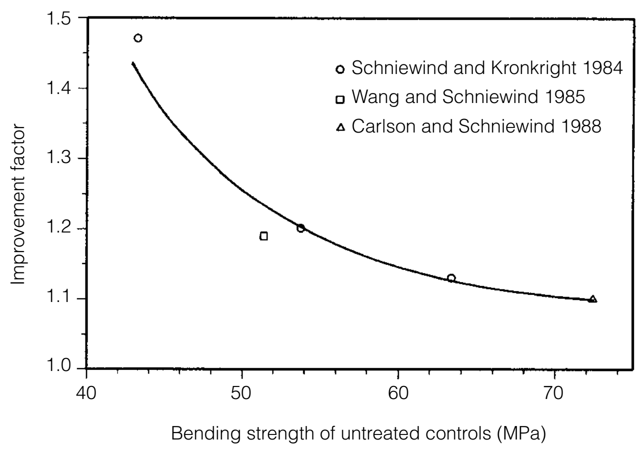

Table 2 Properties of resins and their strengthening capability, or improvement factor, calculated as the ratio of bending strength of treated deteriorated Douglas-fir samples to that of untreated controls. The asterisk denotes a value that is not practical to measure.

Resin	Molecular weight	Tensile strength (MPa)	T_g (°C)	Improvement factor	Reference
Butvar B90	45,000	46	68	1.14	Wang and Schniewind 1985
Butvar B98	34,000	46	68	1.19	Wang and Schniewind 1985
Butvar B98	34,000	46	68	1.20	Schniewind and Kronkright 1984
Acryloid B72	—	—	40	1.16	Schniewind and Kronkright 1984
AYAT	167,000	29	28	1.13	Schniewind and Kronkright 1984
AYAF	113,000	18	24	1.10	Schniewind and Kronkright 1984
AYAA	83,000	10	21	1.03	Schniewind and Kronkright 1984
AYAC	12,800	*	16	1.11	Schniewind and Kronkright 1984

desirable, but this characteristic also means that little strength can be added to the much stiffer material that is being consolidated.

Influence of solvents used for thermoplastic resins

The choice of solvents for thermoplastic resins can influence the ease of penetration, either by the degree of solvent polarity or by the resulting solution viscosity. The property of a given polymer deposited from solution may depend on the dynamic quality of the solvent used. Hansen and coworkers found significantly different mechanical properties of films of AYAT cast from acetone and from toluene, with toluene giving the lower values (Hansen et al. 1991). Wang and Schniewind found evidence that the use of polar rather than nonpolar solvents tended to result in somewhat greater levels of strengthening (Wang and Schniewind 1985). The distribution of consolidant, however, was not significantly affected by solvent polarity (Schniewind and Eastman 1994).

Solvent polarity was also found to be an important factor in the study of the incidental adhesive qualities of soluble resin consolidants (Sakuno and Schniewind 1990). It should be noted that adhesives and consolidants differ fundamentally in their formulation, regardless of the similarities discussed. Consolidants are formulated at low viscosity to achieve maximum penetration; adhesives for a porous material like wood must be formulated to have relatively high viscosity in order to limit penetration, since most of the adhesive should remain on the surfaces to be joined. Thus Koob used Acryloid B72 in acetone as an adhesive at a concentration of 50% (weight basis), as compared to the 10–15% concentration used for consolidation (Koob 1986). Sakuno and Schniewind used 15% solutions (weight basis) of AYAT, Acryloid B72, and Butvar B98, each in two different solvents, to study the incidental adhesive qualities of consolidant solutions (Sakuno and Schniewind 1990). These incidental adhesive qualities of consolidants relate to their ability to reattach loose fragments in the process of consolidation treatment. The results are summarized in Figure 2. Not unexpectedly, none of the consolidant solutions performed as well as the commonly used PVA "white glue" adhesive, the explanation for which is based

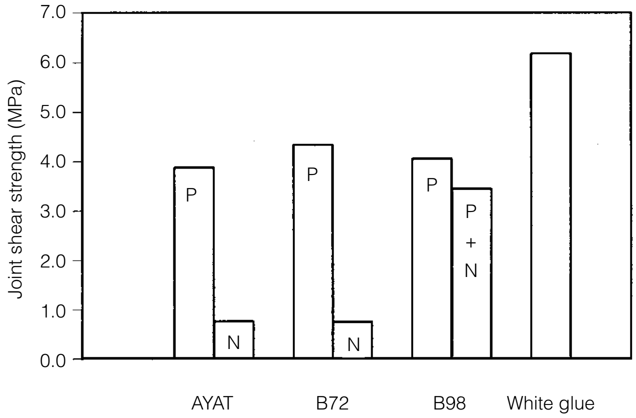

Figure 2
Static shear strength values for adhesive joints in deteriorated Douglas-fir made with AYAT, Acryloid B72, Butvar B98, and PVA emulsion white glue. P = polar solvent; N = nonpolar solvent.

on the relatively low concentration used. When polar solvents were used—acetone for Acryloid B72, and ethanol for AYAT and B98—all three resins performed about the same. For B98 no pure nonpolar solvent could be located, but the adhesive qualities of Acryloid B72 and AYAT in the nonpolar toluene were only a fraction of what was found with polar solvents.

Solvent volatility is another consideration. Solvents may be retained for a period, as shown in Table 3, for cast films of Acryloid B72 and Butvar B98. Missing values of T_g indicate values too low to measure. The more volatile solvents with low boiling points, such as acetone, can be removed more readily following treatment. This relative ease of removal reduces problems with objectionable residual vapors as well as with solvents retained by the consolidant resin. Retained solvents will lower the T_g of the resin and tend to make it less effective (Carlson and Schniewind 1990), but this result can be minimized by the use of solvents with low boiling points. However, less volatile solvents may prove superior in cases when consolidant is applied by brushing, since they would allow more time for deeper penetration.

Schniewind examined the effect of aging on consolidated wood samples (Schniewind 1990b). Bending tests made two weeks, one year, and three and a half years after treatment of deteriorated wood with B98 in ethanol or a mixture of ethanol and toluene, and Acryloid B72 in acetone or toluene, showed no overall aging effect. The sole exception was

Table 3 Glass-transition temperatures (T_g) and retained-solvent concentrations of cast films of Acryloid B72 and Butvar B98. The asterisk denotes the azeotrope boiling point of toluene-ethanol-water.

			Drying condition					
			1 day, 20 °C		30 days, 20 °C		50 days, 20 °C	
	Solvent							
Polymer	Type	Boiling point (°C)	T_g (°C)	Residual solvent (%)	T_g (°C)	Residual solvent (%)	T_g (°C)	Residual solvent (%)
B72	Acetone	56	—	5.8	39	0.3	40	0.0
B72	Ethyl acetate	77	—	6.3	—	2.2	40	0.2
B98	Methanol	65	—	19.7	54	3.2	75	0.3
B98	Ethanol-toluene	74*	—	12.3	49	4.8	66	1.5

Acryloid B72 in toluene, where bending strength increased significantly between two weeks and one year, but not thereafter. This may well have been a case where retained solvent did reduce the short-term strengthening effect of the consolidant.

Consolidant effects on wood-moisture relations

Synthetic polymers introduced into wood can affect the amount and rate of water absorption, as well as the shrinking and swelling. The extent of this effect depends greatly on whether the polymer has entered into cell walls or is contained within the cell lumina. Major reductions in hygroscopicity can be obtained only by polymer occupying sorption sites within the cell wall, but depositions in the cell lumina will affect the rate of moisture sorption while reducing shrinking and swelling by as much as 20% (Schneider 1994). Although vinyl monomers do not swell wood and, therefore, do not enter the cell wall, Simunkovà and coworkers did obtain large reductions in hygroscopicity, water absorption, and swelling with methyl methacrylate polymerized in situ by irradiation (Simunkovà, Smejkalovà, and Zelinger 1983). Butyl methacrylate was less effective. The extent of the changes was proportional to polymer loading, which ranged up to about 60% polymer. By contrast, at a loading of 24%, it was not possible to detect an effect on hygroscopicity by a treatment of Acryloid B72 in acetone (Schniewind 1990b). This was not unexpected because a molecular weight of 3000 is about the maximum that can enter the cell wall—even in the presence of a swelling solvent like acetone—and Acryloid B72 is believed to have a significantly greater molecular weight. Another contributing factor may be that Acryloid B72 introduced in solution does not form a uniform film over the internal lumen surfaces but tends to concentrate heavily in some cells, leaving others with little or no resin in them (Schniewind and Eastman 1994).

Reversibility

Thermosetting synthetic polymers are not soluble in neutral organic solvents and cannot be softened by heat, making treatments with something like epoxy resins irreversible. In contrast, treatments with thermoplastic synthetic polymers are reversible, at least in principle. Grattan and Williams have questioned whether the reversing of consolidation treatments can ever actually be successfully executed—the argument being that if an object is frail enough to require consolidation, it will be too frail to withstand the stresses of having the consolidant extracted again (Grattan 1980; Williams 1988).

According to the principles of thermodynamics, all real processes are irreversible—even the simple act of placing a drop of water on a smooth but uncoated wood surface can result in minute irreversible changes (Schniewind 1987). Horie proposed four standards of reversibility, ranging from clearly irreversible—through a return either to original appearance or to a state that does not interfere with subsequent treatments—to a state where no trace of the original treatment remains (Horie 1983). Thus, in practical terms, it is useful to know if some or most (if not all) consolidant can be extracted again if necessary. Thermosetting resins are clearly irreversible and thus could never be removed if used as consolidants. Thermoplastic resins polymerized in situ are also not likely to be readily removed: Unger and coworkers found it difficult to remove even surface deposits of such resins from treated wooden objects after the polymerization reaction was complete (Unger, Reichelt, and Nissel 1981).

Thermoplastic consolidants introduced into wood in solution, however, do offer at least some degree of reversibility. Hatchfield and Koestler made a scanning electron microscopic study of ancient wood treated with Acryloid B72 in toluene and found that the consolidant could be largely extracted again but that some of the resin did remain (Hatchfield and Koestler 1987). Nakhla treated samples of cedar with Acryloid B72 in trichloroethylene, or polyvinyl butyral (Mowital B30H) in ethanol, and then extracted the consolidants by soaking in the same solvent used for treatment (Nakhla 1986). Although gravimetric measurements indicated that some consolidant remained in both cases, the Acryloid B72 treatment proved, on the whole, more reversible.

It must be emphasized, however, that solvents interact not only with the consolidant but also with the wood. Normal wood contains—in addition to its main constituents cellulose, hemicellulose, and lignin—an extremely varied group of compounds known as extractives. They are so named because they can be extracted with neutral organic solvents. Deteriorated wood may additionally contain degradation products that are also soluble. In the course of extracting consolidant, extractives and degradation products may also be removed (Schniewind 1987, 1988). Some solvents will also cause wood swelling, or they may extract some of the adsorbed water in the cell wall, and some may in turn be adsorbed on the internal wood surfaces.

Table 4 shows results of a systematic study of reversibility of wood consolidation with respect to extractive removal. Deteriorated Douglas-fir specimens (6 × 25 × 50 mm) were treated with 15% solutions (weight basis) of Butvar B98, AYAT, and Acryloid B72, each in two different solvents. After drying, the specimens were extracted by one of the following three methods: soxhlet extraction, soaking with agitation, or soaking only. Soxhlet extraction is the most effective extraction method available and should therefore indicate the limits of what is possible;

Table 4 Reversibility of consolidation treatments as indicated by residual resin content

			Residual resin (%)	
Polymer	Solvent	Extraction method	Measured	Corrected
Butvar B98	Methanol	Soxhlet	–0.3	0.8
	Toluene-ethanol	Soak and agitate	2.7	2.9
	Toluene-ethanol	Soak only	6.0	5.7
AYAT	Acetone	Soxhlet	–1.0	–0.3
	Toluene	Soxhlet	1.2	1.9
Acryloid B72	Toluene	Soxhlet	0.2	0.9
	Acetone	Soxhlet	–0.1	0.6
	Acetone	Soak and agitate	–0.3	0.4
	Acetone	Soak only	0.7	1.3

however, it is not a practical method except in the most unusual circumstances. Parallel samples were used to extract the wood only, to determine the amount of extractives that would presumably be removed along with the consolidant. Before and after each procedure, specimens were conditioned to constant moisture content in a controlled-environment room.

Table 4 shows residual resin content as the difference between original weight and weight after extraction, with correction for extractive removal considered both before and after. Negative values before correction occur if the true residual resin is less than the amount of extractives removed. Only one corrected value is negative, a result that may be due to imperfect matching with the samples for extractive-content determination. The data show that acetone and methanol were more effective generally in extracting consolidant than toluene or the ethanol-toluene mixture, and that AYAT and Acryloid B72 treatments were more reversible than the B98 treatment. The use of agitation was very effective, and for Acryloid B72 and acetone, it achieved results as good as, if not slightly better than, the results of the soxhlet extraction. The AYAT treatment in acetone proved the most reversible (Schniewind 1988). Thus, there is ample evidence that soluble resin consolidants can largely be extracted again, but that small amounts of resin are likely to remain.

Treatment of Wooden Panels

In the discussion thus far, it has been assumed that the consolidant used should not come into contact with either the paint or the ground layers. This constraint represents a severe limitation of accessibility for consolidation of a painted panel as compared to an unpainted wooden artifact, and this limitation would also make it practically impossible to treat a wooden panel that has a painted image on the reverse. Furthermore, soaking by total immersion or vacuum impregnation would not be possible unless an effective, temporary barrier could be created to isolate the paint layers from the consolidant. Still, consolidation of polychrome wooden artifacts by vacuum impregnation, particularly with monomers polymerized in situ, is not unknown, and some examples have been described by Schaffer (1974). For instance, methyl methacrylate monomer is quite volatile, and if care is taken, the monomer will evaporate from the surface layers before polymerization can take place, thus preventing the formation of any surface films. It may also be helpful if a temporary barrier coating can be applied to prevent potential problems. While such a total impregnation procedure should not be rejected outright, it must nevertheless be approached with the utmost caution.

The nature of the deterioration needs to be considered when the consolidation of wooden panels is approached. Deterioration rarely proceeds in a uniform fashion, so it is entirely possible that impregnation will be required only in localized areas. For example, fungal decay may well occur in scattered pockets. If deterioration was caused by insect attack, the nature of the boreholes (i.e., small or large, isolated or coalescent, clean or filled with frass) is an aspect that could have a bearing on treatment choices. In cases where there are large areas of loss, fillers for the larger voids may need to be considered. Wermuth advanced the concept of primary, secondary, and even tertiary consolidants in such a context (Wermuth 1990). There is no reason that this distinction could not apply to panel paintings in particular cases.

Special Problems with Wood-Based Panel Products

Wood-based panel products are often found among the supports for paintings of the twentieth century. In particular, these include fiberboard, hardboard, particleboard (also referred to as pressboard and chipboard), and plywood. All of these consist of wood elements and some type of binder or adhesive. A survey of wood-based composite materials used in twentieth-century furniture and the problems they represent have been discussed by Klim (1990).

Since the adhesives used may not be moisture resistant and because extreme moisture conditions can create significant internal stresses in the material, there is always the danger of failure of the adhesive bonds and subsequent disintegration of the panel material. Particleboard is particularly subject to recovery of the large deformations of the particles incurred during the original pressing process, when it is exposed to high relative humidity. This is known as springback, a condition that may result in thickness swelling of 20% or more, as well as in a disruption and roughening of the surface (Moslemi 1974). For this reason, particleboard has to be considered one of the most unstable painting supports. Prolonged conditions of high moisture may lead to complete disintegration; thus fungal decay is not likely to be a problem with particleboard, because it will disintegrate at moisture contents sufficient to support decay—before the decay itself can do much damage.

In plywood, moisture problems can lead to surface checking, which could easily disrupt thin paint layers (Minor 1993), or to delamination (Williams and Creager 1993). Neither of these problems lends itself to being solved by a bulk treatment such as impregnation. There are no readily apparent methods of dealing with surface checks, especially if they are numerous and the conditions leading to the checking are likely to be persistent (Minor 1993). Williams and Creager have outlined some approaches to dealing with delamination, ranging from local repairs to a partial transfer (i.e., discarding all but the face ply bearing the image and attaching it to an alternate support) (Williams and Creager 1993). The permeability of these new wood-based panel materials additionally differs from that of solid wood. In plywood, the lathe checks can serve as pathways for fluid transport along the grain within a ply, so that the wood is very permeable from its edges. Because of the adhesive layers, however, permeability through the thickness is quite low (O'Halloran 1989a). This factor could make plywood more difficult to treat if there is deterioration of biological origin that does not involve delamination. Particleboard and fiberboard are more permeable than solid wood because they contain interconnected void spaces (O'Halloran 1989b). As in the case of solid wood, whatever type of deterioration takes place will increase permeability, a factor that serves to facilitate treatment by impregnation.

Materials and Suppliers

Acryloid B72, Rohm and Haas Company, Independence Mall West, Philadelphia, PA 19105.

AYAT, Union Carbide Corporation, Old Ridgebury Road, Danbury, CT 06817.

Butvar B90 and B98, Monsanto Plastics and Resin Co., 800 N. Lindbergh Blvd., St. Louis, MO 63166.

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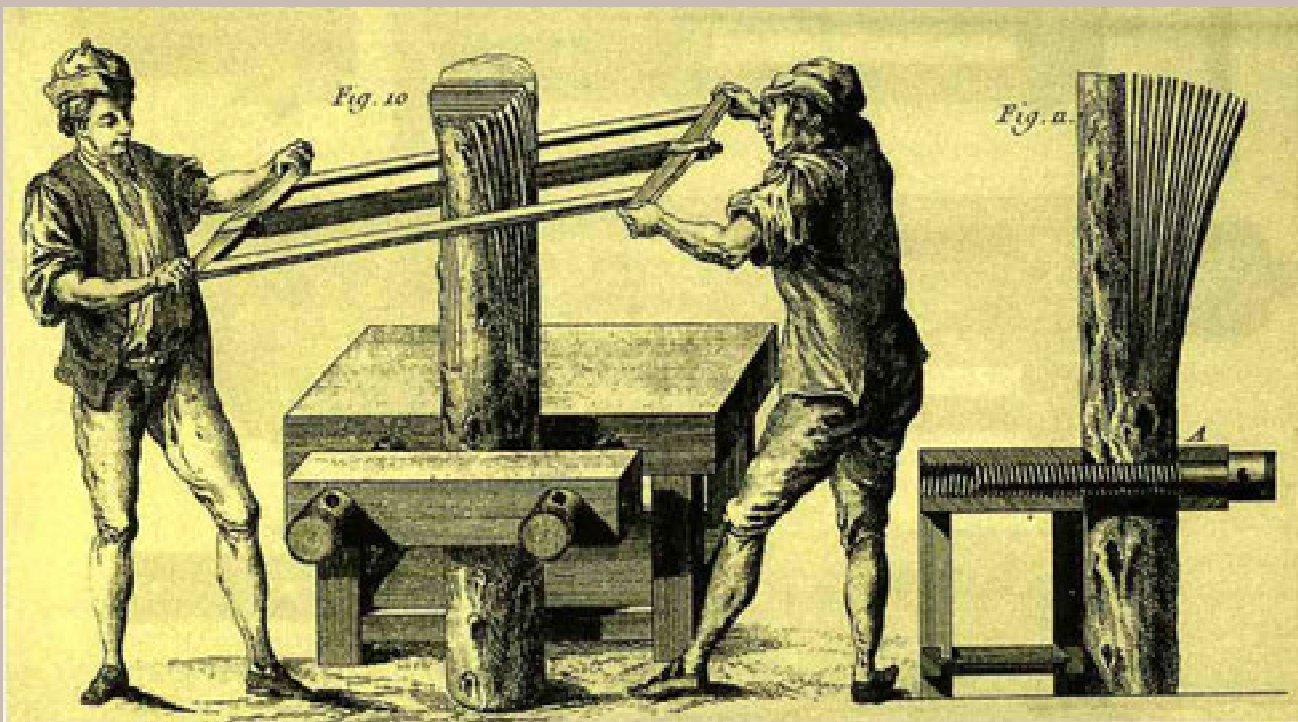
PART TWO

History of Panel-Making Techniques



Historical Overview of Panel-Making Techniques in Central Italy

Luca Uzielli

The present study surveys the techniques used in the making of the wooden supports of panel paintings in central Italy between the thirteenth and sixteenth centuries, a period during which panels played a particularly significant role in Italian painting.[1] An "evolution" in manufacturing techniques, however, does not imply that later panels were technologically more advanced than earlier ones. On the contrary, these changes may be regarded as an "involution," which eventually led to an abandonment of wood in favor of canvas as a support material. During the historical period discussed in this article, supports for wooden panels were subjected to a wide range of influences: changing formal requirements of panel size and shape, including changes in artistic techniques and traditions, the challenges posed by economic constraints, and the need to develop woodworking techniques that would permit panels to respond to fluctuations in environmental conditions.

Early References to Wooden Supports

Perhaps the first detailed information concerning early wooden supports in Italy can be found in *De Coloribus et Artibus Romanorum* by Eraclius (ca. tenth century C.E.). In the eleventh or twelfth century, Theophilus reported further information on the same subject in his *Diversarum Artium Schedula,* the most thorough medieval text dealing with the secrets and techniques of the fine arts. It describes how boards are glued together to form a whole panel for painting and how they may be coated with leather, to which the ground can be applied.

The richest and most detailed information about art techniques in the early literature, however, emerges from Tuscany in the early fifteenth century. While living in the town of Padua, Cennino d'Andrea Cennini, in his classic work *Libro dell'arte* (ca. 1437), described the techniques used in Florence (Cennini 1994). This text was "composed as for the use and good and profit of anyone who wants to enter the profession," which was, he noted, "really a gentleman's job" (Cennini 1994:chap. 145, p. 91).

Cennino's recommendations about how an artist should be trained, what pupils should learn from masters, and how experience should flow through the *botteghe,* or workshops, provide an outline of typical techniques used at the time in preparing panel supports and reflect the highly serious attitude taken toward the craft:

> Know that there ought not to be less time spent in learning than this: to begin as a shopboy studying for one year, to get practice in drawing on the little panel; next, to serve in a shop under some master to learn how to work at all the branches which pertain to our profession; and to stay and begin the working up of colors; and to learn to boil the sizes, and grind the gessoes; and to get experience in gessoing anconas, and modeling and scraping them; gilding and stamping; for the space of a good six years. Then to get experience in painting, embellishing with mordents, making cloths of gold, getting practice in working on the wall, for six more years; drawing all the time, never leaving off, either on holidays or on workdays. And in this way your talent, through much practice, will develop into real ability. (Cennini 1994:chap. 104, p. 64)

A thorough knowledge of various wood species and their properties and uses appears throughout Cennino's writing (see Table 1). That Cennino clearly takes information on wood species for granted suggests that it was common knowledge at this time. However, no mention is made of processing logs into boards, nor of selecting, edging, shaping, drying, or gluing of boards together to form the whole support. This absence may indicate that such expertise was not considered to belong to the artist's field, although the artist would often have specified the size, shape, and other features of the finished panel.

Panel Construction Techniques

Historical evolution of central Italian panel supports

The techniques used in the construction of central Italian wooden supports vary widely according to the period, region, type of artwork, and artist. It should be noted that the morphology and the structural complexity of a support are not directly related to the size of the painting nor to that of the individual boards but, rather, to the period to which it belongs. However, due to the nature of wood, which includes such properties as anisotropy and hygroscopicity, almost all supports shared some common features. The common sensibility that characterized the artisans of central Italy arose from an effort to provide simple solutions to the challenges posed by their craft.

The historical evolution of central Italian panel supports is interesting to follow. The supports of Tuscan paintings (*protopittura toscana*) that were produced until approximately 1250–80 possibly derive from Gothic retables and are made primarily of coniferous wood. During the late thirteenth, fourteenth, and early fifteenth centuries, poplar was the main species used. The complex nature of many paintings (e.g., altarpieces, crucifixes, polyptychs) often required that the support be a complex structure, an artwork in itself strengthened by ad hoc components, such as crossbeams, braces, and the framework on the reverse. Richly molded or carved engaged frames, predelle, cusps, and various ornaments constituted integral parts of the support. The conception of the supports, as well as the details of their manufacture, make clear the skills and knowledge of the artists and manufacturers with regard to the properties and behavior of wood. Even smaller paintings were often made on rather complex supports.

In the second half of the fifteenth century, works of art (including polyptychs and frescoes) made by fourteenth-century masters sometimes

Table 1 Wood species mentioned by Cennino Cennini in the *Libro dell'arte*. Sources: English names (as translated by Thompson); page and chapter where the species is mentioned (Cennini 1994); Italian names in Cennini's original text; and the most likely scientific names (Giordano 1988; Schweingruber 1990), according to the judgment of the present author.

Thompson's translation	Page	Chapter	Italian name in Cennini's text	Latin name
Box	4	5	bosso	*Buxus sempervirens* L.
Broom[a]	87	142	scopa	*Erica scoparia* L.
Chestnut	41	64	castagno	*Castanea sativa* Mill.
Fig	4	6	figàro	*Ficus carica* L.
Linden	69	113	tiglio	*Tilia cordata* Mill.
id.	87	141	id.	id.
Male oak	118	174	rovere	*Quercus* sp.
Maple	41	64	àrgiere	*Acer pseudoplatanus* L.
Nut[b]	61	97	noce[b]	*Juglans regia* L.
id.	110	170	id.	id.
id.	116	173	id.	id.
Oak	118	174	quercia	*Quercus* sp.
Pear	61	97	pero	*Pyrus communis* L.
id.	116	173	id.	id.
Plum	61	97	susino	*Prunus domestica* L.
Poplar	69	113	arbero[c]	*Populus alba* L.
id.	87	141	albero[c]	id.
Whitewood	69	113	povolare[c]	id.
Willow	19	33	saligàro	*Salix* sp.
id.	69	113	id.	id.
id.	110	170	id.	id.

[a]"Broom," rather than "birch," is most likely the correct English translation for the species cited by Cennino.

[b]The correct English name for *noce* is walnut.

[c]Both *albero* (or *arbero*) and *povolare* meant poplar; the current Italian common name for *Populus alba* is *gattice*.

underwent a modernization. This was undertaken not only to repair damages but in many cases to adapt the works to the requirements of new locations or new aesthetic criteria and rules (Filippini 1992; Gardner von Teuffel 1983). In such cases, significant structural modifications occurred to the wooden supports and to the frames.

In the fifteenth and sixteenth centuries, the supports became more sober in design, evolving toward a simple panel composed of various boards inserted in a separate frame. The ground layer also became simpler (see following section).

Usually, the construction of the wooden support was the responsibility of a specialized artisan (the *legnaiolo*), who could work independently of the artist and could even prepare a support according to a client's specifications before the artist was chosen (Bernacchioni 1992). However, especially in the case of the earlier, more complex panel paintings, close cooperation must have existed with the artist, who probably gave the carpenter specific directions, even on subjects relating to the manufacture of the support. In Duccio's *Maestà,* for example, the aesthetic interaction between painting and front frame suggests an intervention by both artist and carpenter, even if such was not provided for by the contract.

In some cases, a specific artist would have had his own carpenter or would have consistently used the services of the same bottega. For example, the same hand may be recognized in several supports of Giotto's paintings, including the *Maestà di Ognissanti* and the *Crocifisso di Santa Maria Novella*. Filippo Lippi and Sandro Botticelli also had exceptional carpenters.

Ground layers

Up to the fourteenth century, great care was used in preparing the ground layer, which, as described by Cennino, was basically made of glue, cloth, *gesso grosso,* and *gesso sottile*. The cloth, generally made of large, overlapping pieces, was often applied not only over the whole panel but over the engaged frame as well (see Fig. 1).[2]

In the fifteenth century, cloth strips were often applied only on the most sensitive areas (such as joints between boards, or knots and other defects in the wood), whereas in later years parchment or vegetable fibers mixed with glue were used. Increasingly, less care was devoted to gessoing.

Correctly chosen and applied cloth created the best results; even in cases where wood movement caused the whole complex of cloth together with the ground layer to separate from the wood, the painting often remained well preserved. In contrast, parchment tended to detach extensively and lift at the edges. Likewise, vegetable fibers did not perform as strongly and efficiently as does the woven structure of cloth. The absence of cloth and the limited care applied to the ground layer resulted in a greater likelihood that wood movement would affect the paint layer, which then suffered from characteristic damage, such as lifting and corrugation into numerous small crests.

The selection of wood species for panels

Although it is customary to think of "supports made of wood," it would be more precise to refer to "supports made from one or more wood

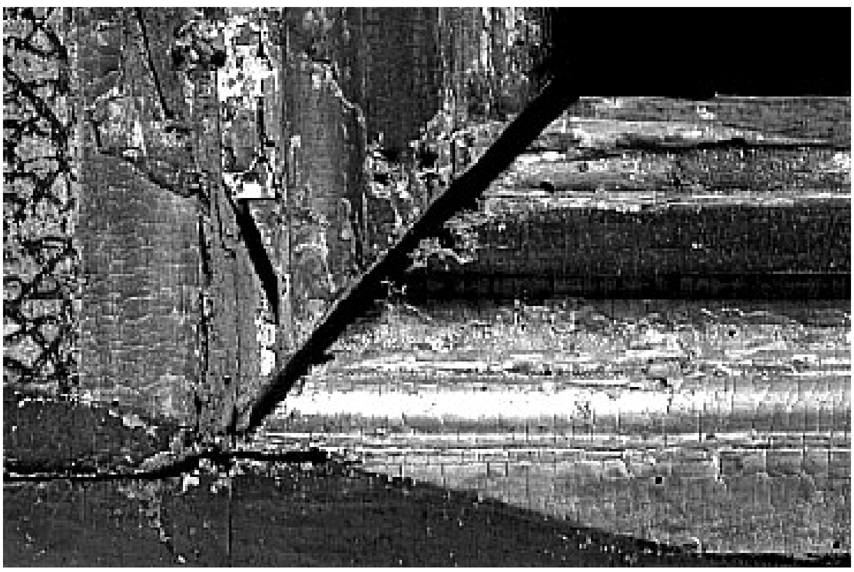


Figure 1
Giotto, *Crocifisso di Santa Maria Novella*. Church of Santa Maria Novella, Florence. Coarse and thin cloth glued on planking and on frame moldings.

species, each having its own individual technological properties." The conservation and behavior of a wooden support during its lifetime are significantly influenced by the wood species used. The selection of a wood species for a panel depended on technical, economic, and practical factors. It was also influenced by the particulars of the artisan traditions.

As already mentioned, earlier supports were made mostly of coniferous wood, especially fir (*Abies alba* Mill.). Later, beginning in the second half of the thirteenth century, poplar (*Populus alba* L. and other *Populus* spp.) started to be used on most panels throughout central Italy.[3] Other wood species have also been used occasionally through the centuries, including walnut (*Juglans regia* L.), linden (*Tilia cordata* Mill.), oak (*Quercus* spp.), chestnut (*Castanea sativa* L.), and others.[4] Engaged frames were mostly made of poplar (especially the earlier examples, which were manufactured integrally with the panel), since the same wood properties were required for the engaged frames as for the panel. The framework on the back (including the crossbeams) was usually made of wood species selected for their strength and rigidity.

The choice of wood by local artisans was strongly influenced by questions of availability and cost. Marette shows that wood species for supports were typically chosen among those growing in the region (Marette 1962).

This and a number of other reasons help explain why poplar was the species most frequently used for panels. Poplar is technically suitable for the manufacture of supports. Poplar's heartwood is undifferentiated, and the absence of extractives such as tannins makes adhesion of glues and ground layers easier and more secure and prevents leaching and staining in the event of high moisture. It is homogeneous, being fine textured, with not much difference between earlywood and latewood, or between normal wood and knots. Poplar also exhibits good dimensional stability in the presence of humidity variations, due to its small shrinkage and distortion coefficients. Moreover, it is strong, light, and easy to dry and process. It offers a plentiful source of large, regular, straight-grained, and relatively defect-free boards. As for its availability, poplar's natural growing area covers practically all of Italy.

The major drawbacks of poplar are its low natural durability against fungi and its nonresistance to wood-boring insects, both a consequence of the absence of extractives.

There is little doubt that poplar (and other similar but less used species, such as linden and willow) was technically a better choice for panels than was fir, the species that had been most widely used previously. Fir is as fine textured and easily processed as poplar, but it is not as homogeneous. With fir, alternating earlywood and latewood tend to show up through the thinner ground layers, and knots are more frequent and prominent. In addition, fir has less dimensional stability than poplar, and it reacts more quickly to changes in environmental humidity.

Until the middle of the thirteenth century, techniques used in northern Europe, including the use of fir, influenced those in central Italy. At some point, however, the idea may have emerged that poplar would fare better in the highly variable Tuscan climate, which subjects panel paintings to great mechanical stresses. This idea may have been a consequence of the greater autonomy in social, political, economic, and artistic spheres in Florence beginning in the thirteenth century. This

Figure 2
Guglielmo, *Croce dipinta*, 1138. Cathedral of Sarzana. The support of this very old cross is made of chestnut.

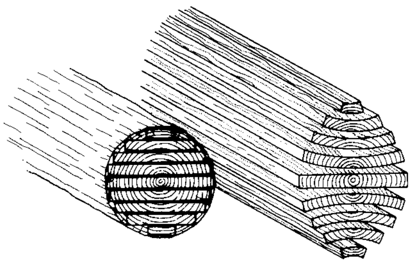


Figure 3
Drawing depicting the sawing of a log and typical deformations of boards after seasoning. Only radial boards remain flat after moisture variations.

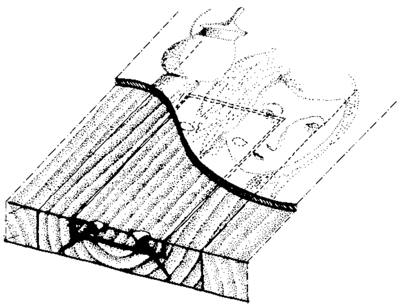


Figure 4
Diagram showing a diametrically cut board made weak by the presence of the pith, which had been removed and replaced by an inset before the ground and the paint layer were applied. Giotto, *Maestà*. Uffizi Gallery, Florence.

autonomy led artists and artisans involved in panel painting to adopt techniques better fitted to local conditions, creating a change of attitude among artists that accompanied the moral and cultural shift that is made clear in Cennino's *Libro dell'arte*. This movement also indicated another shift: the basis for pride in the artwork itself was no longer limited to the achievement of creating a panel that would serve solely as a devotional instrument in the present and near future; pride was also based on the creation of an enduring work of art that would last for posterity.

Economic or time constraints might have encouraged the occasional use of cheaper or more immediately available wood, although at times locally available, well-known woods may have been preferred and deliberately chosen (e.g., chestnut for the support of Guglielmo's painted *Croce* from the Sarzana Cathedral) (Fig. 2). In some cases, artisans may not even have considered the implications of using different species. In reporting on microscopical identification of recently exhibited paintings by Raphael, for example, Fioravanti (1994) concluded that poplar and linden were used interchangeably by the artist.[5] It is also possible that different woods may have been used deliberately for the sake of amusement or experimentation; however, in the cases of complex supports or later interventions, it is likely that an artisan would simply have used any piece of wood available in the workshop.

Wood quality

There is little doubt that no matter how appropriate a wood species seems, boards that are badly manufactured, selected, or seasoned result in undesirable behavior. There is also no doubt that wood properties and behavior were well known by the artisans who made the supports.

Sawing patterns and arrangement of growth rings

Since it is well known that after seasoning, radial boards distort (cup) much less than tangential boards (Fig. 3),[6] it has often been thought and taught that good workmanship requires that only radial boards be used for panel paintings. Although this is true in some cases (e.g., for oak supports used in central and northern Europe), it does not always apply to poplar supports in central Italy for a number of reasons.[7] Although diametrically cut boards can be considered the optimum choice for poplar panels, they were not absolutely required. On the one hand, a diametric board offers two advantages: first, it is the widest board that can be obtained from a given log, and second, it is less prone to cupping than any other board, due to its radial cut. On the other hand, a diametric board has the disadvantage of containing the log's pith, which constitutes a zone of discontinuity and low strength that is prone to longitudinal cracks (Fig. 4).[8] From an economic standpoint, since most logs were likely sawn according to a parallel pattern, a technique that produces a high proportion of tangential and subtangential boards, selecting only the diametric board from each log would result in an unjustified waste of good and expensive wood material. Another economic consideration is that a greater number of tangential and subtangential boards result from a log that is parallel sawn.

As for the arrangement of boards according to their growth-ring orientation, it appears that no general rule may be determined. Boards were often arranged with the "inner" face toward the side to be painted.[9]

However, in many cases no specific arrangement according to growth rings can be observed. Boards with "inner" faces oriented one against the other (one toward the front and one toward the back of the panel) have also been noted (Fig. 5).

This question of board arrangement may be less critical than it appears at first, since the effects of other distortion factors (i.e., the temporary cupping caused by mechanical or hygroscopic asymmetry and the permanent cupping caused by what Buck has termed "compression set") are superimposed and may even prevail over the cupping caused by the wood's transverse anisotropy (Thomson 1994; Uzielli 1994).

Avoiding and repairing wood or board defects

Even the most carefully built fourteenth-century panels, which are characterized by the great care that was taken in wood selection, contain some defects, suggesting that the use of some boards with defects was considered acceptable.[10] The most frequent wood defects found in panels are pith, knots, and grain deviations, whereas board defects relate mostly to wane appearing on the back face.[11] The presence of wane shows that boards have been used at the maximum of their available width and that sapwood is present.[12]

In addition to the gluing of cloth over the defective area before the ground layer was applied, a number of other measures were often taken to prevent or, at least, to reduce the negative consequences of defects in selected boards. Knotholes and similar cavities were plugged with a paste made of glue and sawdust (as Cennino recommends) or with tightly embedded wooden plugs placed with their grain parallel to that of the board (Fig. 6). If wane or a relatively large decayed or defective area were present on the front of the panel, a flat surface was sometimes reconstructed before the application of the ground layer. In the thirteenth and fourteenth centuries, such reconstruction was usually accomplished by the precise embedding of small boards (Fig. 7). Later, various materials were used to plug the voids, including glue paste with sawdust or vegetable fibers (Del Serra 1994).

With respect to widespread incipient decay in boards selected for panel making (the decay of wood in the panel after painting is not discussed here), there is a possibility, which has not been unequivocally confirmed, that boards affected by some early stage of fungal decay (e.g., boards recovered from other uses or boards left exposed to weather) may have been purposely used for panel construction to take advantage of their reduced shrinkage and swelling.[13]

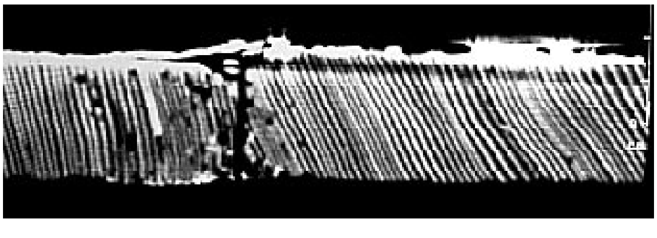


Figure 5
Cross section, obtained by computer tomography, of a panel painting made from two fir (*Abies alba* Mill.) boards, probably cut from the same log, with "inner" faces oriented one against the other (one is placed toward the front and one toward the back of the panel). *Madonna con Bambino,* twelfth or thirteenth century. 127 × 65 cm. Convento Suore Agostiniane della Croce, Figline Valdarno.

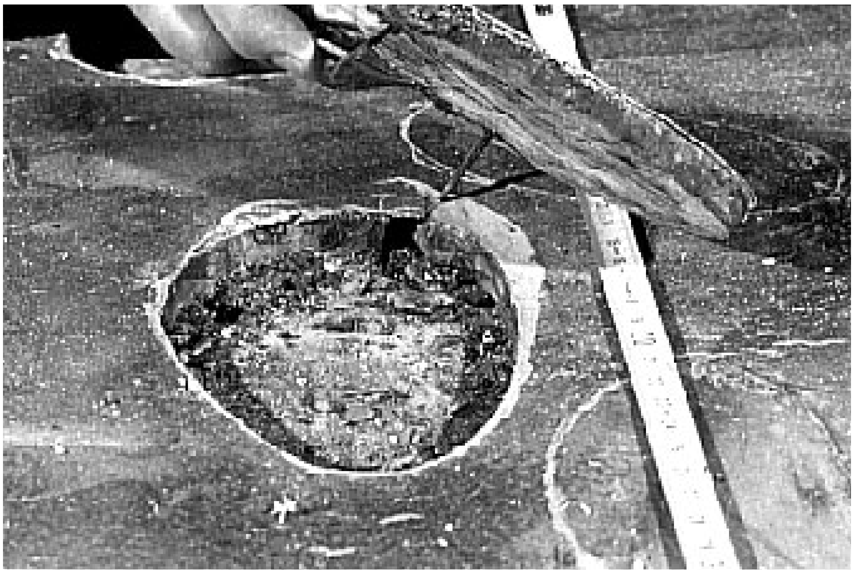


Figure 6
Francesco Salviati, *The Deposition from the Cross,* 1547–48. Oil on panel, 495 × 285 cm. Museo dell'Opera di Santa Croce, Florence. Wooden plug originally embedded in the panel face before painting.

Seasoning

Anybody knowledgeable on the subject (see, for example, Cennini 1994:chap. 108) appreciates that for optimum results, timber should be perfectly seasoned. However, it is well known to artisans today—as it must have been to those of the Renaissance—that in practical terms, the designation "perfect" seasoning does not refer to a static situation or a fixed moisture content. The golden rule of the craft states that the equilibrium moisture content (EMC) of the wooden support at the time of manufacturing or painting should be as close as possible to the average EMC predicted in its subsequent environment.[14]

It may be impossible today to determine the exact values of the moisture content (MC) of supports at the time of their manufacture. One assumption, however, is that the average EMC of panel paintings located in churches, public buildings, or noble houses (most of them usually

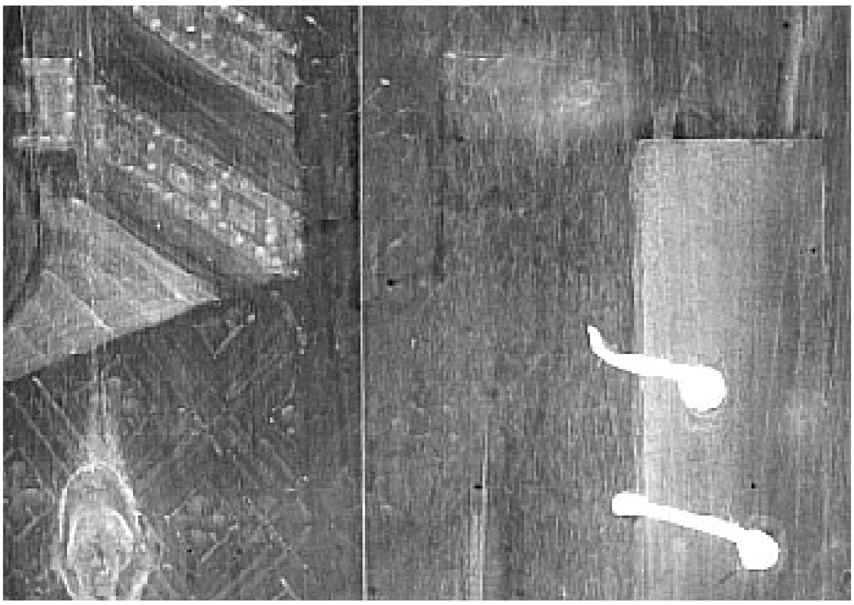


Figure 7
Cimabue, *Maestà.* Uffizi Gallery, Florence. X radiograph of a small insert originally embedded in the face of a diametrical board possibly damaged near the pith, to restore flatness and continuity of the panel suface.

unheated) in central Italy might have been 12–16% (corresponding to typical air temperatures of 0–30 °C and relative humidities of 60–80%).[15]

In exceptional cases, insufficiently seasoned wood was used, as exemplified in the otherwise unexplainable width of gaps (a total of 4 cm over the panel's width of 293 cm) between the boards of Duccio's *Maestà* (Fig. 8) (Del Serra 1990).

Size of boards

Most of the supports were made of two or more boards, depending on their size and shape. Only smaller supports were made of a single board. No general rules may be given on this subject since there is obviously great variability. Boards as wide as 60–70 cm or wider have been occasionally used, although 20–40 cm is the more common range of width.

Using wider boards would certainly have reduced the number of joins required for a panel and the consequent risk of separation along the glued joints. Thicker boards confer greater strength and rigidity, as well as greater dimensional stability under rapid environmental fluctuations.[16] However, disadvantages arise from their greater weight, greater manufacturing difficulties, and often unrestrainable forces that develop following environmental changes, possibly leading to severe distortions or damages (Uzielli 1994).

Typically, the original thickness of boards ranged between 30 mm and 45 mm, the thickness of large supports in particular being kept to a minimum to reduce total weight.[17] Larger boards usually required a greater thickness because of manufacturing techniques and the need to conserve planarity.

Strength and planarity of earlier and more complex panels were usually entrusted to the supporting system (frame, crossbeams, slats, braces, etc.), thereby reducing the need for proportionally thick boards in large paintings; in fact, 30 mm thick boards were often used. However, the boards of some larger supports from the fifteenth century feature greater

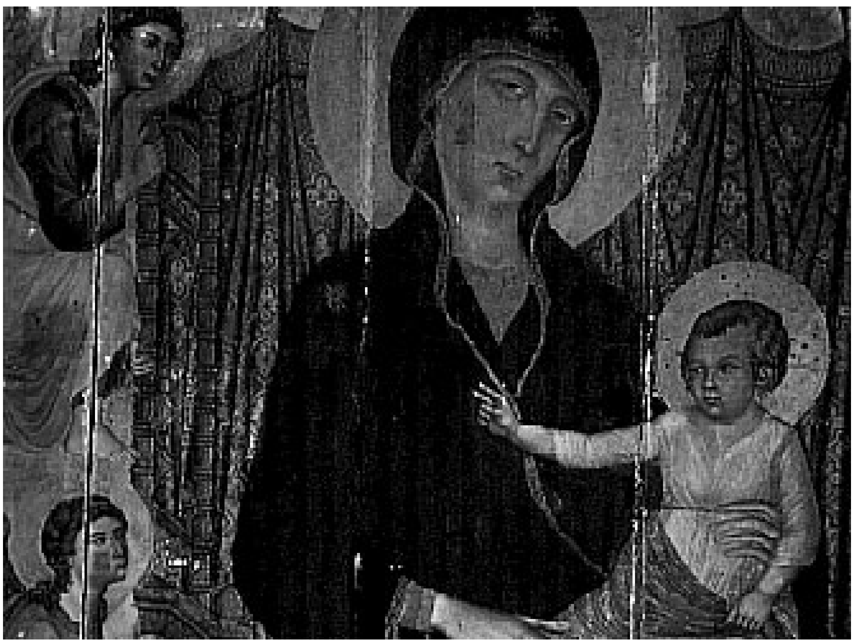


Figure 8
Duccio, *Maestà*. Uffizi Gallery, Florence. Gaps between the boards caused by seasoning of wood after the panel was manufactured and painted.

thickness (35–40 mm), possibly required by their size and their simpler structure, which entrusts the panel's strength and stability to the board's rigidity. The boards of later paintings from the sixteenth and seventeenth centuries are even thicker (40–45 mm) and are practically self-supporting—with crossbeams and slats that are usually intended to guarantee the continuity of the panel rather than its overall strength or shape.

In most cases thickness is constant throughout the whole panel; however, some panels were intentionally manufactured with varying thicknesses.[18] No satisfactory technical explanation has yet been given for this feature, which has been seldom reported in panels from central Italy.[19]

Connections between boards

Boards were usually glued along their edges with "cheese glue" (casein) or hot-melt animal glue (made of clippings), both described by Cennino (Cennini 1994:chap. 108). Typically, boards were accurately square-edged before gluing, and occasionally several incisions were made on the edges, possibly to improve glue adhesion (Fig. 9).[20]

Casein glue, one of the strongest glues known, has been used by woodworkers since ancient times; it does not have tack,[21] and its pot life is relatively short. Hot-melt animal glue features an even shorter preassembly time, since it must be hot while pieces to be joined are pressed together. For both glues, therefore, the assembly of boards had to be performed in a relatively short time, and the process required accurate and definitive positioning before pressure was applied. To satisfy such requirements (which must have been demanding, especially for large supports), wood splines, or dowels, made of hardwood (such as oak or elm) were used (Fig. 10). The splines were circular (*cavicchi*) or rectangular (*ranghette*) in cross section. They fit into mortises bored in the board's thickness and were placed at appropriate distances along the edges in order to maintain the board position until the glue applied on the edges had set.[22]

Other methods for connecting boards, such as groove-and-tongue joints, were possibly also used in earlier times. However, such methods seem to make gluing more difficult, because the internal surfaces were hard to reach and to control. Half-lap joints were used only in special cases.

Although double-dovetailed (i.e., X-shaped) wooden cleats mortised in the boards (Fig. 11) are infrequently found in the original manufacture of central Italian supports, their use has been popular in later restorations, albeit with unsatisfactory results.[23]

As an interesting example, the three higher corners of the cuspidate front frame of the *Maestà* by Duccio featured X-shaped cleats mortised into the boards and then painted by the artist. The subsequent wood

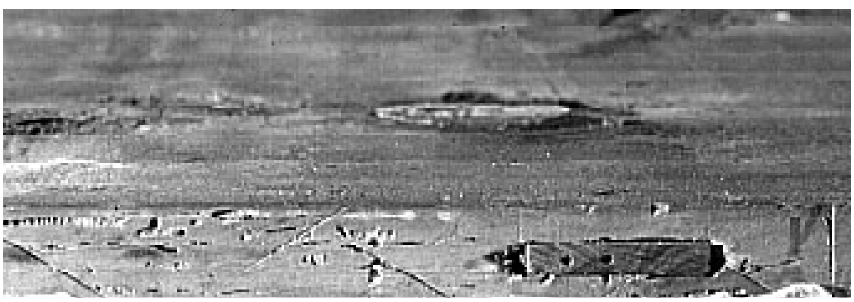


Figure 9
Incisions on the edges of the board to improve gluing, and spline used for the alignment of boards during the setting of the glue. Francesco Salviati, *The Deposition from the Cross.*

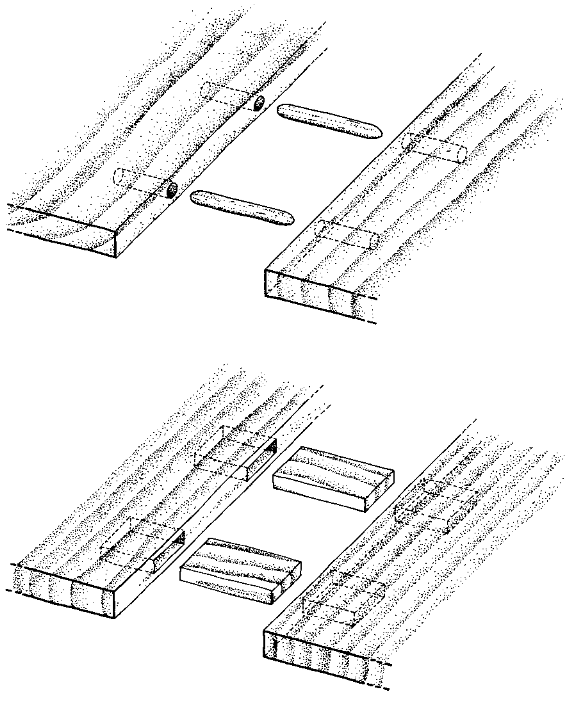


Figure 10
Drawing of wooden splines used for positioning boards during the setting of the glue.

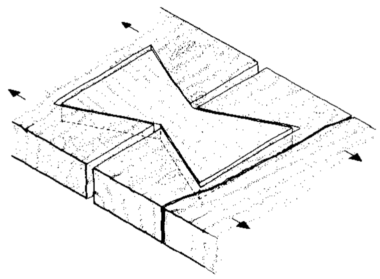


Figure 11
Drawing of X-shaped wooden cleat used to connect adjacent boards, mainly in later restoration works.

Figure 12
X-shaped wooden cleat used to connect two boards of the engaged frame after manufacture of the panel. Duccio, *Maestà*.

movements, in spite of the cleats, severely damaged the ground and paint layer in areas that correspond to the connections, whereas paint is fairly well preserved in other areas of the same front frame (Fig. 12) (Del Serra 1990).

There were several other types of connections—usually done with nails—between the various parts of wood supports. Examples can be seen in the added parts or lateral sealing of boards in thirteenth- or fourteenth-century crucifixes or altarpieces (Fig. 13) (Bracco, Ciappi, and Ramat 1992).

Arrangement of boards

Usually a panel was made of boards placed parallel to one another.[24] The longitudinal axis of the boards coincided with grain direction and was oriented along the greater dimension of the painting. Less frequently, panels were formed by boards connected with their grain direction perpendicular to each other, end joined, or irregularly placed. There were various cases and reasons for this configuration. In painted crosses, the transverse arm was typically made of horizontal boards.[25] A half-lap joint (*incastro a mezzo legno*) was then made, and the two adjacent faces were glued together with the grains positioned at right angles. Dovetail joints and other joining methods were also used (Bracco, Ciappi, and Ramat 1992).

Evidence shows that in some cases modifications or additions of boards (including perpendicular additions) to the wooden support were made before the ground layer was applied, possibly to satisfy the requirements of the artist, who might have changed his mind or have been required to paint on a support that had already been prepared independently from personal specifications (for example, see Giotto's *Crocifisso di Santa Maria Novella,* Florence [Bracco, Ciappi, and Ramat 1992]).

Modifications also occurred as a consequence of later interventions on paintings, as a result of the need to replace deteriorated parts or to modify the shape, size, or proportions of a panel, as with Raphael's

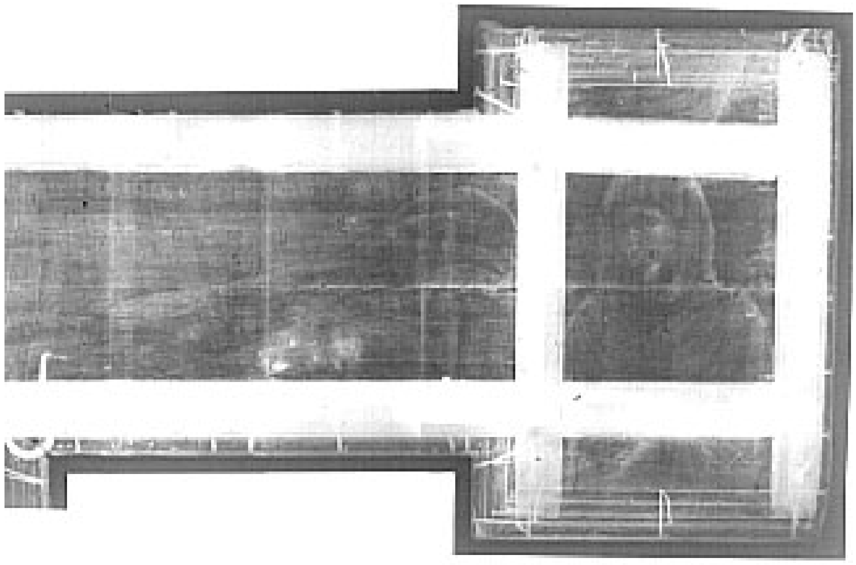


Figure 13
X radiograph of the nailed lateral sealing boards in a crucifix. Giotto, *Crocifisso di Santa Maria Novella*.

Madonna del Baldacchino (Fig. 14); for the purpose of fitting it in a different location; or to satisfy different aesthetic canons (Castelli, Parri, and Santacesaria 1992; Filippini 1992). Also included within this group are the countless paintings that have been dismembered, sawn, modified, or transformed for commercial reasons over the centuries.

Crossbeams and "backframes"

Crossbeams or "backframes" (the latter, in Italian, *telai,* being basically combinations of crossbeams and longitudinal or oblique struts, or *nottole*) are present on most panel supports. Their main functions were to hold the panel together and maintain its general planarity, especially for large or

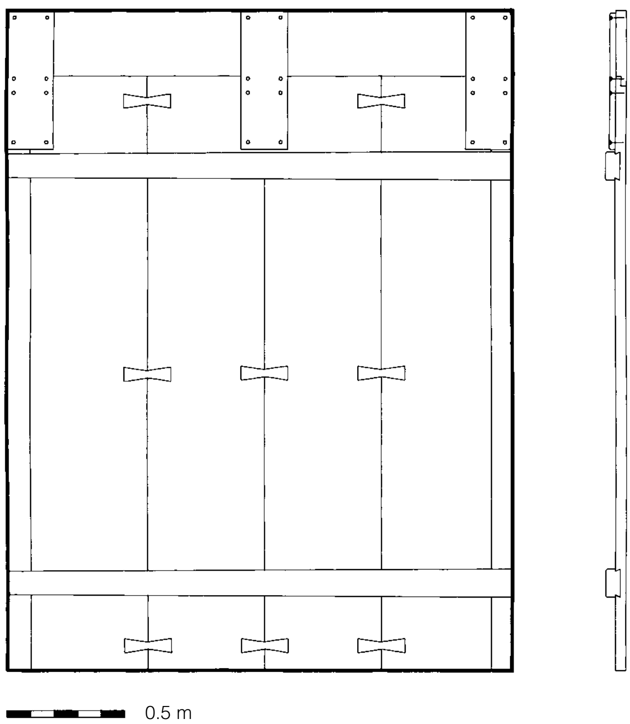


Figure 14
Raffael Sanzio, *Madonna del Baldacchino*. Galleria Palatina, Florence. Drawing showing the structure of a panel originally formed by six vertical boards. In 1697 a horizontal board was added, connected by a half-lap glued joint and three smaller vertical nailed boards. Later the panel was cradled.

complex paintings,[26] even if separations at glue lines or fissures interrupted the structural continuity of the panel. They also distributed throughout the whole panel the forces originating at supports, hanging points, connections, and so on, and helped to conserve the painting by reducing the negative effects of swelling and shrinkage caused by unavoidable moisture changes (Uzielli 1994).

On all but the last point, there is general consensus. However, the question of whether crossbeams and backframes help conserve a painting is still quite controversial today, both in its theoretical and practical aspects. In fact, the real problem lies not in the lesser or greater complexity of the backframe but, rather, with the type and stiffness of the connections between the panel and crossbeams, as well as the stiffness of the crossbeams themselves.

Until the early fifteenth century, connections between panels and frames (including crossbeams and engaged frames, where appropriate) were made mostly with nails. Later, various types of sliding crossbeams, resting on the back face of the panel, were devised. In the late fifteenth and early sixteenth centuries, dovetailed crossbeams (trapezoidal in cross section), inserted in tapered or (rarely) parallel grooves mortised into the thickness of the panel, were often used. On a few occasions, crossbeams were glued.

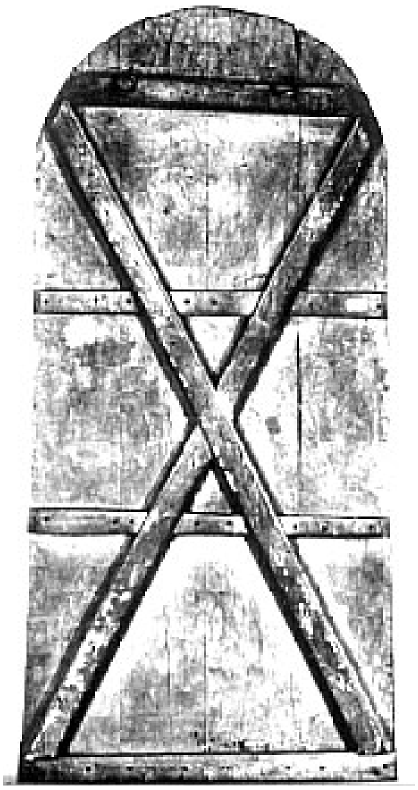


Figure 15
Coppo di Marcovaldo, *Madonna in trono col Bambino,* reverse. Church of Carmine, Florence.

The two criteria taken into consideration by artisans, along with their individual views and experience, in order to obtain the "controlled mobility" required from the crossbeams were, first, the distance between the crossbeams—defining the size of the transversal strip of panel that was "entrusted" to a crossbeam (which in fact was highly variable), and second, the thickness ratio (i.e., ratio of the thickness of the panel to thickness of the crossbeam), with an approximate range of 1:2–1:3.

It should be noted, however, that any general statement regarding the design of the backframe may do a disservice to the creativity and ability of the artisans. The few images given here serve only as examples (Figs. 15–17).

Nailed crossbeams

Nailing is one of the oldest and most frequently used means of connecting pieces of wood. At least with regard to thirteenth- and fourteenth-century panels, nailing should not be considered primitive, rough, or technologically inadequate. On the contrary, a careful analysis shows just how wise and skillful the artisans were who conceived the structures and nailed them together.[27]

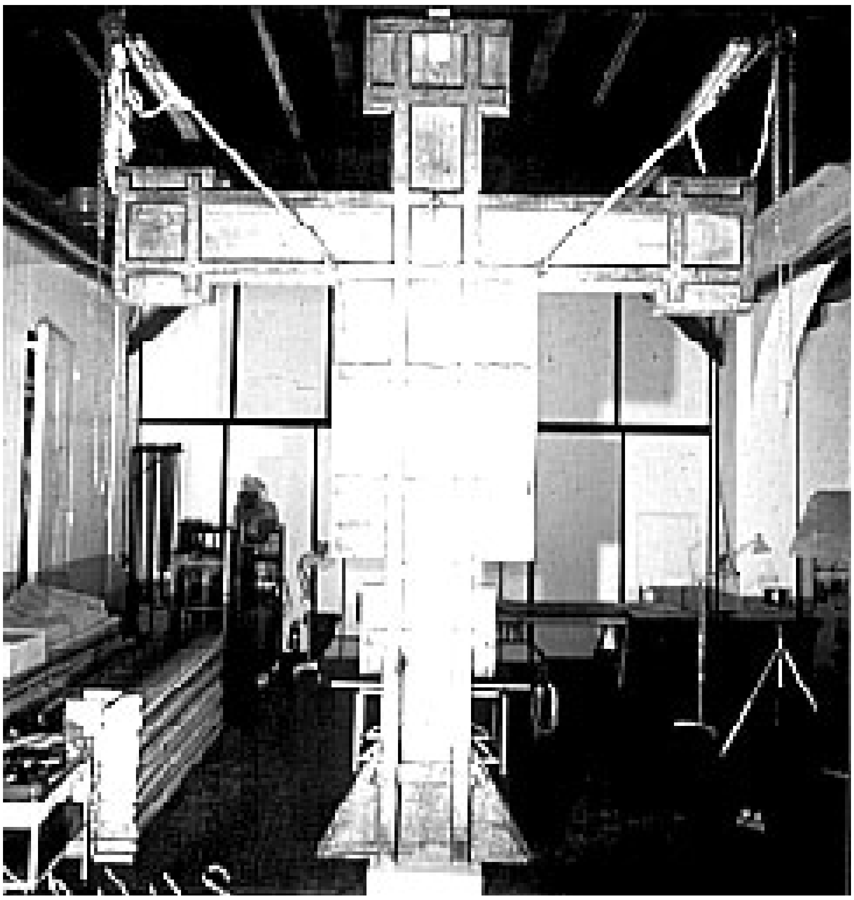
Nails were made of soft, wrought iron. The shanks were square or rectangular in cross section, tapered from their large, thin, round heads to their acuminate points (Fig. 18). They were driven by hammer into partially prebored holes and were clinched back into the wood in a U shape to ensure optimum resistance against pullout.[28]

The spacing of nails was regular and obviously well thought out. No strict spacing rules applied; the artisan's wisdom defined the direction in which the nails were inserted (from the front toward the back or vice versa, or in both directions) (Fig. 19).[29]

Great care was usually taken in separating the nail's end (head or clinched point) from the ground layer (Fig. 20) to prevent repercussions on the paint layers, such as surface irregularities or possible future emergence

Figure 16
Giotto, *Maestà,* reverse, before the 1991 restoration.

Figure 17, below
Giotto, *Crocifisso di Santa Maria Novella,* reverse.



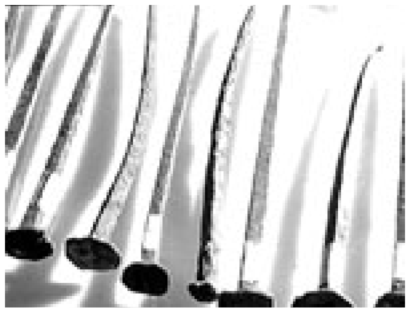
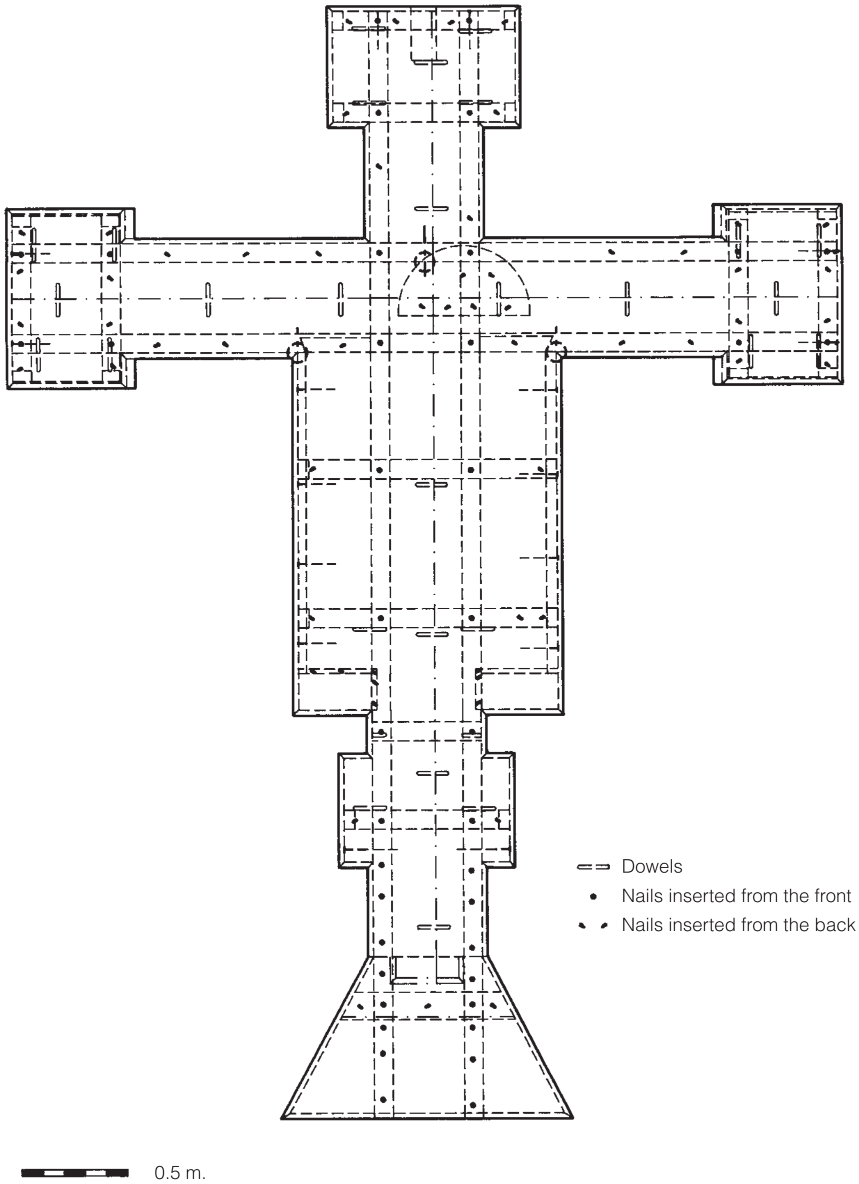


Figure 18
Wrought-iron nails typical of those used in supports.

Figure 19
Drawing showing the placement of nails in Giotto's *Crocifisso di Santa Maria Novella*.



of rust. To ensure this, nail points were clinched deep into the wood. Nail heads, possibly embedded deeper than the wood surface, were separated from the ground layer by means of plaster, cloth, parchment, or—in the most careful constructions—wooden plugs.[30]

Here, however, as elsewhere, no definite rules apply. For instance, in Giotto's *Maestà,* although the whole support was conceived and made with the greatest care (Fioravanti and Uzielli 1992), several nail heads protrude on the front face, bulging through the cloth and ground layer, making clearly visible marks on the painted surface.

On some panels, lines for correctly aligning the nail holes may still be found, especially those that remained protected under a crossbeam and became visible only upon its removal. Obviously, such lines may be found only on the back side, since the ground layer deleted or made invisible those that might have been traced on the front.

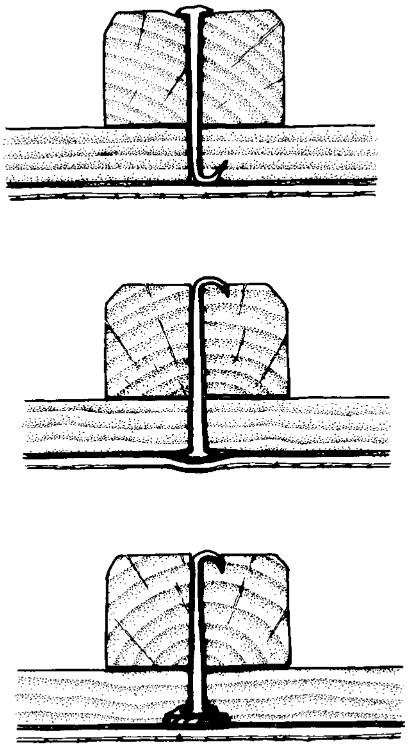


Figure 20, above
Drawings showing typical methods for clinching the nail point and insulating the nail head.

Sliding crossbeams

Many techniques for linking the crossbeam to the panel while allowing for some freedom of movement have been devised by the artisans who originally made these supports.[31]

Some sliding crossbeams were linked to the panel by means of metal bridges that were nailed or screwed on the back face, as in Botticelli's *Primavera*. Other sliding crossbeams featured wooden bridges that were both nailed and glued to the panel, such as Beccafumi's *Madonna e santi* (Fig. 21).[32]

An ingenious system based on iron pins fixed to the panel and passing through slots made in the crossbeam may be found in Fra Angelico's *Annunciazione* (Fig. 22). The pinhead (along with many carefully applied nails) has been embedded lower than the front surface of the panel and protected by means of wood dowels. The distance between the crossbeam and panel is adjustable at the opposite end of the pin by means of small metal wedges.

Another system replaces bridges with a pair of beams appropriately shaped and nailed to the panel to serve as a guide for a sliding crossbeam with a trapezoidal cross section; an example of this system is the support of Matteo di Giovanni's *Madonna e santi* (Fig. 23).

Dovetailed crossbeams

Although they may be considered capable of "sliding," dovetailed crossbeams are described here separately. Dovetailed crossbeams (Figs. 24, 25), which may have been derived from the technique traditionally used in icons, began to be widely used for panel supports starting in the early sixteenth century.

The dovetail joint ensures a positive grip between the panel and crossbeam, allowing the two elements to slide reciprocally but not to warp.[33] In addition, the resulting constraining forces are distributed evenly along the crossbeam, rather than being concentrated at specific points, as happens with nails or similar devices. Hence, there is a smaller risk of ruptures generated by concentrated stresses.[34]

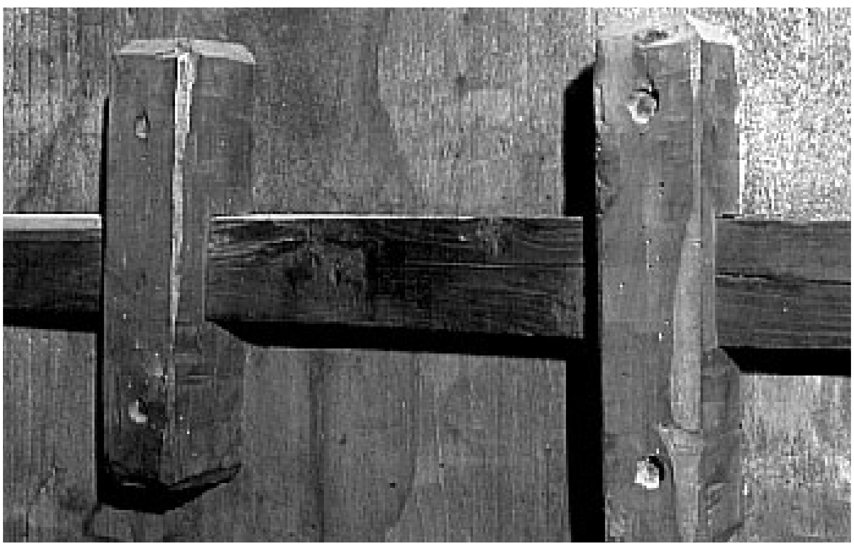


Figure 21, below
Beccafumi, *Madonna e santi,* reverse, detail. Collection of Chigi Saracini, Siena. Wooden bridge of a sliding crossbeam.

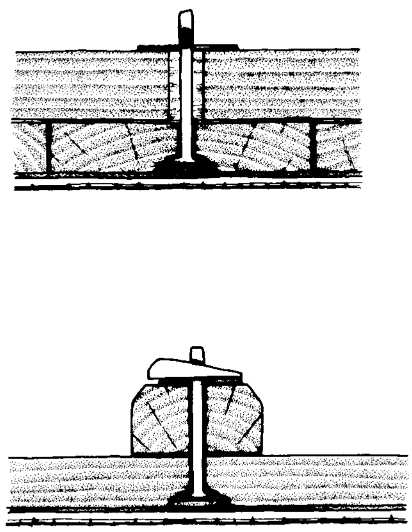


Figure 22, below right
Fra Angelico, *Annunciazione.* Convent of Montecarlo, San Giovanni Valdarno. Drawings of metal pins providing a sliding connection for a crossbeam.

Figure 23
Matteo di Giovanni, *Madonna e santi,* reverse, detail. Cathedral of Pienza. Two wooden bars stabilize a rudimentary sliding crossbeam.

This type of crossbeam typically featured a trapezoidal cross section, inserted in grooves with a corresponding cross section forming a sort of dovetail joint (grooves are mortised across the grain into the planking, as deep as approximately one-third of its thickness).[35] This crossbeam type was also widely known to have a longitudinal taper, which made it possible to tighten the dovetail joint simply by displacing the crossbeam along its axis; adjacent crossbeams were placed with the larger ends oriented toward opposite edges of the support (Fig. 25).

Glued crossbeams

Because glued connections are very stiff, two boards glued with their grain directions perpendicular to each other develop very high stresses in response to even small moisture changes. Therefore, glued crossbeams are seldom found. There are some cases, however, in which complex structures with cross-grain elements glued together behave fairly well over time.

Interlocking crossbeams

In some cases, where distance, exceptional size, or other reasons would make transportation of large polyptychs from the workshop to the church too difficult, the painting would be made in sections for assembly in situ. For instance, Bomford and coworkers (1989) describe Ugolino di Nerio's altarpiece from Santa Croce, whose surviving fragments are scattered in

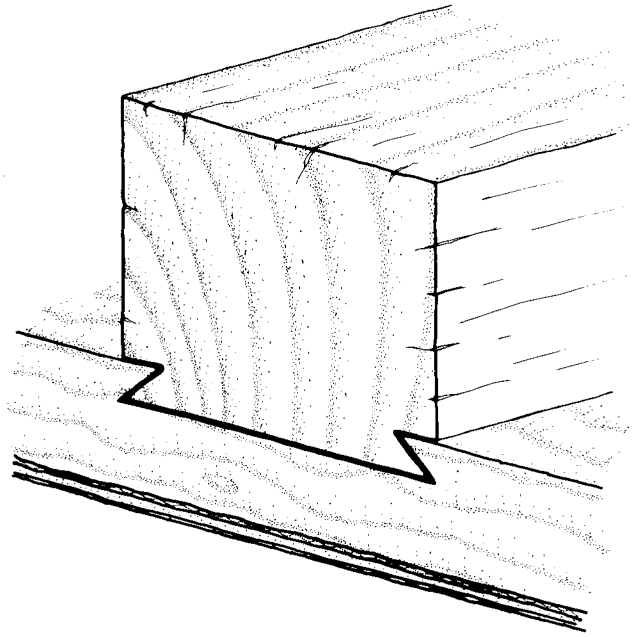


Figure 24
Schematic drawing of a typical dovetailed crossbeam with rectangular cross section.

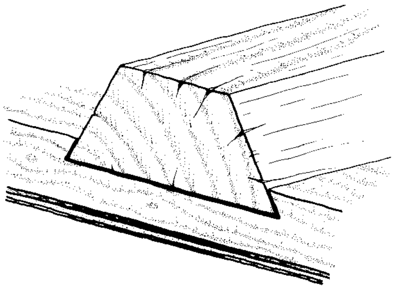


Figure 25
Schematic drawing showing typical fitting of dovetailed crossbeam with trapezoidal cross section. Crossbeams were often tapered to provide a snug fit.

collections throughout the world. The connections between the sections of the altarpiece were made by means of lateral dowels and an ingenious system of interlocking battens, possibly pegged with wood dowels (Fig. 26).[36] Two other rare examples of panels with intact, original, interlocking battens can also be cited: a small altarpiece by Bernardo Daddi, dated 1344 (Spanish Chapel, Santa Maria Novella, Florence), and a polyptych by Taddeo di Bartolo, dated 1411 (Pinacoteca, Volterra).

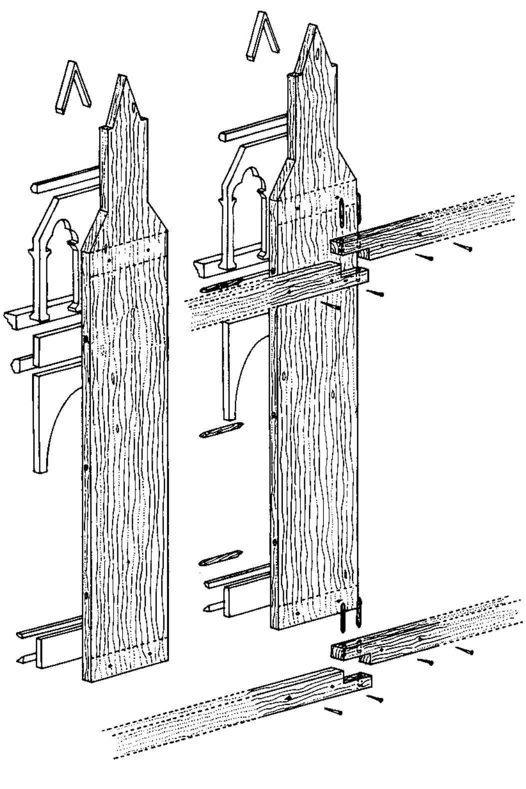


Figure 26
Ugolino di Nerio, fragments from the *Santa Croce Altarpiece,* National Gallery, London. Drawing showing the construction of a vertical unit of a polyptych.

The back side of the panel

While the back sides of many panels are often painted, finished, or treated in some way, the backs of others show no evidence of previous surface treatment or painting. This condition may have been a deliberate decision or simply a loss over time of the original treatment.

Aesthetics of the back side

Some panels, particularly crucifixes, were decorated on the back side because they were intended to be seen from both sides because of their placement (on iconostases, for example) or use in religious ceremonies. With other panels, the back sides have been carefully finished and shaped, even though they probably were not intended to be as visible to the public as was the main painting. This treatment indicates an intention to create a work that would be lovely in itself.

Other panels were occasionally painted on both faces. In some cases, the two faces held the same "rank" (e.g., Beccafumi's *Cataletto* or Duccio's *Maestà* in Siena, which was sawn across its thickness in the eighteenth century). In other cases, the painting on the back face served more as decoration and was possibly made by another artist. Examples include Raphael's portraits *Agnolo Doni* and *Maddalena Doni,* which bear monochrome paintings on their back faces, possibly by a disciple of Raphael; Piero della Francesca's portraits *Federico da Montefeltro* and *Battista Sforza,* which bear the *Trionfi* on the back; and a large triptych (347 × 393 cm) by Rossello di Jacopo Franchi that bears a gesso ground layer on the back with a painted geometrical decoration simulating polychrome marbles, suggesting that it may have been part of a chapel (Dal Poggetto 1981). From the technological point of view, such double-face panels are more stable because of their mechanical and hygroscopic symmetry (Uzielli 1994). The crossbeams, if they exist at all, are confined at the periphery of the support and possibly include the frame, or they may simply be part of the decoration.

Some of the surface treatments of the backs of panels that are discussed below fulfilled an aesthetic function as well.

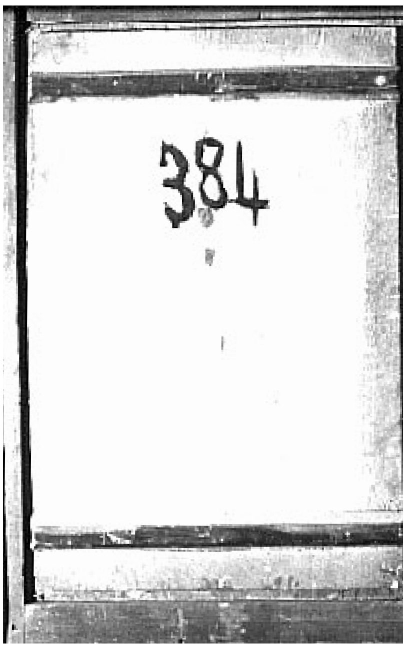


Figure 27
Beccafumi, *Trittico della Trinità,* reverse, detail. Pinacoteca Nazionale, Siena. The back of a panel covered with the original gesso grosso ground.

Surface treatments of the back side

The back sides of panels were sometimes smoothed and treated with certain substances to obtain various results, which might have included the slowing of moisture exchange, protection from the accumulation of dust, preventive action against insects, or an aesthetic finish. As for other features of the supports, treatment of the backs (and of the edges of panels) was generally more frequent and careful in the earlier than in the later centuries.

A number of substances were used for treating the back face. These included a gesso grosso ground layer, which enhanced the symmetry between the two sides, hence improving dimensional stability and the flatness of the panel (Fig. 27). A superficial layer of red lead (i.e., minium-red tetroxide of lead that had both an aesthetic effect and a preservative action against insects) or white lead (basic carbonate of lead), with glue or oil used as binding agent, was also employed, as were earth pigments.[37]

It should be noted that the mixtures of waxes occasionally found on the back of some panels (penetrating the wood only up to a limited depth) have perhaps been applied in later conservation attempts.

Engaged frames

When engaged frames served as integral parts of the support, the implications were structural as well as aesthetic (Cammerer 1990). Structurally, the engaged frame offered a substantial contribution both to the strength and rigidity of the support and to the lateral sealing of the panel. Such sealing in turn acted as a moisture barrier by slowing down rapid variations in humidity and protecting against the egg laying of wood-boring insects. The cross-sectional detail of the engaged frame of Duccio's *Maestà* shows how the thickness of the engaged frame is the result of two overlapping poplar moldings, while two outer moldings serve as lateral sealing (Fig. 28).

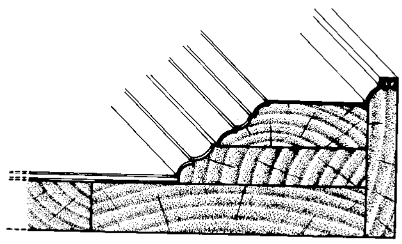


Figure 28
Drawing showing cross section of an engaged frame. Duccio, *Maestà*.

Conclusion

Art-historical studies, technical analyses, conservation, and restoration should unite to further the understanding of works of art. Restoration presents an occasion during which this unity may be fully understood, because of the imperative yet apparently contradictory requirements to both respect and restore the original integrity of the work (Baldini 1992a). In this regard, it has been shown that collaboration among these various disciplines best serves the long-term interest of the work of art (Ciatti 1992).

An important attribute of today's artisans in Florence is their awareness of their connection with the artisans and artists who conceived and made the panel paintings in the Florentine *botteghe* so many centuries ago. Indeed, when faced with a particular problem, they often ask themselves, How would I have done this work or solved this technical challenge, had I *myself* been faced with the original problem? The concepts discussed in this article, therefore, owe a great debt to the past, as well as to the many restorers, artisans, art historians, and fellow scientists (truly good and experienced friends) who have contributed to the technological knowledge of panel supports outlined in this article. The author is indebted to more people than can be mentioned here, fellow Florentines who still maintain continuity with the great masters of our tradition.

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Notes

1 Marette (1962) considers that with regard to the study of panel supports, peninsular Italy may be divided into eight main areas: central Italy (Umbria and Foligno), Emilia-Romagna (Bologna, Modena, and Ferrara), Florence, Marche, Pisa-Lucca, Rimini, Rome, and Siena. In this context, the numerous towns and workshops, or *botteghe,* in central Italy (which includes present-day Tuscany, Umbria, Marche, and Latium) may have been most influenced by the techniques developed in Florence and Siena.

2 In Giotto's *Crocifisso di Santa Maria Novella,* the cloth glued on the panel is coarser than the one glued on the engaged frame, the latter being thinner so as to better follow the molding (Bracco, Ciappi, and Ramat 1992).

3 The three main species of poplar—white poplar, *Populus alba* L. (Italian: *pioppo bianco, gàttice, alberaccio*); European aspen, *P. tremula* L. (Italian: *pioppo tremolo, alberello, farfaro*); and black poplar, *P. nigra* L. (Italian: *pioppo nero*)—as well as several hybrids, have been present throughout Italy since ancient times. The presently cultivated poplars are mostly hybrids, such as *Populus euramericana* [Dode] Guinier, derived from crossbreeding with North American black poplars imported to Europe in the eighteenth century.

The Lombardy poplar (*P. nigra cv. italica* Du Roy = *P. pyramidalis* Roz [Italian: *pioppo cipressino, pioppo piramidale*]) is a clone of *P. nigra,* which apparently originated through a spontaneous mutation. This clone is frequent in northern Italy (hence its English designation, Lombardy poplar), and since male individuals are the vast majority, it is propagated only from cuttings. The woods of all these poplar species are quite similar and cannot be distinguished by anatomical examination. However, it is likely that most boards used for panel making were obtained from *P. alba,* which generally produces wood of better quality.

4 Marette reports data and statistics for more than 1800 panel paintings from various museums (Marette 1962). Gettens and Stout give a summary of woods made from the catalogues of the Munich and Vienna museums, with a few items from the catalogue of the National Gallery, London (Gettens and Stout 1966).

5 The microscopical identifications were performed by the author's late colleague Prof. Raffaello Nardi Berti (Nardi Berti 1984).

6 Cupping is a particular kind of warping caused mostly by anisotropy of shrinkage—that is, by greater shrinkage in the tangential direction than in the radial (Buck 1962, 1972; Thomson 1994; Uzielli 1994).

7 Castelli and coworkers state, however, that exclusive use of radially sawed boards was typical of the most careful works (Castelli, Parri, and Santacesaria 1992).

8 The pith is seldom perfectly straight in poplar logs, so it seldom affects the whole length of the diametric board. Furthermore, its occurrence (although constituting a zone of weakness, occasionally generating longitudinal fissures) will not necessarily imply a dramatic and complete separation in the board.

9 According to Castelli and coworkers, such a choice may be explained by the fact that wood placed nearer to the pith (possibly assumed to coincide with the heartwood) was considered to be of better quality. As a consequence of seasoning, since the cupping convexity becomes oriented toward the "inner" face, the application of the ground to that face should ensure a better "grip" (especially during its application, when its high water content makes the wood swell and then dry again) (Castelli, Parri, and Santacesaria 1992).

10 Defects produce local differences in shrinkage that often result in greater damage to the painted layer in their vicinity. Because local wood defects were seldom a direct cause of a general or widespread deterioration of a painting support, the acceptance of boards with some localized defects may have been a reasonable choice, considering that negative effects could be prevented easily by appropriate techniques (e.g., the gluing of a layer of cloth between the boards and the gesso).

11 Because of obvious geometrical relationships, if the "inner" face of the board is oriented toward the painted face, wane will appear on the rear face. If, on the contrary, the growth rings are oriented so that wane is toward the painted face, the wane will need to be "repaired."

12 The presence of sapwood may not be considered a defect in itself, especially in species in which heartwood is not distinct, such as poplar, linden, and fir.

13 For instance, Del Serra stresses this possibility for the support of Cimabue's *Maestà* (Del Serra 1994). Many Florentine panel restorers use the expression *legno frollo* ("tender wood") to describe partially decayed wood. This expression applies to the early stages of fungal decay, during which the strength properties of the wood are only moderately affected, while shape is retained and hygroscopic stability is higher.

14 According to established experience (which is basically the same today as during the Renaissance), good natural seasoning practice may require years for boards to reach a satisfactory absence of moisture gradients and settling of internal stresses. The specific number of years required varies with wood species and their particular permeabilities.

15 This is supported by the fact that given the typical climate in the area, natural seasoning (i.e., the traditional drying process, by which boards are stacked and left exposed to natural environmental conditions) would have hardly produced a lower EMC. Lower EMC values (around 10%) reached by the paintings that were later kept in heated buildings (after transfer to heated houses or museums, or after heating plants were installed in their original locations) usually led to severe shrinkage (Uzielli 1994).

16 When a support is exposed to humidity fluctuations, a greater thickness of boards contributes to its dimensional stability, since the consequent MC fluctuations in wood are slowed down (damped) by the time required for moisture to move into the deeper layers.

17 In many cases, the current thickness of boards differs from the original one. This difference is due to thickness reduction for cradling, rebacking (usually in the case of severe wood decay, or to remedy the warp), sawing along the central plane to obtain two separate paintings from a double-faced panel, or other kinds of intervention, intended either for conservation or for cosmetic purposes.

18 During recent restoration works performed by Del Serra in 1993–94, the rear surface of Cimabue's *Maestà* (226 × 387 cm) was found to be cambered (cylindrically shaped), measuring 58 mm thick along its central longitudinal axis and growing progressively thinner in a symmetrical fashion to the two lateral edges, 40 mm thick. This shape is clearly the result of the original manufacturing process, since—after removal of the nineteenth-century crossbeams—there were a number of features to indicate that the present surface is the original one, including some remnants of a possibly original red tempera on the surface and red lines made with the string-snapping technique across the panel width, marking the alignment of the nails that connected the original crossbeams.

19 Such a rare feature is characterized by boards becoming progressively thinner from the center to the lateral edges of the panel; it should not be mistaken for the beveled edges that appear frequently in Flemish panels (typically made of radially cut oak boards and thinner than the Italian panels) and that are intended to allow for an easier fitting of the panel within its frame.

20 In some instances, the edging process might leave some wane, particularly when there was a need to take advantage of the maximum possible width of the board.

21 Tack is the property (present in some modern vinyl resin adhesives but not in casein glues) that holds the parts to be joined together while the adhesive is still fresh.

22 Many observations of disassembled supports, as well as expert opinion, confirm that splines fulfilled an alignment function only and were not intended to support or reinforce the connection.

23 X-shaped cleats (*tasselli a doppia coda di rondine,* "double dovetail cleats"; or *farfalle,* "butterflies") were usually mortised into the boards as deep as one-half of the board's thickness, with their grain running crosswise to the board's grain, to hold adjacent boards or parts of a fissured board tightly together.

24 In polyptychs, predelle were often painted on horizontal boards, whereas other sections were on vertical boards; polyptychs should not be considered as single panels, however.

25 On the contrary, Bomford and coworkers report two relatively small painted crosses made from vertical boards by the Master of Saint Francis. The work (92.1 × 71 cm) in the National Gallery, London, was cut from a single plank of poplar, whereas the side terminals of the one in the Louvre were constructed separately and then attached with wooden dowels (Bomford et al. 1989).

26 The need to "hold together" the panel does not exist only while it is on display and therefore subject to the stresses imposed by its own weight and other internal or external static stresses. Other situations—such as transport, earthquakes, explosions, etc.—may impose exceptional stresses on panels. Del Serra describes damages, possibly due to transportation, found on Duccio's *Maestà* (Del Serra 1990).

27 Nailed joints do not behave in the way that some widespread but incorrect ideas suggest. Joints perpendicular to the nail axis may yield significantly, both because of bending of the nail shaft and because of the give of the wood (low strength perpendicular to the grain). When appropriately clinched, however, they will resist large pullout forces. Thus, nailed crossbeams restrain somewhat the transversal shrinkage and swelling of the panel and at the same time prevent it from warping (detaching from the crossbeam) (Uzielli 1994).

28 Preboring of nail holes was carried out in at least the first of the two parts to be joined, in order to to guide the slender nail correctly (the nail was prone to deformation, especially at its thinner point) and to prevent fissures from forming in the seasoned wood.

29 Even though evidence shows no general rule, Castelli and coworkers report that two or three nails could be driven into each board, depending on its width. Nails could be either inserted from the back, in the more complex back frames such as the "lattice structures" of large crucifixes and altarpieces, or inserted from the front, in polyptychs; in some supports, the crossbeams were placed along the edges (making it possible to cover nails on the front face with engaged frames and predelle) (Castelli, Parri, and Santacesaria 1992).

30 Wooden plugs and plaster proved to be the best insulation against rust, since neither parchment nor cloth proved able to block rust. Parchment also proved to be an unstable basis for the ground layer.

31 See Buck 1972; Castelli, Parri, and Santacesaria 1992; and Uzielli 1994, among many others. The use of sliding crossbeams rather than nails is an attempt to provide adequate freedom for the panel to undergo shrinkage and swelling without generating concentrated and potentially harmful stresses.

32 Glued joints are stiffer; nailed joints are more yielding. If a joint is both glued and nailed, during its normal working life it will not differ from one that has been glued only; the presence of nails will not increase strength or stiffness.

33 Even more than in the case of the "sliding" crossbeams, the property of sliding applies for only a limited number of the dovetailed crossbeams. In fact, the higher contact pressure produced by the inclined walls of the dovetail and by the longitudinal taper generate even higher friction, which opposes sliding.

34 Obviously such action will hold only as long as the edges of the mortised groove—the weakest part of the system—are not damaged by insect galleries, decay, or pure mechanical stress. Evidence shows that many of these grooves, whether original or made during later restora-

tion, are much more damaged along the upper margin, possibly because of fungal decay associated with the accumulation of dust and the condensation of moisture.

35 In exceptional cases, a longitudinal distortion (bow) that increases as the MC of the wood decreases may be produced in the panel by forces exerted by the crossbeam along the panel's length (Allegretti et al. 1995).

36 The terms *crossbeam* and *batten* are synonymous. Bomford and coworkers use the term *cross-batten* (Bomford et al. 1989).

37 A few examples include Giotto's *Maestà* and *Crocifisso di Santa Maria Novella* and Cimabue's *Maestà,* which still show the remains of red color; in the case of the latter, the red color remnants (possibly an earth pigment) were instrumental for reconstructing the size and location of the no-longer-existing cradle. Another example is Leonardo's *Adorazione dei Magi,* which is coated so thickly with white lead on the back face that an X-ray inspection of the artwork proved impossible (Baldini 1992b).

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Wooden Panels and Their Preparation for Painting from the Middle Ages to the Seventeenth Century in Spain

Zahira Véliz

SPANISH TECHNIQUES in the plastic arts possess a pedigree unique in western Europe. In Spain the technology of movable works of art, architecture, and urban planning was influenced by the legacy of Islamic culture as well as by practices and traditions originating in Italy and the Gothic North. Islamic prohibitions on recognizable images meant that Muslim artisans understandably had little impact on painted images; even so, the methods of joinery and traditional understanding of wood manifest in Islamic architecture and decorative arts surely informed the techniques evident in painted panels and altarpieces. The climate and materials indigenous to the Iberian Peninsula also affected panel making. This article will discuss the technology of wooden panels and their preparation for painting in Spain from 1400 to 1700 C.E. Contracts and other documents from this period are cited.[1]

Contracts

Perhaps more than elsewhere, retables in Spain (with their integral panels or sculptures) were produced as corporate enterprises. Contracts were often complex documents with subcontracting specifications. Included were the dimensions, type of wood, iconographical subjects, price, time limits, and terms. It was common practice for a master painter to undertake responsibility for all aspects of a large job that he might subsequently subcontract to other specialists. In some cases, there is evidence that even the painting of panels was divided between two different workshops (Navarro Talegón 1984:330). Occasionally the job carried a warranty: "Item, it is agreed that if by chance the retable or part of it loosens [from the wall] or sustains any damage from being badly installed, if for some reason that is the fault of the painters, that they are responsible for damages during six years from its installation if the painters [guild officials] declare that it is needed" (Serrano y Sanz 1914:447).

Clearly, using top-quality materials and techniques was important in a legal climate where such statutes were known, even if they were not actually commonplace. Nevertheless, damage did occur, and when the original artists were no longer available, other painters would turn their hands to restoration, as did the Catalan painter Francesc Feliu, who in 1412 "patched cracks, touched up faded colours, and repaired Jesus's mantle" in the retable of the chapel of All Saints in Santa Maria of Manresa (Sobré 1989:46, n. 59).

The carpentry of the panels and retables was executed in several ways, and local custom varied slightly. In Aragon the carpentry was often carried out in the artist's studio. Elsewhere it was finished prior to the painter's contract (Sobré 1989:35). Separate contracts for painting and carpentry were also frequent, as was the widespread practice of subcontracting the carpentry. In most situations, one can assume that the painters had considerable say about the standards to which their panels would be prepared. The importance given to the quality of work at this stage is underscored by a clause in a contract dated 1561: "Item that [they] are obliged to show all the pieces of the altarpiece once they are worked and clean and prior to applying any colour to any piece, and this is done so that persons named by [the client] can see the work" (García Chico 1946:95).

Woods Used for Painting Support

Wooden panels in Spain, as in other western European countries, were made principally from locally available woods, although, of course—considering the active political and commercial contacts with the Low Countries—panels were fairly frequently imported. Within Spain regional characteristics become evident, with pine predominating in Castile and Aragon, poplar in Catalonia. Walnut is found occasionally in Castilian panels, as is (much more rarely) Spanish oak. The use of thuja (red or white cedar, also the source of sandarac) in Europe seems unique to the southern quarter of the Iberian Peninsula. There is one documented example of Flemish oak having been imported for a specific commission, Lluis Dalmau's *Virgin of the Councillors* (Sobré 1989:51, 288–91). Many panel paintings of the school of Viseu in Portugal are painted on chestnut (Marette 1961:52–53, 67–69). Contracts reflect practical concern for the quality and suitability of the wood—its hardness, ease of working, and freedom from knots, veins, stains, and other defects. The importance of the commission and the client's wealth also influenced the type and quality of wood employed.

The age and dryness required of the wood for retables and panels is frequently specified in the contracts: the retable "must be dry pine from Soria, good and dry, and the figures and columns of wood from Ontalvilla and the said wood must be dry pine from Soria as is said, dry for at least six years" (García Chico 1946:156). In Castile "pine from Soria" is often mentioned, and sometimes exact localities are named, such as Ontalvilla, Cuéllar, San Leonardo, or Quintanar de la Sierra. Occasionally wood from distinct sources is designated for different purposes: "[The architecture] should be of pine wood from Soria, dry and good . . . and the histories [panels?] and sculptures can be of local pine" (García Chico 1946:73). Occasionally even the time of cutting is stipulated, as occurs in a contract of Gregorio Hernández for the construction of the high altar retable of Las Huelgas Reales in Valladolid: "It is a condition that all the wood for the said sculpture must be from Ontalvilla, dry and clean, free of knots, white, not dark wood, and cut in a good moon" (García Chico 1946:160).[2]

Panel Construction

Once the appropriate wood was selected, the assembly of the panels proceeded in a variety of ways. Although most panels of any size were usually joined, the following passage indicates the desirability of single-member panels: "All the retable must be made of walnut and no other wood, and the walnut must be good, dry, and having been cut for as long a time as possible, clear of knots, even if it must be brought from outside Valladolid. . . . And the histories and saints must be made of single pieces . . . should joins be unavoidable, they must be as few as possible for the greater perpetuity of the work" (García Chico 1946:86).

The planks, whether destined to be joined or used as single-member panels, were cut, sawn, and planed with considerable thickness, 3–4 cm being quite common. On the reverse of many panels, the marks left by the planes and gouges are still apparent. The most common joins were butt joins, apparently sometimes without a glue adhesive between the panel members (*juntas vivas*). Butt joins are frequent in panels from the fourteenth to the seventeenth century (Prieto Prieto 1988:201). Concern about the long-term stability of panels joined in this way must have prompted the practice of reinforcing the join. The simplest method was caulking or plastering over the joins with the filling compound used to make good any uneven places on the wood surface, pressing it through gaps in the joins and forming a ridge at the reverse of the panels, effecting a kind of solder (Fig. 1). This procedure was considered so important that standards about panel preparation were included in the *ordenanzas* (ordinances governing civic guilds and commerce) of Cordova (1493) (Ramírez de Arellano 1915:25–36) and mentioned as well in the ordenanzas of Granada (early sixteenth century) and Seville (1632).[3] The earliest text from Cordova is the most specific: "It is further ordered and required that the retables of painted panels should be worked in such a way that all the joins of the panels, and any other cracks whatsoever are caulked[4] and afterward well primed with parchment glue. This glue must be made by a master who has great knowledge in its temper and cooking because it must be very well tempered and heated in the right way" (Ramírez de Arellano 1915:38).

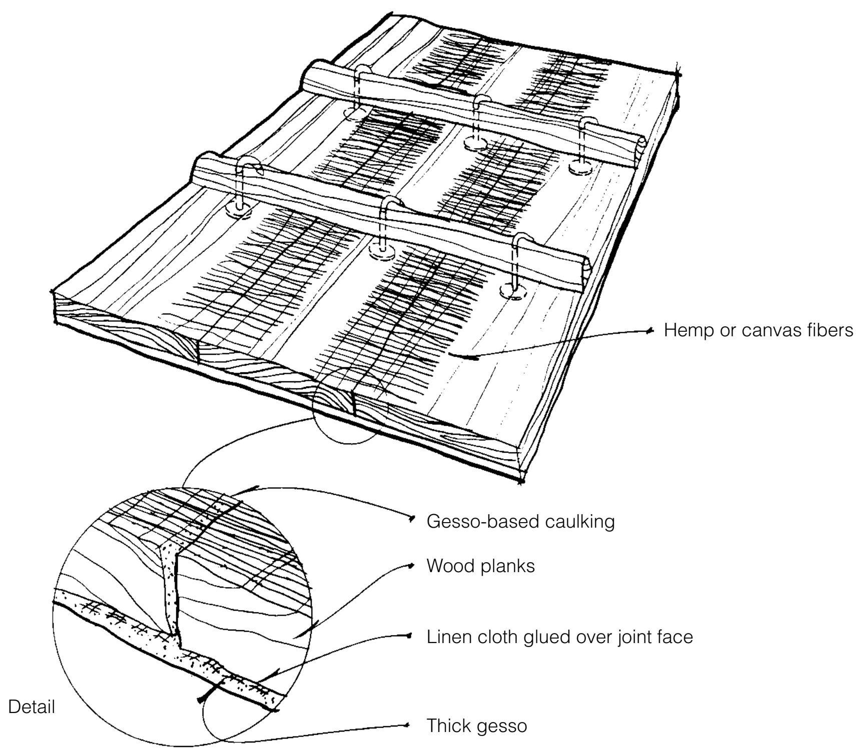


Figure 1
A pine panel prepared for painting in Castile.

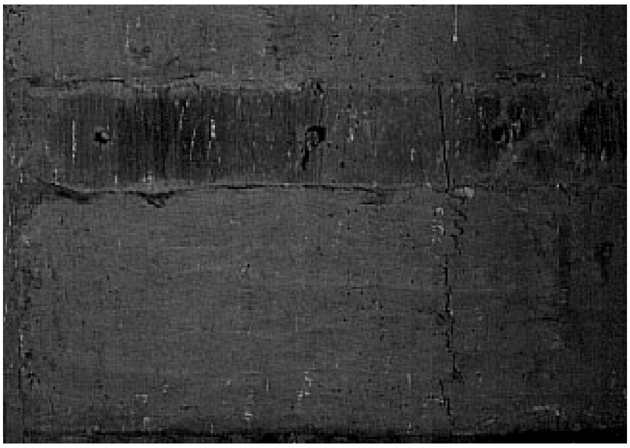


Figure 2, above
Luis de Castilla, *Crucifixion of Saint Andrew,* ca. 1530. Reverse. Oil on panel, 120 × 140 cm. San Lorenzo el Real, Toro, Zamora, Spain. The use of dowels to affix the crosspieces is shown.

Figure 3, above right
Anon., ca. 1580, reverse. Oil on panel. Toledo, Spain. A crossbar engaged in a channel across the grain direction on the back of a pine panel. Randomly applied hemp or flax fibers are visible.

In addition to the universally popular butt-joined panels, dowelled joins, butterfly lap joins, and plain lap joins have been noted (Prieto Prieto 1988:270; Marette 1961:52–53, 67–69), although sound technical studies of Spanish panels are scarce, and the works documented so far form a largely haphazard sample.[5]

Most Spanish panels are reinforced by crossbars and additionally by the application of canvas or vegetable fibers (such as esparto grass) and gesso to either side or both sides of the panel. These materials are used in combination or separately and will be discussed below.

It is fair to surmise that crossbars (*travesaños*) were recognised as important to the long-term stability of the panels as they are frequently mentioned in the contracts: "It is a condition that the painting must be on the church's account . . . and [the church] must provide the panels with their crossbars" (García Chico 1946, vol. 2:312). "Furthermore, the wood must be of good quality . . . the panels will also have good crossbars . . . and [the panels] will be well fixed and maintained by them" (Madurell Marimón 1946:151). In the simplest method, crossbars on the reverse of the panels are fixed by nails pounded through from the face in a cross-grain direction and clinched against the back surface of the crossbar. Very common also was the use of dowels to hold the crossbars to the panels, sometimes in addition to nailing. A variant of this method provides a shallow channel in the reverse surface of the panels that engages the crossbar (Figs. 2, 3).

The use of two to three simple crossbars is most typical of Castile (Fig. 4). From the final third of the fourteenth century, more complex

Figure 4
Anon., ca. 1540, reverse. Oil on pine panel. Church of San Lorenzo, Toro, Zamora, Spain. Heavy crossbars secure the vertically joined pine planks. Esparto grass fibers cover the joins.

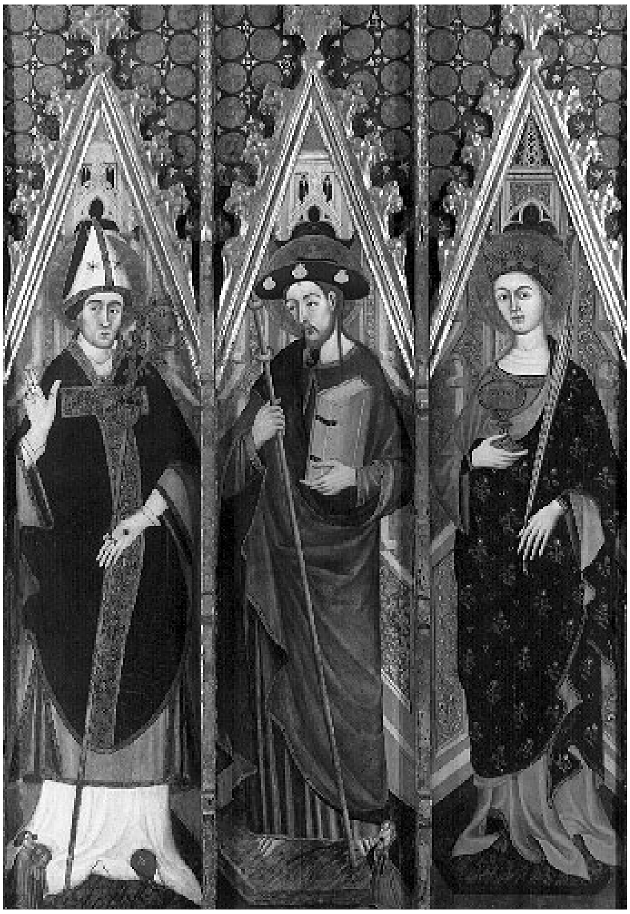
crossbar arrangements, such as diagonal crosses or grids, were common in Aragon, Catalonia, and Valencia, especially for large panels or panels meant to be viewed as a series (Figs. 5, 6). In Valencia a single horizontal crossbar secured the center of the panel, with additional planks radiating, spoke fashion, above and below it. In Aragon a central vertical bar was flanked by several symmetrical horizontal members (Sobré 1989:52).

Additions to the Panels

Although reinforcements such as linen or hemp (cloth or fibers), with or without gesso, are known in all European schools of painting, these materials are most abundant in the preparation of Spanish panels. Linen, like hemp, can be found on both the face and the reverse of panels. When used on the face, it is not infrequent to find the entire surface of the panel covered, while on the reverse it is normally applied in strips to bridge a join. Hemp cloth, similar to burlap, is used in the same way. It is also common to find coarse hemp or flax fibers (*estopa*), sometimes applied across joins only and sometimes distributed in an even, multidirectional layer over the entire face (or, indeed, reverse) of the panel prior to the application of gesso.[6]

The contracts are specific about the use of the additional reinforcements as part of the preparation of the panels for painting. In 1518 the painter Pedro Núñez signed a contract in which he promised to make the retable of wood: "All of it will be caulked [*plastecido*], and the joins will

Figure 5, below
Maestro de Torá, *Three Saints,* early fifteenth century. Oil on panel.



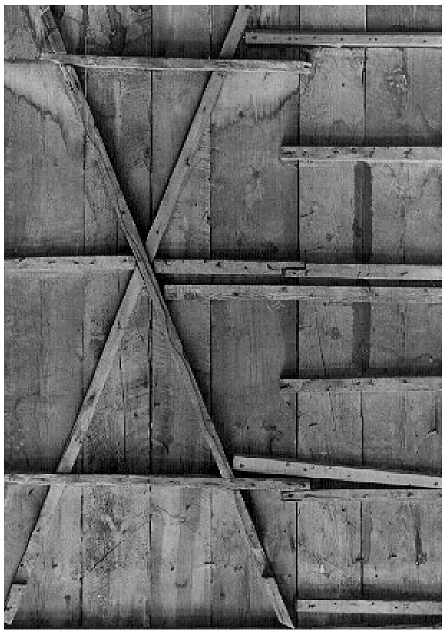


Figure 6, above
Maestro de Torá, *Three Saints,* reverse. The two donor panels are joined together by reinforcing crossbars (diagonal and horizontal) nailed through from the front of the panels prior to painting. The painted panels are fitted together vertically by lap joins and by means of the notched horizontal crossbars.

be covered with linen wherever it shall be needed" (Madurell Marimón 1944:155, 166, 205). In 1570 a contract between a patron and the painter Juan Tomás Celma states that "firstly, the said Juan Tomás and his wife promise that they will cover and reinforce with hemp and linen all of the gaps and fissures to be found when the wood of the said retable is worked, and where necessary over the joins, and then they will prepare [the pieces] with all care and tidiness and delicacy" (García Chico 1946:166). Two further brief references clarify, first, that the canvas was applied to the panel after the first glue priming: "After one application of glue to all the wood, the joins and splits must be covered with strips of linen and strong glue [*cola fuerte,* carpenter's glue]," and, second, that canvas strips should be applied to the joins with cola fuerte in the altarpiece of Santa Cruz in Medina de Rioseco, because "it is necessary so, because only caulked, [the joins] are not secure" (García Chico 1946:372, 154).

It is impossible at present, on either empirical or documentary evidence, to determine a preference for grass fibers or woven cloth for covering joins or knots or other faults in the panel. However, it can be affirmed that in contracts, linen is mentioned more frequently for use on the face and hemp fibers for use on the reverse. Personal preference on the part of the artist, as well as local custom, seem to have been the determining factors.[7]

Francisco Pacheco, whose seventeenth-century treatise *El arte de la pintura* (Pacheco 1965) is one of the most useful sources for Spanish painting techniques, writes on these measures with some critical perspective. In the seventeenth century the use of panels in Spain, as elsewhere, was diminishing. His comments are far more informative than the tersely worded contracts:

> Nowadays gilders avoid covering the openings and joins between pieces of wood used for architecture and sculpture because it seems to them that nothing can be done to prevent the wood from opening. At first glance, the use of linen pieces seems to be unnecessary, but I will state my feeling about this, telling the truth as I see it. It is certain that painters before our time had great interest in preparations and gilding, as is seen in many of their works. Also, they put great care into the applications of these pieces of linen, hoping to prevent the inevitable opening of joins. I concede that it would be better to repair large openings and joins by fastening them with thin [butterfly] wedges of wood and strong glue; but this does not excuse entirely the use of linen as it is still useful in some places, although the pieces must be new and strong enough to stay in place, and they must be firmly fixed down at the ends. They may also be placed over the wedges, adding strength to strength, and plastering them down by going over them with the large soft brush [*brocha*] when applying the first layer of gesso [*yeso grueso*], and making it as level to the wood as possible. Also, all the joins on the reverse of the panels must be covered with hemp even if they have cross-bars . . . some also like to add [hemp] to the front. Others, in Castile, apply hemp over the whole panel, and, after putting on three or four layers of gesso [yeso grueso], they give [the panel] a thick layer of fine gesso [*yeso mate*] with a spatula. Earlier painters covered the fibrous strings with linens and applied the preparation on top, but this is [now] unnecessary, since nowadays cedar or chestnut wood is used for panels, and it is enough to apply the fibers on the reverse.[8]

Preparation Layers

The degree to which the durability of a painting was thought to rely on the preparation is evident in a contract of 1585: "Firstly, it is a condition that the altarpiece and the tabernacle [*custodia*] are to be prepared according the the custom of the master painters in such a way that it fails not, but rather will survive in perpetuity, and otherwise [the painter] must make it again at his own expense if there should be any damage arising from fault in the preparation" (García Chico 1946:153).

The application of glue-based preparation layers to the panels was a complicated affair and one on which importance was placed not only in the contracts but also in the *ordenanzas de pintores* (civic regulations governing trade), if we are to judge by the example of the ordenanzas from Cordova already mentioned. Much attention to the isolation of knots and the resin they could produce is evident in contracts and even merits detailed commentary from Pacheco: "Pine is the wood ordinarily used for architecture and sculpture. It tends to weep resin, particularly from its knots, which are very large. At times, the resin even penetrates the preparation. Experience has taught that the best remedy to avoid this danger is to cover the knots with pieces of linen and very strong paste-glue [*engrudo*] after applying the glue with garlic [*gíscola*] and to make the preparation over this as it is not enough to have punctured, burned out, and gone over the knots with garlic" (Véliz 1987:86). Attempts to prevent such staining indicate that the white pine, free of knots and so prized in Castile, cannot always have been available, since painters sometimes had to deal with knots in this way.

One or several layers of parchment size or other fine glue size were applied over the wood. Contracts and guild regulations suggest that mastery was needed to achieve the successful tempering of the glue mixtures, but since both strong and weak glues are recommended in various documents, it is best to agree with Pacheco that some masters preferred a strong glue, others a weak one. He tells us, though, that whatever its strength, the glue had to be applied very hot (Véliz 1987:86–87). The first glue layer applied to the wood was frequently prepared with garlic (gíscola). The precise purpose of this additive is undocumented, although it is possible to hypothesize that it served not only to lower surface tension but also to act as a fungicide.

After the first glue priming, the linen or hemp cloth or fibers would be applied and then soaked with stronger glue. Although these were the most common materials, parchment (used in conjunction with hemp fibers) is named in a contract dated 1477 (Sobré 1989:53). The panel would then be ready for the preparation layers.

Gessoes were formulated in Spain, as they were elsewhere, with either calcium carbonate or calcium sulphate, depending on the region; calcium carbonate was more common in Castile, calcium sulphate more common in Valencia and Andalusia (Sobré 1989:53). The most detailed account of the application of gesso layers comes from Pacheco, whose comments generally reflect local practice, although his writing is clearly informed by such sources as Cennino Cennini (author of the fifteenth-century *Il libro dell'arte*) (Cennini 1954). He tells us that "the first layer of gesso [yeso grueso] should be applied hot, not too thick . . . up to four or five layers (but never more than these) . . . the yeso mate should be applied with the same glue as the yeso grueso . . . I say it can be the same as the grueso because the thinness of the yeso mate moderates the strength of the glue" (Véliz 1987:66). A further warning is given when he says, "Some think it a good idea to add a little table oil to the yeso mate, especially in winter. . . . I've also seen good gilders add linseed oil to avoid the bubbles the gesso tends to make. In my preparations I would never use either the one or the other" (Véliz 1987:66). In the contracts it is not unknown to find the number of layers of yeso grueso and yeso mate specified: "The painters must prepare all of the retable twice with fine gesso [*guix groso*] and twice with gesso [*guix primo*] very well tempered so that the gold will be very brilliant" (Sobré 1989:53, n. 17).

Advice also emerges from documents and treatises about the best time of year for certain preparations; adaptations for hot, cold, or dry weather also appear. In a contract from 1569 for the *retablo mayor* of Astorga, the season of the year for preparing the panels is stipulated: "And so that the said work is long lasting and permanent they must prepare [the panels] in the season that is necessary and most appropriate, which is in the eight months of winter, two before [the season of] the Nativity and two after, and the said preparation must be made with great care" García Chico 1946:112).

Pacheco advises that the glue priming (gíscola) should be more strongly tempered in winter and comments that in cold places such as Castile, León and Burgos, and Valladolid and Granada, the glues are generally more strongly tempered. He adds that in wintertime the painters from these places gild with red wine in place of water and that they also sometimes add linseed oil to the yeso mate (Véliz 1987:86–87).

Most references to applying the yeso grueso and yeso mate suggest that the ground was applied in a liquid, brushable consistency and subsequently scraped and smoothed when dry. Pacheco describes a Castilian practice in which, after an application of three or four layers of yeso grueso (with a brush), thickened yeso mate is spread on with a trowel (Véliz 1987:86–87). Perhaps this use of thickened or gelled yeso mate has contributed to the notable thickness of Castilian preparation layers.

The final smoothing of the preparations of yeso grueso and yeso mate was accomplished with small, even-bladed knives (*escaretas*), which as early as 1493 were recommended in preference to *lija* (usually interpreted as sandpaper), although it is also possible that dry cuttlefish bone is meant (Ramírez de Arellano 1915:39). Pacheco also recommends a blade rather than lija for this purpose (Véliz 1987:88).

With increasing frequency, from the late fifteenth century through the sixteenth century, a colored priming was applied over the white yeso mate before or after the composition was drawn on the panel. A passage from Pacheco suggests that this was applied prior to drawing: "With lead white and Italian umber, make a color that is not too dark, and grind and temper it . . . with linseed oil. This is the priming. With a large brush, trimmed and soft, give the panel an even, all-over layer. After it is dry . . . it is ready to be drawn and painted upon" (Véliz 1987:67–68). Elsewhere a nearly transparent layer of gesso has been observed to "act as additional priming and to ensure that the underdrawing would not show through in the finished work" (Sobré 1989:55).

Underdrawing

References to drawing on panels are rare in the documents, although there is one interesting contract that required that the master, Jaime Romeu of Zaragoza, draw all the compositions on the narrative panels and the predella, and the hands and faces of all the figures had to be painted by his hand. The date of the contract is 1456—fairly early for such concern about authorship (Sobré 1989:38, n. 31).

Few infrared reflectograms have been published for Spanish panels, and this is an area of research that promises to be interesting. It is to be hoped that both the Prado Museum and the Instituto de Conservación y Restauración de Bienes Culturales (ICRBC) will continue the technical studies in this area that have appeared from time to time in recent years (Silva Maroto 1988:44–60; Garrido and Cabrera 1982:15–31; Cabrera and Garrido 1981:27–47). Features of Spanish underdrawings on panel include the frequent occurrence of rather bold, wide lines that seem to have been applied by brush, and the widespread use of written notations of color areas. In at least one case, an inscription that was to appear in the finished painting was recorded first in the underdrawing.[9] Certainly the carefully worked underdrawing associated with early Netherlandish panels is infrequent, at least in Castilian panels of the fifteenth and sixteenth centuries. This suggests a highly practical role for the drawing stage in the development of the painted image. Perhaps it also points to the use of studio pattern books that served as references for frequently repeated subjects, so that detailed drawings would not have to be worked up on the panel itself. Incised lines are occasionally evident, particularly for indicating planes in architecture or the lines radiating from a halo or dove of the Holy Spirit.

Assembly of the Retable

The delicate appearance of many retables, with intricate gilt tracery surrounding images painted with the saturated tones of oil paints applied over a white ground, gives no hint of the rough construction methods often used to hold these shimmering, glowing assemblies together. This is especially the case in fourteenth- and fifteenth-century Castile, where large retables were often fitted against a preexisting apse wall. First an armature of heavy beams was secured into the wall (Fig. 7). Pieces of timber were

Figure 7
Fernando Gallego, *San Antonio Abad,* 1496. Oil on panel, image approx. 35 × 90 cm. San Lorenzo el Real, Toro, Zamora, Spain. The unpainted margin of a painting on panel. The holes in the gesso margin were made by large nails used to hold a piece of molding in place. The panel is part of an altarpiece that has never been dismantled.

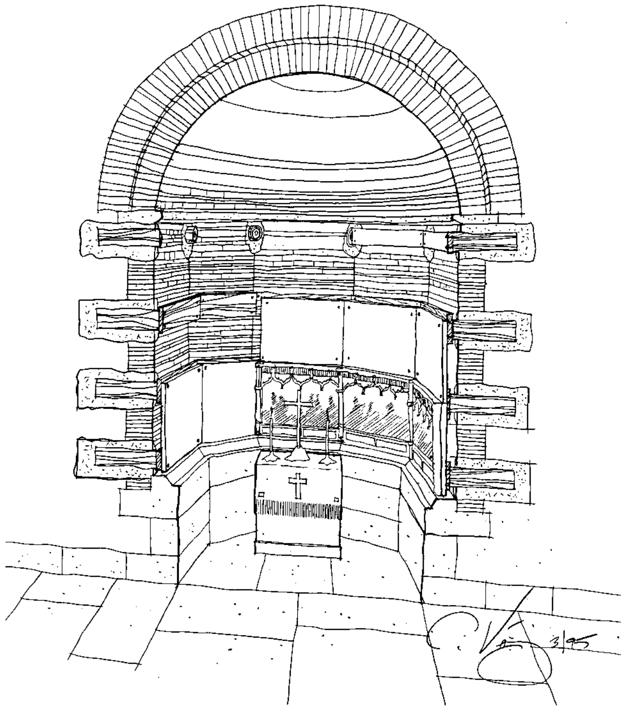


Figure 8
An altarpiece construction typical of Castile, ca. 1500.

fitted at right angles some distance into the wall; holes a meter deep are not uncommon. Rubble and plaster (or adobe) were used to secure the pieces into the wall; alternatively, wooden wedges were driven between the sides of the opening and the beam to make it fast. Into these timbers, which projected 15–30 cm from the wall, upright and horizontal beams were nailed, following the contour of the wall. Most panels destined for retables were not completely covered by the painted image; usually an unpainted margin surrounded the composition (Fig. 8). The margin would eventually be concealed by tracery and served the practical function of providing an area into which the panel could be securely nailed against the timber grid. Once the panels were in place, the tracery, columns, and canopies of the altarpiece were nailed onto the front of the paintings. For most large retables of the fifteenth and early sixteenth centuries, it is unlikely that the architectural elements had any real structural role; they were applied as embellishments to panels already nailed to the armature. It is interesting to note that the use of dowels was generally restricted to the joining of panel members and crossbars or the joining of two pieces of gilt tracery. For construction, large nails, not dowels, were used freely and allowed to remain visible. It was only in the second half of the sixteenth century that countersunk nails or dowels became important, with gesso and gilding obscuring the points of contact. By the seventeenth century, the use of nails for retable construction was almost unknown, and the large Baroque structures are very skillful examples of masterful joinery and gilding. Again, the contracts reflect this change in practice: "All of which must be made with pine from Soria, well dried, and it must be very well assembled and fitted, and nothing must be stuck on or nailed, but rather, everything must be doweled and joined" (García Chico 1941:283).

Even in the late sixteenth and early seventeenth centuries, after canvas had replaced the wooden panel as the most convenient modern painting support, well-crafted pine panels were still used extensively as backings for canvas paintings. This was a prudent measure used to "diminish the effect of our extreme climate"[10] on the paintings and also to render the canvases less vulnerable to damage once in place.[11]

Acknowledgments

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Notes

1 Unless otherwise noted, all translations of these documents into English are by the present author.

2 Presumably, cutting the tree in a good moon (*en buena luna*) is meant to ensure that the sap has not risen, a process that renders the wood more vulnerable to microbiological deterioration. Another interesting, though less pragmatic, possibility: The sculptor Gregorio Fernández was widely held to be divinely inspired when he worked. It is recorded that before carving a statue he prepared himself with prayer, fasting, and penitence. The finished works, especially those of Christ's Passion, were objects of exceptional reverence and extraordinary potency. Perhaps the stipulation of wood cut "en buena luna" has a ritualistic as well as a practical significance in this context. See McKim-Smith 1993:13–32.

3 *Ordenanzas de Granada,* sixteenth century. Biblioteca Nacional R. 31528, fol. 178. *Ordenanzas de Sevilla. Año de 1632.* Biblioteca Nacional R. 30376, fol. 162.

4 Although precise recipes for the material used for caulking have not been noted, it was probably a chalk putty, considerably thicker than the gessoes described elsewhere.

5 The most informative works known to the author are the fundamental study by Marette (1961) and, published more recently, the study by Sobré (1989). Also useful is the unpublished thesis by Prieto Prieto (1988). An admirable study of a late-sixteenth-century Castilian altarpiece provides complete technical documentation of the retable in all its aspects (Hernández Gil 1992).

6 In a document of 1602 recording the sale of the contents of the studio of the painter Martín de Aguirre, it is interesting to note the value of a small amount of hemp valued at one and a half *reales,* whereas one and a half dozen brushes fetched four reales. In the inventory of these studio contents also appear eleven panels for painting (*once tablas de pintar*). This property was held on deposit with a sculptor for several days prior to its auction. It is curious that the eleven panels for painting did not appear at the auction. The inventory and sale documents are published. See Navarro Talegón 1984:333.

7 See Sobré 1989. Sobré, however, feels confident in assigning characteristic uses of fibers and cloth to regions: "In Castile, Andalusia, and sometimes in Aragon, a web of hemp fibers was glued over the back surface of each panel, except where there were bars. In Aragon and in Catalonia hemp fiber strips were commonly placed along the joining of the individual planks, rather than over the whole back. In Valencia the back was sometimes gessoed, the gesso being impregnated with hemp fibers" (p. 52).

8 This and all subsequent translations from Pacheco (1965) were published previously (Véliz 1987:87).

9 Underdrawing in the *Pietà* by Fernando Gallego in the Museo del Prado shows that Latin inaccuracies in the underdrawing note for the inscription were corrected (by a lettered friend or the client?) before being committed to paint (Cabrera and Garrido 1981:27–47).

10 Toledo, Convent of Santo Domingo el Antiguo. The author has seen an early-seventeenth-century contract for the carpentry and assembly of an altarpiece in which reference is made to the pine panels over which paintings were stretched as being necessary to mitigate the influence of Toledo's harsh climate. It is also mentioned that the use of such panels is customary in Toledo. The document was not transcribed.

11 The paintings by El Greco for the high altar (1576) in the convent of Santo Domingo el Antiguo, as well as a large Annunciation by Eugenio Cajés (ca. 1615), in a side altar of the same convent, and the high altar by Luis Tristán (ca. 1624), in the Real Convento de Santa Clara, are all canvas paintings on their original strainer panels. The *Expolio* by El Greco in the Sacristy of Toledo Cathedral is also still mounted on its original pine panel.

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Historical Overview of Panel-Making Techniques in the Northern Countries

Jørgen Wadum

Through manuscripts, as well as through documentation and research in conservation studios, the methods used by old master panel makers to manufacture panels used as painting supports have become much clearer. The guild rules that have been preserved are also an important source of information to the extent that they mention points applicable to the joiners or panel makers (Miedema 1980).[1]

In Antwerp, the earliest documents from the guild of Saint Luke date to the last quarter of the fourteenth century, with the first regulations dated 1442 (Van Der Straelen 1855). The guild comprised not only painters but many members of the various crafts related to art production, including lace makers, instrument makers, and panel makers (Miedema 1980; Rombouts and Van Lerius 1864–76).[2] Joiners were not members of the guild of Saint Luke in Antwerp, but panel makers were. Both groups made panels, but for different purposes. The sculptors had the specialized *bakmakers* (box makers) make boxes and panels for their retables; however, joiners were also allowed to make panels. When the production of altars began to slow down in the sixteenth century, the box makers began making panels on a larger scale. Thus, the box makers actually became the new generation of panel makers. During the seventeenth century, when canvas became the preferred support for paintings and the demand for panels decreased, panel making again shifted, this time to the frame makers. During the same time period, frames developed increasingly sophisticated profiles and elaborate carvings, a development that demanded a separate association of frame makers (van Thiel and de Bruijn Kops 1995). Aside from producing frames, these frame makers continued making panels for painters who preferred this rigid support.

In Germany quality control had already been introduced in the late Gothic period. In Munich the regulations of 1424 stated that four representatives from the guild of cabinetmakers were to control all panels made by fellow cabinet and panel makers (Hellweg 1924). Any irregularities were to be reported to the head of the guild, and the panel maker was to be punished accordingly.

However, as the guild rules and the relationships among the different crafts varied from town to town, a comparison is difficult (Verougstraete-Marcq and Van Schoute 1989; Dunkerton et al. 1991).

Species of Wood

The artists would often use wood native to their region. Albrecht Dürer (1471–1528), for example, painted on poplar when he was in Venice and on oak when in the Netherlands and southern Germany. Leonardo da Vinci (1452–1519) used oak for his paintings in France (Nicolaus 1986); Hans Baldung (1484/5–1545) and Hans Holbein (1497/8–1543) used oak while working in southern Germany and England, respectively (Fletcher and Cholmondeley Tapper 1983). In the Middle Ages, spruce and lime were used in the Upper Rhine and often in Bavaria. Outside of the Rhineland, softwood (such as pinewood) was mainly used. A group of twenty Norwegian altar frontals from the Gothic period (1250–1350) were examined, and it was found that fourteen were made of fir, two of oak, and four of pine (Kaland 1982). Large altars made in Denmark during the fifteenth century used oak for the figures as well as for the painted wing panels (Skov and Thomsen 1982).

Lime was popular with Albrecht Altdorfer (ca. 1480–1538), Baldung Grien, Christoph Amberger (d. 1562), Dürer, and Lucas Cranach the Elder (1472–1553). Cranach often used beech wood—an unusual choice. In northern Europe, poplar is very rarely found, but walnut and chestnut are not uncommon. In the northeast and south, coniferous trees such as spruce, fir, and pine have been used (Klein 1989). Fir wood is shown to have been used in the Upper and Middle Rhine, Augsburg, Nuremberg, and Saxony. Pinewood was used mainly in Tirol and beech wood only in Sachen.

In general, oak was the most common substrate used for panel making in the Low Countries (Peres 1988), northern Germany, and the Rhineland around Cologne.

In France, until the seventeenth century, most panels were made from oak, although a few made of walnut and poplar have been found.

The oak favored as a support by the painters of the northern school was, however, not always of local origin. In the seventeenth century about four thousand full-grown oak trees were needed to build a medium-sized merchant ship; thus, imported wood was necessary (Olechnowitz 1960). In recent years dendrochronological studies have traced the enormous exportation of oak from the Baltic region to the Hansa towns. This exportation lasted from the Middle Ages until the end of the Thirty Years War (Klein 1989). Oak coming from Königsberg (as well as Gdansk) was, therefore, often referred to as *Coninbergh tienvoethout* (10-ft., or 280 cm, planks) (Fig. 1) (Sosson 1977; Wazny 1992; Bonde 1992). The longest planks available on the market (12 ft., or 340 cm) were used by Peter Paul Rubens (1577–1640) for his *Elevation of the Cross* in the Antwerp Cathedral (Verougstraete-Marcq and Van Schoute 1989; D'Hulst et al. 1992; Verhoeff 1983).[3] Karel van Mander (1548–1606) was aware that oak was being imported by ship from the North Sea, although he thought it came from Norway.[4] The ships did come to the Netherlands from the north, after passing the Sound, the strait that now divides Denmark from Sweden, on their way from the Baltic. However, the Sound-dues records show that in 1565, 85% of the ships carrying wainscots set out from Gdansk (Wazny and Eckstein 1987).

In the last decade of the seventeenth century, Wilhelmus Beurs, a Dutch writer on painting techniques, considered oak to be the most useful wooden substrate on which to paint. Beurs reported that not all wood is favorable for panels, "and what was used by the old masters who had very durable panels, then we today can say, so much seems to be known, that we can use good oak wood" (Beurs 1692). If possible, smaller paintings

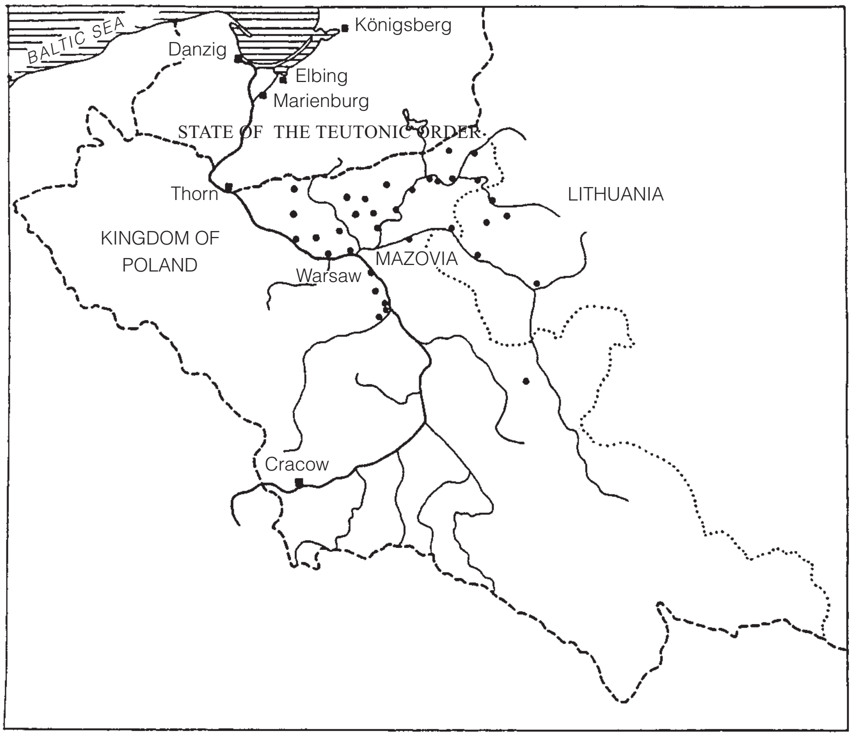


Figure 1
Vistula River basin with the main sources of wood (marked by dots). Political borders are those of the first half of the fifteenth century.

should be of only a single plank free from sapwood. The text of Beurs implicitly suggests that the use of other wood species would probably have been experimental in nature.

This recommendation for using oak is in accordance with practice. However, exceptions are seen rather early in the seventeenth century: sometimes walnut, pearwood, cedarwood, or Indian wood were used instead. Mahogany was already in use by a number of painters during the first decades of the seventeenth century and was used often in the Netherlands in the nineteenth century. Even so, when canvas or copper was not used, the main oeuvre of the northern school was painted on oak panels.

Quality of Wood

The quality of an oak panel can be seen from its grain. If the medullary rays in an oak panel are visible, the quality should be good, because this shows that the plank was radially split or cut out of the tree trunk (Fig. 2). The density of the wood is also important to the quality. Before 1630–40 the year rings (whose formation depends on age, physical location, and climatological factors) are often found to be narrower than those of oak trees available after this date.[5]

In the sixteenth century sapwood is rarely seen on panels, but in the seventeenth century a narrow edge of it is often recognized on one side—in violation of guild rules that threatened a fine for the use of sapwood (Van Der Straelen 1855). However, as panels inspected by the guild *keurmeesters* (assay masters/inspectors) also show faults in the wood, this may well be a consequence of the higher price of wood during the politically turbulent years in the beginning of the seventeenth century; or perhaps there was such a high demand for panels that less control was exercised over their production.

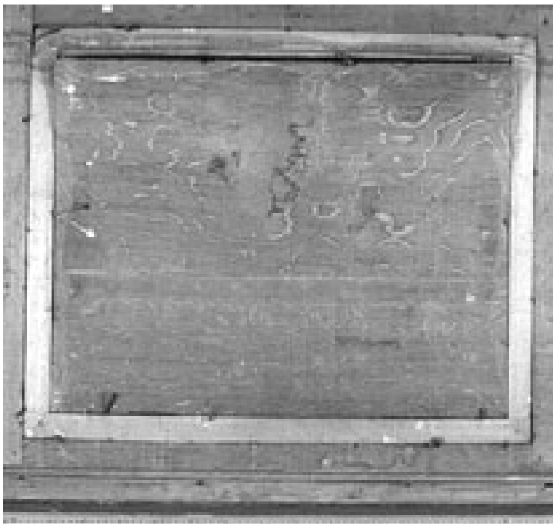


Figure 2
Medullary rays on a radially split and cut plank. Royal Danish Collection, Rosenborg Palace, Copenhagen.

Sometimes oak shows the signs of insect attack in a light area in the middle of a plank. This light part of the wood is called a *Mondring*,[6] and it consists of sapwood that has not transformed itself into hardwood. This phenomenon is due to an incomplete enzymatic reaction in the wood tissue, usually caused by strong frost (Fig. 3).

Tools

Splitting the timber was the usual method for obtaining radial planks of good quality, and this procedure was used by Dutch and German artisans until the sixteenth century, when the sawmill became standard for cutting large planks (Tångeberg 1986). The saw, which was known in classical times but forgotten until rediscovery in the fourteenth century, was mainly used from the fifteenth century onward. Later the wood was further treated with axes and scraping irons. The wood plane was also known to the Romans, but planing of panels did not become common until the fourteenth century (Fig. 4).

In some cases a wedge-shaped plank would be used directly; in other cases, it would be planed down. The planing would often be per-

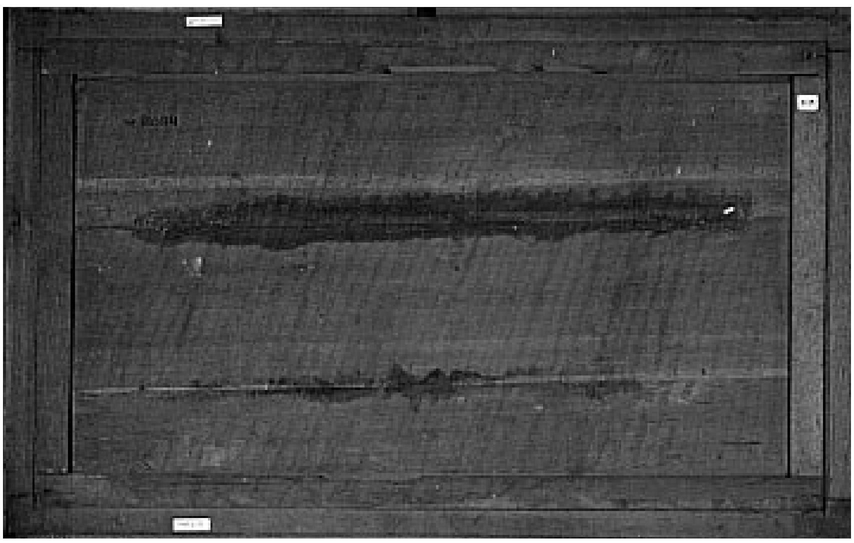


Figure 3
The Mondring, an area of sapwood in the middle of a plank. Royal Danish Collection, Rosenborg Palace, Copenhagen.

Figure 4
Gillis Mostaert, *A Landscape with Christ Healing the Blind Man,* ca. 1610. Oil on panel, 35.5 × 53 cm. Woodworkers cutting trunks with different types of saws. To the right, planks are stacked for seasoning.

formed after the gluing of the separate planks (Fig. 5a). Plane marks crossing the joins were very common in sixteenth- and seventeenth-century planks. Tools used for this work were planes, scrapers, and, in rare instances, small axes (Marette 1961).

The toolmarks on the backs of panels constructed of multiple planks do not always reveal the same treatment. One plank, for instance, might show saw marks, where other planks on the same panel show either the use of a plane or an ax (Fig. 5b–d). The plane would often have a dent in the blade that created a ridge. These ridges have, in some instances, established that the same plane was used on different panels, which then

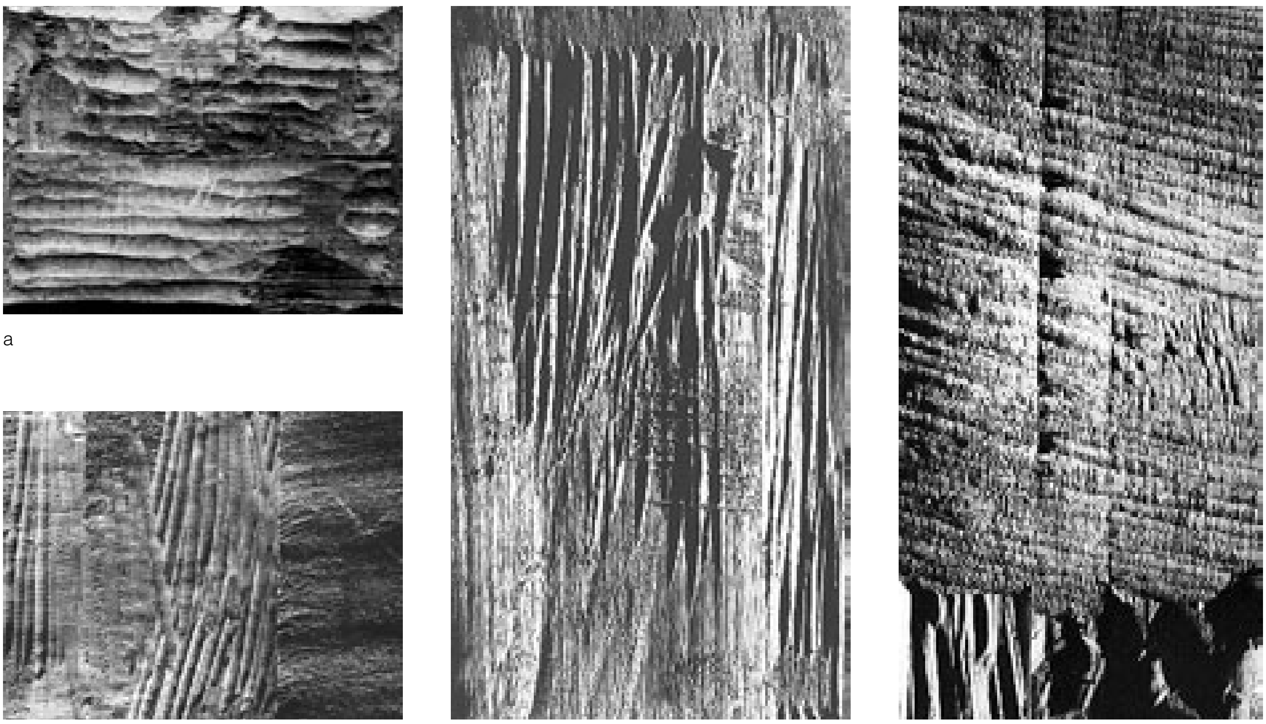


Figure 5a–d
Toolmarks on the backs of panels: (a) After joining, the panel has been partially thinned by a roughening plane. The untreated areas in the lower right and upper middle show the surface created when the wood was split into planks. (b) Three planks, all showing saw marks from a handheld saw, giving the surface a slightly (here, horizontally) wavy surface; thicker parts were planed down with a narrower roughening plane. (c) First a broad plane, with two dents in the blade clearly visible on the wood, and later a narrow plane were used to thin the planks down; remains of the saw marks are still visible in the center. (d) Three planks having been treated transversely to the grain, after having been previously treated as in Fig. 5c.

a b c d

could be attributed to the same panel maker (Christie and Wadum 1992; Wadum 1988). Tools for carpentry dating from the seventeenth century are not particularly rare, but Skokloster Castle in Sweden houses more than two hundred planes, axes, and gouges produced in Amsterdam around 1664; they are in excellent condition (Knutsson and Kylsberg 1985).

Panel Construction

The guild rules emphasized that the wood used in the construction of panels should be well seasoned. Seasoning the wood is very important for its stability. Wood shrinks during drying, and it may warp or show diagonal distortions if seasoning is not completed before the thinner planks are made ready for joining.

Based on dendrochronological studies, we have been able to estimate that the seasoning period in the sixteenth and seventeenth centuries was approximately two to five years, whereas it was eight to ten years in the fifteenth century (Fletcher 1984; Klein et al. 1987). The regulations of the Antwerp guild of Saint Luke were very specific about manufacture of panels for altars, wings, and smaller paintings. In 1470 a set of standards was issued stating that all altar cases and panels should be made of dry *wagenschot*[7] and that no painter was allowed to paint on either sculpture or panel if the wood was not dry (Van Der Straelen 1855).[8]

Gothic altar frontals in Norway were, on average, approximately 20 mm thick. The planks were aligned (but not glued) in the join by wooden dowels[9] 100–150 mm long and 10–15 mm thick. The joins of the planks were secured by parchment or canvas strips before a relatively thick (1–4 mm) ground was applied (Kaland 1982).

When more oak planks were joined together to form a large panel, planks could vary in width, although they were usually 25–29 cm wide. The panels were usually 8–30 mm thick. Panels from the fifteenth and sixteenth centuries tend to be thicker than those from the seventeenth century (Nicolaus 1986).

Planks of varying thickness were joined and then planed. In other cases, the backs were left uneven.

Traditionally, when two or more planks were glued together, heartwood was joined with heartwood, and sapwood with sapwood (Klein 1984). The planks were usually joined in such a way that the heartwood was on the outer edges.[10] Smaller panels consisting of two planks glued together sometimes show the remains of the lighter colored sapwood in the center of the panel (Fig. 6). This arrangement may have created problems because the remains of the weaker sapwood could cause joins to break open, and the softer sapwood would attract insects, whose infestation would be further stimulated by the animal glue used for the join.

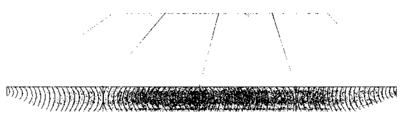


Figure 6
The traditional method of joining planks would be like against like: sapwood against sapwood, or heartwood against heartwood.

Planks were joined in various ways (Fig. 7a–h). The majority of planks were butt-joined (Fig. 7a). Some planks would have the two edges roughened to make a better tooth to receive the animal glue (Fig. 7b).[11] Butterfly, or double-dovetail, keys and dowels were commonly applied for reinforcement. In the Middle Ages, the panels were glued and further reinforced with butterfly keys (Fig. 7c). If butterfly keys were used, they were placed mainly on the front of the panel, and with time they often began to show through the paint layer (Fig. 8). Butterfly keys on the backs of panels were usually later additions. As panels became thinner toward the end of the sixteenth century, dowels replaced the butterfly keys for stabilizing and aligning the joins during gluing (Fig. 7d). On X radiographs the dowels

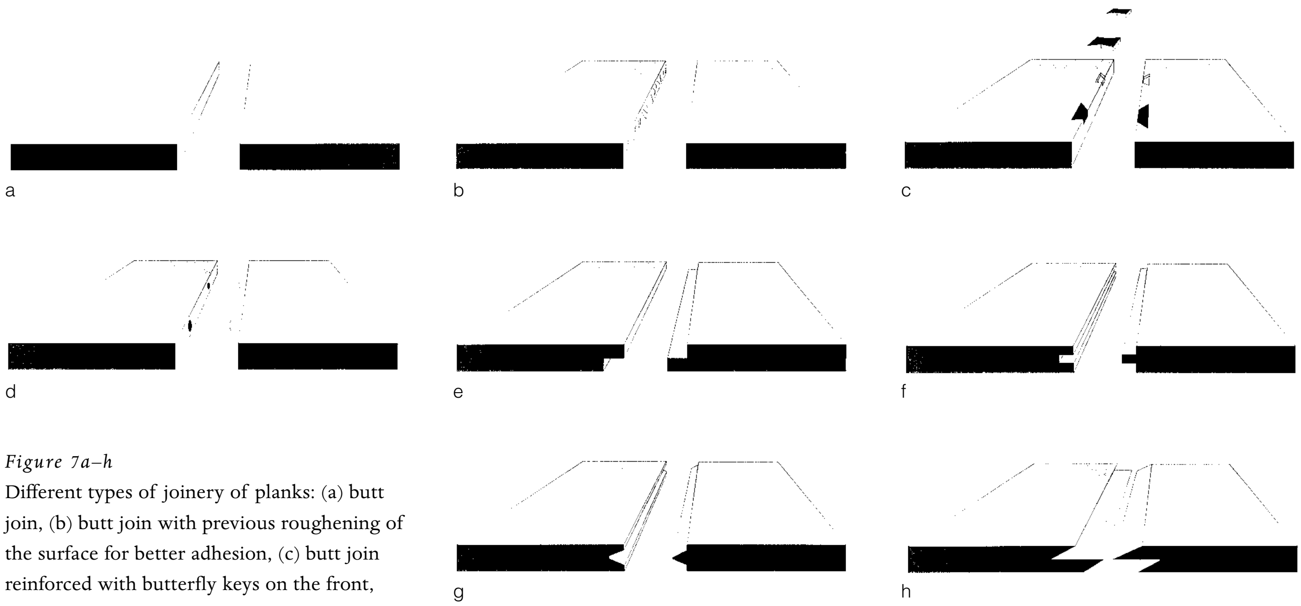
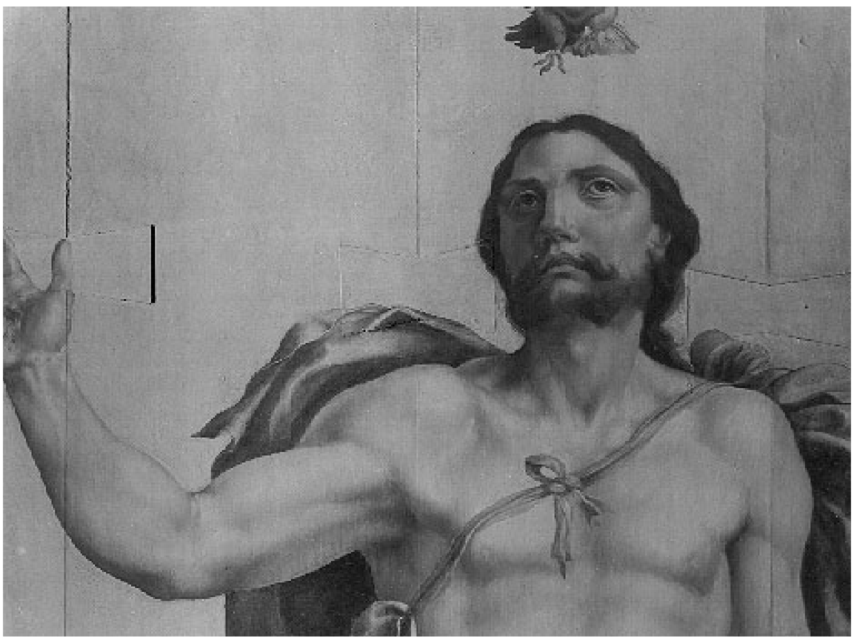


Figure 7a–h
Different types of joinery of planks: (a) butt join, (b) butt join with previous roughening of the surface for better adhesion, (c) butt join reinforced with butterfly keys on the front, (d) butt join aligned with dowels, (e) lip join, (f) tongue-and-groove join, (g) wedge-shaped join, (h) Z-shaped chamfered join (mainly used where planks with transverse grain are assembled).

and dowel holes can easily be traced, revealing the differences in method between one panel maker and another (Wadum 1987). In small panels (48 × 63 cm) consisting of two planks, two dowels would normally be placed in the join, whereas larger panels (75 × 110 cm) made of three planks would have three dowels in each join. Smaller panels (50 × 60 cm) made for portraits were sometimes composed of three planks—the middle one wide and the two at the edges much narrower—so that there would be no join down the middle of the panel that might run through the subject's face.

Lip joins and tongue-and-groove joins do occur in some instances; the wedge-shaped joins are rarer (Fig. 7e–g). Additions on a panel made by Michiel Vrient for Peter Paul Rubens show a refined Z-shaped chamfered join (Figs. 7h, 9). This type of join was used to make a large overlap for better adhesion when the grain of the added plank ran transversely in

Figure 8
Maarten van Heemskerck, *The Resurrection of Christ,* ca. 1550. Detail. Oil on panel, 172 × 131 cm. Department of Conservation, Statens Museum for Kunst, Copenhagen. Original butterfly keys on the front of a panel (see Fig. 7c) show through the paint layer.



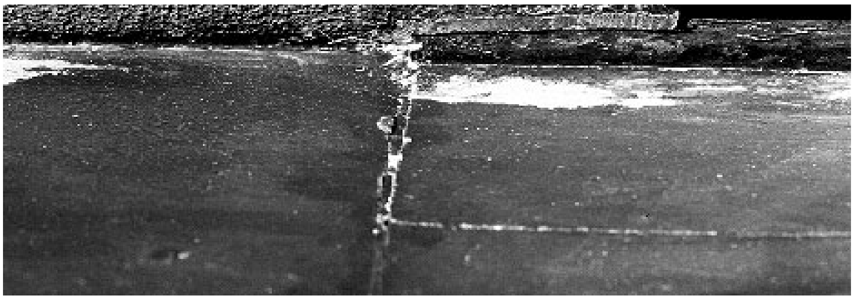


Figure 9
Peter Paul Rubens, *Portrait of Helena Fourment,* ca. 1635. Oil on panel, 98 × 76 cm. Conservation Department, Royal Picture Gallery Mauritshuis, The Hague. A join between two planks assembled with a Z-shaped chamfered overlap (see Fig. 7h) for better interlocking of the join between planks with transverse grain.

relation to the first piece.[12] The panel maker was obviously aware that the joining of boards with the grain running perpendicular to each other would cause instability—something the conservation history of the panels confirms only too well.[13]

The south German Benedictine monk Theophilus (ca. 1100) describes the process of making panels for altars and wings (Theophilus 1979).[14] The individual pieces for altar and door panels are first carefully matched with the shaping tool that is also used by cask and barrel makers. The pieces are then affixed with casein. Once the joined panels are dry, Theophilus writes, they adhere together so well that they cannot be separated by dampness or heat. Afterward the panels should be smoothed with a planing tool such as a drawknife.[15] Panels, doors, and shields should be shaved until they are completely smooth. Then they should be covered with the hide of a horse, an ass, or a cow (Fig. 10).[16] On some altar frontals in Norway, several of the cracks in the wood of the panel were filled with parchment prior to application of the ground (Wichstrøm 1982).[17]

If the panel maker lacked hide, panels might be covered with a new medium-weight cloth, with glue made from hide and staghorns (Cennini 1971:chap. 19).[18]

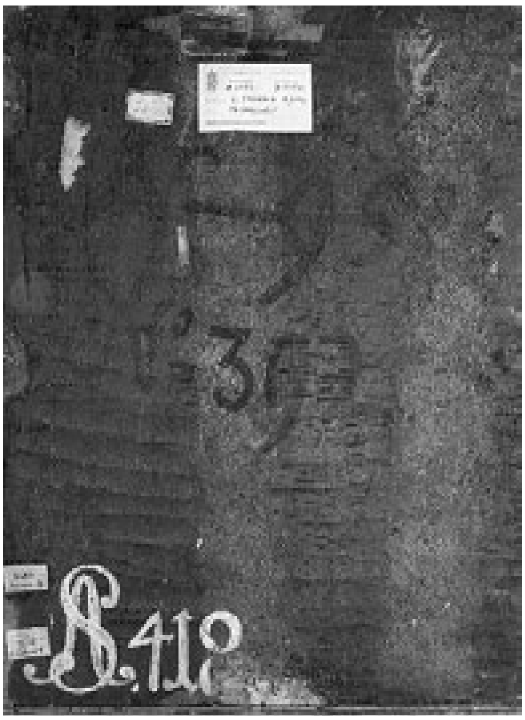


Figure 10
Lucas Cranach the Younger, *Portrait of a Man with a Red Beard,* 1548. Reverse. Oil on panel, 64 × 48 cm. Royal Picture Gallery Mauritshuis, The Hague. Two joins reinforced with horse or cow hair.

The method of applying linen to the panels was also used by panel makers of the northern countries, as in a large ($28\ m^2$) painted fir wood lectern (1250–1300) in Torpo, Norway, in which the joins were glued and covered with canvas prior to the application of size and ground (Brænne 1982).

In Germany canvas was also applied to panels. The *Adoration of the Magi* by Stefan Lochner (active 1442–51) in the cathedral of Cologne has two wings and a main panel made of oak wood (Schultze-Senger 1988). The butt ends of the single planks (2.5 cm thick) have been glued together (Verougstraete-Marcq and Van Schoute 1989). The completed panels—on what was to become the inside of the wings and the front of the middle panel—were then completely covered with canvas. In 1568 Vasari described this method in some detail (Berger 1901:26).[19] A rather thick (1.5 mm or more) ground was used, which became somewhat thinner on the outside of the wings. Applying ground and paint on both sides of the wings naturally reduced movement in the wood.

The joins, knots, and resinous areas of softwood panels were continuously covered with strips of canvas. In the fifteenth century Danish cabinetmakers used the same procedure—joins and knots were covered with pieces of coarse canvas before sizing with a strong glue (Skov and Thomsen 1982).

The method of securing joins by applying parchment and gluing horse or cow hair transversely to the join, while used mainly in the fifteenth and sixteenth centuries, also continued in the first quarter of the seventeenth century (Sonnenburg and Preusser 1979). The use of canvas as a reinforcing material for panels is documented into the seventeenth century.[20]

The *Last Judgment* by Lucas van Leyden (1494–1533) was painted around 1526–27. The triptych consists of a center panel, with an unpainted back, and two wings, which are painted on both sides. All three panels are constructed of vertical oak planks glued flush and secured with wooden dowels placed at regular intervals (Fig. 11). The back of the center panel shows planks worked rather roughly with a curved spokeshave. The panels

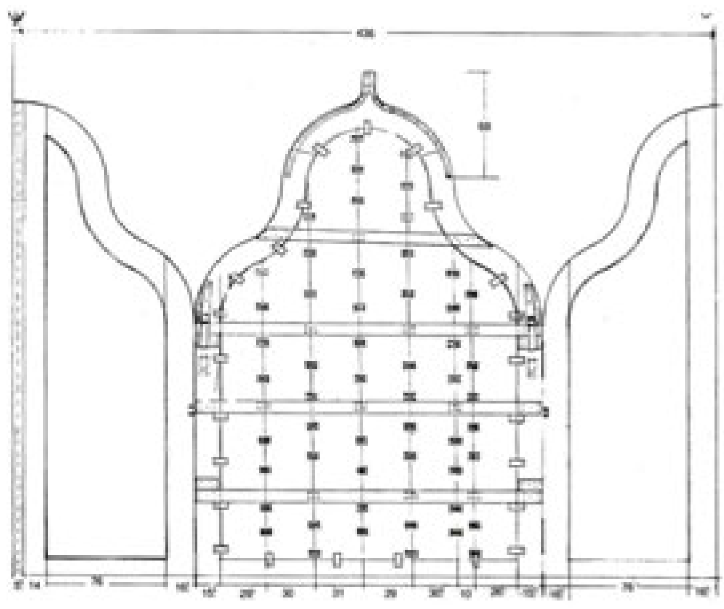
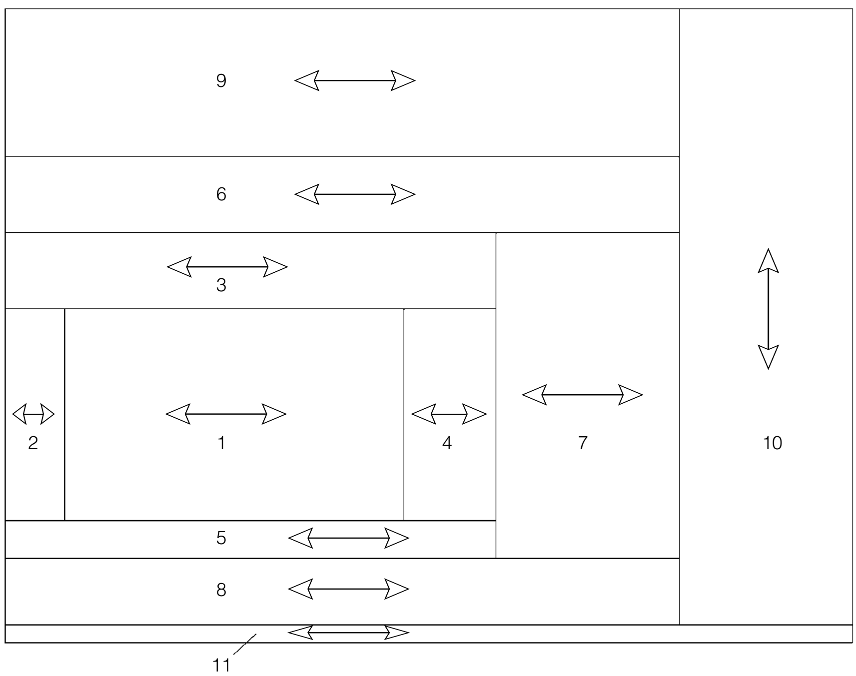


Figure 11
Construction of a triptych from the first quarter of the sixteenth century. Lucas van Leyden, *The Last Judgment,* 1526–27. Oil on panel, 300.5 × 434.5 cm (open). Municipal Museum "De Lakenhal," Leiden.

were not glued but instead were fitted into a groove in the frames. The center panel has a rabbet around the edge on the back that enhances the join with the frame. Four horizontal battens, all fastened with wooden pins, hold the center panel in place in the frame.

Although the altar was made in Leiden, it appears that the Antwerp regulations were applicable to its construction. The rule for Antwerp altars more than 2 m high required the back to be secured by transverse battens—one at the neck, with more behind the main corpus (Van Der Straelen 1855).[21] The whole construction would have its original greenish gray paint layer (probably original) on the back. Analysis has revealed lead white and carbon black in an oleaginous binding medium. Translucent particles (glue) were also present. It can be seen that frames and panels were all grounded in one sequence. A burr is visible along the edges of the panels, where they have been shrinking slightly (Hermesdorf et al. 1979).

Some of Rubens's panels present a particular problem: that of enlargement with odd planks on more than one side (Sonnenburg and Preusser 1979). Sometimes the grain of these additional planks ran perpendicular to the grain of the other planks, making the composite panels especially vulnerable to fluctuating environmental conditions (Brown, Reeve, and Wyld 1982). In *The Watering Place* by Rubens, the grain of ten out of eleven planks runs horizontally. The construction of the panel took place in four successive stages, starting from a standard-sized panel of 35.9 × 56.7 cm (Fig. 12a, b). This panel was extended with additions of oak planks all having the same grain orientation, except for the final plank on the right side, which has a vertical grain. It was likely not possible to find a plank with a horizontal grain of the same height as the panels (approximately 1 m) (Brown 1996). The joins between the planks are butt



a

Figure 12a (right), b (opposite page) Construction of the panel used by Peter Paul Rubens for *The Watering Place,* ca. 1620. Oil on panel, 99.4 x 135 cm. National Gallery, London. The sequence of added planks (a) is indicated by the numbering, and the direction of the grain is indicated by the arrows. The joins are all butt joins, except for the join of plank 10, the only plank with vertically oriented grain. Here the planks are assembled with the Z-shaped chamfered join (see Fig. 7h). The front of the painting (b) is also shown.

b

joins, except for that of the large vertical plank, which has a chamfered 3–5 cm overlap.[22] Such additions were often done by professionals (Rombouts and Van Lerius 1864–76).[23] On X radiographs these additions appear to have been made after Rubens began his composition (Poll-Frommel, Renger, and Schmidt 1993)—toolmarks beneath the latest paint layer are observed (Sonnenburg and Preusser 1979).

In the northern Netherlands we see that Rembrandt's panels from the Leiden period are all on oak. The grain always runs parallel to the length of the panels, and joins are always butt joins (van de Wetering 1986). The panel makers in Leiden belonged to the joiners and cabinetmakers guild but are not mentioned in the guild regulations until 1627. At that time the joiners and cabinetmakers requested that the Leiden guild specify them as the producers of these panels. This request was made because a certain woodturner—not a guild member—was making and selling panels, and the joiners wanted him stopped (van de Wetering 1986).

The tradition of the Netherlandish school of the seventeenth century was applied to the French methods of the eighteenth century (Berger 1901:416). Studies of English panels show that up to about 1540, many are of crude workmanship and often have uneven joins (Fletcher 1984). However, in 1692 Marshall Smith recommended the use of old wainscot for panels because it was less likely to warp (Talley 1981).

Standard Sizes

Smaller panels used for easel painting were often made in standard sizes. By the fifteenth century, altars had already been standardized (Jacobs 1989), and in the late sixteenth century, standardization was then further applied to panels made for use as painting supports (Bruijn 1979). Naturally, this standardization also became the rule for canvases (van de Wetering 1986).

The use of standard sizes for panels has been questioned (Miedema 1981); however, it has become clear that this was indeed the case for *dozijn* panels—made by the dozen (Van Damme 1990). The term has erroneously been understood by some as an evaluation of the artistic quality: it was thought that paintings on dozijn panels were made by mediocre painters for trade on the year markets (Floerke 1905).

The standard sizes may also have varied between towns rather than between individual panel makers.[24] The inventory made after the death of Frans Francken I in 1616 records nineteen *tronie*-sized (portrait) panels and forty-nine smaller, *stooter*-sized (a designation referring to a seventeenth-century coin) panels in one of his rooms (Duverger 1984). The fact that the standard sizes were also evident in the north is shown in the inventory of Jan Miense Molenaer (1610–68), which indicates that he had twenty-six single-plank panels of one size and thirty-two of a slightly larger size (van de Wetering 1986). Standard sizes are still commonly available for painters—nowadays they are called landscape, marine, or portrait sizes.

Frans Hals (1589–1666) also used standard-sized panels for many of his portraits. Hals bought panels made by members of the joiners guild in Haarlem; almost all his panels consist of a single plank (Groen and Hendriks 1989).

Frames

In prints or paintings depicting a painter's atelier, frames for temporary use are often seen on the short sides (perpendicular to the grain) of a panel (Fig. 13). On panels from the fifteenth and sixteenth centuries, at the sides of the panel, one can see a small tongue that would fit into the grooves of such a temporary frame.

Panels from the fourteenth and fifteenth centuries were constructed with a fixed frame. The ground was applied at the same time to the frame and the panel, the two forming an inseparable ensemble (Dunkerton et al. 1991). If the temporary frame that was originally fixed at the short end of a panel or the full frame were removed, one would find a small beard of ground indicating the former presence of a fixed frame (Fig. 14a–d).

Frames in Antwerp were also made of beech wood—but only inner frames, in accordance with guild regulations. Additionally, for altar panels or other large works, the panel makers were *never* to use beech wood, only oak.[25] Original frames from the early seventeenth century are rare, but in Rosenborg Castle, Copenhagen, more than fifty are still preserved (Wadum 1988).

Beveling at the edges of a panel, often down to a few millimeters, makes it thinner and therefore easier to mount in a frame. If a panel has been reduced in size, part or all of such beveling has been removed. On small single-plank panels, however, beveling may be visible only on three sides, because when a plank is split out of a tree trunk, a wedge shape is automatically formed, so that beveling at the pointed edge is often unnecessary.

Figure 13
Maarten van Heemskerck, *Saint Luke Painting the Virgin and Child,* ca. 1550. Oil on panel, 205.5 × 143.5 cm. Musée des Beaux-Arts (inv. 307), Rennes. A narrow-grooved frame mounted at the end grain prevents the small panel from warping.

Among the hundreds of items found in the inventory made after the death of the widow of panel and frame maker Hans van Haecht (1557–1621) are thirty-six eight-*stuijvers*-sized (another seventeenth-century coin) double frames in a storage room, sixty-eight more of the same size in the attic, and two dozen small ebony frames (Duverger 1987; Van Roey 1968).

Members of the various disciplines within the guild of Saint Luke manufactured articles such as frames that would fit the standard panels (Wadum 1988; van Thiel and de Bruijn Kops 1995).[26] Standard frames were also constructed with a groove in which the beveled edge would fit—a method that originated with the large altar panels. The beveled edges, often varying slightly in thickness, were kept tight in the frame by means of wedges (sometimes secured by glue) placed at regular intervals on the back (Figs 14c, 15). Frames were also made with a rabbet so panels could

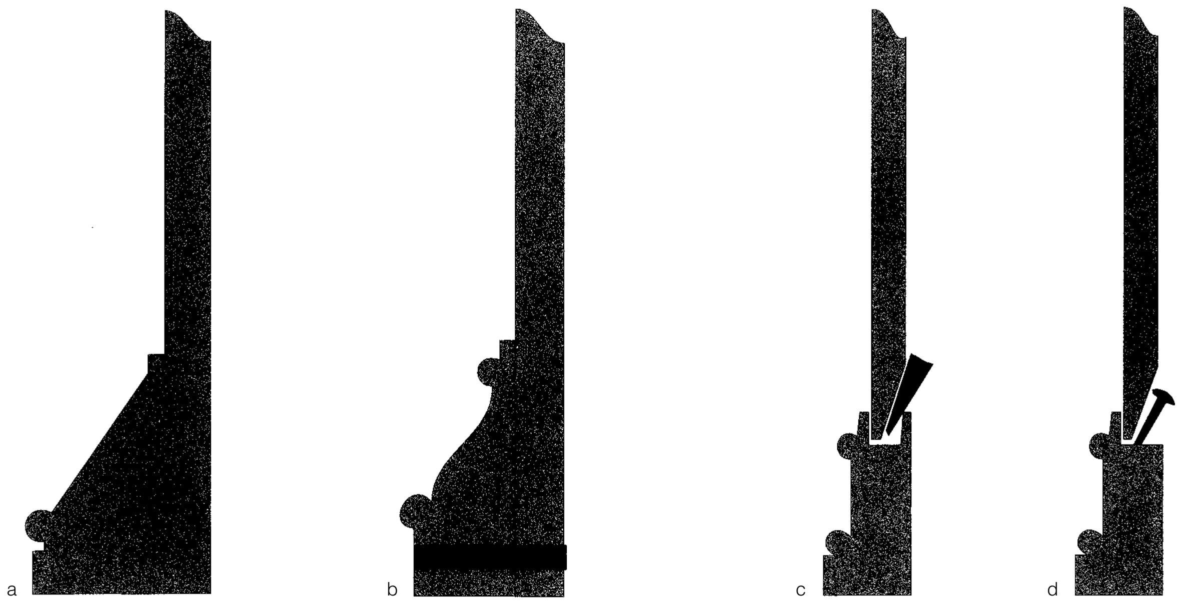


Figure 14a–d
Different methods of framing: (a) a panel and frame in one piece, (b) the frame is mounted on front of the panel with dowels, (c) the panel is inserted as a tongue in the groove of the frame and is often secured by wedge-shaped blocks mounted with glue, (d) the panel is mounted in the rabbet of the frame and held with nails.

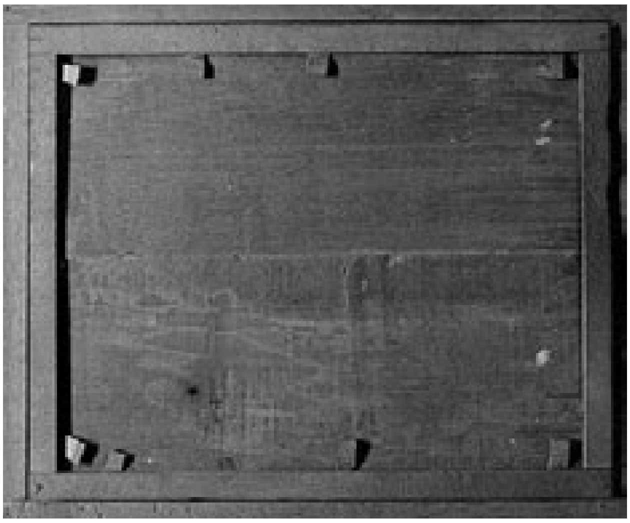


Figure 15
A panel framed in Antwerp in 1620, with the method shown in Fig. 14c. The double frame consists of a narrow beech wood frame that is itself fitted into an oak frame; the tongue-and-groove principle is followed throughout. Royal Danish Collection, Rosenborg Palace, Copenhagen.

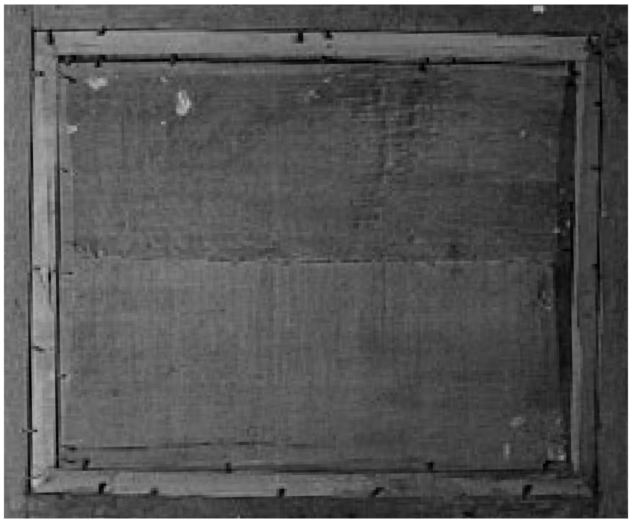


Figure 16
A panel framed in Antwerp in 1620, with the method shown in Fig. 14d. Beech wood has been used for the narrow frame; all is mounted in rabbets and held in place by hand-made iron nails. Royal Danish Collection, Rosenborg Palace, Copenhagen.

be mounted with iron nails, an easy method of framing, as the frame itself could be assembled before the panel was fitted into it (Figs. 14d, 16) (Wadum 1988; Verougstraete-Marcq and Van Schoute 1989).

Marks

Mainly on the back of Brabant panels, one can sometimes see lines cut with a gouge that cross one another, creating a pattern of complicated marks. It is interesting to note that these marks do not continue across joins between two planks. It has been suggested that the marks may have been made by timber tradesmen or made as a sort of quality mark for wood in stock (Marijnissen and Michalski 1960). It was also most convincingly suggested that the large planks may have been marked by the lumberjacks in the Baltic area (Glatigny 1993). The planks with such marks never have saw marks—a phenomenon showing that the planks were all split from tree trunks.

All the panels with longitudinal cut marks, found in altars or on panel paintings, seem to have been made between the end of the fifteenth century and the last quarter of the sixteenth century (Fig. 17). Most of the panels with these marks were used by painters in Brabant, Antwerp, Bruges, Brussels, or Louvain; however, a number of north German altars also have these cut marks (Tångeberg 1986). Such cut marks are to be expected on panels used in other regions in northern Europe, if the wood originated in the Baltic area where it was marked before shipment to the Hansa towns for further manufacturing.

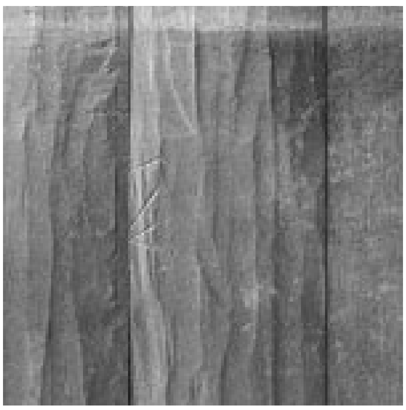


Figure 17
Maarten de Vos, *Moses Showing the Tables of Law to the Israelites,* 1574–75. Reverse. Oil on panel, 153 × 237.5 cm. Conservation Department, Royal Picture Gallery Mauritshuis, The Hague. Gouge marks made by Baltic lumberjacks can be seen.

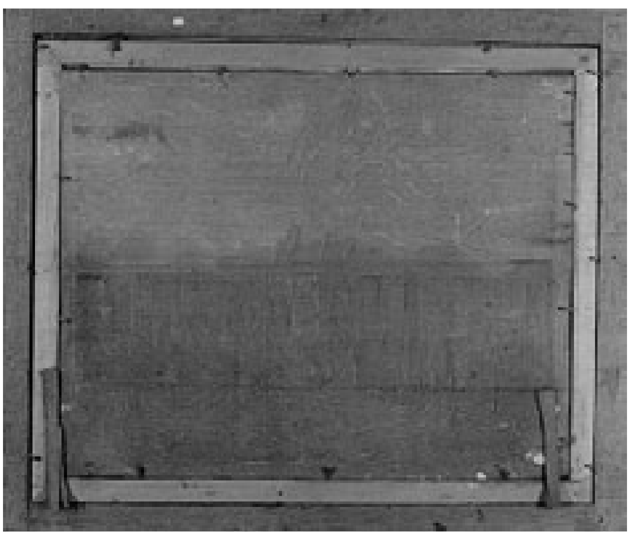
In the early seventeenth century, when an Antwerp panel or frame maker had a large number of panels ready in his workshop, he would call for the dean, who would then pay a visit to the panel maker and check the quality of his panels (Fig. 18). If, however, the panel maker had only a few

Figure 18
David Ryckaert II (1586–1642), *A Painter's Atelier*. Oil on panel, 74 × 108 cm. Musée des Beaux-Arts, Dijon. The Antwerp branding mark (upside down) appears on the reverse of the small panel leaning against the back wall.

panels he wanted to have branded, he would take them to the dean himself for approval (Van Damme 1990). This procedure was required before the panels were grounded.

If the panels had no worms, rot, or sapwood, they were accepted and branded with the hands and castle, the Antwerp coat of arms (Van Damme 1990; Wadum 1997). If, however, any faults in the wood were observed, it was the dean's duty to break the defective panel without any intervention from the panel maker or assistant (Van Damme 1990). (There are, nevertheless, numerous examples of approved panels that did have faults.) After approval and branding of the panels, the panel maker would stamp his own personal mark into the wood (Van Damme 1990). It appears that not all panel makers' marks were stamped into the wood; some were also written in red chalk directly on the board. These inscriptions are often overlooked. Yet they can be seen when the backs of panels are viewed in ultraviolet light (Fig. 19a, b) (Wadum 1990).

Figure 19a–b
The same panel back photographed in normal (a) and in UV-fluorescent (b) light. The UV-fluorescent light reveals the panel maker's check marks, the number of the panel and frame (no. 68), and the personal mark (GA in ligature), just below the join and as a fragment on the left side of the frame. The identification of the panel maker, Guilliam Aertssen, and his different inscriptions are made visible only by UV-fluorescence photography. Royal Danish Collection, Rosenborg Palace, Copenhagen.



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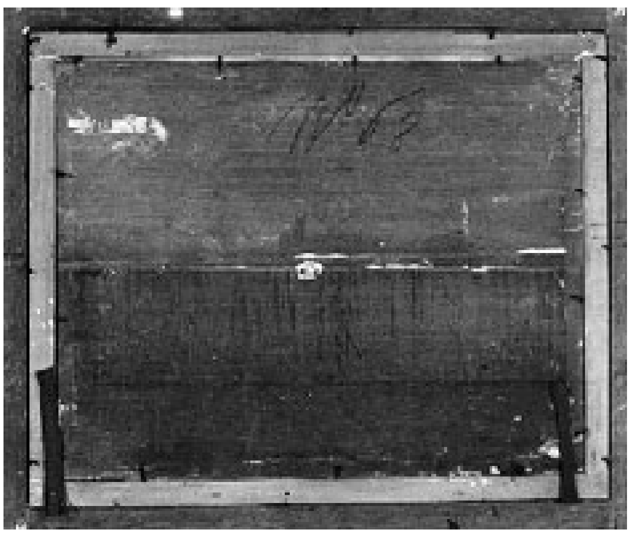

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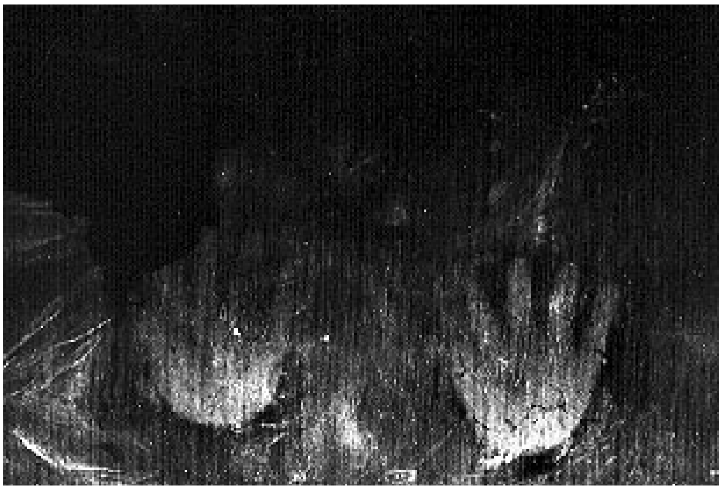

Figure 20
X radiograph of Frans Francken II, *Salome with the Head of Saint John the Baptist,* ca. 1625. Detail. Oil on panel, 50.5 × 65 cm. Department of Conservation, Statens Museum for Kunst (inv. 4457), Copenhagen. Two hands from the Antwerp branding iron show up white, as their impression is filled with a ground containing lead white.

Branding of panels generally took place before the ground was applied. This can be illustrated in two particular incidents, where in both cases the ground for one reason or another was applied on the same side of the panel that had just been branded. In the first example, an X radiograph of a Rubens panel in Munich shows a white letter A, indicating that the impression of the mark had filled with ground (Sonnenburg and Preusser 1979). In a similar example, a pair of hands from the Antwerp brand shows up on an X radiograph of a panel in Copenhagen (Fig. 20).[27]

Panel marks existed a few years before 1617 (a panel with the maker's monogram, RB, has been found dated 1612) (Wadum 1993),[28] but were not standardized and regulated until a guild rule was designed to that effect the same year (Van Damme 1990). Twenty-two panel makers, as well as their respective marks, were recorded in a list.[29] The year 1617 has therefore in the past been regarded as the terminus post quem in the manufacture of panels with a maker's mark, and in general this still seems to be the case today (Figs. 21, 22). Only three other panels show the same grain and panel mark as the aforementioned panel dated to 1612, and all originate from the same large tree. The planks have been separated only by the panel maker's saw cut (Broos and Wadum 1993).[30] As none of the four panels show any sign of the Antwerp branding mark, one could speculate that this panel maker was a joiner, rather than a registered panel

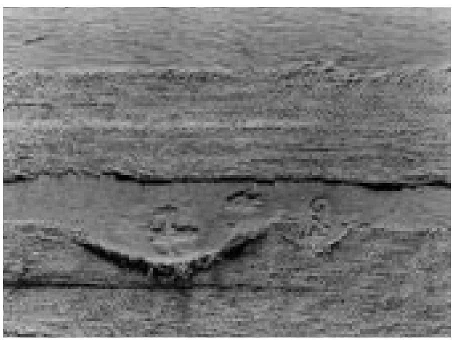

Figure 21, right
The Antwerp castle, one of the two hands, and the personal mark of the panel maker, Guilliam Aertssen (GA in ligature), were partly hidden under a strip of canvas reinforcing a join.

Figure 22, far right
The Antwerp branding mark and the personal mark of Lambrecht Steens (LS in ligature) very thoughtfully left intact on the back of a shaved and cradled panel.

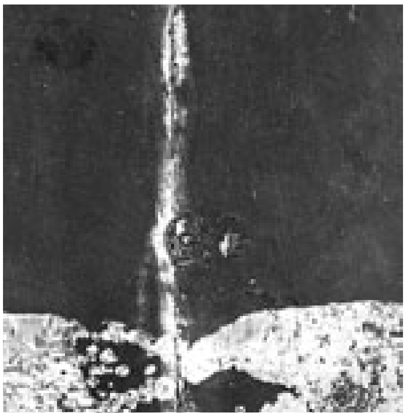

Figure 23
Guilliam Gabron's personal mark (GG around a floral motif) pressed into the ground applied on the back of a panel, from ca. 1619. Conservation Department, Royal Picture Gallery Mauritshuis, The Hague.

maker. Joiners were not members of the guild of Saint Luke at this time and, therefore, were not monitored until 1617 by the *keurmeester* (assay master/inspector) who approved panels (Van Damme 1990).

Both the panel makers and the joiners received a new set of regulations in 1617, but the marking decree was, in fact, based on an already existing practice.[31] The panel maker Guilliam Gabron was already using his own mark in 1614, this mark being identical to the one we find in his early period (Fig. 23).[32] These exceptions only prove the rule: marking on a larger scale took place mainly after 1617.

Although ready-made panels were exported from Antwerp to other countries (Duverger 1972; Fletcher 1984), the archives mention a number of works by panel makers who were active in Holland during this period. In 1607 Evert Gerritsz of Amsterdam charged the painter Gilles van Coninxloo sixteen guilders for frames and panels. In Rotterdam in 1631 the panel and frame maker Cornelis was owed money by an art dealer, and in 1648 Dirck Willemsz received twenty-five guilders for frames delivered to an art dealer (van Thiel and de Bruijn Kops 1995).

Ready-Made Grounds

Because panels with ready-made grounds were available in the painters' materials shops from the late sixteenth century onward, a short survey of the way the ground is described in the guild regulations, manuscripts, and painters' manuals is included here.

The application of the ground is a natural step after the panel's production; even the back of some panels may still have their original ground. This ground is generally of the same material as that used on the front, and it is often covered by a single layer of brown and/or green pigment in an oily binding medium. There are even examples of an almost black layer that is bound in thick glue. Hans van Haecht, who also operated as a dealer in paintings, had large quantities of ready-ground panels available for his customers. From an inventory we know that he had eleven gulden-sized, eighteen long eight-stuijvers-sized, and one large sixteen-stuijvers-sized panel *geprimuert* (primed) on both sides ready in his shop (Duverger 1987).[33]

A perusal of the panel makers' rules from the end of 1617 makes it clear that panel makers were taking over panel preparation as well. The regulations state that no panel maker may allow a panel to leave his workshop, or let it be grounded, before inspection by the dean (Van Damme 1990). Interestingly enough, the rule specifically stresses that a fine for breaking this law would be imposed, regardless of whether the offender is a man or a woman (*tsij man oft vrouwe*). Thus it is indicated that a woman, in the case of her husband's death, could take charge of a panel maker's workshop and fall subject to guild rules herself. It is also interesting to consider that women may very well have been grounding the panels produced in the workshops. This would be a fascinating piece of information regarding the division of work within the social structure of Antwerp art production, but to current knowledge, no women are titled as *witters* (grounders) in the official guild records from the seventeenth century.

It is not completely clear exactly when panel makers in Antwerp began making ready-to-paint-panels (Wadum 1993). However, when Philips de Bout (d. 1625) was registered in the *Liggeren* (the archives of the Antwerp guild of Saint Luke) in 1604, he was the first to have the title of *witter en lijstmaker* (grounder and frame maker) (Rombouts and Van Lerius

1864–76; Rooses 1878).[34] The availability of panels fully sized and grounded would save time and labor for an artist's atelier, so that work on a painting could start straightaway. Perhaps this is the reason why there are only three recipes in the de Mayerne manuscript (nos. 1, 2, and 4) that record how to ground panels, but many recipes (nos. 6–20) that describe how to ground canvases (Berger 1901:92–408). Canvases were also sold ready-made, although the practice was not common in this early period. On the pregrounded panel, the artist could immediately apply the imprimatura, or *primuersel,* a semitransparent colored insulation layer placed directly on the ground before painting, in whatever tone desired.

What is believed to be the mark of Philips's son Melchior (d. 1658) has been observed and recorded a number of times. In the year that he succeeded his father (1625 or 1626), Melchior de Bout is referred to as a *witter en peenelmaecker* (a grounder and panel maker); in the same year his late father is recorded only as a witter (Rombouts and Van Lerius 1864–76). Panels bearing the MB monogram[35] have been recorded four times; the mark is placed close to a corner and pressed into a ground layer also present on the back of the panels (Fig. 24).[36] No Antwerp brands have been found in conjunction with this monogram. These witters were the initiators of this special profession of preparing panels for the artists' studios (van de Wetering 1986). In 1627 Hans van Haecht (1557–1621) had six dozen stooter-sized panels, as well as seventy-five panels of half that size, that were ready-ground with *primuur,* several on both sides (Duverger 1987).

In 1643 Leander Hendricx Volmarijn from Rotterdam got permission to sell paintings and painters' materials in a shop in Leiden. Permission was granted since no such shop existed there at that time. This fact meant that prior to this time, the painters had bought their panels directly from the joiner and panel maker (van de Wetering 1986).

In the early years, the tradition of grounding panels appears to be parallel to the method used south of the Alps.[37] The colored ground, or imprimatura, originated in Italy and is described by both Filarete and Vasari.[38] The Italian painter would make his preparatory drawings on top of the insulating, nonabsorbing, colored ground.

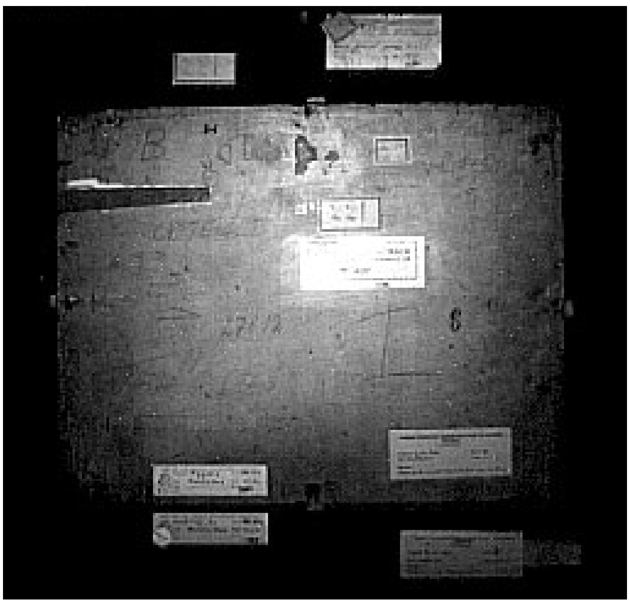

Figure 24
Back of a panel that has been grounded and marked by the panel maker Melchior de Bout (MB in ligature). His mark is found twice impressed into the ground on the reverse. Bonefantenmuseum, Maastricht.

Figure 25
Jan Brueghel the Elder and studio of Peter Paul Rubens, *Nymphs Filling the Horn of Plenty,* ca. 1615. Detail. Oil on panel (single plank), 67.5 × 107 cm. Conservation Department, Royal Picture Gallery Mauritshuis (inv. 234), The Hague. The streaky, transparent primuersel is seen on an infrared reflectogram.

In the north this practice changed during the sixteenth century. The underdrawing would be made directly onto the thin white ground, on top of which a translucent insulating layer, the primuersel, would be placed. This primuersel would leave the drawing visible for further development in the painting process. It is obvious, then, that the primuersel was applied in the artist's studio, not by the witter.

Karel van Mander wrote in 1605 that his predecessors ground their panels thicker than in his time and that afterward they planed or scraped the surface as smooth as they could (Miedema 1973:256–57). The technique of Hieronymus Bosch (ca. 1450–1516) is described by van Mander as a method used by many other old masters: Bosch drew his images on the white ground, placing over them a thin translucent, flesh-colored primuersel that would allow the ground to play a role in the finished painting. The fact that the old masters did indeed draw directly on the ground, using a thin, flesh-colored layer in oil as an isolation layer, has been duly confirmed by intensive studies on this subject (Federspiel 1985).[39] It is this pigmented oil layer that van Mander named primuersel (Fig. 25) (Plesters 1983; Coremans and Thissen 1962; Sonnenburg and Preusser 1979).[40]

In 1620 de Mayerne gave advice on priming a panel. If one wants to paint on wood, he wrote, it is the custom first to size with chalk. One can mix a little honey in it in order to prevent cracking; but in de Mayerne's opinion it is better not to size wood too much. Then one should apply a good and strong ground (*imprimeure*) in oil, with a knife or horn spatula, in order to close the pores of the wood.[41] An English manuscript from 1622 by Peacham describes a similar method (Talley 1981:61–71).[42]

In 1692 Wilhelm Beurs wrote that a ground should first be applied to the panel with a weak glue mixed with chalk. After this, the panel should be scraped again in order to make it even and plane, so that the grain stays filled (van de Graaf 1958).

The same year that Beurs published his manual, the Englishman Marshall Smith gave the recommendation to apply six to eight layers of whiting mixed with a strong size. After drying, the layer should be smoothed "with a Joyners Palm, then water plain'd with a rag dipt in water" (Talley 1981:375–96). Finally, an unspecified priming is applied before a layer of colored oil imprimatur. In France in 1757, Perteny gave the advice to apply a layer of *Handschuhleim* (hide glue) on both sides of the panels, on top of which the ground should be applied (Arnold 1826:101).

The recipes are consistent with what one actually sees on sixteenth- and seventeenth-century northern European panels. In the northern Netherlands, increasingly less ground was used, so that sometimes only the holes between the more pronounced parts of the grain in the oak panels were filled. This minimal grounding caused the grain of panels painted in the seventeenth century to be partly visible through the paint film (Gifford 1983). Also, the double ground is found to have been applied to panels from the Gothic period well into the eighteenth century.

It is necessary to mention that caution must be exercised in drawing conclusions about artists' practices from the analysis of the ground layers on paintings dating from the end of the sixteenth century onward. Indeed, the grounding—be it a single or a double ground layer and an oil, a glue, or an emulsion ground—may very well show the characteristics of what was in the pot of ground at the witter's workshop. Therefore, no relation to the tradition of a painter's studio may be deduced from a sample of ground. The imprimatura, or primuersel, layer was often the first layer applied by the artist on the already grounded panel; it, therefore, can be considered to reflect a specific practice in the painter's studio.

Conclusion

It becomes clear that, over the years, thick split panels for large altars evolved into smaller panels for easel painting. This shift was caused by social, religious, and economic changes. The manufacture of panels by the panel makers also underwent a development: from rough surfaces with primarily untreated backs to panels with backs that were either planed or, in some cases, protected by an isolating layer to prevent warping. The evolution of different tools, from ax to saw to plane, shows a progress in the finishing of the painter's board that seems to decline toward the end of the seventeenth and eighteenth centuries. This development occurs along with a drop in the quality of the raw material, the wood; the presence of sapwood and broader year rings clearly tell a story about a less-consistent quality check and an apparent scarcity of dense oak.

Information garnered from treatises and manuscripts is consistent with what can be detected from the analysis of the supports, and guild rules emphasize the care and concern brought by the art-producing society to the inspection of its members. This careful oversight partly derived from a syndicalistic concept, but it is clear that its purpose was also to guarantee a purchaser works of art made of materials of high quality.

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Notes

1 In 1581 the painters guild was founded in London; in 1595 it was founded in Prague by Rudolf II. In Leiden, however, it was founded after 1641. In Haarlem the guild of Saint Luke had been in existence since 1497 (Miedema 1980).

2 See Miedema (1980:94) for the structure of the guild in Haarlem; see Rombouts and Van Lerius (1864–76:699ff.) for the list of professions in the Antwerp Liggeren.

3 The size of the foot in selected towns in Europe in the fifteenth to the seventeenth century (one *duim* is the distance between the tip of the thumb and the first joint):

Riga (12 duims; 1 ell = 54.8 cm)	27.41 cm
Gdansk/Königsberg (12 duims; 1 ell = 57.4 cm)	28.69 cm
(35 Gdansk feet = 32 Rhineland feet)	
Rhineland (12 duims)	31.38 cm
Rhineland timber foot	29.43 cm
Antwerp (11 duims; 1 ell = 69.5 cm)	28.68 cm
Brussels (11 duims; 1 ell = 69.5 cm)	27.57 cm
Gent (11 Parisian duims; 1 ell = 69.8 cm)	29.77 cm
Herenthals (10 duims; 1 ell = 68.6 cm)	29.18 cm
Liège (10 duims; 1 ell = 65.6 cm)	29.47 cm
Amsterdam (11 duims; 1 ell = 68.78 cm)	28.31 cm
Copenhagen (12 duims; 1 ell = 62.8 cm)	31.38 cm
London (12 inches; 1 ell = 114 cm)	30.48 cm
Paris (12 duims; 1 ell = 111.9 cm)	32.48 cm

4 Here, Miedema's study, *Karel van Mander: Den grondt der edel vry schilder-const* (1973), has been used. In chapter 8, verse 3 (fol. 34v), van Mander writes, "Die ons al dienen om Landtschap te stichten / Op vlas-waedt / oft Noorweeghsch 'hard' eycke plancken / Comt [which will serve us in making a landscape on either canvas or on hard Norwegian oak planks]" (see Miedema 1973:204–5).

5 Dendrochronological dating of the two panels in the Mauritshuis, by Dr. P. Klein in 1993, visualized this statement. On a small panel painted by Hans Memling (inv. 595), measuring 30.1 × 22.3 cm, 167 year rings were present on its narrow edge, whereas a panel approximately three times larger, measuring 62.5 × 101.1 cm, by Abraham Govaerts (inv. 45; signed and dated 1612) showed only 158 rings on its short edge. Both oak planks came from the Baltic area; the felling date, at the earliest, of the former was 1474, of the latter 1608.

6 The German term Mondring, literally "moonring" in English, does not seem to have an English equivalent when used in this context.

7 Long thin oak planks sawn out of the full length of the split pieces of timber.

8 On 9 November 1470 the rules of the guild of Saint Luke were further specified (Van Der Straelen 1855:13–14).

9 The dowels were inserted from the front, through the frame and into the panel. On the back, the ends of the dowels were split, and wedges were hammered into them in order to prevent movement of the dowels.

10 For the frontals of Norwegian altars, this was far from the case. As previously mentioned, the planks were not glued; also the back and front of the tangentially split fir wood were not oriented in the same direction. This arrangement caused an inward and outward warping of the single planks, resulting in a wavy frontal surface.

11 Lindberg (1990) and Skans (1990) demonstrated that ancient glues, such as those recommended by Cennino Cennini, contained from 4.5% to 8% animal fat. They state that in fifteenth-century Italy, manufacturers of glue knew the different working properties of fat and lean glues and had the capability to control the fat content of their products.

12 Peter Paul Rubens, *Portrait of Helena Fourment,* ca. 1635. Oil on panel, 98 × 76 cm. Royal Picture Gallery Mauritshuis (inv. 251), The Hague.

13 Courtesy of the archives of the Mauritshuis Conservation Department.

14 See chapter 17, "Panels for altars and doors; and cheese glue."

15 A drawknife is curved and sharp on the inside of the blade; it has two handles so that it can be drawn with both hands over the panel.

16 The hide was first to be soaked in water, then wrung out, and while damp laid on top of the panels with cheese glue.

17 It is interesting to note that the parchment (ca. before 1300) had some writing upon it. Apparently the parchment was scrap from the royal library in Bergen. The panel maker or the grounder must have been in possession of this scrap parchment for use in filling the unevenness prior to grounding.

18 Cennino Cennini (ca. 1437) advised his fellow Italian painters to take some canvas or white-threaded old linen cloth, soak strips of it in sizing, and spread it over the surface of the panel or ancona. See chapter 114: "Come si dè impannare in tavola [How to put a cloth on a panel]."

19 Vasari describes the method of applying canvas or linen to the panels before grounding and painting them. In his description, the linen not only had the advantage of covering unevenness and joints in the board but also offered a good grip for the ground (Berger 1901:26).

20 A premature conclusion regarding this should be avoided before thorough research has been employed, since later paintings on canvas were glued onto panels—a conservation measure already practiced by the seventeenth century.

21 This requirement was incorporated in a new set of rules received by the Antwerp guild of Saint Luke on 20 March 1493 (Van Der Straelen 1855:30–35).

22 This is comparable to the addition perpendicular to the grain on the Helena Fourment portrait in the Mauritshuis (see nn. 12, 13).

23 On 22 April 1626 the churchwardens of the Cathedral of Our Lady agreed that the panel set created for Rubens to paint for the high altar was too narrow. The panel maker Michiel Vrient was therefore asked to glue another plank onto the existing panel. On 11 May 1626 Vrient was paid thirty-eight guilders for enlarging the panel, and a painter named Adriaen Schut was paid to ground the panel. Drinking money was additionally given to four men who carried the panel back to the church. The artist's sole payment on 30 September 1626, however, was the gratitude of the churchwardens.

24 Information courtesy of chief conservator Martin Bijl, Rijksmuseum, Amsterdam, who is currently preparing an article on this topic. See also Verhoeff (1983).

25 These stipulations were incorporated in the regulations of 11 December 1617 for the joiners' trade (Van Damme 1990).

26 Also note the frame maker Reynier Roovaert (from Antwerp), who produced simple square frames or "dozen frames" ("simpel viercante lysten oft dosynwerck") and in 1637 became a master of the *kistenmakersgilde* (guild of cabinetmakers).

27 This information was kindly made available by conservator Mimi Bang, Statens Museum for Kunst, Copenhagen.

28 The panel in question is Abraham Govaerts, *Forest View with Gypsies,* 1612. Oil on panel (single plank), 62.5 × 106.2 cm. Royal Picture Gallery Mauritshuis (inv. 45), The Hague. Signed and dated: ·AGovaerts· / ·16·12·.

29 The most important contributions on panel makers' marks, organized chronologically by publication date, are as follows: A. Heppner (1940), G. Gepts (1954–60), H. von Sonnenburg and F. Preusser (1979), B. Cardon (1987), J. Wadum (1990), J. Van Damme (1990), M. Schuster-Gawlowska (1992), and J. Wadum (1993).

30 The panels in question, all of which are single planks, are (1) Jan Brueghel the Elder and studio of Peter Paul Rubens, *Nymphs Filling the Horn of Plenty* (see Fig. 25); (2) Hans Jordaens III (attrib.), *The Horatii Entering Rome,* ca. 1615, oil on panel, 67 × 110.5 cm, National-museum (inv. NM 6844), Stockholm; (3) Abraham Govaerts, *Landscape with Figures,* oil on panel, 64 × 101 cm, Kunstsammlungen der Universität, Göttingen (inv. 39), signed: A.GOVAERTS.

31 Meetings concerning the new regulations seem already to have taken place by the summer of 1616, when the panel makers' deans and representatives from the guild of Saint Luke met at the *Robijn* (the Ruby). An agreement was not, however, reached at this point. See Rooses 1878:73–83.

32 The mark of Gabron can be seen on the back of a pair of landscapes painted by Abraham Govaerts: *Woodlandscape with Huntsmen* and *Panoramic Landscape with Fishermen* (1614). Both are oil on panel, 35.5 × 51 cm. The *Panoramic Landscape* is signed: A. Govaerts 1614. Galerie De Jonckheere (cat. 7; *Œuvres de Pierre Brueghel le Jeune,* nos. 29, 30), Paris. His device of interlinking the two Gs in the monogram with a small four-leafed flower was already in use before he registered on the act of 1617, where he used only the two Gs. It bears mention that neither of the two Govaerts panels has any sign of the castle and hands of the Antwerp branding mark. Several panel makers used more than one punch during their career. The author will attempt to determine when the punches changed in a forthcoming article.

33 In 1757 Perteny advised applying a layer of *Handschuhleim* (hide glue) to both sides of the panels, in order to prevent swelling of the wood. As soon as the glue is dry, the side to be painted is scraped, and both sides subsequently grounded, with a soft brush and a mixture of chalk and glue. Two or three layers of ground are applied. The surface of the side to be painted is evened with a damp sponge. Finally, a thin, even layer of oil paint is brushed on. Perteny refers to this layer as the isolating layer. It is stated that oil is normally mixed with lead white, a bit of *"Braunrot"* (the precise meaning of this term is not clear), and carbon black, in order to obtain a reddish gray layer. A second layer of this ground is often applied after the first one dries; this layer transforms the ground into a colored ground (an imprimatura). The last step is to smooth the final layer with a pumice or to scrape it with a knife. Panels prepared in this way, Perteny concludes, have far more value than canvases and can furthermore be used for small and detailed works.

34 The surname de Bout can be found in other versions: de Bont, de Baut, and Debbout. No panels with the monogram of Philips de Bout (PDB), as recorded in 1617, have been found up to the present. Other witters besides de Bout lived in Antwerp during this period: one of his neighbors in St. Antonisstrate, Adriaen van Lokeren, was also a witter, and a little farther away, in Hoplant, lived Frederick de Bout, another witter from the de Bout family. (A Frederich de Bout is mentioned in 1581 as a master violin maker) (Rombouts and Van Lerius 1864–76).

35 The B is written in reverse on the inside of the right leg of the M.

36 The four panels are as follows: Sebastian Stosskopf (1597–1657), *A Bowl of Fruits,* oil on panel, 26 × 34.3 cm, Galerie Leegenhoek, Paris; Wouter Gijsaerts (1649–74), *Fruits,* oil on panel, ca. 30 × 25 cm, Kunsthandel Xaver Scheidwimmer, Munich; a pair of pendants by Peeter Gysels: *A Market,* oil on panel, 40.3 × 52.2 cm, and *A Market in a Town,* oil on panel, 40.4 × 52.1 cm. On the second of the pair, the monogram of M. Bout has been pressed into the ground of the back twice. The pair of pendants is in the Bonnefantemuseum (inv. 526, 525 [RBK-NK.1790, 1863]), Maastricht.

37 At this stage it is useful to make a short excursion to the southern European countries in order to evaluate their method of applying the ground. Cennino Cennini (ca. 1437) (see Lindberg 1989) describes how to start work on a panel by first covering or filling holes, knots, nails, etc., with caution, so as not to smooth the surface too much. Next the panel is sized with a glue made from the clippings of sheep parchments. Two or three coats of glue are recommended; the first coat is thin in order to give the wood an "appetizer." Then the *gesso grosso* and the *gesso sotile* would be applied successively and, finally, made completely smooth (chap. 113).

38 Antonio Filarete (ca. 1400–1469), tells us that the colored imprimatura is applied in an opaque layer. First, the panel is made smooth, and then a layer of size is applied. Following this, a layer of paint ground in oil is applied. (The obvious color choice is lead white, but another color would also be acceptable.) Finally, the drawing is made on top (Berger 1901:6–9). Vasari (Berger

1901:27) says the *mèstica* should first be mixed to an even color out of drying pigments such as lead white, naples yellow, or *terra da campagna*. When the ready-sized panel is dry, the mixture is applied to the entire panel surface with the palm of the hand. Vasari claims that this layer is called the imprimatura by many. Another earlier Italian recipe by Armenini uses this practice of mixing different pigments with a varnish or oil, in order to make a necessary color base for the other colors to be applied during the painting process. See van de Graaf (1958:22).

39 This extensive study is devoted to an explanation of creating a spatial illusion through the use of a primuersel, the thin colored isolation layer between the ground and the paint layer.

40 This primuersel is noted by some to have been applied in an aqueous medium, but no particulars of the testing methods are given.

41 De Mayerne does in fact state here that the grounding of wood does not have to be done exclusively with chalk and glue-water—a weak glue and a strong oil ground on top will suffice as well. However, earlier in his manuscript the contrary is stated: first, he advises the application of a ground of chalk with glue, with glue in two pots of water. When the glue is diluted, enough chalk is added to give the mixture a good consistency; the mixture is then applied smoothly and evenly with a knife. After this procedure, cerise and umber ground in oil are applied, and the panel is left to dry. Later in his manual, he recommends first priming the panel with calf- or goat-skin glue mixed with chalk. When dry, the primer should be scraped and planed with a knife and finally given a thin layer of lead white and umber. He adds that raw umber spoils the colors, suggesting instead Braunrot yellow or red ochre, lead white, and carbon black (de Mayerne, in fact, got this recipe from Abraham Latombé in Amsterdam). He later concludes that the ideal ground consists of lead white and a touch of ochre, red lead, or another color.

42 First the panel is planed quite evenly, and then three layers of ground (with glue) are applied. The last layer should be scraped with a knife in order to create a smooth surface, to which a final layer of colored priming, containing red lead or some other color, can be applied. After this step the underdrawing is made.

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The Making of Panels

History of Relevant Woodworking Tools and Techniques

Philip Walker

Wood has an extraordinary combination of properties that enable it to be used—even to be the material of choice—for thousands of different purposes, including the constitution of panels on which to paint. However, it presents the would-be user with a few minor problems, one of which is that nature delivers it to us in the round, whereas most of its uses require a flat surface. Hence, one of the tasks that woodworkers have faced throughout the ages is the conversion of round trunks or logs into flat beams or boards with square edges. This has been achieved by cleaving (Fig. 1), hewing (Fig. 2), sawing (Fig. 3), or a combination of these techniques.

Cleaving, which may be the oldest method, can be done with simple wedges, nowadays usually made of metal, even though wooden ones can be just as effective; with handled wedges, which look like axes but have important differences in their construction; or with a long, knifelike tool called a froe or riving knife (Fig. 4). It is distinctly possible, at least for the smaller and more modest paintings, that panels were produced by a cleaving or riving process similar to that still used for making roof shingles (Fig. 5).

Figure 1
Monks cleaving tree trunks, ca. 1100. It is likely that this rather knotty log is being split for firewood; nevertheless, the same technique was used to get boards for woodworking purposes. With a series of wedges, often themselves made of wood, flat slabs can be produced that require only a little work with an adze or a plane to true and smooth them. Note that the tool held by the smaller monk is a handled wedge, not an ax; most axes would soon be ruined by pounding, even with a wooden maul, and in any case they were too slim to act as effective wedges.
S. Gregorius Magnus, *Moralia in Job,* part 2, Cîteaux, twelfth century. Manuscript illumination. Bibliothèque Municipale de Dijon, Dijon, France.

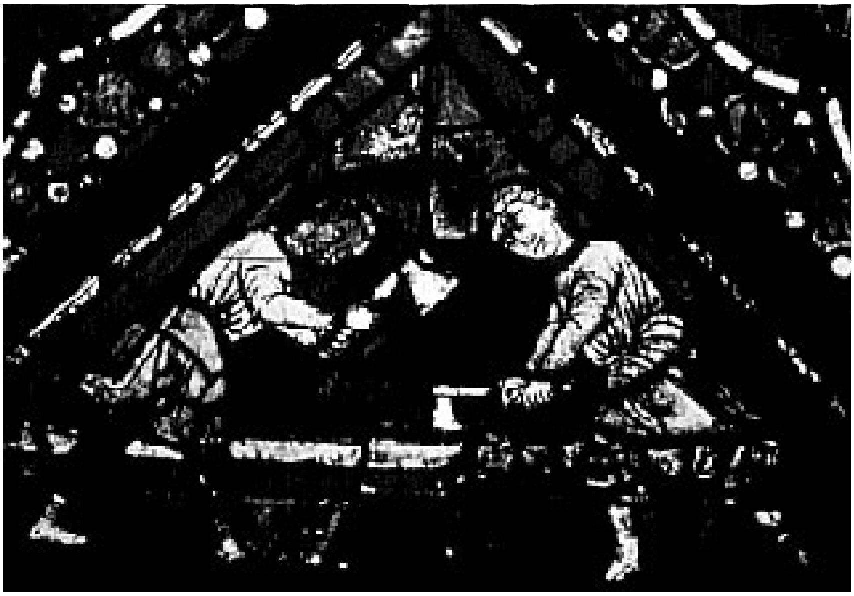


Figure 2
Hewing a tree trunk into a balk. There are many medieval representations of this process, some of which show that the artist was confused about the practical details. This example, with the tree supported on trestles and each man working the timber to his left, his right hand and his right leg forward, is entirely feasible, although there are refinements of the technique that had certainly been practiced in Roman times. Carpenters' window, Chartres Cathedral, ca. 1250. Stained glass.

Figure 3
Ripsawing a balk into planks using a two-man framed saw. The balk is supported at an angle on a single pair of crutches in a procedure that has become known as the seesawing method. *Noah Directing Sawing for the Ark,* thirteenth century. Fresco. Basilica San Francesco, Assisi.

Figure 4
Two froes. The froe is a riving tool that is started into the end grain of a piece of timber with a blow from a wooden club. The split that has thus been started is then extended and controlled by up-and-down leverage on the handle.

Hewing is done with axes. Like cleaving, it appears to have been practiced, in a crude way, from the very earliest period of humankind's use of tools. By the later Middle Ages, it had become a sophisticated technique involving specialized axes (Fig. 6), which was fast and accurate as well as economical, in that much of the waste could be used productively. It is unlikely that panel material was ever produced by hewing alone. Beams were habitually taken straight from the ax, but when thin panel stuff was required, it would normally have been sawn from a hewn balk, a procedure that took advantage of the flat surfaces and right-angled edges produced by the preliminary hewing. Nevertheless, the hewing ax (or side ax, as it is often called, by virtue of its edge being beveled on one side only) was a tool of preference in all stages of woodworking up to the final

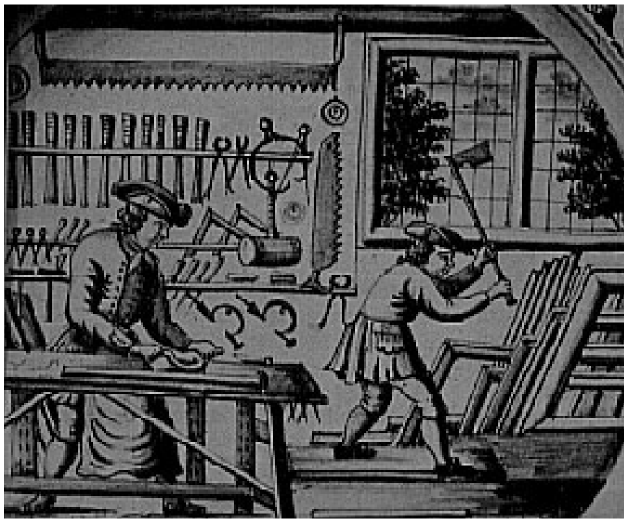
Figure 5
Thin slabs of wood being split off by the use of a froe. Today the method is best known as a way of making roof shingles, but there is clear evidence of its having been used for the production of panels in the Middle Ages.

finishing, as can be seen in illustrations of seventeenth- and eighteenth-century workshops (Fig. 7a, b).

Sawing, although depending on a tool that is modern in comparison with the wedge and the ax, has quite a long history, as ancient Egyptian and Etruscan evidence shows (Fig. 8). Until some three hundred years ago, the limitations of metallurgy and of metalworking techniques meant that an open saw blade could not be pushed without its buckling. But this was not a serious drawback as the saw could either be pulled, as it still is in some Asian countries, or be held under tension in a wooden frame, still the preferred solution in many continental European countries. In either case, quite astonishing accuracy was obtainable by specialist sawyers (Fig. 9). J. A. Roubo, in *L'art du menuisier,* published in 1769, warns his readers that even though it is possible to saw eleven sheets of veneer out of one inch of timber, in his opinion, eight to the inch gives the minimum thickness to allow proper finishing after the veneer has been laid

Figure 6
Some of the types of broad ax used for shaping timber in medieval Europe. Most have edges beveled on one side only, like chisels, and are therefore designed for either right-handed or left-handed use.

a



b

Figure 7a, b
Workshops belonging to joiners who appear to have specialized in supplying artists' needs such as frames, boxes for paints, palettes, easels, and panels. Note the prominence of ax usage even in such workshops engaged in light and delicate work. (a) Jan Joris van Vliet (associated with Rembrandt), 1635, etching; (b) decoration of a delftware plate, 1769.

(Roubo 1769). Admittedly the French inch was then 27 mm—about one-sixteenth greater than today's inch—but even so, taking into account the loss in sawdust, the skill that would have been required is almost beyond imagination.

With such accurately sawed timber available, artisans could proceed directly to the next stage in preparing a panel, but cleft or hewn surfaces might well require some preliminary trueing and flattening, normally done with an adze (Fig. 10). Here again, the accuracy achieved by skilled

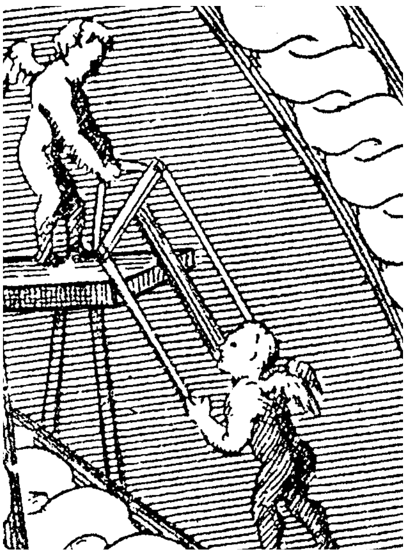


Figure 8, above
Line rendering of painting on an Etruscan bowl (ca. 500 B.C.E.?), which demonstrates the antiquity of sawing as a method of converting timber. Here the two-putto saw is cutting a thick plank held horizontally on high trestles. Saws like this, held under tension in wooden frames, could have long, thin blades and could be pushed or pulled. Open-bladed saws, which had been used in Egypt for similar purposes since at least 2000 B.C.E., could not be pushed without buckling.

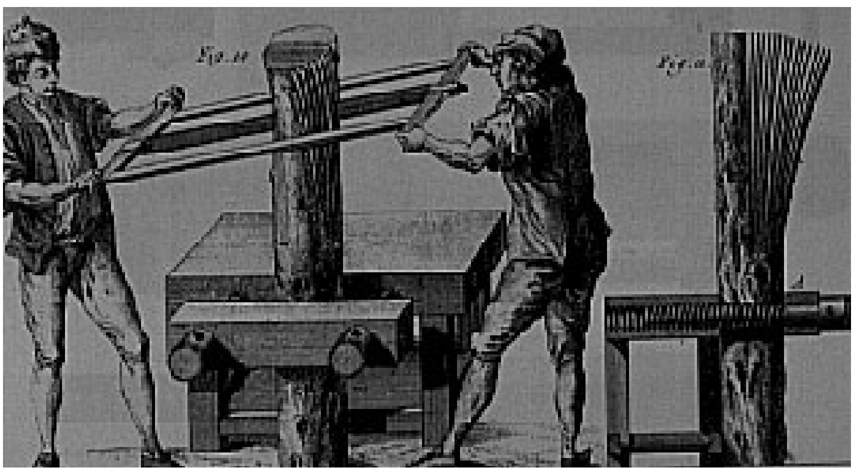


Figure 9
Sawyers producing veneers (Roubo 1769:pl. 278).

Figure 10, right
A group of adzes. Used with a chopping action toward the user and usually cutting across the grain, adzes were the tools of preference for smoothing or hollowing wood. The long-handled example is still fairly familiar in wooden boatbuilding and certain other trades, but the shorter ones, known as stirrup or slot adzes, were likely to have been the panel maker's choice. Ancient Egyptian adzes have been dated to 1450 B.C.E.

Figure 11, far right
Workman, using a stirrup adze, works across the grain of a board that he is holding in his hand. Detail of Lasinio's nineteenth-century engraving (from his *Pitture a fresco del Camposanto di Pisa* [Florence, 1812, 3/1828]) of Piero di Puccio's 1390 fresco *Noah's Ark,* in the Camposanto, Pisa.

workers is such that the surface may appear to the modern eye to have been planed (Fig. 11).

Once reasonably true and flat surfaces have been produced, the next step is to obtain sufficient width for the desired panel. Here we come up against the second problem that nature presents.

More than half the total weight of a newly felled tree may be water. As the wood dries out to the point at which it reaches stability with the ambient humidity, it will shrink in its width and is liable to crack or warp, depending on how it has been cut. The only boards reasonably free from these tendencies are ones radiating directly from the tree's heart (Fig. 12a–c). Since the heart itself is pith and must be discarded, the widest quartered (that is, radial) board will be somewhat less than half the diameter of the tree. Various methods have been used to get the maximum number of such quartered boards from any given log, all involving a certain inevitable wastage. But one might imagine that through most of history, merchants were content to take the four radial, or eight virtually radial, boards that presented themselves when the log was first opened into quarters, sell those at a high price, and saw up the remainder as less valuable material.

If a panel of greater width than one quartered board is required, and if a heavy and willful wood such as oak is being used, it will be necessary to join two or more boards edge to edge. As N. E. Muller has pointed out, an alternative that seems to have been preferred in fourteenth-century Italy was to use a milder, lighter wood such as poplar; take a full-width board produced by the simple method of "plain," or "through-and-through," sawing; and then restrain its tendency to distort by fixing it to a substantial framework or battening (Muller 1993).

If boards are to be joined edge to edge, they must be made to fit closely. This almost inevitably requires the use of a long, finely adjusted plane, although the ancient Egyptians, who did a lot of painting on their elaborately assembled and jointed wooden coffins and mummy cases, did not possess planes. They probably managed by the tedious process of rub-

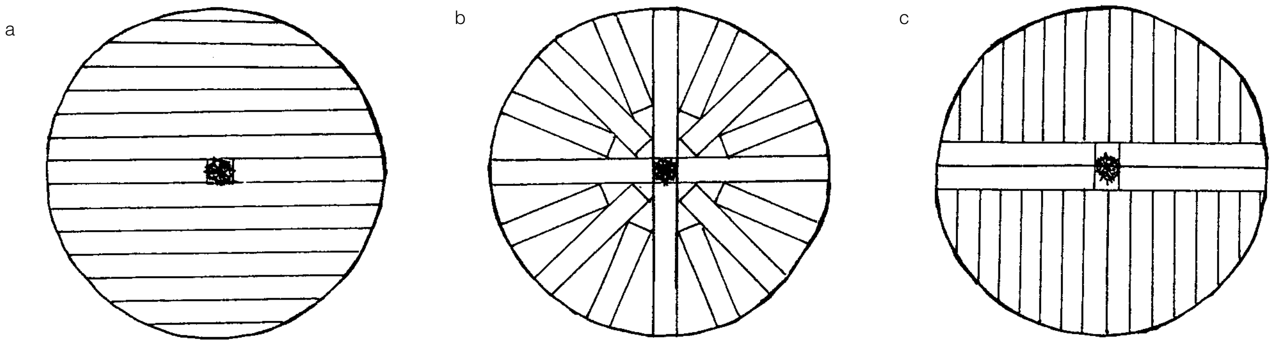


Figure 12a–c
Three ways of sawing a tree into boards: (a) the simplest method, producing only two truly radial boards; (b) another method yields all radial boards, but the pattern is difficult to saw, and it leaves a lot of waste; and (c) a simple method that yields eight virtually radial boards.

bing adjoining parts together with sand as an abrasive. Roman planes—the earliest known examples of this valuable woodworking tool—have been found up to 44 cm in length. This is rather shorter than the modern joiner's try plane, but considerably longer ones are evident from the later Middle Ages (Fig. 13).

The preferred method of producing an accurate edge joint with a long plane is to lay out all the pieces side by side in the order in which they are to be assembled, identifying the top, or face, side with a mark across all the pieces (Fig. 14) and then "folding" each adjoining pair in turn, putting them back to back into a vice or other holding device. Shooting with the long plane along the two edges thus held closely together will produce two surfaces that are straight along their length. Any inaccuracy in their width caused by the plane's having been tilted to one side or the other will automatically be compensated for when the two pieces are "unfolded" back into a single surface.

A closely matching fit between each pair of boards having thus been achieved, the joint must be fixed. In the case of panels for painting,

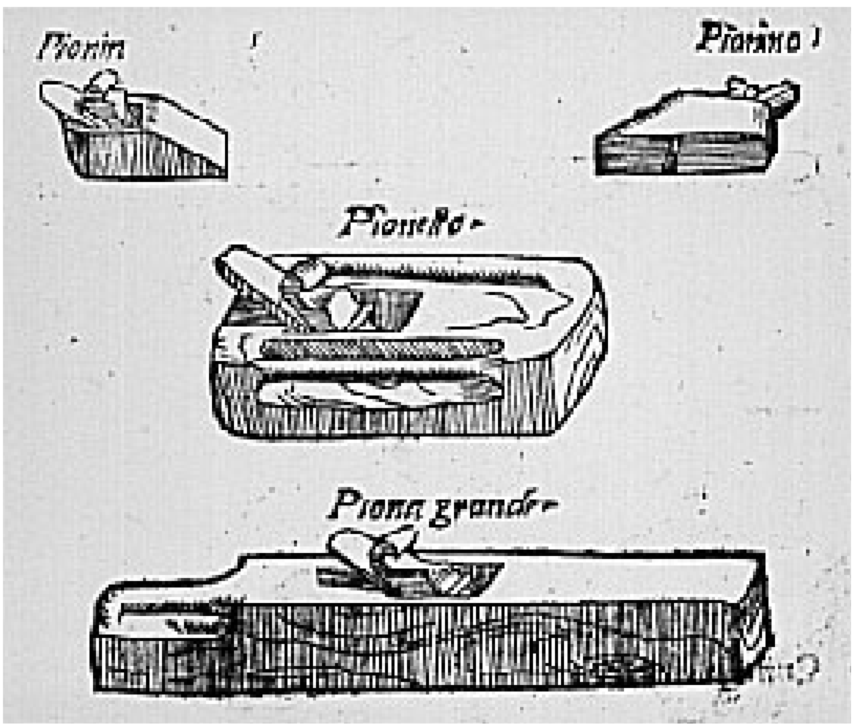


Figure 13
Illustration from Agostino Gallo's *Tredici Giornate* (published in Venice in 1566 by Bevilacqua), showing three types of plane that perform the three basic functions of the woodworking plane, regardless of the great variety of external appearances and names favored in different countries at different times. These functions are (1) getting rid of waste as fast as possible in order to produce a workpiece of roughly the desired dimensions. The plane in the center fills this role and would today be called a jack or roughing plane; (2) producing geometrically accurate faces on workpieces, usually so that they will form a perfect fit with other pieces, as in the case of the multisection panels under discussion. The length and truth of the plane's sole (underside) are the essential features, as a straight plane pushed over an uneven face will go on cutting off high points until the surface is as true as the plane itself. Such planes, of which that at the bottom is an example, are called try planes because they true (or "try") the workpiece; and (3) smoothing the visible surface of a finished artifact so that it is agreeable to touch and sight. For this purpose the plane's cutter must be finely set in a narrow mouth in the plane's sole, and smoothing planes should be short, as geometric accuracy is no longer important, and the plane can be allowed to ride the ups and downs of major undulations without having to level them. The top two planes fit this requirement.

Figure 14
Roubo's illustration for the making up of panels (Roubo 1769:pt. 1, pl. 18). At the bottom, four boards are marked so that they will be kept in the intended order and relative position when they are trued and glued. There are clamping devices to hold them together while the glue is setting, glue pots and brushes, and, at the top, tonguing and grooving planes with their cutters, in case it is desired to joint the board edges in this way.

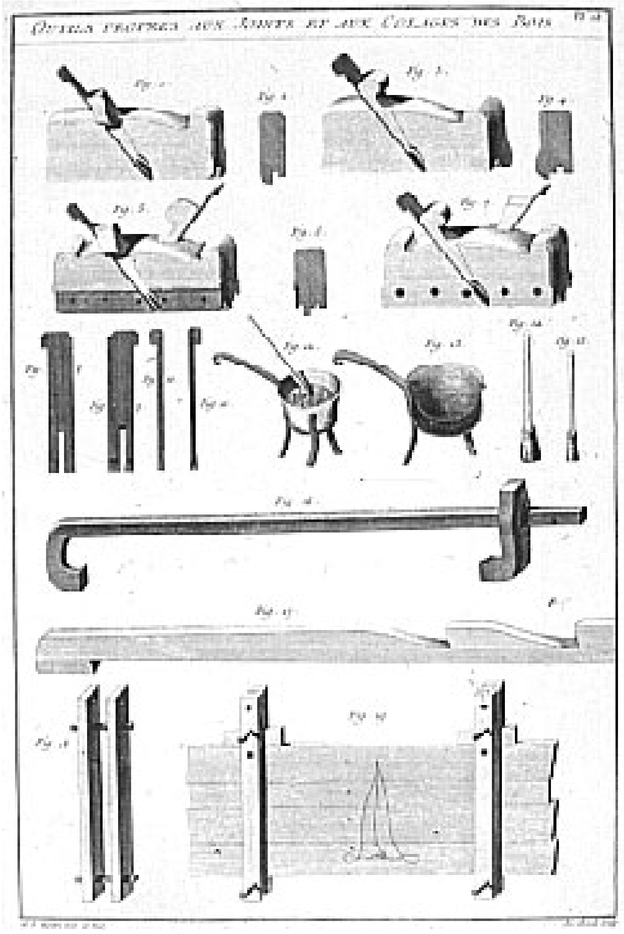


Figure 15
Routing out of the housing across a multi-section panel, as part of the installation of a tapered dovetail batten (from G. Heine's article on historical and technical aspects of tapered dovetail battens [Heine 1984]).

glue alone would seem adequate. Various mechanical fixings, such as battens, loose tongues, tongue and groove, or dovetail keys might also be employed. Battening serves to resist warping as well as to hold several boards together. As G. Heine (1984) has demonstrated, a particularly effective method is tapered dovetail battening, which holds firmly in all directions while permitting a certain amount of shrinkage (Fig. 15). Muller has recorded that both Florentine and Sienese composite panels are found with internal dowels (Muller 1993). However, properly applied to well-fitted joints and protected from damp, the traditional animal glues have proved their strength and durability over many centuries, even on edges—such as the backs of stringed musical instruments—that are much thinner than those of panels for painting.

Finally, the now-solid board of required dimensions needs a finely smoothed surface to receive the paint. Since geometrical accuracy is no longer as important as in the preparation of the joints, the first approach to this task is with a short plane for smoothing, some 15–20 cm long. If the wood has been carefully selected and does not present any wild or contrary grain, the smoothing plane will achieve a surface ready for finishing with abrasives. If, however, there is difficulty with the grain tearing out in places under the plane, then recourse will be made to scrapers, such as pieces of broken glass or, more recently, thin steel plates the edges of which have been turned to form microscopic hooks.

The ultimate finish has always been achieved by abrasion. The ancient Egyptians used stone rubbers. In Europe various dried fish skins, or rushes that in their natural growth had picked up silicates, were the norm until the arrival of accurately graded glasspaper. Glasspaper of a sort was available in the eighteenth century, but it must have been coarse or inconsistent, as Sheraton's *Cabinet Dictionary* (1803) states that its use was followed by rubbing with rushes.

Acknowledgments

In an almost undocumented field, that of the woodworking trades before the eighteenth century, it has been necessary to pick up information from a wide variety of sources not originally intended as technical treatises. In this task the author has been greatly helped by the observations recorded by Norman E. Muller, Elliot M. Sayward, and other members of the Tool and Trades History Society and of the Early American Industries Association. The author is also indebted to Elliot M. Sayward for drawing attention to the illustrations that are used in Figure 7.

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PART THREE

History of the Structural Conservation of Panel Paintings

Critical History of Panel Painting Restoration in Italy

Andrea Rothe

Modern Italian panel conservation techniques are directly related to a long history of panel construction that dates to antiquity and flourished from the Middle Ages to the Renaissance (see Uzielli, "Historical Overview," herein). The ingenuity and intuition of the woodworkers of the past compensated for their lack of scientific understanding of this complex and widely diverse material. Central Italy, in particular, produced a large quantity of paintings on panel. Many of them—such as the Cimabue Crucifix in the Church of Santa Croce in Florence—were constructed to the highest standards of craftsmanship. The early woodworkers often used techniques or methods similar to those applied by modern-day restorers in treating panels—techniques such as movable crossbars (Figs. 1, 2) and coats of gesso, paint, or red lead to seal the backs of panels (Fig. 3). These sealants were probably applied as humidity barriers and protection against wood-boring insects, and panels treated in this manner have often survived better than untreated panels.

The large number of panel paintings in Italian churches and museums created the need for appropriate conservation work, particularly in modern times. The state-run centers of Florence and Rome have become the largest and most advanced in Italy and have generated a group of highly qualified experts in this field. The volume of panel work that has been executed in Florence far surpasses that of any other conservation center in the world.

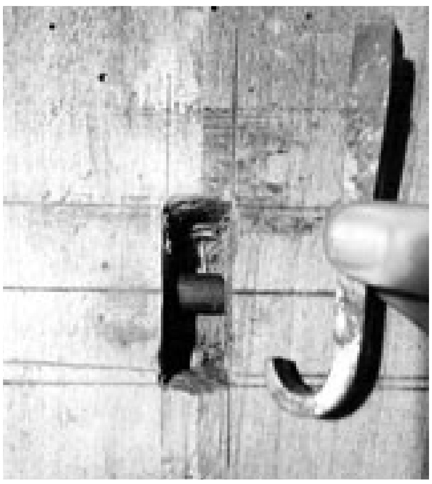


Figure 1, right
Fra Angelico, *Annunciation,* ca. 1440. Reverse. Tempera and gold leaf on panel, 95 x 158 cm. Convent of Montecarlo, San Giovanni Valdarno. The original metal pin inserted from the front of the panel, along with the hook that latches onto it, is shown.

Figure 2, far right
Fra Angelico, *Annunciation,* reverse. This detail of the original crossbar shows the metal hook inserted into it and the metal wedge that holds it in place (see Fig. 1 for the hook-and-pin mechanism). This mechanism ensures free lateral movement of the panel.

Figure 3
Riminese, *Crucifixion,* fourteenth century. Reverse. Tempera on panel. Galleria Nazionale delle Marche, Urbino. Back of the panel showing a gesso ground covered with a red tempera layer (possibly red lead) and an ornate decoration.

More conservative methods have replaced the radical ones of the past. Up to the late 1950s, it was common practice in Italy to transfer onto a new support those panel paintings that had severe woodworm damage, flaking paint, or warping. Such interventions date to Napoleonic times, when many of the paintings that had been plundered from Italian churches and collections were transferred onto new supports because of severe flaking problems, caused particularly by the stress suffered during the long trip to Paris. One such example is Raphael's *Saint Cecilia* (now in the Pinacoteca in Bologna), which was taken to Paris in 1798 and subsequently transferred from panel to canvas. Because of this drastic intervention and the additional effects of aging, it has adopted the surface characteristics of a canvas painting. Fortunately, as methods of wood conservation became more effective and less radical, transfers have become nearly obsolete.

Splits in the wood and failure of original joins are caused by various factors, such as rigid restraints, defects in the original construction, and excessive fluctuations of humidity and temperature. Until the dawn of synthetic adhesives such as polyvinyl acetate (PVA) emulsions and epoxies, panels were rejoined with animal glue and casein. Panels that had completely separated were planed on both sides of the split to level the surface for a butt join, but this was often achieved with a considerable loss of original color. In other cases—such as the large panel by Fra Filippo Lippi, *The Coronation of the Virgin* in the Uffizi—the splits were rejoined, but no care was taken to realign the planks, and the paint layer was simply planed down and repainted. The insertion of dovetails straddling splits was common until the late 1950s. The V-shaped wedges, which are still used today, are mentioned in a book by Secco-Suardo, although he recommends adding the dovetails as a precaution (Secco-Suardo 1866:68–70). The use of dovetails to repair split panels dates to at least the sixteenth century. They can, for instance, be made of walnut, such as in the original construction of the back of the panel for Lorenzo Lotto's Martinengo Altarpiece in San Bartolomeo in Bergamo, dated 1516 (Brambilla Barcilon 1978:60–63). There are original dovetails found in the front of some paintings, such as Luca Signorelli's *Adoration of the Shepherds* (Fig. 4). Cross-grain wedgelike

Figure 4
Luca Signorelli, *Adoration of the Shepherds,* 1496. Oil (?) on panel, 215 × 170.2 cm. National Gallery, London. Detail. The dovetail set into the front of the panel is original.

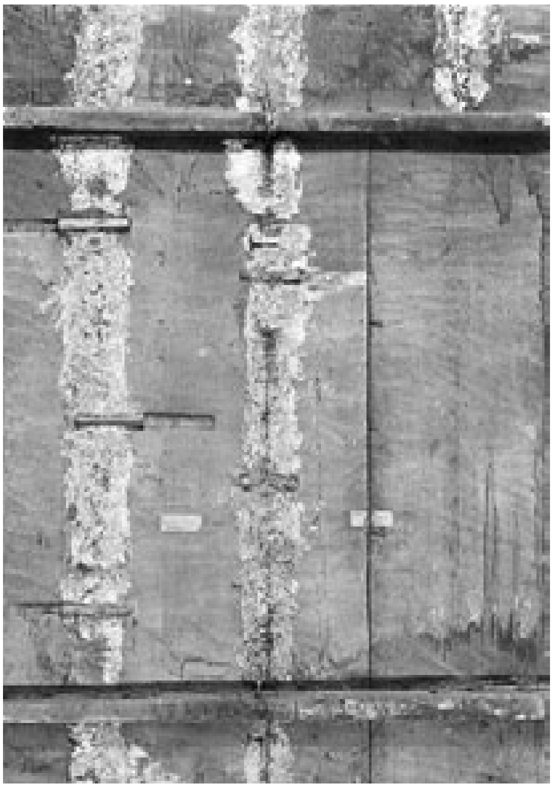


Figure 5
Domenico Puligo, *Virgin and Child with Saints,* ca. 1522. Reverse. Oil (?) on panel, 195 × 289 cm. Cathedral, Laterina, Italy. Repairs, dated 1634 on the crossbar, with applications of flax fibers and gesso over the cracks, which have also been reinforced with wedgelike insertions placed into carved-out channels.

insertions are present on a panel, Domenico Puligo's *Virgin and Child with Saints,* from the cathedral in Laterina, with the inscription "RESTA[urat]a 1634" on the crossbar (Fig. 5). On some occasions one finds dovetails set into the front, a method that destroys the paint layer locally, as in the organ shutters by Amico Aspertini, *The Miracle of the Workman,* in San Petronio in Bologna (Fig. 6).

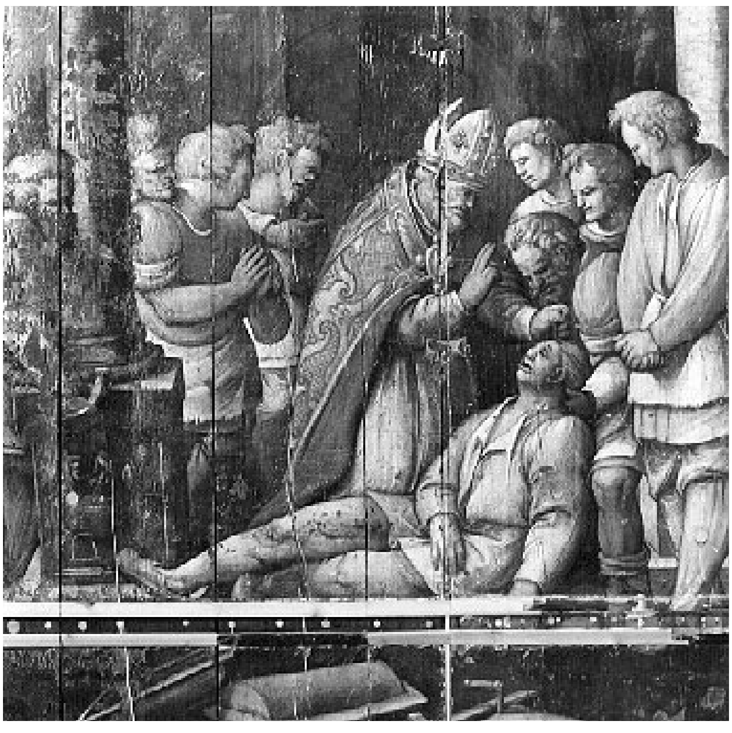
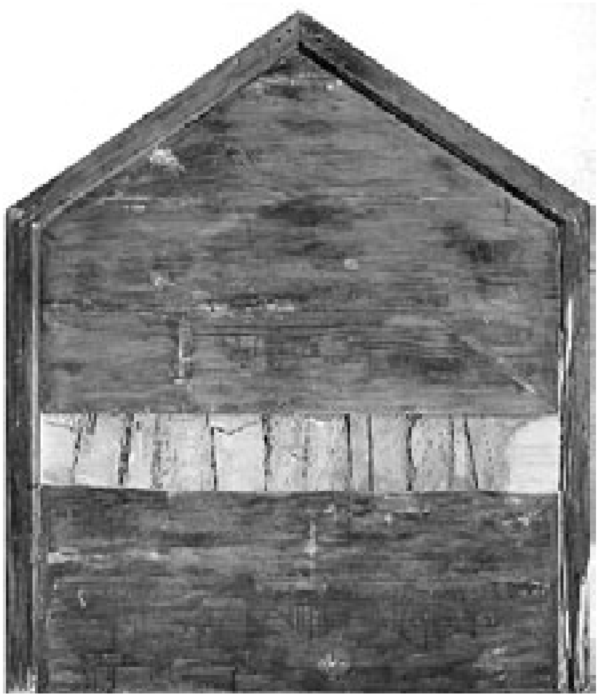


Figure 6
Amico Aspertini, *The Miracle of the Workman* (organ shutter), 1531. Oil or mixed technique (?) on panel, 500 × 202 cm. San Petronio, Bologna. Old repairs were made with dovetails set into the front of the panel.

Figure 7
Parri di Spinello, *Madonna della misericordia,* 1437. Reverse. Tempera on panel, 199 × 174 cm. Museo Statale di Arte Medievale e Moderna, Arezzo. Exposed by the removal of a fake fir backing, inserts of fir with animal glue can be seen; they were inserted into lost areas of the severely worm-eaten original poplar panel.



In other cases, such as the dated restoration from 1634, futile attempts were made to reinforce the splits by gluing strips of wood and hemp fibers over them. On some panel backs, however, one can find hemp fibers in very good condition that date from the time the panel was made. In two cases that were probably nineteenth-century interventions, severely worm-eaten and hollowed-out panels were filled with many different pieces of wood and abundant animal glue. These had caused extreme contractions and cleavage effects on the front, as on the painting by Parri di Spinello, *Madonna della misericordia,* from the Museo Medievale Moderno in Arezzo (Figs. 7, 8).

Figure 8
Parri di Spinello, *Madonna della misericordia*. This close-up of the ground and paint layer shows extreme distortions caused by the contraction of the glue on the back and by the imperfect fit of the fir insets shown in Figure 7.

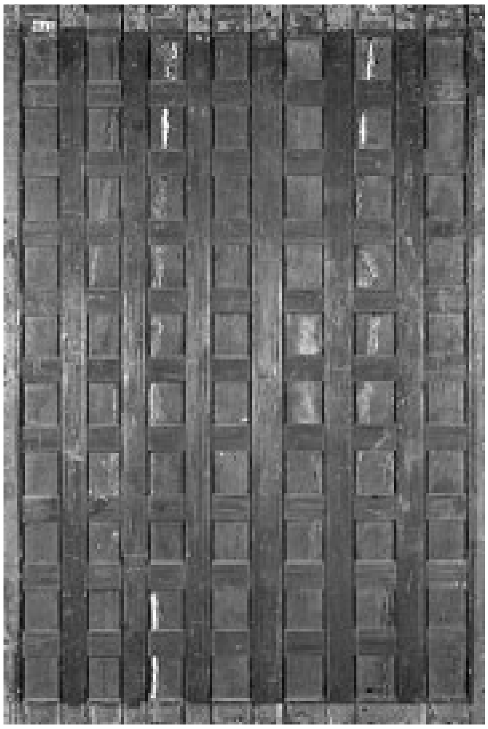


Figure 9, above
Giulio Romano, *The Birth of Bacchus,* ca. 1533. Oil on panel, 127.3 × 79 cm. The J. Paul Getty Museum, Los Angeles. Splits and surface deformations, creating what is often called the "washboard" effect, have been caused by a nineteenth-century thinning of the panel and application of a heavy cradle.

Figure 10, above right
Giulio Romano, *The Birth of Bacchus,* reverse. The cradle was applied to the back when the panel was thinned. Rigid and heavy, it has contributed to the splits and deformations on the front (Fig. 9).

In nineteenth-century Italy, as in the rest of Europe, more in-depth interventions treating warpage problems became common practice. The brutality with which deformed panels were straightened generates respect for the malleable and resilient nature of wood. Panels were planed down to a fraction of their original thicknesses and often humidified to relax the warp. Then, invariably, a heavy cradle would be applied. Often the thinning process and application of the rigid cradle later caused severe deformations of the surface (Figs. 9, 10). Some of the methods described by Secco-Suardo include the application of hot cinders and sand, as well as the addition of hot bricks, if necessary, to prolong the process. If the panels were severely deformed, he recommended cutting longitudinal grooves at intervals of 1–2 cm before applying the above-mentioned hot cinders. After the panel had been straightened, strips of wood were glued into the grooves (Secco-Suardo 1866:55–65). Unfortunately, cutting grooves to straighten panels is still practiced today by some restorers and accounts for the dreaded "washboard" effect.

For partially deformed panels, Secco-Suardo also mentioned a method developed by a certain Déon, a Frenchman. In this method, tapered longitudinal V-shaped channels are sawn into the panel at intervals of 1–2 cm; V-shaped wooden strips are wedged into these with the aid of animal glue and humidity. Next the panel is placed face down on a bench and clamped tight with crossbars and wedges for an extended period (Secco-Suardo 1866:75–88). Unfortunately, all of these drastic interventions can lead to the formation of a new series of cracks and splits.

Today the disastrous effects of most of these radical interventions are apparent, and the general tendency is to leave distortions alone so as not to cause other problems (Stout et al. 1954). Cradles that pose no danger are best left on; and if the battens stick, they are removed and sanded. Paraffin is then applied to make them slide more easily. Many cradles, though, have had to be removed because of the excessive restraint they

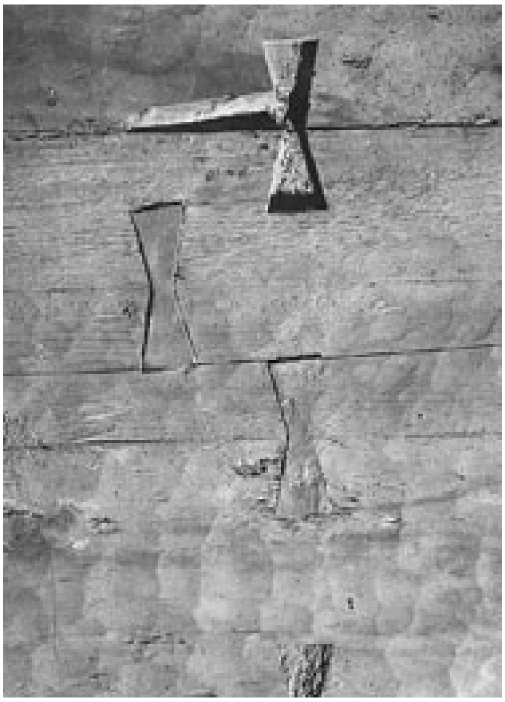


Figure 11
Simone de Magistris, *Deposition,* 1576. Reverse. Tempera (?) on panel, 265 × 182 cm. Convento dei Cappuccini, Potenza Picena, Italy. These old dovetails have caused a new series of splits in the panel.

Figure 12
Two grooves cut into a poplar panel at different depths contain the same poplar wedges glued with a PVA emulsion glue. There is a marked cracking of the ground opposite the top groove, which is cut only halfway into the panel; opposite the bottom groove, which is cut into the whole thickness of the panel, there is no cracking of the gesso.

exerted on the original panel and have been replaced with others of different designs and varying degrees of effectiveness. In this context it is interesting to note the shrinkage that has occurred on many panels that were thinned and cradled in the nineteenth century. The shrinkage can be measured by how far the battens extend beyond the sides of the panel (Buck 1978)—sometimes as much as 0.5 cm on a panel only 90 cm wide.

In postwar Italy, methods of panel painting conservation became more sophisticated. Splits were rejoined with wedges, in the method mentioned by Secco-Suardo in 1866, but the wedges were tightly fitted into carefully cut V-shaped grooves and glued with PVA emulsion glues.[1] Dovetails were no longer used because it was observed that they did not properly secure breaks and splits and, in fact, created new ones (Fig. 11). Opinions have differed on how deep the V cuts should go into the panel. Ultimately a general consensus was reached that they be cut as close as possible to the original gesso from the back and that the wedges be carefully fitted into these to ensure a lasting hold. Deformations and cracking have been observed in those cases where the incisions have gone only halfway into the panel, such as in a sample made in 1961 (Fig. 12).

Modern restraints or cross braces are made to be as unobtrusive as possible, and original battens are often readapted if they still exist. Otherwise new ones are made that require the least intervention to the original panel. It is interesting to observe how new battens have become progressively lighter since the early 1950s, thus reducing to a minimum the amount of reworking required on the back of the panel. Many different constructions were designed by the various conservation centers. Metal T bars were used, as well as brass tubes that slide inside wooden braces or cleats attached to the panel with or without metal sleeves. These sometimes have the drawback that they behave more like clamps and actually block the movement of the panel if there is a tendency for it to warp. Other crossbars—such as the wooden ones constructed at the various

Figure 13, above
Duccio di Buoninsegna, *Maestà,* 1311. Tempera and gold leaf on panel, 214 × 412 cm. Museo dell'Opera del Duomo, Siena. This detail of the left section before the restoration in the 1950s clearly shows two of the six vertical cuts made in 1771.

Figure 14, above right
Duccio di Buoninsegna, *Scenes from the Life of Christ,* 1311. Tempera and gold leaf on panel, 214 × 412 cm. Museo dell'Opera del Duomo, Siena. The left section of the former reverse side of the *Maestà* before the restoration of the 1950s, showing the horizontal cracks (marked with tape) that formed after the separation from the *Maestà*.

restoration departments in Florence—have proved to be very effective. The present-day interventions at the Fortezza da Basso in Florence are described by Castelli (see "Restoration of Panel Painting Supports," herein).

In the 1950s the Istituto Centrale per il Restauro in Rome carried out some of the most complex interventions that had ever been attempted on panels. One of them is the *Maestà* by Duccio di Buoninsegna in the Opera del Duomo in Siena (Fig. 13). The large altarpiece was originally painted on both sides. It was constructed with two layers of poplar running perpendicular to each other, but in 1771 the altarpiece was divided into seven panels; subsequently, the scenes depicting the life of Christ (Fig. 14) were separated from the sections of the large frontal scene (Fig. 15). During this process the blade slipped twice, cutting through the front of the central and widest panel and causing severe damage to the Virgin's face and her blue robe (Istituto Centrale per il Restauro 1959:17–19) (Fig. 16). After the front was separated from the back, the panels of the *Maestà* were rejoined.

For nearly two centuries the newly exposed wood was subjected to atmospheric fluctuations that caused new tensions that resulted in a series of large splits, cracks, and severe cupping of the paint layer (Istituto Centrale per il Restauro 1959:20–26). During the last restoration, these cracks were stabilized with the insertion of wedges, and the irregularly cut areas of the back were filled and reconstructed with seasoned poplar insets to create an even surface (Fig. 17).

Given the size, weight, and proportionately extreme thinness of the front panels, a system had to be developed to sustain the large *Maestà* altarpiece. For this purpose a steel support system was devised consisting of fifteen flat steel braces about 0.5 cm thick and 2.5 cm wide. The braces

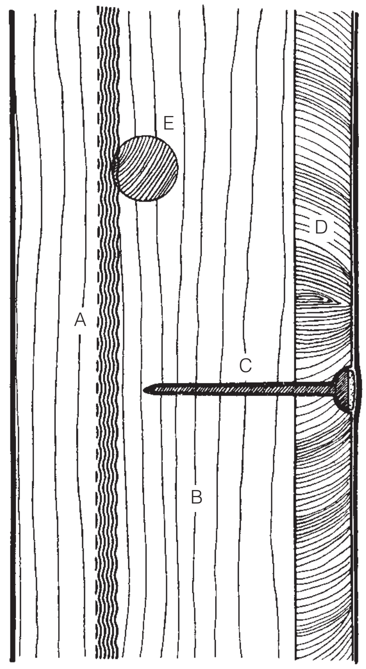
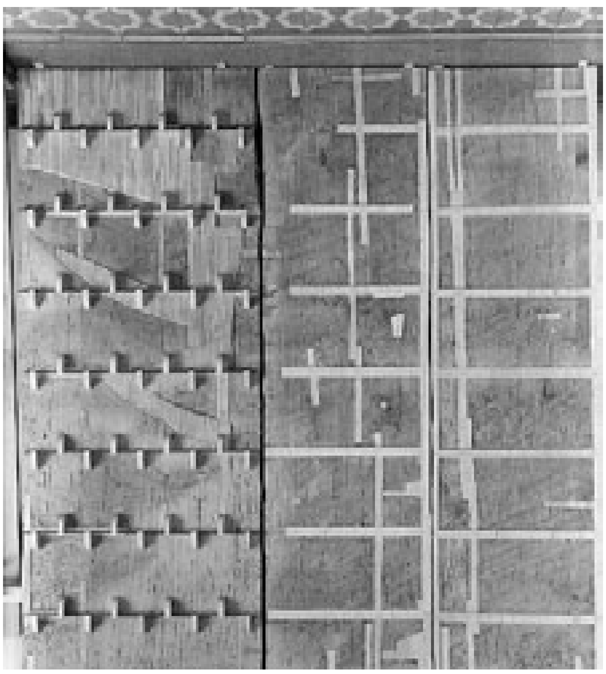


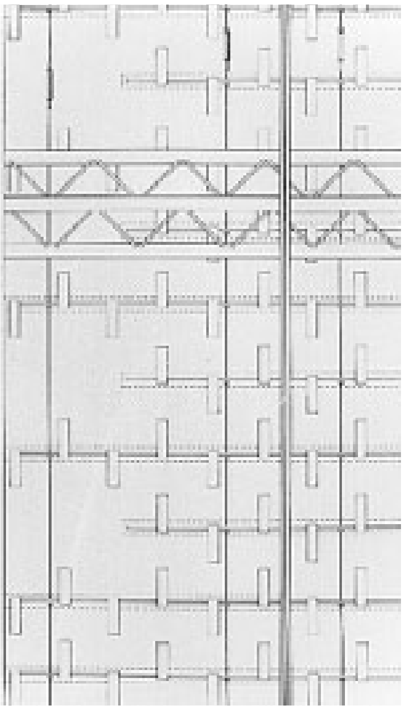
Figure 15, above
Duccio di Buoninsegna, *Maestà* and *Scenes from the Life of Christ*. Drawing showing the cut (A) that separated the front from the back. The portion remaining attached to the *Scenes from the Life of Christ* (Fig. 14) consisted of a horizontal layer (D) and a vertical layer (B). The thickness of the vertical layer, which is the part that is missing from the back of the *Maestà,* was dictated by the depth of the nails (C). One of the original dowels (E) is shown. In this manner, the two painted surfaces (F) were divided.

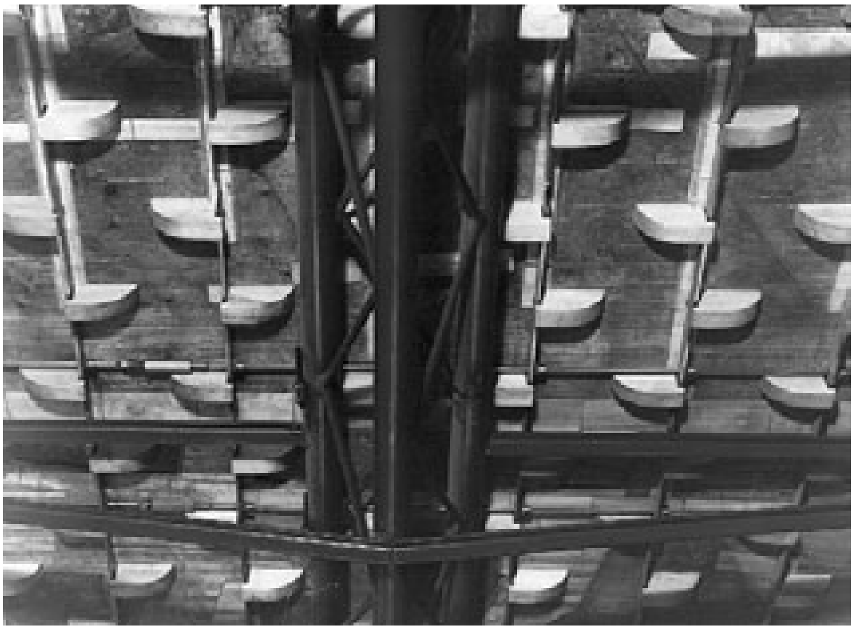
Figure 16, above right
Duccio di Buoninsegna, *Maestà*. This scene of the Virgin with the Christ Child before restoration, photographed in raking light, clearly shows one of the cuts caused by a blade that slipped during the separation process of 1771.

Figure 17, right
Duccio di Buoninsegna, *Maestà,* reverse. On the left, the irregularly cut areas on the back of the central panel have been filled, and the cradle has been attached. On the right, the splits have been repaired, and the panel is ready for cradling.

run across the width of each of the seven panels, perpendicular to the grain of the wood (Fig. 18). The braces were attached on edge with a series of wooden pegs with metal reinforcements (Fig. 19). About sixteen thin, vertical steel rods were inserted through these steel braces. Each steel rod had a series of small clamps placed below each brace. The clamps were later individually calibrated. The vertical rods were attached to a steel frame that was constructed on a principle similar to that of an airplane wing (Fig. 20). With this sturdy support, an even distribution of the weight of the panel was ensured (Istituto Centrale per il Restauro







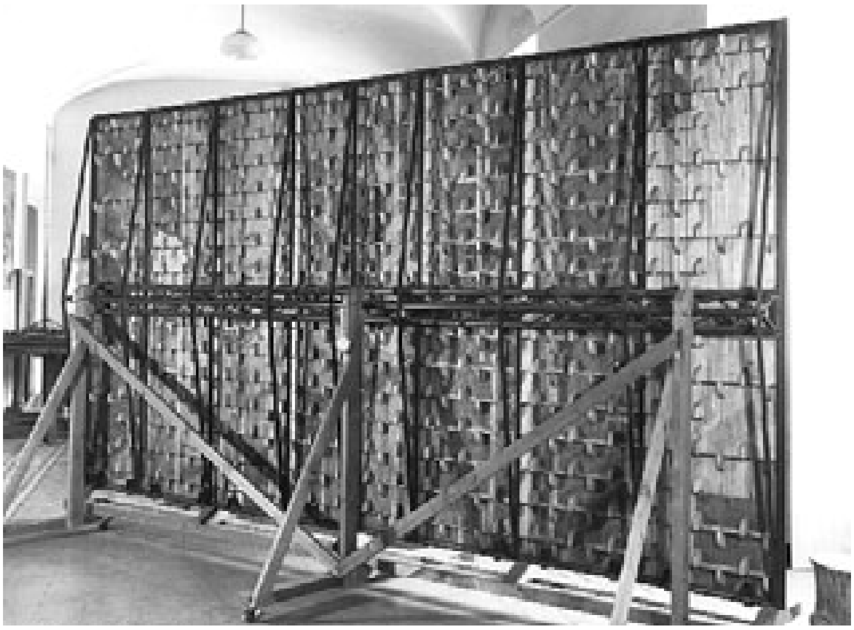


Figure 18, above
Duccio di Buoninsegna, *Maestà*. Drawing of the metal support attached to the horizontal cradle on the back of the panel.

Figure 19, above right
Duccio di Buoninsegna, *Maestà,* reverse. Detail of the support mechanism.

Figure 20, right
Duccio di Buoninsegna, *Maestà,* reverse. The completed support mechanism on the back of the panel.

1959:35–47). Although the room in which the painting is exhibited was the first in Italy to have a climate-controlled environment, damage to the installed equipment by lightning and general neglect (such as wide-open windows) have severely tested the support of the *Maestà,* which, nevertheless, is holding up very well.

The back panels, with the scenes from the life of Christ that had not been thinned in the separation, still had the original nails that had held the two panel layers together. A slice of the wood belonging to the back of the *Maestà* also remained, but it had to be removed. The nail heads that were under the paint layer had to be removed because of the damage from the progressive accretion of rust (Istituto Centrale per il Restauro 1959:29–34). After the nail heads were removed from the back with a hole saw, the holes were filled with poplar plugs inserted parallel to the wood grain. The cross braces were constructed in the same way as those of the *Maestà* (Carità 1956).

Another example of even weight distribution is found on Raphael's large altarpiece, *The Transfiguration,* in the Vatican Museums. The panel is constructed with planks that have been glued together vertically. The Vatican restoration team devised a system similar to that used on the Duccio altarpiece by hanging the painting on horizontal steel crossbars. These steel crossbars are fitted into slots cut into the vertical sections of a large metal frame. Clamp screws attached to the vertical frame sections sustain each of the crossbars. They are calibrated and tightened individually in order to distribute the weight evenly over the whole height of the panel. This gives the heavy panel greatly improved support; fortunately, it has not been thinned and still has the original crossbars.

As mentioned above, many different systems were invented for building crossbars or braces out of materials such as steel and brass. Many of these systems were proposed by the Istituto Centrale per il Restauro (Carità 1953). Today most of them seem rather cumbersome and incompatible with the artworks (Carità 1956). The *Maestà* metal support system still seems to be the most functional. One proposal, however, seems promising: it uses plastic pegs and thin steel rods to hold a panel suspended inside a metal frame (Carità 1956:124–31).

Del Zotto and Tonini (1993) developed some interesting proposals for extremely flexible battens. Their system makes use of ball-knuckle joints attached to the panel with hardwood plugs and inserted into a flexible sleeve that acts as the crossbar. The spring action of the sleeve combined with the free movement of the joint gives the panel maximum freedom to move laterally and permits limited movement perpendicular to the crossbar.

The great flood of 4 November 1966 caused enormous damage to artwork in Florence and Venice. The tragedy helped promote an increased understanding of the behavior of wood and the effectiveness of some of the past interventions on panels. Wooden crossbars with pegs made out of *mansonia*[2] proved to be very effective in holding together the waterlogged panels that expanded with absorption and then, upon drying, contracted drastically. Of all the woods that were tried, none has been as stable as mansonia, which shows practically no deformation or splitting, even under severe conditions, yet has the necessary flexibility and give. PVA emulsion glues proved to be very suitable for poplar panels because of the elasticity of the adhesive, which kept new splits from forming next to the old ones. The glue had sufficient strength to keep these panels well bonded, even after having been immersed in the floodwaters for up to eighteen hours. PVA emulsions have been found to be less effective on hardwoods such as oak or walnut, so epoxy glues are used instead (see Rothe and Marussich, "Florentine Structural Stabilization Techniques," herein).

Wax infusions and applications of balsa wood have never been popular in Italy. While this is principally an aesthetic decision, it may also stem from the knowledge that once a panel has been impregnated with wax, it is practically impossible to remove all traces of it. Attempts to reglue the splits that might form afterward when this method has not been effective (as with the *Resurrection* by Girolamo da Santacroce in the Blaffer Foundation, Houston, Texas) can be frustrating (Figs. 21, 22). Animal

Figure 21
Girolamo da Santacroce, *The Resurrection,* ca. 1525. Oil on panel, 54.6 × 82.5 cm. Sarah Campbell Blaffer Foundation, Houston, Texas. This detail shows the severe formation of cracks after the painting delaminated from a support constructed with wax-resin and balsa wood.

Figure 22
Girolamo da Santacroce, *The Resurrection.* Side view, detail. The edge shows the delamination of the panel from the balsa and wax-resin support.

glues, PVA emulsion glues, and epoxy do not adhere well when there are even minimal traces of wax.

One of the main problems facing Italian conservators today is the certainty that many of these objects are destined to return to environments with severe fluctuations in their ambient humidity and temperature. Many Italian museums have little or no climate control, and it is not unusual to see a great masterpiece—such as a polyptych by Giotto in the Pinacoteca in Bologna—close to a wide-open window. Panel paintings housed under such unsympathetic conditions will eventually blister, deform, or split. To offset some of these effects, attempts have been made to create microchambers that attach to and seal the backs of panel paintings to reduce drastic exchanges of humidity (Del Zotto and Tonini 1993:684–85). Most Italian restorers are faced with the daunting task of finding a solution to establishing an equilibrium among unsuitable environments, minimal intervention, and the natural tendency of wood to constantly react to changes in humidity and temperature.

Acknowledgments

The author's particular gratitude goes to Miguel Angel Corzo, Marta de la Torre, and Kathleen Dardes for making this conference possible. He is also grateful to Giovanni Marussich and Renzo Turchi for their invaluable help and inspiration throughout many years of their work together in Florence and at the J. Paul Getty Museum. He would also like to thank Giorgio Bonsanti, superintendent of the Opificio delle Pietre Dure, and Marco Ciatti, director of the Restoration Laboratories at the Fortezza da Basso, for their generous support. Additionally, he would like to thank his colleagues Ciro Castelli, of the Fortezza, and George Bisacca, of the Metropolitan Museum of Art, New York, conservation studios, for their professional collaboration.

Notes

1 Vinavil NPC, Stella Bianca, is a nonionic dispersion of a medium plasticized polyvinyl acetate emulsion in water (see Materials and Suppliers).

2 *Mansonia altissima;* the tree comes from the rain forests of Ghana, Ivory Coast, and Nigeria. The sapwood has characteristics similar to those of the heartwood; the heartwood, which is slightly toxic, is most often used.

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History of Structural Panel Painting Conservation in Austria, Germany, and Switzerland

Ulrich Schiessl

This article presents a survey of the history of structural panel painting treatments in Austria, Germany, and Switzerland. Since much historical research remains to be done on this subject, the present discussion must be somewhat schematic.

Critical Survey of the Historical Sources

Beginning in the late eighteenth century, some literature about restoration appears in the German language. Contemporary journals in technology and fine arts published news about art techniques and gave information about recent restoration treatments of famous works of art. Articles published in French or English were usually translated into German, very often within the same year. For example, a translated extract from the important English book *The Handmaid to the Arts* appeared immediately in 1758 (*Bibliothek* 1758). Names of prominent eighteenth-century restorers, such as Robert Picault, were well known among the educated German classes. The first German report about Picault appeared in 1759 (*Bibliothek* 1759:830). From 1816 to 1849 the historian Ludwig Schorn edited the *Kunstblatt* (Dahn 1953), which presented, among other subjects, much information about current restoration treatments and discussions about critical conservation situations in museums, such as the circumstances in the Dresden Painting Gallery during the early nineteenth century. Recent research about the activities of Italian restorer Pietro Palmaroli in Dresden proves that these journals received much public attention (Schölzel 1994:1–24).

All of the eighteenth- and early-nineteenth-century literature shows a lack of precise technical information about restoration. Due to the zeitgeist, only a change in the aesthetic quality of a painting was considered worthy of description. Except for some small restoration books, not one word concerning treatments of wooden painting supports appears in the literature.

Three of the earliest important German-language books on restoration appeared between 1827 and 1828 (Wagner 1988:11–30). The first small work, *Über Restauration alter Oelgemälde* by the painter-restorer Christian Köster (1784–1851) came out in 1827 in Heidelberg. It was followed by two more booklets, in 1828 and 1830 (Köster 1827, 1828, 1830). In the third booklet we find an appendix by Jacob Schlesinger entitled "Über Tempera-Bilder und deren Restauration" (Köster 1830:35–47). Together Köster and Schlesinger, who belonged to the group of so-called romantic painter-restorers, carried out some restoration for the Boisserée brothers in

Heidelberg. In 1824 Schlesinger was the first paintings restorer of the Royal Museums in Berlin (Schiessl 1990:97–117). Köster's small booklet with Schlesinger's appendix emphasized the ethical basis of restoration work. The 1828 German translation of the noteworthy book about oil painting by M. B. L. Bouvier (1828:465–96), a painter from Geneva, contains an appendix about paintings restoration written by the translator Christoph Friedrich Prange. In 1832 the famous restorer's book by Friedrich Lucanus, connoisseur and pharmacist in Halberstadt, appeared (Lucanus 1832). The restoration books by the painter and restorer Welsch (Kurer 1988:2), published in 1834, and by Hampel, published in 1846, are also important. Born in 1796 in Breslau, Hampel studied architecture and learned restoration work at the Academy of Vienna (Kurer 1988:1). One may presume that Hampel's descriptions are most representative of Austrian methods. A translation by Hertel of Horsin Déon's book, *De la conservation et de la restauration des tableaux* (1851) appeared in 1853. Completing the list of German books on paintings conservation are a booklet by Voss published in 1899 and one by Goetz (1916). An Austrian book about paintings restoration was written by Kainzbauer in 1922.

The establishment of the journal *Technische Mitteilungen für Malerei* in 1884 provided an important new platform for the exchange of experiences and techniques in the field of fine arts, conservation, and restoration.

Finally, in the early twentieth century, publications in conservation and restoration began to include more details of particular methods and treatments. Since that time, good information about treatments for the supports of panel paintings has been available.

How was German conservation literature linked with the literature of other countries in earlier times? As mentioned, the literature on conservation and restoration shows international references dating from the eighteenth century, including translations from English, French, and Italian. In the twentieth century, translations from other languages appear frequently until the 1930s, and then again after the Second World War. Today international exchange of conservation publications is common, although many conservator-restorers are not acquainted with the publications from other countries, as they are limited in their knowledge of foreign languages.

It is quite evident that the circumstances of international exchange in the past were limited to the professional "upper classes" among the academically trained painter-restorers of the nineteenth century and later. For example, some Italian restorers worked in Germany, and some German restorers worked in Italy. This international exchange may have been the consequence of the relationships between governments and of the contacts between the collectors and connoisseurs, as clearly seen in the example of the Boisserée brothers, the most important collectors of medieval painting in German-speaking countries in the nineteenth century. The German restorer Andres worked at the end of the eighteenth century in Naples, and restorers named Metzger and Roeser worked at the same time in Paris. The Italian restorer Palmaroli worked in Dresden at the beginning of the nineteenth century. The restorer Andreas Eigner was conservator and inspector at the Gallery in Augsburg beginning in 1830, after which he worked for museums in Bavaria, including the Alte Pinakothek, and, in the 1860s, for the Öffentliche Kunstsammlung Basel and the Kunstverein Solothurn in Switzerland. Contemporary literature is filled with critical commentaries citing differences among national methodologies and attitudes in restoration, such as the case of Palmaroli. Köster's booklet is full of insinuations regarding the "Italian methods."

Beyond this international level in conservation and restoration exists a level of national and regional tradition—and perhaps even an additional level, defined by particular museums or individuals. These different levels are reflected in the various traditions of cradling panel paintings.

Other, more accurate historical sources are the unpublished and published reports about particular restoration treatments, as well as the larger reports about collections management. In earlier times, such references were usually very short and lacked detail, but in certain archives there are documents with more complete information. The well-known official report of the transfer of Raphael's *Madonna di Foligno* in Paris by Louis Hacquin in 1799–1800 was finally translated into German (Hertel 1853:14; see also Schaible 1983:122). Archival documents also provide some useful information about the 1867 conservation treatment of the *Solothurn Madonna* by Hans Holbein the Younger (Brachert 1972:6–22; Griener 1993:104–20). Some museum catalogues also provide useful information about previous treatments of objects (Zehnder 1990).

Recent studies of restorers and their activities are also helpful; these include research on Christian Friedrich Köster (Rudi 1996), Jacob Schlesinger (Schiessl 1990), Andreas Eigner (Vogelsang 1985), and J. A. Ramboux (Vey 1966; Mandt 1987–88), as well on Alois Hauser Jr., former restorer in Munich (Mandt 1995).

Field research, including a consistent collection of data about previous treatments, rarely exists. An exception is the unpublished diploma thesis of Werner Koch on the support treatments of panel paintings at the Kunsthalle Karlsruhe (Koch 1981).

The development of technological literature concerning panel paintings and their materials has an interesting history. Almost all books on painting techniques address the qualities of wooden supports and their preparation (Schiessl 1989:9–10). Theodor von Frimmel, an art historian in Vienna, addressed the character, wood species, and conservation treatment of wooden supports for panel paintings in *Gemäldekunde* (von Frimmel 1894). The scientist Franz von Frimmel published a study about examinations of wood species of painting supports (von Frimmel 1913–15). Alexander Eibner, professor of chemistry at the Institute for Technology of Painting at the Technical University of Munich and corresponding member of the Royal Academy of Arts in London, wrote many important texts about the development and materials of painting, among them a 1928 publication that described the history of wooden supports and the influence of some supports on the degradation of the paint layer. Many publications on types and qualities of wooden supports for artists may be found in the *Technische Mitteilungen für Malerei*. New boards such as Masonite, plywood (Laue 1891; Hengst 1940), and particleboard were first recommended as new supports for use by artists but were soon used as backings for wooden panels.

Historical Evolution of the Profession

Within the context of this article, there is no place to describe the situation in private collections and museums in the eighteenth and the nineteenth centuries. The heads of the galleries were usually painters and often professors from fine arts academies—simultaneously connoisseurs and conservators. These gallery inspectors usually executed restoration work by themselves and supervised restoration work done by others (Koller 1991:81). Sometimes these inspectors were supervised by a commission, as was done at the Alte Pinakothek in Munich. This Commission for Restoration Affairs was assigned to the Royal Bavarian Board of Directors of the Public Galleries until the end of the First World War.

In German regions in Austria and in the German-speaking regions of Switzerland, the classic distinction between the reliner (in French, *rentoileur;* in Italian, *foderatore*), who was responsible for relining paintings, and the painter-restorer, who was responsible for aesthetic retouching, did not exist as it did in other countries—where the person who treated the wooden support was normally a joiner or a cabinetmaker, and the restoration of the painting itself was the task of the artist painter-restorer.

Köster did not wish to do repair work on wooden supports without the help of a joiner (Köster 1827:14). Almost all the larger museums had specialized joiners for cradling. Most of the authors of restoration books advised leaving all practical work—such as planing, sawing, removing wood, gluing, and cradling—on the wooden support to an experienced cabinetmaker (Welsch 1834:66). Theodor von Frimmel wrote, "The repair work on wooden panels is the work of the joiner, it has to be done under control and on the instructions of the restorer" (von Frimmel 1904:140).[1] Hertel noticed that even the best cabinetmaker should not work immediately on the wooden support but should gain experience in working with panels first, after which the cabinetmaker may become a specialized *parqueteur* (Hertel 1853:16–19). The tasks of a parqueteur consisted of flattening and joining broken panels, paneling paintings, joining wooden strips, reinforcing panels, and cradling (Hertel 1853:16–19). Thus, for all daily needs in the house, every larger museum had its own cabinetmaker who could also, if necessary, assume the duties of a parqueteur. Sometimes, as is reported in an 1828 report from a museum in Cologne, joiners also worked as museum attendants and guards. An instance of a joiner who worked as a museum attendant and was also responsible for restoration work was cited by Vey (1966:46).

Martin wrote that a paintings conservator should possess all the knowledge a joiner requires to cradle panels or else hire a joiner (Martin 1921:168–69). In the same year, the German restorer Victor Bauer-Bolton noted that even the facing of the paint layer with paper before treatment of the reverse was usually executed by a joiner (Bauer-Bolton 1921:39–40). Voss, however, wrote that the panel painting should first be faced on the front side by the restorer before it comes into the joiner's hands, and that the restorer should instruct the joiner not to subject the panel to too much heat. In general, a restorer should leave a panel to a joiner only in the most challenging cases (Voss 1899:70).

Remarks critical of the work of the cabinetmaker first appear in 1952 in a summary of a survey on the treatments of panel painting supports conducted in twenty-eight conservation laboratories in West German museums and monument conservation offices. The analysis of this survey, based on detailed interviews of restorers, was performed by Christian Wolters and will henceforth be referred to as the Wolters Report. This report discusses the joiner's position in panel painting conservation from a new point of view: "Cradling work should not be done by the joiner.

Craftsmanship is not enough. . . . Only a well trained conservator is in the position to judge all conditions of the paint layer and its ground, of humidity, temperature and the tension of the wood" (Wolters 1952:11).

Surely, however, some cabinetmakers of the time must still have worked on the backs of panel paintings.

History of Conservation of Supports of Panel Paintings

The history of the conservation of panel painting supports in earlier times is a history of mistreatments, rather than of treatments. Most were executed not to satisfy conservation-related requirements but to render the panel painting into a particular aesthetic form in accordance with contemporary taste. Most of the early treatment methods for panel paintings, and for canvas paintings as well, had to render the surface smooth and clean. The support was not accepted as an integral and authentic part of the painting, which was considered to consist only of the thin paint layer; the rest could be altered.

Sawing double-sided panels

The earliest known examples of this horrifying procedure date from the eighteenth century. This drastic treatment was applied to the large altarpiece dating from 1539 by Lucas Cranach the Younger in Saint Wolfgang's Church in Schneeberg, Saxonia (Figs. 1–4). In 1712 the altarpiece was altered to the Baroque style. Whereas the central painting was integrated into the new altar, the two wings were left separated and sawn into four paintings that were mounted on the walls in the choir at either side of the new altar. The full history of these pieces cannot be described here, but in recent years they were finally mounted together again. When the restoration work is complete, they will finally return to the church in Schneeberg (Magirius et al. 1994).

Another very important altarpiece, the main altar by Hans Holbein the Elder dating from 1502, was originally mounted in the church of the monastery of Kaisheim. The altarpiece remained in its original place until 1673, when the church was changed during Baroque renovations. The wings were separated into eight component parts. In 1715 they were sawn through and put separately into splendid frames that were mounted in the church on both sides of the main entry. By the secularization movement in 1803, the paintings became possessions of the Bavarian authorities and are presented today in the Alte Pinakothek in Munich, where the paintings are reassembled in their original arrangement as wings (Bayerische Staatsgemäldesammlungen 1986:247–50).

An Austrian example from an important 1440 altar work of the Albrechtsmeister, initially made and mounted in the Kirche am Hof in Vienna, may mark the end of the history of the splitting of panels in the eighteenth century. The Gothic altarpiece was removed around 1700 to allow the construction of a new Baroque altar. Sometime before 1799 they were sawn through "with much deftness" by a joiner (Koller 1972:144).

Secularizations at the end of the eighteenth century in Austria and from 1798 on in Germany spurred the dismantling of many Gothic wing altarpieces. The secularization in Germany and Austria transferred a considerable amount of movable church artifacts, including many Gothic altarpieces, into public collections or private hands. Many paintings also were

Figure 1
Lucas Cranach the Younger, high altar of Saint Wolfgang's Church, Schneeberg, Saxony, 1539. Oil on panel, 285 × 99 cm. Left rigid wing with Lot and his daughters (reverse of the formerly double-sided wing) during restoration treatment and before retouching. The vertical cut in the center of the panel was made to delineate two parts for splitting, a procedure probably performed in 1712.

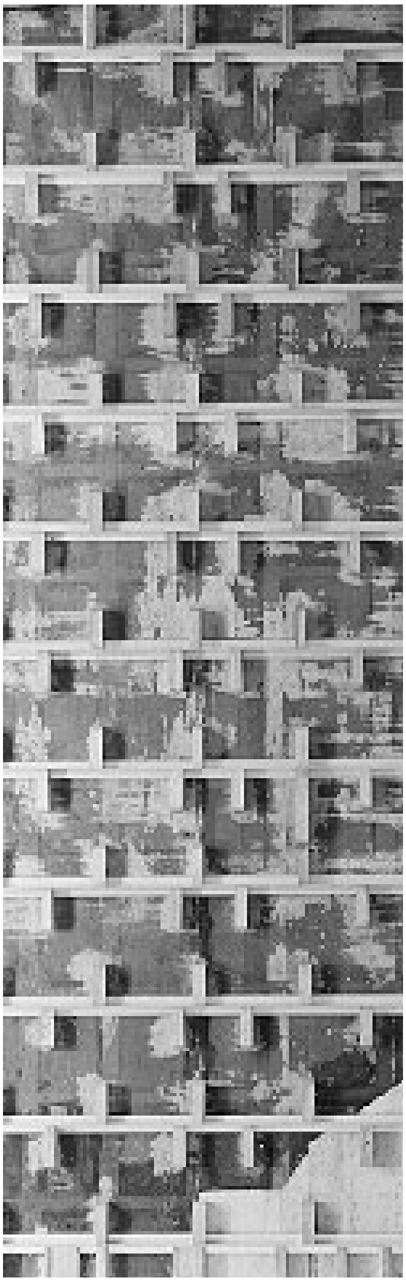

Figure 2
Lucas Cranach the Younger, high altar of Saint Wolfgang's Church. Split wing with Crucifixion (reverse of the formerly double-sided wing). The condition of the reverse since 1970 and before conservation treatment is seen. A cradle with aluminum edges of the Italian type was mounted (see Fig. 3).

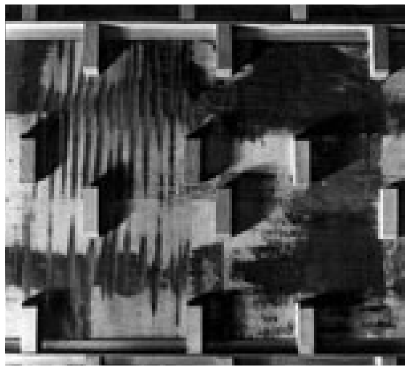

Figure 3
Lucas Cranach the Younger, high altar of Saint Wolfgang's Church. Split wing with the Fall of Adam and Eve. Reverse, showing traces of treatment since the splitting, a procedure probably performed in 1712; traces of the saw blade and the plane, a dark paint layer, and traces of rasping done in 1970 to prepare the Italian cradle can be seen (photograph taken after conservation treatment of 1991).

put on sale. Collectors at that time did not want the complete altar work (including its shrine architecture, ornamental carving, and sculpture); only the primitive medieval paintings were of interest. For aesthetic reasons and ease of presentation, hundreds of double-sided paintings were separated, a

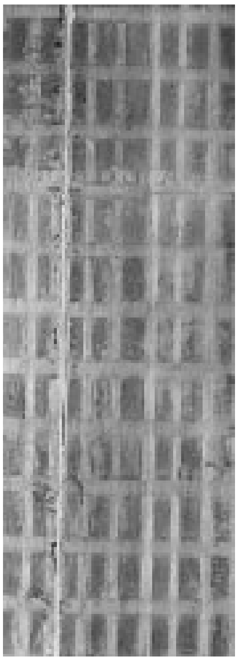

Figure 4
Lucas Cranach the Younger, high altar of Saint Wolfgang's Church. Split wing with Adam's expulsion into hell. Reverse. The panel wing, probably split in 1712, received a wooden cradle in 1886 with flat and broad strips; the condition after removal of the cradle is seen.

practice that became relatively common in all museums and continued into the twentieth century. Hans Thoma, director of the Kunsthalle in Karlsruhe between 1899 and 1919, noted: "Many of the old altar paintings had painted back sides. These are at least of the same interest as the front sides. That's why I gave the order to split them. Thus some fine paintings are added to the Gallery's collection" (Fig. 5) (Busse 1942:280).

Few, if any, gallery reports record by whom, when, and how often splitting occurred. Thus, the date of splitting remains unknown for a huge number of paintings. Written notes by conservator J. A. Ramboux in the Museum of Cologne record that about thirteen paintings were split after their acquisitions in 1846–47 and 1854 (Mandt 1987–88:316).

Because joiners and, above all, cabinetmakers were expert in the use of veneer frame saws, they—as well as some parqueteurs—were well-trained "masters" in splitting paintings. To make splitting easier, a painting was frequently cut into two parts vertically before splitting, with the placement of the cut chosen to avoid important parts of the painting. The preparatory vertical cutting happened to the wings of the Schneeberg Altar of Cranach mentioned previously. There are also early examples in Switzerland (von Imhoff 1973:90–91). Typically, larger panel paintings were cut into more "handsome" parts for easier splitting, as was the case for the double-sided *Crucifixion* (front) and *Saint Drusiana Raised from the Dead* (back), of around 1440, now in the Bayerisches Nationalmuseum (inv. MA 2343, 2358), Munich (Figs. 6, 7). The artwork was cut through vertically along the beam of the cross (Christ's head was avoided) using a 5 mm thick saw blade. After the separation into halves, splitting was easier. According to Dorothea Preyss of the Bayerisches Nationalmuseum, the date of splitting is unknown (Preyss 1994). Adelheid Wiesmann-Emmerling of the

Figure 5
Late Gothic altar wing, Swabian school (probably Ulm). Painting on panel, 147 × 100 cm. Kunstmuseum Saint Gall, Switzerland. This formerly double-sided painting was split and then combined into a composite one-sided painting. After the splitting, which was done in the nineteenth century, Saint Anne and Saint James the Great were brought together and repainted for continuity. The drapery and the floor on the left side were copied from the right, and the whole background is overpainted. Condition before the 1978 conservation treatment at the Schweizerisches Institut für Kunstwissenschaft, Zurich.

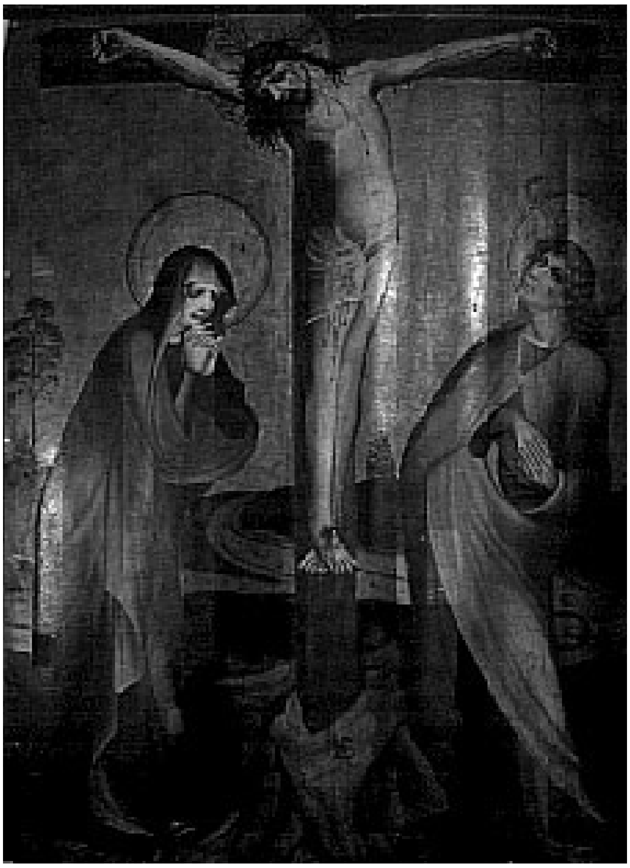

Figure 6, above
Bavarian master, *Crucifixion,* ca. 1440. Altar wing. Painting on panel, 179.5 × 138.5 cm. Bayerisches Nationalmuseum (inv. 2343), Munich. This formerly double-sided painting was split about 1804, around the time it came into the Royal Bavarian Collections. An earlier flat wooden cradle caused a very strong washboard effect. The painting is unrestored.

Figure 7, above right
Bavarian master, *Saint Drusiana Raised from the Dead,* ca. 1440. Painting on panel, 179.5 × 138.5 cm. Bayerisches Nationalmuseum (inv. 2358), Munich. This painting was split away from the painting in Figure 6. The panel, shown during conservation treatment and before retouching, shows the vertical cut that divided the panel into two parts before splitting (white line). To avoid sawing through the head of the Christ on the other side, the the sawyer took a small detour at the top of the panel.

Hessisches Landesmuseum Darmstadt cites other examples of paintings as large as 203 × 106 cm that were split without being first divided vertically (Wiesmann-Emmerling 1994).

No statistics about the disasters of splitting have been collected, and it is clear that there was not sufficient interest to make accidents public knowledge. Few reports on splitting problems exist, but enough traces remain on the original objects themselves to provide relevant information. In 1874 the sawing of a painting of Lucas van Leyden in the Alte Pinakothek in Munich by a gallery attendant and joiner named Nüsslein resulted in an unfortunate failure. The order to split the painting was given by a retired director of the gallery who wanted to hang both sides of the panel side by side on a museum wall. The front side of the painting sustained some damage, and a third of the painting on the reverse was lost. This accident is well documented in reports at the gallery (Kok, Eickemeier, and van Asperen de Boer 1976:252–54).

Another dramatic accident happened in 1943 to a painting by Niklaus Manuel at the Schweizerisches Landesmuseum, Zurich (Figs. 8, 9). The painting was put between zinc plates and held firmly so that the joiner could saw through the panel. The saw drifted to one side of the panel and destroyed huge sections of the paint layer (Kersten and Trembley 1994:159–78).

Little discussion of the splitting of double-sided panels appears in the conservation literature. A very rare comment can be found in the 1912 conservation report by the conservator Kinkelin about the damages to paintings in public possession in Bavaria and their restoration. Kinkelin describes how double-sided paintings were split and discusses the

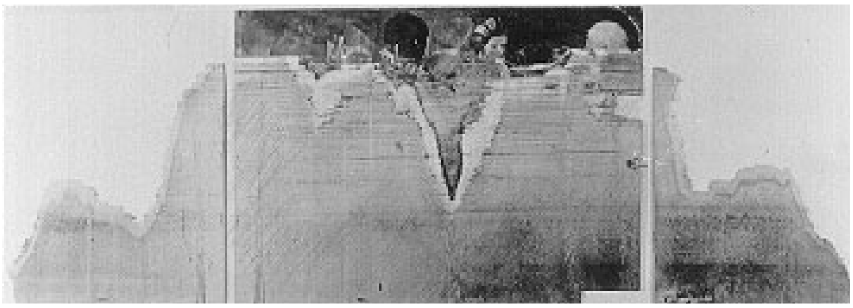

Figure 8
Niklaus Manuel, *Adoration of the Kings,* ca. 1518. Oil on panel, 899 × 149 cm. Kunstmuseum Bern. Disastrous mishaps that occurred during the splitting of panels were not publicized; even so, these procedures destroyed many panel paintings. Heavy damage was caused by the 1947 splitting in Zurich of Niklaus Manuel's double-sided painting *Adoration of the Kings* and *Sending of the Apostles*. The damage to the front of the *Adoration of the Kings* is shown.

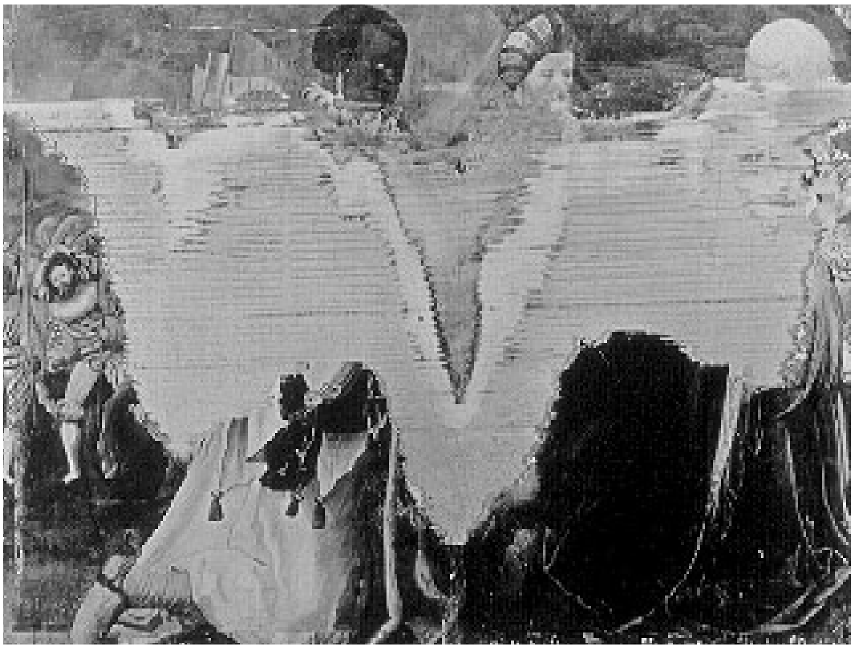

Figure 9
Niklaus Manuel, *Adoration of the Kings*. Results of the first repair in 1955, after the partial destruction of 1947 (see Fig. 8).

subsequent damage resulting from this treatment: "Until dividing, this type of panel was healthy. Humidity and heat could not react with the wood because it was covered on both sides with priming and paint layer. Now the situation of both split paintings was changed. Each painting was open at the back. Sawing diminished their stability. From now on, the backs could react to heat and moisture. The effect was shrinking by the influence of heat on the sawn side and warped back. Thus, many cracks developed in the paint layer, and in the worst case, cracks in the wood were the consequence. In cases of high humidity, the wood swells from the back; therefore, the support warps forward, [resulting in the] loosening and loss of the paint layer" (Kinkelin 1912:fol. 4).

Finally, the Wolters Report describes the negative effects and the possible ways to correct and control the damages provoked by splitting. The thickness of the paintings is often reduced to 2 mm. Due to the very thin supports after separation, treatments were necessary to reinforce the panels and to keep the supports flat. Usually the supports were cradled with various systems, or they were glued onto auxiliary supports such as wooden panels, and later to plywood or Masonite boards. Only very small panel paintings remained untreated after splitting.

Thus, it seems evident that splitting of double-sided panel paintings was done less frequently after the beginning of the twentieth century.

But splitting was still recommended when a damaged support required a partial transfer. In such instances, it was noted that the separated back side should always be preserved (particularly if there were inscriptions, seals, and marks) and that after the transfer of the painting with its split, thinned support to a new rigid support, this original back side should be glued onto the reverse of the new support (Goldkuhle 1932:15).

Finally, splitting of double-sided panel paintings has been done for conservation reasons. Thomas Brachert discussed the method again in 1955 (Brachert 1955b). He pointed out that splitting a double-sided panel painting spells the destruction of an original, organic work of art, although it can sometimes be the indicated treatment when blistering panel paintings cannot otherwise be preserved. There are occasional examples of this. In 1957 Schmidt-Thomsen published a well-documented case study about the partial transfer of a double-sided panel painting (Fig. 10a–f) (Schmidt-Thomsen 1957:6–11), and an unpublished treatment was executed by the conservator-restorer Adolf Jobst in 1969 at the Hessisches Landesmuseum in Darmstadt.

Thinning of the support

Split double-sided panel paintings were sometimes left without any other treatment on the newly exposed surface, so that the saw marks remained visible (Fig. 11). But frequently, auxiliary supports or auxiliary constructions such as cradle systems were added to the reverses, and then the sawn surfaces were treated to obtain an even surface or smooth thickness. To accomplish this, the saw marks and the drifts of sawing were usually smoothed with a tooth plane or smooth plane. If the thinning and planing were done well, it may be impossible—except for the extant corresponding side of the painting—to determine if the painting had been double-sided and was split or if it had originally been one-sided. Through such treatment, even the supports of some larger-sized paintings have been thinned to 2–5 mm thick.

In southern Germany, Austria, and parts of Switzerland, supports were mostly of coniferous wood, but oak supports were also thinned to a minimum of 2 mm (Zehnder 1990:passim; Goldberg and Scheffler 1971:passim). Italian wooden panel paintings, consisting mostly of poplar, were also thinned to 0.5–1.2 cm (Boskovits 1988:18–19, 27, 85, 136–37). The sawn surfaces often retain evidence of dowel holes.

In general, all panels required cradle and auxiliary supports after thinning. It is easier to flatten very thin panels than thick ones. The reverses of one-sided panel paintings have also been thinned by planing to expose the tunnels of burrowing wood insects for better impregnation treatment. Thus, not only split panels but also numerous (originally) one-sided paintings appear today with only a small portion of their original support.

Pest control

Many methods have been used to attack insects and fungi in wood, especially in painted panel supports. Solutions of salts were used for impregnation (Schiessl 1984:10–11). Treatments against insects were used against fungi in anticipation of good results, but to no avail. The opposite approach, using known fungicides as insecticides, was also unsuccessful. Mercury chloride was often used in the eighteenth century and recommended in

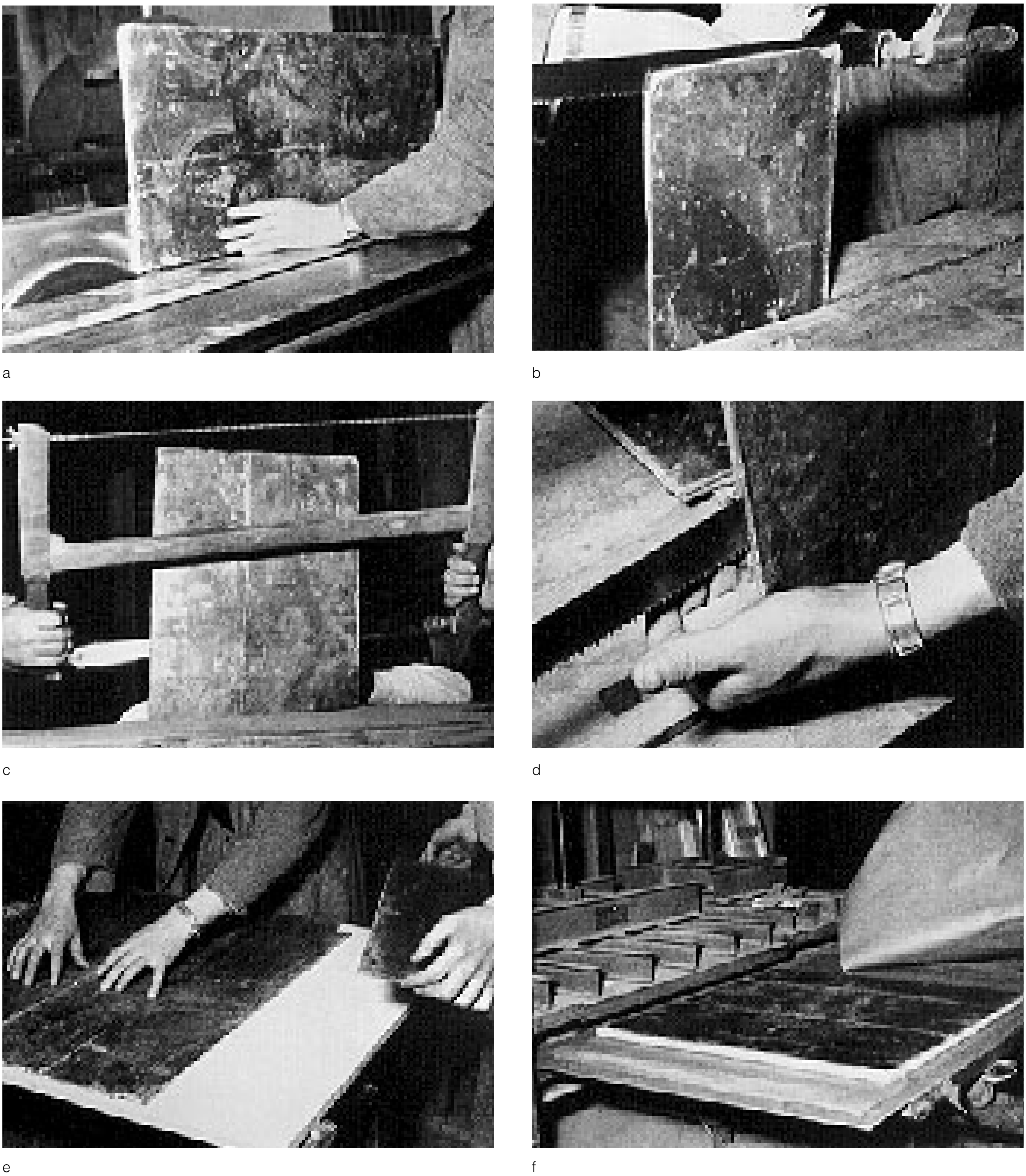

Figure 10a–f
Splitting of panels for conservation reasons, done in 1957 (Schmidt-Thomsen 1957). The very degraded support of a double-sided painting urged partial transfer of the paintings, as follows: (a) first, slits were made with a circular saw; (b–d) the phases of splitting followed; (e, f) then the two thinned panel parts were mounted on new auxiliary supports of chipboard.

the nineteenth century. In 1867 Andreas Eigner treated Holbein's *Solothurn Madonna* with mercury chloride (Brachert 1972:6). In Austria in 1911, many altarpieces were totally impregnated with mercury chloride, a strong poison that was recommended until the 1950s (Aberle and Koller 1966:7). Many soluble salts were tested in combination with arsenic. Acids were thought to be effective mainly against fungi (Schiessl 1984:12; Unger 1988:48), as were some alkaloid mediums. Concoctions of tobacco leaves, blackthorn, pepper, bay leaves, aloe, myrrh, and garlic were believed to kill woodworms (Schiessl 1984:13).

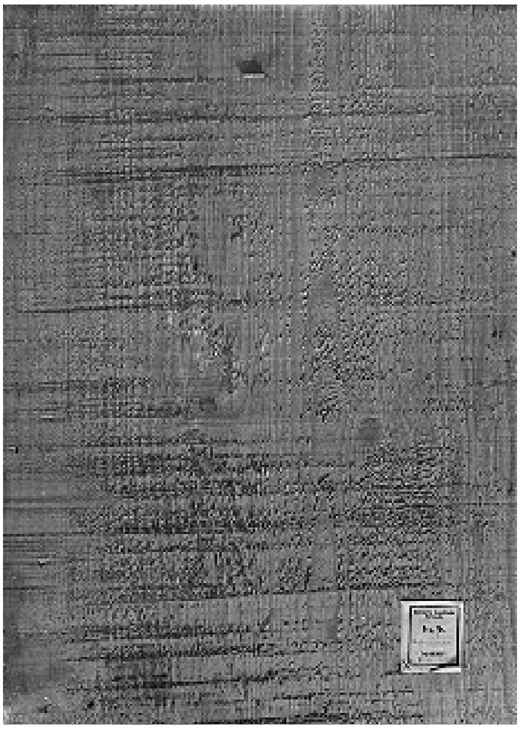

Figure 11
Master of Rottweil, *God the Father with the Body of Christ,* ca. 1440. Reverse. Painting on pinewood panel, 590 × 435 cm. Kunsthalle Karlsruhe (inv. 1135; in the collection since 1858). The panel is one half of a double-sided split panel; traces of the saw blade are visible. All edges have been cut and reduced.

In 1910 the conservation chemist Friedrich Rathgen cited an old recipe, a concoction of 1.5 l vinegar, 12.5 g garlic, 25 g onions, 11.5 g salt, 80 g vermouth leaves, and 2.25 g ground pepper (Rathgen 1910:23–27; Trillich 1924:23–27; Rasser 1925:42–43).

Beginning in the nineteenth century, oils from turpentine, juniper, birch, clove, lemon, thyme, and lavender were recommended (Schiessl 1984:13). According to one source, boiling turpentine oil provides superior penetration (Fernbach 1834:6). First mentioned in a conservation context as "stone oil" (in Old German, *Steinöl*), petroleum and all its derivatives have been used widely as conservation materials since the mid–nineteenth century (Schiessl 1984:14). Similar to wax, petroleum derivatives imparted the dark, heavy, metallic character of bronze color to the unpainted wooden surface, especially to oak (Schiessl 1984:14). The same effects are caused by tar oil. The new taste for special surfaces and structures (the so-called *Materialgerechtigkeit*) in the early twentieth century is perfectly put into words by Haupt, who stated that if the reverse of a panel painting were impregnated with tar oil, the wood grain would be beautifully intensified (Haupt 1908:559). The demand for noncoloring, nondarkening conservation materials did not arise in the wood conservation field until the 1950s. The trade names of "classic" mediums include Arbezol, Basileum, Creolin, Carbolineum, Jakutin, Mobe R, and Xylamon (Brachert 1955b:27). At the time, all these materials consisted in part of mineral oils that cause irreversible darkening of wood. Materials with the same trade names are today formulated differently.

Industrial pest control products containing naphthalene chloride, dichlorodiphenyltrichloride (DDT), pentachlorphenole, or lindane have also been used, the latter in the former German Democratic Republic. Most of these toxic agents continue to effloresce today from the treated wood. Grave concern about these highly toxic chemicals undoubtedly contributed to the development of preventive conservation.

Pest fumigation of wood has also gone through fundamental changes. Having been practiced since antiquity, fumigation may be one of the oldest methods of impregnation of wood (Unger 1988). In the eighteenth century sulfur dioxide was used for fumigation. Prussic acid, first used around 1880, is no longer used. Today new experiments with nitrogen and carbonic acid have shown promising results.

Consolidation of panels damaged by insects and fungi

Until the 1950s the diagnosis of extensive damage by insects or fungi on a wooden panel painting support always led to drastic treatment measures: total or partial transfer of the support. Less pronounced damage provoked responses that would be considered aggressive today. One such "light" operation was planing the whole reverse to open the burrowing passages of wood insects to enable better impregnation.

Exhaustive studies about wood consolidation and especially about wooden painting supports have been written in the German language; only a few are mentioned here. R. E. Straub wrote the first systematic critical introduction to both pest control and wood consolidation (Straub 1963:128–40). The general study published by Brigitte Aberle and Manfred Koller in 1966 on wooden sculptures is also valuable for panels (Aberle and Koller 1966). Achim Unger's important book about wood conservation contains a very complete bibliography, material descriptions, and recipes used for treatment materials (Unger 1988).

There is insufficient room in this article to describe all the materials used for wood consolidation during the history of conservation. Today scientific identification of old consolidation materials remaining in the objects and the study of the degradation of such materials has become a new, highly problematic topic in conservation research. Thus, exploring old restoration texts may be of value. In 1834 Welsch recommended an impregnation mixture of copal varnish, turpentine oil, and boiled linseed oil (Welsch 1834:65). An early method for the consolidatation of degraded wood was impregnation with animal glue mixed with alum as a hardener. A mixture of casein glue and alum is also mentioned (Wolters 1952). Attempts to reinforce wood include the application of shellac, followed by a putty of hardwood sawdust, chalk, dextrin, and carbolic acid (Kainzbauer 1922:38).

The advice to remove all of the wood possible, however, as well as to cradle, appeared frequently in early literature (Lucanus 1832:77). In some instances, wooden supports have been so weakened by degradation that they have required consolidation before they could be thinned with a plane.

The Wolters Report of 1952 provided a good overview of the consolidation materials used for panel paintings until the 1950s. It noted discussions both for and against cellulosic acetate and cellulosic nitrate. Some laboratories preferred solutions of natural resins such as colophony in turpentine oil, shellac in alcohol, and mixtures of wax-resin solutions. Compositions of resin, wax, and linseed oil or Chinese wood oil, and casein glue with alum were also described. All restorers interviewed for this report rejected bone glue and hide glue. The use of combined conservation materials for the dual purposes of pest management and wood reinforcement was remarkable (Wolters 1952).

In the 1960s Straub described a preference for consolidation materials that hardened without solvent action (e.g., some types of wax, mixtures of wax with resins, epoxy resins, and polyester resins) (Straub 1963). An immersion method is also described. Melting a wax-resin mixture in a flat tub on the hot table is recommended (Straub 1963:138–40). In 1957 Peter J. Hermesdorf modified such a type of wax bath on the hot table for impregnation (Hermesdorf 1963). Synthetic resins, especially acrylic resins, have been in use since the 1970s (Unger 1988). Many experiments and conservation techniques used for other types of wooden works of art have not been executed on wooden panel painting supports (e.g., application of the conservation material under vacuum, or polymerization of monomers in the degraded object itself). Current methods are, for the most part, restricted to local treatments.

Flattening of warped panels without cradling or other auxiliary constructions

Flattening methods used in the past could—at best—be considered restoration efforts rather than conservation treatments. Many such treatment types of the past are also classified today as impractical and inconvenient for our standards of practice.

Flattening panels with a plane was also preparatory in nature, inasmuch as flattening was a necessary antecedent to the thinning or removal of the wooden substance of the support. It was almost impossible to mount thinned panels on an auxiliary support without prior flattening. Thus, the flattening of panels was considered a preliminary step to mounting thinned panels on an auxiliary support.

Flattening of panels with water

The easiest way to straighten a split or one-sided warped panel is to bring the reverse into contact with water to swell the wood. When this side is swollen, the panel is flat. After drying, the panel returns to its original orientation, perhaps becoming even a little more warped than it was before. Considerable measures must be taken to keep the swollen panels straight.

Lucanus recommended moistening the reverse of the panel once or twice (Lucanus 1832:114). Welsch recommended moistening every half hour with warm water until the painting is straight (Welsch 1834). Hertel recommended spreading moistened fabric sheets over the reverse of the panel painting (Hertel 1853). Following advice given in a 1912 report at the Alte Pinakothek in Munich, moistened sawdust was spread over the reverse of panels to straighten them (Kinkelin 1912:fol. 4; Wolters 1952:8). In 1952 most of the public conservation laboratories in West Germany rejected flattening methods for panels that involved direct contact of water with the wooden surface (Wolters 1952:8).

Wet cloths, wet sawdust, wet sand, and wet split bricks were also used to allow the water vapor to affect panels in climate chambers or similar constructions (Wehlte 1958:106). Climate chambers or tents for flattening panel paintings were more frequently used after 1950 (Wolters 1952:8).

Before the use of climate chambers became more frequent, simple moistening methods were practiced to prevent the direct contact of water with the panel's surface: the warped panels were exposed only to water vapor. Hampel described how small warped panels can be positioned on a pot filled with water, remaining there for about twenty-four hours until flat (Hampel 1846:8). Traditionally, the water was heated. Another humidification method, possibly a very old one, involves placing the warped painting on a slightly humid support such as a stone or brick floor, sometimes with a load on the warped panel to straighten it (Wolters 1952:8).

Flattening of panels with polar solvents

Polar solvents such as ethanol mixed with water or pure ethanol may have been used to moisten panels for the purpose of flattening. It may have been observed that the flattening of a warped wooden panel could be effected by ethanol when mercuric chloride was used in an alcoholic solution for pest control in wood. The use of organic solvents to straighten panels is rarely documented. Spraying ethanol on the reverse of a warped panel to moisten it has been reported (Wolters 1952:9). In two cases, when the so-called shellac method was performed without efficacy, swelling of the panel reverse was initiated with Cellosolve. Such treatments were carried out in 1957 and 1959 in the Schweizerisches Institut für Kunstwissenschaft laboratories in Zurich (SIK 1957, 1959).

Cutting the backs of panels

During the nineteenth century and in the first half of the twentieth century, the reverses of panel paintings were treated on the surface to assist in humidification. Typically, such treatments drastically altered the original surface of the reverse. The most aggressive method consisted of planing the whole surface of the reverse to obtain pure and fresh wooden material for moistening. From the 1950s this opening of the wooden structure was done with a scraping tool to reduce loss of the original substance (SIK 1957, 1959). Another "classic" method was to make cuttings, notches, and slits with a knife along the grain of the panel to promote penetration of water into the wood structure (Lucanus 1832:115; Welsch 1834:63–64). Such cuttings were also carried out in the same way as the Italian *sverzatura* by sawing along the grain. Around 1950 a modified paring chisel was used to make slits in panel reverses (Wolters 1952:9; Brachert 1955b:14).

Shellac, or Munich, method

A technique to flatten warped panels was developed at the Doerner Institute in Munich by Christian Wolters (1952:10). Initially, water-insoluble binding media were postulated for use, particularly those that contain water in their liquid phase, such as watery dispersions of synthetic polymers, urea resins, cellulosic esters, and high-molecular alcohols (Wolters 1952:10). Repeated applications of such binding media on the reverse of warped panels were intended to flatten and reinforce the support simultaneously. Solutions of shellac in ethanol and Cellosolve were applied as a type of solvent compress on the wooden surface. The polar solvent vapors penetrate the wooden structure and cause swelling, while the shellac film serves as a solvent-retention barrier. This so-called shellac method, or Munich method, was described by Christian Wolters at the 1961 conference in Rome of the International Institute for the Conservation of Artistic and Historic Works (IIC) (Wolters 1963:163–64).

Today the Munich method is understood to have rather negative effects, as the shellac film has a very strong gloss that covers the entire reverse (Fig. 12). Typically, conservators no longer apply materials directly to the support. However, at that time shellac was not the only coating applied to panel reverses—wax layers were also used. That technique may have the advantage of not requiring the removal of original material (Straub 1965).

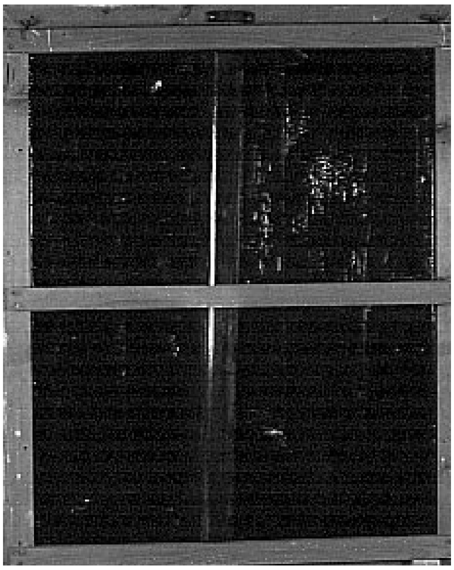

Figure 12
Frankonian master, *Epitaph for the Nun Gerhäuser,* 1443. Reverse. Tempera on panel, 114 × 875 × 2.2 cm thick. Bayerisches Nationalmuseum (inv. MA 2586), Munich. The painting was treated in 1960–61 with the shellac method to flatten it. This photograph of the reverse, from 1994, before conservation, shows a rigid cross slat that contributed to the enormous crack in the middle of the support. The thick and glossy shellac layer is remarkable.

The shellac method for flattening wooden panel paintings may be beneficial in that, unlike other systems, it does not require pressure. The method aims to make corrections of warping only as far as it is allowed by the condition of the individual support.

Pressure for flattening

Lucanus and Welsch were the first to write about the application of pressure. The warped panel painting may be positioned on small wooden slats and covered with a cloth. Then, after every moistening, the load on the top of the panel is made increasingly heavy (Lucanus 1832:116; Welsch 1834:62). The Austrian Ludwig Kainzbauer recommended an even easier straightening method—laying a moistened panel (painted side up) on the floor and toploading it (Kainzbauer 1922:36). Although in the German literature there is little technical information about the application of pressure to panels, there is one good example from Secco-Suardo (Zillich 1991:40–45). All tools of the joiner, such as screw clamps, were used to set pressure to flatten. Most of the panels, however, may have been thinned and cradled, or glued to an auxiliary support. Later case studies on flattening and cradling mention the affixing of screw clamps after flattening and up to the moment of cradling (Wehlte 1958:106).

Drying under tension was another method to flatten panels. Small and thin panels were first moistened and flattened by swelling of the reverse. They were then immediately nailed into their frames to keep them straight (Welsch 1834:63; Kainzbauer 1922:36). According to the Wolters Report, one conservation laboratory applied slight pressure on the panels, working with a veneer press and many cauls of wood and rubber (Wolters 1952:10).

Slots and wedges

Another practice was cutting along the grain in the reverse of a warped panel to facilitate effective penetration of water into the wood structure. Water was dripped into the cuttings and slots. When the painting was flat, it remained under pressure. These slots were then filled. After drying and hardening, pressure was removed from the panel. The fillers kept the panel straight (Wolters 1952:9). Wider slots, made with saws, were normally filled with small strips or wedges of wood to keep the panel straight (Zillich 1991:46–50).

Flattening by cradling

Many panel paintings are cradled from earlier conservation treatments. Cradling was the normal procedure after double-sided paintings were split; it was also the classic system used to reinforce thinned panel painting supports. Cradle systems are well known and widely published; therefore, the technical details of particular cradling systems will not be described.

Cross cleats or lattice systems of the eighteenth and nineteenth centuries
In Germany, Austria, and Switzerland, cradle systems were not used until the eighteenth century. An early method to maintain the flatness of panels involved setting cross cleats into the support (Fig. 13). Lucanus did not adhere to the method of gluing or screwing slats to the panel reverse, as he stated that slats or cross cleats are not necessary for small panels and are ineffective for huge panels (Fig. 14) (Lucanus 1832:116). Köster recommended a movable system of two slats laid across the grain (Köster 1828:13). Hampel described movable cross cleats, left loose without adhesive joins in a dovetail halved joint (Hampel 1846:22). A 1912 restoration report from the Alte Pinakothek in Munich summarized all problems with rigid slats fixed across the grain of the panels. Such slats were removed from many Gothic and Renaissance panel paintings to set the wood of the panels free (Kinkelin 1912:fol. 8). Brachert discussed cross-cleat systems and their disadvantages, as did Straub (Brachert 1955b:15; Straub 1963:153).

Starting in the eighteenth century, rigid wooden frameworks and lattices were mounted on the reverses of panels to reinforce them (Zillich 1991:59). There were many early treatments that preceded movable cradles. Many such rigid frameworks and lattices mounted on panel paintings were well documented in the Kunsthalle Karlsruhe before they were removed during this century (Koch 1981:passim). These simple but potentially

Figure 13, right
Lucas Cranach the Elder, *Mary with the Child,* ca. 1518. Reverse (photographed during the 1950s). Oil on limewood panel, 345 × 226 cm. Kunsthalle Karlsruhe (inv. 108). The very small and thin panel was probably glued in the eighteenth century onto a rigid cradle that was obviously originally a canvas stretcher with crossed reinforcements. Traces and drops of glue can be clearly seen.

Figure 14, far right
Master of the Bamberg Altar, *Legend of Saint Wolfgang,* ca. 1490. Reverse. Oil on panel, 675 × 375 cm. Kunsthalle Karlsruhe (inv. 54). This photograph from the 1950s shows the conservation treatment of the nineteenth century. All the edges were cut, and four strong cross braces of oak were adhered to keep the painting flat.

harmful rigid lattices and frameworks were still made during the nineteenth century by joiners and restorers.

Evidently, Hacquin's movable system of cradling became known in Germany and Austria through his articles in art journals. Lucanus and Köster were the first to describe a movable cradle system (Lucanus 1832:117; Köster 1828:14).

The quality of the wood species used for the slats along and across the grain may be significant. Even in the Wolters Report, however, there was no consensus. Some laboratories used softwood cradles, while others preferred cradle slats of the same wood species as the original support. It was proposed that the slats glued along the wood grain should show growth-ring structure in a perpendicular position with respect to the support (Wolters 1952:12–13).

In some collections, all or most of the panel paintings were systematically cradled. According to H. Dietrich of the Hochschule für Angewandte Kunst in Vienna, oral legend reports that between 1825 and 1835, most of the panel paintings in the Kunsthistorisches Museum in Vienna were treated, thinned, flattened, and cradled (Dietrich 1994). Apparently, during the nineteenth century there was no discussion about the quality of cradling; it was a common and unquestioned practice.

Cradling in the late nineteenth and early twentieth centuries

A positive attitude toward cradling was so pervasive that the treatment was even recommended by the painter and restorer Aloys Hauser as a preventive measure for new wooden panel supports used by contemporary painters (Hauser 1885:6). At the beginning of the twentieth century, cradling still had not been discussed in a negative light. If paintings were damaged, the cause was usually attributed to a technically incorrect cradle. Until the middle of the twentieth century, flat cradles were still in use (Figs. 15, 16). In the 1930s cradle systems with huge slats positioned on their sides were preferred (Zillich 1991:63). At that time the first discussions about cradling can be found in the literature. Painter-restorers like Doerner had no doubt about the necessity of cradling (Doerner

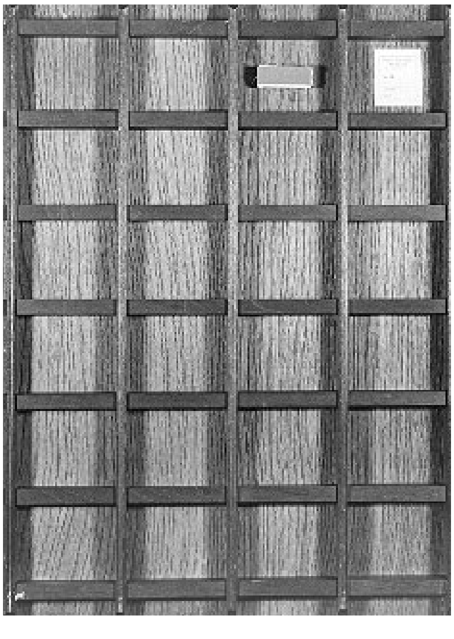

Figure 15

Hans Müelich, *Portrait of Pankraz von Freyberg,* 1545. Reverse. Oil on panel. Kunsthalle Karlsruhe (inv. 2477; in the collection since 1961). A rather delicate treatment that must have been done before 1961 is shown. The panel was thinned to 1 mm, then glued onto a particleboard as an auxiliary support. To hide the particleboard, a counterveneer was glued over it. Finally, a very fine wooden cradle was mounted.

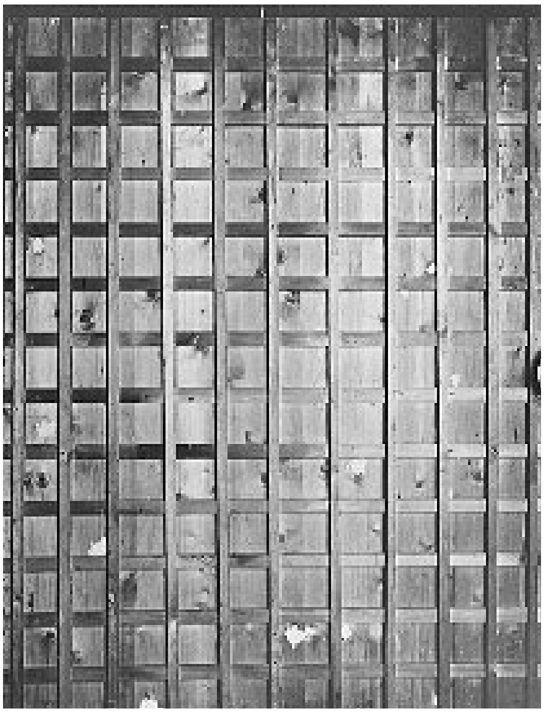

Figure 16
Matthias Grünewald, *Our Christ Carrying the Cross,* 1520–24. Reverse. Tempera on pinewood panel, 195.5 × 142.5 cm. Kunsthalle Karlsruhe (inv. 994; in the collection since 1900). The painting is one part of a formerly double-sided painting. In 1883 the restorer A. Hauser split, cradled, and cleaned the paintings. This photograph from the 1950s shows the old, flat wooden cradle.

1921:294). Other restorers who voted against cradling pointed out the disadvantages—but their criticisms were directed toward a recommendation that thin panels be mounted on plywood instead of being cradled (Bauer-Bolton 1933:99–100).

International exchange facilitates communication about other methods—even methods that were first proposed seventy or eighty years ago. Secco-Suardo's method of a reduced cradle system without slats along the grain of the panel seems to have become known in Germany during the middle of the twentieth century (Zillich 1991:63). In Germany this cradle system was called the Italian cradle. It was described in detail in 1949 by Toni Roth in Doerner's ninth edition (Doerner 1949:418). The Italian cradle system was apparently invented a second time by Kurt Wehlte (1958:110). But here the old conservation master adopted a system that had been described as the Italian system three years earlier by Thomas Brachert, who briefly summarized all cradling systems (Brachert 1955b:8). The only differences between the methods were broader slats across the grain.

Discussions about cradling in the 1950s and 1960s

Cradling was discussed more in detail in the 1950s and the 1960s. The 1952 Wolters Report summarized all positive and negative aspects of cradling. It emphasized that cradling with flat slats should be avoided and that cradling with slats positioned on their sides, or with the Italian system, would be more convenient. It is evident that the Wolters Report supplied much fundamental material for the important article "The Care of Wood Panels" by the International Council of Museums (ICOM) Commission for the Care of Paintings (1955:139–94).

In 1960 Keyselitz presented an article on the so-called Vienna method of cradling in the journal *Maltechnik*. It was a call to reestablish traditional artisans' techniques, which were in danger of disappearing in a theoretical world of new conservation attitudes. Under the guidance of the chief restorer, Professor Haysinek, and Mr. Sochor, the head of the technical department, who had practiced that special method of cradling since 1930, the reinforcement of wooden supports was accomplished in a quite traditional way with the use of flat cradle systems. It is quite remarkable that partial transfers were executed on some Rubens's panel paintings: paintings situated on portions of the panels whose grain orientation was not parallel to the rest of the support were transferred to new supports of the same wood species with parallel grain; they were then inserted back into the overall ensemble (Keyselitz 1960:73–75). The Vienna method is also known as the Sochor method.

A very concise summary about all the problems of cradling and the reasons to avoid it was written by Straub (1963:139–64).

Balsa-block systems

Straub made a major contribution by bringing to the German conservation scene the discussion about structural panel painting conservation raised by Richard Buck in the United States (Straub 1963:154). Several years later Roettger published a case study about an application of the new balsa-block system (Roettger 1967:13–17). During the following fifteen years, this method was frequently used in cases where formerly thinned panels were reinforced after the removal of rigid lattices or cradles. Some interesting case studies are in the archives of the Schweizerisches Institut für Kunstwissenschaft, among them Holbein's *Solothurn Madonna* (the treatment of which will be described in detail below). Normally the balsa blocks, cut longitudinally into little bricks, were applied as an initial layer along the grain of the panel. Then a second layer of blocks was set across the grain, or again along the grain. The glue was usually wax cement with filler. Christoph von Imhoff proposed the application of quadratic balsa blocks affixed diagonally in relation to the grain of the support with the use of Master Model Paste (a putty of sawdust and epoxy resin, also marketed under the trade name Araldite) as glue; the blocks also served as an equalizer for the support's surface (von Imhoff 1973:94).

Transfer to a new support

Wooden panel paintings have been transferred to new supports for many years. The significance of such a treatment in relation to the original substance of a panel painting, comprising a support and its paint layer, was not yet recognized at the beginning of this century (Krattner 1910:150).

Total transfer

In comparison to partial transfers of thinned wooden supports, total transfers were not frequently done in Germany. Total transfer was often described in early restoration texts. The most extensive coverage of the subject can be found in Hertel's 1853 translation of Hacquin's work on the *Madonna di Foligno*. Köster clearly stated that the paint layer should be controlled and that blisters should be consolidated before the joiner's work begins (Köster 1827:16). Welsch described how the joiner is involved in the transfer work (Welsch 1834:66).

Transfer from wood to wood. Until the end of the nineteenth century, wooden panels were used as new supports for the transferred paintings. Since the only technical possibility was to transfer the painting to another wooden panel, the transfer of paintings did not occur often

(Hertel 1853:24). In 1904 von Frimmel described wood-to-wood transfer as an impractical method no longer in use (von Frimmel 1904:136).

There is no mention of this topic in earlier German literature, but oral traditions regarding the quality and species of wood for new supports seem to be summarized in the Wolters Report. The use of the same wood as that of the panel—from trees cut in winter, growing on the west side of mountains or in the forest—is recommended. Wood from higher mountain regions was considered preferable. The cut trunk was stored vertically during the winter in a protected place. In spring, the bark was removed and the trunk dried in a place protected from sun and wind. If the trunk were floated or boiled for a long time in water, the quality of the wood improved. Only the heartwood board could be used for the new support (Wolters 1952:20). Sometimes restorers were secretive about their new supports; one of these "secrets" was plywood (Goldkuhle 1932). (New types of rigid supports are described below in the context of auxiliary supports.)

Transfer from wood to canvas. Hacquin's work on the *Madonna di Foligno* is one of the most famous transfers of a wooden panel painting to canvas in the history of conservation and restoration. Canvas was preferred as a new support for panel paintings during the nineteenth century. The arguments against this method, however, started early. In 1834 this treatment was thought to be very difficult and dangerous (Welsch 1834:66). In 1873 the transfer of paintings from wooden panels to new canvas supports was officially rejected by museum custodians, conservators of monuments, and restorers (Koller 1991:78). In the first half of the twentieth century, negative opinion about total transfer increased very quickly. Painters voted against it—among them Doerner (1921:290). The loss of the genuine character of a panel painting and its transformation into a canvas painting was decried. It was noted that the painting so treated would then have two types of craquelure at once (Bauer-Bolton 1933:110). The survey of public conservation laboratories revealed that, on the whole, transfer of paintings from wooden panels to canvas was no longer accepted. Transfer in general was now classified as a treatment that could be carried out only as a last resort (Wolters 1952:19). Straub's important paper on the conservation of panel paintings does not address that subject, as he considered the technique unnecessary (Straub 1963:108). Today many old transfers on canvas require additional conservation treatment, particularly if the transfer was not done properly. According to A. Schulze, at the conservation laboratories of the Saxonian Institute for the Care of Monuments and Sites in Dresden, a painting transferred improperly from wood at the beginning of the twentieth century was heavily damaged, with wooden particles left on the back of the paint layer (Figs. 17, 18) (Schulze 1994).

Auxiliary supports since about 1865

The history of total and partial transfer has been related to the history of new rigid auxiliary supports since about 1865, when plywood was first produced industrially in the United States. Around 1900 the first plywood mills were founded in Germany; they appeared in Austria in 1903 and in Switzerland in 1920. The history of wooden fiberboards began in the early nineteenth century. Production started in Germany in 1932 (Schiessl 1983:72–77). Masonite and Sundeala boards were often used in Germany. Particleboards were invented in 1943 in Switzerland; industrial production began in 1950 (Schiessl 1983:72–77).

Figure 17
Gothic altarpiece, late fifteenth century. Tempera on panel. Chapel of Kriebstein Castle, Saxonia. In 1913 two wings were split and transferred to canvas, resulting in four paintings. This detail of Christ before conservation treatment shows the very irregular surface, caused by wooden particles left on the paint layer. Climatic influence caused further damage.

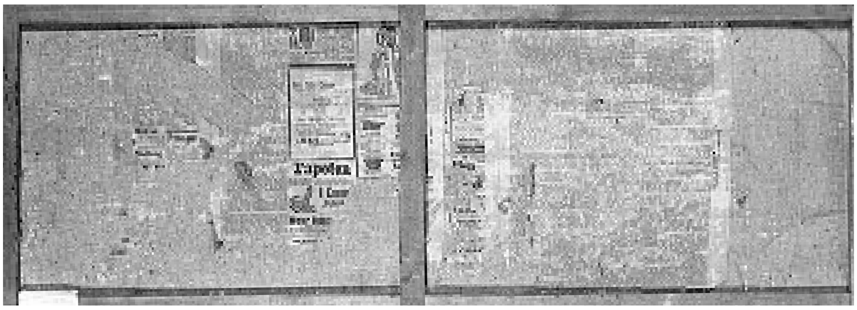

Figure 18
Reverse of one of the four paintings transferred to canvas from the Gothic altarpiece from the chapel of Kriebstein Castle, Saxonia (see Fig. 17). The newpaper backing enabled the precise dating of the transfer.

Chipboards have a more extensive history, as they have long been produced for the furniture industry (Schiessl 1983:72–77). They were highly recommended in the conservation literature of the 1920s and 1930s (Bauer-Bolton 1933:111).

Aluminum sheets and aluminum honeycomb-wave supports were introduced as auxiliary supports in the 1950s. Most of the restorers interviewed for the Wolters Report considered aluminum sheets unsuitable as new supports for transfers (Wolters 1952:21).

Insufficient information is available about the use of these new types of boards for the transfer of paintings to new rigid supports. The Wallraf-Richartz-Museum in Cologne owns eleven surviving paintings from an altar work of the Master of Saint Laurent, dating from 1425–30. These paintings were split in the early nineteenth century. All subsequent treatment (mostly reinforcements of the reverses) caused such heavy damage that in 1964–70, part of these paintings was transferred from wood to chipboard. The other part of this altar consists of very thin panels mounted on chipboard as auxiliary supports (Zehnder 1990:500–509). Another early example of the transfer of a painting from wood to chipboard (19 mm thick) with a canvas interlayer was published by Fritz Reimold in 1972. The transfer of the painting, *The Annunciation* by Konrad

Witz, was considered necessary to treat drastic problems caused by climate changes in the new wing of the Germanisches Nationalmuseum in Nuremberg. The particular character of the support was determined by the wooden panel, which consisted of boards of different wood types (Reimold 1972:825–27). In general, it seems that chipboards were the preferred type of all the new rigid supports after 1950.

Partial transfer to auxiliary supports

In the German-speaking countries, partial transfer was practiced much more often than total transfer of wooden panel paintings. Partial transfer began no later than the middle of the nineteenth century. In this technique the thinned original panel was reinforced by being glued to another wooden panel. Welsch recommended gluing the original panel, whenever it had become too thin, to a very old oak board (Welsch 1834:66). The original panel should not be thicker than 3–6 mm (Hampel 1846:23).

Although the treatment dates are unknown for most of the paintings that received partial transfers, the technique seems to be one of the early ones. To repair the *Last Supper* of Hans Holbein the Younger in the Kunstmuseum Basel, the restorer Andreas Eigner removed a spruce board about 3 cm thick (Vogelsang 1985:142). The Wallraf-Richartz-Museum owns large panel paintings (inv. 137, 143 × 46.8 cm; inv. 146, 93 × 68 cm) reinforced by adhered oak boards (Zehnder 1990:347, 476). In one case it is possible to date the treatment to before 1925. Other treatments of this type were presumably done in the same museum in the nineteenth century (Zehnder 1990:124). The same treatments can be found in other galleries, such as the Alte Pinakothek (Goldberg and Scheffler 1971). It is possible that some of these paintings with adhered auxiliary wooden panels were cradled later on. But the auxiliary wooden panel support was also cradled at the same time. This treatment is documented on Gothic panel paintings in the Alte Pinakothek (Goldberg and Scheffler 1971:88–89). Other examples were performed at the Schweizerisches Institut für Kunstwissenschaft on a Gothic panel painting (101 × 92 cm) (SIK 1961). In 1989 the same situation was seen in a painting measuring 48 × 64 cm. The original, 5 mm thick support was glued to a wooden sheet 2–3 mm thick that had been cradled (SIK 1989).

Partial transfer of wooden panels was sometimes done with the grain of the reinforcement positioned across the original support and sometimes with an adhered counterveneer sheet on the reverse. This type of treatment has probably not been performed since the middle of the nineteenth century, but the technique itself is an old one and is still used in furniture manufacturing. The painting, with its thinned original wooden board, was understood as a veneer sheet. The new auxiliary panel was glued across the grain of the original support, having the effect of a crossbanding. A third, thinner wooden sheet (of the same thickness as the original support) was glued across the grain of the auxiliary panel. Thus, this layer's grain was parallel to that of the original support, so that the effect of a counterveneer was created.

This technique for reinforcing diminished wooden supports has been mentioned only once, but it was frequently used (von Frimmel 1904:140). Many panel painting support treatments executed by the restorer Andreas Eigner (1801–70) were executed with this reinforcing technique, which seemed to be a specialty of Eigner or, rather, of the joiner who worked for him, as seen in some Holbein paintings Eigner treated. In 1865 Eigner restored the so-called *Madonna in the Strawberry Field* (Kunstmuseum Solothurn in Switzerland); he planed the back of the panel to 2 mm thick and mounted it to a wooden reinforcing system, as described above. This support is still in good condition (Vogelsang 1985:145).

From 1865 to 1867 Eigner restored the *Solothurn Madonna* from the same museum (Fig. 19) in his studio in Augsburg; the reinforcing work was done by his joiner E. Huber (Brachert 1972:8). In documents, Eigner reports a total transfer of the painting, but he actually left 2–3 mm of the original support; thus, he performed only a partial transfer. In 1960 the support was still in good condition (Vogelsang 1985:147). The painting was treated in 1971–72 at the Schweizerisches Institut für Kunstwissenschaft in Zurich by Thomas Brachert (1972:6–21). Eigner's auxiliary support was removed, and a new balsa-block reinforcement was applied.

Eigner's typical reinforcing system can also be found on Hans Holbein the Younger's *The Last Supper* in the Kunstmuseum Basel (Vogelsang 1985:142). The panel painting *Saint Christopher and Saint Peter* (Bernese School, about 1480) in the Kunstmuseum Berne was treated in Augsburg by the joiner E. Huber after Eigner's death. Huber continued to use the same system of reinforcement (Wagner 1977:22, 28).

The archives of the Schweizerisches Institut für Kunstwissenschaft contain many reports of plywood as an auxiliary support to reinforce thin, reduced wooden painting supports. Plywood reverses are often described, but in most cases, treatment dates are not available. All plywood types, such as three-, five-, and seven-ply boards, with thicknesses of 3–10 mm, were reported.

In the early twentieth century, reinforcing reduced panel supports with plywood was highly recommended as a good alternative to cradling. Victor Bauer-Bolton rejected cradling, arguing that plywood is an absolutely rigid material that does not respond to climatic changes (Bauer-Bolton 1933:110–12; Goldkuhle 1932). In the Wolters Report it was noted that German plywood products were insufficient for reinforcing panel

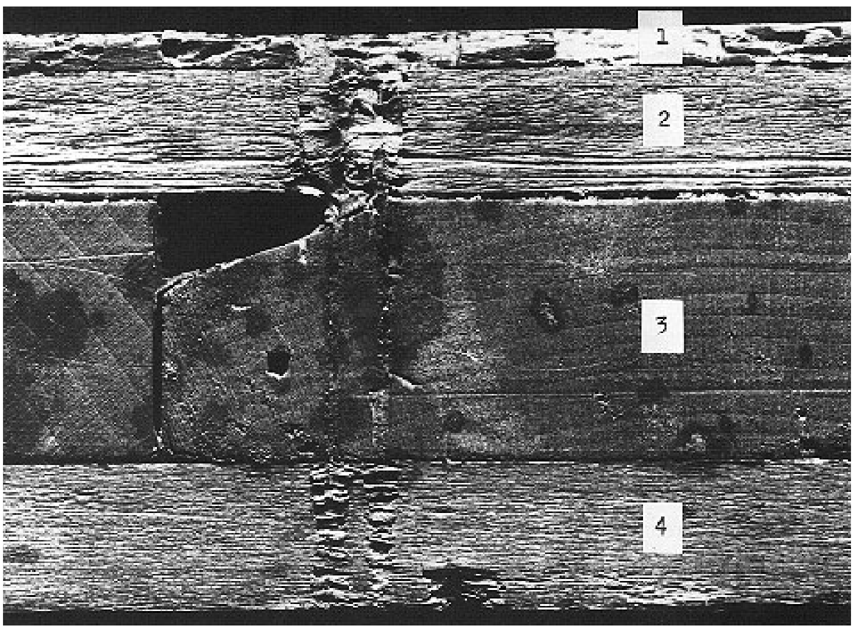

Figure 19
Hans Holbein the Younger, *Solothurn Madonna*. Side view, detail. The German restorer A. Eigner treated, among many other masterpieces, a great number of paintings by Hans Holbein the Younger. Eigner, who worked in the latter half of the nineteenth century, was probably the first to use partial-transfer techniques in panel treatment. In 1866 and 1867, he transferred this painting onto his auxiliary system, composed of the following: (1) the thinned original support and paint layer; (2) limewood boards of 8 mm thickness glued onto the original support following its grain orientation; (3) limewood boards of 12 mm thickness glued across the grain of the first layer of limewood; and (4) limewood boards of 8 mm thickness glued following the grain of the original support.

paintings, that quality U.S. products were preferable, and that only high-quality chipboards should be used for reinforcement (Wolters 1952:20). Thinner plywood auxiliary backings for weak wooden supports were also sometimes cradled to maintain an even configuration (SIK 1990).

Fiberboards were rarely used as auxiliary supports in panel painting conservation. Sundeala boards were used in 1958 as auxiliary supports for thinned Gothic paintings.

Partial transfer to particleboard has been possible since about 1950. An example is the portrait of Johann Caspar von Laubenberg by Bernhard Strigel, acquired by the Kunsthalle Karlsruhe in 1955 (inv. 2375; Lauts 1966:286). The thinned wooden panel is glued to particleboard, and the back of this auxiliary support is covered with an oak veneer. In addition, a cradle is mounted (Koch 1981).

In the Wolters Report, particleboard is not recommended for use as an auxiliary support because of its uneven surface (Wolters 1952:21). According to Wiesmann-Emmerling, a treatment of the epitaph painting of about 1420 for Count Dietrich von Wernigerode is documented in the Hessisches Landesmuseum Darmstadt. The central painting was thinned and reinforced with particleboard in the 1960s (Wiesmann-Emmerling 1994).

Other modern types of auxiliary supports in use since the 1960s are frequently identical to those used for the conservation of transferred wall paintings. These include aluminum honeycombed panels covered by a fiberglass tissue and laminated with epoxy resin.

Materials for gluing auxiliary supports to original supports include wax-resin mixtures or hide glue; wax-resin was preferred because of its reversibility.

Installations and tools used to mount the thinned original panels on the auxiliary supports with the use of pressure are part of the joiner's technical equipment. The use of veneer presses or similar constructions also used for canvas painting relining seems to have been understood as a great "improvement." Since about 1968, the vacuum table has also been used.

Rejoining broken and cracked panels

Traditionally, rejoining broken and cracked wooden panel paintings was considered the task of the joiner, perhaps working under the supervision of a painter-restorer (Hertel 1853:33). Welsch recommended flattening the damaged portions of the painting before gluing (Welsch 1834:65). The bonding medium was probably bone glue, hide glue, or casein glue. The addition of natural resin such as colophony made these glues somewhat water-resistant.

Numerous new types of glues became available in the early twentieth century. Synthetic adhesives for cold application were attractive for gluing wood. *Kauritleim,* a watery dispersion of urea resins, was used with a hardener (Gerngross and Goebel 1933:477).

Around 1950 environmental climatic conditions for the paintings became the determining factor in the choice of glue. Normally most German public conservation studios use neutral bone and hide glue, sometimes with added chalk or zinc oxide. In the process of gluing with hide glue, the butt-joint surfaces of the panel were warmed slightly with infrared spotlights. Casein glue is still frequently in use. The new synthetic glue types were mentioned in the Wolters Report (1952:14–15). But Brachert shows that animal glues are still in use (Brachert 1955b:19).

Straub prefers an adhesive type that is water- and mold-resistant. He emphasizes casein glue over animal glues and discusses all new synthetic glue types, among them epoxy resins, following the outlines of Anthony Werner (Straub 1963:141, 145, 171).

To support the bend of a warped panel during the gluing process, auxiliary constructions should be made. Sometimes butt joints are damaged by insects, reducing the quality of adhesion. Cuts can be made, and a small slat of the same dimensions can be inserted and glued (Wolters 1952:14–15). Brachert also describes this early technique, noting the use of the *Keillade,* an old joiner's tool (Brachert 1955b:19, 21). Wehlte also refers to this tool and illustrates its advantages in a case study (Wehlte 1965:37–41).

This apparatus proves helpful for rejoining smaller panel paintings. Broken panels can be warped nearly spherically, making it necessary to hold the parts of the panel in complicated positions to get the joints into perfect three-dimensional contact. Straub presented a modified apparatus for rejoining thick, heavy Catalan panel paintings, the basic mechanism of which had been developed by Hermesdorf (Straub 1956:192–94; Hermesdorf 1953:87–91). Some years later Straub presented a construction in steel and iron that was very similar to his first construction of wood (Straub 1961:44). In the international conservation scene in the 1960s, more technical constructions were described that permitted better rejoining of panels. Niedermann presented another simple apparatus (Niedermann 1979:51–54).

Early and modern auxiliary methods to reinforce glued joints

An examination of the original backs of medieval and later panel paintings reveals the numerous methods that have been used to reinforce the joints of a panel (Straub 1984:139–42). Oakum, calf hair, or horsehair was glued along the butt joint. In other cases, canvas strips cover the joints (Zehnder 1990:471, Wallraf-Richartz-Museum, Cologne, inv. 128). Sometimes butterfly inserts, as well as original cross cleats, keep the panel together. All these techniques have been used by restorers in the eighteenth and nineteenth centuries to reinforce glued joints (Bünsche 1984:70–74).

Early examples of butterly insert treatments can be found on panels in the Wallraff-Richartz-Museum in Cologne (Zehnder 1990:198, inv. 653.223, 67.422, 179). This method was in use around 1900 at the Alte Pinakothek in Munich. Annual reports describe how butterfly inserts were taken out of the structure and the remaining holes filled with putties or pieces of wood whose grain was parallel to the grain of the original support (Kinkelin 1912:fol. 9). Around 1950 setting of butterfly inserts to reinforce joints was totally rejected (Wolters 1952:15; Straub 1963:147).

Brachert recommended reinforcing open joints with wooden strips inserted along the joint; mortises should be made along the joint to set and glue the strips (Brachert 1955b:21). This method of treatment is very old and no longer used today.

Around 1950 veneer strips glued across the flow of the grain across the joints were described. An older technique is to mount very small wooden blocks over the joints. In the early twentieth century, the annual reports of the Alte Pinakothek in Munich described how small wooden blocks could be glued to reinforce joints, to replace the old butterfly inserts and cross cleats (Kinkelin 1912:fols. 8–10). Some conservators glued these blocks across the grain, others along the grain (Wolters 1952:15). Straub pointed out that in both directions of the wood grain, tensions in the wood caused by these wooden blocks had the same deleterious effect. The new, high-quality modern adhesives were to make reinforcement with blocks unnecessary (Straub 1963:147). Nevertheless, the setting of small wooden blocks is a reinforcing system that remains in use (Fig. 20). Fine wooden veneer strips are also used instead of these wooden blocks.

Repair of partially damaged supports

Repair of such damages to panels as cracks, holes, broken corners, and edges has always been made with wood or filling materials. Cracks normally are filled with wooden splints. Wormholes were filled with crushed paper (Köster 1827:13) or with small sticks of oak wood (Welsch 1834:64). Holes in the support could be filled with very old oak wood (Welsch 1834:64).

The gluing of wooden splints into holes is still in use today. This type of reintegration of damaged parts of the support was in recent years executed during the very difficult and delicate conservation and restoration of the Grünewald painting at the back of the Lindenhart Altarpiece; the conservation was conducted in the laboratories of the Bavarian Office for the Care of Cultural Heritage (Bachmann 1978:7–19). It is still debated whether it is beneficial to fill with the same wood as that of the original support; some believe that the wood of reintegrated parts in the support should be softer than the support, in which case balsa wood is convenient.

Many recipes exist for filling materials to be applied on the wooden support. Köster worked with a traditional chalk or gesso ground (Köster 1827:13). Welsch also preferred typical priming materials, such as animal glue and chalk, or oily putty (Welsch 1834:64). Kainzbauer utilized a mixture of sawdust, chalk, dextrin glue, and carbolic acid (*Karbolsäure*). Wax-colophony mixtures also served as preferable filling compounds (Brachert 1955b:30). Such compositions are well known in cabinetmakers' traditions. In the early 1950s the first filling compounds bound with synthetic resins became available. For example, polyvinyl acetate (PVA),

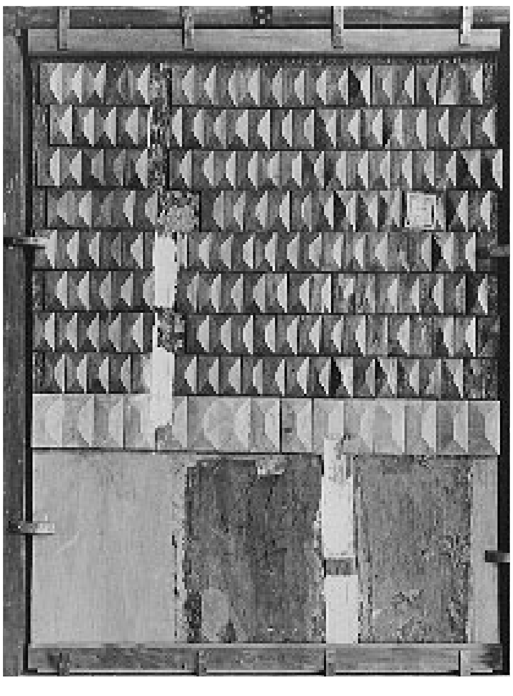

Figure 20
Hans Baldung, *Birth of Christ,* 1539. Reverse. Oil on pinewood panel, 103 × 775 cm. Kunsthalle Karlsruhe (inv. 90). The upper part of the painting came into the collection as a fragment in 1878; then in 1895 Friedläner found another part. Both fragments were combined in 1937, and the area where one part is still lacking has been completed. The photograph of the reverse from the late 1950s, before conservation, shows a reinforcement of small faceted blocks, which were removed in the subsequent conservation treatment.

toluene, chalk, and sawdust were combined to make a filling material (Brachert 1955b:30), or sawdust was mixed with cellulosic nitrate or acetate. Mixtures of epoxy resins with filling pigments, such as Master Model Paste, were also used. Not all these fill materials containing modern adhesives are reversible.

Protection of unpainted backs of panels

Authors of early restoration books complained that the old masters had often failed to apply a protective barrier to the backs of one-sided painted panels to protect against warping (Köster 1828:16). An application of linseed oil with red pigments, typically red ochre, was recommended (Köster 1828:14–15). Old brownish, reddish, or yellowish paint layers on the original backs of paintings can be found in the Alte Pinakothek in Munich and in the Wallraf-Richartz-Museum in Cologne (Goldberg and Scheffler 1971:passim; Achternkamp 1991:18; Zehnder 1990:passim). Other authors were convinced that oil paint layers on the back would help suffocate woodworms (Hampel 1846:21). Panel backs were sometimes painted with red lead (Wolters 1952:6). In Munich around 1900, hot linseed oil was used to impregnate the wooden back, after which an oily pigmented paint layer bulked with chalk or mixed with shellac was applied (Kinkelin 1912:5). At the end of the nineteenth century, some new binding media such as cellulose nitrate were recommended.

Linseed oil impregnation was sometimes done before cradling. Köster recommended covering the entire reverse, including all cradle slats (Köster 1828:14–15). Application of shellac is often reported (Zehnder 1990:422, Wallraf-Richartz-Museum, Cologne, inv. 179.59, 208). Sometimes marks or labels are helpful for dating the application of the paint layers (Zehnder 1990:335). Application of shellac after cradling was an important part of the Vienna method of cradling (Keyselitz 1960:73–75). Since the 1950s wax-resin mixtures have been used for impregnation.

Wolters summarizes a wide range of binding media that can be used to protect the reverses of panel paintings: beeswax; beeswax mixed with natural resins; beeswax mixed with colophony and linseed oil; wax combined with AW2 resin (cyclohexanone resin); pigmented oil paints; hot unpigmented linseed oil with subsequent layers of shellac; shellac mixed with Manila copal; cellulose nitrate; cellulose acetate; latex emulsions combined with paraffin, sodium silicate, and water; PVA dissolved in toluene; and an emulsion of animal glue and linseed oil pigmented with chalk or gesso, sometimes followed by a pigmented oil paint layer (Wolters 1952:6).

Concerning the effectiveness of paint layers applied to protect the backs of painted panels against humidity, Wolters presented the results of important experiments (Wolters 1963). Mühlethaler tested the effectiveness of Saran coatings, recommended by Buck (Mühlethaler 1975).

Paper, foils, and metal sheets were also used to protect the backs of panel paintings. Large paper sheets, probably applied in the nineteenth century, have been documented on some panel backs in the Kunsthalle Karlsruhe, sometimes as a type of counterveneer on sawn panels (Fig. 21) (Koch 1981; Achternkamp 1991:23). The use of paper to flatten thin panels before partial transfer is also reported (Wolters 1952:10). Apparently, foils of synthetic materials such as polyethylene are not used as frequently outside the United States (Achternkamp 1991:23), but there are some examples with cellophane foil (Wolters 1952:5). Tin and aluminum foils were first

Figure 21
Hans Brosamer, *Portrait of Wolfgang Eisen,* 1523. Reverse. Oil on limewood panel, 479 × 305 cm. Kunsthalle Karlsruhe (inv. 128). Sometimes paper sheets were glued on split or thinned panels to reinforce them. The treatment shown dates from the nineteenth century.

recommended about 1920 but were rejected in the 1950s (Basch-Bordone 1921:10; Wolters 1952:5).

Loose wooden boards, glass plates, and metal sheets were some options explored since the 1920s (Achternkamp 1991:25). Hygroscopic materials such as wooden boards, compressed fiberboards, and plywood are still used today.

Conclusion

The very young history of the conservation of wooden panel supports has a very long prehistory. The period of the joiner working under the supervision of the painter-restorer is concurrent with this long prehistory and ends in the early twentieth century. In summary, this period can be considered a period of neglect and suppression of the inherent nature of wood.

During that prehistory, pure aesthetic opinions and preferences for even, smooth panel paintings heavily influenced treatment methods. There was no understanding of the wooden support as an integral part of the picture itself; at that time, only the paint layer was considered to compose the picture—all the rest could be changed. This attitude is most clearly demonstrated by the practice of transferring paintings from wooden to textile supports. There is no doubt that total transfer of a painting was, for a long time, a technically difficult but ethically accepted procedure.

The practice of sawing a double-sided painting into halves was, therefore, not uncommon. In the nineteenth century, the concept of the gallery picture on the museum wall was dominant. It is obvious that other possible presentation methods for double-sided paintings were not considered, nor was there any discussion about this method of transforming altar wings into gallery paintings.

Finally, the dubious effects of cradling methods were never discussed. If there were damages, it was assumed that the individual cradle system was incorrect, the thinning of the original support was not extensive enough, or the remaining wood from the original support was too "lively." The next treatment to be adopted was total transfer.

The same disrespectful attitudes toward the original and integral character of the painting support appear also in the early techniques of removing wood from the support for purposes of pest control and wood consolidation.

In the nineteenth century, the difficulty of totally transferring paintings from wood without respect for the original support may have been the determining factor when it became more common to retain a thin portion of the wooden panel in partial transfer. New, rigid, wooden auxiliary supports have been advocated since the beginning of the twentieth century; partial transfer was easy to accomplish with these new types of supports.

The "prehistory" period of panel paintings conservation ended during the 1920s and 1930s. The history of the conservation of wooden panels began with a new understanding of wood's natural material characteristics and their influence on supports of works of art.

At the time of the 1930 conference in Rome, organized by the International Office of Museums, restorers started to explain the relationships between humidity and wood (Bauer-Bolton 1933). The Second World War barred further development until a new period of activity and exchange was possible, a period documented in the 1952 Wolters Report. The substantial impact of this report as a symbol of new international activity and cooperation in conservation cannot be emphasized enough (Wolters 1952). An important subsequent development in the field was the 1961 conference in Rome of the IIC. The late 1950s and the early 1960s were, in fact, the years when—under the great influence of the research of Richard Buck—the care of wooden panels definitively changed, and the knowledge that formed the basis for the choice of treatment evolved from empirical to scientific. For German-speaking conservators, Straub's published work was much more than a dissemination of that new thinking: Straub also heavily influenced ethical and technical thinking about the conservation of panel paintings.

In Germany, as elsewhere in the conservation world, research about the conservation of panel paintings diminished significantly after the 1960s. At that time, research on wooden panels was no longer a trend; it became more of a special interest. The conservation of wood in general became a more common concern—particularly the areas of wood consolidation, pest control, and climate control (including climatic boxes for panel paintings). The main subjects in international conservation research in the 1970s and 1980s were the conservation of canvas paintings and of stone. It is now time to return to the questions concerning the conservation of wooden panel paintings.

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Note

1 Unless otherwise indicated, all translations are by the author.

Materials and Suppliers

Cellosolve, Fisher Scientific Co., P.O. Box 12405, St. Louis, MO 63132.

Master Model Paste, Ciba-Geigy Corporation, 4917 Dawn Avenue, East Lansing, MI 48823.

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History of Structural Conservation of Panel Paintings in Great Britain

Ian McClure

This article is an attempt to describe the techniques used to conserve panel paintings in Britain from the seventeenth century to the first quarter of the twentieth century. It is probably impossible to write a continuous history of painting conservation practice in Britain. Restorers before the middle of the twentieth century rarely kept detailed records. Such records as survive often note only invoices and payments and offer, at best, insight into the provenance of particular paintings. While references to full-time restorers exist from the seventeenth century, artists also worked regularly as restorers, and on occasion artists would direct the work of restorers. Structural conservation of paintings on both canvas and panel was increasingly carried out by artisans and was considered so routine as to be unworthy of detailed discussion. In the literature on paintings conservation, a tendency to emphasize restoration—that is, the cleaning and retouching of paintings—undergoes steady development. Through the nineteenth century, improving their status became a matter of increasing concern to restorers. It was only in the 1930s that the beginnings of the museum conservation profession as we know it began in Britain, with treatments proposed, reported, and discussed. This development coincided with increasing awareness of practices elsewhere in Europe as well as in the United States.

Some idea of the development of structural conservation techniques before the 1930s can be gained first by the study of the backs of paintings, where the marks of previous treatments can sometimes be seen. Notes and other entries in inventories of collections can also provide clues. Second, it is fortunate that the Royal Collection has a series of inventories and papers with many references to restoration of the collection, starting with the inventory made by Abraham van der Doort, who was appointed the first surveyor of paintings by Charles I in 1625. From these sources, at times informative and at times tantalizingly obscure, comes the most complete picture of the treatment of paintings in Britain from the first quarter of the seventeenth century.[1] Third, information can be found in other documentary sources, such as artists' manuals, works devoted to conversation written by conservators, reports of commissions set up to inquire into aspects of conservation, and the occasional published record of a conservation treatment.

Unlike in the rest of Europe, relatively few early British panel paintings have survived in Britain. The destruction of church furnishings during the Reformation has resulted in only a few chance survivals where an altarpiece or a devotional painting was hidden or lost. Such a circumstance had the added benefit of delaying the painting's entry into the conservation cycle, leaving the support virtually untouched. Religious paintings that are now found in churches are most likely to have been installed much later (Grössinger 1992). There were, therefore, very few indigenous painted panels to enlist particular conservation techniques, good or bad—such as the splitting of altar panels, as was a common practice in Germany in the nineteenth century, as mentioned by Ulrich Schiessl (see "History of Structural Panel Painting Conservation," herein). The Thornham Parva Retable, found in 1924[2] and generally accepted to have been made and painted in about 1340 in an East Anglian abbey, possibly Thetford, has undergone little structural alteration, although parts were crudely overpainted in the eighteenth century (Figs. 1, 2). The Westminster Abbey Retable, painted around 1275, was first noticed by George Vertue about 1725; it formed the top of a large press built to house several effigies (Wormald 1949:166–74). Until the beginning of the nineteenth century, the painted surface was damaged by neglect and deliberate vandalism, but the complex wooden support is largely untouched.

The majority of English panel paintings that have survived are portraits painted up to the beginning of the seventeenth century. Many of these were painted by itinerant Italian, German, or Flemish artists who, like Zuccaro, Holbein, and Stretes, might have made several extended visits to the Tudor court. These painters competed with British painters such as Robert Peake. Some larger panels also survive from the sixteenth century, a notable example being *The Family of Henry VIII: An Allegory of the Tudor Succession* by Lucas de Heere (Royal Collection, Hampton Court Palace), who escaped religious persecution in the Netherlands and worked in England from 1566 to 1576. The painting,

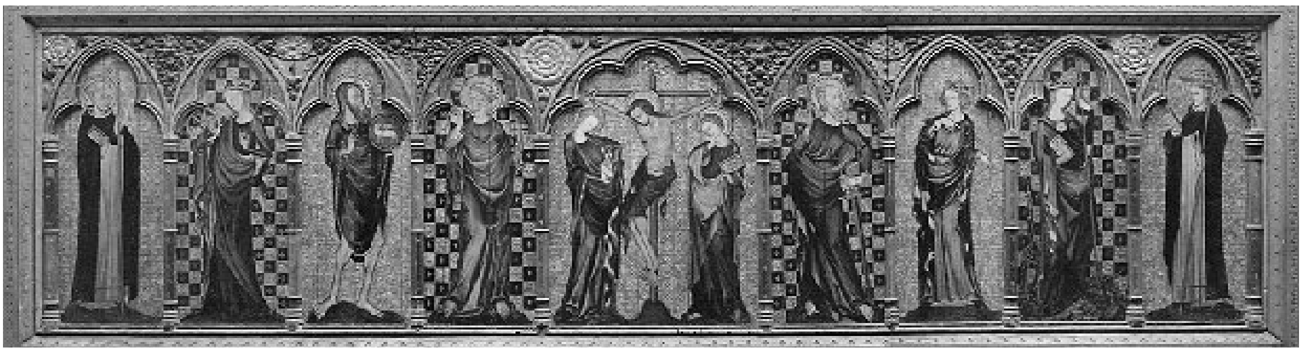

Figure 1
British school, Thornham Parva Retable, ca. 1340. Oil on panel, 381 × 94 cm. Church of Saint Mary, Thornham Parva.

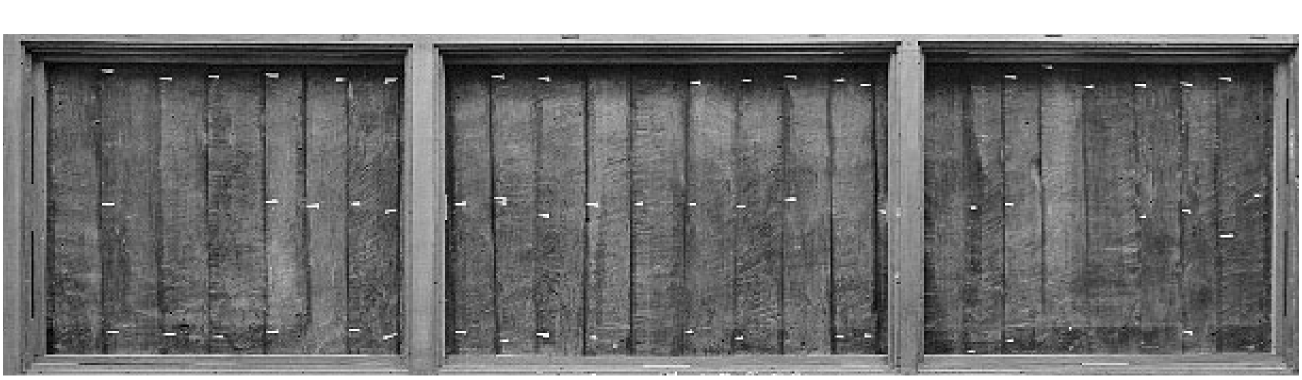

Figure 2
British school, Thornham Parva Retable, reverse. The white arrows indicate the placement of dowels. The frame is modern.

made up of horizontally aligned planks and measuring 129 × 180 cm, was commissioned by Elizabeth I and presented to her ambassador to France (Jackson-Stops 1985:82–83).

The arrival first of Daniel Mytens, and then of Rubens and Van Dyck at the invitation of Charles I, precipitated a renewed interest in painting and collecting. With the purchase of most of the collection of the dukes of Mantua between 1625 and 1628, Charles amassed the most spectacular collection in Europe, reflecting his passion for Titian and Van Dyck (Millar 1977:42–49). Painters came to England to satisfy the demand for commissions, predominantly portraits. Peter Lely settled in England around 1643 and found little competition to prevent his establishing a large and flourishing portrait studio. Talley has described the large number of painting treatises published in the seventeenth century, some of which contain advice on the conservation of paintings (Talley 1981:14–18). While this development undoubtedly reflects an increased interest in painting, it also occurs at a time when many old masters on canvas would be reaching the age when they would require lining for the first time (Percival-Prescott 1974). Many of De Mayerne's experiments in conservation in the first half of the seventeenth century were directed toward obtaining a more stable priming that resisted flaking, treating flaking with glue impregnation, strengthening unlined canvases with glue, and sealing the backs against dampness. The purpose of the passages on conservation in Robert Salmon's *Polygraphice,* published in 1695, is not clear. It is possible the instructions were enough to interest the public without providing practical instruction. The passage on panel paintings reads, "If your painting be wainscotting, or any other Joynery or Carpentary Work, you may take the Wood-ashes . . . and mixing them somewhat thick with Water, rub them over the Painting with a stiff Bristle Brush, as a Shoo Brush, and so scour, wash and dry it, as aforesaid, and then varnish it with common Varnish." A more gentle though abrasive treatment is suggested using water and smalt, in cases in which "the Painting be more curious, as Figures of Men, Beasts, Landscips, Flowers, Fruits etc." (Salmon 1695: addenda to chap. 3, secs. 4, 5).

Eighty years later Robert Dossie in his *Handmaid to the Arts,* published in 1764, has as the only section on panel treatment a set of instructions for the transfer of a panel to canvas, with a warning to practice "with some old pictures of little value" (Dossie 1764: addenda, 422–23). In his preface Dossie dismissed Salmon's *Polygraphice,* as the relevant parts are "confounded with such a heap of absurd stuff and falsities," but it is hard to imagine "the lover of the polite arts" finding Dossie's advice of any practical use either.

Figure 3
Joseph Noel Paton, *The Good Shepherd* (right wing of a triptych), 1877. Oil on panel, 106.7 × 55.5 cm. Royal Collection, Sandringham.

After the seventeenth century, panel supports (apart from those used for sketches) do not appear to have been used again extensively until the nineteenth century, with the manufacture of mahogany panels by artists' suppliers.[3] These panels are often extremely stable, having been primed on both sides. A panel of a triptych (otherwise on canvas) prepared in this manner, commissioned by Queen Victoria from her limner, Sir Joseph Noel Paton, survived years of neglect in a damp church without warping, although the paint and ground layer developed a marked craquelure (Fig. 3). Large panels, less well prepared, were also used in the nineteenth century by, for example, Sir William Allan (1782–1850), as an archaizing element in romanticized scenes from Scottish history. *Heroism* *and Humanity* (Glasgow Art Gallery and Museums), painted on a mahogany panel measuring 127 × 197 cm, had originally been heavily battened and subsequently developed splits.

A notable exception is the series of large oak and mahogany panels used by George Stubbs in the 1770s and 1780s, when he was seeking a stable support for his experiments with media such as wax and animal fat. In a memoir of Stubbs's life given by his common-law wife to Ozias Humphry, Mary Spencer described Stubbs as taking conservation measures with his work; she recalled Stubbs as having a large portrait of George III lined before it was exhibited. The series of *The Haymakers* and *The Reapers* at Upton House in Warwickshire (National Trust), painted in 1783, have cradles attached to them. It is possible that Stubbs had the panels cradled as a preventive measure to make the wooden supports as dimensionally stable as the large ceramic plaques he had made for him by Josiah Wedgwood.

From this brief overview it is clear that apart from sixteenth- and seventeenth-century portraits, most panel paintings that have been treated since the seventeenth century were brought to Britain, principally from Italy, France, Holland, and Spain. Many were bought by agents, such as Nicolas Lanier, who negotiated for the Mantua collection for Charles I in 1626, or those whom Sir Charles Eastlake employed to find paintings in Italy for the National Gallery in London after his appointment as its first director in 1855. Many works of more variable quality were purchased as part of the grand tour, and, depending on the taste of the collector and of the period, particular schools would be favored. The cabinet at Felbrigg, for example, was remodeled by William Windham II in 1751 to house his collection of paintings purchased while on his grand tour in Italy a decade earlier, and to demonstrate his taste for Rococo Italian landscape (Jackson-Stops 1983:19–20). The Spanish collection at Kingston Lacy was put together by William Bankes from about 1814, when the disruption of the Peninsular War made the purchase of many fine paintings possible (Cornforth 1986[3]:1576–80). The collection has a panel of a *Madonna and Child with Angels,* attributed to Francisco Ribalta (Figs. 4, 5). The panel is in an untouched condition and has the original loose fibers glued over joints, as well as dovetailed battens that are set in, top and bottom, at right angles to the grain. Little work was carried out on the Bankes collection until it was bequeathed to the National Trust in 1984, and so this panel was never subjected to cradling and thinning.

The value of the archival material referring to the conservation of the Royal Collection was first recognized by Oliver Millar in his book *The Queen's Pictures,* which contains many references to reports, estimates, and accounts. There were two periods of particular activity in the conservation of panel paintings in the period covered by this article: the reign of Charles I and the period from 1857 to 1879, during Queen Victoria's reign, when the post of surveyor of Crown pictures was held by Richard Redgrave. Other periods during which the collection received particular royal attention have fewer references to panel conservation. The interest of Frederick, Prince of Wales, in augmenting and rearranging the collections, occasioned a report of a memorable visit to a restorer in 1732: "On Saturday in the evening her Majesty, the Prince of Wales, The duke and the five Princesses went in Coaches from Kensington to Chelsea Hospital, where after taking a turn in the Great Hall, they walked to the Water-side

Figure 4
Francisco Ribalta (attrib.), *Madonna and Child with Angels*. Oil on panel, 76 × 100 cm. National Trust, Kingston Lacy House, Dorset.

Figure 5
Francisco Ribalta (attrib.), *Madonna and Child with Angels,* reverse.

and went on board the Prince of Wales fine Barge, Lately built under the Direction of Lord Baltimore; and being attended by the Officers and Ladies in Waiting of the Court in another Barge, and a Set of Musik in the third Barge, they proceeded to Somerset House . . . there they viewed Mr Walton's Progress in cleaning and mending the Royal Pictures."[4]

George IV, when refurbishing Carleton House as prince regent, spent lavishly on paintings. The attempt to settle the prince's debts in the 1790s produced accounts from George Simpson for cleaning and repairing a large number of pictures (Millar 1977:129–30).

In his publication of the inventory prepared for Charles I by Abraham van der Doort, Millar published some of the earliest remarks on condition and conservation in English (Millar 1960). Van der Doort's inventory is spread over several manuscripts. One was a working copy annotated and updated by the surveyor.[5] The inventory usually records each painting bought from the Mantua collection as a "Mantua Piece." The paintings recorded in "Whithall [the Palace of Whitehall] in the Second and Midle Privie Lodgings Roome" include "A Mantua peece done by Julio Romano . . . Item [:] A Highe and Narrowe peece. In a carved whited and guilded frame. Being a Sacrifice of Some ffower [four] entire litle figures and a goat lying by to be Sacrificed."[6]

This painting is still in the collection.[7] Its indifferent quality has preserved it from attention and inevitable conservation. The construction of the softwood panel is untouched apart from woodworm attack, which has now been consolidated (Figs. 6, 7). This painting is indicative of the condition of pictures received into the collection at this time, when little structural work was required apart from treatment for flaking. Another painting after Giulio Romano, *The Rape of Europa,*[8] mentioned as being "defaced by quicksilver" from the voyage from Italy to England, has nevertheless survived, although it was probably repainted and enlarged soon after its arrival. Its panel, with the brand of Charles I on the back, has also survived untouched. The panel was constructed of three horizontal planks of softwood with an original vertical strip on the right side and a later addition along the top edge; the central joint has opened, and a split and separation have occurred where the wood grain meets at right angles. On the left side, where the horizontal planks are unrestricted, each plank has warped, so that a permanent washboard set has been formed. The linen strips reinforcing the joins are probably early repairs (Figs. 8, 9). Had the

Figure 6, right
Studio of Giulio Romano, *Sacrifice of a Goat to Jupiter*. Oil on panel, 123 × 66.5 cm. Royal Collection, 109.

Figure 7, far right
Studio of Giulio Romano, *Sacrifice of a Goat to Jupiter,* reverse.

Figure 8
Follower of Giulio Romano, *The Rape of Europa*. Oil on panel, 99.7 × 127.4 cm. Royal Collection (131).

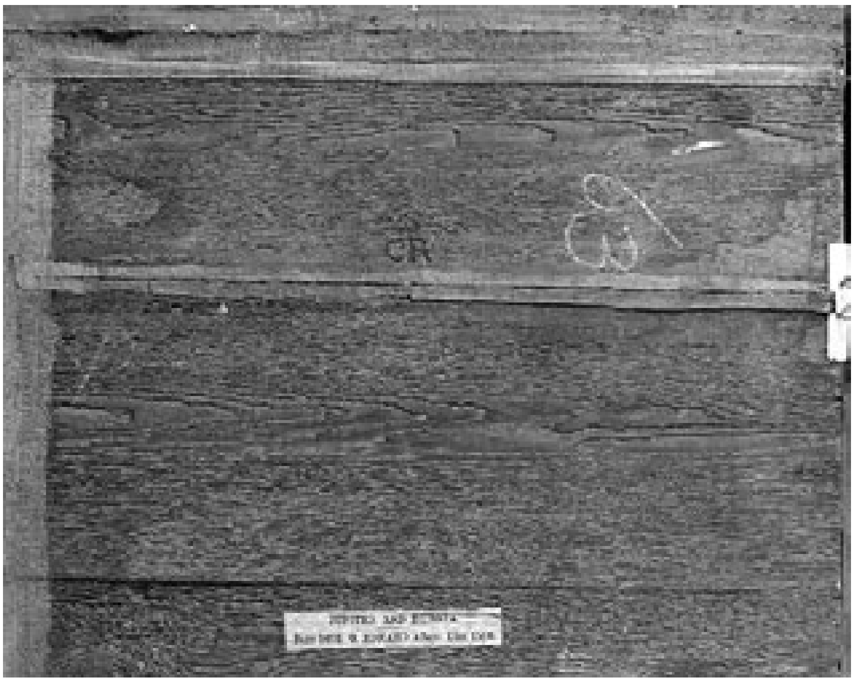

Figure 9
Follower of Giulio Romano, *The Rape of Europa,* reverse.

painting been considered of first quality, this complicated panel construction would have received major panel work: it would perhaps have been thinned and placed on a latticework, as was a posthumous double portrait of Sir Philip Sidney and his sister, attributed to Daniel Mytens, which was thinned to an overall thickness of 3 mm (Figs. 10, 11). The latticework may be datable to the early eighteenth century and is very probably English. Later, had the Romano panel received attention in the nineteenth century, it would have been thinned, flattened with moisture, and cradled—and it would have subsequently developed more splits after the cradle seized.

Figure 10
Daniel Mytens (attrib.), *Sir Philip Sidney and His Sister,* ca. 1620. Oil on panel, 46 × 66 cm. The condition before treatment is shown. Private collection.

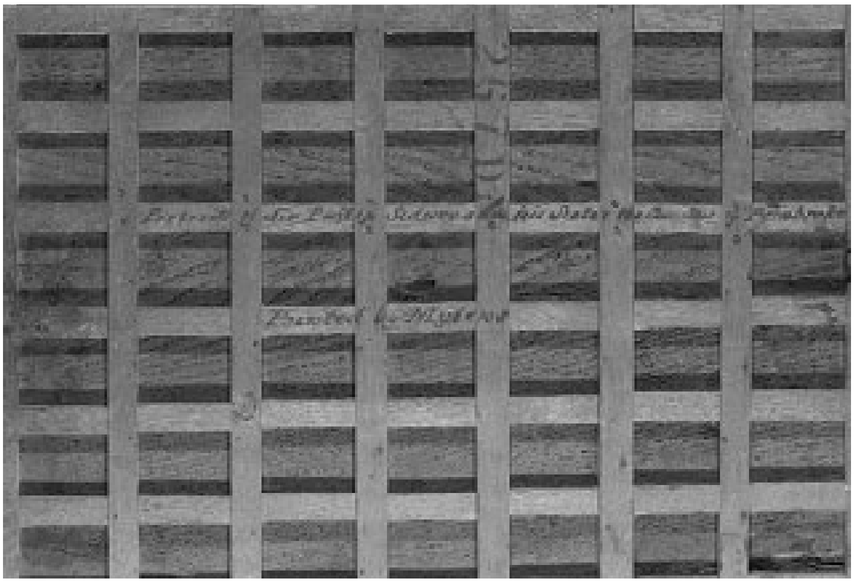

Figure 11
Daniel Mytens (attrib.), *Sir Philip Sidney and His Sister,* reverse.

The van der Doort inventory also gives a list of fifteen paintings recently repaired.[9] Van der Doort never spoke English well, and his notes seem to be phonetic renditions of his Flemish accent; among the problems treated were extensive flaking, blistering, splitting of the support (Holbein's portrait of Thomas More was described as "dikat" [decayed]), flaking due to "woreting" (presumably woodworm damage), warping, and cracking from being placed in a warm room.[10] Here the panel, a *Sacra Conversazione* by Giacomo Palma Vecchio, was affixed to another oak board, in which state it remains today (Figs. 12, 13).[11] Van der Doort also mentions restoration and said that works thought to be beyond repair had been restored.[12] In another note attached to a list of "34 pictures which are remaining in Nonsuch House this of March 1639," van der Doort noted that Mr. Sorffijor broke a little piece off a "jong brugel." Mr. Sorffijer promised to restore it.

Figure 12
Giacomo Palma Vecchio, *Sacra Conversazione*. Oil on panel, 60 × 81.1 cm. Royal Collection (181).

Figure 13
Giacomo Palma Vecchio, *Sacra Conversazione,* reverse.

When van der Doort mentioned the defacement of *The Rape of Europa* by quicksilver, he was referring to the damage to the paintings brought from Mantua by sea. The paintings were blackened when a cargo of currants fermented beside a cargo of mercury (by some process about which we can only speculate). De Mayerne, the physician to James I and later to the queen of Charles I, Henrietta Maria, suggested methods of cleaning. Jerome Lanier, the restorer brother of Nicholas, had success in cleaning the oil paintings but had less success with tempera panels.[13]

Some 225 years later, Richard Redgrave set himself the task of making an inventory of the paintings in the Royal Collection, which had steadily increased after a portion of the collection of Charles I, which was dispersed during the Commonwealth, was bought back after the Restoration (Millar

1988:86–92). Redgrave proposed that a catalogue be compiled, with a description and photograph of each painting. He started the project in 1858 and covered the pictures at Windsor, Buckingham Palace, and Hampton Court, completing his task in 1879. The catalogue sheets were specially designed and were updated by Redgrave and his successors.

The inventory survives to this day. The photographs are still legible. A small panel from Hampton Court of *Jupiter and Io,* attributed to Lucas de Heere, is recorded as having "the middle joint broken and ill-formed" (Fig. 14). The picture was examined in April 1869, and under the heading "State of the picture at the above date" is written, "wants atten-

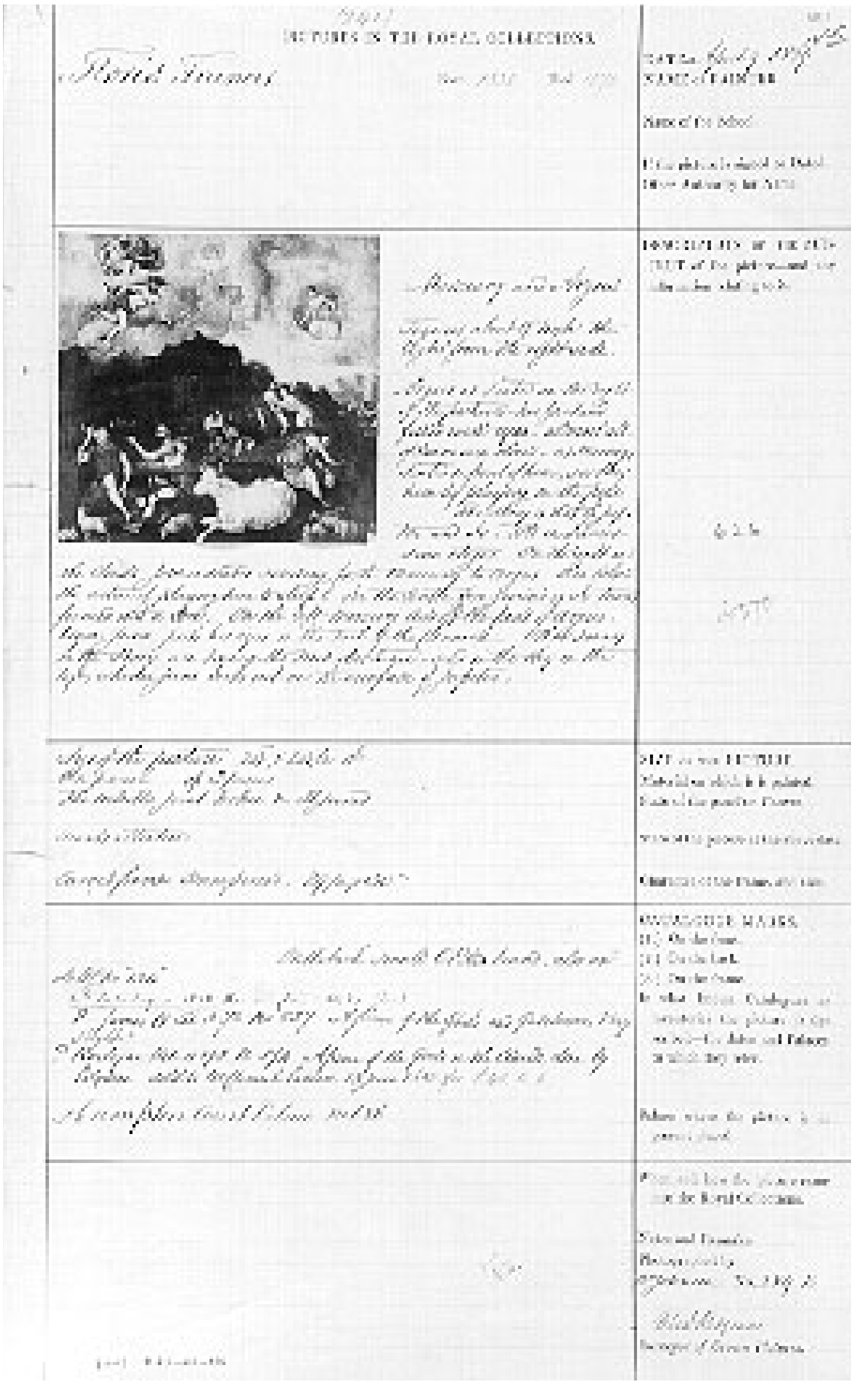

Figure 14
Redgrave Inventory, entry for *Jupiter and Io,* now attributed to Lucas de Heere. Royal Collection.

tion." Redgrave was able to obtain an annual sum for conservation and to plan programs of conservation. Other entries describe more extensive work. The sheet made in 1868 for Rubens's *Assumption of the Virgin* includes a photograph that shows the panel joins very prominently, as well as a split on the left side (Fig. 15). Redgrave notes that the panel has now been "carefully parqueted to keep together the 4 pieces sound." The careful parqueting of Rubens's *Farm at Lachen* (Royal Collection, Hampton Court Palace), recorded in March 1861, did not last, as the panel was treated for blistering in 1901, 1950, 1963, 1964, and 1975.

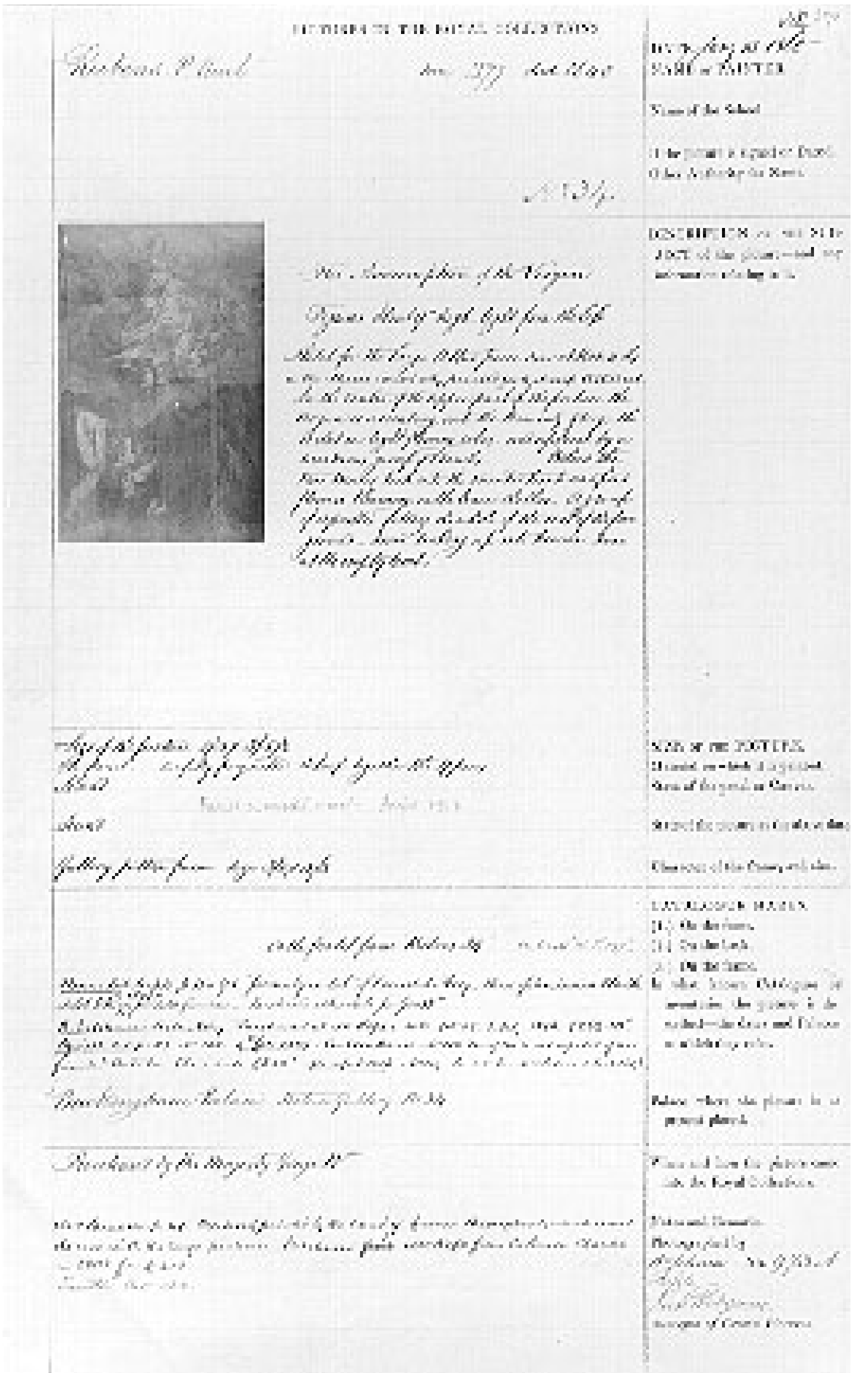

Figure 15
Redgrave Inventory, entry for Rubens's *Assumption of the Virgin*. Royal Collection.

Redgrave had most of the conservation work carried out by particular restorers. Morrills of Duck Lane submitted accounts for work from 1863, largely for lining and parqueting. The firm continued to work for the collection well into the twentieth century, recommending cradling as late as 1946. The company continued in trade until 1981. In the nineteenth century it had a wide practice and worked for the National Gallery as well as for private collections. The firm regularly stamped its cradles and favored quite radical thinning of a panel before the cradle was applied. The glued members often vary in width to cover splits and disjoins. Redgrave also employed restorers to treat the fronts of the paintings, as he was the first surveyor who didn't work on the paintings himself, although he was an artist of considerable talent (Millar 1977:189).

Redgrave also employed as a restorer Henry Merritt, who published a book on restoration in 1854 entitled *Dirt and Pictures Separated*. Although he briefly discusses the transfer of panel paintings, citing *The Raising of Lazarus* by Sebastiano del Piombo in the National Gallery, London, he is chiefly concerned with distancing the professional restorer from the "professors of picture-restoration . . . numerous in London, familiarly known by the sign hung out at their doors; generally, an old portrait, one half clean, the other half dirty, as a specimen to convince the unwary connoisseur that the proprietor of the shop can restore pictures" (Merritt 1954:64–65). The publication of this book coincided with the publication in 1850 and 1853 of the reports of select committees appointed to inquire into the management of the National Gallery. William Seguier, first keeper of the National Gallery beginning in 1824, had also worked as a restorer for the prince regent and had been appointed surveyor, cleaner, and repairer of the King's Pictures in 1820. His work on the National Collection passed without comment. However, the work done in 1852 by his younger brother John provoked criticism. While the evidence gathered by the committees is of great importance in displaying the widely differing views on cleaning and the terrible climatic conditions within the galleries, structural work is hardly mentioned (Bromelle 1956:186–87; Anderson 1990:3–7). Charles Eastlake, the Gallery's first director, recommended Francis Leedham as a skillful panel repairer. William Morrill took over Leedham's studio in 1861. Eastlake avoided controversy by having purchases in Italy cleaned and restored before importing them, often employing the creative talents of Molteni in Milan (Anderson 1990:6). Merritt worked on *The Incredulity of Saint Thomas* by Cima da Conegliano when it arrived at the National Gallery in 1870, but only removed varnish under the supervision of Eastlake's successor as director, William Boxall (Wyld and Dunkerton 1985:42). He worked with the artist George Richmond on the restoration of the portrait of Richard II in Westminster Abbey in 1866. They were observed by George Scharf, who had access to their reports on the progress of the work—"an elaborate daily record of operations kept by Mr. Merritt" (Scharf 1867). Unfortunately, these do not appear to have survived. The panel itself required little work: "The picture is painted on oak, composed of six planks joined vertically, but so admirably bound together as to appear one solid mass" (Scharf 1867:28). Merritt and Richmond removed layers of what was undoubtedly overpaint and, more controversially, removed the raised diaper pattern in the background, which they considered a later addition (it was, in fact, original). However, "a square piece of the diaper pattern in relief has been intentionally left undisturbed in the upper left-hand corner" (Scharf 1867:37).

While this account of the treatment of the portrait has a contemporary feel, restorers in Britain continued to work in an independent yet subservient tradition. Even as late as 1949, the restorer Johann Hell worked for two days in Cambridge cleaning the Fitzwilliam Museum's *Man in Fanciful Costume,* then thought to be by Rembrandt, supervised by the director of his office. The Conservation Department of the National Gallery was not established until 1947 (Bomford 1978:3–10). In 1917 Margaret Talbot Jackson still described cradling as a sound technique and decried as old-fashioned the use of fixed steel bars as battens (Jackson 1917:115–16). By 1933, however, reports in professional journals had created an increased awareness of advances in conservation practice. In that year, Plenderlieth published in the *Museums Journal* a report on the conference in Rome on the examination and preservation of works of art, held under the auspices of the League of Nations.[14] Different methods of transfer are discussed. Methods of facing are reported. Cradling is discussed critically and the edge-on type of cradle reported by Helmut Ruhemann supported. Professor A. P. Laurie contributed a discussion on the warping of panels; he recommended sealing the back and end grain of a panel to slow its response to changes in relative humidity, a topic that still occupies us today.

Acknowledgments

The author is grateful to Christopher Lloyd, surveyor of the Queen's Pictures, for permission to see the Redgrave Inventory, and to Charles Noble, assistant surveyor, for his most valuable help in finding relevant information and sharing his knowledge of the history of the conservation of the collection. Permission to quote material from the Redgrave Inventory is from the surveyor of the Queen's Pictures, Royal Collection, Saint James Palace. By gracious permission of Her Majesty Queen Elizabeth II.

Notes

1 See Millar 1977. There are many references to picture restorers and their work on the collection.

2 See Lillie 1932:pt. 2:4. For a description of the construction of the retable and its altar frontal, now in the Cluny Museum, Paris, see Norton, Park, and Binski 1987.

3 See Mogford ca. 1865: appendix, catalogue of Winsor and Newton. The catalogue advertises prepared panels ranging from 8 × 6 in. to 36 × 28 in. (20.3 × 15.2 cm to 91.4 × 71.2 cm). Mogford recommends "panels of well-seasoned mahogany . . . prepared with exceedingly firm and smooth grounds, for works requiring great detail and finish) (p. 16). The text is datable to approximately 1865, as Mogford describes the pigment aureolin (cobalt yellow) as among "the latest and most important contributions of science to the Artist's palette" (p. 15). Winsor and Newton introduced the pigment in 1861.

4 Quoted from *Read's Weekly Journal,* 15 July 1732, in Beard 1970:492.

5 Millar 1960, Bodleian Library, Oxford, MS Ashmole 1514.

6 Millar 1960:fol. 19.

7 Shearman 1983. Catalogued as workshop.

8 Shearman 1983, cat. 131:132. Catalogued as follower.

9 Millar 1960:191: "alta piturs dat er mended auff lat dat wer [extremely?] spijl and pilt auff vrom de bord and wor et and roten so dat auff som War but left te bord Was most all tu bi taken awar als ju M partlij knowes" (Bodleian Library, Oxford, MS Ashmole 1514, fol. 193).

10 Shearman 1983, cat. 181:178; Millar 1960:191: "[auff standing in a Warm rom?] itm da pis auff our ladi auff old palmo Wraff de bord Was Warp and Krack and Woren tin and muz [out of?] fram Was set opan a new streng bord terfor and in guldit new fram terfor 3 pant."

11 Shearman (1983, cat. 181:179–80) records that the original panel, measuring 60 × 81.1 cm, was thinned to 0.4 cm. The oak panel affixed to the back measured approximately 0.7 cm.

12 Millar 1960:191: "item de [excellent?] Womans had inde kabinet auff beling Wij Was holij rint and pilt auff in a manner als if Eij taught it to hauff bin posibel tu bi mendis terfor 4 pant."

13 See Trevor-Roper 1993:277; Talley (1981:203) quotes Symonds's account of Lanier's experiences of cleaning these paintings.

14 Plenderlieth 1933. The conference papers were published in *Mouseion* (1931) 15:13–16.

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The Conservation-Restoration of Wooden Painting Supports

Evolution of Methods and Current Research in the Service de Restauration des Musées de France

Jacqueline Bret, Daniel Jaunard, and Patrick Mandron

SINCE THE 1966 CAMPAIGN to restore the Italian primitives of the Campana Collection in the Musée du Petit-Palais in Avignon (see Bergeon et al., "Two Hundred Years of History in France," herein), several factors have influenced the evolution of the restoration of wooden supports in the Service de Restauration des Musées de France.[1]

Research

In the wake of the 1978 Oxford congress of the International Institute for the Conservation of Historic and Artistic Works, several studies were carried out jointly with the Centre Technique du Bois (CTB) during the 1980s to test and improve restoration methods.[2] An initial study focused on the behavior of experimental oak boards,[3] which were painted on one or both sides according to a technique of the masters[4] and subjected to artificial aging in a climate-controlled room.[5] Systematic testing was conducted to determine if the way the wood was sawn had an influence on its behavior when it was submitted to an alternation of wet and dry cycles; results confirmed that panels painted on both sides remained stable under variations of relative humidity (RH), whereas panels painted on one side only showed distortions and, moreover, retained some residual distortions throughout the entire sequence of cycles.[6]

These results led to the search for a product with a degree of permeability close to that of the paint layer but that would also be transparent, reversible, and applicable as a backing. A coating composed of a layer of gelatin and two sheets of Saran[7] proved to be most effective, but this isolated result has thus far not been extended into practical application.

The next study involved simulated repairs of cracks by the insertion of triangular-section pieces, according to a technique developed at the Istituto Centrale del Restauro in Rome. Some thirty test samples[8] were submitted to accelerated aging,[9] and the best results—little distortion, no splits or cracks—were obtained when the groove was shallow and at a 90° angle, and the inlay was made of wood cut on the quarter.

Another study tested two methods for backing severely thinned-down panels[10]—one with two superimposed layers of balsa-wood rectangles, the other with two layers of cork held rigid by an inert material.[11] After artificial aging, the cork-backed panel showed considerable distortion, whereas the balsa-backed panel remained flat. The balsa backing was therefore recommended; the last study of the behavior of experimental reinforced painted panels confirmed the validity of this option.

Restorations of the Last Twenty-Five Years

Data obtained from the observation of restorations done in recent years—involving supports as well as reinforcement systems—have enhanced understanding of the behavior of material when it is confronted with the various constraints caused by these interventions.

Such considerations are particularly interesting because the restorations in question were carried out on a large number of paintings from various periods and schools and, moreover, involved works marked by a long tradition of restoration, with its modifications, amputations, and, at times, complete elimination of the support.

Development of Preventive Conservation

In the museum world in recent years, an increased awareness of the importance of the conditions of conservation, particularly of works painted on wood, has allowed the staff of the Service de Restauration des Musées de France to design more minimal interventions and thus to respond better to the essential notion of respect for the integrity of the work.

The combination of the three factors mentioned above—research, observation of recent restorations, and the development of preventive conservation—has led the staff to develop a more rigorous protocol for the approach, the execution, and the follow-up of each particular case, with an endeavor to be as little interventionist as possible.

Once a scientific file has been assembled, the first choice to be made by the responsible conservators is whether to take simple conservation measures by acting on the environment (indirect action) or to restore the support by an intervention on the material itself (direct action), a process sometimes completed by the addition of a reinforcement system. Conservation interventions by direct action are described below; they are presented in chronological order for the sake of clarity.

Fungicide and Insecticide Treatments

The very first intervention, to be carried out before any actual restoration procedure, must aim at restoring the soundness of the material by halting insect attack and invasion by microorganisms, thus eliminating further risk of contamination. The remedial effectiveness of the means used will depend on the product penetrating evenly and thoroughly into the panel, which, in turn, depends on the accessibility of the areas to be treated; good preventive results will be achieved if the treatment is rigorously applied to all unpainted surfaces.

The presence of a paint layer limits the choice of fungicide and insecticide products that can safely be employed. Because of its high toxicity, lindane[12] is no longer used as an insecticide. Instead, such active agents as cypermethrine[13] in a heptane solution are brushed on, injected, or sometimes sprayed on. Nitrogen gas treatment is now beginning to be tested against xylophagous insects.[14] Mildewed paintings are carefully vacuumed, the dust being drawn through a biological filter (Cortet 1988); they are then placed in a controlled climate. After strain identification, fungi infestations are treated with the appropriate fungicide.

Repairs to Supports

It is important to keep in mind that a preliminary treatment of the paint layer is necessary when repairs must be made to the support. This treatment allows control of the cohesion and adhesion of the paint layer, as well as facilitating effective elimination of fillings and overpaintings.

Figure 1
School of Novgorod, *Crucifixion,* sixteenth century. Reverse. Tempera on panel, 71.2 × 57.3 cm. Louvre Museum, Paris. Detail of the reverse of an icon, showing readjustment of the inlaid crosspiece after shaping.

Conservation or removal of reinforcements on the reverse of the panel

The original reinforcing elements (Marette 1961), such as nailed crosspieces, are usually left in place; they are removed only if severe deterioration affects the front of the panel. Inlaid crosspieces that are blocked are made mobile again or, if necessary, shaped according to the curvature of the panel, as was done with an icon in the Louvre Museum (Fig. 1).

In cases of significant deterioration, original cross-grain elements such as rabbet joints or decorative elements applied to the front are rendered mobile and left attached to the support.

If reinforcing elements have been modified, or if some have been added—as, for instance, a cradle—the conservators try to loosen the panel to permit free movement again.

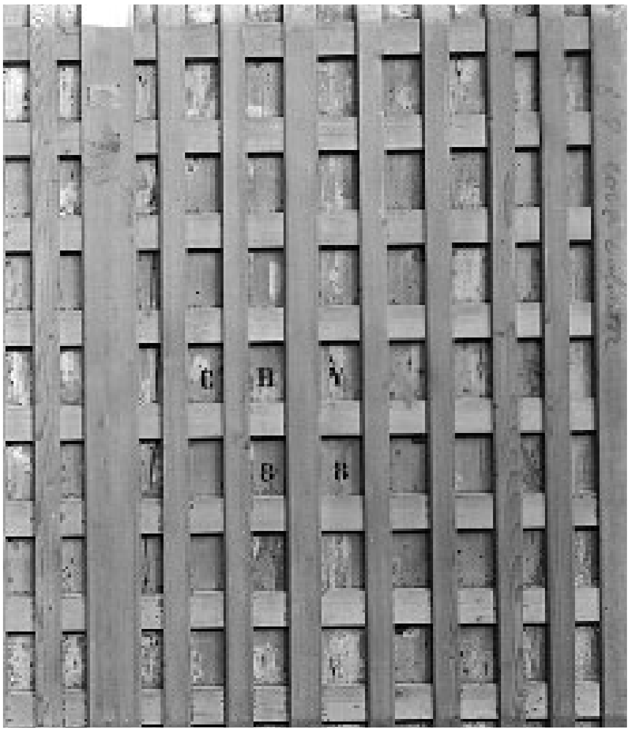
If the front of the panel shows significant deterioration, the elements applied to the reverse are removed, either completely or, if it is sufficient for treatment, partially. Such was the case with a painting in the Musée Condé in Chantilly, France, where only two vertical uprights were removed and changed to allow the treatment of joints and fractures (Fig. 2a, b).

Treatment of Fractures and Joints That Cannot Be Separated

Depending on the configuration of fractures or openings of joints that are sometimes accompanied by distortions, interventions can be carried out by means of simple gluings, which can sometimes be reinforced by V-shaped grooves and wooden inlays. The conservators try to keep the angle of the groove to a minimum, despite the results of the CTB study. This seems more suitable to the actual cases we encounter, and it also results in the least possible elimination of original wood. With the same concern for the preservation of the support, the V-shaped grooves are made only at the two extremities of the joint, as daily observation has shown that splits start more often at the ends of a board—rarely at the center.

The tip of the incision is in the axis of the fracture, and it usually reaches a depth of about two-thirds the thickness of the panel. The wood used for the inlay is always one whose density is equal to or less than that of the original material; it is sawn on the quarter and cut at regular intervals to limit tensions.

When, because of significant wood shrinkage, the two edges of a fracture are too far apart and can no longer be joined, a sliver of wood of the same species is cut to size and inserted into the fracture. It is glued along both sides to ensure renewed cohesion. When the joints cannot be separated because of the complexity of their assembly, and the gap between the two pieces is frontally visible and, therefore, aesthetically disturbing, the sliver inserted is glued on one side only; this procedure allows a reduction of the gap between the boards while preserving a clear reading of the structure, and maintains the free play of the wood necessary to prevent new fractures.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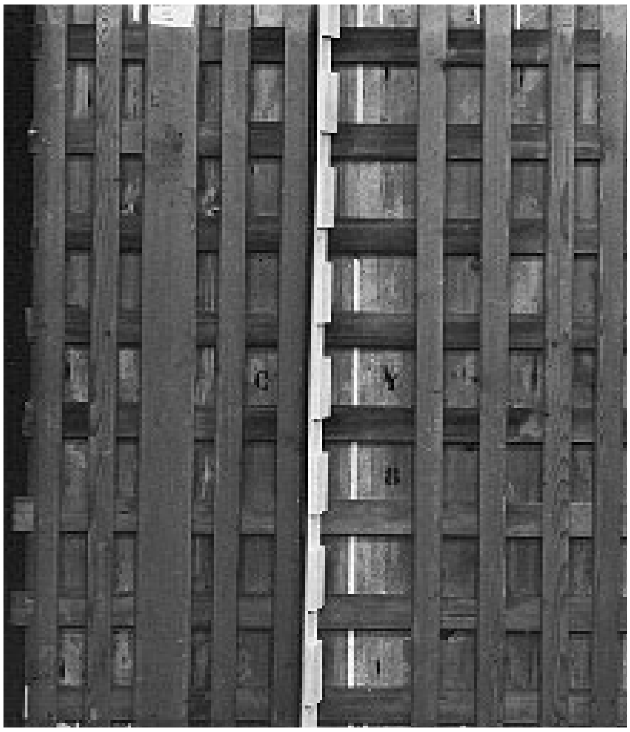

b

Treatment of Fractures and Joints That Can Be Separated

Figure 2a, b, above
Salvatore Rosa, *Christ Resuscitated,* eighteenth century. Reverse. Oil on panel, 109 × 96 cm. Musée Condé, Chantilly, France. A heavy cradle (a) that required partial removal of elements. During the process (b), a new vertical upright is shown before being placed.

For joints whose original assemblies still exist with no deterioration of their support but which have come apart because the adhesive has deteriorated, a simple regluing after preliminary cleaning is indicated; such gluing is also desirable in the case of simple fractures.

However, in treating joints and fractures that affect large or severely and unevenly distorted boards, it may be necessary to resort to inserting false tenons (Fig. 3).[15] In fact, the two flat surfaces presented by the upper and lower parts of the false tenon allow, when the edges are adjusted, a compensation for the difference in level between the two edges of the split; this is done by the application of a piece of wood of corresponding thickness to one of the false tenon's surfaces. Additionally, this technique provides good visibility of the work and easy access to the joints at the time of gluing, by reducing the need for clamps and other clamping devices. This method, which the staff of the Service de Restauration has used for a long time, has recently evolved toward a reduction in the size

Figure 3
Jean de Saint-Igny, *Adoration of the Magi,* seventeenth century. Oil on panel, 57.5 × 45.7 cm. Musée des Beaux-Arts, Dunkerque, France. Reassembly with false tenons of the central joint of a panel painting.

of the false tenons—and, hence, of the mortises made in the original supports as well.

Over the centuries, certain original joint assemblies, because of technical developments such as pegged false tenons and tongue-and-groove joints, have caused serious alterations to the paint layer. In such cases, their readjustment or modification seems necessary when the joint is repaired. Thus, for example, in the case of pegged false tenons, where the pegs generate splits, the staff removes some of those pieces, working from the back of the panel. This procedure eliminates the constraints caused by the initially blocking joint and allows the false tenons to move in the mortises when the wood undergoes dimensional changes.

Reestablishing the Panel's Structural Cohesion

Sometimes there is a need to first consolidate the structure of a wood badly weakened by various assaults. This brings up the problem of choosing a consolidant (taking into account its viscosity, reversibility, and aging properties) as well as the problem of finding a method of treatment aimed at preventing an overly heterogeneous consolidation that would cause areas of different rheological behavior to develop.

Consolidation is currently achieved with an acrylic resin, Paraloid B72, usually dissolved in toluene and usually applied by injection, brushing, or, should the panel so permit, by capillarity. Since, given the present state of knowledge, it is not always possible to diagnose the extent and effectiveness of the treatment, it is important to limit as far as possible the penetration of the consolidant into the material—especially considering that its reversibility is not total. It would be very interesting, in the future, to be able to measure the product's degree of penetration and its cohesive strength inside the work.

Accidental lacunae in the wood are filled with a material chosen according to several criteria: the state of conservation of the support, the localization of the lacunae, their influence on the structure, and their aesthetic impact.

Small lacunae are filled with an emulsion of polyvinyl acetate in 50% water mixed with sawdust or mechanically reversible Master Model Paste.[16] A large lacuna—after precise measuring and cutting that carefully respects the integrity of the work—is generally filled with a piece of wood of the same grain and species, inserted at a slightly lower level than the original wood. For severely worm-eaten panels whose density has been reduced considerably by insect tunneling or for areas not requiring any special mechanical property, the staff prefers to use balsa wood. And for very weak, seriously thinned-down panels, structural cohesion is reestablished by backing of their surfaces.

A specific restoration problem was posed by nineteenth-century works painted on supports that were composed of several strata of wood artificially held together. The best-known example was developed in 1845 by Tachet; he devised a method of gluing three crossed sheets with shellac, which was sprayed on and then heat sealed in order to reduce the wood's movement. However, with time, the glue weakened, the support loosened, and cracks appeared on the paint layer. The restoration method that has been developed to address such supports attempts to reconcile the necessities for recovering cohesion of the support, maintaining reversibility, and preserving the work's aesthetic appeal. It consists of replacing the thick central core with a thin sheet of plywood[17] and an interlayer of balsa, then regluing the painted wood on the front and the wood of the back on the reverse, so as to preserve intact the work's appearance, as was done for the *Study of Hands* by Jean-Auguste-Dominique Ingres at the Louvre Museum (Fig. 4a–d).

Present-Day Maintenance Systems

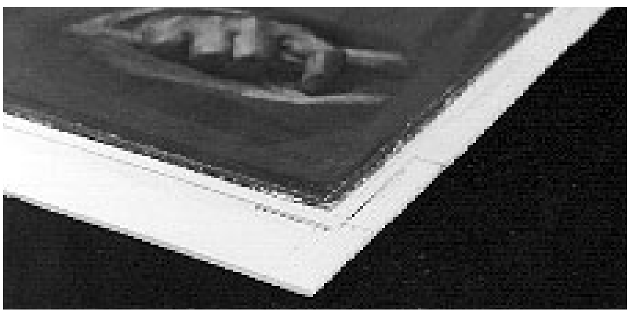
The elaboration and application of added reinforcements to the reverse of certain panels was made necessary by the gradual lessening of the initial support's mechanical properties, owing to centuries of drastic interventions.

Until recently most maintenance systems required thinning down of the panel and leveling of the reverse to allow the positioning of a set of planed-down and sometimes sliding wooden pieces, such as a cradle. These interventions were meant to respond to the two priorities of straightening and flattening of the panel, but they did not take into account the fact that the wood becomes more reactive as a result of being thinned down and that, moreover, the thinning of the panel destroyed the precious information on the original reverse.

The systems elaborated in recent years perform the sole function of maintenance in "supervised freedom"; to do so they must respond to two contradictory requirements: first, they must provide support sufficient to slow and limit the play of the wood, and, second, they must provide support limited enough so as not to constrain the wood and risk the formation of splits. Moreover, they must respect the existing reinforcement by adapting to its unevenness while reducing the surfaces that are glued or

a

b



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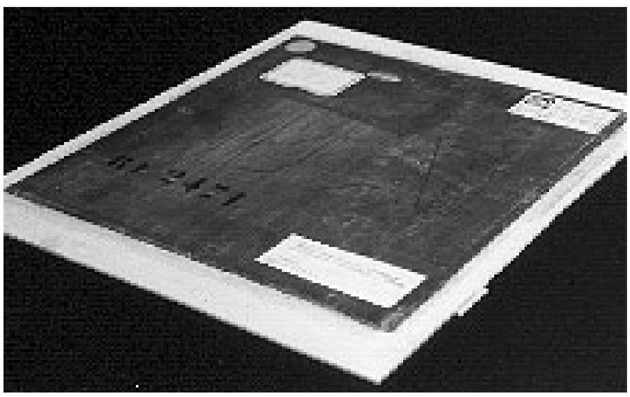

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Figure 4a–d
Jean-Auguste-Dominique Ingres, *A Study of Hands,* nineteenth century. Oil on panel, 33 × 30.9 cm. Louvre Museum, Paris. Before restoration, the support had separated into three layers (a). This type of support was developed by Tachet, whose patent stamp is still visible (b). During the work (c), the painted sheet, plywood, and balsa are stacked; the reverse view (d) shows the back layer and the balsa layer.

that rub against each other. Last, their mechanisms must not be too complex for simple maintenance.

Three types of maintenance systems have been developed for application to the reverse of panels. They are (1) reinforcement systems that replace original elements on the reverse of panels, (2) maintenance systems that offset significant loss of cohesion of original supports, and (3) backing systems that consolidate overly thinned supports.

Reinforcement systems that replace original elements on the reverse of panels

These systems are used in cases where there is no risk that the weight or tension they exert could deform the support—that is, they are designed for supports that are sufficiently sturdy or structured. The most widely used system of reinforcement involves sliding crosspieces, or runners. Adapted to the curve of the panel, they are composed of pieces of mahogany fitted on both edges with U-shaped metallic bands into which slide Teflon or brass rollers attached to wooden cleats that are themselves glued to the original panel in the direction of the grain. The current trend is toward reducing the thickness of these crosspieces in order to make the whole construction lighter and more flexible.

Maintenance systems that offset significant loss of cohesion of original supports

These systems are used on panels whose structure is fragile because of their thinness or because of severely deteriorated areas. They are based on a perimetric maintenance of the object, either by fitting of the frame with a rabbet into which the painting will be positioned or by the assembly of such structures as the *châssis-cadre,* a modern version of the grooved structures into which the panels of the Nordic schools of the fifteenth and sixteenth centuries were imbedded and which surprise us still by their quality of conservation. Such a system is composed of a fitted wooden frame to which is screwed an L-shaped brass cornice that reinforces the perimeter of the painting (Fig. 5a, b); enough space is left to allow for expansion and retraction of the wood. It should be noted that the panel does not support the weight of the châssis-cadre. For large panels this system can be combined with sliding runners attached to the frame.

The current trend in stretcher-frame fabrication is toward enhanced flexibility and capacity to follow the dimensional variations of the panels. First, to lighten it, the frame is hollowed out slightly with a cylindrical bit. Insertion of a system of springs into some of the cavities thus created enables the panel to move in three directions, rather than exclusively in a line. The same result is obtained by replacing the frame's sliding runners with plain perforated crosspieces connected to the support by means of cleats equipped with springs (Figs. 5a, 6a, b); this also reduces the mechanical leverage effects produced by the traditional lateral arrangement of cleats with rollers. The L-shaped metal cornices are made somewhat less rigid by evenly spaced sections cut into the narrow side that is screwed onto the frame (Fig. 5b). Finally, to reduce friction, the inside faces of the frame are lined with Teflon.

In certain cases it will be necessary to replace the wooden frame with a sheet of Altuglass to allow an unobstructed reading of the two

Figure 5a, b
Cosmè Tura, *Saint James the Great,* fifteenth century. Tempera on panel, 75.1 × 40.9 cm. Musée des Beaux-Arts, Caen, France. The reverse (a) shows the panel in a châssis-cadre with a central support; the side view (b) of the cornice shows that it is sawn at regular intervals.

a b

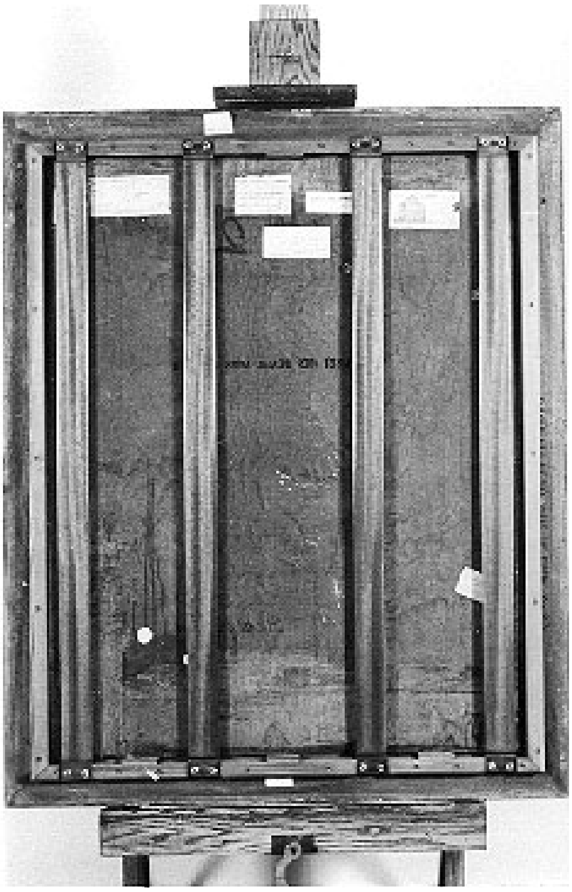
faces of a panel. This system, called mobile backing, is also used for extremely fragile supports.

Currently the Service de Restauration is making less use of the châssis-cadre in favor of a specific rabbet arrangement for the frame. A structure specifically adapted to the curvature of the panel, usually made of balsa wood lined with Teflon and with flexible attachments, allows simple and effective maintenance of the perimeter (Fig. 7a–c).

Since few museums in France are climate controlled, and RH can vary considerably throughout the year, treatment can be completed by the use of a microclimate box that is secured to the back of the frame; the box

Figure 6a, b
Cosmè Tura, *Saint James the Great,* reverse. Two cleats that connect to the crosspiece are shown (a); the detail (b) shows a cleat with its double-spring support system.

a b



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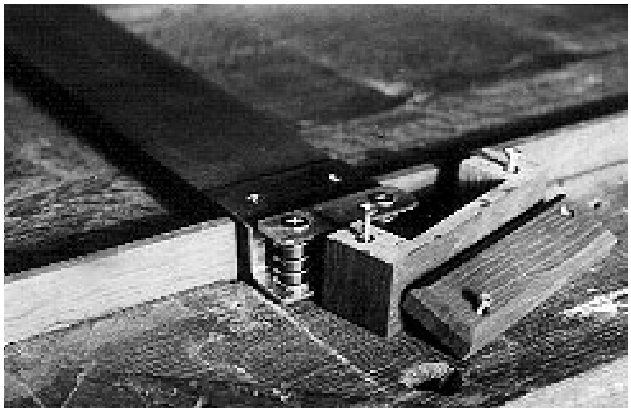

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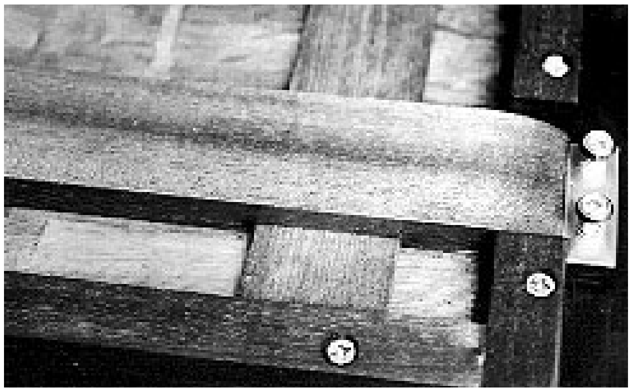

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Figure 7a–c
Frans Floris, *Portrait of an Old Woman,* sixteenth century. Reverse. Oil on panel, 107.7 × 83.4 cm. Musée des Beaux-Arts, Caen, France. The panel is positioned in its frame (a), maintained by crosspieces fitted with compensatory springs. Two other panels (b, c) have different kinds of compensatory mechanisms with springs.

considerably limits the risks of hygrometric shock and, additionally, allows the work to move.[18] These boxes are particularly suitable for panels that, because of the nature of their wood or because of the deteriorations they have undergone, are very fragile and reactive.

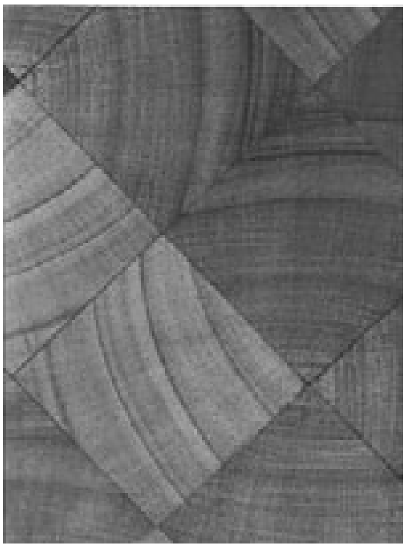
Backing systems that consolidate overly thinned supports

These systems are intended to restore enough cohesion and solidity to the work to make possible safe handling and display. The maintenance systems described above are not appropriate for severely thinned panels, as they require specific fixings not feasible with heavily deteriorated works. The more homogeneous distribution of mechanical stresses obtained by gluing a support system on the whole of the surface was a consideration that led the Service de Restauration to develop a number of backing methods.

Materials such as inert honeycombed panels will be used as replacement supports for the remounting of previously transferred panels, as the rigidity of their honeycombed structure prevents any possible movement of the material (Bergeon 1990:77, n. 10).

The use of square or hexagonal balsa elements cut along or across the grain and adhered with wax-resin seems a fitting temporary solution in certain cases (Fig. 8a, b). The low permeability of its cell walls as well as its low density give balsa wood a stable structure with a flexibility that enables it to absorb some of the stresses exerted by the panel. The use of wax-resin ensures rapid and total reversibility. Application of this tech-

Figure 8a, b
Reverse of panel painting (a) with a backing made of square balsa blocks cut along the grain (Lucas Cranach the Elder, *Saint Peter,* sixteenth century; oil on panel, 113 × 54 cm; Louvre Museum, Paris). Another panel (b) has a backing made of hexagonal balsa blocks, cut along the grain (Peter Neefs the Elder, *Cathedral of Antwerp, Interior View,* seventeenth century; oil on panel, 62 × 102 cm; Musée des Beaux-Arts, Grenoble, France).



a

b

nique was carried out in close collaboration with the Institut Royal du Patrimoine Artistique, Brussels (Glatigny 1990; see also Glatigny, "Backings of Painted Panels," herein).

Conclusion

The authors hope to have shown in this account that the Service de Restauration des Musées de France, heir to a long tradition of restoration of wooden supports of paintings, continues to explore working methods tending toward minimal intervention as well as use of lighter support systems.

Because of the highly specific nature of the material and the added complexity due to a paint layer, panel paintings must be restored by specialists who, through their daily contact with old techniques and earlier restorations, have acquired a deep awareness of the repercussions their interventions may have in the future.

In recent years, research on the treatment of wooden supports has shown a need for close collaboration between practitioners of various disciplines—curators and scientists—who should join forces to design a new approach to conservation. This approach seeks to emphasize treatment of the causes of deterioration and, in turn, assumes both a thorough knowledge of the material itself and a clear understanding of the material's environment: when the condition of the work is weighed against the treatment it requires, we are still facing the need to compromise between the benefits of the treatment and the drawbacks that intervention may entail.

Considerable research remains to be done, in particular regarding very thinned-down panels as well as disinfection and consolidation products and treatments, in order to improve their effectiveness and reversibility. There is, therefore, an urgent need for the kind of international collaboration that can improve our understanding and lead to the resolution of these problems.

Acknowledgments

The authors would paricularly like to thank France Dijoud, who was kind enough to read over this article; they would also like to extend their gratitude to Sophie Le Guischer for her help.

Notes

1 The Service de Restauration des Musées de France, currently under the direction of chief curators France Dijoud and Nathalie Volle, is the result of the merging in 1993 of the Service de Restauration des Musées Nationaux and the Service de Restauration des Musées Classés et Contrôlés (the state-controlled museums' conservation department). Its function is to restore the collections of the museums of France; work is performed in the studios of the Petite Ecurie du Roy at Versailles, in the workshop of the Louvre Museum, and in specialized regional workshops.

2 These studies were initiated by chief curator René Guilly, who was then in charge of the Service de Restauration des Musées Classés et Contrôlés, with the collaboration of France Dijoud; the studies were carried out by Jean de Leeuw, who was in charge of research at the CTB.

3 Twelve panels, 800 × 900 × 8 mm thick, composed of four to eight boards sawn in different ways.

4 A layer of sizing (a solution of 10% rabbit-skin glue in water); eight layers of ground (*blanc de meudon* [natural calcium carbonate] and rabbit-skin glue); one layer of yellow ochre diluted with turpentine; one final layer of Rembrandt varnish.

5 Originally, the twelve sample panels were placed for forty-nine days at 25 °C and 30% RH, then for thirty-six days at 25 °C and 65% RH. Next, four panels representative of the twelve were subjected to five seven-day cycles of aging at 25 °C and 30% RH, then seven days at 25 °C and 65% RH; they were then stabilized for thirty-six days at 25 °C and 30% RH. During these two periods, the masses, widths, and cambers of the panels were systematically recorded.

6 After the five cycles of aging at 30% RH, this residual distortion was from 17 mm to 21 mm for slab-cut panels and 18 mm for panels cut on the quarter; at 65% RH it was from 5 mm to 6 mm for slab-cut panels and 1 mm for panels cut on the quarter.

7 Saran F-310, made by Dow Chemical, which is a copolymer of acrylonitril and polyvinylidene chloride.

8 Poplar, 120 mm wide with the grain of the wood, from 290 mm to 450 mm long and 45 mm thick, painted on one side with the technique described above (n. 4); the angle of the grooves was systemically varied (60° or 90°), as was their depth (the tip is at 3 mm or 13 mm from the paint layer) and the conversion of the wood of the inlays, which were glued with vinyl glue.

9 Originally the test pieces were subjected to four long cycles (twenty-eight days at 25 °C and 30% RH, twenty-eight days at 20 °C and 65% RH, twenty-one days at 25 °C and 85% RH, twenty-eight days at 25 °C and 30% RH), then four shorter cycles (fourteen days at 25 °C and 85% RH and fourteen days at 25 °C and 30% RH); the masses and the cambers were regularly recorded; visual observation was simultaneously carried out to detect ungluing, splits, and craquelures in the paint layer.

10 Thinned to 3 mm.

11 Panel F-Ciba board, composed of an aluminum honeycombed laminate faced with fiberglass impregnated with epoxy resin.

12 Hexachlorocyclohexane, a fungicide and insecticide product.

13 Synthetic pyrethrinoid. Compare Gérard 1988.

14 Supervised by Marie-Odile Kleitz, research engineer and head of the preventive conservation department.

15 Unlike the tenon, the false tenon is a piece of wood set into mortises hollowed into both edges of the boards that are to be fitted together.

16 Master Model Paste SV/HV 427, made by Ciba-Geigy; compare Grattan and Barclay 1988.

17 Two mm thick, composed of three sheets of birch.

18 The atmosphere of the microclimate box is controlled with silica gel; the box was devised by Marie-Odile Kleitz.

Materials and Suppliers

Altuglass (polymethacrylate), ElfAtochem, Group elf aquitaine, 4, cours Michelet, La Puteaux-Cedex 42, 92091, Paris La Défense, France.

Master Model Paste SV/HV 427, S.A. Ciba-Geigy, BP 308, 92506 Rueil-Malmaison Cedex, France.

Panel F-Ciba board, S.A. Ciba-Geigy.

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The Restoration of Wooden Painting Supports

Two Hundred Years of History in France

Ségolène Bergeon, Gilberte Emile-Mâle, Claude Huot, and Odile Baÿ

In France today, the policy governing the stabilization of wooden painting supports can be summarized by the term "supervised freedom," indicating a delicate balance between restraint and freedom.[1] The evolution of this approach can be traced through two hundred years of panel restoration, from the earliest work carried out for the Louvre in the eighteenth century to the significant recent developments that are evidenced in the work on the Campana Collection, at the Musée du Petit-Palais in Avignon. The experience of two centuries has contributed to our present approach of minimal intervention, and this experience informs the choices that are currently made with respect to panel stabilization.

The History of the Restoration of Painted Panels in France from the Eighteenth Century to 1965

While the documentary sources are rich with information, they do not shed light equally on all areas of potential interest. The two major interventive procedures—transfer and cradling—have been well documented since the eighteenth century, but there are few references to the third important operation—backing—which emerged in the nineteenth century. There is even less mention of the practices of disinfection and the consolidation of worm-eaten wood.

These interventions, as well as interventions on canvas, from the simplest and most poorly documented to the most ingenious work on very prestigious paintings, seem to have been largely the product of two major Parisian studios—the first founded in 1740 by Jean-Louis Hacquin, at 4, rue des Bourdonnais, in the First Arrondissement;[2] and the second, established in 1841 by Paul Kiewert, at 17, quai des Grands-Augustins, in the Fifth Arrondissement. Through each of these studios has passed a long line of panel and canvas restoration specialists, workshop managers, and studio owners which continues to the present day.

The studio at 4, rue des Bourdonnais, Paris: From Hacquin to Joyerot

Writing in 1779, Jean-Louis Hacquin stated that "ever since a skillful incident of lifting pictures on wood and cradling them,"[3] he decided, in 1757, to qualify as a master cabinetmaker. These words are important for two reasons: they show that prior to 1757 Hacquin had gained some experience

Translated by Barbara Harshav

in cradling and transfer and that the corporations of the Ancien Regime played a role in approving the qualifications of artisans.

After Jean-Louis died in 1783, he was succeeded by his son, François-Toussaint Hacquin (1756–1832). The elder Hacquin had earlier recommended his son to the painter Pierre, then in charge of the studio of restoration in the administration of the Bâtiments du Roi.[4] François-Toussaint may have been more a reliner than a cabinetmaker, for although he was concerned with all types of support for pictures, he apparently did not make the cradles, consigning this job to a joiner. However, he did attach the cradles to the paintings.

Was François-Toussaint Hacquin, therefore, a "cabinetmaker" like his father? He seems to have diversified his profession, and although he himself was more concerned with canvas supports, he was assisted by genuine specialists in wood. But in what precise tasks? And to what extent? There are still many uncertainties with regard to the roles of the various actors in the early restoration of wooden supports.

François-Toussaint Hacquin was succeeded by his son-in-law, Guilloux Mortemard (1794–1870),[5] who also dealt with both wooden and canvas supports. Mortemard was quite skilled at relining and transferring, and in 1832 he was to transfer onto a new wood support a picture painted by Van der Werff.[6] While he was very active between 1827 and 1832, his traces disappeared in 1836. He reappeared at the competition of the Louvre of 1848, organized by Villot; he won that contest and received orders until 1870.

The studio at 4, rue des Bourdonnais, then became Maison C. Chapuis (a reliner mentioned as advisor to the Louvre by the curator Gruyer in 1882), qualified to work on supports of either wood or canvas. The studio became Maison Henry Leguay et Brisson, Successeurs Chapuis, until 1911; Maison Brisson until 1922; Maison Leguay from 1924 to 1938–39; and, finally, Maison Trinquier et Léon Gard, Successeurs Leguay,[7] qualified in all aspects of restoration, and focused especially on wood and canvas supports. Puget, who had specialized in cradles in the Gard studio in 1924,[8] trained Ernest Cosson (1882–1947), who subsequently trained his grandson, Jacques Joyerot (b. 1930), in the restoration of supports. Joyerot worked for the Gard studio (1945–48), then for the Malesset studio (1951–57); he finally began work for the Louvre in 1962, moving to 13, rue Sedaine, Eleventh Arrondissement, Paris, in 1964; in 1980 he moved to Gagny, near Paris. This studio still works on both wood and canvas supports. Joyerot makes cradles but no longer works on wooden supports for the Louvre.

The studio at 17, quai des Grands-Augustins: From Kiewert to Rostain

In 1841 Paul Kiewert,[9] a reliner who had come to Paris from Belgium, set up shop at 17, quai des Grands-Augustins and went into partnership with the restorer Govaert. At the beginning of the twentieth century, the senior Chauffrey, a reliner, went into partnership with Govaert.[10] In 1945 Gaston Chauffrey (d. 1955) went into partnership with Marc-Rodolphe Muller (d. 1955).[11]

The studio of Chauffrey-Muller subsequently became very important. In addition to Gaston Chauffrey, it comprised his son Jean, a painter; Marc-Rudolphe Muller, a restorer; and the specialists brought by Muller—

the cabinetmaker Paul Maridat and the reliners A. Pouget and Raymond Lepage.[12] Shortly after the end of the Second World War, Maridat and Lepage left the studio, establishing their own business together in 1948 and doing cradling work for the Louvre in 1949[13] before they separated.

Maridat, known as a reliner, moved in 1957 to 21, rue Cassette, Paris, and did work in 1957 and 1958 for the Campana Collection, independent of the studio of the Louvre.[14] Examination by S. Bergeon of the Campana paintings, which are still in excellent condition, shows that this work included cradles with slats placed on edge (*de chant*) or flat (*plats*), attached either to panels backed with oak or to a back that had been only somewhat thinned. Around 1968, Maridat, who by then had moved to 18, rue Dulac, was doing work for the Château de Versailles.[15]

Raymond Lepage established himself at 5, rue Christine, in the Sixth Arrondissement, between 1963 and 1968. In June 1963 he gave estimates for work on important paintings by David in the Louvre. This work involved adding dovetail tenons to the portrait *Mme Seriziat* and straightening curves on the *Portrait de Lenoir*. Lepage still followed the old tradition of inlaid dovetails seen in the system he provided for Clouet's *François I*.[16] René Bertin, a specialist in wood, was not really a part of the Chauffrey-Muller studio but did work for it around 1945. Later, Gilbert Malesset, who started out with Chauffrey-Muller, also treated wood on his own in the 1950s (Rostain 1994).

The studio became known as Chauffrey-Muller, Gérant Rostain, from 1954 to 1975. In its attempts to replace the expertise of Puget, Bertin, and Maridat, the studio eventually discovered the cabinetmaker Georges Huot. In November 1957, when the studio was contracted to transfer, back, and cradle the portrait *Clément Marot* for the Louvre,[17] the wooden support was subcontracted to Huot (Rostain 1994).

In July 1965 the Chauffrey-Muller studio performed another transfer onto wood for the Louvre: *La Circoncision,* of the Swabian School, painted in 1480.[18] A new support that by this time is used by Rostain is marine-grade plywood with a cradle often made in the Huot studio. However, transfer from wood onto canvas was still practiced, as seen in Lorenzo di Credi's *Le Christ et la Madeleine,* which Rostain transferred on 24 January 1968.[19]

The studio became the Rostain studio in 1975; it was located for 150 years at 17, quai des Grands-Augustins, and is now at 12, rue Gît-le-coeur. The studio works on the restoration of wooden and canvas supports as well as treatment of the paint layer. However, for museums it is authorized to perform work only on canvas supports.

The scope of the studio's work and the range of interests of its various managers has earned it premier status for more than a century. It has achieved an excellent knowledge of the complex and specialized world of restoration, which eventually led it to advise the Louvre to choose the fine cabinetmaker Claude Huot for the museum's own specialized cabinetmaker studio.

The roles of Landry (1840–1848) and Roger Castor (1953–1957) at the Louvre

The archives indicate that Landry, "reliner at the Louvre," 47, rue Saint-Denis, was very active between at least 1839 and 1848.[20] He did many relinings with *marouflage*[21] on the back side, as protection against humidity, for the Louvre, as well as for the studios of Versailles, Compiègne, Chantilly, and the Château d'Eu. In 1839 Landry put "four cleats and marouflage" on the back side of Rubens's *La Kermesse.* Among a huge quantity of work of unknown date are some invoices concerning wood, one indicating that he cradled a picture by Holbein.[22] In 1843 he removed the paint layer of *Portrait d'homme,* by an unknown artist, from its wood.[23] He also proposed to transfer Raphael's *La Vierge au voile,* because it was very worm-eaten. However, the latter intervention, proposed to the painter Granet, who was in charge of restoration at the Louvre, must not have satisfied Granet, and, fortunately, the transfer was not done.[24]

The administration of the Louvre has long held tests to select restorers.[25] When Villot, the new head curator of paintings, arrived in 1848, Jeanron, director of the Musées Nationaux, sent the minister of the interior a "report on the situation of the studios of restoration of paintings of the Louvre Museum and their reorganization." A plan for a competition for restorers and reliners was drafted. Landry was required to pass it, even though he had already been working in the Louvre for a long time. A rough draft of the decision resulting from the competition does not mention Landry but does mention others, including the elder Momper, Mortemard, the younger Momper, and Piolé (or Poile).

Yet, Landry—following the work of Robert Picault in 1750, J.-L. Hacquin in 1780, and F.-T. Hacquin in 1803—had performed the fourth transfer of Andrea del Sarto's *La Charité* in 1845 so perfectly that it still remains solid (Emile-Mâle 1982b). A cleaning has recently been done, but the support has remained in its 1845 condition. Perhaps Villot was annoyed by the length of time necessary for those works. He was a difficult man, who had an inspection made in 1848 when he arrived, which was especially unpleasant for Landry.[26]

Gruyer, curator of paintings, in his detailed 1882 report to Mantz, director general of the Musée des Beaux-Arts, on the state of the restoration of paintings, indicated that the paintings in the Louvre seemed neglected.[27] But a large-scale policy of restoration was not established, and by the end of the century the authorities and Gruyer's successors considered a single restorer—Briottet, followed in 1887 by Denizard, assisted by C. Chapuis—to be sufficient for all the interventions required for supports.[28] The wood specialist M. Bouvard, at 63, boulevard Garibaldi, Paris, was called on to assist with works that were particularly important, such as the Avignon *Pietà* in 1905 and, prior to 1911, the *Mona Lisa*.

Roger Castor (b. 1914) worked at the Louvre between 1953 and 1957. A cabinetmaker by profession, he was probably recommended to Germain Bazin, chief curator of paintings at the Louvre, by Lucien Aubert (restorer at the Louvre beginning in 1910). During Castor's tenure at the Louvre, he was entrusted with important paintings, and for the first time the invoices for interventions are very detailed.[29] His work has a somewhat traditional and systematic character: dovetail tenons across the grain inlaid in the thickness of the original panel, and cradles, which are either simple and functional or purely aesthetic, placed on backings of silver fir[30] or oak.[31]

But some of his works have an innovative nature, like the creation of frames in new material (Permali or Bakelized wood) fitted with corrugated iron in the groove.[32] He was also the first to use Xylamon[33] to disinfect worm-eaten panels, such as the *Annonciation* by Cosimo Rosselli. For that picture, he carefully preserved the existing mobile upper crossbar with iron pins—which was either an original or a very old restoration (Bergeon 1976:62)—and copied it to construct the lower crossbar.[34]

After 1957 there was no longer a cabinetmaker at the Louvre who specialized in painted panels. At that point, compelled by necessity with the purchase in 1956 of Sassetta's triptych of the Virgin and two saints,[35] and with the purchase of the *Calvaire* by J. Lieferinxe in 1962,[36] Germain Bazin sent these two pictures to Rome to be restored at the Istituto Centrale del Restauro, where particularly Angelini and then later Bellafemina, both restorers of wooden supports, had achieved an internationally recognized mastery. By 1965 Germain Bazin had come to recognize the need for a cabinetmaker specializing in wood supports at the Louvre and a specialized studio devoted to the restoration of panel paintings. The consequences of this realization will be presented below.

Techniques Used in the Studios Prior to 1965

Transfer

French artisans, particularly those working in the Hacquin-Joyerot and Kiewert-Rostain dynasties, became extremely skilled in the technique of transfer, which was practiced for a long time in France. The technique had already been practiced for several decades by the time Jean-Louis Hacquin established his studio.[37] It had originated in Italy, where it developed simultaneously in Cremona and Naples between 1711 and 1725. It was introduced into Lorraine by Léopold Roxin in 1740 and into France by Robert Picault between 1747 and 1750 (Emile-Mâle 1982a, 1982b, 1987). Considered perhaps the major development of the eighteenth century, transfer was widely seen as a genuine universal panacea. The replacement of the original support by another, "ideal" one was intended to remedy all the structural problems associated with wooden supports—curving, splitting, worm tunnels, and cleavage of the paint layer.

Robert Picault's particular technique of a "sparing" transfer, in which the paint layer is separated from the wooden support, saves the support at the cost of some uncertainties and dangers.[38] On one occasion, Picault gave a dazzling display of his expertise to the king and his whole court as they filed past Andrea del Sarto's *La Charité,* admiring both the painting and, next to it, its support of old, "rotten" boards. In spite of this, no one had much faith in the technique, and it disappeared. Picault was then dismissed as a charlatan (Emile-Mâle 1982b).

After Picault, it was Jean-Louis Hacquin, and, especially, his son François-Toussaint Hacquin, who advanced the other technique of transfer, which is better for the paint layer but destructive of the support.[39]

Although the legitimacy of transfer was not questioned for nearly two centuries, the nature of the new support had always given rise to very interesting misgivings, particularly with respect to the choice of material. In a 1799 report on restorations for paintings, Picault wrote that the new support should be the same as the original (copper or wood) support "to conserve the purity of the design, the honesty of the stroke and their enamels [*sic*] which the grain of canvas takes away from them."[40] However, canvas was the support recommended by Robert Picault in 1750 and Jean-Louis Hacquin in 1780 for Andrea del Sarto's *La Charité,* and by François-Toussaint Hacquin for Raphael's *La Madone de Foligno* (transferred in 1801) and for *Sainte Cécile* (transferred in 1803) (Emile-Mâle 1982b).[41] In 1798, after arguments with François-Toussaint Hacquin, Jean-Baptiste-Pierre le Brun, then *commissaire-expert* of the administration of the Musée Central des Arts, set the rates for payment for "lifting from wood and transfer on panel [as] 10 Frs per foot then 12 Frs per foot" (Emile-Mâle and Borelli 1957:410). Le Brun, a connoisseur with an excellent eye, seems to have preferred wood to canvas.[42]

Gruyer, curator of paintings at the Louvre, mentions on 8 June 1882, "eighty-nine pictures to be transposed onto new canvases or panels."[43] The usual choice at the time seems to have been a new support made of canvas, a material lighter than wood and "less sensitive to hygrometric change, hence not causing any more cleavages." Canvas was also not susceptible to attack by worms, and it provided flat support. The marouflage used between the paint layer and the new support was supposed to keep the grain of the canvas from appearing (Emile-Mâle 1983b:227).

Transfer was widely practiced until 1938, and it continued more sporadically until 1950. After transferring onto canvas several times, in 1950 Emile Rostain, in one of his last major transfers for the Louvre, used a rigid support of marine-grade plywood with a cradle for Francia's *Calvaire* (Rostain 1981:113–15).

Cradling

The cradle has been known in France since 1740, at about the time that the Widow Godefroid, a professional reliner who did not make the cradles herself, ordered one from a cabinetmaker. However, she prepared the back of the painting and placed the cradle herself (Emile-Mâle 1983a:871). In 1755 a number of prestigious artists (Restout, Louis de Silvestre, Carle Vanloo, Pierre, Boucher, Vien, Portail, Cochin) signed a document indicating that Rubens's portrait *Marguerite de Valois* had to be straightened out and the splits repaired with a cradle.[44]

In 1788 François-Toussaint Hacquin was said to have cradled the damaged *Saint Pierre dans sa prison,* painted by Steenwyck (Louvre).[45] In 1798 he was put in charge of cradling Titian's *Le Couronnement d'épines,* which was split in three parts. Between December 1800 and February 1801, Hacquin "joined the [disjointed] boards and applied a cradle of silver fir, which the joiner had prepared for him."[46] The archives provide proof of a closer collaboration between the restorers of the support and the joiners than we have imagined to this day. In 1796–97, the joinery enterprise of the Louvre "employed six persons for rough-hewing and *raplainssage* of a painting."[47] Similarly, in August 1798, on Rubens's triptych *La Pêche miraculeuse,* François-Toussaint Hacquin "joined the boards and directed the work necessary to apply a woodwork cradle to it" (Emile-Mâle 1994).

Were these early cradles badly devised? Apparently the one that Widow Godefroid placed on the back side of Rubens's *La Kermesse* (more than thirty years before Jean-Louis Hacquin was assigned to the work in 1770) had added to the damage. It must have been fixed, since the new cradle, devised by Hacquin, is "a new type that plays and anticipates unevenness of the wood during the change of seasons."[48] The sliding cradle is a great French discovery of the eighteenth century; the cross-grain crossbars, which ensure the real security of the panel, are mobile and slide in fixed slats, which are glued in the direction of the grain of the support (Fig. 1).

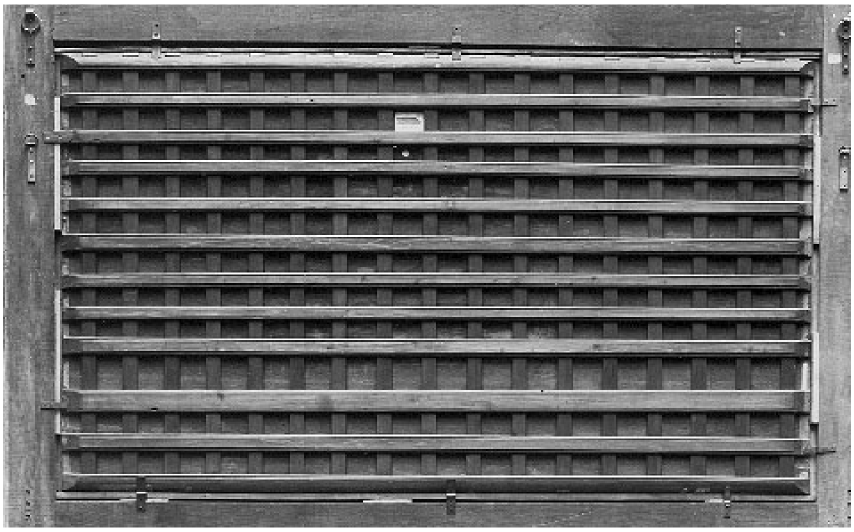


Figure 1
Peter Paul Rubens, *La Kermesse,* ca. 1636–38. Reverse. Louvre Museum (inv. 1797), Paris. Sliding cradle of the Hacquin type, with slats glued in the grain direction and mobile crossbars running against the grain. The first sliding cradle for this painting was placed in 1770 by Jean-Louis Hacquin. The cradle was redone by François-Toussaint Hacquin in 1825; perhaps it was then that the simple slats were replaced by slats ornamented with moldings.

Originally the purpose of these cradles was to hold a straightened panel flat while avoiding splits through the use of sliding crossbars. The straightening was carried out by thinning, the wood being first prepared by applying damp linen cloths to introduce moisture to the wood, then letting it dry under pressure and, if neccesary, inserting pieces of wood to prevent it from resuming its previous curvature. In general, the back sides of cradled panels present open worm tunnels, which allow the extent of the thinning to be assessed and the original thickness of the support to be deduced with more or less certainty. Moreover, cradling helps consolidate splits when crossbars are placed on both sides of a split.

The double function of straightening and repairing splits is included in Mérimée's major text of 1830, which talks of the "bars" of the cradle: "When a panel is split or is crooked, it is corrected by gluing behind what is called a cradle; this is a lattice of silver fir to which only part of the bars are glued, those which are in the direction of the grain of wood of the panel. The crossbars are held by the former in notches made in their thickness, in which they are engaged. They are not glued to the panel, for since the movement of the wood is always working on the width, they would not adhere there solidly; they serve only through their pressure to hold the panel so it can no longer be crooked" (Mérimée 1830:260).

In 1851 Horsin-Déon praised the work of the French cradlers, illustrated by the work of Constant in Paris, in whose hands the cradle was a creation of rare elegance carried out with unequaled lightness and perfection. He also spoke of the "uprights" glued in the direction of the grain and of the mobile crossbars in the uprights. The Gruyer report of 1882 also mentions recradling, which shows that cradles already existed and that their use, according to Chapuis, remained current.[49]

In 1909 Meusnier discussed the quality of work of the cradler and spoke of "support" slats (glued in the direction of the grain of the wood) and the mobile crossbars that are engaged in the former (Meusnier 1909:31–33). This is the first text to mention the "odd pieces, thin sheets of hard wood" inserted into the cavities after straightening and drying, in order to hold the whole thing flat, which corresponds to what is now probably called *sverzatura* (Bergeon 1976:20, 1990:20). Meusnier also distinguished between those mobile cradles "of absolutely French origin, in which our workers have achieved perfection, followed by Italy and Flanders," and the fixed, so-called simplified cradles for small pictures painted "on thin mahogany or tulipwood. . . . Cradles with glued [hence fixed] battens can also be applied to the back side of pictures painted on metal (copper and zinc)" (Meusnier 1909:33–35).

In 1938 *Mouseion* referred to the main purpose of the cradle as a remedy for curving or warping and mentioned the old, classical, so-called flat cradle, which is, in fact, French (*Mouseion* 1938:241–42). Various drawbacks were noted, among which are the risk of breakage on both sides of the glued slats, which are too strong in relation to the original support. In this text there is mention, for the first time, of another kind of cradle *de chant,* then called *de champ,* with crossbars placed on their narrow side.[50] The purpose of this type of placement is to reduce the surface area given to gluing and hence to stress, while increasing the resistance of the crossbars.

The cradle is a common intervention performed by cabinetmakers, such as Paul Maridat and Roger Castor, and by other specialists in wood who are "skillful at making cradles." René Bertin, who worked for Chauffrey back in 1945, is credited with having a role in their development (Rostain 1994). Cradles were also made by reliners in the Maison Leguay, such as Puget, in 1924.

It is difficult to get a clear overall idea of this subject. Reliners make cradles, while cabinetmakers do transfers and relining. The division between the two crafts is unclear, particularly since transfer, a major operation for wooden supports, often consists of replacing the wood with canvas.

The history of the cradle shows that while it started as a functional object, it eventually became an aesthetic one (Marijnissen 1967:46). Every painting on wood *must* present a cradle on the reverse, often of mahogany, sometimes of oak. It presents fixed bars, and the whole is carefully "patinated old wood." The cradle is sometimes nothing but an ornament without a functional role, for it is even found on the backs of some new stabilized wooden supports.

Backing

Backing is the addition of a new support on the back of an older support of a painting whose original wooden support still exists, at least partially, but has undergone thinning. The date of the beginning of this intervention is very uncertain. In 1909 Meusnier says that a little painting can have a double support "backed with strong glue" (Meusnier 1909:33). What was the new support? Likely it was wood, similar to the woods that were chosen for transferred paintings.

There are so many cases of paintings backed and then cradled that, in a cursory examination, the addition of a backing may escape the attention of the nonexpert.[51] The wood chosen is often solid oak, walnut, or mahogany; the panel is then equipped with a superb plain, "aesthetic" cradle of oak or mahogany, with glued slats.

It would be helpful to follow the possible uses of the so-called anhygrometric inert support, a discovery made in 1845 by Tachet, who took out a patent in Paris for it (Volle 1989:12). This support was composed of "alternating sheets of wood, impregnated with shellac, squeezed and heated to a fusion of the shellac and then pressed." This description corresponds to the beginnings of plywood, which is certified as an original support of painting, at least by Victor Mottez in about 1860 (*Portrait de son* *fils,* preserved in the Louvre).[52] This inert support was called *trésailles* (Lameere 1930:245). This word was used differently by Diderot in the eighteenth century, de Littré in the nineteenth century, and Larousse in the twentieth century.[53] This support is proposed for use in the backing of panels that have been thinned to 2 mm. In fact, this material, which was considered inferior to wood, does not seem to have been used very much, even though in 1948 Gilbert Malesset did use it to back one of the thinned boards of a famous Rubens painting, *Sainte Hélène,* at the Hospice de Grasse (Bergeon 1990:39–41).

Treatment of splits

In addition to the procedures of transfer and cradling, whose "longitudinal slats allow splits of wood to be repaired" (*Mouseion* 1938:242), the dovetail tenons inlaid across the grain seem to have been used very early to repair splits, as was the type of intervention made by Bouvard on the *Mona Lisa* before its theft in 1911. Two dovetail tenons inlaid in the panel against the grain (one of which still exists) in order to stop the progress of the upper split fulfilled their function perfectly.[54] This procedure was also to be used by the cabinetmaker Castor, who specialized in wood supports in his work for the Louvre between 1953 and 1957. But the constraining nature of the dovetail against the grain and the removal of the old wood were two important disadvantages of the method, which was usually used too routinely.

Treatment of worm-eaten wood

In the documentary sources, there is no mention of the different types of biological attacks to which wood is susceptible, and in any event, authors often seem to confuse mold with insect damage. The archives mention "rotten boards," but subsequent references suggest boards that have been attacked by worms and insect larvae rather than damaged by mold.

Removal of the worm-eaten wood was generally preferred, with radical treatment by transfer often proposed as the only means to restore the bearing function of the support. Lead white was chosen to fill in the cavities.[55] In the nineteenth century shellac was chosen, since it is a much better treatment for worm-eaten wood than lead white. Shellac rigidifies the inner tunnels but becomes reddish black, transforming the appearance of the wood by giving it a dark sheen. In 1950 Henri Linard, a restorer at the Louvre, gave up shellac in favor of wax-resin (beeswax and damar resin). Shellac was still used in the Louvre in the 1950s, although not systematically, as a rigidifier of the inner tunnels of worms. Worm-eaten wood was also replaced locally by an inlay of healthy wood, as can be seen in Bouvard's 1905 treatment of the *Pietà* of Avignon, for which he used tulipwood from Virginia (Bergeon 1990:35–38).

Early examples of frames fitted to panels

Germain Bazin has noted that pictures preserved in their old frames have often behaved better than others. Bazin, who was in constant contact with Cesare Brandi, the art historian and founder of the Istituto Centrale del Restauro in Rome, was well informed of international developments in restoration as of 1950 and, reflecting the spirit of the age, wanted prestigious paintings to be subjected to only minimal intervention. In 1953 he asked the cabinetmaker Castor simply to fit a frame for van Eyck's famous painting *La Vierge d'Autun,* or *La Vierge du Chancelier Rolin.* This frame was made of Permali, a very stable Bakelized wood, fitted with an ingenious system of corrugated iron in the groove to ensure a flexible hold for the painting.[56] Similarly, shortly before 1955, Castor equipped Antonello da Messina's *Portrait d'homme* at the Louvre with crossbars lined with felt and attached only to the frame. Even as early as 1951, the crossbars for Leonardo da Vinci's *Mona Lisa* were similarly shaped to the warp of the panel, lined with felt, and attached only to the frame, in order to hold the poplar support without stressing it (Fig. 2).[57]

Restoration of Painted Panels after 1965

Creation of a specialized cabinetmaker studio in the Louvre

In 1965 Germain Bazin, who was soon to create the Service de Restauration des Peintures du Louvre,[58] realized the need for a cabinet-maker specializing in wood supports at the Louvre, particularly for the important restoration program of the Campana Collection, consisting of more than three hundred Italian primitive paintings on poplar (de Loye 1976; Kjellberg 1976). Soon after meeting cabinetmaker Claude Huot, Bazin established the Louvre's first such specialized cabinetmaker studio, and Huot then turned his attention to paintings belonging to the state.[59]

From January 1962 until the beginning of his work for the Louvre, Claude Huot had been manager of the studio established by his father, Georges Huot. Founded in September 1939 at 24, rue St.-Lazare, the Huot studio had specialized in the restoration of eighteenth-century furniture. In October 1941 it moved to 26 and 28, rue St.-Lazare, and the building at number 24 became a storehouse of old wood needed for restoration. In July 1945 René Perche, a *compagnon* (an artisan who has completed apprenticeship but is not yet a "master") cabinetmaker trained in Brittany, brought his exceptional ability to the studio, where he remained until he retired in January 1977.

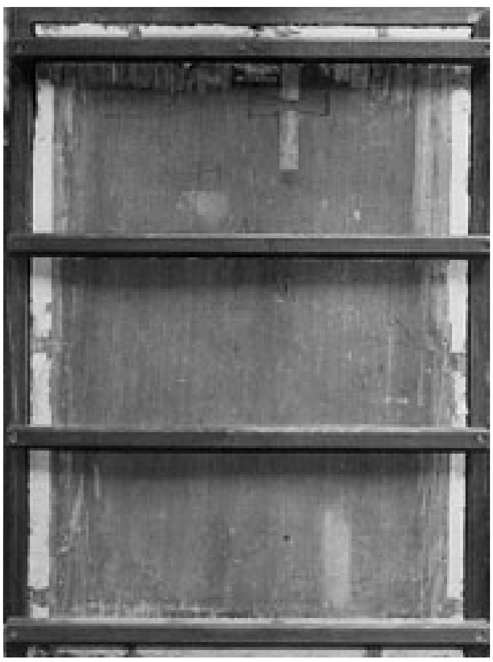


Figure 2
Leonardo da Vinci, *Mona Lisa,* ca. 1503–5. Reverse. Oil on panel, 77 × 53 cm. Louvre Museum, Paris. A dovetail tenon inlaid in the panel at the top was an early stabilization of a split. A flexible frame is made of attached crossbars designed to follow the warp of the panel and lined with felt. The original panel is made of a single poplar board.

Claude Huot began his apprenticeship in October 1951, studying theory in the cabinetmaking department at the furniture industry's Ecole d'Apprentissage and, after three years, acquiring a *certificat d'aptitude professionelle.* His teachers were his father and René Perche. At the same time, Claude Huot took courses in commerce and accounting. In 1964, two years after assuming the management of the studio, Claude Huot hired Robert Legris, and the studio carried out its first interventions on the wooden supports of paintings belonging to private owners, particularly those consigned by the Chauffrey-Muller studio, whose director was E. Rostain.

Huot's first work on paintings that belonged to the state were similar to the types of restorations that he had carried out previously for private clients.[60] (For examples illustrating the techniques discussed below, see Figures 3–17.) In 1965 the first mobile crossbars with hollowed-out surfaces on the side of the panel appeared; they were held by cleats adhered with a vinyl adhesive in the direction of the grain.[61] Also in 1965, the Huot studio performed its first thinnings of pictures either originally painted on poor-quality plywood (a picture painted by Picasso on wartime material) or on cross-grain boards.

In 1967, on Germain Bazin's advice, Claude Huot attended a monthlong course at the Istituto Centrale del Restauro. Upon his return, he immediately introduced at the Louvre the technique of consolidation with Paraloid, an acrylic resin tested and chosen for use by the Istituto Centrale, along with hollow, cylindrical mobile crossbars of the Carità type in wood cleats sheathed with brass.[62] In addition, Huot introduced the use of a system in which cross-grain elements of a frame could be reattached to the panel by means of screws placed in oval-shaped holes in the panel; this system allows the free play of the wood of the panel in the frame.

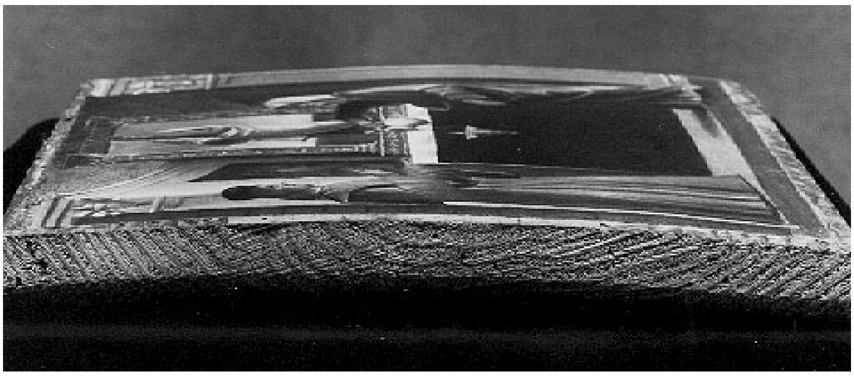


Figure 3
Rondinelli, *Le Miracle de la lampe.* Side view. Musée du Petit-Palais (MI 590), Avignon. Curve acquired by a panel cut tangentially to the rings of the tree and painted on a single side. The painting will not be straightened.

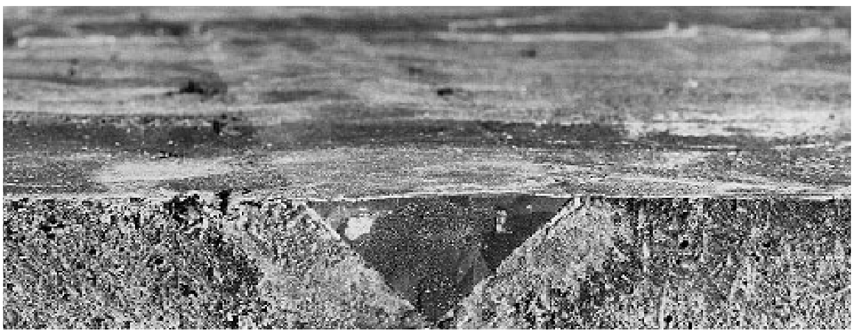


Figure 4
Il Sollazzino, *La Vierge d'humilité.* Reverse. Musée du Petit-Palais (MI 558), Avignon. Restoration of a split: incision and V-shaped inlay of the same type of aged wood is seen in section. The inlay allows the rejoining and the evening of the edges. This method was developed at the Istituto Centrale del Restauro, Rome.

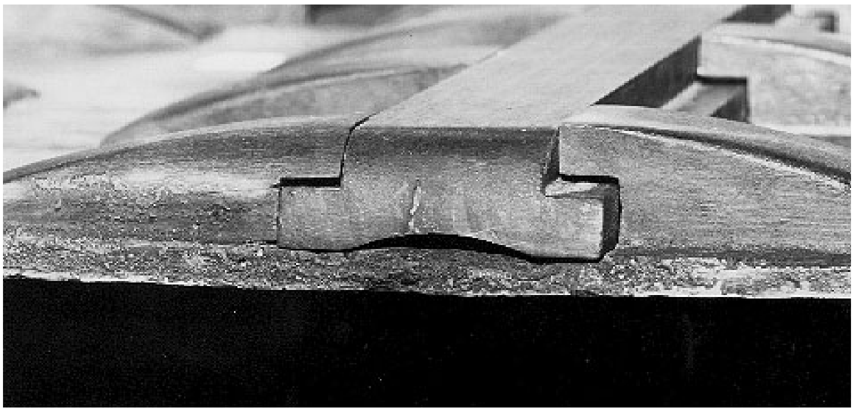


Figure 5
Benvenuto di Giovanni, *Martyre d'un évêque.* Reverse. Musée du Petit-Palais (M 514), Avignon. Hollowed crossbars. The wooden crossbar slides in cleats glued to the back of the panel. The hollowing reduces friction with the panel and improves mobility.

In 1969 Claude Huot made a second tour of Italy, visiting Siena, Florence, Bologna, and Rome, and he also had the opportunity to collaborate with aeronautical engineers on a number of ingenious procedures.

Other members of the Huot studio included Daniel Jaunard, a compagnon cabinetmaker from the Gaston Hullin furniture restoration studio, who was with the studio from 1975 until 1990. In 1983 the Huot studio hired Juan Garcia, a compagnon cabinetmaker from the F. Dolhen studio.

Techniques used by the Huot studio

The Huot studio carried out interventions for almost twenty years for the Service de Restauration des Peintures des Musées Nationaux, from its creation in 1965 to its move to Malmaison in 1982, and then to its final move to Versailles in 1985. These interventions illustrate a restoration policy that advocates removing the stress on the wood, treating splits minimally, gradually ceasing to do backing, reducing the amount of surface area affected by adhesives and friction, and minimizing "orthopedic" surgery. Eliminating surgery in favor of milder remedies also involved abandoning the sverzatura (straightening by incisions and insertion of a thin, triangular wood section piece), which was carried out only twice for the Campana Collection and was hardly practiced at all after 1968.[63]

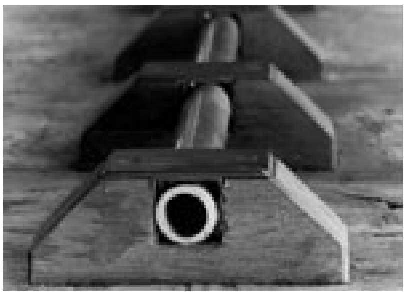


Figure 6
Carlo Crivelli, *La Vierge et l'Enfant trônant entre deux anges,* fifteenth century. Reverse, detail. Musée du Petit-Palais (MI 492), Avignon. Hollow cylindrical metal crossbar, which slides in cleats lined with brass. This system is called "Carità," after its inventor at the Istituto Centrale del Restauro, Rome.

Germain Bazin was well aware of the drawbacks of transfer and considered the removal of a painting's original support a genuine mutilation of an inherent part.[64] A new wooden support raises a risk of splitting and, inevitably, new cracks, while a new canvas support raises the risk of distortions, tearing, holes, and, inevitably, a new network of craquelure. The transformation of the condition of the surface, which acquires the grain of a canvas and a new "flatness," is no longer relevant to the original support; the work is therefore betrayed. The overall fragility of transferred paintings, whose gauzes soaked in glue can react to hygrometric variations, has been demonstrated for several years.

New supports were, therefore, very rarely devised. Solario's *La Déploration sur le Christ mort* at the Louvre required a change of support because of the development of microorganisms in the preparation layer and the chronic loss of adhesion of the canvas from the original marouflage of the original support. The painting was given a new support consisting of a metal honeycomb panel sandwiched between two sheets of fiberglass coated with epoxy resin; this panel was fitted on the front with

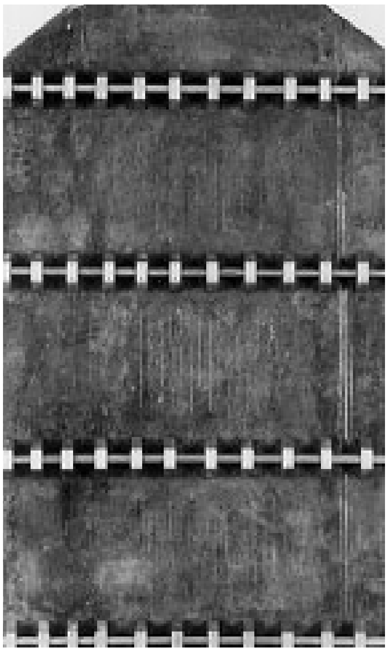


Figure 7
Bartolo di Fredi, *L'Adoration des bergers.* Reverse. Musée du Petit-Palais (C 71, inv. 20267), Avignon. This mobile support consists of Carità sliding crossbars. The warp of the boards was formerly straightened by incisions made in the direction of the grain; the edges were separated, and odd pieces of wood were inserted in the technique known as sverzatura.

Figure 8
Jacopo di Paolo, *Le Couronnement de la Vierge.* Reverse, detail. Musée du Petit-Palais (MI 428), Avignon. Crossbar of two aluminum U-shaped sections that slide on Teflon cylinders.

an intervening layer of balsa, shaped to follow the surface contours of the painting, while the reverse was covered by a rigid sheet material (Bergeon 1985:104; Volle 1989:18). *La Vierge et les Saints* by Botticcini (Jacquemart André), on which the double ground—thick chalk on the support and thick gesso on the side of the paint layer—had split in two, was treated in a similar manner. After several attempts to repair and preserve the support, it was changed to a metal honeycomb panel between two sheets of fiberglass coated with epoxy resin; as in the previous example, it was furnished with an intervening layer of balsa on the front and a sheet of oak on the reverse (Volle 1989:19).

In the mid-1970s, after much experience with transferred paintings being returned from exhibitions with signs of cleavage of the paint layer, the Louvre decided that if the certificate of condition issued by the restoration service mentioned "transfer," a painting in such a weakened state would not be allowed to travel.

The first backing the Huot studio did for the Louvre dates from 1966.[65] The painting in question was thinned, placed on marine-grade ply-

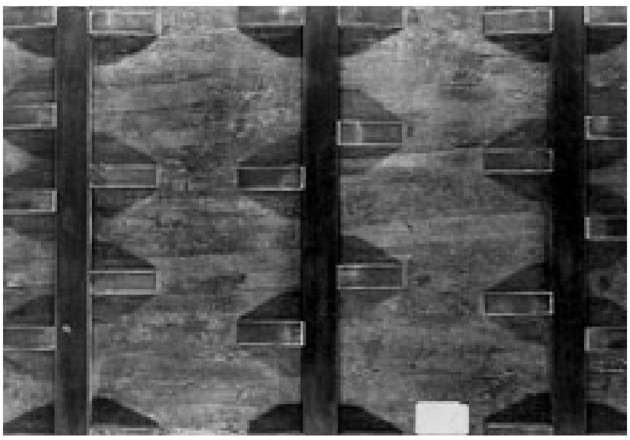


Figure 9
Jacopo di Paolo, *Le Couronnement de la Vierge,* reverse. The half cleats that hold the sliding crossbars are glued to the back of the panel; they can be staggered on either side of the crossbars.

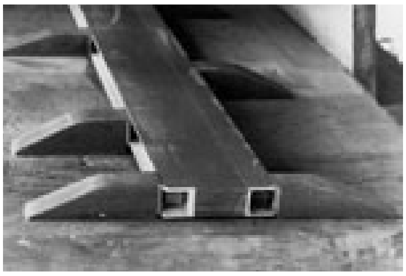


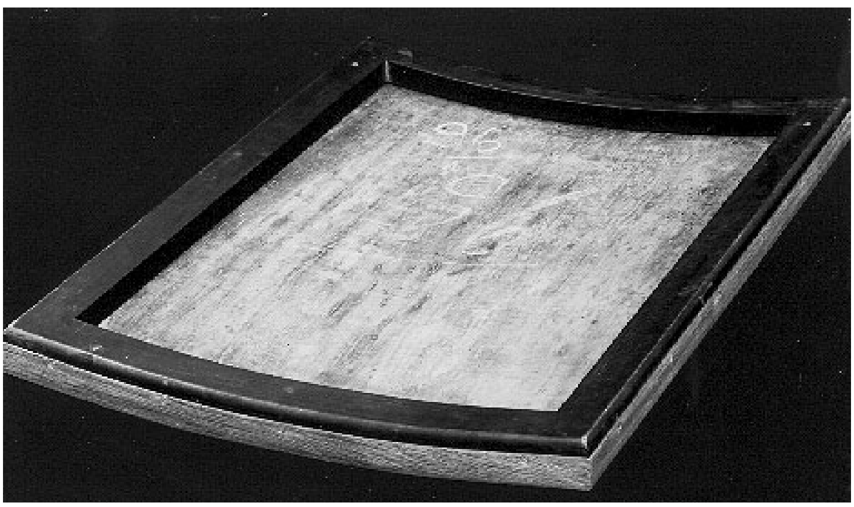
Figure 10
Master of Stratonice, *La Vierge et l'Enfant avec deux saints et deux anges.* Reverse, detail. Musée du Petit-Palais (MI 542), Avignon. Metal crossbar composed of two U-shaped aluminum sections and reinforced with mahogany. This system is suited to big panels.

wood, and equipped with a flat, aesthetic cradle. Other approaches to backing have appeared over the years. A simple gluing of a sheet of old wood replaced a nonfunctional cradle on the reverse of a plywood sheet in 1968.[66] A latté, consisting of two sheets of plywood sandwiching a number of juxtaposed wooden boards, replaced a plain plywood backing in 1970,[67] while in 1975 the last thinning followed by backing was done for the Campana Collection.[68] The choice of backing has moved toward the most inert supports possible and thus has led to the use of so-called marine-grade plywood, which is stronger than ordinary plywood, and to the use of a latté (1970)[69] system, honeycomb panels, first in cardboard (1968),[70] then in metal (1978),[71] and finally in balsa wood.[72]

Whenever fixed cross-grain crossbars, nailed through to the face of the painting, had caused splits, the shafts of the nails were sawn in order to separate the crossbars and thus to remove the stress. Whenever cross-grain crossbars inlaid with dovetails in the thickness of the wood had to be removed because they had contributed to splitting, the gap that remained was filled with wood in the direction of the grain to avoid the risk of local weakness. Joints that have completely come apart are connected with tenons and mortises one-third as thick as the panels. However, when the joints have only partially come apart, or when the split affects only a part of the length of the panel, the practice since 1965 has been to replace the old inlaid dovetail tenons by V-shaped incisions of a maximum of two-thirds the thickness of the panel, each followed by an inlay of the same section in the same kind of aged wood. The aperture of the V has to be as narrow as possible, so that little of the original wood is removed; at the same time it should be wide enough to allow good adhesion at the bottom of the V. Claude Huot adopted V-shaped incisions upon his return from one of his trips to Rome. By 1979 these inlays were sometimes replaced by cleats set on the reverse in the direction of the grain in the case of splits that did not have projecting edges (Emile-Mâle 1976:21), and by small tenons, as thick as one-third of the panel, placed at the ends of the boards in case of simple incipient splits.

To reduce the portions of the surface given to gluing, the fixed slats running in the direction of the wood grain of the panel were replaced by cleats and, in later work, by half cleats to support mobile crossbars. After 1965 the crossbars were made with hollowed-out surfaces facing the

Figure 11
Machiavelli, *La Vierge et l'Enfant avec deux anges.* Reverse. Musée du Petit-Palais (MI 522), Avignon. Châssis-cadre system. A mahogany stretcher for perimetric support was formed to follow the warp of the panel. The stretcher is secured with a brass L-shaped frame lined with felt. A space is left between the frame and the painting to allow for the play of the wood.



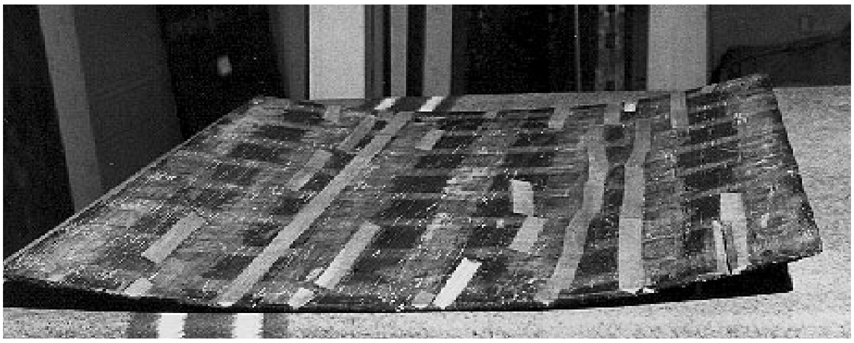


Figure 12
Cima da Conegliano, *La Vierge et l'Enfant*. Reverse. Louvre Museum (RF 2100), Paris. The wooden support of this painting, which was formerly thinned, is worm-eaten and split. After the old cradle was removed, it was disinfected and its fractures were reduced by incision and V-shaped inlays.

panel, in order to lessen the friction of wood against wood.[73] In the system of cylindrical steel crossbars used from 1967 to 1969, the crossbars slide in cleats sheathed with brass; friction is therefore limited to those areas. Finally, crossbars of H-shaped cross section, made of an aluminum alloy, began to appear in 1967. After 1970 these are sometimes reinforced by Bakelized wood or mahogany; this system limits friction to the small Teflon rollers that allow the metal crossbars to slide easily (Emile-Mâle 1976:113).

There was a gradual attempt to eliminate crossbars and the use of adhesives; by 1969 this progression resulted in a simple perimetric reinforcement: the *châssis-cadre* system. This device is formed of an L-section brass perimeter stretcher, lined with felt on the side of the painting, or formed of a frame of mahogany or Permali, possibly shaped to fit the warp of the panel and spaced 2–3 mm from the panel to allow for the possible expansion of the wood. Adhesives are no longer used, and there is a minimum of friction.

A variant of this procedure features a mobile backing in acrylic resin (Altuglass). First used as a flat sheet in 1970,[74] this type of backing was then contoured to follow the warp of the painting as of 1974. This system replaced the châssis-cadre system, with the Altuglass taking the place of the stretcher; it allows a thin, fragile, and locally brittle painting to be supported; weak areas of the panel can be reinforced with a local restraining cleat through the Altuglass. The advantage is a transparency that allows all the information on the back of the work to be read. The major drawback is the considerable weight of the whole.

When the picture is too thin to justify a châssis-cadre but too big to allow a mobile backing, a modified châssis-cadre can be prepared,

Figure 13
A rigid support plate of acrylic resin (Altuglass), shaped to follow the warp of the panel, in the treatment of Cima da Conegliano's *La Vierge et l'Enfant*.

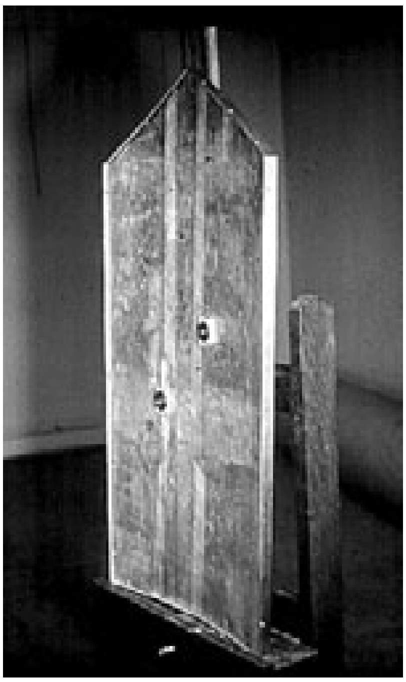
Figure 14
Cima da Conegliano, *La Vierge et l'Enfant*. The perimetric support, preserving the acquired curve of the painting, consists of a brass frame shaped to follow the contour of the panel. The frame is attached to the acrylic support plate by means of an L-shaped fitting. Felt lines the inner part of the metal frame that adjoins the painting.

with crossbars that slide within cleats equipped with rollers; this method was devised in 1971 for Titian's *Le Couronnement d'épines* and is still in use.

When the original elements are across the grain, a mobile framework based on the principle of elongated holes can be used. Examples of this technique can be found in the frames of several paintings in the Campana Collection which have been maintained like this since 1967.

Sometimes precious original tenons, even across the grain, can be preserved, as seen in the treatment of the *Pietà* by Enguerrand Quarton in the Louvre. The 1977 intervention on this panel was very extensive and exceptionally difficult, but it could be carried out because René Perche was still with the Huot studio at the time. Since Perche was due to retire, hesitations were overcome, and the decision was made to restore the support of the *Pietà,* which had been at risk for some time, so as to take advantage of Perche's extraordinary ability. The work required the preservation of original tenons across the grain of the boards and through four pegs; all these were preserved as elements of the original fifteenth-century joining work.[75] This intervention was Perche's last museum work.

Examples of minimal intervention—typified by the relinquishing of backings and the increased role of frames—can also be seen in the treatment of Tarascon's *Pietà,* treated in 1974, in the Musée Cluny, and in



a

b

Figure 15a, b
Ombrie, *La Dormition et l'Assomption de la Vierge,* fifteenth century. Reverse. Musée du Petit-Palais (MI 453), Avignon. Mobile backing shaped to a panel with retaining cleats (a). In the Altuglass plate, a cavity is made slightly wider than the size of the small wooden cleat (b) glued to the panel. Fixed by a very short screw, the cleat holds a brass disk whose edges rest on the resin plate and secure the Altuglass to the panel.

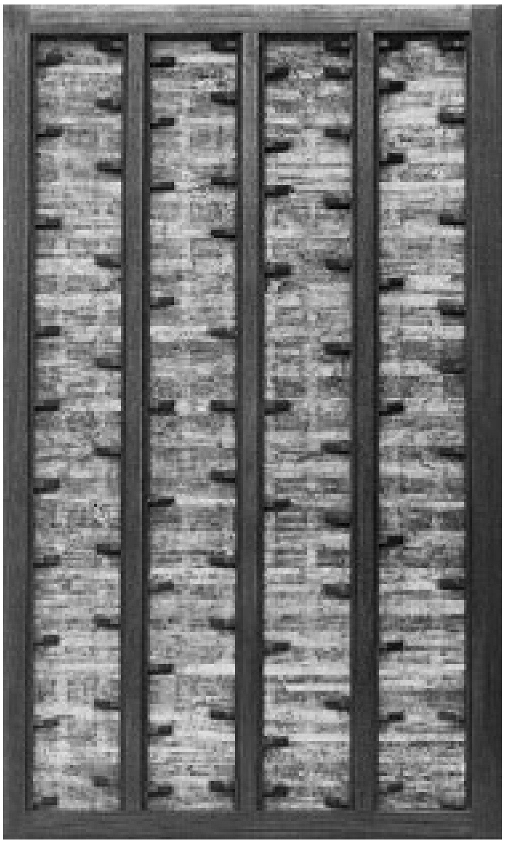


Figure 16
Titian, *Le Couronnement d'épines,* sixteenth century. Reverse. Louvre Museum (inv. 748), Paris. Châssis-cadre. The perimetric stretcher of Bakelized wood has crossbars reinforced with Bakelized wood, which are attached to the frame. Cleats fitted with Teflon cylinders allow the crossbars to slide. The very large painting was too thin to support itself and required more than a perimetric support.

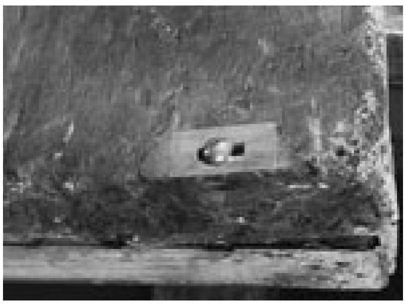


Figure 17
Florence, *Christ au tombeau,* fifteenth century. Reverse, detail. Musée du Petit-Palais (inv. 20253), Avignon. Screws placed in elongated holes; the mobile framework allows for the normal play of the wood, even if certain elements are across the grain.

that of Raphael's *Madone de Lorette,* treated in 1977, in the Musée Condé, Chantilly. For the Tarascon *Pietà,* a very precious and rare painting of the French fifteenth century, it was decided simply to place a cleat on the wood at the beginning of the split rather than to do a V-shaped incision and inlay. After regular surveillance and an eventual determination of the fragility of the painting, it was decided to fit a perimetric châssis-cadre instead of adhering crossbars and cleats to the back of that important artwork. A system of perimetric reinforcement following the exact contour of the painting was enough to mitigate the risks resulting from the inevitable handling.

Raphael's *La Madone de Lorette* from the Musée Condé, Chantilly, was treated in a similar manner (Bergeon 1979:48–49). The unevenness of a split required a V-shaped incision and inlay rather than just a cleat. Before crossbars were attached, the frame of *La Madone de Lorette* (even though not original) was adapted by the insertion of a brass perimeter frame shaped to follow the warp of the panel and lined with felt on the side of the painting. The edges of the frame had to be thickened so that it could receive the crossbars, which were also contoured, lined with felt, and fixed only to the frame.

The desire to maintain what exists and to reuse an old system by making it functional prevailed in the restorations carried out from 1978 to 1986 on Rubens's large *Sainte Hélène* at the Hospice de Grasse. The former glued stretcher, thick and of fine-quality walnut, was unglued and its crossbars hollowed and equipped with aluminum slats sliding over Teflon rollers fitted with cleats glued to the panel. It now constitutes a mobile support system (Bergeon 1990:39–40).

The same sensibility prevailed in a 1979 intervention on *L'Annonciation,* a work by the Master of the Altarpiece of Arceteri (Musée du Petit-Palais [MI 446], Avignon). In this work, the worm-eaten old crossbars were preserved, consolidated, and hollowed to receive two metal I-shaped pieces. The function of the crossbar has been reestablished and the old wood preserved.

With respect to insect damage, carbon tetrachloride is used to disinfect worm-eaten wood, on the advice of the Centre Technique du Bois. Consolidation with Paraloid dissolved in xylene has been standard from 1965 to the present.

Conclusion

From the first half of the eighteenth century, France enjoyed an excellent reputation with respect to the "mechanical" area of restoration—that is, in the treatment of the supports of painting.[76] Ever since the advent of those great innovations—the sparing transfer and the sliding cradle—French artisans of painting supports have been highly regarded. The art of the cradler has always seemed specialized and was generally admired, despite the facts that the work sometimes seemed undifferentiated and that some interventions were performed by specialists who described themselves as reliners.

The tradition of excellence in craft has continued. Cradles can still follow artistic standards, even if their functional role is now subsidiary to the aesthetic value they contribute to paintings; this is particularly true for cradles of the best period, which are especially prized since the art market has expanded.

The desire for the presence of a cabinetmaker in the Louvre devoted solely to wooden supports began tentatively, but by the 1960s the ground was ripe for a thorough consideration of the importance of having such expertise near at hand. There had been regular demands for the restoration of newly acquired works that previously would have been restored with the indispensable assistance of Italian colleagues. This assistance, however, became a keen indicator of the need for such skills in France. The need would eventually be filled by the Claude Huot studio, when the vast project arose of repairing the three hundred panel paintings in the Campana Collection, which was destined for a new museum in Avignon. This challenge was an extraordinary opportunity to initiate a policy of restoration on a technically homogeneous group of works, and it would compel Germain Bazin to seek the requisite technical, financial, and human resources for the task. The latest Italian thinking in this regard was combined with the excellent French techniques of cabinetmaking mastered by Claude Huot and his head compagnon and teacher of apprentices, René Perche, resulting in important new progress in the restoration of wooden supports.[77]

Cabinetmakers specializing in wooden supports, with their ever-lively curiosity, now constitute an important part of the studio team, and they work alongside curators who are highly interested in this technical subject and who have, in fact, specialized in restoration. The treatment of many different works has allowed the progressive evolution of methods, the pursuit of research informed by a dialectic between observation and thought, and the refinement of atelier practice—a combination indispensable to the progress of the proper care of works of art.

Acknowledgments

The authors wish to dedicate this article to René Perche, cabinetmaker (1913–89). They are especially grateful to Mme Y. Cantarel-Besson, in charge of the Archives of the Louvre, who has contributed her outstanding research.

Notes

1 This expression (Fr. *liberté surveillée*) was used by Bergeon (1976:22) in reference to the Campana Collection.

2 An inscription over the entrance gives 1740 as the founding date.

3 Archives Nationales, O^1 1922^A (1779).

4 Nouvelles Archives de l'Art Français, 1880–81 (p. 44).

5 For information on the Hacquin-Mortemard dynasty, the authors are grateful to Mr. Guilloux for the genealogical information conveyed to the authors on 26 March 1993.

6 Archives of the Louvre, P 16 (July 1832).

7 Oral communication from Jacques Joyerot, reliner at the Musées Nationaux, for the entire Leguay period.

8 We know Puget's thin face and silhouette from four photos that appeared in an article in *Science et vie* which reported on the techniques used at Leguay's studio (cf. Routy 1924:149–52).

9 A publicity label of 1914 that mentions cradling bears the name of Kiewert and the date 1841.

10 A publicity label of 1914 that mentions cradling bears the names of the partners Chauffrey and Govaert.

11 Before forming this important partnership, Muller had practiced from 1930 to 1931 on rue de Seine and then formed a partnership with A. Pouget. The studio became R. Muller Successeur (from 1932 to 1938 at 8, rue Christine, then, from 1938 to 1945, at 11, rue Jean Ferrandi) (Archives of the Rostain studio, Paris). There are bills from this period for cradling pictures of the Louvre (Archives of the Louvre, P 16 [1942–56], Muller, estimate of 10 October 1942).

12 Oral communication of E. Rostain regarding the entire Chauffrey period to the present.

13 Archives of the Louvre, P 16 (invoice of 2 April 1949).

14 Archives of the Louvre, P 16 (invoice of 1 August 1957).

15 Archives of the Louvre, P 16 (1968), Maridat.

16 Archives of the Louvre, P 16 (1957–74), Lepage.

17 Archives of the Louvre, P 16 (1957–74), Rostain.

18 Archives of the Louvre, P 16 (1957–74), Chauffrey-Muller, Gérant Rostain, 31 July 1965; and personal communication from Emile Rostain, 13 April 1964.

19 Archives of the Louvre, P 16 (1968).

20 In the Archives of the Louvre, there is no Landry file in the biographical index; however, there are many invoices for the period 1840–49 in the archives P 16 (1840–49).

21 Under Louis-Philippe there was a tendency to put a brown coat of oil on the backs of panel paintings as a means of preventing rapid shrinkage of the wood. This coat resembles the *maroufle,* the residue of the paint cup, oily and full of lead, often reddish, pigments, a composition with multiple benefits. As a nonaqueous adhesive, it is used to glue canvases to walls and ceilings without shrinking the fabric; it also functions as a barrier against humidity. However, there is the risk that any paint layer put on the reverse of a cradled panel could block a sliding cradle, causing eventual stress and thus a split (Bergeon 1990:30–31).

22 Archives of the Louvre, O 30.

23 Archives of the Louvre, P 16 (1843).

24 Archives of the Louvre, P 16 (1843); a letter from Landry annotated by Granet.

25 Selection tests for restorers are documented in the archives of 1769–98 and 1848; since 1936 they appear quite regularly.

26 Archives of the Louvre, P 16 (May 1848): draft by Villot, unsigned but in his handwriting.

27 Archives of the Louvre, P 16 (1882).

28 On the history of the restoration of paintings at the Louvre, see Emile-Mâle 1991.

29 Archives of the Louvre, P 16 (1942–56); see, for example, Castor, estimate of May 1953 for the repair of the *Retable du Parlement de Paris:* "to unglue all the sliding bars of the cradling, which were glued by a former painting [*sic*], to make each bar function in its notched slats to secure the effectiveness of the cradling. To tighten the two vertical fractures and fasten them with notched dovetails, the notched slats constricting the placing of the dovetails, which were taken off and then put back: 16,000 Fr."

30 Archives of the Louvre, P 16 (1957–74, invoice of 28 June 1957).

31 Archives of the Louvre, P 16 (1942–56, Castor, invoice of 15 December 1955).

32 *Museum* 1955; and Archives of the Louvre, P 16 (1953), Castor, van Eyck, *La Vierge du Chancelier Rolin*.

33 Xylamon: pentachorophenol and octochloronaphthalene (Baldi et al. 1992:217–18).

34 Archives of the Louvre, P 16 (1942–56), Castor: (M 503) Rosselli, *Annonciation*.

35 Rf 1956, Sassetta, *La Vierge et l'Enfant Jesus entourés de six anges, Saint Antoine de Padoue,* and *Saint Jean l'Evangéliste*. These three poplar panels, previously unbacked, were entrusted to the Istituto Centrale del Restauro in Rome between 1956 and 1959; the central panel was previously restored by Brisson-Leguay in 1903–4 but split in 1956. It was treated by (very narrow) incisions and inlays, then received a modern Italian-style cradling "of the edge [*de chant*]" (metal crossbars sliding on wooden cleats).

36 Rf 1762-1, Josse Lieferinxe, *Le Calvaire;* the walnut was particularly burred and worm-eaten, and the boards had come completely apart. Entrusted in 1964 and 1965 to the Istituto Centrale del Restauro, the panel received three sliding crossbars.

37 On transfer in France, see Marot 1950; Emile-Mâle 1957, 1962, 1982a, 1982b, 1983a, 1983b, 1987; Emile-Mâle and Borelli 1957; Emile-Mâle and Delsaux 1984, 1987. On transfer in Italy, see Baruffaldi 1834; Bodart 1970; and Bergeon 1975.

38 The sparing transfer was practiced in 1747 on Van den Meulen and that of 1748 on Palma Vecchio's *Mise au tombeau;* see Vindry 1969:46–47. The phrase "sparing transfer" means that the support is saved, or spared; cf. Vindry 1969. G. Emile-Mâle, in conjunction with the chemist Jean Petit (former director of research at the Centre National de la Recherche Scientifique), has demonstrated the technical possibility of such a procedure, although it is not without real danger, as this lifting of the paint layer involves a distinctive microfragmentation. This phenomenon is noted in Andrea del Sarto's *Charité* (transferred in 1750–51) and in Raphael's *Le Grand Saint Michel* (Louvre), which must have been transferred in the same way in 1751.

39 The transfer of the support with destruction of the original wood has been the usual procedure, in any case, ever since Raphael's *La Vierge de Foligno* (cf. O'Reilly 1801). It was probably already the procedure used for Raphael's *Sainte Famille* (Louvre), transferred in 1777, which has proved to be in only a slightly fragmented condition. *L'Incrédulité de Saint Thomas* by Salviati (Louvre), transferred in 1809 by the younger Hacquin, is in only a slightly fragmented condition, as is Raphael's *Le Portrait de Jeanne d'Aragon* (Louvre), transferred in 1810 by the younger Hacquin (cf. Lautraite 1983).

40 Archives of the Louvre, P 16 (26 May 1799).

41 Archives of the Louvre, Accounts, Year 11 (1803), fourth quarter; and Emile-Mâle 1983b.

42 Proceedings of the administration of the Musée Central des Arts, 28 nivôse, Year 7 (17 January 1799).

43 Archives of the Louvre, P 16 (1882).

44 Archives of the Louvre, P 16 (10 July 1755).

45 Vindry 1969; in fact, it was a picture of Neefs, *Saint Pierre délivré de prison,* Louvre (inv. 1591).

46 Inv. 748, Titian, *Le Couronnement d'épines:* Archives of the Louvre Z[4]O-1796-sd (but actually from 31 July 1799). See also IBB[4]Z (25 August 1798); IBB[5] (4 and 19 December 1800): and Archives Account, Year Nine (1801).

47 Archives of the Louvre, Accounts (second quarter, 1796–97), administration of the Musée Central des Arts.

48 Marijnissen 1967:n. 62: letter from the marquis de Marigny dated from Ménars, 18 September 1770. The cradle currently visible on the back of Rubens's *La Kermesse* (Louvre, inv. 1797) either is from 1770 or is the cradle that could have been redone in 1825 by François-Toussaint Hacquin (Archives of the Louvre, P 16, September 1825); it comprises twelve slats, one of which is thicker and glued (not molded), and seventeen mobile crossbars.

49 Archives of the Louvre, P 16 (1882) (cf. n. 43).

50 *Mouseion* 1938:243: this expression, "of field [*de champ*]," will become "of edge [*de chant*]" in Marijnissen 1967:319.

51 Painting on poplar backed with chestnut but not cradled: Ambrogio di Baldese, *La Vierge et l'Enfant avec six saints*. Pictures backed and cradled: Matteo di Giovanni, *Sainte Catherine de Sienne,* and Master of the Crucifix of Pesaro, *La Crucifixion* (Avignon, Musée du Petit-Palais, C 215, MI 369; C 200, MI 578; and C 216, MI 420, respectively).

52 Investigation of S. Bergeon, 1982.

53 See Diderot and d'Alembert 1765:596.

54 Archives of the Service de Restauration des Musées Nationaux. The very old split affecting the upper part of the *Mona Lisa* was the subject of a palliative treatment of two walnut dovetail tenons, glued with a fabric in between to prevent what was believed to be too much stress. These dovetail tenons required that the poplar be hollowed, but only slightly (less than a third of the thickness of the original panel). The restorer Denizard, who came to the Louvre in 1887, said that this repair was made by Bouvard; this examination of the back is mentioned in 1911, just after the theft of August 1911, as a major testimony for the identification of the work.

55 Lead white, basic carbonate of lead, with its excellent drying properties, has often been used mixed with oil. It was believed that this would harden wood. After such treatment, the back was covered up with brown paint: X radiography reveals the very worm-eaten condition of the wood when the tunnels are filled in this way (Rembrandt, *Le Boeuf écorché,* Louvre, M 169).

56 Permali is the commercial name of a wood impregnated with Bakelite, a hard resin, so that the wood is not highly reactive to variations of atmospheric moisture content.

57 Archives of the Service de Restauration des Musées de France: Leonardo da Vinci, *Mona Lisa;* attacked by worms, those very flexible beech crossbars were replaced in 1970 by similar ones of maple, which was aged and pretreated with Xylamon.

58 Initially part of the Musées Nationaux, but as of 1966, incorporated into the adminstration of the Musées de France.

59 For two centuries, it was the practice at the Louvre for an artisan or a member of a profession to work in a state building, to be supervised by the state within the large-scale apparatus of the state, but to retain private status and supply self-owned equipment.

60 Archives of the Louvre P 16 (1957–74, invoice of 15 November 1965). C. Huot's first work concerns the cradle of *La Déposition de la Croix,* by the Master of Saint Barthelemy.

61 Illustrated in Bergeon 1990:24, fig. 2: Benvenuto di Giovanni, *Le Martyre d'un évêque,* Musée du Petit-Palais (MI 514), Avignon; this precise intervention was made in 1967.

62 For a discussion of Paraloid, see Mora and Toracca 1965. For a discussion of the mobile crossbars, see Carità 1956.

63 In 1968 works of sverzatura were undertaken for Bartolo di Fredi, *Adoration des bergers* (C 71, inv. 20267), and Zanino di Pietro, *Polyptyque* (C 74, MI 421).

64 Bazin insists on "the importance of the support in the historical document which the painting constitutes"; the destruction of the support comes from "radical measures affecting the integrity of the object" (Marette 1961:11).

65 Archives of the Louvre, P 16 (1957–74), Huot RF 1981, G. Moreau, *Hésiode et la muse* (thinned to 2 mm; glued on marine-grade plywood of 8 mm and cradled): 900.

66 Archives of the Louvre (17 May 1968), C 426, Pérugin, *La Vierge et l'Enfant dans un gloire de séraphins* (MI 551).

67 See, for example, Archives of the Louvre (18 June 1970), Florence, Jacopo di Cione, *Le Mariage mystique de Sainte-Catherine* (MI 409, C 73) (thinned to 2 mm and glued on a latté with the back re-covered with a thin plate of old wood).

68 School of Romagne, *La Vierge et l'Enfant entre Saint-Pierre et Saint-Jean-Baptiste avec deux anges agenouilleés* (MI 491, C 267).

69 See Rostain 1981. The plywood approved for marine use derives its resistance to humidity and to severe external stresses from the choice of excellent wood and of adhesives that age well. The latté is composed of boards pressed between two thin sheets of wood the grain of which runs perpendicular to that of the boards. The thickness of the boards corresponds to three-quarters of the total thickness.

70 Fresco V. Mottez, *Mme Mottez* (Louvre, RF 1296), previously unfastened; the reinforcement of the support was done by Mme Berteaux (cf. N. Volle 1989, p. 16).

71 A. Solario, *La Déploration sur le Christ mort* (Louvre, RF 1978-35) (cf. Volle 1989:18).

72 The first experiments with balsa took place in the United States at the Fogg Museum and were carried out by R. D. Buck in about 1930. Balsa backings are still in use; the issue was recently discussed in Brussels at l'Ecole de la Cambre under J.-A. Glatigny (Habaru 1990–91).

73 Archives of the Louvre, P 16 (1957–74): Huot, 15 November 1965: Palmezzano, *Le Christ mort entre deux anges* (Louvre, MI 680), three wood crossbars hollowed on the side of the panel and cleats glued.

74 In working out the system of mobile backing in Altuglass, the important role of René Guilly (d. 1992) must be noted. Guilly advocated ongoing research as a component of the restoration policies governing wood supports.

75 The system of cross-grain tenons is found not only in Quarton's fifteenth-century work *La Pietà* but also in Hugo van der Goes's *La Mort de la Vierge* in Ghent; the system is found later, more rarely, in the seventeenth century, as in Le Sueur's series on the history of Saint Bruno for the charterhouse of Paris.

76 The term for "mechanical" (Fr. *méchanique,* It. *meccanico*) is generally used in the eighteenth century in archival texts and has to do with the supports of painting; this term is used in opposition to "picturesque"—referring to aspects that have to do with the paint layer.

77 Concurrent with the emergence in Rome of the study of the history of art, in late eighteenth-century Italy a great deal of thought was devoted to restoration. The comments of the restorers and their technical analyses of various styles were very influential (Chastel 1974). The philosophy of restoration was formalized with regard to architecture in 1809 by G. Valadier; only later was it formalized for painting, in 1936–38, by the art historian Cesare Brandi. Brandi's role was extremely important and explains why, from 1950 to 1970, Italy was the crucible of several experiments, including those concerning wood. The research projects of Giovanni Urbani in 1970–71 must also be mentioned.

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Richard Buck

The Development and Use of the Balsa Backing for Panel Paintings

James S. Horns

The notoriously reactive nature of wood to environmental conditions presents special problems for the conservation of panel paintings. Occasionally the construction and history of particular paintings have resulted in excellently preserved objects. Unfortunately, splitting, warpage, and insecure design layers of many panels have justly inspired concern for their stability.

Ideally, environmental control provides the least intrusive and best protection. This is not always possible, or it can sometimes be only partially achieved. Allowing an unencumbered panel to react with dimensional and conformational changes can prevent imposed stresses, but the movement itself can result in an unstable design layer. Moisture barriers and enclosures can reduce these changes, but in many cases it may be necessary to consider various forms of restraint and reinforcement to stabilize the panel structure. The discontinuous reinforcement of cradles and various batten systems has the disadvantage of allowing the panel to react to environmental change and subject it to unevenly distributed stresses. Reinforcement, which provides a continuous and uniform support, can take several forms. The complete transfer of the design layer to a new support has often been accomplished. Success in stabilizing and adding dimensional security has been reported for a partial transfer system in which the panel is substantially thinned and mounted on a more dimensionally stable support (Suhr 1932; Tintori and Rothe 1978).

Another approach grew out of work done at the Fogg Museum of Art of Harvard University in the 1930s and 1940s; this approach was developed by Richard Buck into the balsa-block backing that has been used successfully for many years. This system is intended to provide structural reinforcement, a moisture barrier, and some mechanical restraint of the panel, while keeping the alteration of the original to a minimum (Buck 1963, 1972; Spurlock 1978).

Treatments at the Fogg Museum of Art, 1927–1952

Under the direction of George Stout, the conservation program at the Fogg Museum of Art made many important contributions to the treatment of paintings, not the least of which is a treatment policy that stressed stability through removal of aspects of insecurity and addition of uniform reinforcement where necessary. David Kolch has provided an invaluable review of the development of this treatment approach and its results (Kolch 1977, 1978). He was able to compare the artworks' condition described at the time of treatment at the Fogg with their condition in the mid-1970s. The panels were found to be stable; flaking and other instabilities, which had plagued these paintings prior to their treatment, had been eliminated.

Stout, who initiated the consideration of characteristic panel paintings problems at the Fogg, was soon joined by Murry Pease and Richard Buck. Kolch documented the treatments done over the years from 1927 to 1952. The paintings treated suffered from unstable design layers and supports, wood deterioration and deformation, and inappropriate reinforcement. The intention of treatment was to stabilize and preserve the design and structure without removing more of the original than was necessary for consolidation. Furthermore, the treatments were designed to avoid the addition of reinforcement that would be incompatible or introduce new problems (Buck 1947; Stout 1955; Pease 1948).

While details of these treatments vary greatly, it will be useful to review the general approach. Additions such as cradles or previous transfer panels were removed where they caused damaging stresses or interfered with access for consolidation. Severely deteriorated or insect-damaged wood was removed. These removals occasionally extended to the gesso or paint layer in local areas, or even to the entire painting. The intention, however, was to preserve as much of the original structure as possible. Reconstruction materials included gesso, wax-resin, bulked wax-resin mortar, fabrics, redwood strips, balsa-wood strips and blocks, and aluminum strips and tubing in a variety of combinations. Where the original gesso or paint was exposed, gesso and fabric reinforcement were often used prior to the filling of voids with wax and balsa, or the building up of larger areas with wax and redwood strips. Several panels were flattened with moisture—a procedure aided by channels cut in the panel—prior to the final backing. Wax and fabric were often used to finish the back and to provide a final moisture barrier.

It is instructive to review several of these treatments to understand the development of this method. The information here is based on David Kolch's research on the conservation records of the Fogg Museum of Art, as well as some of the original treatment records (Kolch 1977). These records show that the end-grain, balsa-block backing method is an outgrowth of extensive treatment experience.

One of the earliest treatments reviewed was carried out from 1934 to 1936. The treatment involved a panel with areas of severe deterioration from insect tunneling. In the first stage of treatment, the powdery damaged wood was removed down to the original gesso in local areas, and the voids were filled with a layered structure of a damar-wax mixture (4:1), linen gauze, damar-wax putty with chalk and hemp fiber, and redwood blocks. Two years later, deteriorated wood was more extensively removed over most of the panel, but apparently a thin layer of original wood was left next to the gesso. In this treatment, wax-resin bulked with shredded cork and hemp fibers was used to level the back over the thin remaining wood. This layer was covered with fabric and layers of balsa wood strips embedded in the wax-resin putty. In Kolch's examination, this painting was one of the two that showed adverse effects from treatments. On this painting, a slight surface depression, visible in raking light, roughly follows the area of reconstruction; within this area a bulge (approximately 8 × 15 cm) is presumed to correspond to part of the first excavation and reconstruction. It is interesting to note that in the first stage of reconstruction, the adhesive used was made mostly of resin, with wax added. In contrast, the second stage used a largely wax adhesive, with resin added. The wax-resin mixture used in the second stage was also used in various forms in the subsequent reconstructions.

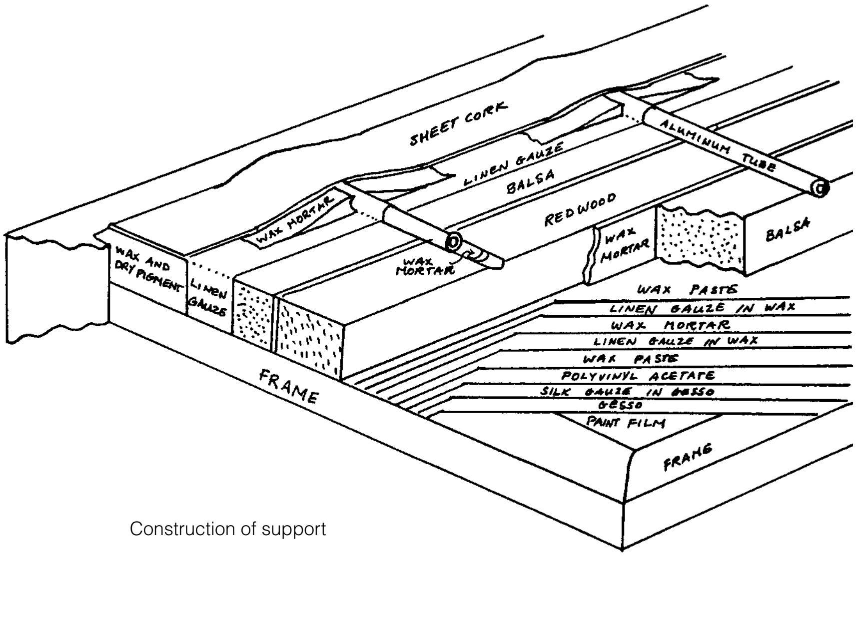
The treatment of many panels followed this general form: original panel material was removed where the wood was too damaged by insect tunneling to provide adequate support or where it seemed necessary to allow secure consolidation of the paint film. Occasionally this meant a complete transfer, but often the excavations were limited to only small sections of the panel. Sometimes these excavations extended to the back of the paint film, but, where possible, a layer of original wood was left in place next to the paint.

Where an overall backing was required, it was usually made up of wooden battens and cross bracing. A diagram taken from the treatment records shows the elements of the 1937 reconstruction of two panels (Fig. 1). Although he did not examine these panels personally, Kolch reports that the condition of the treated panels was stable as of 1966, while an untreated companion panel continued to show blistering of the paint.

In 1938 a set of four panels was treated to flatten and reinforce them. These panels were scored diagonally on the reverse and moistened to reduce the warp. Channels were then cut parallel to the grain and filled with bulked wax-resin and hemp fibers. This treatment also included the addition of aluminum tubing set across the wood grain to add strength. The stability and surface conformation of these panels were found to be excellent. Channels cut along the grain to reduce the warping and aluminum tubes or bars placed across the grain were used on several paintings in the following years.

A dramatic example of this reconstruction method was carried out in 1939 and 1940. The treatment record includes the initials of both Murry Pease and Richard Buck. The painting measured 170.5 × 123.0 cm and had a thickness of 1.9 cm. It had been thinned and cradled before 1917 and after that continued to show instability of the paint and multiple convex warps. Insects had done extensive damage to the panel. The treatment included the complete removal of the original panel, as well as much of

Figure 1
Diagram of a panel reconstruction, Fogg Museum Laboratory, 1937.



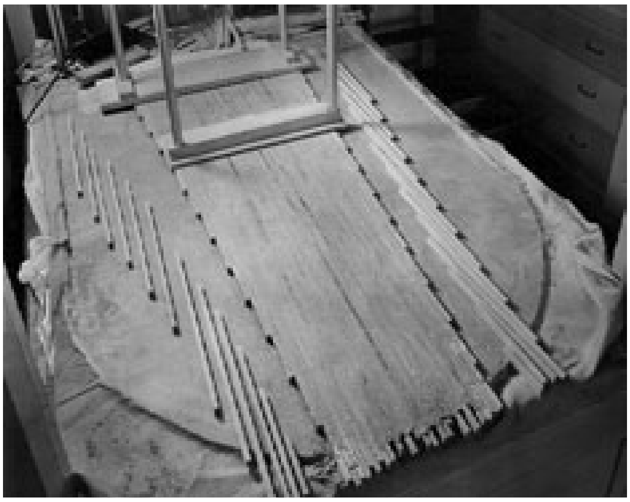
the gesso layer. New gesso and silk gauze were applied to the back of the remaining gesso layer, followed by a linen fabric and wax-resin paste. The backing was constructed with redwood strips parallel to the original grain of the panel; a wax-resin bulked with sawdust was used as an adhesive. This backing was reinforced with a grid of aluminum bars and tubing, and the spaces were filled with balsa-wood blocks. The back was then covered with linen fabric (Figs. 2–4). Kolch's examination found this painting sound, except for flaking in one small area that had been retouched.

A painting treated in 1945 also involved the building up of a panel on a complete transfer in a similar way. In this case, because a previous transfer backing had left the paint layer insecure, the backing was removed. Unfortunately, the redwood backing applied to this painting differed from that described above, in that three horizontal strips of redwood were applied first, and the vertical strips applied between them were "nicked" to allow air and excess wax to escape. Kolch reports that a pattern from this backing is now visible on the face of the painting. It seems likely that structural discontinuities of wood-grain orientation and pockets of wax are responsible for this distortion. Other paintings built up with redwood strips do not show such distortions relating to the backing.

Figure 2, right
Panel reconstruction, Fogg Museum Laboratory, 1940. The attachment of redwood strips.

Figure 3, below
Panel reconstruction, Fogg Museum Laboratory, 1940. The addition of balsa blocks and an aluminum grid.

Figure 4, below right
Panel reconstruction, Fogg Museum Laboratory, 1940. The sheet cork and linen finishing layers.



Kolch quotes from a treatment proposal prepared by Richard Buck in 1948 that clearly illustrates the thinking behind these treatments:

> The weakness which contributed to the present disintegration lies in the gesso which was added at the time the painting was transferred to its present oak panel. This gesso is now chalky, and can be ruptured by minor tensions or compressions which are transmitted to it by the wooden panel. . . . The risk to the security of the painting can hardly be exaggerated. In order to get at this region of weakness, it will probably be necessary to remove the present oak panel, replace the granular gesso support with a safer gesso layer and rebuild a composite wood support which will relieve the dimensional compressions now plaguing the paint. The composite panel I speak of is one that was developed by George Stout and this laboratory, and has been used on a number of paintings. Its particular merit is that it is almost completely unresponsive to atmospheric variations. (Kolch 1977:41)

Two of the last treatments carried out at the Fogg Museum while Buck was there seem to lead directly to the balsa backings that were characteristic of those done in the early 1950s at the Intermuseum Conservation Association at Oberlin College, Oberlin, Ohio; this organization is a cooperating group of museums that supported a conservation center as a joint resource.

In 1950 a panel at the Fogg Museum that had been backed with a secondary mahogany board was treated by removing the backing and revealing the original panel. This panel was thinned, but no channels were cut to reduce the warp, and, in fact, the warp was intentionally retained when the back was reinforced with balsa boards (approximately 1.25 × 15 cm) that were adhered with a bulked wax-resin. These balsa boards were oriented with the grain parallel to the original grain of the panel.

The last treatment Kolch describes from this period at the Fogg Museum makes use of a grid of balsa blocks cut across the grain (Fig. 5). This grid was applied to the back of a small circular painting with a history of insecurity; it had been treated with consolidants since 1939. Finally, in 1951, the cradle was removed and the panel thinned to 2 mm. The treatment record includes the following description by Buck:

> The insect tunneling was filled with a gesso-like mixture of polyvinyl acetate and white inerts. Into this layer a piece of linen was pressed and allowed to dry under moderate pressure. A new support was built by applying a wax resin plastic filler, molten, to small rectangular crosscut blocks of balsa wood,

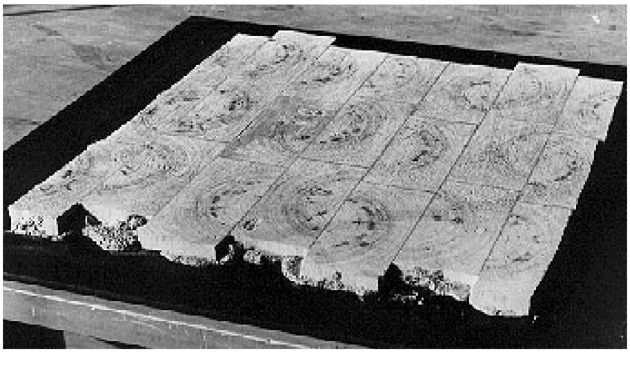


Figure 5
Balsa-block backing, Fogg Museum Laboratory, 1951.

> about 5/8 [in.] in thickness. These blocks with adhesive were pressed by hand onto the fabric surface in a brick-like pattern and allowed to cool. After covering the surface of the painting, the edges were trimmed and light hardwood strips were attached with the same adhesive to all edges. The back of the construction was smoothed and a sheet of 1/8 inch Masonite was attached to the back surface in the same adhesive. (Kolch 1977:46)

This panel has remained stable and free from the insecurities that had been chronic prior to the treatment.

Balsa-Block Backing at Oberlin

In 1952 Richard Buck established the Intermuseum Conservation Association at Oberlin College. There he continued to refine the backing methods. He and Delbert Spurlock used this end-grain balsa-block method with more emphasis on backing and reinforcement, less emphasis on excavation and reconstruction. The method also featured the inclusion of fiberglass cloth embedded in Saran F310 resin between the panel back and the block-and-wax backing. While this layer provided a moisture barrier, it was also designed to function as a natural layer of separation that would release if internal stress became too strong. This is possible because of a relatively weaker bond between the Saran and wax layers. Warped panels were generally backed in a relaxed state, with the backing conforming to the warp. Buck has reported that over the period from 1952 to 1970, the treatment of some fifty paintings in this manner greatly reduced or eliminated paint instability (Buck 1970, 1972).

The details of the balsa-block backing used at Oberlin are described elsewhere (Spurlock 1978), so the method will only be described here briefly (Figs. 6–10). All extraneous elements are removed from the back surface, and the exposed wood is coated with Saran F310 resin.[1] A layer of open-weave fiberglass cloth is adhered with a second coating of Saran resin. The balsa blocks are cut across the grain and attached with a wax-resin mortar made up of wax-resin bulked with wood flour and kaolin. Strips of pine are often added across the grain of the panel at the back surface of the balsa blocks as reinforcement. Finally, the back is smoothed and coated with Saran resin and a finishing varnish.

Buck did not view this method as a recipe for the treatment of all panel paintings but saw it, instead, as a method appropriate for many cases. He recognized that details of the method can be varied without compromise to the general principles. For example, the thickness of the balsa blocks and the use of pine battens can be adjusted to suit the panel. The Saran layer can be replaced with a more stable but less effective moisture barrier such as Acryloid B72, or the wax can be applied directly to the panel. Variations, however, should be considered in light of his summary of the desirable attributes of this backing method: "In theory this treatment combines the favourable aspects of the relaxed panel with those of the system of fixed mechanical control. The supplementary panel contributes high moisture barrier efficiency to reduce the movement of the original support, and imposes some mechanical restraint to persistent swelling and shrinking. It stabilized warp near the point of minimum normal strain. Although the applied panel has sufficient rigidity to serve its purpose, it possesses a degree of yield. The danger of panel rupture from the rigid control is not eliminated, though I believe it is not high" (Buck 1961:162).

Figure 6
Back of a panel painting after cradle removal.

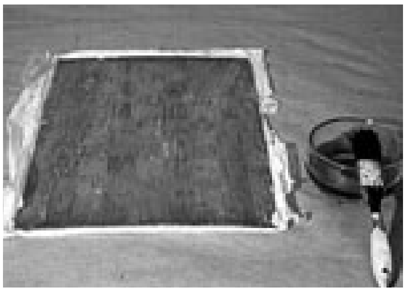


Figure 7
Fiberglass cloth and Saran F310 resin layer added to the panel back.

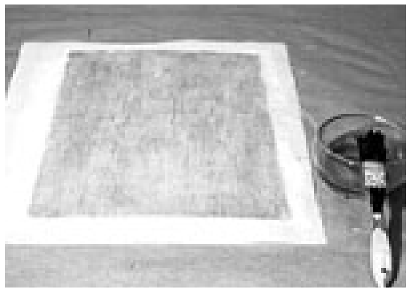


Figure 8
Fiberglass cloth and Saran F310 resin backing after drying.

Figure 9
Balsa-block backing in place.

Figure 10
Balsa blocks trimmed and smoothed.

Warp Reduction with Balsa Backings

Eventually the success of this backing system suggested that it could be used safely to reduce deformation in warped panels without thinning and channeling, as was done at the Fogg Museum. This process is accomplished by exposing the panel to moisture at the back surface until sufficient flattening has occurred. The Saran and fiberglass cloth layer is then applied, and while the panel is flat, the wax and balsa blocks are added (Buck 1972). The backing acts as a mechanical restraint while the panel, which has been flattened by exposure to moisture, slowly dries and undergoes relaxation of stress. This extension of the basic backing obviously adds many uncertainties and complications and was not a technique Buck frequently practiced. A painting treated by this method in 1967 (Buck 1972) has been examined recently; it remains in stable condition in its flattened state. At least one other flattening by this method has been published, with good results (Reeve 1981).

Moisture Movement and Panel Paintings

It may be useful to review some of the principles involved in interpreting the behavior of panel paintings, particularly as they illustrate the success of this backing method. Buck has carefully presented the essential material (Buck 1963, 1972); only a brief expansion on this framework will be attempted here.

Wood is clearly a nonuniform and variable material, for which sample differences can be of great significance. Certain consistent principles, however, can be used to understand and predict its behavior. Of particular importance is the relationship of wood and water. Buck demonstrated that aged wood retains its hygroscopic nature over time (Buck 1952).

He also demonstrated that while moisture barriers can slow the reaction of panels to environmental change, they probably cannot eliminate it (Buck 1961). Although wood structure, physical or chemical deterioration, environmental history, and so on, can affect the panels, in general, dimensional change follows moisture change. Many variables determine how this change manifests. In turn, these variables can be used to modify behavior in particular cases.

Wood can react to stress with changes that take the form of elastic or plastic deformations. By definition, elastic deformation will be reversed if the stress is removed, while plastic change will remain. In wood, however, the relation of these can be complicated, with moisture levels, moisture gradients, internal stresses, and external loads or restraints contributing significant variables. Buck, whose work was based in particular on that of W. W. Barkas (1949), stressed the importance of the potential for plastic change to take place below the fiber saturation point (Buck 1972). Barkas and Buck placed strong emphasis on the spring-and-dashpot model of elasticity and plasticity (Barkas 1949:80; Buck 1972:3). This description uses the spring to represent the totally recoverable elastic element and the dashpot (a plunger moving through a viscous material) to represent the plastic aspects of wood movement. The interaction of these two aspects is complex and highly dependent on moisture content and other variables. Buck has argued: "As the moisture content approaches the fiber saturation point, the bound water becomes almost a lubricant, permitting actual slippage of elements past each other under stress, as the much weakened bonds break and change partners. This kind of behavior is plastic. It creates none of the tensions that cause elastic reversal" (Buck 1972:4).

Barkas considered wood as a gel material and stressed the importance of moisture level and moisture movement in determining elasticity and plasticity in wood: "Wood fibres would behave elastically both longitudinally and transversely for strains which do not exceed the limit of bond recovery, but plastically for those strains which involve a change of hydroxyl partners. Also, if the moisture content were lowered while the displacement was maintained, the new shape would become 'frozen in' by the formation of a new set of direct hydroxel linkages in place of water bridges. But if the distortion were also to involve elastic strains, these would also be frozen in by the structure thus leading to the recovery when the wood is rewetted, even after a considerable lapse of time" (Barkas 1949:82).

While much work remains to achieve an understanding and theoretical model of these relationships, this passage reminds us of the importance of moisture movement in the development of elastic and plastic deformation. It is also important to remember that elasticity and plasticity can be dependent on defined conditions. For our purposes, for example, the elasticity released by very high moisture content and temperature could for all practical purposes be considered a stable situation in a panel painting; thus, the separation between plastic and elastic deformation becomes somewhat ambiguous.

Wood structure can retain two types of elasticity that can be undetected until released by mechanical or environmental change. The first type is differential stress in the larger wood structure. For example, if a case-hardened board is sawed, the two sections can show a pronounced warp due to the release of elastic strain. If such discontinuities are present in a panel painting, they could be released mechanically by thinning or environmentally by moisture change. The second type of elasticity involves the minute structure that Barkas has defined as a gel and that has the potential to revert when exposed to high or cycled moisture content.

The understanding of plasticity and elasticity presented by Barkas has been somewhat modified by evidence that places even stronger emphasis on the importance of moisture movement in wood in these behaviors. Since it is the cycle of moisture change that we know to be of concern for panel paintings, it is useful to consider this evidence.

Much work has been done by wood technologists on the phenomenon of creep. When wood is placed under load, it will slowly deform; the extent of this deformation depends on the stress and, in particular, on the moisture content. Beginning in the early 1960s, many studies have shown that cycling of moisture content greatly increases the rate and extent of creep (Armstrong and Christensen 1961). It has become clear that the movement of water in the wood structure is of primary importance in this behavior. The creep development that relates to moisture movement has come to be called mechanosorptive creep (Grossman 1976), while creep unrelated to moisture change is referred to as viscoelastic creep. As this second designation implies, creep unrelated to moisture movement is substantially elastic. Creep developed under moisture change also has elastic aspects. When the load is removed, the wood recovers somewhat, but if the sample is also then cycled through high-moisture content, there will be additional recovery. It has become apparent, however, that the permanent plastic deformation involved in creep depends primarily on moisture change.

A closely related phenomenon in wood is stress relaxation. If wood is placed under fixed strain, the stress will gradually decrease. Although much less work has been done on this behavior with cycled moisture than has been done for creep, moisture movement can also increase the potential for stress reduction (U.S. Department of Agriculture 1974:4–37). It should also be noted that there is some evidence that in stress relaxation, the potential for plastic change is as great in tension as in compression; under conditions of room temperature and moisture content below the fiber saturation point, it may even be slightly greater (Youngs 1957).

It seems then that moisture change and internal stresses may be significant in the development of warping. To elaborate on the functioning of the uniform backing, it is useful to consider the development of warping in panels and the potential for stabilizing or reversing it. The work done on creep seems to imply that moisture changes in the wood structure facilitate strain, which manifests in the direction of stress. In panel paintings, the typical convex warp can be the result of at least two factors. When a painting is brought into a drier environment than that of the original fabrication, the back surface can shrink, but the paint and ground layers restrain the wood on the front, and an initial warp develops. Subsequently, cycles of moisture change influence the back surface preferentially, and compression shrinkage develops as the outer layer of wood tries to expand against the restraint of the inner core, due to the uneven moisture gradient. One might wonder why the reverse process does not neutralize this effect during the cycles. If a panel equilibrated to a high moisture content dries preferentially at the back surface, would not a moisture gradient develop and a strain in tension reverse some previously established compression shrinkage? This outcome certainly could happen, as the well-known phenomenon of case hardening in the lumber industry illustrates.

Several factors reduce the ability of this process to prevent the development of warping in panel paintings. In the first place, many cycles of moisture change are short-term; therefore, the important changes do not penetrate to the core of the panel—thus, compression at the back surface is the predominant effect. Second, under extreme conditions, wood structure may be more easily altered in compression, where the structure can collapse in various ways; while in tension, structural changes are more difficult, and rupture can result before significant deformation is reached. Finally, studies of mechanosorptive creep have shown that it is difficult to reach a limit in compressive creep, but in tension, a limit does seem to be present (Mohager and Toratti 1993; Rice and Youngs 1990). The implication of these findings is that the warp in a panel painting can develop simply from the reaction to moisture cycles.

As an illustration, the author has produced a warp of this type. Six samples of poplar were coated on one side with a moisture barrier, and a strain gauge was applied to this side across the grain of the wood. The samples were then exposed to various moisture conditions at which their weight, dimensional change at the strain gauge, and warp were recorded. In two cycles where the samples were equilibrated to very high relative humidity (RH) and then equilibrated to lower levels, only a slight change in the measured warp was found. They were then exposed for shorter periods to high RH and equilibrated to the lower levels. After these shorter exposures, the warp of the samples increased noticeably. The strain gauge measurements suggest that this warp was due largely to dimensional change at the concave surface, which is analogous to shrinkage at the back of a panel painting. This study emphasizes the potential of short-term moisture changes to induce warping and, therefore, the important function that moisture barriers and environmental control serve. From this reasoning, one might infer that even if the sliding members are not restricted in their movement, a cradled panel could develop the typical "washboard" conformation because of the continued buildup of compression at the back surface. Of course, many panels, both cradled and uncradled, appear to have survived many cycles of environmental change with little or no warping. This fact emphasizes how difficult it is to generalize about a material when so many variables separate one sample from another.

Because it serves as a moisture barrier as well as a mechanical restraint, the balsa backing should protect the painting against the increasing stress or warp that can develop from exposure to short-term moisture fluctuations.

Flattening of Panels

When the balsa backing is used to reduce a warp in a panel, the potential for introducing compression at the paint surface increases, bringing the risk of insecurity between paint and support. Therefore, if one can produce deformation in tension at the back surface, this method may reduce compression at the painted surface that could aggravate paint insecurity. For example, Figure 11 shows that a warped board forced flat will develop planes of strain in which compression increases toward the formerly convex surface, and tension increases toward the formerly concave surface.[2] Thus, in a panel held flat by a cradle in elastic strain, one would expect substantially increased compression at the paint surface. Can this risk of compression be reduced? One way to do so would be to thin the panel prior to flattening. By reducing the distance between the neutral plane and the paint, the compression will be lessened. The intention of the balsa-backing method is to introduce as much deformation in tension at the back surface as possible. One of Buck's favorite demonstrations was to swell samples of wood and then glue battens to one side with their grain running perpendicular to that of the samples. When the samples were dried, the battens were removed, revealing a permanent warp due to the restraint the batten provided to the shrinkage of one side of the sample. Part of the intention of flattening with the balsa backing is to similarly restrain the shrinkage of the back surface and allow for plastic deformation and relaxation of stress as the panel slowly dries to equilibrium. By reduction of the warp with moisture and application of a balsa backing, it is hoped that the reduced compression of the painted surface will result in a panel with a minimum of elastic strain. Figures 12 and 13 show that it may be difficult to eliminate compression at the paint surface during any flattening with moisture. While strain gauge measurements on this sample show that compression at the upper surface was somewhat less during flattening with moisture than when the sample was simply clamped flat, there is still substantial compression. As the moisture content was raised past the point of initial flattening, this compression began to decrease (Fig. 14). Buck's description of the flattening and balsa backing includes just such an extended exposure (Buck 1972:8). This approach could help to reduce the risk of permanent compression being introduced at the paint surface. The individual circumstances of each flattening operation make the conditions at the paint film uncertain, however. There are risks with any flattening operation, and such treatments should be approached with the greatest caution.

Summary

Perhaps the most appropriate use of the balsa-backing method is for paintings that have a history of insecurity and that will be exposed to a poorly controlled environment. In the author's experience with balsa backings, panels show good stability after treatment, as well as a reduced susceptibility to movement and insecurity. One case in particular seems to illustrate this point. This panel is privately owned and has been subjected to the rather severe environmental fluctuations of a northern climate. The panel was brought to Minnesota in 1977 and immediately developed extensive tenting of the paint during the first winter. Previous losses indicated that this had been a chronic problem. A cradle (perhaps fairly recently applied) was present. It was restraining the panel in such a way that a slight concave warp developed. When the cradle was removed, the relaxed panel took on a slight convex warp. This warp was retained when the balsa backing was applied. In the years since the treatment, there has been no new flaking in the original paint, although recent examination found a small area of filling that had loosened. The owners indicate that some movement of the panel from season to season is visible in relation to the frame edge, but this has not been measured precisely.

Similarly, the balsa backings done at Oberlin of which the author is aware have shown good stability. There is one instance in which a mechanical problem led to a precipitous drop in RH in a gallery. Several panels developed tenting and insecurity in the paint, but two panels backed at Oberlin showed no adverse effects.

Although the elastic and plastic aspects of deformation are not easily separated, their presence has much to do with the treatment of

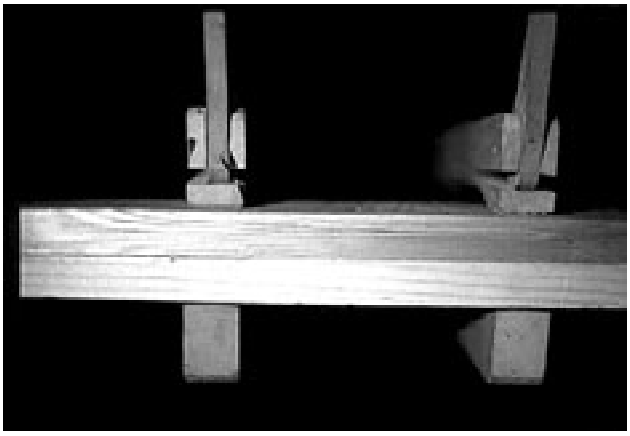


Figure 11
A warped wooden sample, with polycarbonate glued to one edge over a layer of silver paint, has been clamped against a flat surface to eliminate the warp. When illuminated with polarized light and viewed through a polarizing filter, this photoelastic material shows the variations in strain as colored fringes. The darkest lines (one-third of the way down from the top surface) represent the least strain. Compression increases toward the top, tension toward the bottom.

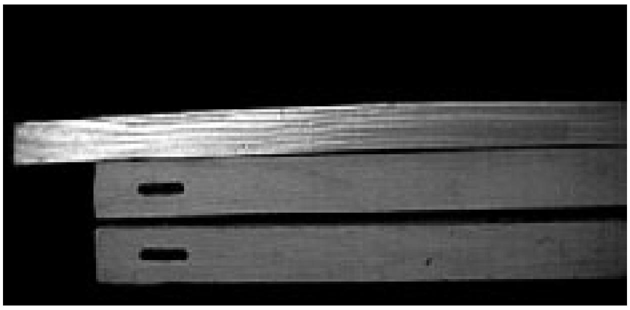


Figure 12
The same sample shown in Figure 11, after exposure to moisture at the concave surface for several hours. The warp was slightly reduced, and compression began to develop at the top surface. Swelling produced tension in the photoelastic material at the concave lower surface.

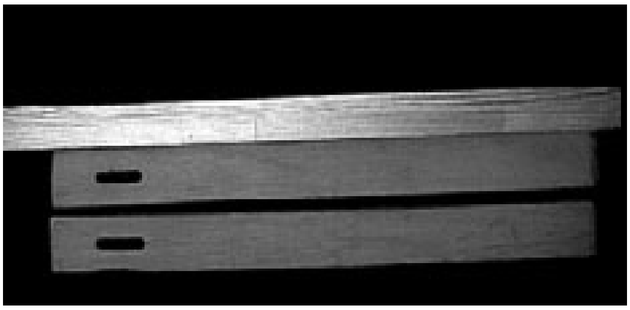


Figure 13
After twelve hours the sample was flat, and substantial compression developed at the top surface, along with tension from swelling at the bottom. Strain gauge measurements at the top surface indicated that the compression produced by this flattening was somewhat less than that produced by the clamping seen in Figure 11.

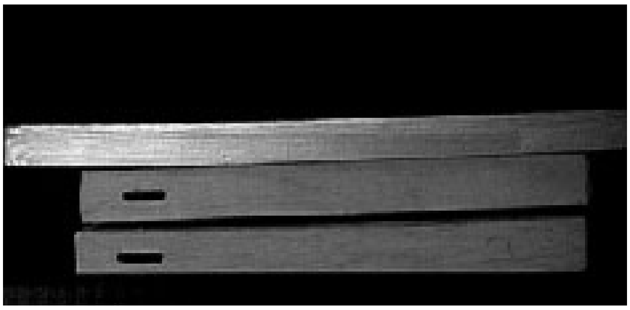


Figure 14
After further exposure to moisture, the sample began to develop a slightly reversed warp, and compression at the top surface began to decrease.

panel paintings. It seems fair to say that the intention of the uniform backing is to produce a panel with a minimum of elastic strain, so that the wood structure is as relaxed as possible. Thus, if a panel is warped and the backing simply supports this conformation, the previously developed plastic change is retained. In the event that the backing has imposed a reduction in the warp, it is intended that the reduction of warp will have a high degree of plasticity due to the gradual drying under restraint from the backing. Furthermore, Buck felt that although the balsa backing itself might tend to react to environmental fluctuations slightly, it would, nevertheless, provide some restraint to the movement of the panel, thereby reducing the stress imposed on the paint film (Buck 1963:162).

The uniform balsa backing can provide a stable support that resists warping from environmental exposure or from the release of undetected elastic strain. In addition, in future cycles of moisture change, this restraining backing may reduce some internal elastic strain, a factor that is particularly significant when the reduction of a warp is involved. In such cases it is anticipated that the restraint of the backing during the initial drying of the flattened panel and during subsequent cycles may allow a form of mechanosorptive relaxation to establish an increased internal stability in the wood structure.

It seems clear that the use of a uniform backing—and in particular the balsa-block method—has a history of success and is an important treatment option.

Acknowledgments

Use of the records and photographs from the Fogg Museum Laboratory, as well as permission to use unpublished material compiled by David Kolch, is through the courtesy of the Straus Center for Conservation, Harvard University Art Museums.

Notes

1 Saran F310 resin is soluble in methyl ethyl ketone for brushing.

2 For this sample, a 2 mm thick sheet of Lexan polycarbonate was attached with clear epoxy resin. In this sample, the author used an SR-4 model strain gauge (BLH Electronics).

Materials and Suppliers

Acryloid B72, Rohm and Haas Co., Independence Mall Street, Philadelphia, PA 19105; Conservation Materials, Ltd., 100 Standing Rock Circle, Reno, NV 89511.

Clear epoxy resin, Devcon Consumer Products, 264 Howard Ave., Des Plaines, IL 60018.

Lexan polycarbonate, (General Electric) Cadillac Plastic and Chemical Co., 1218 Central Ave. N.E., Minneapolis, MN 55414.

Materials specifically designed for photoelastic stress analysis, Photoelastic Division, Measurements Group, P.O. Box 27777, Raleigh, NC 27611.

Saran F310 resin, Dow Chemical Co., Main Street, Midland, MI 48674.

SR-4 model strain gauge, BLH Electronics Inc., 75 Shawmut Rd., Canton, MA 02021.

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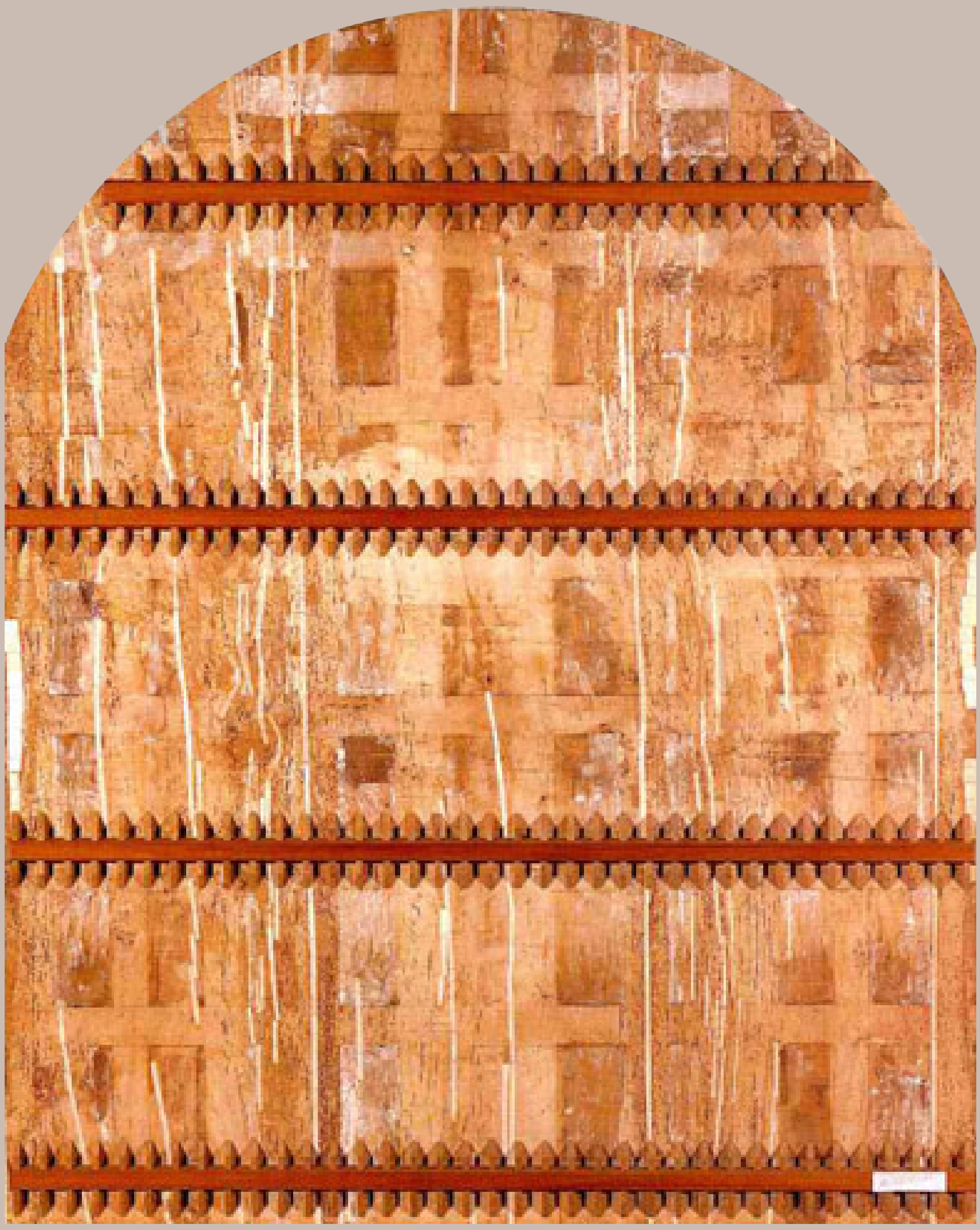
PART FOUR

Current Approaches to the Structural Conservation of Panel Paintings



Florentine Structural Stabilization Techniques

Andrea Rothe and Giovanni Marussich

More damage was caused by the great flood of 1966 in Florence than by both World Wars combined. Many paintings and other artifacts were submerged in the floodwaters for more than eighteen hours. They were covered with mud mixed with heavy deposits of heating oil that had seeped from the storage tanks housed in the many basements of the city. The worst damage was done to the large number of panel paintings in Florence and the surrounding countryside; those that had been submerged swelled many inches beyond their original size.

Subsequently, these paintings were subjected to a long and gradual drying process, first in the *limonaia,* the old hothouses built by the Medici in the Boboli Gardens for their favorite collection of citrus plants. These hothouses were quickly converted into one large humidity chamber. The humidity was raised to 95% at a temperature of 12 °C over a two-year period. Afterward, the treatment was continued in the former army barracks of the Fortezza da Basso, which in the meantime had been transformed into the largest restoration laboratory in the world; it had, in fact, become an independent governmental department, a *soprintendenza,* by special decree.

Despite the carefully controlled drying process, many of the panels shrank considerably. This shrinkage caused severe blistering and cupping of the paint layers, as well as deformation of the supports (Cianfanelli, Ciani Passeri, and Rossi Scarzanella 1992). Consequently, many of the panel paintings had to be transferred to canvases and to new, rigid supports. The oil deposits were removed with a poultice made from Shellsol A and talc applied to a Japanese-tissue interleaf.

The devastation caused by the flood was, to some degree, offset by the benefit of the better understanding that was gained about the behavior of wooden artifacts—panel paintings in particular. For instance, the negative effects of dovetails, which had already gone out of style by the end of the 1950s, were confirmed (see Rothe, "Critical History," herein). The negative effects of rigid restraints or crossbars in relation to the natural flexibility of panels were better understood. It became clear that those restraints that held the panels in place but did not hinder their need to expand and contract were the most effective.

It also became obvious that the materials that were used for crossbars had to be stable and unaffected by environmental fluctuations. *Mansonia,* which had been widely used in Florence by the restoration departments of the Vecchie Poste at the Uffizi and Palazzo Pitti before the flood, proved to be the most stable wood, with the least tendency to deform (see Rothe, "Critical History," herein).[1] Used for more than forty years in the construction of crossbars, mansonia functions very efficiently and, in fact, appears to be better than any other type of wood because of its density and workability. Panels with mansonia crossbars expanded and contracted drastically after the flood but did so with little or no buckling. Planks of mansonia that had been immersed for over a week and then inadvertently used as gangways to wheel mud out from the ground floor of the Vecchie Poste did not deform or crack, and they were later utilized to make new crossbars. Today mansonia is still used—although much less often because of its toxic properties. Other woods, such as steamed beech, have also been used but have not given such satisfying results. Metal crossbars, such as those used successfully in Rome by the Istituto Centrale del Restauro, have rarely been used in Florence, primarily because of aesthetic considerations (see Rothe, "Critical History," herein).

If a panel is in good condition, the conservator usually chooses not to intervene. Unfortunately, this is not always possible. Intervention is necessary whenever the original crossbars have been lost (causing warpage), the panel has previously been thinned, splits have caused loss of color, or panels have cracked apart. The restraint that a brace or crossbar should exert on a panel is difficult to measure or predict, but today the rule is to give the panel ample lateral freedom to move and to manipulate the original surface as little as possible by making the braces much smaller than was formerly considered appropriate, and thus more flexible (Figs. 1, 2).

Excessive restraint such as that caused by older cradles tends to block the movement and facilitate the formation of new cracks and even of splits (Figs. 3, 4). Conversely, too little restraint can allow panels to deform, especially those that have been thinned and have lost their original coating (see Rothe, "Critical History," herein) or the aged "skin" that

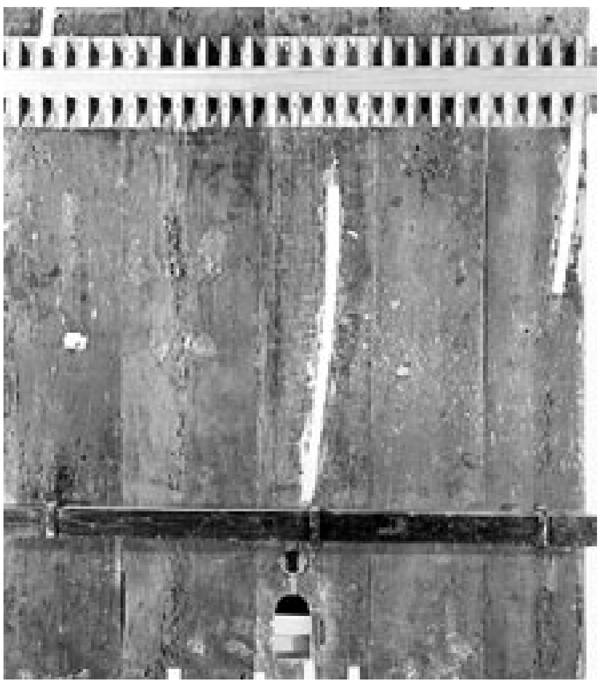


Figure 1
Guglielmo di Pietro de Marcillat, *Annunciation,* 1524. Reverse. Oil or mixed technique (?) on panel, 180 × 150 cm. Convent of S. Francesco, Sargiano, Arezzo. A typically heavy crossbar of the early 1970s, with pegs glued and screwed to the panel; a wide swath of original wood surface was removed to create a level area. The crossbar on the bottom is original.

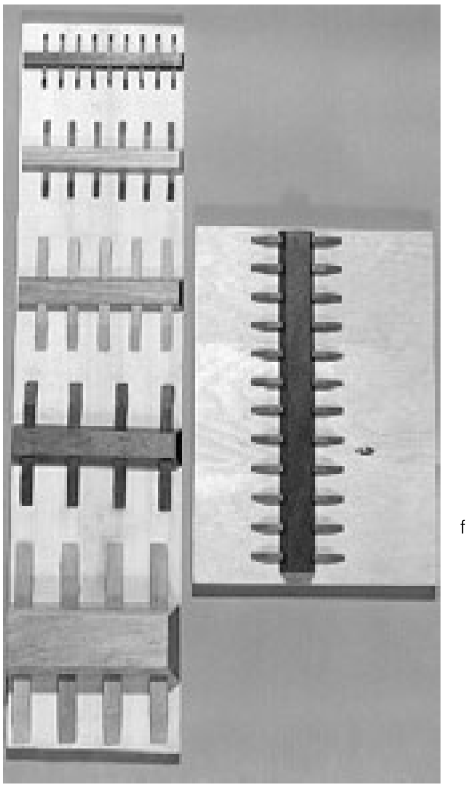


Figure 2
Examples of crossbars showing progressive reduction in size. (a) Crossbar used in 1975 on the *Annunciation* by Guglielmo di Pietro de Marcillat, Convent of S. Francesco, Sargiano, Arezzo; the panel is 150 cm wide, the crossbar 7.5 cm wide. (b) Crossbars used in 1988 on the *Nativity* by Girolamo di Benvenuto, The J. Paul Getty Museum, Los Angeles; the panel is 161 cm wide, the crossbars 4.5 cm wide. (c) Crossbars used in 1989 on *The Birth of Bacchus* by Giulio Romano, The J. Paul Getty Museum; the panel is 80 cm wide, the crossbars 3.2 cm wide. (d) Crossbars used in 1987 on *The Card Players* by Joos van Crasbeeck, The J. Paul Getty Museum; the panel is 31.1 cm wide, the crossbars 2.7 cm wide. (e) If crossbars were to be placed on *The Card Players* today, a smaller version (1.8 cm wide) would be used. (f) Crossbars used in 1990 on *The Abduction of Proserpine* by Alessandro Allori, The J. Paul Getty Museum; the panel is 228 cm wide, the crossbars 3.3 cm wide.

forms on the back of old panels (consisting primarily of compacted wood cells and accumulated dirt).

In the Florentine approach to rejoining panels, the precision with which the work is carried out is key to the success of the treatment. This approach is described as *risanamento delle tavole,* "making panels sound again." The pivotal task is to cut precise V-shaped grooves of approxi-

Figure 3, below
Girolamo di Benvenuto, *Nativity,* ca. 1500. Reverse. Tempera on panel, 204 × 161 cm. The J. Paul Getty Museum, Los Angeles. A heavy cradle is glued to the panel, which had been thinned to less than 12 mm. This intervention dates to about 1900.

Figure 4, above
Girolamo di Benvenuto, *Nativity*. Detail. This raking-light photograph shows distortions and cracks on the surface caused by the thinning of the panel and the restraint of the heavy cradle.

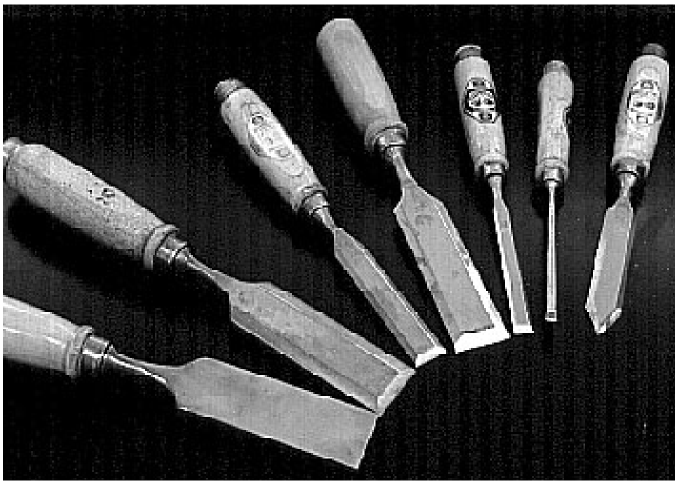


Figure 5
Some tools used in the preparation of V-shaped grooves.

mately 55°. The groove should straddle the crack all the way down to the gesso preparation; short, individually fitted wedges are then inserted into these grooves. The grooves should be made as deep as possible without causing damage to the paint layer, so as to avoid the formation of hairline fissures (see Rothe, "Critical History," herein).

The type of wood used to reconstruct these panels should be well-aged material of the same type as the original painting support. The various chisels used, including a pointed chisel for the finishing of the V-shaped grooves, must be maintained in constant sharpness (Fig. 5). If percussion is needed, the ball of the hand (never a mallet) may be used. In some instances, when the cracks are straight and long, two angled planes are used—one for the left side of the split, the other for the right side (Fig. 6).

Before the wedges are inserted, the detached sections of the panel must be perfectly flush with each other. This is accomplished by a simple system of temporary braces, or *tiranti,* that are screwed into the panel

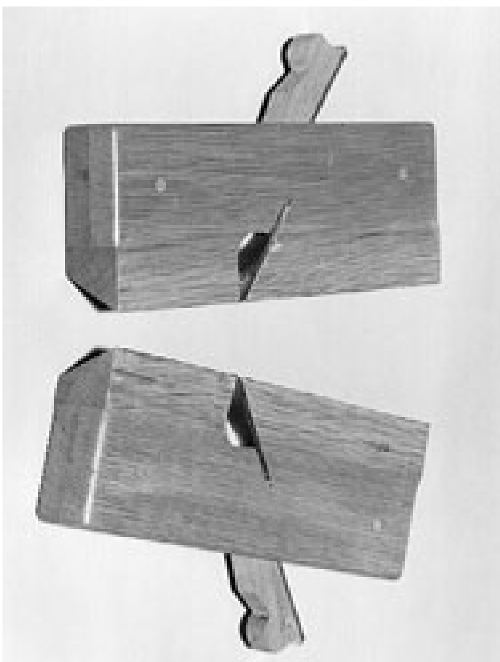


Figure 6
Two angled planes, sometimes used for preparing long, straight grooves.

Figure 7
Temporary tiranti, or levers, used to pull distorted surfaces of separated panel boards back into plane before wedges are glued into previously prepared grooves.

wherever necessary along the crack. By strategic placement of the screws and the small blocks under the braces, either side of the split can be pushed down or pulled up (Fig. 7). If the panel is very thin, little blocks of wood can be temporarily glued onto the panel to hold the screws in the areas that need to be leveled. The glue used for softer woods, such as poplar and limewood, is mostly a polyvinyl acetate (PVA) emulsion glue such as Vinavil, thinned with water.[2] Woodworkers point out that the glue that oozes out is what ensures a lasting bond—meaning that the less glue that remains between the wedge and the wood of the panel, the better. For harder woods such as oak, a two-component epoxy glue such as Araldite is used.[3]

For those who are not master artisans, a simpler and quite effective method was developed by Barbara Heller at the Detroit Institute of Arts after she worked for many years in Florence (Heller 1983). She cuts the grooves with a router and uses precut V wedges that are set in with Araldite carvable paste.[4] The results have been very encouraging and seem to be stable, especially in the case of softer woods such as poplar.

The movable crossbars are held in place by pegs, or *nottole,* that are glued to the panel with an epoxy adhesive. The section of the crossbars is trapezoidal, and particular care is used in planing the sole and the two side edges. To ensure a perfect glide, hot paraffin is applied to the edges and polished, and the same is done to the face of the pegs.

The crossbars and pegs of the early 1950s were much heavier and wider. The pegs were not only glued to the panel but also screwed on, thus locally blocking the movement of the panel. Two or three wide swaths were also planed flat across the panel to accommodate the width of the crossbars with the pegs (Fig. 1). This method removed much of the aged skin, something that is no longer done today. To overcome the irregularities of the panel, individual spacers are now fitted and glued between the pegs and the panel.

The Opificio delle Pietre Dure restoration department at the Fortezza da Basso has carried out more panel restoration than any other institution in the world; consequently, it has gained a wealth of unique experience. It has introduced and perfected many new systems that reduce interference with the tendency of wood to move. Where deemed appropriate, the angle of the V-shaped cuts has been reduced at times from 55° to just 7.5° with a special router bit (Castelli, Parri, and Santacesaria 1992). Although this approach interferes less with the original wood, the woodworker does not have as much control with a router as with a handheld chisel and therefore cannot cut as close to the original gesso layer; this deficiency might, in time, result in a weaker joint (Castelli, Parri, and Santacesaria 1992).

Other systems may be used to minimize the interference with the original panel, such as the method of attaching the crossbars without pegs. Instead, a system of sparsely distributed brass threaded inserts is screwed and glued into the panel. The crossbars are slotted lengthwise at the same intervals as those of the threaded inserts, and identically slotted brass plates are set into the crossbars. These crossbars are then attached with long bolts that fit into the center of the slotted brass plates and are directly screwed into the threaded inserts glued into the panel. The bolts are not tightened excessively, and a Teflon washer can be used to facilitate lateral movement. A simplified version of this method consists of fastening the crossbars, which are also slotted, with long, round-headed brass

Figure 8
Various screws and bolts used in less invasive types of crossbar attachments.

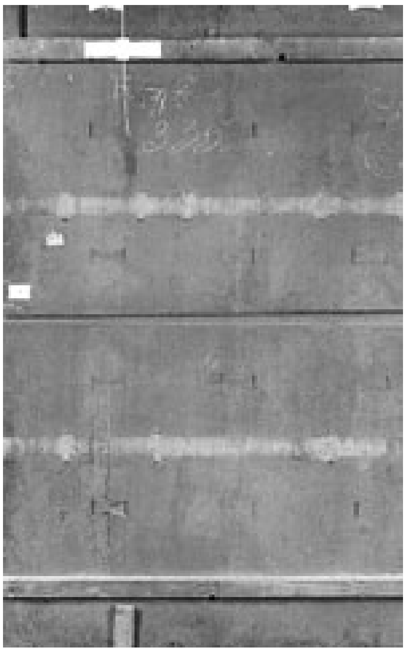


Figure 9
Lorenzo Sabbatini, *Madonna and Child Enthroned with Two Saints,* ca. 1560. Reverse. Oil on panel, 151.8 × 229.0 cm. Staatliche Museen zu Berlin, Preussischer Kulturbesitz, Gemäldegalerie. The loss of the central crossbar has caused severe convex warpage. The dovetail insets are probably original.

screws that are inserted directly into the original wood of the panel. Unfortunately, if the crossbars need to be removed and reattached several times, the screw holes will eventually wear out if this simpler method is used. In either case, to prevent rusting, only brass screws and steel bolts are used (Fig. 8).

At times panels need to respond in more than one direction to humidity fluctuations. Expansion and contraction are sometimes augmented by a tendency of the panel to warp—a tendency that, if impeded, might cause the panel to split. For this reason methods have been devised to add some form of spring action to the construction of crossbars. The simplest method consists of adapting existing older cradles with springs that are fitted into carved recesses at the junction of the braces and battens. For this purpose the battens are also thinned to facilitate movement (Castelli, Parri, and Santacesaria 1992).

Another method improves the system of bolts discussed above in the construction of new battens or the adaptation of original ones. It consists of steel springs of approximately 2.5 × 7.5 cm that are lodged into slotted and carved recesses in the crossbars so as to give the bolts ample space to move and to allow the panel not only to expand and contract but also to flex up and down (Castelli, Parri, and Santacesaria 1992). A more sophisticated method makes use of conical springs that are inserted into the crossbar. The brass nuts are held in place by pegs made out of limewood glued to the back of the panel (Castelli, Parri, and Santacesaria 1992).

A system for thin panels that provides the most freedom of movement consists of a strainer that is constructed around the panel. The strainer holds the panel in place with springs attached to small wooden blocks that are glued to the panel. This system is not ideal for environments that have no climate control, as it does not offer enough restraint to the panel: in some cases panels treated in this manner have deformed and cracked. A much simpler and more effective solution in this case is the mounting of the painting into its frame with steel springs, as has been done at the Bavarian State Galleries in Munich (by Christian Wolters).[5] The newest methods, which are mentioned by Castelli (see "Restoration of Panel Painting Supports," herein) deal with more sophisticated spring mechanisms that permit panels to flex.

The guiding idea behind all these constructions should be to give the panels ample room to move while at the same time exerting a certain amount of restraint to keep them from deforming. The authors have observed old panels—such as a painting by Lorenzo Sabbatini, *Madonna and Child Enthroned with Two Saints* from the Staatliche Museen zu Berlin (Bode Museum)—that have deformed because they have lost all or part of their original restraints (Fig. 9). The general guideline is not to treat a panel if it has survived in good condition, but if original crossbars are missing and the panel has a tendency to deform, the crossbars need to be replaced. Wooden panels need to be held in plane gently but firmly; otherwise they may deform, especially if exposed to uncontrolled climatic environments, as is the case with the great majority of panel paintings in the world.

Moisture barriers can be of some help in the centuries-old drying process of a panel by slowing down its constant response to changes in humidity (Buck 1978). The most commonly used materials have been Lucite 2044 or 2045 and Acryloid B72.[6] Saran and wax have also been used.[7] Fortunately, the unaesthetic and sometimes heavy constructions of wax and balsa wood that have been used often in the United States and England

Figure 10
Gherardo Starnina, *Madonna and Child with Musical Angels,* ca. 1410. Tempera and gold on panel, 92 x 51.3 cm. The J. Paul Getty Museum, Los Angeles. The pronounced cracking of the paint film was caused by excessive drying of the back following an intervention of more than sixty years ago. At that time, the poplar panel was reduced from its original thickness of more than 25 mm to less than 5 mm.

have rarely been adopted in Florence. New problems for future interventions are created when materials such as wax cannot be removed completely; their residues can prevent the effective use of PVA or epoxy glues.

Some previous attempts to straighten poplar panels were made by thinning them down to less than 7 mm and attaching heavy cradles to the backs, as in the case of the *Madonna and Child with Musical Angels* by Gherardo Starnina in the J. Paul Getty Museum in Los Angeles, California (Fig. 10). The effects—such as severe cupping or flaking of the paint film—of these radical interventions can often be seen on the front of the painting (Fig. 11). In cases in which the original support has been severely altered, it may actually be beneficial to attach the panel instead to a rigid support, such as a laminated strip board, rather than to let it move freely, as previously described (Fig. 12). For example, a painting attributed to Giovanni Bellini, *The Presentation in the Temple* (private collection, Venice), which has a severe flaking problem, had been thinned to less than 5 mm and cradled. It was decided to attach the panel painting to a laminated strip board after it was evenly planed to a thickness of about 4 mm. The glue used was Vinavil, a PVA emulsion, although today (as was used on the Starnina) an epoxy adhesive such as Araldite is preferred in order to avoid the excessive absorption of water from the PVA emulsion. Since treatment in 1966 the Bellini has been exposed at various times to a completely uncontrolled environment (Tintori and Rothe 1978). As with the

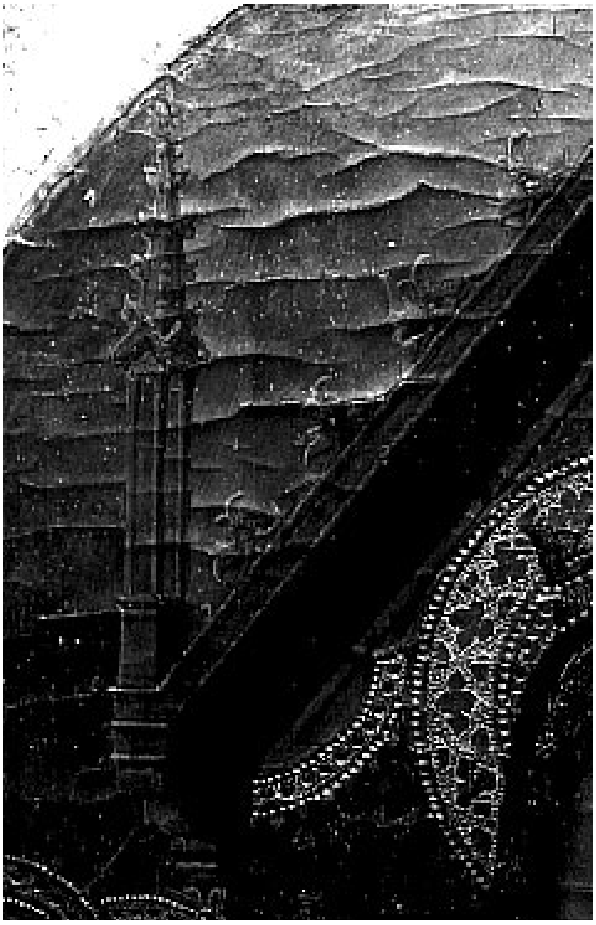


Figure 11
Gherardo Starnina, *Madonna and Child with Musical Angels*. Detail. This raking-light photograph of the upper left portion shows pronounced cracking of the paint film.

Figure 12
Gherardo Starnina, *Madonna and Child with Musical Angels,* reverse. After the back of the painting was planed even, it was attached to a laminated strip board with an epoxy adhesive (see note 4). This method also creates a humidity barrier.

Starnina panel, the treatment of which was carried out in 1982, the condition is stable, and no new signs of cupping or flaking have been observed.[8]

The conservator must always keep in mind where objects are to be housed. In a climatically stable environment, even a heavy cradle will have very little negative effect on a painting; consequently, it might be wiser to leave well enough alone. Many paintings, however, must be returned to environments that are not climate controlled. These paintings need adequate freedom of movement, some form of moisture barrier (without complex constructions), and protection from structural experiments. New methods and ideas are constantly being developed, and though it is in the nature of conservators to continually change, one sometimes cannot help but wonder if is not better to stay with some of the structural conservation methods that have proved their effectiveness over time, rather than constantly expose panel paintings to experimental innovations.

Notes

1 *Mansonia altissima;* the tree comes from the rain forests of Ghana, Ivory Coast, and Nigeria. The sapwood has characteritics similar to those of the heartwood; the heartwood, which is slightly toxic, is most often used.

2 Vinavil NPC, Stella Bianca, is a nonionic dispersion of medium plasticized acetate emulsion in water (see Materials and Suppliers).

3 General-purpose epoxy structural adhesive AW 106 and hardener HV 953 (see Materials and Suppliers).

4 Epoxy structural adhesive (carvable paste, wood) AV 1253 and HV 1253 (see Materials and Suppliers).

5 Wolters has also supplied information—verbally and by demonstration—about this type of mounting (Munich, 1956).

6 Lucite 2044 and 2045 are the Italian product names; in the United States they are also called Elvacite. The adhesive 2044 is an n-butyl methacrylate, and 2045 is an isobutyl methacrylate. Both are of high molecular weight. Acryloid B72, also known as Paraloid B72 in Europe, is an ethyl methacrylate copolymer. (See Materials and Suppliers.)

7 Saran F.120 is a vinylidene chloride-acrylonitrile copolymer. It was first introduced by Richard Buck in 1961. After the flood, Sheldon Keck came to Florence and proposed a 30% solution in methyl ethyl ketone as a moisture barrier. Saran F.220 was also used. (See Materials and Suppliers.)

8 Both treatments were executed by Giovanni Marussich and Renzo Turchi.

Materials and Suppliers

Acryloid B72, Rohm and Haas Co., Independence Mall Street, Philadelphia, PA 19105.

Araldite AV 1253/HV 1253 and AW 106/HV 953, Ciba-Geigy Corporation, 4917 Dawn Avenue, East Lansing, MI 48823.

Elvacite, Du Pont Company, Polymer Products Dept., Methacrylate Products Group, Wilmington, DE 19898.

Saran F.120 and F.220, Dow Corning Corporation, Midland, MI 48640.

Shellsol A, Shell Oil Company, P.O. Box 4320, Houston, TX 77210.

Vinavil NPC, Stella Bianca, Enichem Synthesis, Italy.

Buck, R. D.

1978 The use of moisture barriers on panel paintings. In *The Behavior of Wood and the Treatment of Panel Paintings,* 26–36. Minneapolis: Upper Midwest Conservation Association, Minneapolis Institute of Arts.

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1992 Supporti lignei: Problemi di conservazione. In *Problemi di restauro, riflessioni e ricerche,* ed. Umberto Baldini, 41–63. Florence: Edizione Firenze.

Cianfanelli, T., F. Ciani Passeri, and C. Rossi Scarzanella

1992 Il consolidamento dei dipinti su tavola. In *Problemi di restauro, riflessioni e ricerche,* ed. Umberto Baldini, 89–108. Florence: Edizione Firenze.

Heller, B.

1983 The joining of wood panels with Araldite epoxy system. Abstract of a paper presented at the Paintings Specialty Group, 11th Annual Meeting of the American Institute for Conservation, 29 May, Baltimore.

Tintori, L., and A. Rothe

1978 Observations on the straightening and cradling of warped panel paintings. In *Conservation of Wood in Painting and the Decorative Arts,* ed. N. S. Brommelle, Anne Moncrieff, and Perry Smith, 179–80. London: International Institute for Conservation of Historic and Artistic Works.

The Restoration of Panel Painting Supports

Some Case Histories

Ciro Castelli

THIS ARTICLE PRESENTS work by the Division of Restoration for Canvas and Panel Paintings at the Opificio delle Pietre Dure e Laboratori di Restauro (OPD) in Florence.

General Criteria for Conservation Intervention

The paintings described below were selected because of their varied construction techniques and the conservation problems they pose, problems that were not remedied by past restoration attempts. Presentation of these works provides an opportunity to explain various options for the repair, consolidation, and construction of support and control systems for panel paintings. Effective examples of restoration have in common critical methodologies that offer the least possible invasion of the artwork. All the original components of the work are respected. It is understood that every intervention to the wooden support entailing alterations, intrusions, or substitution of support parts or of the control structures may give rise to dangerous, difficult-to-control tensions and deformations in the wooden construction.

Interventions were tailored for each painting with the aim of designing a coordinated restoration plan that addressed each panel's particular problems. To prepare for such a plan adequately, the data-gathering phase in conservation is fundamental.

Understanding a work of art begins with the study of its original construction technique, the state of preservation of all its constituent materials, and any past restorations. Subsequently, the conservator should select appropriate diagnostic tests that deepen this understanding and assist in identifying past conservation attempts. Finally, the conservator can outline a plan for the various restoration phases.

For the design of the plan, it is imperative to know the relative humidity (RH) of the environment from which the painting came, as well as how it will be exhibited in the future, so that the necessary steps can be taken for climate control. If this information is not available, as is often the case, or if there is too much uncertainty, the conservator will need to apply a protection directly to the work, or in proximity to it, that is compatible with the principles already cited. It is hoped that these introductory remarks and the presentations that follow make it clear that the author does not believe in the existence of a miraculous substance or in a restoration intervention that is capable of solving every kind of conservation problem for panel paintings. Rather, it is possible to obtain good results by applying a series of interventions, whether they be in the form of treatments or of preventive conservation efforts.

The primary goal in restoring panel paintings is to renew the functionality of the structural support and to improve stability (with resulting benefits for the preparatory and paint layers) while adopting methods with minimal invasiveness. The following examples of works restored during the past few years in Florence will better clarify these concepts.

The Coronation of the Virgin by Domenico Beccafumi

The first example is *The Coronation of the Virgin,* an altarpiece painted by Domenico Beccafumi in 1540 (Fig. 1). The painting, which comes from the Church of the Santo Spirito in Siena, was executed for the Camaldolite monastery of Ognissanti, outside of Porta Romana in Siena. After the monastery's abolishment, the panel painting was moved to the Accademia in Florence and exhibited until 1810. In 1832 Romanelli recorded it in the sacristy of the Church of the Santo Spirito following its replacement with the *Annunciation* by Girolamo del Pacchia. The work was finally placed over the third altar on the right side of the church.

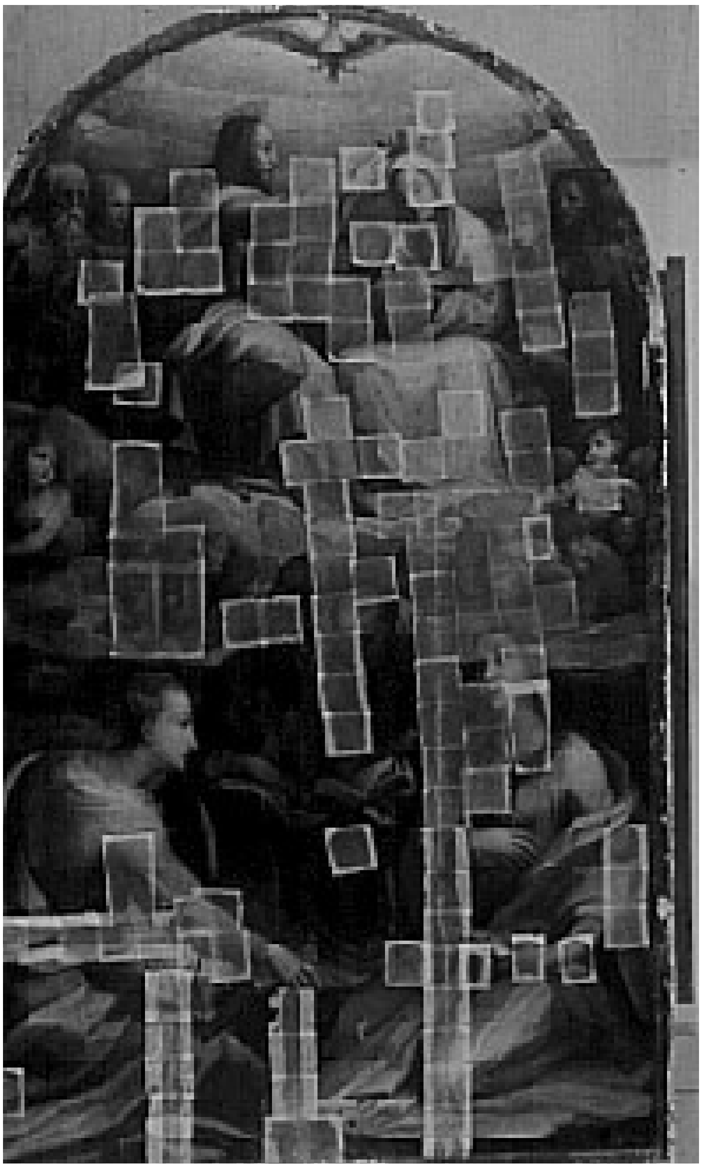


Figure 1
Domenico Beccafumi, *The Coronation of the Virgin,* 1540. Oil on panel, 310 × 187 cm. Church of the Santo Spirito, Siena. Front of the panel before restoration.

Diagnostic studies

To arrive at a precise understanding of the painting's support, it is important to analyze the consistency of the wood and to establish with certainty the various construction phases. Radiography and infrared reflectography (IR) are deemed useful tools for studying these aspects of panel paintings. In general, radiography is the most effective analytical technique for examining the construction of the support and for identifying the state of preservation of the wooden material (Fig. 2). For painted works, however, the data this type of analysis can provide about the structural condition of the wood fibers are related to the thickness of the preparation and to the presence of pigments that are particularly opaque to X rays. The X radiograph of *The Coronation* reveals wormholes in the support, as well as their displacement close to the surface. This study also provided information on the characteristics of the preparation, which showed up as slightly denser in X rays of the lower section, a possible indication of a greater thickness and different applications of the ground. Above all, the study revealed the two-phase construction of the support. Naturally, this study was compared with visual observations, an evaluation of resistance to touch on the back of the support, and an assessment of the weight of the work in relation to the type of wood. IR also proved useful for studying the support, as it showed the preparatory image to be continuous between the upper and lower sections. Thus, even if the preparation had been applied at different times, the painting was conceived all at once.

Photographic documentation with diffuse and raking light revealed the state of preservation of the preparatory and paint layers. The same techniques allowed documentation of the structural condition of the support and the treatment carried out in the 1950s.

Construction technique

The painting, executed in oil on wood, measures 310 × 187 cm; it is arched in the upper section. There was no cloth present as an isolation layer between the wood and the preparatory layers. By 1540 such a

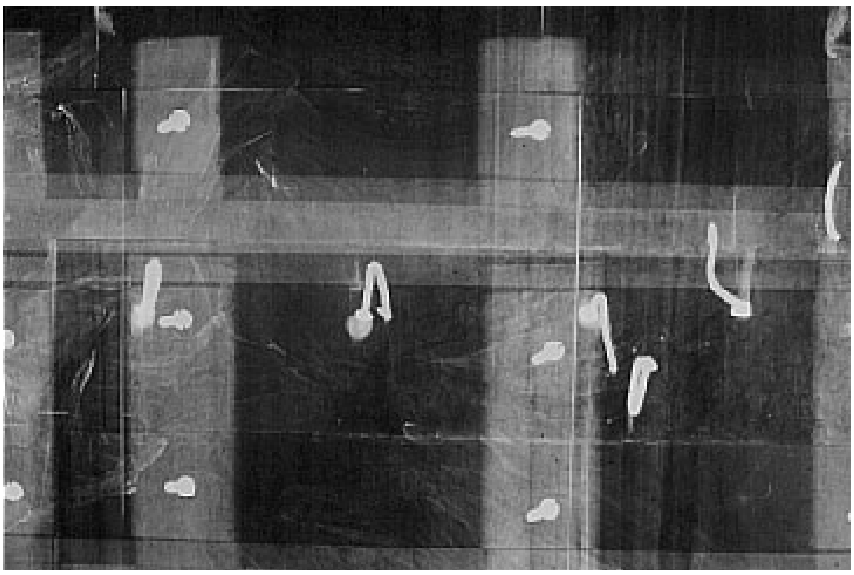


Figure 2
Domenico Beccafumi, *The Coronation of the Virgin*. Radiography of the lap join.

Figure 3
Domenico Beccafumi, *The Coronation of the Virgin*. Nail in the lap join of the painted surface.

characteristic isolation layer had fallen into disuse, as the construction technique for the preparatory layers no longer required the presence of the cloth as a buffer between the movement of the wood and the preparation.[1] The support is made of poplar—more precisely, white poplar (*Populus alba* L.)—and is formed of two distinct sections: an addition was made to the already existing support before the application of the paint layers. Thus, the support consists of two sections united with a 13 cm wide lap join. The connection is reinforced with glue, as well as with nails that are driven in from both the front and back and bent under the preparation (Fig. 3). The upper section comprises five vertically oriented planks.[2] The tree ring pattern is subradial, the quality is good, and the presence of knots is rare. The lower section consists of six planks (also oriented vertically)[3] of the same type of wood, with a medium tangential cut. The planks of the entire panel, according to the customary technique noted in the field of Italian panel paintings, are arranged with the internal side facing the preparatory layer; they are butt-joined and glued together with lime casein.

The variations in width of the planks in the two sections and the method by which they are joined give the impression that the two sections of the support may have been built at different times. It is certain that the extension was made before the paint was applied, because the painting presents a single pictorial composition, as revealed by visual and IR readings and chemical analysis of the pigments. Conversely, the preparation was carried out at two different times. This last piece of information, as already mentioned, is confirmed by radiographic studies that showed a greater density of the lower part of the painting, caused by the greater thickness of the gesso layer. Last, the ground and paint layers of the lower part are in better condition than those of the upper part. This is also true for the wooden support, whose condition can be attributed to the use of better-quality wood, which was almost certainly obtained from a different tree with denser fibers and greater resistance to attack by wood-boring insects. A shaped frame (which is not the original) was placed along the perimeter on the surface, covering 7 cm of the original paint. The frame was held in place with screws, inserted from behind, that passed through the planks.

Apparently the back of the support had originally been sustained and controlled by three crossbars, each attached to the painting by five small wooden brackets that were fastened with glue and with nails driven in from the back and bent over on the front of the support. Both the nails that connect the lap join and those used to attach the wooden brackets to the support are simply bent, hammered into the wood, and covered by the gesso preparation.[4]

State of preservation

Upon the painting's arrival in the laboratory, large-scale lifting of the preparation and paint layers was observed; this damage followed the grain of the wood in the main section of the panel (Fig. 4). The failure of the horizontal join on the back was also caused by the loss of extensive sections of worm-eaten wood that rendered several nails (those reinforcing the connection between the two sections) isolated and useless. On the front side of the area that corresponded to the join, a fracture affected the preparatory and paint layers. In general, various glued joins between the planks of the main support had opened. The stability of the paint layer was good in the lower section; cracks were noted exclusively along the joins. The state of preservation of the support appeared considerably degraded overall from diffuse attack by wood-boring insects that left the wooden material extremely fragile and weak in some areas. These conditions were worse in proximity to the vertical joins and the horizontal join between the two sections; the greater degradation there can be attributed both to the presence of protein substances from the glue and to the sapwood in the edge of each plank. The bottom section of the support did not show the harmful effects of the wood-boring insects. Its damage problems consist essentially of gaps in the joins caused by a greater contraction of these planks with respect to those in the upper part, and of a slight convex curvature of the surface. All the wood used for the previous restoration, particularly for the crossbars, had been extensively attacked by wood-boring insects, leaving the wood extremely weak.

Figure 4
Domenico Beccafumi, *The Coronation of the Virgin*. Lifting of the paint.

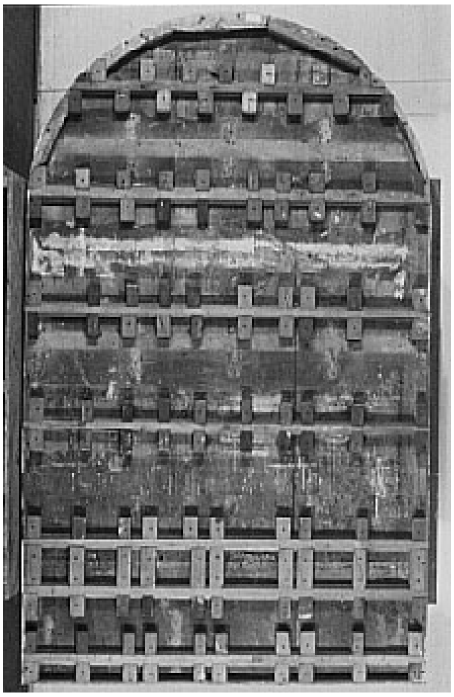


Figure 5
Domenico Beccafumi, *The Coronation of the Virgin*. Back of the panel before restoration.

Previous restorations

The restoration work done at the beginning of this century was carried out with an invasive technique and with materials that were harmful to the preservation of the wood (Fig. 5). This method created conditions favorable to infestation by wood-boring insects and produced tensions within the structure, causing the deterioration of both the support and the painting. In previous restorations, the original crossbars had been removed, and the missing areas had been reconstructed with a paste of hide glue and sawdust.[5] Also, seven crossbars made of cypress and plane-tree wood with an upside-down T cross section had been mounted to the support with large, notched wooden blocks.[6] These elements had been fastened with hide glue and large screws. Poplar strips had been attached along the entire perimeter with glue, screws, and several nails hammered in from the front. This intervention—extremely invasive for the quantity of wood added and for the method and materials used—also made extensive planing of the panel surface necessary. This planing facilitated the exchange of moisture between the environment and the wood, a process that, in turn, favored a tendency toward deformation of the planks, which nevertheless was blocked by the interventions described above.

Another damaging intervention was the already cited application of the frame to the painting; the operations necessary to adjust the frame and hold it in place had produced twenty holes (each 6 mm in diameter) as well as six deep tracks into the painted surface (Fig. 6).[7]

Figure 6
Domenico Beccafumi, *The Coronation of the Virgin*. Marks in the painted surface caused by adjustment of the frame during previous restoration.

Restoration proposal

Given the severely deteriorated state of preservation of the wooden support and the ground, the following program was outlined:

1. Consolidation of the most degraded parts of the wooden material with acrylic resin (Paraloid B72).

2. Reinforcement of the addition by the insertion of several rectangular wooden pieces to hold the two parts of the join together.
3. Construction of two temporary crossbars to hold the painting during the removal of the existing crossbars.
4. Gradual removal of the existing crossbars.
5. Repair and correction of the separated edges by the cutting of tracks with a V-shaped section.
6. Leveling of the painted surface along the edges of the individual planks.
7. Exact fitting and placement of the wedge-shaped inserts, to be made of old wood (of the same type as the support), into the specially prepared V-shaped tracks.
8. Construction of a laminated oak framework that has a load-bearing function and also controls the deformation of the planks that make up the support.
9. Development of a plan for the microclimate control of the back of the panel.

Restoration interventions

Fumigation

The painting was fumigated in a gas chamber without vacuum, and then protected on the back with Permethrin, a fumigant that remains active.

Consolidation of the wooden material

Before the removal of the crossbars and the wooden blocks of the previous restoration, the join between the two sections of the support, which was in danger of separating, was reinforced. The technique used for this operation consisted of placing twelve rectangular inserts, made of the same wood as the support, on edge in the same grain orientation as the fibers of each plank, positioned across the horizontal junction. These inserts were distributed in the grain direction of the planks, penetrating the thickness of the support to within 5 mm of the painted surface. Thus the inserts reunited the two elements of the lap join.

One of the more problematic aspects of this restoration was the need to regain sufficient strength in the areas of the wood that were degraded by biological attack. The choice of consolidant was proposed in consideration of the uncertainties consolidants had generated in the past in the Florence laboratory; particular concerns were the efficacy of consolidants and their possibly negative effects over time. These concerns are tied to the stability of the product, possible color alterations, and nonuniform penetration into the wood (so that different areas of the wood are conditioned to respond differently to variations in RH). In this case, however, it was decided to use a 5–12% solution of acrylic resin (Paraloid B72) in lacquer thinner applied by brush until a sufficient consistency was reached. Before this operation began, all the hide glue and sawdust fillings were removed from the support, and two temporary crossbars were made. These crossbars were modeled to the curvature of the painted surface to support the panel adequately and make it possible to work on the back.

The removal of the wooden blocks that held the existing crossbars followed; this procedure freed the entire back surface of the support and prepared it for the initiation of the consolidation technique. Repair and reconstruction of the structure proceeded with the reintegration of the missing parts of the support, in particular in the lap join. For this operation, small blocks of old wood (of the same type as the support) were placed in superimposed layers that intersected in width and length (Fig. 7). The use of this method makes it possible to firmly bond the various wooden elements of the reintegration and, in addition, favors increased stability by reducing to a minimum the possible deformation of the added material.

The repair and rejoining of the separated joins and cracks were carried out by the cutting of triangular tracks into the support. These tracks conformed approximately in width and depth to the extent of the degradation in the areas of the join edges.[8]

The tracks were cut by hand with chisels (the traditional and effective method to rectify gradually the degraded condition at the edges of each plank), but wherever the consistency of the wood was good and the split was straight, an extremely narrow, cone-shaped router bit (5 mm maximum diameter) was used in order to remove as little original wood as possible.

Successful experiments had already been performed with this bit, made expressly for our laboratory, on samples that simulated V-shaped openings in panel paintings. As usual, in the preparation of the wedge for gluing, the surface levels along the joins and splits were aligned with the help of wooden levers. These wooden levers bridged the edges of the fractures and were adjusted with screws and wooden blocks. This step was followed by the fitting of the wedges, which were made from old wood (the same type as the support). Care was taken to ensure that the positioning of the grain was consistent with the grain at the edges of the opening. During this work phase, the undulation of the painted surface, caused by the curvature present in the two central planks, was slightly corrected, so that part of this deformation was distributed over the entire width of the painting. This operation has been shown to be useful in reducing the deformations visible near the joins and in improving painting readability.[9] The correction of the edges produced an average curvature of 9 mm over the entire painted surface. It is not useful to plot deformation measurements without considering the ambient RH, because the wood is in constant equilibrium with the surrounding microclimate and consequently

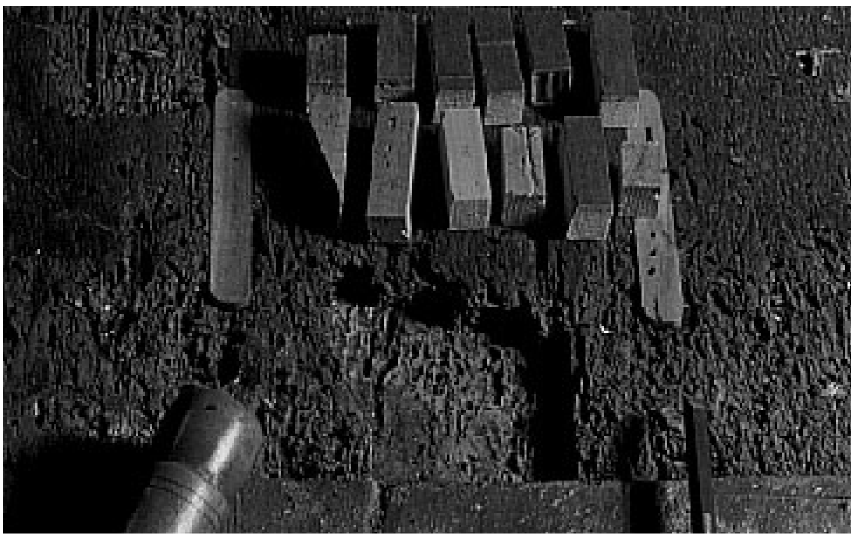
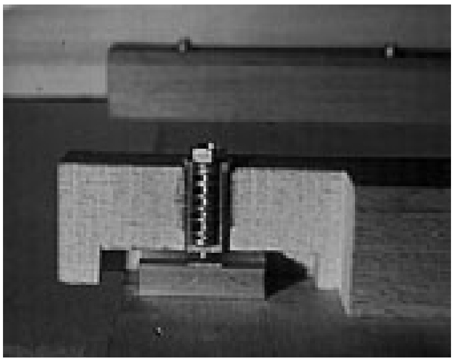


Figure 7
Domenico Beccafumi, *The Coronation of the Virgin*. The integration of missing parts in the support with blocks of old wood.

Figure 8
Example of the mechanism that attaches the framework to the painting support.



continually modifies its warp. The RH considered suitable to ensure the stability and uniformly flat surface of the wooden support varies between 55% and 60%. A polyvinyl acetate (PVA) emulsion was used to adhere the wedges, since its strength and moderate elasticity enable it to adapt better than other glues to the conservation needs of wood.

Support control system

After repair and reconnection of the joins, reconstruction of the missing wood parts, and reinforcement of the junction of the lap join, the support appeared quite solid. The only remaining phase was the construction and mounting of a crossbar system to control and reinforce this particular construction.

The author selected a system that could simultaneously respond to the expansion and contraction and, in addition, serve as a sound reinforcement, assuming the role of a true load-bearing structure. A perimeter strainer, or framework, was built with crossbars made of laminated oak from Slovenia. The crossbars had the same 9 mm curvature as the support, so that the strainer would conform to the shape of the panel. The framework was attached to the support without leveling of the back surface. Instead, small wooden spacers were inserted at the attachment points where the contact between the two parts was not perfect. A special mechanism to unite the two parts allows for potential expansion and contraction of the support and regulates possible warping of the planks. This mechanism consists of a brass shoe in the form of a closed U-channel section, held to the back of the support with a single screw (Fig. 8). Inside this U-channel section glides a nylon slide with a bolt at the center. The bolt passes into the framework through a brass sleeve, in which there is a spring regulated by a nut.[10]

The invasiveness of this mechanism to the painted support is limited to a single screw for each element. The presence of the spring between the support and the framework facilitates the regulation of stress and possible slippage between the two parts, as well as reduces tension. Designed to respond to problems of tension and deformation that may appear over time, the mechanism is extremely simple and does not require any intervention to the support (Fig. 9).

The selection of a means of deformation control with a framework system goes against the concept of the traditional crossbars, which act as a load on the support. Instead, the framework is a load-bearing structure to which the painting is anchored by means of attachments freed from mechanical tensions. In addition, if the RH of the exhibiting environment is uncertain, the framework makes it possible to enclose the back of

Figure 9
Domenico Beccafumi, *The Coronation of the Virgin*. Back of the panel after attachment of the framework for support and deformation control.

the panel easily. This enclosure creates a volume of air that slows climatic exchanges with the environment, thus facilitating stabilization. At the end of the intervention, the support is protected actively by a brush application based on Permethrin. The protection of the reverse is completed with a mixture of beeswax (60%), paraffin (30%), and rosin (10%) applied with a spatula to form a surface film.[11] This treatment can prevent new infestations and slow the rate of air exchange with the environment.

Jesus and Saint Peter on the Water by Herri met de Bles

From 1987 to 1988, the author was involved in the restoration of three panel paintings from the Flemish school. These works by the painter Herri met de Bles (nicknamed "Il Civetta") came from the Museum of Capodimonte in Naples. Two of the paintings presented conservation problems that also involved the wooden support. The following paragraphs describe one of these works with regard to its construction characteristics, its particular conservation problems, and the restoration intervention to which the work had previously been subjected (Fig. 10).

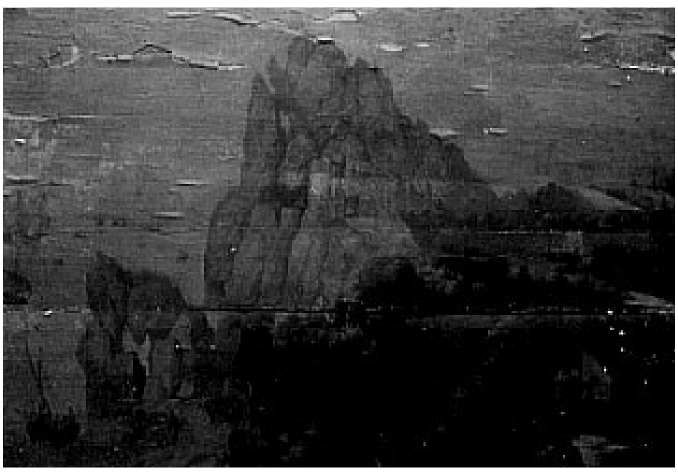


Figure 10
Herri met de Bles, *Jesus and Saint Peter on the Water*. Oil on panel, 26 × 37 cm. Museum of Capodimonte, Naples. The state of preservation of the panel before restoration.

The restoration intervention that can address such conditions effectively requires special solutions in methodology and technique.

Diagnostic studies

Full-scale and detailed photographic documentation was carried out with diffuse and raking light. Raking light photography revealed the type and quantity of the lifting paint on the painted surface, as well as the support's deformation, especially in areas affected by cracks. Low-magnification observation was all that was required to identify the wood species, as the type of wood grain, the color, and the characteristic sheen of the parenchymal rays left no doubt about its identification as oak. While the RH was kept constant, relief drawings were made on graph paper to determine whether the curvature varied after the cracks were rejoined.

Construction technique

This small oil painting on panel consists of a single board of oak (*Quercus peduncolata* or *Q. sessiliflora*). The board has a straight, horizontal grain, with the tree rings positioned subradially. No knots or defects were noted in the support. Cloth was not used for the preparatory layers. It was clear that crossbars had never been used, both because of the painting's small size (26 × 37 cm and currently 3–4 mm thick) and because of the customary way supports were made in the Low Countries. In fact, for the great majority of these panel paintings, deformation is controlled and the wood fibers are supported horizontally and longitudinally simply by means of the frame. The frame had a channel routed in its thickness that made it possible to enclose the painting around the perimeter without restricting eventual expansion and contraction. A few exceptions to this rule employ reinforcement crossbars on the back.

State of preservation

The painting presented diffuse lifting of paint along the grain of the wood, as well as warping of the painted surface, which could be seen in three pronounced curves. At the edges of these deformations were two cracks that followed the grain, affecting the entire width. Although oak characteristically has a mechanical strength, durability, and resistance to wood-boring insects, the general conservation conditions were decidedly precarious. The wood, especially along the borders, was eroded and friable. The diffuse attack of wood-boring insects had produced many cavities, some of which had a diameter equal to half the thickness of the support. The weakened mechanical resistance of the support fibers was aggravated by a crossbar system that presented two drawbacks: it was extremely rigid in comparison to the size of the painting, and it functioned as a brace at a distance of only about 5 mm from the plane of the support. The planing of the back of the support contributed to the deterioration of the panel by causing the loss of the surface "skin" of the wood, so that a more rapid exchange of moisture between the support and the environment was encouraged.

Previous restoration

The last restoration of this painting occurred in the early 1950s. At that time, consolidation of the ground and paint layers, cleaning, filling of

Figure 11
Herri met de Bles, *Jesus and Saint Peter on the Water.* Back of the panel upon its arrival in the laboratory.

losses, and retouching were done. The back of the support had been planed down, a procedure that removed a small amount of wood. Three mobile crossbars were attached to the panel with poplar blocks, positioned in line with the grain of the panel, and glued in place (Fig. 11). The crossbars were circular-section aluminum rods that passed through holes made in the blocks attached to the support.

Restoration proposal

The following solutions were identified: removal of existing tension in the support; consolidation of the ground and paint layers; repair of the wormholes that had weakened the wood; and development of a sound support and control system for the panel. All of these operations had to take place with minimal invasiveness to the support—in accordance with a philosophy that is increasingly valued in the Florence laboratory. In this particular case, it is apparent—given the small size of the support—that excessive use of wooden material and glue could potentially damage the painting over time.

Restoration interventions

With the painted surface protected by Japanese rice paper and rabbit-skin glue, the consolidation of the paint layer was carried out by the vacuum technique with the same type of glue in a different concentration.[12] Two temporary crossbars were constructed to hold the painting in its current deformed state. A gouge was used to remove the supports that held the crossbars added during the previous restoration, thus liberating the support. While the temporary crossbars held the support orthogonal to the grain, the cracks were repaired by small V-shaped tracks opened with the traditional chisel method. With this operation, the two faces of the cracks were aligned and prepared for the wedges, and the painted surface was leveled. This initial phase was essential in giving the disjointed and deformed front faces a uniformly flat surface. It also made it possible to rotate slightly the disconnected edges of the cracks, while still preventing the back edges of the cracks from touching. In this way the panel took on an uninterrupted surface in correspondence with the cracks. To arrive at this solution, the painting was inserted into a special cagelike structure in which the correction of the warp and the alignment of the edges was begun (Fig. 12). This structure, built especially for this project, makes it possible to enclose the painting at the bottom, top, front, and back. The author and others were able to work on the edges of the opened cracks and adjust the levels of the painted surface by means of screws (the heads of which are protected by wooden caps) that can slide inside the vertical slats of the cage structure. With the aid of this system, the temporary crossbars were removed and the profile of the painting corrected. After this procedure, the wedges made from old oak were fitted, in correspondence with the orientation of the grain, and a PVA emulsion was used to hold them into place. This operation was repeated with the other crack.

The holes caused by the wood-boring insects—the problem that posed the greatest threat to the structural soundness of the support—were rebuilt with inserts made from the same type of wood as the support. Triangular or rectangular inserts—depending on the shape and depth of the holes—were held in place with PVA emulsion.

To restore solidity, control, and protection to the edges of the painting, a perimeter framework was made with the same curvature as the

Figure 12
Temporary jig for adjusting the surface level.

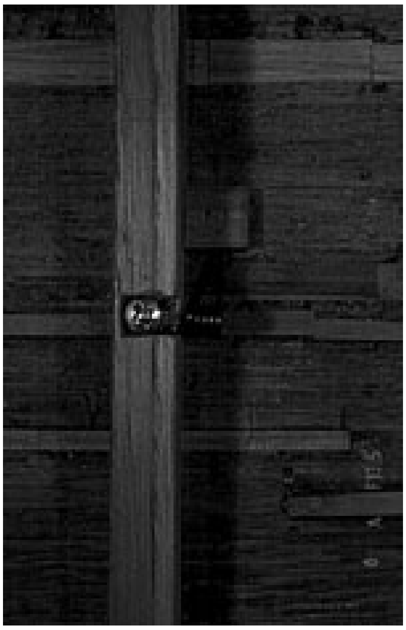


Figure 13
Spring attaching the framework to the support.

back of the support, and a central crossbar was installed. The framework, made of chestnut, was anchored to the support with nine springs. The springs were attached to the framework on one end and to the painting on the other end with an equal number of small blocks (9 × 9 × 4 mm thick). These blocks, made of the same type of wood as the support, were created with a hole to house the end of the spring. They were attached in the direction of the grain and glued in place. The blocks were placed inside the framework, and a nearly 2 mm space perpendicular to the grain was left to allow for possible expansion of the panel. Elastic control of the warping is provided by the springs, primarily by those positioned in conformity with the central axis (Fig. 13). Thanks to its solid and stable construction, the framework protects the edges and provides a secure support for the panel. This type of construction to control movement of the support does not put any weight on the panel, as do traditional crossbars. Instead, the panel is supported by anchor points distributed over the surface. Because of the reduced size of the framework—corresponding to the small size of the artwork—and the small blocks glued to the support, which allow the springs to connect the framework to the panel, it is possible to reduce substantially the invasiveness of the intervention (Fig. 14).

In future conservation efforts, it may be possible to adjust the tension in the springs without tampering with the anchor points of the support. This use of springs to control deformation is best applied to supports that consist of a single board, as independent deformation of other boards is not a factor. This structure can be closed on the back; the backboard creates a volume of air that functions as a buffer, slowing RH variations. The wood used can be of the same type as the painting support. Such a device, already described in the preceding intervention, slows climatic exchanges between the back of the support and the environment. Because of the small size of this painting, the back enclosure also provides increased stability to the support, augmenting the wood mass by filling up the framework's two cavities. To make this possible, the wood put inside the framework must be oriented with the grain of the panel and placed so that it is completely independent of the panel. Naturally, the restoration of the support also protects the back from wood-boring insects.

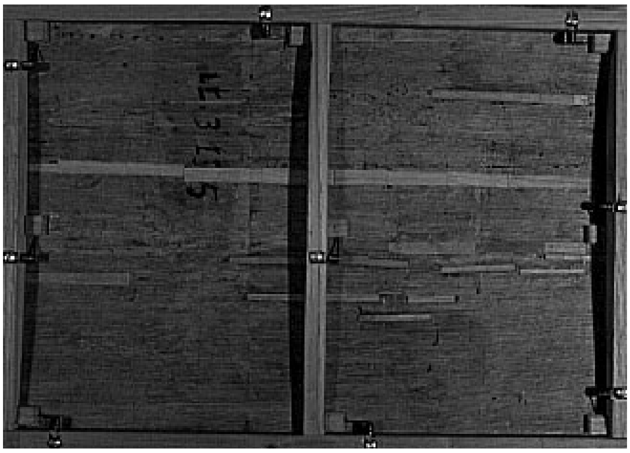


Figure 14
Herri met de Bles, *Jesus and Saint Peter on the Water*. Back of the panel, with the framework for support and deformation control in place.

The Deposition from the Cross by Francesco Salviati

This panel painting (495 × 285 cm) is executed in oil on panel and was painted around 1547–48 for the Dini Chapel in the Church of Santa Croce in Florence.

Diagnostic studies

The analyses done in preparation for the restoration of the wooden support consisted of measuring the moisture content in the wood. This was accomplished with the aid of probes attached to the planks (other probes measured the RH in the surrounding environment). All the probes were connected to a computer. The aims of this survey were to establish the relationship between the wood and the environment and to determine the importance of the reaction of the support to variations in these values. For this inquiry, a gauge was used that made it possible to obtain the values of the horizontal expansion with a centesimal scale.[13] For the curvature, the control was simply a reference plane. Traditional photographic documentation of the condition of each plank was carried out. Particular attention was given to the parts of the painted surface that were affected by such problems as lifting paint, detachment of the original inserts (originally placed to repair large knots), cracks, and defects in the wood. Finally, several interesting details of the original construction technique were documented. Identification of the wood species was made with macroscopic and microscopic studies.

Construction technique

The painting, which is arched at the top (Fig. 15), was constructed without cloth between the wood and the preparatory layers; strips of cloth are not even found along the joins. The support consists of six planks of poplar—more precisely, white poplar (*Populus alba* L.). The planks are of average size with solid and relatively straight grain.[14] The exception is the second plank from the left (seen from the back), which presents a curvilinear grain. The planks are of a medial cut, and the fibers are generally arranged subradially at the edges of each plank, becoming tangential at the center. Two radially cut planks that contain the pith are an exception to this characteristic. Because the plank is wavy along the length, the surface level changes from one plank face to the other—high on one side of the joint and then high on the other side. In addition, a considerable number of large knots, which have had a negative impact on the preparatory layers,

Figure 15
Francesco Salviati, *The Deposition from the Cross,* 1547–48. Oil on panel, 495 × 285 cm. Church of Santa Croce, Florence. View of the front of the panel shows the separated planks before wood restoration.

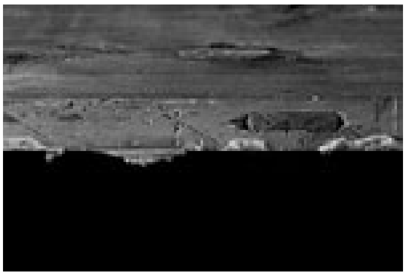


Figure 16
Francesco Salviati, *The Deposition from the Cross*. Side view of the plank, showing parts of the original floating tenon and the diagonal scores made to improve the hold of the glue.

were noted. Because of these defects, many planks were repaired during the original construction with the application of plugs of wood (also of white poplar) held in place with hide glue and nails. The assembly of the planks was achieved by butt-joining and accurate planing of the faces to be united. Diagonal scratches were also made, to improve the bond of the glue. Housings were carved inside the thickness of the planks, in proximity to the joins, in which floating tenons were inserted (Fig. 16).[15] These elements of joining between the planks, regularly spaced in height on the painting, are made of walnut and have a rectangular shape. They were inserted without glue into the housings with the grain perpendicular to that of the support, and held by dowels that pass through the thickness of the planks. Three fir crossbars that tapered in length were mounted on the back and inserted into dovetailed tracks cut into about one-third of the thickness of the support. The panel is relatively thin for its size and undergoes only light restraint from the crossbars. It was discovered that in real-ity, the large carved and gilded frame that held the panel not only served an aesthetic purpose but had a structural function as well.

State of preservation

The painting had been immersed during the flood of 1966 in Florence. During this time, the water, which was full of various materials, covered four-fifths of the altarpiece for approximately eighteen hours. In the Museum of Santa Croce, the panel was immediately protected with tissue papers of various sizes that were made to adhere to the surface with acrylic resin (Paraloid B72). Next the painting was moved to the *limonaia* in the Boboli Gardens, where the humidity of the environment was purposely kept at 90–95% to protect flooded artwork. The negative effects of the immersion on the planks are well known; the initial reaction was an expansion of the surface, after which the preparation and paint layer were loosened by water. During the next phase, the various materials within the painting dried at different rates, causing detachments and the overlapping of the panel's preparation and paint layers during shrinkage.

The initial papering done on site was repeated several times while the painting was sheltered at the limonaia. The first intervention on the wooden structure was the mechanical removal of the original crossbars.[16] Before this operation, the painting was laid flat and faceup on a wooden structure that made it possible to work from below. Rectangular wooden blocks applied to the back bridged the joins and attached to the planks by two screws on both ends of the blocks. This served to reinforce the joins in order to hold together the planks that made up the painting. When it was brought to the laboratory at the Fortezza da Basso in June 1967, the panel was already separated at the joins, with the exception of a small part in the upper right of the last plank. The entire structure remained united only by the floating tenons that were left in the housings and held by the dowels placed at the ends of the tenons. There were convex warps on the painted surfaces of the planks, and two of the lower planks had become concave and twisted in the longitudinal direction. The preparatory layers were extremely deteriorated and unstable. The plugs placed to repair the knots exhibited their own deformations: they had detached from their housings and marked through onto the painted surface (Fig. 17). The particular characteristics of the deformations in this painting—related to the

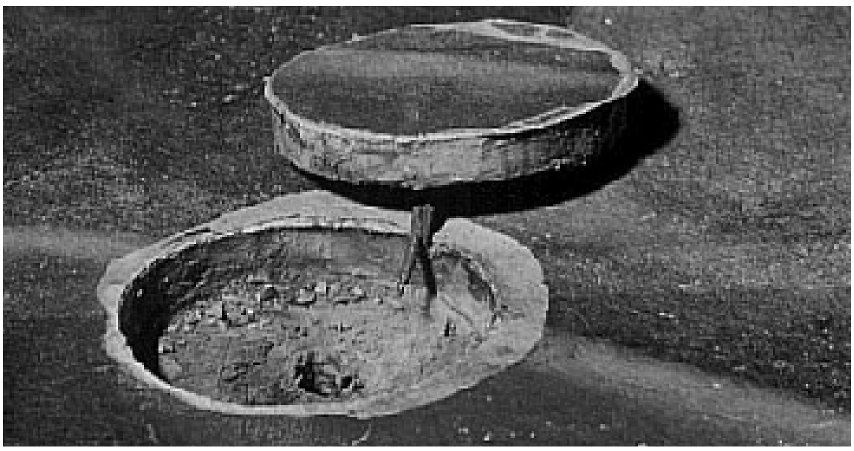


Figure 17
Francesco Salviati, *The Deposition from the Cross*. An original plug present in the painted surface; it had come unglued during the panel's immersion in floodwaters during the flood of 1966 in Florence.

direction of the grain—manifested themselves in two planks that were simultaneously concave at the bottom and convex at the top.

Restoration interventions

The painting was followed through its stabilization phases for many years. During this time, thorough consideration was given to possible working solutions for consolidating the paint layer, guaranteeing sufficient stability, and restoring the lost unity of the entire work by the application of a support and control structure for the planks.

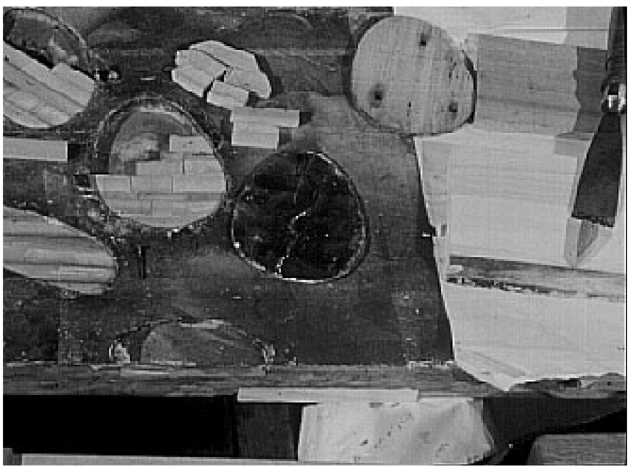
The traditional intervention technique often used in such cases involves destroying the wood and transferring the paint layer to another support, incurring all the changes and risks connected to this type of operation. In this case, however, the conservator followed an intervention that would respond to the criterion of greatest possible respect for the original components and that would, in addition, allow the possibility for a later intervention. After evaluating the results on the consolidation of the paint layer, the author and coworkers designed and carried out the restoration of the support. This plan required an intervention on each individual plank to repair the original detached and disjointed plugs, upon removal from the painted support, by cutting the anchoring nails. Next came the addition of wooden blocks into the housings of the plugs in a parquet fashion (Fig. 18).[17] This procedure was followed by a reduction of the thickness of the plugs to facilitate reestablishment of the level between the blocks and the surface of the painting.

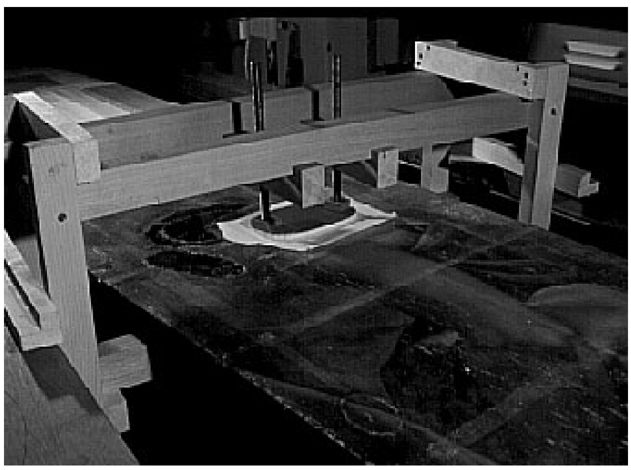
Each section was adhered again to its own place, so that the proper level between the edges of the paint layer was re-created (Fig. 19). The wedge technique was used to close the cracks at the edges of the planks. Finally, the author inserted into the original tracks of the crossbars a double layer of small pieces of white poplar, placed in the same grain direction as the support.

Filling the original tracks with a double-block system superimposed widthwise and, especially, lengthwise, responded to the need to improve the adhesion between the added parts and the original panel, particularly in the areas where there is an end-grain join (Fig. 20).[18] Next the planks were rejoined through a slight correction of the edges, so that a solid union could be obtained by means of wedges.[19] For this operation the

Figure 18, below
Francesco Salviati, *The Deposition from the Cross*. Repair of the housings and plugs.

Figure 19, below right
Francesco Salviati, *The Deposition from the Cross*. Treatment to re-create the proper level between the edges of the paint layer.





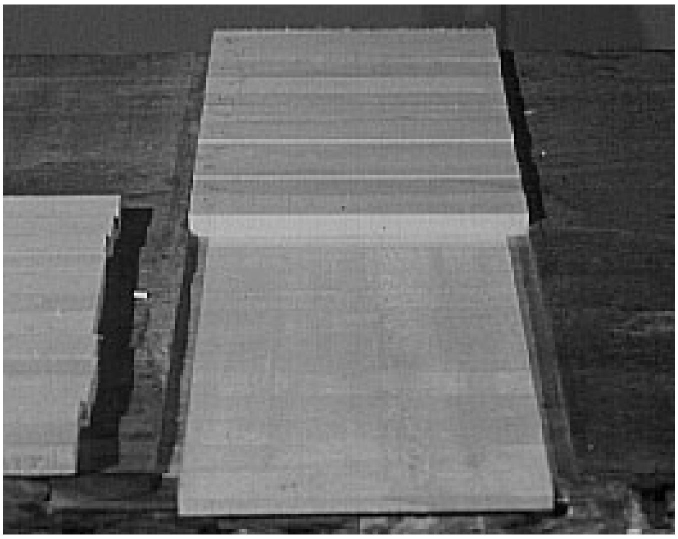


Figure 20
Francesco Salviati, *The Deposition from the Cross*. Wood-block system used to fill in the tracks of the original crossbars.

author aligned the planks according to a regular curvature that followed the individual deformations of the planks and that took into account both the visual unity of the work and its structural needs. This operation was of critical importance and required a lengthy time for study and the preparation of different simulations to help determine the proper equilibrium between the deformations of the individual planks and the general curvature that derives from them. When the correct equilibrium was reached between the curvature and a good visual unity of the work (with its placement in the original frame considered), two temporary crossbars were made that served as a reference during the final assembly phase.

Another difficulty was the need to bring together at an equal level the painted edges between the individual deformed planks. Through observation of the defects that emerged in this painting, it was possible to confirm that the deformations that appeared are not casual ones but clearly respond to the composition and direction of the grain and, more particularly, to the arrangement of the tree rings in the planks. This information also confirms that the planar stability of a painting hinges on a careful selection of wood at the time of construction.

The author and coworkers then began work on rejoining the panel from the two central planks, starting from the center and moving toward the outside, using the already described crossbars as a reference, and proceeding gradually both with the leveling of the painted surface and with the gluing of the wedges (Fig. 21).[20] The remaining parts of the painting were reassembled with this same method (Fig. 22).

After this phase, a crossbar system was built that was identical to the original in both the kind of insertion used for the crossbars and the mode of function. This system, which appropriately limits the expansion and deformation over the entire surface, seemed the most suitable for the state of conservation of the pictorial surface of this particular work. Movement is controlled by the friction encountered by the crossbar within the tapered, trapezoidal shape of the track in the support (panel). Conversely, the elasticity of appropriately sized crossbars controls deformation. To function appropriately, the crossbars were made with a curved profile, part of a circle that follows the curvature of the support. This

Figure 21, right
Francesco Salviati, *The Deposition from the Cross*. Reassembly of the planks.

Figure 22, far right
Francesco Salviati, *The Deposition from the Cross*. Reassembly. Seen from the front.

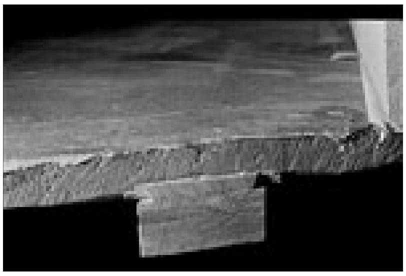


Figure 23
Francesco Salviati, *The Deposition from the Cross*. End view of the inserted crossbar.

operation was accomplished with the double-block system used in the tracks of the original crossbars. The original tracks were widened into a new track, which maintained the trapezoidal section of the original. The new crossbars were made out of laminated oak assembled on a preconstructed negative form; they were fashioned with the same curvature as the track in the panel (Fig. 23). The crossbar dimensions were determined by the large size of the entire work and by the design's likely stability over time. The frame will regain its important structural function, completing the support of the painting as it did originally.

The back of the painting was next protected with a thin coating of beeswax, paraffin, and rosin spread on with a spatula. Isolation from the environment was further guaranteed by placement of the work inside the original frame and installation of a backboard. This feature will make it possible to improve the climatic factors in contact with the support.

The Annunciation by Lorenzo Monaco

One additional example completes the presentation of the various operating methods that can be applied to the restoration of painting supports. Changes are not introduced for their own sake but as a study of solutions to the problems of individual works. This flexible attitude is vital and is based on the understanding that every intervention that changes—even a little—the original construction, if not required by the state of preservation of the work, is to be considered a loss of evidence and cultural patrimony. The restoration presented briefly here was recently concluded on the triptych, *The Annunciation,* by Lorenzo Monaco (Fig. 24). This work was executed in the period from 1424 to 1425 for the Bartolini Salimbeni family; it came from the Church of Santa Trinità in Florence, where it had been installed in the fourth chapel on the right side of the nave. As with the preceding examples, the particular choices that governed the intervention follow the rule of respect for the original construction while also providing an appropriate functionality to the support and conferring the best stability to the paint and preparatory layers.

Diagnostic studies

With regard to the wooden construction of this painting, the current state of preservation and the deformations present in the panel were documented. The construction technique was analyzed and the wood species identified.

Construction technique

The painted panel (265 × 236 cm), with three cusps in the upper part, consists of a support of seven planks made of white poplar oriented with the grain in a vertical direction and butt-joined with lime casein glue (Fig. 25). Inside the joins, at the center of the thickness of the planks, are wooden dowels that connect the planks. Most of the planks were obtained with medial cuts; only the central plank was radially cut. The technique for the painting preparation uses a cloth and a thick layer of gesso and glue; the painting medium is egg tempera. On the upper part of the panel front, there are also cusps superimposed on the main plank, with carved ogival framing elements that contain, inside tondi, the figures of God the Father and the prophets. Below, there is a small predella with inscriptions. The work itself rests on a larger, stepped predella, where scenes from the Nativity are depicted.

The support is reinforced on the back by three crossbars of poplar, placed at right angles to the panel planks and fixed with nails, which were driven in from the front prior to the preparation and then bent over on the back of the crossbars. The small predella at the lower edge of the painting is made of a board placed at a right angle to the grain of the support and fastened with nails.

Figure 24, below
Lorenzo Monaco, *The Annunciation,* 1424–25. Egg tempera on panel, 265 × 236 cm. Church of Santa Trinità, Florence. Photographed in raking light.

Figure 25, below right
Lorenzo Monaco, *The Annunciation*. Back of the panel photographed in raking light.

Figure 26
Lorenzo Monaco, *The Annunciation*. A split on the back of the panel; some ring separation is evident in the wood of the support's central plank.

State of preservation

The planks that make up the support show slight convex warping on the painted surface. This phenomenon is greater on the outside planks, and on the painted surface, a pronounced misalignment is noted at the open splits. The central plank, from a radial cut, shows separation of the tree rings in correspondence with the pith. The phenomenon of ring separation (the "onion effect") is typical for chestnut but rare in poplar (Fig. 26). Finally, the joins were open, and cracks were noted in the bottom part of the support.

Previous restorations

The last restoration carried out on the painting dates from the 1950s. On that occasion, the paint layer was cleaned, and the gesso that had been applied on the gilding of the architectural part was removed. To restrain the planks that had separated, butterfly inserts were inset across the joins. Some of the planks of the support were warped, so that a double convex deformation was formed across the painted surface. To lighten the tension in the planks, the crossbars were reduced in thickness. The upper one was thinned though not removed from its housing, while the central one was removed by the cutting of its original nails; it was then thinned and put back into place with normal screws. Finally, in the case of the bottom crossbar, it could be seen that the nails had been straightened and the crossbar slipped off, reduced in thickness, and reattached with the same elements, since the heads of the nails could be reached by removing the smaller predella.

Restoration proposal

The plan for the intervention was established after careful evaluation of the condition of the painted surface, the consistency of the wood, the uneven surface alignment at the splits, and the hold of the crossbars.

The removal of butterfly inserts was justified in that their function is only partial, and, in fact, they are even harmful, since the grain is placed in the direction opposite to that of the support, so that tension points are created between the planks.

The following were planned: repairing the splits with the wedge technique, adjusting the surface level at the splits, overhauling the crossbars, and protecting the back with an antiwoodworm product based on Permethrin.

Restoration interventions

By use of an electric router attached to a pantograph template, the walnut butterfly inserts were removed. This made it possible to obtain the perfect refacing of the cavities on both the edges and the bottom. In this case the author felt that the slight vibration of the instrument would be well tolerated by the support and by the entire, rather solid preparation-paint layer. The cavities were corrected and filled with small elements of old wood of the same type, and arranged in the same grain direction, as the support.

The separated edges of the joins and cracks were repaired with the traditional method: triangular-section blocks were custom-fitted into

Figure 27
Lorenzo Monaco, *The Annunciation*. Ring separation in the wood on the back of the panel before repair. Also visible is the reconstruction in the grain direction of the old butterfly inserts.

prepared tracks and glued in place with a PVA emulsion.[21] The degraded part of the wood was eliminated by the correction of the edges, and the level of the painted surface in those areas was realigned.

In this operation our intervention was limited to removing only the parts affected by degradation, so that, as much as possible, the triangular angle of the cut was retained. It was considered vitally important that each wedge be positioned in such a way that the grain be parallel to that of the panel and that the annual rings be arranged radially with respect to the plane of the support. Such positioning is more compatible with the wooden construction and, in case of dimensional changes, guarantees less deformation and, thus, a greater bond to the support. The most difficult part of this operation was the repair of the onion effect seen in the central plank (Fig. 27). The author and coworkers thus proceeded with the removal of the wood affected by the phenomenon, following its irregular disposition. The intervention was carried out in multiple steps, by alternating opening, leveling, and gluing of blocks in many layers for the reconstruction of the weak parts. Then wedges were inserted to join the faces of the opening. This technique made it possible for the surface to be perfectly adjusted: the multistep integration reduced the forces in the wooden material, lending greater stability to the intervention. Even the leveling of this area had to be done in different phases to obtain good results without the application of especially strong force. The solution adopted for the crossbars followed the concept used in the previously described intervention—that is, to make modifications only in the bonds between the various components.

The method of reducing the rigidity of the crossbars is altogether valid today when the panel's planks are subjected to a warping stress that is thought to be irreversible. Such situations generally are the cause of the formation of cracks and instability of the paint and preparatory layers. These phenomena can be caused by the aging of the material in relation to the characteristics of the wood in terms of quality and positioning of the grain, or by environmental factors that have affected the life of the painting.

Removal of the upper and lower crossbars proceeded with the cutting of the tips of the nails that were hammered over onto the back. This operation made it possible to observe that two sides of nails had some space in the horizontal direction as a consequence of the yielding between the parts (the walls of the wood and the flexible metal) that occurred over time. The next step consisted of widening the holes left by the nails in the crossbars (by 3 mm) and threading (with a 4 mm pitch) the uppermost centimeter or so of the nails that protruded from the support for the entire thickness of the crossbars. The crossbars were then inserted onto the protruding nails. Because the crossbars had been thinned on the back to a thickness of a few millimeters, it was possible to reconnect the crossbar to the support in a stable manner with a nut. For the central plank, which was missing the original nails, a mechanism was used that consisted of a brass stop plate with a rectangular slot inside, held onto the lower face of the crossbar in contact with the panel with two screws and epoxy resin; a bolt was free to move within the slot but was held in by its head. A double-threaded brass bushing was inserted into the support—the external thread to anchor the bushing to the support, the internal thread to receive the bolt. The bolt passes through a hole made into the crossbar and attaches itself to the support. Movement is ensured by the head of the

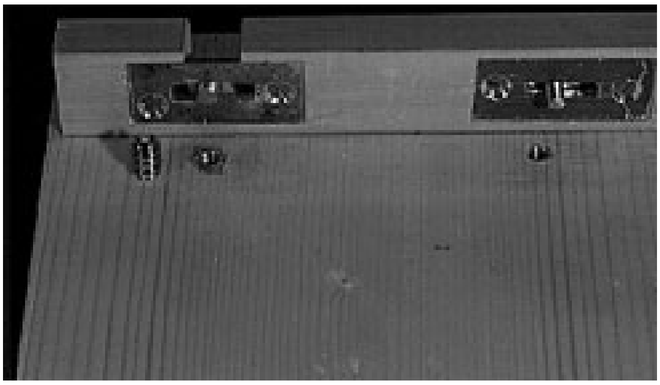


Figure 28
Model of the anchoring system used for the central and lower crossbars.

screw, which is held by the slot of the stop plate, and is aided by the interposition of two convex washers and one Teflon washer (Fig. 28).

Choosing to remove the existing crossbars in this case is based on a study of the equilibrium between the crossbars and the support planks, and on the stability of the paint and preparatory layers. It did not seem appropriate to intervene with new crossbars, even if they would function better, because of the risk of disturbing the existing equilibrium. The chosen intervention—which was believed to be sufficient to guarantee the solidity of the structure—preserved what remained of the original crossbars, limiting the intervention to reestablishing the integrity of the support with the repair of the cracks. This operation interrupts the circulation of the microclimate through the openings present between the planks, guaranteeing greater stability. Naturally, taking appropriate precautions for the painting's exhibition in the church, preparing a microclimate analysis of the environment, and establishing the appropriate interventions are necessary.

Acknowledgments

Restoration of the works presented here was carried out at the Opificio delle Pietre Dure e Laboratori di Restauro by the following individuals: Dr. Marco Ciatti, director of the work; C. Castelli, M. Parri, A. Santacesaria, R. Buda, P. Bracco, O. Ciappi, N. Bracci, T. Cianfanelli, and M. Rosa Sailer, restorers for the wooden supports and painting; Dr. A. Aldrovandi, reflectography studies; Dr. A. Aldrovandi and O. Ciappi, radiography studies; C. Castelli, M. Parri, and A. Santacesaria, 35 mm photography; Sergio Cipriani and Lamberto Cerretini, archive photos; A. Santacesaria, AutoCad designs. I thank the many colleagues and friends who collaborated on the work presented here—in particular, Dr. Giorgio Bonsanti, superintendent of the OPD, Dr. Cecilia Frosinini, and Dr. Marco Ciatti for their collaboration in outlining this article. Further thanks to my friends Andrea Rothe and George Bisacca for helping with the translation from Italian.

Notes

1 The use of cloth for the preparation of panel paintings is noted from 1138 (Croce di Sarzana) until the early 1400s. This element reduces the effects of settlement and movement of the support wood, helping to preserve the preparatory and paint layers. A heavy layer of gesso and glue several millimeters thick is added. This technique is described by Cennino Cennini in his *Libro dell'arte* (ca. 1437). After this period and throughout the 1400s, cloth or parchment strips were applied on many panel paintings in correspondence with joints, nailheads, and imperfections in the wood.

2 The widths of the planks that compose the upper support measure as follows, starting from the left: 21, 46.5, 56, 49, and 13.5 cm.

3 The widths of the planks of the support's lower section measure as follows, starting from the left: 15, 38.5, 31, 40, 33, and 28.5 cm.

4 Of the several ways to guarantee that the heads or tips of nails do not contact the preparatory layers, the most suitable method recreates a uniform support surface for the preparatory layers by recessing the nail a few millimeters into the thickness of the support and then covering it with a wooden plug. This method is most prevalent in the oldest works. In less careful preparations, pieces of cloth or parchment were applied with the aim of isolating the metal.

5 A mixture of paste, made with hide glue and sawdust, is frequently found in restorations of painted wooden supports. This mixture shrinks in volume over time. The shrinkage produces a tension in the area where paste was applied and in the surrounding areas, causing stress in portions of the original wood that renders it weaker than before the application of the paste.

6 These crossbars were mounted in such a way that the attachment blocks also reinforced the join between the upper and lower parts of the support.

7 In the adjustment of the frame junctures, the various pieces had been cut directly on the painting, during which procedure the serrated blade scraped the painted surface.

8 The use of wedges for rejoining gaps and cracks in panels has already been treated by Giovanni Secco Suardo in the first chapter of his manual *Il restauratore dei dipinti* (1866). This system is still valid for the restoration operations described here. This method makes it possible to realign the disconnected edges and rejoin them perfectly through part or all of the entire thickness, depending on the support condition, without tampering with the preparatory and paint layers. With regard to destroying original material, it is important to limit such treatment reasonably to the areas of existing degradation: the smaller the area of wood treated, the greater the stability of the intervention. The wedge's positioning, both with the grain and with the annual rings, is important in obtaining the best stability between the panel and the added inserts. The wedges must be placed radially with respect to the plane of the support.

9 The correction of the overall curvature was carried out after the V-shaped tracks were cut, so as to prevent the back edges from pressing against each other during the correction and thereby spreading apart the painted surface.

10 The mechanism consists of a brass shoe in the form of a closed U at right angles; it is 3 cm long and 1 cm high and is held to the support with a screw. If the consistency of the wood is poor, a double-threaded brass bushing is used for attachment to the support; the external threading anchors to the panel and the internal threading receives the screw that holds the brass shoe to the support. This 1 cm diameter bushing is 1.5 cm high, according to the characteristics of the support, and is screwed and glued to the planks with epoxy resin. Inside this brass shoe glides a nylon slide with a screw at the center that is inserted into the thickness of the framework; the hole has a cylindrical brass sleeve that receives a spiral spring inside it; the upper end of the bolt is adjusted by a nut.

11 This type of intervention—even if it presents some difficulties with the possible removal of the wax from the back of the panel—was considered useful given the precarious stability of the painted surface.

12 The vacuum technique is very important for the consolidation of the preparation and paint layers; its use requires a deep understanding of the application method, which is related to the solidity of the support and to the particular characteristics of the paint.

13 The method used to carry out this measurement took advantage of a measuring device sufficiently sensitive to plot the movement of the object in response to variations in RH. The gauge is a suitable device for obtaining these measurements. Such an instrument—having a centesimal scale and a useful field of 10 mm—was modified for use by the attachment to each of the two ends (fixed and sliding) of a perpendicular support ending with a 3.5 mm steel sphere. On the back of the support, the reference couples were attached in a stable and easily removable manner. These consisted of nuts with an internal hole ground to 3.5 mm, glued with epoxy resin to three-prong thumbtacks that allowed the terminals of the sphere to be housed stably.

14 The painting's planks measure, starting from the left of the painted surface: 50.5, 47.5, 45, 50, 47.5, and 36 cm.

15 The floating tenon is a rectangular element of hardwood, often walnut; it works as a connection and reference point between the planks during gluing of the joins. Floating tenons are inserted in the housings without being glued and are held in place with one or two dowels per side inserted into the thickness of the planks. A wooden peg also has the same function, although it has a circular section.

16 For crossbar removal, the painting was laid flat on a wooden grill. With a portable circular saw, the crossbars were cut longitudinally from below through the entire thickness without damage to the support.

17 As described in the previous intervention, this method attempts to prevent the creation of fracture lines by the positioning of small blocks of the same type of wood, united together and staggered along the length.

18 First, blocks are inserted to four-fifths of the depth of the track in the original support. After the glue has dried, the upper face of the blocks is planed, a procedure that widens the track about 1–1.5 cm in the longitudinal direction of the wood fibers. Thus, the block applied to complete the plane with the support will be adhered to the surface of the panel in the direction of the fibers.

19 This method requires the planing of the edges by a slight angling of the utensil toward the back without its touching the paint edge. With such a system, the reunited planks create a V-shaped space to receive the wedge-shaped block.

20 The wedge, the central element of this operation, must follow specific criteria: wood selection, grain orientation, and leveling of the edges of the painted surface. Adjustment of the wedge in the housing is carried out in the traditional manner.

21 The term "traditional method" here refers to the opening of V-shaped tracks with a chisel, correcting the edges, straightening the faces, and adjusting the wedge in the V-shaped track.

Reference

Secco Suardo, Giovanni
1866 *Il restauratore dei dipinti.*

Structural Considerations in the Treatment of a Nativity by Francesco di Giorgio Martini

George Bisacca

To explain the approach to the structural conservation of panel paintings described in this article, the author believes that it may be more useful to chronicle a single, complex intervention rather than catalogue the range of technical solutions employed for specific problems, because he considers the decision-making process related to a particular intervention to be the most critical factor determining its success. Obviously, an accomplished level of woodworking skills, knowledge of the properties and behavior of wood, and a general technical and mechanical versatility are important, but ultimately they are not enough to ensure the suitability of a proposed treatment.

The danger of approaching a structural intervention (or any restoration) from a purely technical point of view is that of unwittingly causing some kind of aesthetic shift inappropriate to the work of art in question. Many transfers, for example, can be considered technically successful but may have been executed at the expense of certain textural qualities in the surface. Conservators have sometimes been unqualified to judge the extent to which these subtle shifts compromised the overall aesthetic of the object and, ultimately, much of its meaning. Critical aesthetic judgment should be an essential component of any conservation project, as it provides the only means to evaluate the appropriateness of a proposed treatment in proper context. This ability is continually developed by broadening one's general art-historical knowledge, by closely examining and comparing similar works of art (particularly those in excellent states of preservation), and by learning how to predict the natural aging behavior of materials under various conditions. Building this kind of knowledge sharpens one's ability to deduce the fabrication methods and treatment history of an object accurately, prior to intervention; it also helps in projecting what kind of improvement can reasonably be expected.

Conservators who believe that aesthetic choices are subjective and therefore inappropriate relinquish their responsibility to understand the object in a larger context. Because visual acuity and the complexities of cultural context are limitless, one's current level of understanding is always inadequate; consequently, there is a danger inherent in all interventions. Since any intervention can potentially disrupt the aesthetic and physical integrity of the object, conservators are bound to consider both of these aspects in order to minimize the risk of causing some inappropriate shift.

In general, post-treatment environmental conditions should also be a factor in deciding the extent of a proposed treatment. For example, a cradle that has blocked and caused splits in the panel in the past but is now housed in a stable environment may require no treatment, provided that the painted surface is acceptable and the exhibition conditions will not further aggravate the state of the panel. Finally, some consideration should be given as to whether the amount of risk involved in a proposed intervention is justified by the amount of projected gain.

Overview

In 1964 Federico Zeri published an article in *Bollettino d'arte* linking a *Nativity* by Francesco di Giorgio in the Metropolitan Museum of Art in New York with a fragment, *God the Father with Angels,* in the National Gallery in Washington, D.C. (Figs. 1, 2) (Zeri 1964). He recognized that, given the size of the Metropolitan *Nativity* (62.2 × 59.1 cm) and its likely date, the rectangular format was improbable. He suggested that, stylistically, the upper portion of the panel required an arched top, and that iconographic considerations would have dictated the representation of God the Father giving a blessing or, at the very least, some sort of compositional closure. The Washington panel furnished precisely these elements.

The oval format of the Washington panel had long been considered suspect. In fact, various additions to the lower edge could be discerned with the naked eye beneath the overpainted sky. Close examination of the Metropolitan panel revealed a horizontal addition of approximately 10 cm along the top edge.[1] Consequently, Zeri hypothesized that the two

Figure 1
Francesco di Giorgio Martini, *Nativity,* 1471–72. Tempera on panel, 62.2 × 59.1 cm. Metropolitan Museum of Art, New York.

Figure 2
Francesco di Giorgio Martini, *God the Father with Angels,* 1471–72. Tempera on panel, 36.5 × 51.8 cm. National Gallery of Art, Washington, D.C.

panels were actually fragments of the same picture. Zeri's reconstruction was generally accepted in the literature and later confirmed by X radiography. It was not, however, until the planning stages of the Metropolitan exhibition *Painting in Renaissance Siena: 1420–1500,* held in 1988 in honor of John Pope-Hennessy's seventy-fifth birthday, that a decision was made to exhibit the pictures together.

The treatment of the panels evolved from the initial idea of minor cleaning and corrective retouching for the purpose of exhibiting the pictures side by side, to a major cleaning and structural intervention, which ultimately included the reconfiguration of the Washington panel into a lunette, the permanent rejoining of the two panels and, finally, joint ownership between the two museums.

The scope and objective of the intervention broadened several times during the process because of the emergence of new information that continually expanded the understanding of the work as a whole. New physical evidence uncovered at various stages pointed toward the need for increasingly extensive interventions that the conservators and curators concluded were justified by the prospect of real aesthetic gain with the least conjecture. At each step, intervention was limited to the minimum necessary to achieve a clearly attainable goal, based on structural and aesthetic integrity within the given context. As the context changed, the permanent rejoining became a more and more logical alternative; and it stands as a credit to the conservation, curatorial, and administrative staffs of the National Gallery and the Metropolitan that the needs of the object were allowed to prevail at every turn.

Initial Phase

The rocks and bricks depicted in the addition to the Metropolitan panel had always appeared aesthetically unsuccessful. In light of the upcoming exhibition in which the two pictures were to be exhibited side by side, the Metropolitan decided to reconstruct the work more accurately in relation to the artist's original intention. The reconstruction was based on the information available in the radiograph taken in Washington, D.C., in the 1960s, shortly after the appearance of Zeri's article. Washington produced a new radiograph on more modern equipment that greatly clarified the original depiction, and the Metropolitan made adjustments that more accurately reflected the new information.

The National Gallery had not previously considered removing the overpaint in the sky because the outcome was likely to be even more confusing and difficult to resolve aesthetically. Since the new radiograph revealed much sharper and more extensive detail than was previously visible, however, the National Gallery decided that it was now worthwhile to remove the overpaint and expose as much of the original surface as possible (Fig. 3). The result was surprising, because the overpaint in the sky had obscured much of the exquisite detail in the depictions of the thatched roof and all of the brickwork in the lower fragment—elements that were

Figure 3
Washington panel after removal of overpaint by Sarah Fisher, head of paintings conservation at the National Gallery. The opacity of the overpaint had prevented much of the detail in the thatched roof and all of the brickwork in the lower fragment from reading in the radiograph.

not even visible in the new radiograph. The approximate positioning of the fragments outside the lower left and right of the oval was now clear. Enough new information was now available to consider returning the painting to a lunette format. The respective museums agreed not only to turn the Washington picture permanently into this format but also to remove the addition from the Metropolitan picture and to abut the two pictures one above the other in a single frame made specifically for the exhibition.

Removal of the Metropolitan Addition

The removal of the addition on the Metropolitan picture was relatively straightforward. The panel had been thinned to approximately 1 cm overall and heavily cradled (Fig. 4), and while many splits and surface distortions were present (Fig. 5), the panel showed no signs of recent movement. It was, therefore, decided to remove only as much of the cradle as was necessary to facilitate the removal of the addition. The grain of the addition was oriented horizontally, while that of the original panel was vertical. Close examination of the joint revealed an extremely asymmetrical tongue-and-groove joint (Fig. 6a). The upper lip of the groove section measured less than 1 mm thick, which is an unlikely configuration. It was speculated that this must have originally been a symmetrical joint, the sections of which measured 5, 6, and 5 mm, for a total of 16 mm (Fig. 6b), which is still too thin for an Italian poplar panel of this size. Based on comparison with other unthinned Sienese panels of this period and date, it seems more likely that the original thickness was between 2 and 2.5 cm. Once the panel was cut in two, it may have seemed unnecessarily thick. At this point, it was probably partially thinned (to 16 mm), and the addition, with a symmetrical joint, was added. At some later date, after slight warping, the panel and the addition were further thinned, probably to obtain a flat surface for the application of the cradle, leaving what for all practical purposes was a half-lap joint.

Figure 4, below
Reverse of the Metropolitan *Nativity*. The joint of the cross-grain addition can be seen just below the first crosspiece from the top.

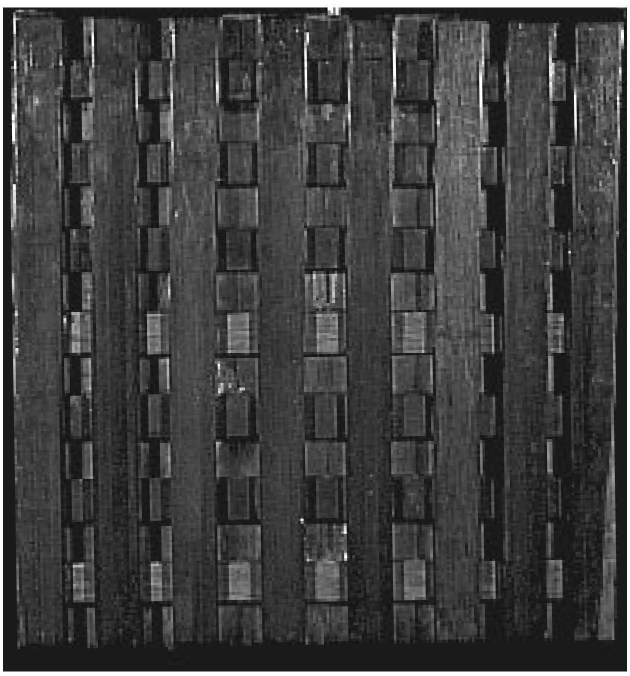


Figure 5
Raking light photograph clearly showing splits and distortions in the Metropolitan panel and the smooth surface of the addition.

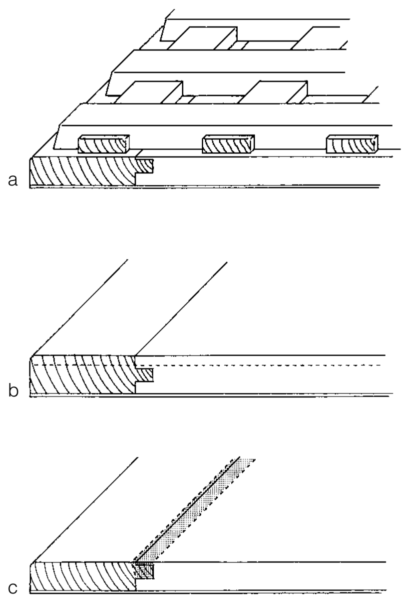


Figure 6a–c
Metropolitan panel prior to intervention. Note (a) the extremely thin lip of the groove section toward the back of the panel, and (b) the presumed thickness of the Metropolitan panel at the time the addition was added; the dotted line indicates the thickness at the time the cradle was applied. After removal of the cradle (c), the shaded area was carved away by hand, leaving only one weak, end-grain bond between the addition and the original panel.

Because of the inherent weakness of any end-grain bond (especially with hide glue), it was necessary to pare away only the tongue of the addition that overlapped the original panel and the 1 mm lip (Fig. 6c). Then, when the addition was rocked gently, the brittle hide glue fractured neatly along the joint without disturbing the original panel.

Removal of the Washington Additions

Close examination of the Washington panel seemed to indicate that the abrasion around the edges of the fragments had been caused largely by an attempt to level uneven surfaces *after* the fragments had been glued in place (Fig. 3). Again, the initial idea here was to separate the fragments and reposition them while causing as small an alteration to the existing structure as possible.

The cradle, applied by Stephen Pichetto in 1944,[2] was typical of the method he almost invariably employed (Figs. 7, 8). He thinned the panel to approximately 5 mm and then laminated it to a mahogany panel of 1 cm thickness oriented in the same grain direction. He then "neatened" the ragged edge of the original poplar panel by the addition of a very thin mahogany band around the perimeter to match the laminated layer (Figs. 8, 9). A cradle was then attached; it consisted of mahogany members oriented in the same grain direction as the panel, with maple crosspieces.

The plan was to dismantle only the section of cradle behind the fragments and then to attach a platform (extending from the two wide lobes on the left and right of the cradle) on which to position the fragments and reconstruct the lunette (Fig. 7).

Two crosspieces at the lower edge were removed, and the mahogany cradle members were sawn through and pared away. The joint line was then marked precisely on the reverse and cut about halfway through the mahogany laminate. The saw cut was made perpendicular to the picture plane, and some additional mahogany was then further pared away on the fragment side to form a V-shaped opening, which enabled a better view of the bottom of the cut (Fig. 10). By repetition of this process, sawing and carving slowly advanced the cut without the risk of cutting into the original poplar.

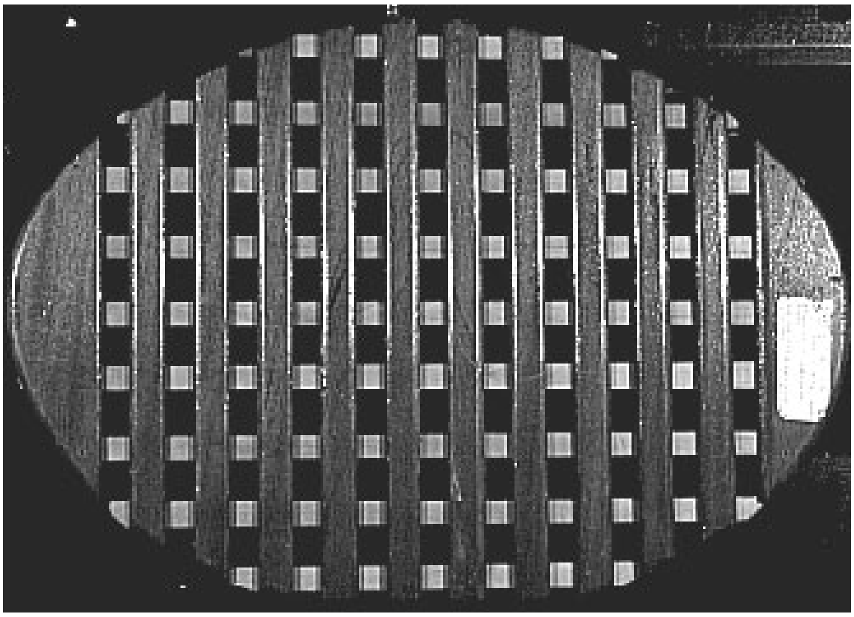


Figure 7
Reverse of the Washington panel prior to intervention.

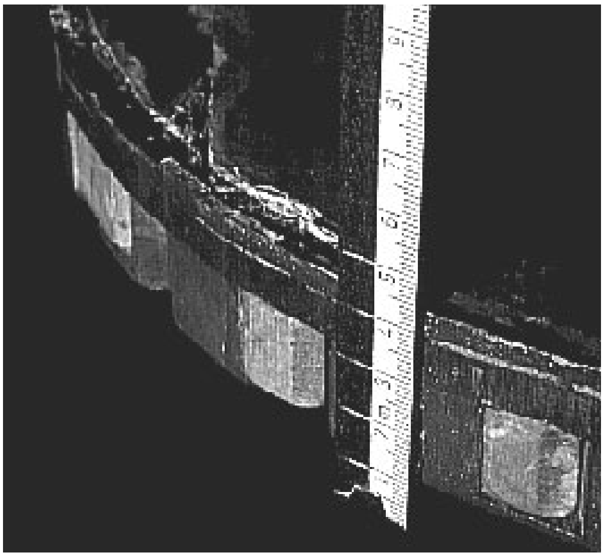


Figure 8
Side of the Washington panel. The cradle is approximately 2 cm thick, followed by a mahogany backing 1 cm thick and finally by the original panel, approximately 5 mm thick.

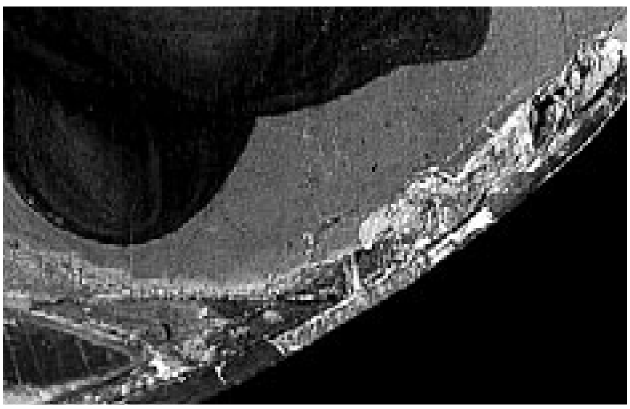
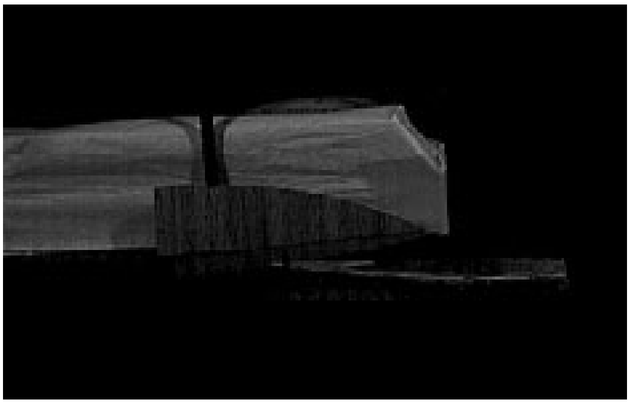


Figure 9
Edge of the Washington panel after removal of fill material. The thin mahogany strip can be seen around the perimeter.

Figure 10
Carving into the mahogany laminate of the Washington panel, in order to read the depth of the saw cut.



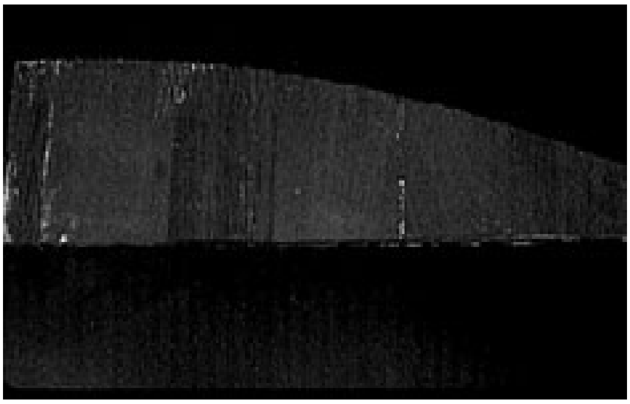


Figure 11, above
Separation of the fragments of the Washington panel.

Figure 12, above right
Fragments after removal of the bulk of the mahogany from the Washington panel with the band saw. The 1.5 mm thickness of mahogany can be seen attached to the blue fragment in the foreground.

Figure 13, right
Alternating bands of mahogany and poplar between the original panel and the mahogany backing of the Washington panel.

Once the original poplar panel could be seen at the bottom of the cut, the panel was turned over, and the mahogany edging strip was cut in correspondence with the saw cut. Since the grain direction of the panel ran opposite to the fragments, as was the case with the addition to the Metropolitan panel, the hide glue bond was tenuous. Gentle rocking pressure was enough to fracture the glue easily and separate the fragments (Fig. 11). The bulk of the mahogany remaining on the fragments was then removed with a band saw, leaving approximately 1.5 mm attached to the poplar (Fig. 12). The band saw was used because it exerted far less downward pressure on the paint film than the amount that would have been required to carve away the remainder of the mahogany. The operation took only a few seconds and, with a well-tuned band saw, required nearly no pressure and little risk.

The next step was to pare away the remaining mahogany from the fragments. During this step, a layer less than 1 mm thick of alternating bands of mahogany and poplar was encountered (Fig. 13); it formed a continuous layer between the original panel and the mahogany laminate in the entire Washington picture. (It was oriented in the grain direction and consequently ran cross-grain only under the small fragments.) The purpose of this layer is not understood at present, but it may have had something to do with adhesive compatibility. The poplar would perhaps adhere better or react similarly to the poplar panel, and the converse would be true for the mahogany. These alternating bands were literally paper-thin and could easily have gone undetected. The existence of these bands is interesting, given the fact that, in contrast to most cradles, those applied by Stephen Pichetto usually function well, even after fifty years. This small detail may contribute in some way to their success.

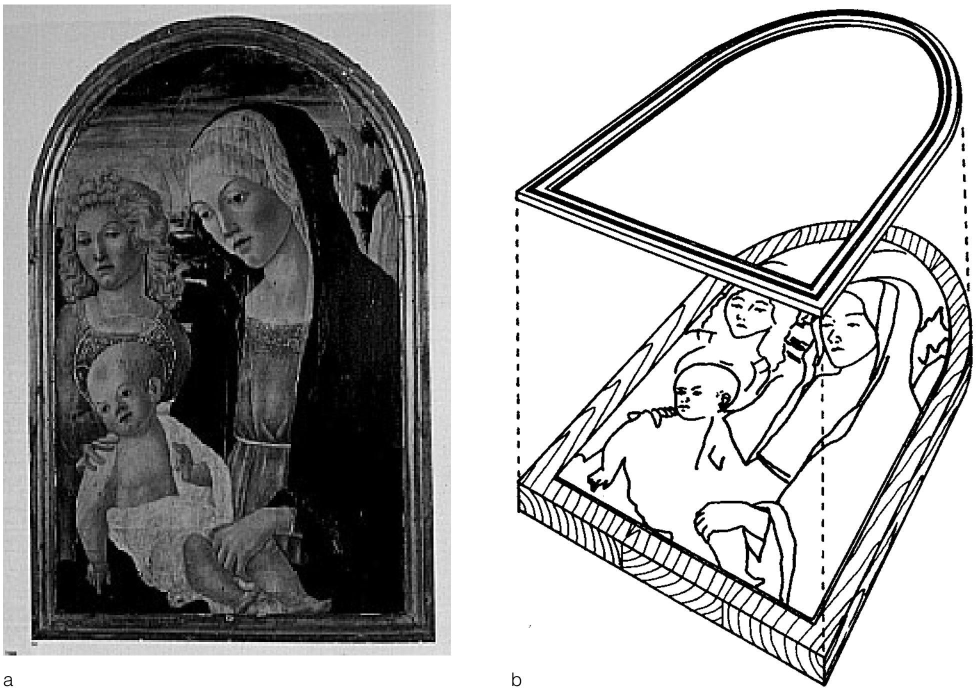


Figure 14a, b
Francesco di Giorgio Martini, *Madonna and Child with Angel,* 1474. Tempera on panel, 74.5 × 49 cm. Pinacoteca, Siena (cat. 288). The panel and frame are integral to this work (a). Gesso was applied continuously over the frame and panel before gilding and painting. The exploded view (b) of the engaged framing elements shows that if they were removed, the uncoated portion of the panel would be visible. The unpainted tips of the small fragments in the Washington panel indicate that this was the original method of construction.

During the removal of this layer, another detail came to light that substantially altered the plan for completing the lunette. After removal of the alternating bands on the small fragments, it was found that the original poplar extended beyond the painted areas at the pointed ends of the fragments (Figs. 3, 9). It had been previously assumed that these areas had been filled with additional scraps of old poplar, but, instead, the poplar was continuous.

Since the curve traced by the edge of the painted surfaces of the fragments contained the lip or barb characteristic of the perimeter of painted panels with engaged frames, it was deduced that the tips of the fragments had not been painted originally and were instead part of the panel onto which the original framing elements had been affixed before gessoing, as was common in the late quattrocento (Fig. 14a, b). A preliminary arrangement of all four fragments based on the convergence of lines in various design elements showed that the unpainted tips of the small fragments extended beyond the painted surface of the main fragment (Fig. 15). Obviously, they could not be trimmed off because they were the only evidence clarifying the original structure of the panel; instead, wood was added around the perimeter to encompass these tips. This addition would not be visible ultimately, because it would eventually be cropped by the frame, but it was considered necessary, nonetheless, to protect the fragments better while more clearly indicating their function. To attach the addition, however, further alterations would have to be made to the cradle.

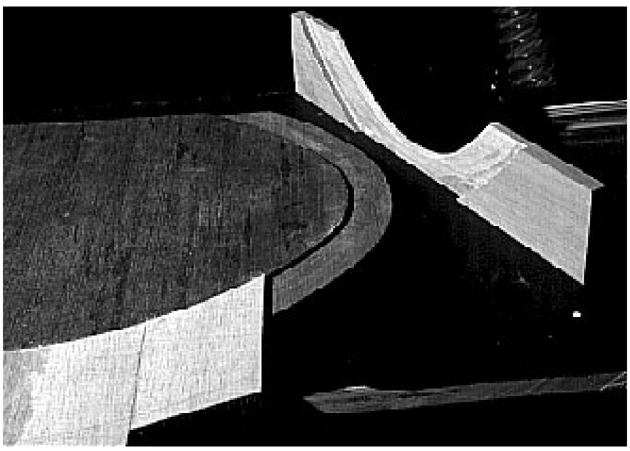
Since the bottom of the cradle was already altered, and the author was also planning to alter the lobes at the left and right, altering the upper curve as well would mean that the only undisturbed section of cradle would be a small area in the center. In light of this new information, retaining the cradle became a less logical alternative. After consultation with the conservation department of the National Gallery, it was decided to remove the entire cradle but leave the mahogany laminate attached to the original poplar panel. Although this alternative appeared unnecessary

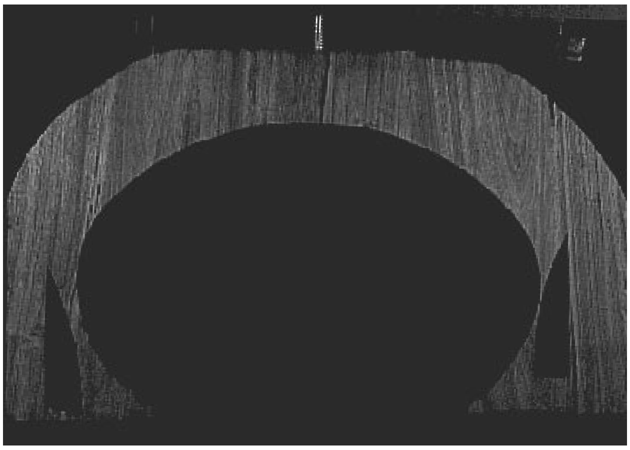
Figure 15
Preliminary arrangement of all fragments.

at the beginning of the intervention, it became more obviously logical and efficient after the discovery of the unpainted tips. All additions would be built onto the mahogany without disturbance to the poplar panel. After the cradle was removed and the back scraped clean, a track was routed to half the thickness of the mahogany, and new mahogany pieces were fitted to extend that plane to accommodate the fragments, including their protruding tips (Figs. 16, 17). After the exact placement of the fragments was decided, the areas that were completely missing would need to be built up from the mahogany to the level of the gesso preparation (see Figs. 8, 9). Very old poplar brought from Italy was used for this purpose in order to maintain a consistent structure (Fig. 18). After the poplar collar was glued to the mahogany with a polyvinyl acetate (PVA) emulsion (Fig. 19), the fragments were set into the cutouts in the collar and precisely aligned with the surface of the main part of the panel, both along and across the grain. Rabbit-skin glue thickened with calcium carbonate was used as an adhesive to fill any gaps caused by adjusting for surface level. Other adhesives, such as Ciba-Geigy Araldite 1253 carvable paste, have excellent gap-filling properties as well as much longer curing times; however, the traditional

Figure 16, below
Fitting of the mahogany extensions for the Washington panel.

Figure 17, below right
Washington panel after the completion of the mahogany additions.





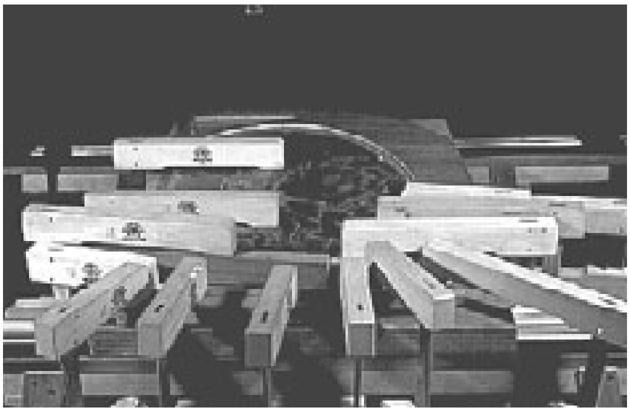


Figure 18, above
Poplar collar used to build up the missing areas to the surface level of the original poplar panel of the Washington panel.

Figure 19, above right
Gluing of the collar to the mahogany backing for the Washington panel.

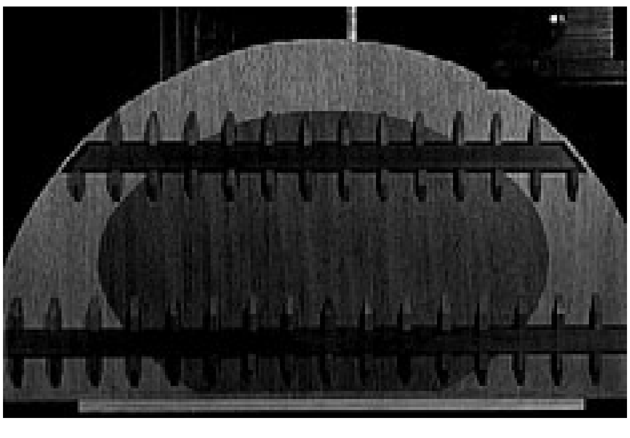
organic adhesive was selected because it is more easily reversible.[3] The disadvantage of its quick setting time was minimized by repeating the clamping procedure dry several times until the same results could be achieved consistently, accurately, and quickly. The perimeter was then drawn and trimmed on the band saw (Fig. 20).

Two crosspieces of the Florentine type described elsewhere (see Rothe and Marussich, "Florentine Structural Stabilization Techniques," herein) were then fabricated and applied (Fig. 21). The contact faces of the crosspieces themselves, as well as the small retaining pegs that hold the crosspieces, are machined to an angle of 22.5°. The two rows of pegs create a sort of dovetail track within which the crosspiece can slide, allowing for any lateral expansion and contraction of the panel. The trapezoidal shape of the crosspiece also permits convex flexing of the panel, and the small contact faces of the pegs minimize friction against the crosspiece, making it virtually impossible for it to bind. The pegs were attached to the panel with Ciba-Geigy Araldite 1253 carvable paste, the gap-filling properties of which make it possible to set the contact between the peg face and crosspiece precisely, while the resin adequately compensates for any irregularity between the peg bottom and the panel. If inordinate pressure were eventually to accumulate in the panel from warpage, the small pegs would tend to delaminate rather than cause the panel to split.

This type of secondary support (later abandoned because of developments described on the following pages) was applied only to a panel that had previously been thinned considerably for warp reversal or for the application of a cradle. It would generally not be used for a panel

Figure 20, below
Band saw being used to trim the perimeter of the Washington panel.

Figure 21, below right
Reverse of the Washington panel after application of the crosspieces.



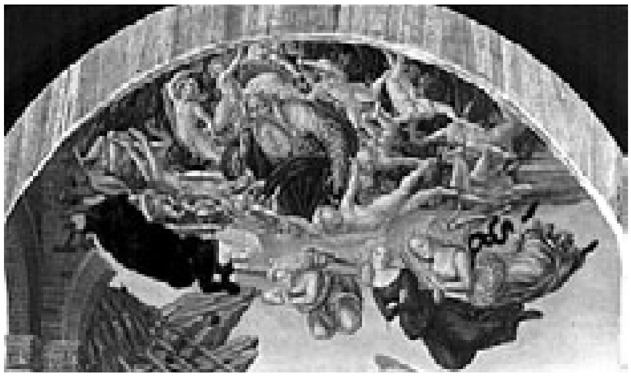


Figure 22, above
Washington panel after application of gesso.

Figure 23, above right
Washington panel after inpainting by Sarah Fisher.

that had retained its original surface, because the support was considered too great an aesthetic intrusion.

The missing areas were then gessoed and inpainted by Sarah Fisher, head of paintings conservation at the National Gallery (Figs. 22, 23). Both pictures were then butted together without glue in a single frame made for the exhibition (Figs. 24, 25).

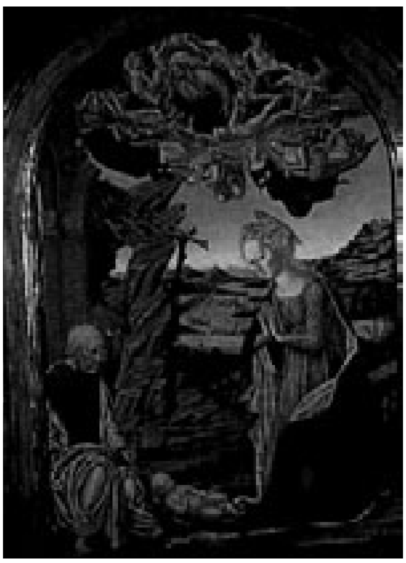
This arrangement proved successful enough to prompt the two institutions to agree to the permanent rejoining of the panels subsequent to the exhibition and joint ownership thereafter.

Permanent Rejoining

Among the problems presented by the permanent rejoining, the most difficult to resolve was the discrepancy between the beautiful, uniform surface of the Washington panel and that of the Metropolitan panel, which displayed such problems as several open splits, warps, and planar distortions, most of which were related to the cradle (see Fig. 5). Although the condition of the Metropolitan panel was less than ideal, it was nonetheless stable, given the satisfactory environmental conditions within the museum. While the aesthetic improvement of the surface had always been an attractive idea, it was felt that the subtle aesthetic gain did not justify the extensive structural treatment to which the panel would have to be subjected. Now, however, in light of the permanent rejoining, the relationship between the upper and lower surfaces seemed important enough to justify the intervention.

Figure 24, right
The two pictures abutted together without glue in a single frame made for the 1988 exhibition *Painting in Renaissance Siena: 1420–1500.*

Figure 25, far right
Reverse of the panels during the exhibition. The Washington panel (above) is wider than the Metropolitan panel because of additions made to the perimeter.



The cradle (Fig. 4) not only limited access to the splits but also impeded the improvement of the surface alignment and adjustment of the overall curvature of the panel. These problems were compounded by a thick layer of wax that had been poured hot over the entire cradle and panel, probably in the 1950s.

The wax and cradle were removed. The splits were repaired using the Florentine wedge method, which consists of the following procedure: First, V-shaped tracks are cut as narrowly as possible along the splits, and wedge-shaped pieces of wood are then fitted with extreme precision and glued into the tracks. The wood used is of the same type as the panel and as close in age as possible. An attempt is made to match the grain direction, cut, and even the degree of worm tunneling, so that the repair does not exert a greater or lesser structural force within the panel. (For examples of this technique, see Rothe and Marussich, "Florentine Structural Stabilization Techniques," herein.)

This controversial method was developed for a number of reasons. Of course, whenever possible, simple splits that fit together well should merely be reglued; however, in many cases they are too tight for glue to be introduced to the full depth. As a result, they continue to move near the paint surface, causing new fills to reopen and splits to continue to lengthen. In the case of older splits, some are considerably more open on one end than on the other and cannot be closed without excessive pressure; in such cases, filling them with relatively large amounts of adhesive would become necessary. Others, because they have warped differently on both sides of the split, have complicated surface leveling problems and other planar distortions. And others, because of repeated treatments in the past, are filled with wax, dirt, varnish, gesso, and organic and inorganic adhesive residues that impede accurate regluing.

By cutting a narrow, V-shaped track, one gains full access to the entire depth of the split while removing any extraneous material and exposing pristine gluing surfaces for a better adhesive bond. Surface curvature and level can be precisely adjusted in very short segments—even one wedge at a time—ensuring highly controlled results. The precision of the fit can reduce the amount of adhesive necessary by several hundred percent. By the fitting of short wedges, the faces of each segment of the V-shaped track can be readily prepared perfectly flat, and irregular splits can be followed with greater accuracy. Moreover, if the wood of the wedge were to have any tendency to move differently from the panel, its strength would be minimized by the interruption of the cell chains due to the short lengths of the wedges: it is unlikely that individual wedges could do more than simply follow the movements of the panel.

The controversial aspect of this method is, of course, the removal of original material. Two factors come into play in this regard. One is the undeniable primacy of the painted surface and its ability to function or convey its particular pictorial meaning. The second is the contribution the panel makes toward the overall aesthetic of the work of art as an object, including the practical information that can be gleaned from tool marks, dowel holes, edges, metal attachments, and so forth; this evidence can shed light, for example, on fabrication techniques, placement within an altarpiece, and original collocation, and it must be scrupulously respected.

These two factors must be considered together in the planning of the extent of any structural intervention. The situation is substantially different, however, when a panel has been thinned and cradled. Any

Figure 26
The Washington panel (left) and the Metropolitan panel, aligned in position for permanent rejoining.

Figure 27
Planing of the track between the two panels. Note the gesso filling added into the slightly irregular joint at the center.

aesthetic aspect or technical information contributed by the original wood surface has already been eliminated. Therefore, the decision to remove a small amount of material that had never been visible from the exterior, in a process that could greatly facilitate the aesthetic improvement of the painted surface as well as the future stability of the panel, can be justified. If, to take a hypothetical example, a panel were to lose both its back surface as well as its painted surface, would the core material retain any value as a work of art or even as a historical document?

It should be stressed that the removal of original material—even that which was never visible on the surface—remains a radical decision and should not be undertaken as a matter of course. The fitting of these wedges is a dangerous operation and, unless it is very precisely executed, offers little advantage over simpler methods of regluing. When executed precisely, however, it produces a repair of exceptional stability and durability while allowing uniform, uninterrupted expansion and contraction across the panel. It also permits extremely accurate surface-level and curvature adjustments with minimal aesthetic compromise.

An interesting solution for Botticelli's *Man with a Medallion* in the Uffizi Gallery was recently presented by Ezio Buzzegoli and Marco Marchi of the Soprintendenza per i Beni Artistici e Storici di Firenze e Pistoia (Buzzegoli, Marchi, and Scudieri 1993). In this example, the panel retains its original surface, but a split traveling upward from the bottom was causing the *pastiglia* medallion held by the sitter in the picture to fracture. With a scalpel, conservators removed the "skin" of wood around the split in one continuous piece, fitted the split with wedges, and reattached the skin so as not to disturb the overall aesthetic.

Attachment of the two panels

After all the splits in the Metropolitan panel were fitted with wedges, thereby improving the surface leveling and overall curvature, the two panels were then aligned (Fig. 26). The top of the Metropolitan panel already had a routed track from the attachment of the old addition. It was decided to rout a similar track into the mahogany of the Washington panel without cutting into the original poplar (Fig. 27). Short poplar blocks were then made to bridge the two panels. The blocks were fitted and glued a few at a time, beginning at the center, so the paint surface could be carefully leveled as each piece was glued in place (Fig. 28). Before each piece was glued, the end-grain joint between the panels was filled from the back with gesso to produce a tighter fit. Each fixed piece provided a point of leverage from which to level the next piece—and so on, until the track was completed. Rabbit-skin glue thickened with calcium carbonate was used again as an adhesive.

The sides of the Washington panel were wider than those of the Metropolitan panel because of the additions that were made around its perimeter (Figs. 25, 29). No additions had been made to the Metropolitan panel because, although the same amount of wood was missing around its perimeter, as long as the panel existed as a separate entity, there was no pressing need to reconstruct it. Besides, it would eventually only be cropped by the frame. Other evidence (the raised lip or barb at the edges of the painted surface) made it clear what was missing, and this was considered sufficient. The decision to add the missing wood in the

Figure 28
Gluing of the blocks.

Washington panel was motivated primarily by the need to find a solution that would physically protect the tips of the fragments without falsifying the aesthetic of the object. Now that the panels were permanently rejoined, it made sense to add the missing strips to the sides of the Metropolitan panel as well, in order to simplify the perimeter, reflect the original fabrication method, and strengthen the entire construction.

It was decided not to continue the addition across the bottom edge of the picture because it was considered unnecessary. Not only would the end-grain attachment present its own problems, it would not in itself resolve any other problem.

The back surface of the Metropolitan portion of the panel had been scraped in order to remove all wax and glue residues, and it was now judged to be potentially highly reactive to humidity fluctuations. A coat of Acryloid B72 was applied; this product is not totally impermeable but merely slows down the moisture exchange rates.

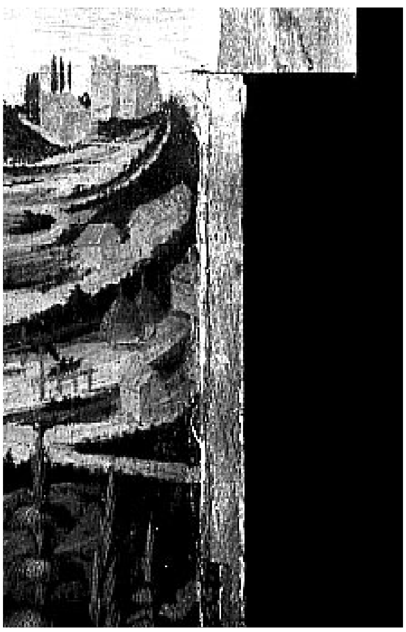
Two crosspieces similar to those already applied to the Washington portion were fabricated and attached (Fig. 30). The coat of Acryloid B72 applied as a moisture barrier would also facilitate the release of the retaining pegs of the crosspiece system in the event that too much stress were to accumulate at some point in the future.

The two institutions formally agreed to alternate custody of the newly rejoined panel every five years (beginning in Washington, since it had first been exhibited briefly at the Metropolitan for the exhibition of Sienese Renaissance painting). The interval was considered reasonable given the proximity of the two museums. A custom-designed crate equipped with cushioning for shock as well as vibration absorption and thermal insulation was then provided. Whenever the painting travels, it will be accompanied by museum couriers and transported via truck with air-ride suspension and climate control, for better control of cargo handling and climatic variables than if the painting were transported by air.

One final alteration was made to the secondary support upon its return to New York in October 1994. Although the four Florentine-type

Figure 29, right
Upper right portion of the joined panels.

Figure 30, far right
Reverse of the joined panels after application of the crosspieces on the Metropolitan panel. Note the strips newly added to the sides of the panel, as well as the continuous narrow strip of poplar that forms a bridge to the Washington portion, greatly increasing the stability of the joint.



crosspieces described above functioned adequately, they were substituted with the type of secondary support first published by Ciro Castelli and Marco Ciatti (1989). This system consists of a strainer that follows the perimeter of the panel exactly and, in this case, has two fixed crosspieces and one fixed vertical member. The strainer is simply held in place by springs, fixed to the strainer on one end and attached on the other end to small blocks of wood oriented in the grain direction; these blocks are, in turn, spot-glued to the back of the panel (Figs. 31, 32). The spring is not fixed rigidly to the small block but instead slides freely within a predrilled hole, allowing for expansion and contraction of the panel, as well as convex flexing or even straightening. The bottom edge of the strainer has a small lip that protrudes to accommodate the thickness of the panel and prevents the weight of the panel from fatiguing the springs over time.

This system offers several advantages over the traditional Florentine-type crosspieces previously employed, especially in the case of very thin panels. The strainer protects the fragile perimeter and offers greater resistance to torquing and better overall stability, while more closely approximating the original thickness of the panel and making it easier and safer to handle. The system also reduces the surface area adhered to the panel while distributing the support more regularly and without adding any weight to be supported by the panel. It also allows more localized, independent movement of any specific area of the panels, and the spring tension can be calibrated to take into account the species of wood, thickness, cut, degree of worm infestation, and past treatments.[4]

Finally, if the screws that attach the springs to the strainer are recessed, a lid or cover can be fitted over the back. Not only does this cover offer protection, it also creates a microenvironment that can buffer humidity fluctuations. Furthermore, silica gel tiles can be attached to the inside of the lid between the various crosspieces. It should be noted, however, that this solution makes no attempt to function as a climate-controlled vitrine. There is no glass in front of the picture, and the sides are not sealed. Prolonged exposure to low humidity will produce the same effects as the absence of silica gel. However, the semicontrolled environment can constitute a substantial buffer to humidity fluctuations, even eliminating movements of the panel that would be caused by daily humid-

Figure 31, right
Reverse of the panel with the spring tension strainer in place.

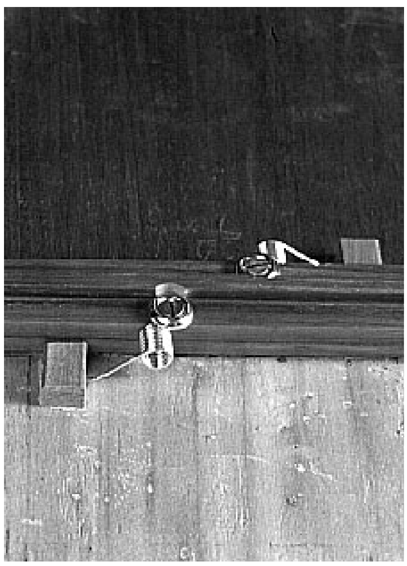


Figure 32, far right
Spring mechanism shown in place.

Figure 33
Metropolitan and Washington panels after permanent rejoining.

ity oscillations in the range of 10–15%. Essentially, the panel reacts more or less as though it were unthinned.

Silica gel tiles were not added to the Francesco di Giorgio Martini work; however, had the panel been more quickly reactive or had the environmental conditions within the two institutions been less stable, they would have been a likely option (and they remain an option in the future).

Whenever this type of secondary support is used, care should be taken to secure the object in its frame by means of some kind of flexible clip. If it were fixed rigidly and the panel were to increase its convex warp, the necessary movement would otherwise be blocked by the frame rabbet.

Although the various phases of treatment of these panels offer no technical innovations, the project as a whole demonstrates the degree to which overall context plays a determining role in assessing the appropriateness of any proposed treatment. In this instance, solutions were repeatedly modified throughout the treatment process to accommodate new physical and contextual information that came to light during the course of the intervention (Fig. 33).

Acknowledgments

The author would like to thank Keith Christiansen, Jane Wrightsman Curator for Italian Paintings at the Metropolitan Museum of Art, New York, for his inspired and enthusiastic collaboration; Tom Wilmering, head of furniture conservation in the Objects Conservation Department of the Metropolitan Museum, and Ciro Castelli of the Opificio delle Pietre Dure, Florence, for their valuable technical advice; and Sarah Fisher, head of paintings conservation, National Gallery, Washington, D.C., and Laurent Sozzani, then an intern at the Metropolitan Museum, for their dedicated work on the painting surfaces.

Notes

1 A photograph taken in 1897 in the files of the Metropolitan Museum already records the addition to the top of the Metropolitan panel.

2 Stephen Pichetto was trustee and/or curator of the Kress Collection from 1932 until his death in 1949. He maintained a large conservation studio with several employees, and many important pictures purchased in America during this period were treated in his studio. A man named Angelo Fatta was apparently responsible for the thinning and cradling of panels under Pichetto's direction.

3 In conservation practice, *reversible* is often synonymous with *soluble.* Obviously, the Ciba-Geigy Araldite is not reversible in this sense. In many cases the solubility of an adhesive would not be physically possible or even desirable. For instance, attempting to dissolve a water-soluble adhesive sandwiched between wooden elements beneath a gesso ground, all of which are hygroscopic, would have disastrous results. Often, as in the present example, mechanical reversal of an insoluble adhesive would be preferable to any attempt at dissolving an adhesive layer. Since rabbit-skin glue becomes brittle, it is possible to carve down to the glue line and scrape away the glue without further damage to the original panel.

4 These variables would be very difficult, if not impossible, to quantify. Consequently, spring tension must be set according to an empirical understanding based on knowledge accumulated from the handling and flexing of similar panels.

Materials and Suppliers

Acryloid B72, Rohm and Haas Co., Independence Mall Street, Philadelphia, PA 19105.

Araldite 1253 carvable paste, Ciba-Geigy Corporation, 4917 Dawn Avenue, East Lansing, MI 48823.

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The Cradling of a Relief of the Annunciation Attributed to Martin Schaffner

Frédéric J. M. Lebas

This relief, dated to around 1515 and part of a retable of unknown provenance in Ulm, has been attributed to Martin Schaffner (1477/78–1546/49), an artist active in Ulm and the duchy of Swabia (Fig. 1). Its composition, reminiscent of an engraving by Martin Schongauer (ca. 1430–91), could be a model for other Swabian reliefs of the Annunciation of the same period (Sprinz 1925).

The relief, on limewood, is 104.8 cm high and 118.1 cm wide. Mary is represented in front of a tent-shaped baldachin kneeling at her prayer stand; she is holding her cloak with her right hand, and her left is resting on her open prayer book. Mary's eyes are cast down pensively. Gabriel has appeared on her left; he is holding a scepter in his left hand, which also lifts the curtain to open the baldachin. In the center of the background is a vase with lilies (Eckhardt 1982).

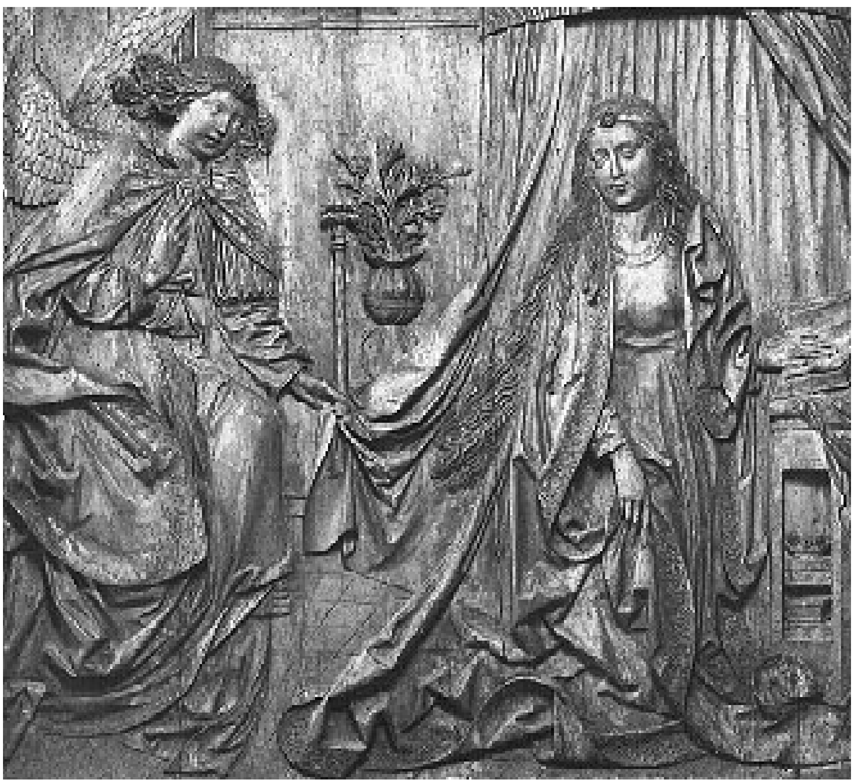

Figure 1
Martin Schaffner (attrib.), *Annunciation,* ca. 1515, before restoration. Relief on panel, 104.8 × 118.1 cm. Ulm, Germany.

Figure 2
Martin Schaffner (attrib.), *Annunciation*. Back of the relief before restoration.

The relief is composed of four vertical slab-cut boards, reversed and glued together (Marette 1961). It was reinforced with seven 3 cm thick limewood boards (five uprights and two crosspieces), apparently glued and held together by forty screws (Fig. 2). For hanging, two attachments, each affixed by three screws, were added to the upper crosspiece; the frame was held in place by four long nails inserted into the sides of the cradle. Two 3 mm wide cracks had run up the whole length of the panel, while two shorter ones, each about 50 cm long, started upward from the bottom of the panel. The wood has been heavily eaten by *Anobium punctatum* worms. A prior restoration is indicated by numerous fillings of holes, reconstructions in places with wood filler, and portions of various sizes reworked with limewood. Tunnels left by xylophagous larvae, visible on the surface of the relief, suggest that the panel may once have been painted; the small remaining amount of ground does not allow us to be more definitive. The maximum thickness of the relief is 10 cm. The cradle, with its two crosspieces, created the stresses in the panel that caused the cracking discussed above. Therefore, the cradle had to be removed.

Treatment

The relief was placed facedown over a thick pad of foam; the cavities in the wood were then filled with pieces of the same foam cut to size. The boards were removed one at a time; they were first cut into pieces of various sizes according to the thickness of the relief and the location of the cracks. Each piece was then thinned down with a chisel, and the surface was carefully finished with a scalpel and damp pad, which removed all traces of animal glue. This work uncovered nails and wooden pegs that had been inserted from the front of the panel to maintain the reconstructions. The back of the relief being very uneven and the cradle boards quite flat, the cradle boards had not adhered in all places, and in some areas the glue was 2–3 mm thick between the relief and the cradle—it is easy to imagine the stresses these irregularities caused on the surface of the wood. After cleaning, saw marks became visible on the back, indicating that the panel had been thinned by sawing (Fig. 3). The relief, now in several pieces, had to be glued together again.

As the relief was not solid enough to support itself in its frame, a new structure had to be built. There were many options. The relief is very irregular: heavy and thick, especially at the left and right margins, and thin in the center for almost the whole height. A light support was required, capable of adapting to the potential movements of the original, including swelling, shrinking, and convex and concave warping. Moreover, the back of the panel is very uneven. After a few weeks, during which the relief was left flat without constraints, a cradle design was selected: it was to be made of small balsa-wood pieces, 10 cm long, 4 cm wide, and 1.5 cm thick, glued in two staggered layers, with the grain direction following that of the relief. The size chosen for the pieces was related to the width, height, and thickness of the relief, as well as to the irregularities of the surface.

The back of the panel was very uneven and had many holes, which needed to be filled in to even out the surface to some extent. Sheets of limewood veneer, with the edges thinned down and the angles and edges rounded, were adhered to the panel with Keimfix and clamped. After several attempts to fill other holes with various glues, these other cavities were filled with sifted limewood sawdust mixed with ethyl cellulose glue in a toluene solution: this produced a fine, soft, and easily worked elastic paste. Next, the back of the panel was coated with a solution of 10% Paraloid B72 in toluene, to isolate the panel from the wax used to attach the cradle, thereby preventing penetration of wax into the panel's wood. This wax is a 50–50 mixture of beeswax and Lascaux 443-95 adhesive wax (pure beeswax would not have been strong enough; the adhesive wax would have been too strong). The wax mixture was heated in a double boiler and brushed on the back of the panel; the mixture was then warmed with an industrial-type heat gun to spread it evenly in a thin layer.

The cradle was started in a vertical line in the center of the panel. The balsa pieces were dipped in the hot wax and arranged side by side as one might build a wall. However, before they were actually glued, they were set into place to see how well they fit. If there was a gap between

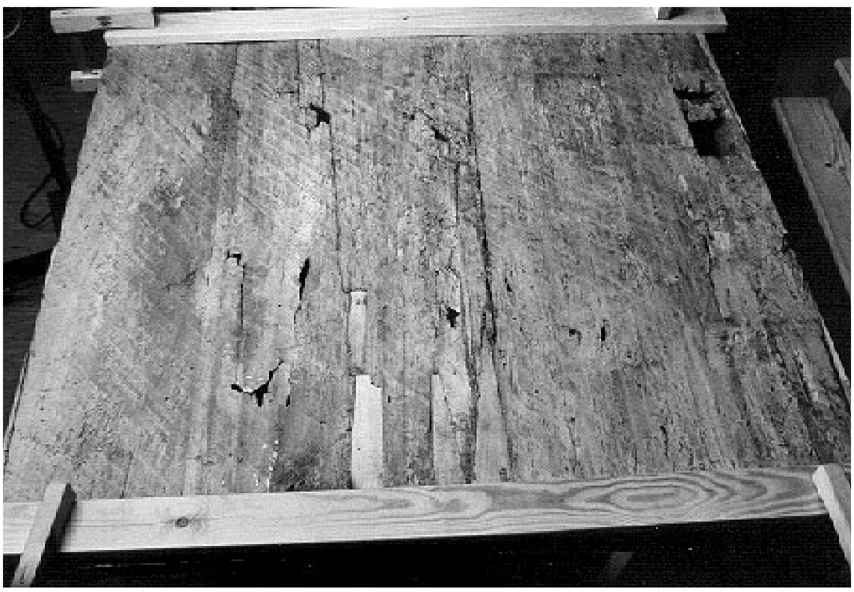

Figure 3
Martin Schaffner (attrib.), *Annunciation*. Saw marks on the back of the relief.

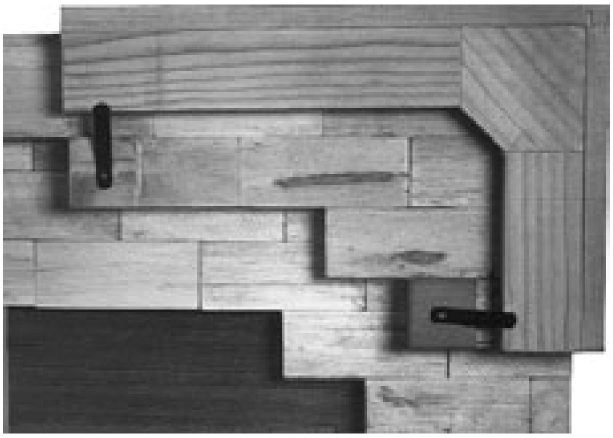

Figure 4
Martin Schaffner (attrib.), *Annunciation.* Model showing the construction of the cradle and the new attachment of the frame.

the panel and the balsa, an extra piece of balsa was shaped to fill in the gap; if, on the other hand, there was a protrusion on the panel, the block was shaped or grooved to accommodate the protrusion, allowing the block to fit closely against the relief panel. The blocks were then glued down. Once the first layer was finished, it was leveled by planing. The second layer of balsa was placed in the same direction as the first but was staggered so that the joints were not superimposed (Fig. 4). That layer was also planed down after it was in place. The edges were smoothed all around and the cradle brushed with a solution of 10% Paraloid B72 in toluene, a coating intended to ensure a good finish. The first phase of the treatment was over.

The problem of maintaining the relief in its frame, however, remained. As the frame was made simply of four lateral gilt-edged boards, the question arose of how to attach it to the relief. Four boards were added to the inside of the frame, so that an opening was left in the back. They were glued and pegged; then cleats were glued on the cradle 1 cm from the inside of the frame with pure Lascaux 443-95 wax, and springs were screwed onto the cleats to hold the relief in the frame (Figs. 4, 5).

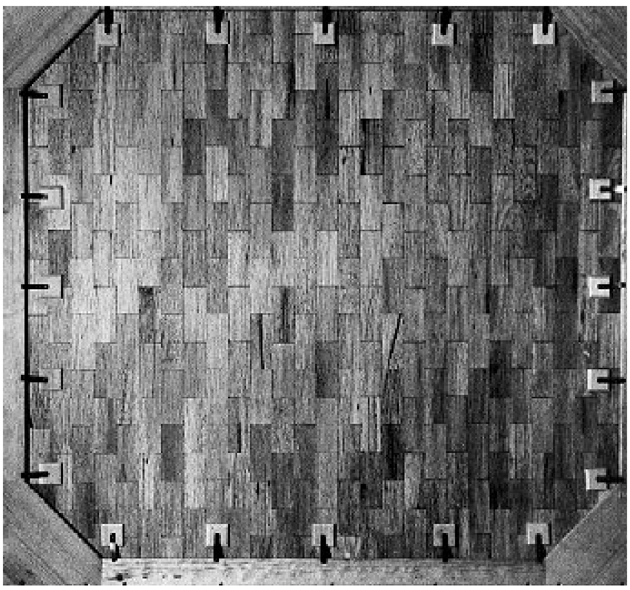

Figure 5
Martin Schaffner (attrib.), *Annunciation.* Back of the relief after restoration.

The advantage of this structure is that it allows the relief to move freely in all directions within the frame. The attachments for hanging were affixed to the back of the frame and not, as previously, on the cradling. Finally, the surface of the relief was cleaned, and the old repairs, putty fillings, and gaps were reintegrated with watercolor.

The restoration was completed on 5 May 1982 and has been inspected regularly since then. It remains in good condition.

Materials and Suppliers

Ethyl cellulose glue (N 50), Hercules Inc., 910 Market Street, Wilmington, DE 19899.

Keimfix, Keim Leim AG. and Co., Mechternstr. 57, 5000 Cologne 30, Germany.

Lascaux 443-95 adhesive wax, A. K. Diethelm AG, Ch 8306 Brüttisellen, Germany.

Paraloid B72 (in U.S., Acryloid B72), Rohn and Haas Co., Independence Mall West, Philadelphia, PA 19105.

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Backings of Painted Panels

Reinforcement and Constraint

Jean-Albert Glatigny

Backing panel paintings with balsa-wood blocks glued with wax-resin is an uncommon technique rarely used by the Institut Royal du Patrimoine Artistique, Brussels (IRPA). In ten years, it has been applied to only about ten paintings. These were oil paintings on oak panels from the sixteenth or seventeenth century that needed to be reinforced, maintained, or constrained for stability or display. At IRPA, reflections regarding this type of treatment have been based on the published descriptions of several authors (Buck 1970; Spurlock 1978; Beardsley 1978; vom Imhoff 1978).

Since at IRPA reversibility is considered to be an absolute requirement for an adhesive, we opted for damar wax-resin rather than a tridimensional resin. Subsequently, collaborative work with our French colleagues[1] as well as comparative studies made by students (Habaru 1990–91; Mori 1992–93) have enabled us to refine this technique. Each intervention has led to discussion and research aimed at improving the technique and adapting it to the specific problem of each panel.

First, the two types of deterioration of painted panels that we believe justify a balsa backing will be described. The choice of materials and work method will then be explained.

Reinforcement of Thinned Panels

Frequently, panels are found whose original construction has been altered by earlier, well-intentioned restorers. The history of treatments for painting supports has seen many changes in fashion. Some problematic panels underwent the addition of crosspieces, cradling, or even transfer. To perform these so-called restorations, the supports were thinned down or eliminated.

Today these restorations are faulted, first, for radically transforming the structure of the work and, second, for proving ineffective. Moreover, the irremediable loss of technological and historical evidence is very unfortunate. These restorations must now often be reversed to save the lifted and distorted paint layer. Once the additions have been eliminated, we are left with a work whose support is so thinned down that it is no longer able to stand by itself.

The backing of these thinned-down panels with balsa-wood blocks adhered with wax-resin presents a significant advantage—namely, the method is easily thermoreversible. Because it is made up of a multitude of waterproof cells whose pure cellulose walls are difficult to permeate, balsa wood is an inert material that is not subject to distortion over time. Once the panel is backed, it is resistant but not much heavier. The adhesive used, a mixture (by weight) of seven parts beeswax and two parts damar resin, is relatively flexible, and its adhesive strength is moderate. These particular qualities, while they contribute security to the panel, are at the same time the technique's weak point. Paintings treated this way will require special precautions, especially with regard to mechanical shocks and high temperatures.

Constraint and Straightening of Distorted Panels

Panel paintings, which don't have a paint layer on their reverse, are often more or less convex. If the distortions are distributed evenly over the whole of a panel, the viewer will not be troubled. But the presence of a single, limited distortion can be so disturbing as to alter the look of the painting completely. These distortions have internal causes—for example, the wood's nature, density, or method of conversion (the way it has been sawn). They emerge as a result of poor conservation conditions, such as serious fluctuations of relative humidity (RH) and the constraints wrought by framing.

Balsa-wood backing glued with wax-resin has been used to maintain distorted panels after flattening. The method consists of increasing the water content of the whole panel in an air-conditioned chamber and locally applying damp compresses over extremely distorted areas. The aim is to reach a point of balance at which the boards recover their inherent flatness. Once this condition is achieved, the backing is applied to the whole back of the panel. Balsa-wood backing with wax-resin acts as a mechanically uniform maintenance device; moreover, it slows down humidity exchanges. It forces the panel to remain flat during the drying period, a process that completes the treatment and subjects the wood cells to plastic distortion. The return to an RH of about 60% takes place gradually, in a matter of two to three months.

Balsa-wood backing, in this case, fulfills a provisional function. It can be removed as soon as a panel is stabilized in an environment where the RH is controlled. To date, however, as a precaution, such backings have been left on. Balsa and wax-resin act as barriers against humidity.

The advantage of this technique lies in the fact that if the constraint on the drying panel is higher than the adhesive strength of the wax-resin, the backing will come unglued. In such a case the panel will reassume some curvature and will not be threatened with splitting.

Among the treated paintings, three thin (less than 2 cm) oak panels that were formerly distorted are currently backed. This way, while keeping them at a stable RH, we have succeeded in keeping them flat. If the RH were not controlled, the backing would retard the emergence of distortions, but it would not prevent them. The treatment can be applied again if necessary.

Materials

Balsa wood is commonly used in restoration. It is valued for its extremely low shrinkage, its light weight, and its waterproof qualities. The kind used at IRPA comes from Ecuador, and its weight varies from 80 kg m^{-3} to 290 kg m^{-3}. The elements used were all of the same density, 170 kg m^{-3}.

After experimenting with rectangular, square, and hexagonal blocks, in radial and transverse conversion, we opted for 8 cm squares that were 1 cm thick. The sawing was done in a transverse direction on end-grain wood in order to obtain elements that were as rigid and as easy to work with as possible.

The adhesive is a mixture of seven parts beeswax and two parts damar resin. This adhesive is one that has been used for fifty years by IRPA for certain relinings of painted canvases and for consolidations of paint layers as well. To make the adhesive, raw beeswax is obtained from a beekeeper. It is then washed in boiling water and filtered. This weak adhesive, solid at room temperature and liquid at 60 °C, is stable and flexible, and it can be easily dissolved or reactivated. It is also a good barrier against humidity. It impregnates only the surface of the wood. The reverse of a panel is traditionally sized with rabbit-skin glue at the time of manufacture. This method of insulation, which prevents penetration of the wax, is an option to consider before backing.

Method

Before a panel painting is backed, the adhesion of the paint layer is examined. A facing is applied to the painted surface, the joints and splits of the support are glued, and the lacunae in the wood are filled.

The painting and the balsa blocks are then brought to the same RH level. With a brush and spatula, a layer of warm wax-resin is applied over the entire reverse of the panel, in order to level the irregularities in the wood surface. The wax-resin mixture shrinks as it cools. To control the extent of shrinkage, it is applied in thin, successive coats. The balsa blocks are immersed for a few seconds in the melted adhesive, positioned on the cooled layer of wax-resin on the panel's reverse, and held in place until the wax cools.

The joints between the blocks are aligned diagonally with regard to the grain of the boards that form the panels. Two levels of blocks are glued in this way, the second level being staggered so that the joints are not superimposed. Experience has shown that the joints are the weak point in the handling of panels, and therefore, that a rigid support is desirable. The most rigid support is achieved with balsa blocks sawn in a transverse direction, then placed in two staggered layers, diagonally with regard to the panel's grain.

A sheet of very thin, long-fiber paper (12 g m^{-2}), such as bamboo-fiber paper, is next glued with wax-resin to the backing. After gluing, this paper is transparent. It allows for the control of the possible opening of the joints, and it holds the blocks in place in case of significant ungluing.

The treated panel must be replaced in its frame, which fulfills a dual function: it distributes strains during handling, and it supports the painting when it is hung.

Straightening of a Distorted Panel

A balsa backing was carried out in the conservation-restoration workshop at La Cambre school, Brussels, where the author teaches. Paul Duquenois, a fifth-year student of painting restoration, was in charge of this treatment.

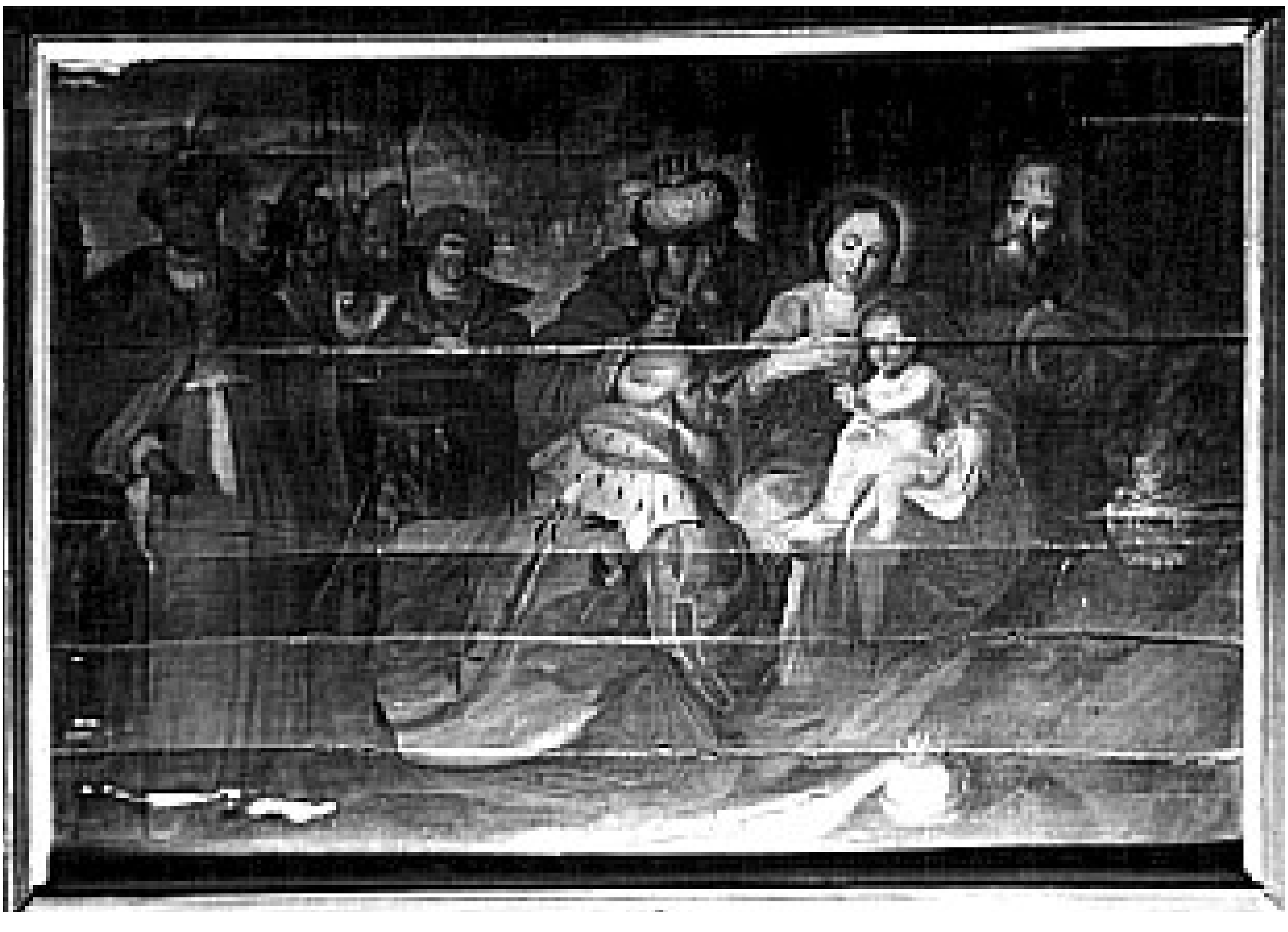
The painting, which represents the Adoration of the Magi, is a seventeenth-century oil-on-wood panel attributed to a member of the very productive Francken family of Antwerp. The support consists of three thin (8 mm) oak boards, sawn on the false quarter and held together with pins. The panel measures 71.4 × 104 cm. The seal of the guild of Antwerp, a castle and hands, is stamped on the reverse.

The panel comes from the museum of the city of Ath, located in a large eighteenth-century house whose rooms are damp and barely heated in winter. There is no RH-control system. The harsh climatic conditions had caused serious damage to the support. The joints of the panel, blocked in its frame, had come apart, and several cracks had appeared (Fig. 1). The boards presented a severely convex profile, in addition to a spiral distortion. Tunnels of xylophagous insects had caused the wood to become more reactive to variations in RH.

Except for an old restoration consisting of glued strips of linen over the open joints, the support had never been altered. The paint layer, however, was coated with numerous overpaintings. To mask irregularities in the support, the joints and crack areas had been broadly filled in and retouched.

The distortions were disturbing to the viewer and made it impossible to frame and display the work. Therefore, a decision was made to straighten it with a backing while leaving the Antwerp seal visible. The treatment of the support consisted first of eliminating the linen reinforcements, then consolidating the worm-eaten wood with a solution of 10% Paraloid B72 in paraxylene, and finally of gluing the splits and joints (Fig. 2). All the cavities were filled with oak sawdust sifted to less than 0.25 mm in a 25% polyvinyl acetate and water emulsion. Subsequently the paint layer was protected by a facing of silk paper glued with beeswax, and the panel was placed in a microclimate box, where the humidity was

Figure 1
Francken family (attrib.), *Adoration of the Magi,* seventeenth century. Oil on panel, 71.4 × 104 cm. Musée Athois, Ath, Belgium. The condition of the painting before conservation, with splits and cracks, is shown.



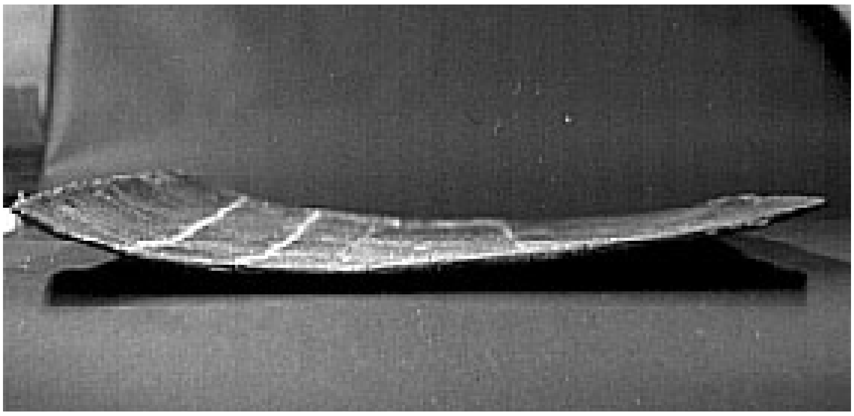


Figure 2
Francken family (attrib.), *Adoration of the Magi*. The panel is shown after the gluing of the splits and joints, and before straightening.

gradually increased. At 75% RH the panel was practically flat; it showed some remaining spiral distortion but had gained good flexibility (Fig. 3). At this juncture it was kept flat in a room where the RH had been stabilized at 75%. A layer of beeswax and damar resin (seven parts to two) was spread over its surface. The wax-resin was applied with a warm brush and smoothed out with a heating spatula. After it cooled, the first 1 cm end-grain layer of balsa wood was placed diagonally across the surface; then the second was placed, overlapping the first (Fig. 4). Finally, the excess wax-resin was wiped off after it had been heated with warm air, and bamboo-fiber paper was glued with the same adhesive. Oversized balsa blocks were sawn to fit the panel. The Antwerp seal was made visible again when an opening was cut out of the backing (Fig. 5).

The panel was gradually brought back to 50% RH. Once the facing was removed, the painted surface was cleaned and retouched (Fig. 6). The painting was fixed in its frame with springs and returned to the museum in Ath. In the year since, no distortion has been observed. The balsa-wood backing provides the work with good support and excellent protection from that environment's significant fluctuations of RH.

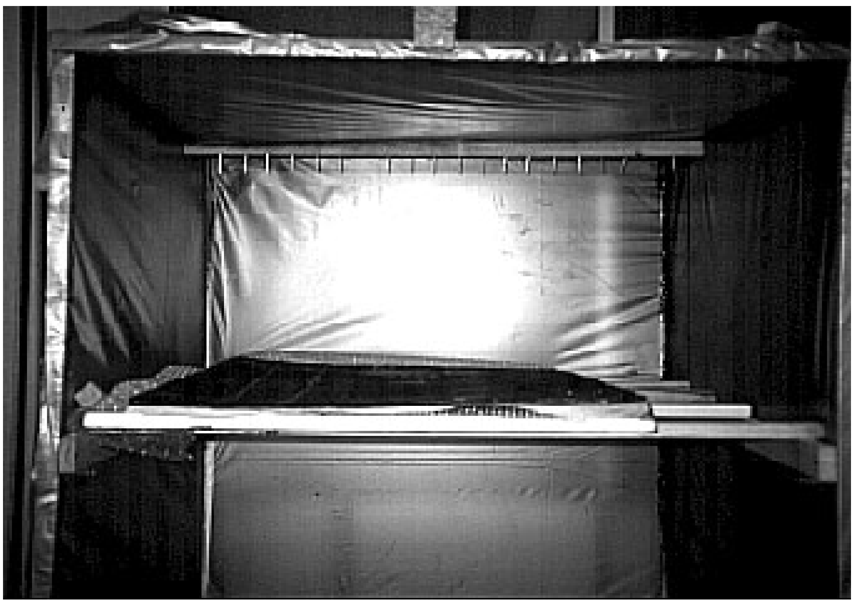


Figure 3
Francken family (attrib.), *Adoration of the Magi,* in a microclimate box. The panel has been considerably straightened.

Figure 4
Francken family (attrib.), *Adoration of the Magi,* reverse. A second layer of balsa blocks is placed on top of the first layer.

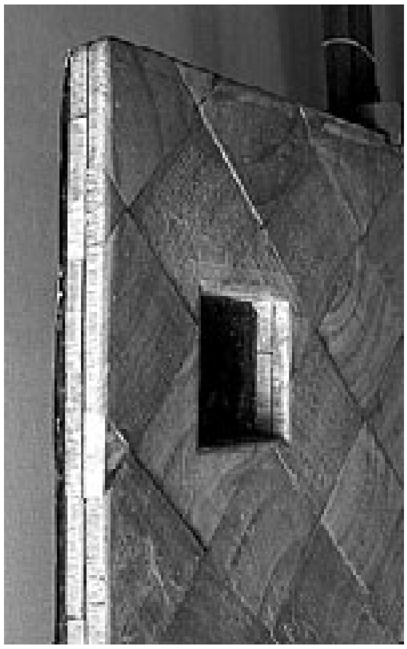


Figure 5
Francken family (attrib.), *Adoration of the Magi,* reverse, detail. An opening cut in the backing allows viewing of the Antwerp seal.

Figure 6
Francken family (attrib.), *Adoration of the Magi,* after conservation.

Note

1 Patrick Mandron, from the Service de Restauration des Musées Nationaux; Aubert Gérard, from the Centre Régional de Restauration et de Conservation des Oeuvres d'Art; and Jean-Albert Glatigny, from the Institut Royal du Patrimoine Artistique backed two paintings on limewood, using the balsa-wood/wax-resin treatment. These works, which are by Lucas Cranach the Elder, represent Saint Peter and Saint Paul, and they belong to the Louvre Museum.

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A Flexible Unattached Auxiliary Support

Simon Bobak

A large proportion of panel paintings that have been thinned and cradled exhibit damage caused by the cradle or signs of stress from it. Environmental conditions play a large part in this equation. Much can be done by altering the environment to achieve stability, even with the cradle left largely unaltered.

However, many panels are so stressed or damaged by the cradle that it is essential to remove it. Some thinned panels are self-supporting but vulnerable after removal from the cradle, basic consolidation, and rejoining. Their response to environmental changes can be rapid and damaging. In some cases an unattached auxiliary support can offer further protection and stability—more than that provided by careful framing and fitting of backboards. The auxiliary support allows reduced movement of the panel within set limits. The panel is able to become alternately convex and concave with changes in relative humidity (RH) while being retained in the panel tray.

Cradling

The reasoning of the cradle maker when thinning and fitting a cradle to a panel is as follows: The panel is thinned sufficiently to allow it to be flattened without immediate obvious damage occurring, and the cradle is then glued in place. It holds the panel in a flat plane while allowing cross-grain expansion and contraction. The elements glued in the grain direction are sometimes used to reinforce joins, damages, and splits while retaining the sliding battens at suitable intervals. The sliding battens hold the panel in a flat plane and provide rigidity for the complete structure.

Several factors have been either disregarded or underrated in the design and construction of cradles. For example, the influence of the glued members lying parallel to the grain should be considered, inasmuch as the overlying areas of the panel are more stable, more rigid, less hygroscopic, and stronger than the unsupported areas; areas of adjacent stress concentrations close to the glued members (Fig. 1)—where the stress transitions are greatest—can show effects such as those seen in Figure 2a and 2b; the relative freedom of the unsupported areas between the glued members allows them to react to stress and develop "washboarding" from differential movement movement (Figs. 2b, 3a), and the differential caused by unequal stresses can result in, or exacerbate, blistering and flaking in the ground and paint film. It is important to note that all of these points

Figure 1
Representative areas of stress concentration (marked by arrows) in a cradled panel.

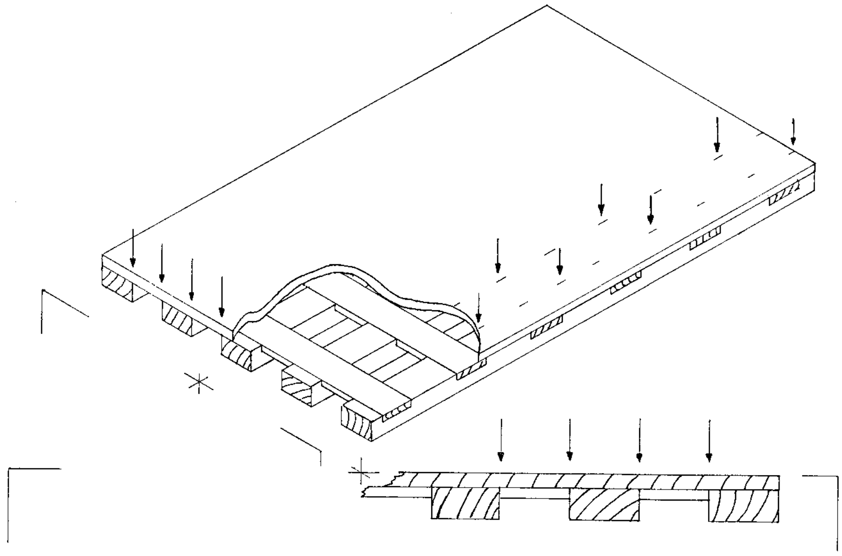


Figure 2a, b
Damage caused by a cradle (a), and washboarding caused by a cradle (b).

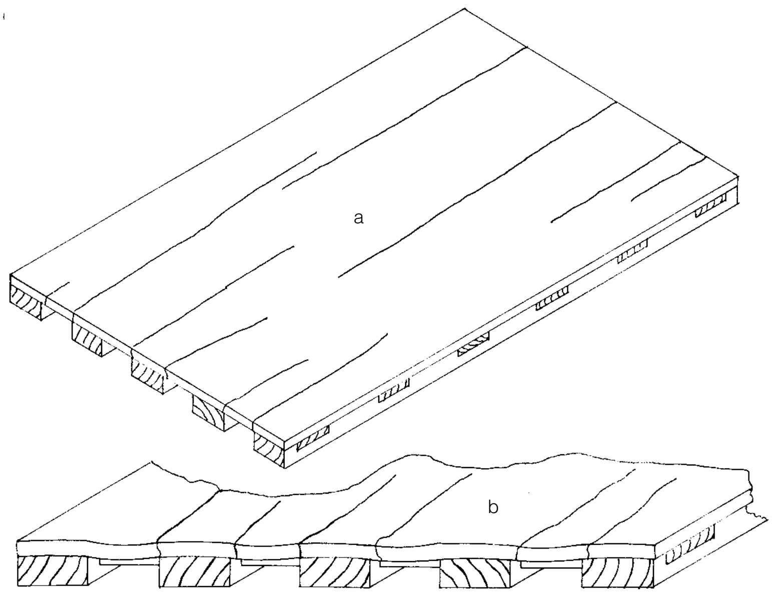
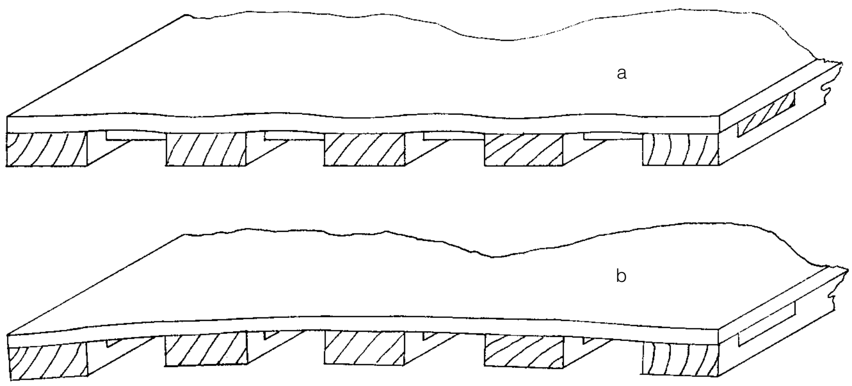


Figure 3a, b
Washboarding. This phenomenon is more pronounced when the sliding battens are in place (a); note the new camber when the sliding battens are removed (b).



assume the correct functioning of the cradle. In practice, however, many cradles "lock up" (because of inadequate clearance, poor construction, or overgenerous use of glue in assembly), causing the type of damage typically exhibited by functioning cradled panels—although the damage is often more severe.

Modifying the cradle

The type and amount of stress and damage from the factors discussed above will determine the degree of intervention required. Decisions about intervention are made on the basis of experience rather than of analysis. It may be possible to remove the sliding battens from the cradle safely and, by observing the change in curvature, make an assessment of the amount of stress within the panel. The difficulty of removal and the abrupt change in curvature can make this a hazardous procedure, one requiring considerable care and experience. After the removal of the battens, it is important to monitor the movement of the panel through several cycles of low and high RH. It may take some days, depending on the RH required, for the panel to reach an initial equilibrium, such as that shown in Figure 3b.

Some thinned, cradled panels show no signs of obvious damage. Even if it has caused washboarding, a cradle may not appear to have promoted further damage. It may be sufficient (and, indeed, prudent) to ensure the free movement and function of the cradle by one of the following means: removing the sliding battens and sanding them to achieve a looser fit; reducing the thickness of the battens even further to increase their flexibility, a technique that allows the cradle and panel to achieve a degree of curvature, as seen in Figure 4a–d (the relationship between

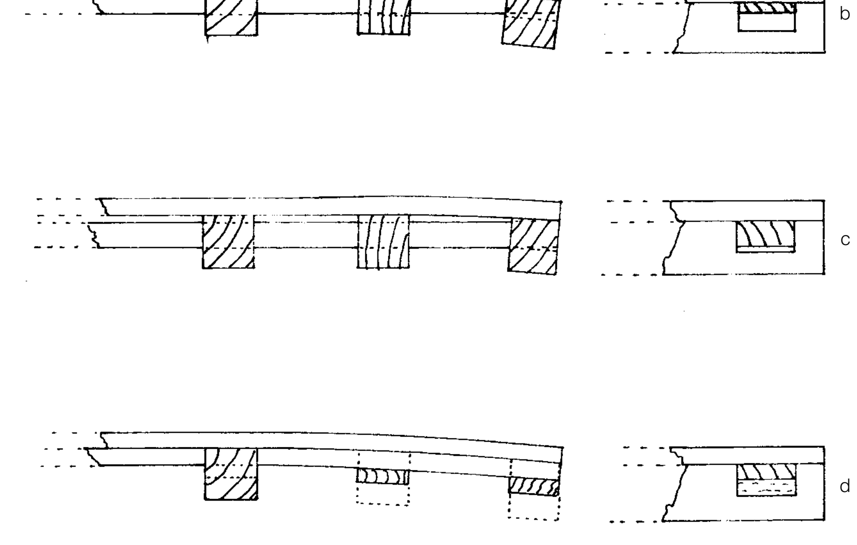


Figure 4a–d
Side elevations and end views of sliding battens and cradled panels showing reduction in thickness by four methods: (a) the battens relieved on the back face at their tips, a technique that increases cradle flexibility at the outer edges; (b) the battens relieved on the front face at their tips, a technique that increases their flexibility and allows an immediate unrestrained increase in panel curvature at the outer edges; (c) the battens slightly reduced in thickness, a technique that ensures their free movement and the basic functioning of the cradle, with very little increase in cradle flexibility; (d) the battens significantly reduced in thickness, and the consequent gaps in the glued members filled with packing spacers, a technique that increases cradle flexibility.

thickness and flexibility is fully explained in Marchant, "Development of a Flexible Attached Auxiliary Support," herein);[1] or applying self-adhesive Teflon PTFE tape to the sliding battens to reduce friction.[2] If needed, in addition to easing the cradle, other possible improvements include construction of shaped slips for the frame that follow the panel's profile; assurance of adequate retention in the frame even while it accommodates some change in curvature without excessive restriction; fitting of backboards, which also offers additional physical protection and slows the rate of moisture exchange; provision of microenvironments (such as microclimate boxes, glazing, and backboards) to stabilize the panel; and control of the environment in the room or display area by attention to heat sources and local hot spots (such as fires and picture lights), drafts, and proximity to windows, outside walls, and direct sunlight. While in many cases these measures may be sufficient, some panels are so stressed or damaged that complete removal of the cradle is essential.

Cradle removal

Although this article does not propose to cover cradle removal in detail, the following points should be considered: humidifying the panel before cradle removal can reduce any sudden changes in curvature;[3] making a bed that follows the panel's curvature and irregularities and safely contains the panel is vital;[4] and determining in advance the progression or direction of removal is important, as it is possible inadvertently to increase the stress locally while reducing it in another area.

The reaction of the panel to cradle removal may be discernible as having several stages. The removal of the sliding battens can often trigger an immediate increase in curvature. The removal of the glued members down to a veneer thickness may not alter the curvature further. The removal of the remaining veneer and animal glue can sometimes cause the panel to increase its curvature (Fig. 5a–f), although it may occasionally decrease the curvature.

After cradle removal, rejoining, and consolidation of any damaged areas, the panel may be self-supporting, although fragile and difficult to handle safely. In that case, an unattached auxiliary support may be considered as an option to support and protect the panel while allowing it movement.

Suitability of a Panel for an Unattached Auxiliary Support

Size and thickness

In practice it has been found that panels larger than approximately 1 m × 75 cm are not easy to accommodate using this system. Either they are of such thickness that they do not require an unattached auxiliary support or they are too thin, their strength-to-weight ratio being such that an attached auxiliary support is required.

In addition, with a very thin, large panel, the weight alone can trap the bottom edge and reduce the panel's ability to move with changes in humidity. This may lead to damage, even when Teflon PTFE is used to line the frame/tray rabbet.

Type of wood

There are great variations in the rate and amount of movement among different types of wood, even aside from variations resulting from the cut

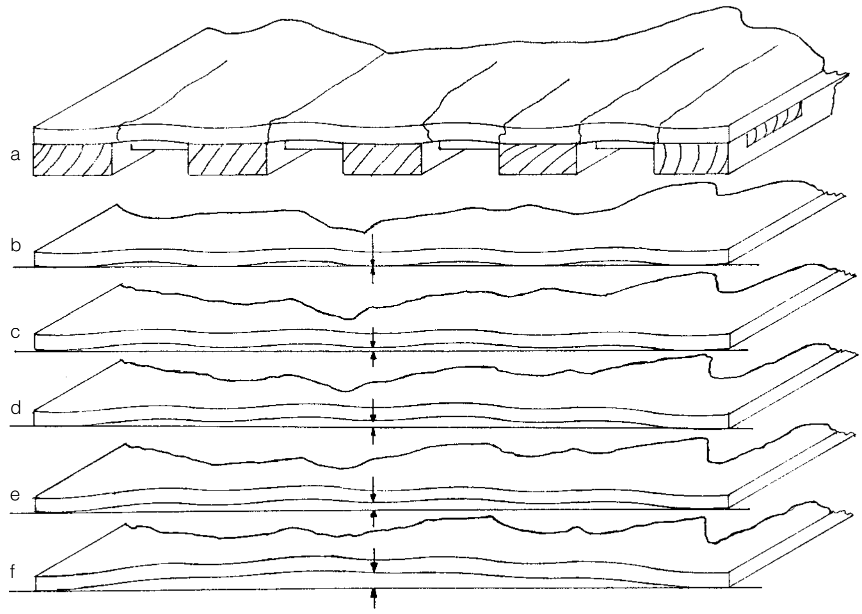


Figure 5a–f
When the cradle is removed from a cradled panel (a), the panel (shown in five sections) assumes typical curvature profiles (b–d) as it moves toward an initial equilibrium (f).

of the timber, irregularities, or damage. No definitive rules can be followed, but the amount of movement a panel is expected to make must be considered. The depth of the frame or tray required will need to be considered if the curvature is expected to be great.

Grain orientation

Preferably, the grain of a painting panel should be vertical, because the endgrain is less prone to accidental damage and compression and is best at load bearing. When the grain is vertical, the flexible battens also function more easily because the bottom edge is less likely to be trapped, as there is no change in the angle of the bottom of the panel in relation to the tray's bottom rabbet. However, a panel with a horizontal grain direction can still be accommodated by the tray and flexible support if attention is paid to the weight of the panel and to its bottom bearing edge with regard to its frictional resistance to movement.

Panel condition

In assessing the condition of a painting panel, several points should be considered, including worm damage; areas of sapwood; timber decay; cracks; checks; repaired splits; original joins and rejoins; buttons,[5] insets, "butterflies,"[6] and other kinds of repairs; and any other previous conservation work. All of these can affect the strength and modulus of elasticity[7] of the panel and must be considered in any assessment. No conclusive advice can be given; however, the conservator must be confident that the panel is strong enough to deflect the auxiliary support safely.

The flexible unattached auxiliary support, described herein as a system for retaining and supporting vulnerable panels while allowing convex and concave movement, could also be considered as an alternative (albeit a time consuming and complicated one) to conventional framing of panels that do not require a support per se. In view of the number of panels that are damaged by misconceived framing techniques, perhaps the greater investment in time would be worthwhile.

Principle of the Auxiliary Spring System

The flexible auxiliary support and tray, in addition to retaining the panel, damp[8] its movement by applying a measured restraint while allowing convex and concave (or reduced-curvature) movement. The flexible battens accommodate an increase in curvature while encouraging a return to the neutral position against the shaped profile of the panel tray. The back spring accommodates concave or reduced curvature and also encourages a return to the neutral position toward the panel tray profile.

The assembly is composed of several parts: the flexible batten, the back spring, the central bearing, and the bases (Figs. 6–9).

Flexible batten

Flexible battens, if correctly rated for flexibility to the panel, are able to be deflected by the panel. This allows for an increase in curvature when the RH drops (Fig. 10). The interdependency of the flexible batten and the back spring should be noted. The flexibility of the batten is increased toward the tip by one of the following methods:

Tapering of thickness

This method involves the reduction in the thickness of the batten by thinning toward the tip from the center. This reduces the stiffness toward the tip, thus alleviating the problem of all the loads being referred inward toward the central area of the panel and, consequently, increasing the moment[9] toward the central axis.

Tapering of width

This method (as outlined in Marchant, "Development of a Flexible Attached Auxiliary Support," herein) is also suitable and may be preferred because graduating the flexibility is more accurate and more easily achieved. (The number and spacing of the flexible battens are covered in

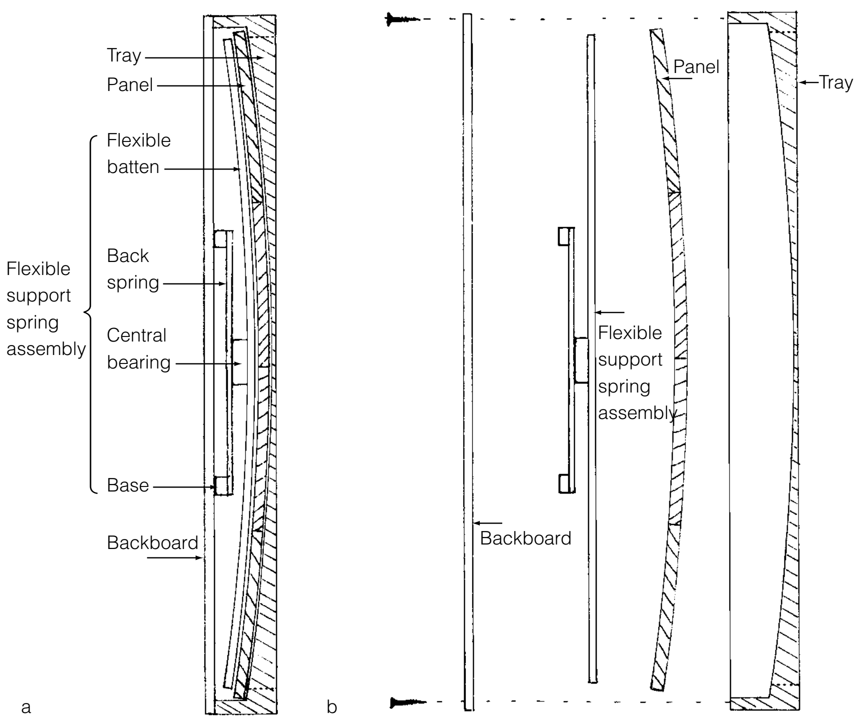
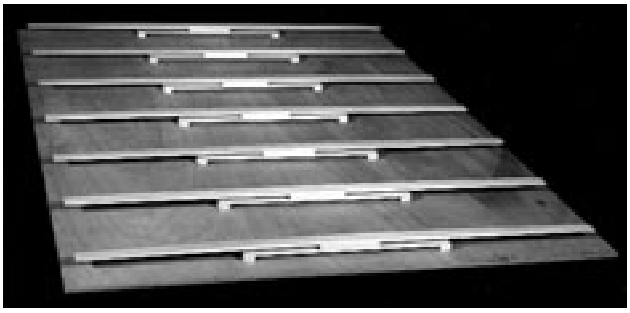


Figure 6a, b
Complete system (a) consisting of a tray, panel, flexible support spring assembly, and backboard; the same components are shown disassembled (b).



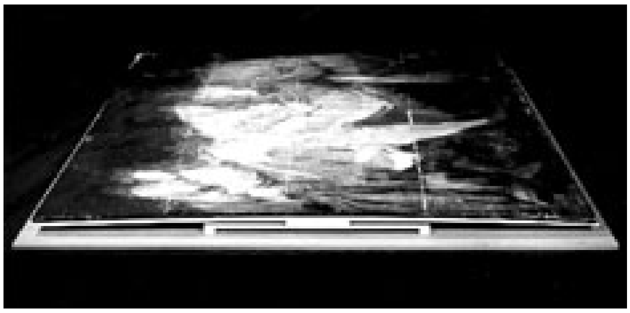


Figure 7, above
Flexible support spring assemblies on a backboard.

Figure 8, above right
A panel in place on flexible support spring assemblies.

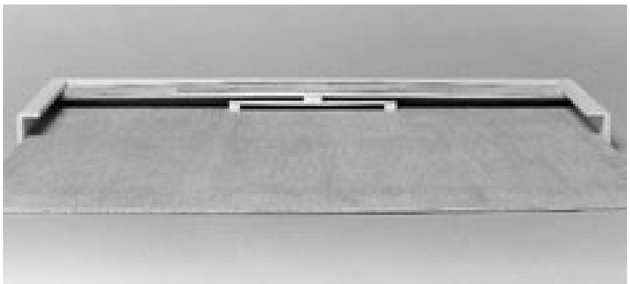


Figure 9, right
Model of the spring support assembly with a panel at a neutral curvature profile (55% RH).

the section entitled "Matching the Support to the Panel," below.) In all cases the flexibility of the battens and back springs combined must be greater than that of the panel in order to ensure that the support yields to the panel.

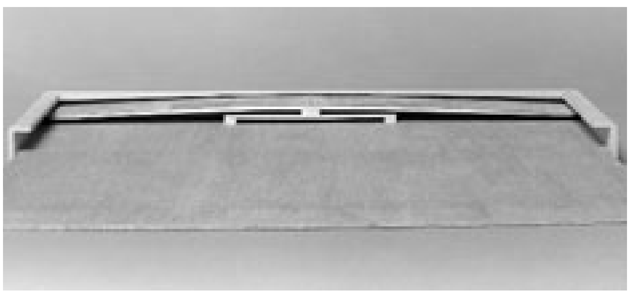
Back spring

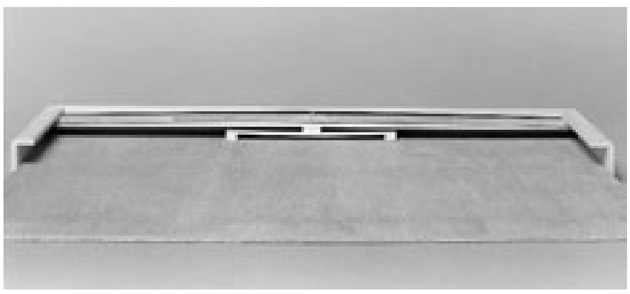
The flexibility of the back spring will determine the preload that keeps the panel in position against the frame rabbet and the ability of the panel to become concave or to decrease its curvature (Fig. 11). The flexibility of the back spring can be varied by increasing or reducing its width, *b*, increasing or reducing its thickness, *d*, or altering its span. These three factors can be adjusted according to the panel's size, weight, and curvature.

It should be clearly understood that the deflection of the back spring is in a constant ratio to load, and most of the forces generated by the panel will be referred to the central area of the panel parallel to the grain if it becomes concave or reduces its curvature from the neutral slip shape. Thus, of the two flexible parts, the back spring can have the more critical influence. However, this fact should be balanced by the knowledge that most problems occur when panels are restrained from becoming convex (viewed from the front) rather than from becoming concave.

Figure 10, below
Model of the spring support assembly with a panel at an increased curvature (low RH) in comparison to that shown in Figure 9.

Figure 11, below right
Model of the spring support assembly with a panel at a decreased curvature (high RH) in comparison to that shown in Figure 9.





Central bearing

The thickness and area of the central bearing is determined by the maximum curvature expected (Fig. 12a), the available depth within the frame and tray, and the desire to make the bearing as short as possible to reduce the "hard point" in the center of the flexible batten and the back spring.

Bases

These form a bridge enabling the back spring to function. Their area and depth are guided by the same factors as the central bearing. The bases are glued at the ends of the back spring and consequently will reduce the effective span of the back spring by their length.

Only one of the two bases should be fixed to the backboard. If both were glued, then a rigid arch would be formed, and the flexibility of the back spring would be greatly reduced. The maximum height of the bases must allow for the further expected deflection of the back spring. In more recent developments, Plastazote foam,[10] sandwiched between timber, has been used in the bases to allow movement in the back spring when both bases are fixed to the backboard (Fig. 12a, b).

Matching the Support to the Panel

By taking profiles at frequent intervals with the RH constant at 55%,[11] it is possible to monitor the curvature of the panel and record its profile when it has reached equilibrium. This curvature, if any, is taken to be the neutral position. When there is regular slight curvature, it is not necessary to shape the battens to the panel, since a small preload is desirable to keep the panel in position against the tray rabbet and to bias the panel's movement in the preferred direction.

Where the curvature is large or uneven, the batten will need packing to the surface profile of the back of the panel. This is done by the use of short, shaped sections of balsa wood glued to the front of the batten. The balsa grain running at 90° to the batten grain will minimize any change in flexibility (Fig. 13).

Safe deflection of the panel

In order to establish safe deflection, test samples and model panels can be made. Although they must not be relied upon to give analytical informa-

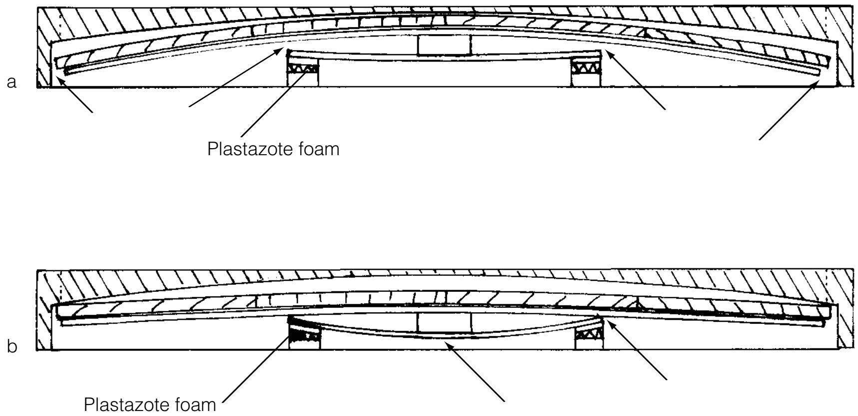
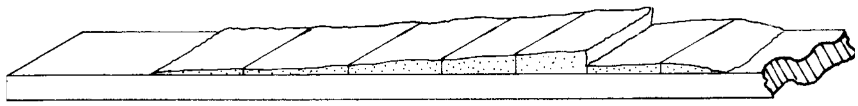


Figure 12a, b
Critical clearance points (marked by arrows) for maximum (a) and minimum (b) curvature.

Figure 13
Part of a flexible batten showing cross-grain balsa-wood packing pieces shaped to fit the back of an irregular panel.



tion, they are nevertheless helpful in establishing the broad range of likely forces. Test samples can never represent the exact structure of the panel, its paint and ground layers, or the weaknesses of irregularities and aging. Gently flexing the panel can help to verify sample data and must be done with the greatest possible prudence. A rig using a spring balance or small weights can also relate load to movement.

Once the total safe load for the panel is established (including a safety margin to ensure that the support will yield to the panel), the safe load is divided by the number of elements in the support to find the load per element, which produces a determined deflection. The flexible batten is then thinned to give the determined deflection at that load. The number of elements in the support will be determined by the area of the panel and the length of the panel along the grain. In practice, most panels have spring elements with centers between 100 mm and 150 mm. The back spring must be just stiff enough to ensure that the flexible batten is held fully engaged, in contact with the back of the panel, thus providing an even support. It must not be so stiff that the concave movement of the panel is restricted.

Effect of batten curvature on panel curvature

To summarize, if the neutral curvature profile of the flexible batten is less than that of the panel, then the panel will be moved toward a flatter plane. If the neutral curvature profile of the flexible batten and that of the panel are the same, then the panel will have no tendency toward either concave or convex movement. Thus it is possible to tailor the spring system to encourage a panel toward a flatter plane.

Construction

The timber used is Sitka spruce (*Picea sitchensis*). It is straight grained, largely free of faults, light, elastic, and of consistent density. It has been used in aircraft construction for more than ninety years and is available with aircraft release notes.[12] The face of the flexible battens touching the verso of the panel can be covered with felt or cotton tapes to protect the panel from abrasion. The panel tray is constructed from hardwood (mahogany or a similar wood) to achieve rigidity for a minimum size of section. Saw kerfs[13] can be cut in the mitered corners and hardwood tongues glued in place to increase rigidity (Fig. 14). This method is especially good for small trays when the timber section is insubstantial. In some cases there may be insufficient space for a tray within an existing frame; it may be possible to use the frame as the basis for the shaped slip pieces and to build up the sides of the rabbet so as to make the frame effectively into the tray. The backboard and spring supports may be fitted by the same method.

All four sides of the panel have their profiles taken, and these are transferred onto the tray edging section. It is generally easier to construct the shaped profiles and glue them into a basic section than to carve them

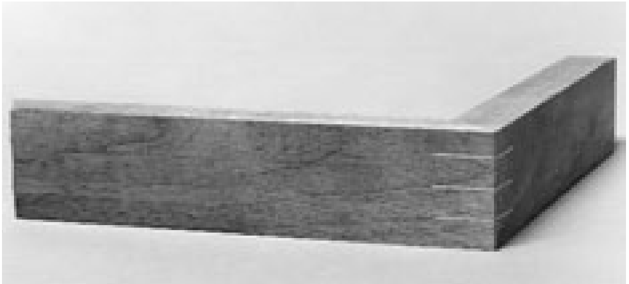


Figure 14
The corner of a panel tray showing saw kerfs in which hardwood veneers have been inserted, to increase rigidity and the strength of the joint.

out of the solid wood. Many panels have a propeller-like twist in addition to any curvature. Such twisting must be carefully considered when establishing datums for construction within the tray in order to balance the diagonal distortion evenly.

All visible edges of the tray can be toned, gilded, and distressed to match the existing frame. Frequently the sight size of the frame is too large, and consequently part of the tray's edge can be made to project beyond the rabbet and become visible as an inner slip.

The backboard is made of marine-quality plywood,[14] which may be obtained with good-quality veneers. Other stable sheet materials may be used, the choice being made on rigidity, thickness, weight, and appearance. The backboard must be strong enough to withstand the loads imposed by the support with little deflection.

The panel is placed in the tray and retained by the spring supports and backboard. The backboard is then screwed into the tray edge section. Finally, the completed assembly is fitted into the frame with brass strips and screws.

Assessment of the Unattached Flexible Auxiliary Support System

There are disadvantages to the flexible unattached auxiliary support system: it is only suitable for a limited range of panels; the assessment of forces and panel strength is largely empiric; some panels and frames will not accept a deep tray without the result appearing ungainly; and it is not possible to see the back of the panel without the removal of the backboard and support. Despite these limitations, there are several advantages to the system. For example, there is a minimum of interference with the original panel; concave and convex movement of the panel is possible without overstressing; known forces are applied to the panel; the panel's movement within the tray indicates changes in RH and alerts conservators to inadequate RH control; RH changes are buffered by the tray and backboard; and physical protection of the panel is provided—an especially important consideration when the panel is out of the frame.

Notes

1 $I = bd^3 \div 12$, where: I = moment of inertia; b = breadth (width); and d = depth (thickness). With a constant thickness, d, if the width, b, is halved, the deflection for the same load will double. If d is halved, the deflection will increase by eight times with the same load (see Marchant, "Development of a Flexible Attached Auxiliary Support," herein).

2 Teflon PTFE (polytetrafluoroethylene) is a tape with very good properties for reducing friction.

3 To humidify a panel, the RH in the room may be increased to 65–70% for several days to reduce the stress within the panel if the convex curvature is expected to be large.

4 A bed may be made from a prepared board that is packed with balsa wood strips of varying size and thickness to support the panel over its entire surface during cradle removal. While the cradle is being removed, it will need to be adjusted continually if the curvature alters.

5 Buttons, also known as cleats, are the rectangular reinforcing blocks frequently glued over the back of the panel to repair cracks. While they are generally cut into the surface, they may be left "proud."

6 Butterflies are the bow-tie or butterfly-shaped repair blocks often cut into the back of the panel to reinforce cracks, splits, and joins.

7 The modulus of elasticity is constant for a particular material. It is the force above which the panel will deform or be damaged and not return to its original condition by elastic behavior.

8 To damp the movement of the panel is to reduce the amplitude of the cycles.

9 The moment is the product of the force and the distance from its point of action.

10 Plastazote foam is a closed-cell, cross-linked polyethylene foam (see Materials and Suppliers).

11 In the United Kingdom, 55% RH is generally considered the best average humidity in which to keep panel paintings.

12 In the United Kingdom, aircraft release notes identify timber that is tested to Civil Aviation Authority standards, for consistency of density, quality, and moisture content.

13 Slits made by a saw blade.

14 British Standard 1088 signifies "marine quality," indicating that the stability and quality of construction are assured by testing. It is not the same as waterproof plywood (WPB), which is produced to a lower standard.

Materials and Suppliers

Plastazote foam (REF LD 24), BXL Plastics, Mitcham Road, Croydon, Surrey CR9 3AL, U.K. (distributed by Hemisphere Rubber Co., 65 Fairview Road, Norbury, London SW16 5PX, U.K.).

Teflon PTFE, CHR Industries, 407 East Street, New Haven, CT 06509. European supplier: Furon CHR Products, P.O. Box 124, 7640 AC Wierden, Netherlands. United Kingdom distributor: Polypenco, now part of DSM Engineering Plastic Products UK, 83 Bridge Road East, Welwyn Garden City, Hertfordshire AL7 1LA, U.K. (The PTFE tape is marketed as Temp-r-tape HM series.)

The Development of a Flexible Attached Auxiliary Support

Raymond Marchant

Most panel mounting and display requirements can be achieved with conventional methods of framing and retention, but occasionally a difficult problem will arise in which recognized methods of support are inadequate. This article documents the development of an alternative approach to some of the more difficult problems encountered in the support of weak or responsive panels.

First Case Study

Description

One such problem occurred in 1989 with the conservation of a large sixteenth-century Flemish panel. The painting, measuring 1.2 × 1.7 m, consisted of six oak boards joined horizontally. It had been thinned to between 6 mm and 8 mm and had a late-nineteenth-century heavy pine cradle attached, constructed from nine fixed horizontal members, each measuring 50 mm wide × 25 mm thick, and six vertical sliding battens, each 60 mm wide × 15 mm thick.

As with so many cradles of this period, the device exhibited good workmanship but was intended to flatten the panel. Because the cradle was of a rigid construction with minimum tolerances allowed for movement of the sliding battens, it was potentially damaging. Subsequent to the cradle's installation, variations in environmental conditions caused the panel's moisture content, and hence its curvature, to alter. The cradle could only accommodate a small change in the panel's warp before the battens became locked, preventing further movement. Stresses then developed, causing fracturing and partial disjoins to occur in a number of places on the panel. An assessment of the condition of the painted surface showed that many of the structural faults had produced corresponding damages to the ground and paint layers.

When the panel arrived for treatment, its profile viewed from the front was concave, and the cradle was totally seized. The panel painting was in very poor structural condition and the concern was that it would deteriorate further. It was considered that just freeing the sliding elements of the cradle would not provide an adequate solution to many of the problems. Therefore, it was decided that removal of the cradle was necessary to complete the repairs satisfactorily, as well as to ensure future stability.

Structural condition

When the cradle was removed, the extent of the weaknesses and damage to the panel could be fully appreciated. One fracture, which ran almost the whole length of the panel, had occurred in an area of worm-damaged sapwood adjacent to a join. The fracture was so severe that one of the board sections was virtually hinged to the main body of the panel only by a number of small areas of intact fibers.

There were also traces of two 10 cm wide cross-grain channels across the panel that could just be discerned in the thinned surface. These traces indicated that battens may have been present before the cradle was fitted. Exposed dowels showed that the panel's original thickness had been reduced by about half when it was thinned. It was likely that this panel had had a history of structural problems long before the cradle was fitted.

After structural repairs, rejoins, and consolidation had been carried out, the panel's cross-grain profile was monitored and recorded several times during a period when the relative humidity (RH) was allowed to vary widely. To judge the panel's response to likely extremes of environmental conditions, its profile was recorded at 40%, 55%, and 75% RH, and its condition was reassessed. Monitoring was carried out with the panel standing vertically on its endgrain.

Released from the cradle, the panel's profile altered considerably, becoming convex when viewed from the front and responding quickly to even small changes in RH. Because of its thinness, the strength-to-weight ratio, although improved by repairs, was so poor that it could be handled only with great care. If laid horizontally, it was subject to the risk of fracture if any attempt had been made to lift it by one of the long-grain edges.

Another cause for concern was an area of severe worm damage, again in a band of sapwood extending across the board, close to the bottom, supporting edge. This weak edge would be subject to damaging forces imposed by the weight of the panel bearing on it and the need for it to move to accommodate changes of curvature. If this natural tendency to warp were again restricted by a rigid secondary support, further damage—caused by compression and/or tension perpendicular to the grain—would be likely to occur.

Identifying the need for an attached auxiliary support

It was apparent that if the panel were to remain stable without suffering further damage, a method of support other than those normally used was needed. Because the problems presented by this panel were known to be difficult to resolve satisfactorily, it was decided that the options should be considered very carefully before a course of action was decided upon. Conventional techniques of support and retention of RH-responsive panels include sprung-metal clips, secured within a frame rabbet; a foam-cushioned panel tray support (Brough and Dunkerton 1984); and unattached auxiliary flexible supports (see Bobak, "A Flexible Unattached Auxiliary Support," herein).

In these examples of unattached supports we find a common principle: retainers exert pressure on the back of the panel, and this pressure—frequently concentrated around the perimeter or on the line of the central long-grain axis—is balanced by the reaction of the lip of the frame rabbet acting against the edge of the face of the panel.

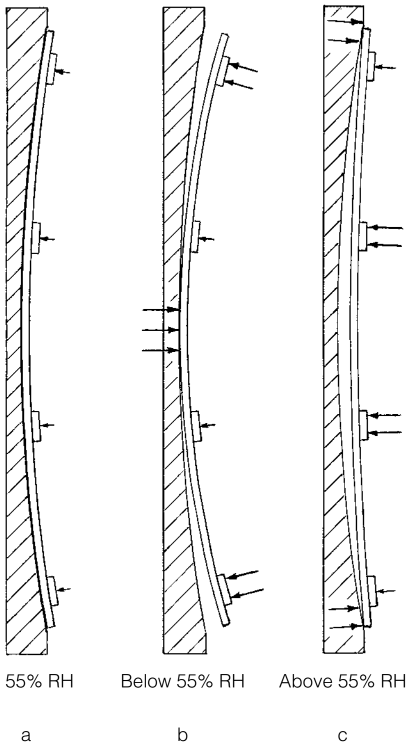


Figure 1a–c
A panel retained against a slip profile using spring framing clips. The magnitude of pressure at these points and the reaction of the profiled support is shown by the arrows. At 55% RH (a), minimum pressure is applied at four retaining points. Below and above 55% RH (b, c), the magnitude of pressure increases and the reaction of the profiled support is concentrated at the contact points. These forces would be similar if other unattached support systems were used as a method of retention.

For a self-supporting panel, a shaped slip would normally be made to suit the panel profile when the panel is stabilized at 55% RH. If environmental conditions remain stable, good contact should be maintained with the shaped slip on all four edges, and only small, balanced reaction forces will result (Fig. 1a). Problems can arise, however, as soon as conditions change (Fig. 1b, c).

Figure 1 shows a panel's response to environmental changes. Differential absorption or loss of moisture content in the panel, due to changes in RH, cause it to warp (Thomson 1978:208–10). The opposing forces illustrated in Figure 1b and 1c may result in bending stresses, which in an already weak panel could result in fracture. These adverse effects are further accentuated when the grain runs horizontally, because the weight of the panel resting on its supporting edge causes frictional resistance to the movement needed to accommodate a change in curvature. In large panels, forces can be magnified by leverage to produce dangerously high concentrations of stress some distance from where the resistance to movement occurs. If an area of weakness exists, failure is likely to occur there. Under these circumstances, the use of one of these types of secondary supports would not be satisfactory.

Having fully assessed the condition of a panel, the panel conservator must make a decision as to whether an attached support will be necessary. After removal of a cradle or damaging support from a panel, it would be preferable not to have to make any further attachment. However, there are circumstances in which this measure cannot be avoided.

As a general rule, if an unframed panel cannot be handled confidently or will not safely support its own weight when placed horizontally on a surface, then an attached support should be considered in order to provide the required reinforcement. It is almost impossible to reinforce a weak panel without using an attached support. But an attached support can be designed to ensure that it is in sympathy with the panel's requirements.

A reinforcing structure is required to help strengthen a weak panel and assist in spreading stresses more uniformly. The other function of a secondary support in this situation should be to act as a restraint by allowing changes of curvature to take place in a controlled manner and within predetermined limits. Therefore, the secondary support should be flexible. This design concept was successfully established by Simon Bobak (see "A Flexible Unattached Auxiliary Support," herein) for the unattached support of small panels but would need considerable development before it could be applied to an attached support for large, heavy panels.

Batten design

In an attempt to design an attached support that would fulfill these basic requirements, an analysis was first made of the effect of attaching a uniform rectangular-section batten to a curved surface. It was hoped that this would also provide a better understanding of why some cradles, even if they allow movement, still have a damaging effect on panels.

The simplified representations in Figure 2a–d show curves achieved by loading a uniform rectangular-section batten. The curvature of the panel is shown exaggerated as an arc with a constant radius of curvature (Figs. 2a, b). The batten is deflected within the arc by the application of a force at its center (Fig. 2b). This situation may also be represented diagrammatically as a simply supported beam loaded at its center (Fig. 2d).

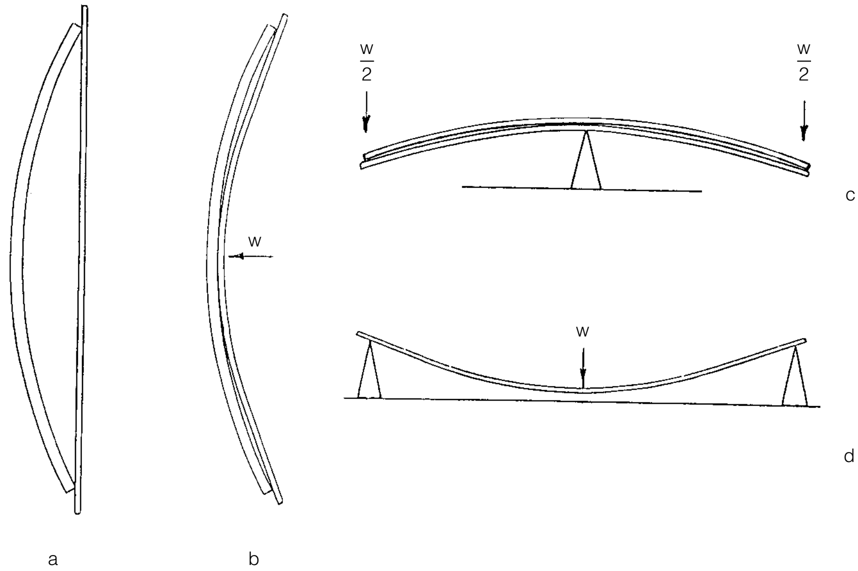


Figure 2a–d
A uniform rectangular-section batten deflected within an arc by a force at its center. A section of panel is shown (a) with constant radius of curvature and a straight uniform-section flexible batten. The batten deflected by a force (W) at its center (b) contacts the curved surface only at the center and the outer edges. A batten supported horizontally at its center (c) deflects in the same way as in b and d when supporting the weight of a curved panel. A batten simply supported at its ends and loaded at its center (d) deflects into a parabolic curve.

If the batten is deflected within the arc by a force at its center, the only point of contact with the arc other than the outer edges will be at the center. The deflection curve in Figure 2b will be the same as that represented in Figure 2d. It will not have an equal radius of curvature over its length but will be straighter toward its ends in the form of a parabolic curve.

To produce contact with the arc at points toward the ends of the batten, greater force would be required at those points to make the batten deflect. If the uniform rectangular-section batten were to be attached at a number of points to the curved surface, as in Figure 2b, it would have a greater straightening effect on the surface (inducing greater tension at the attachment points) toward the outer edges. To avoid the problem of creating high stress toward the edges of panels (which occurs with many conventional cradles), the battens should be made progressively weaker toward the ends.

Shape and section

Ideally, therefore, a batten is needed that would have an equal straightening effect at all points along its length. To produce a batten that will bend with a constant radius of curvature under the conditions outlined, it is useful to understand some basic structural theory. The relationship between stress and curvature of a member when subjected to a simple bending moment is given by the equation:

$$\frac{M}{I} = \frac{E}{R}$$

where: M is the bending moment (a function of load and distance); I is the moment of inertia of the section (a function of breadth and depth); E is the modulus of elasticity[1] of the material (a constant); and R is the radius of curvature.

Therefore, for R to be constant along the length of the batten, EI/M must also be constant. As M decreases linearly away from the center toward the ends and E is not variable, then I must decrease in the same ratio as *M*. As $I = bd^3 \div 12$, either the breadth, *b,* or the depth, *d,* could be chosen as the variable factor to produce the linear decrease.

The breadth of a rectangular-section member is directly proportional to its deflection—that is, if the breadth, *b,* is doubled, then twice the load is required to produce the same deflection. But if the depth, *d,* or thickness, is varied, the stiffness will alter as the cube of *d*. That is, if the thickness is doubled, then eight times the load needs to be applied to produce the same deflection, or if the thickness were halved, then under the same applied load, the deflection would increase eight times.

It follows that it would be difficult to produce the linear decrease required if thickness were chosen as the variable factor. The resulting batten would have a complex curved profile that would be difficult to determine and to execute accurately (Fig. 3a).

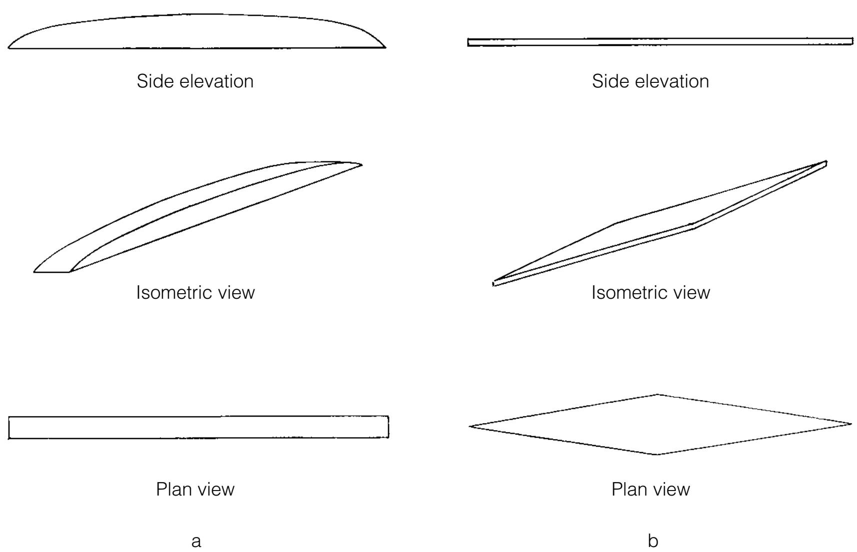
The alternative is to vary the width. Simply reducing the width at a constant rate from the center toward the end satisfies the conditions for producing a configuration of section which will deflect into the uniform curve required (Fig. 3b).

This shape of section is easy to produce. Its flexibility can be increased simply by reducing its thickness, and because it is a flat section, it is easy to incorporate into a support system. If this tapered batten is now brought into contact with a curved surface until it deflects, it will conform more closely to the surface profile. If a number of attachment points are made so that the batten has a straightening effect on the curved surface, the tension at those points will be more equally spread, producing an even restraint.

If calculations are made for deflection based on a uniform rectangular section, which then has its width tapered, the deflection will increase by about 50%. Allowance can be made for this. It is preferable, however, to err on the side of flexibility. An excessively stiff support may damage the panel, but problems are unlikely to occur if the support is too flexible. It should be able to yield to the bending force exerted against it by the panel.

To achieve reliable results from calculations, a suitable timber needs to be specified. The timber chosen for the lattice components was Sitka spruce,[2] which has excellent properties for this type of application. It can be obtained in large, straight-grained, knot-free sections. It is also light but strong, with consistent characteristics of flexibility (i.e., *E* values).

Figure 3a, b
Two configurations of batten shapes that deflect with a uniform radius of curvature.



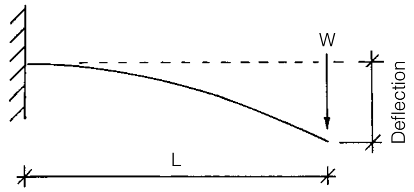


Figure 4
Diagram of a cantilever deflected by point load at end. W = load; L = length of cantilever.

Calculating batten flexibility

To calculate the required flexibility of a batten for restraint, it is necessary to know what bending force will be exerted against it by the panel. When environmental conditions alter, moisture transference in the panel structure generates internal forces. This bending force will produce pressure against anything that restrains the panel from changing its curvature. It is possible to measure empirically how much resistance is necessary to counteract this change, but with a fragile panel, there is the risk that it may fracture before any relevant information is obtained. It is not possible to predict the resistance to bending that a weak panel will withstand before it fails; therefore, some other means of assessing a loading figure for the batten needs to be found. This can be done by considering reinforcement rather than restraint.

For simplicity, the calculation example that follows is based on a batten supported at its center treated as a cantilever, with a fraction of the panel weight used as the load figure (Fig. 4). (This concept will be explained more fully in the section below entitled "Evaluation of batten flexibility.")

For a cantilever, the deflection (Δ) at the end under a single point load is given by the equation:

$$\Delta = \frac{WL^3}{3EI}$$

where: Δ = deflection; W = load; L = length of cantilever; E = modulus of elasticity;[3] and I = moment of inertia.

Example. The following is a calculation of the thickness of the battens that will support the weight of a panel horizontally within a known deflection. All other factors have been specified, including the number, length, and width of the battens and what is considered to be a safe limit of deflection of the panel.

Deflection (Δ)	30 mm	
Panel weight	22 kg	
Number of battens	10	Load at each end of each batten = 1.1 kg Therefore, $W = 1.1 \times 9.80665 = 10.787$
Length of batten	1200 mm	
Cantilever length (L)	600 mm	
Width of batten (b)	50 mm	

Modulus of elasticity for Sitka spruce,
$E = 11100.6$ n mm^{-2}

Moment of inertia, $I = \dfrac{bd^3}{12}$

$$\Delta = \frac{WL^3}{3EI} \qquad \text{Therefore, } I = \frac{WL^3}{3E\Delta}$$

$$\frac{bd^3}{12} = \frac{WL^3}{3E\Delta} \qquad d^3 = \frac{12WL^3}{3E\Delta b}$$

$$d^3 = \frac{12 \times 10.787 \times 600 \times 600 \times 600}{3 \times 11100.6 \times 30 \times 50}$$

$$d^3 = \frac{10.787 \times 576000}{11100.6} = \frac{621.9}{1.11006}$$

$$d = \sqrt[3]{560.24} = 8.25 \text{ mm}$$

Therefore, thickness of batten, d = 8.25 mm

The results of calculations are easily verified using prepared sample battens and weights. It is not suggested that support battens be specified purely by theoretical calculations but rather that calculations may serve as a useful shortcut to produce sample sections for empiric evaluation. It then becomes a question of judgment based on experience to decide whether, or by how much, to alter such a batten to suit the particular requirement.

It should also be stressed that even for those with no understanding of structural design theory, there is at least one important relationship included in the equations that should be recognized. This is the correlation between section thickness and flexibility (as discussed above). In the design of a secondary support, or even in the thinning of battens to ease an existing cradle, the result of reducing thickness by what may appear to be only a small amount can have a very dramatic effect on the flexibility of the support. Conversely, it is very easy to produce an auxiliary support many times more rigid than is necessary to perform its function—with a consequent risk of damaging the panel.

Method of attachment

With the form that the flexible battens should take having been established in principle, the next problem to consider was the method of attachment to the panel.

The main factors to consider were as follows: It should not be possible for the battens to seize, thus restricting dimensional changes in the panel. The attachment of retaining points to the panel should be achieved without the creation of rigid glue areas that are larger than necessary or that extend too far across the grain, as this could contribute to the characteristic "washboard" effect and the tendency to fracture at the transition edges of glue areas. And it would be an advantage if the means of attachment allowed for removal of the battens.

All of these basic requirements were achieved by the use of flexible retaining strips against the surface of the battens, held in place parallel to the panel grain with slotted retaining blocks glued to the panel. The blocks were made narrow in the cross-grain direction, and their size was limited according to the number used. The greater the number of blocks, the less tension each had to bear individually and the smaller the glue area needed for safe attachment. For compatibility with the panel, the blocks were made of oak. Evo-Stik polyvinyl acetate (PVA) woodworking adhesive was used for the glue joins.[4] The number of retaining strips, and hence the distribution of blocks, is determined by such factors as the number of boards making up the panel,[5] surface irregularities that may make attachment points difficult, areas of weakness that should be avoided, and original features that one would prefer to leave unobstructed.

Using retaining strips against the face of the battens instead of anchoring the battens directly to the panel ensured that there was little risk of seizure occurring. However, it was also necessary to stop the individual battens from moving and becoming misaligned. This was done by linking them together in an accurately spaced configuration, with thin, flat timber strips used to create a lattice.

Finally, a supporting timber section was made to fit under the bottom edge of the panel. This skid strip was joined to the tips of the lattice. It provided protection for the weak load-bearing edge, as well as providing

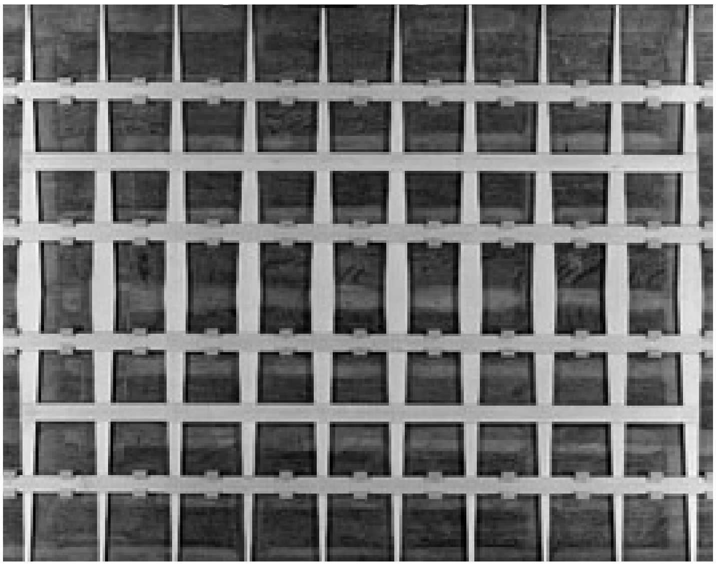


Figure 5
Back of sixteenth-century Flemish oak panel (first case study), 1.2 × 1.7 m, after structural conservation, with flexible auxiliary support engaged, providing reinforcement.

a smooth, flat surface to aid movement, reducing the risk that the panel would stick in the frame rabbet or tray. Free movement was further improved by using Teflon/PTFE (polytetrafluoroethylene) pressure-sensitive adhesive tape[6] to line the rabbet.

Upon completion, the support lattice was attached to the panel by engagement of the flexible strips in position in the retaining blocks (Fig. 5). When this procedure was done, the panel tended to flatten out slightly and, when handled, could be felt to be appreciably less flexible than before the auxiliary support was in place.

Monitoring panel warp

At this stage, the slip profile was considered. Assuming that enough time has been available, the panel should preferably have had its end-grain profiles monitored and recorded three times during cycles of RH—initially with whatever cradle or restriction was in place when the panel arrived for treatment; again, with restrictions removed and the panel totally free to respond; and, finally, with the new support attached. This profile would be expected to fall somewhere between the first two recorded profiles.

Consideration should also be given to simulating the conditions under which the panel is going to be displayed in the future. In some countries the extremes of RH may be outside of the limits normally used in a monitoring cycle (i.e., 40–80% RH). After the slip profile has been determined by monitoring under appropriate conditions[7] with the support attached, some thought can be given to the depth of the tray or rabbet. This depth needs to be sufficient to accommodate the anticipated extreme limits of movement of the panel; it should also be adequate for the spring bridge supports, which will be used to hold the assembly in place within the frame.

Back springs

The principle of using back springs was conceived by Simon Bobak (see "A Flexible Unattached Auxiliary Support," herein) for use on unattached supports. It consists of individual flexible battens, each attached by a center pad to a spring bridging strip, with feet at each end for mounting on the backboard (Fig. 6a).

This arrangement, which allows both increase and decrease of curvature to take place in the panel while it maintains contact with the support, was retained in principle but modified to suit the new lattice design (Fig. 6b).

It was considered that one function of the action of the bridges could be improved if they were inverted with both feet mounted onto the battens, thus providing two reasonably spaced points of pressure against the battens. This arrangement would encourage return movement equally of the top and bottom of the panel to a neutral position, when the curvature reduces, rather than the panel pivoting on the center pads. In order that both feet could be mounted on a surface with variable curvature, the timber pads were given a Plastazote[8] foam core, allowing them to adjust to the changes. The pressure pad, which would now be in contact with the backboard, was also made into a timber-foam sandwich so as to prevent the creation of a rigid area being in the center of the spring strip. The modification to the pads improves the overall cushioning effect and allows differential changes of curvature, dimension, and alignment to be absorbed.

Another advantage gained by inverting the bridges is that a narrow bar can be used to bear against the pressure pads. Previously, if a bar were used, it would have had to be wide enough to engage both bridge feet, or else a backboard would have had to be rigid enough to take the spring pressure without bowing.

If a retaining bar is used to take the spring pressure, then the backboard can be reduced in thickness and weight (which may be considerable on a large panel) and can then act purely as a lightweight environmental barrier (Fig. 6c illustrates this later development). The position of the bar should be such that it engages to produce a slight preload of the spring bridges just adequate to retain the panel against the slip profile. (Note: Most pressure will occur against the bar during high RH, when the panel will tend to flatten, producing a far greater deflection of the spring bridges than when curvature increases.) In this particular case, the backboard was a single sheet of plywood with a reinforcing section of timber glued to the underside to stiffen it (Fig. 6b). In later supports, the improvement of a rigid framing bar was adopted.

Evaluation of batten flexibility

Throughout this development, probably the most difficult judgment to make was to determine the degree of stiffness or flexibility of the support lattice to match the panel's requirements. With experience, it is possible to make a reasonable assessment of the strength of small panels, but when a panel is so large that it cannot safely be lifted, handled, and flexed by one person, this becomes very difficult. Even when it is within a manageable size, it is not easy to evaluate hidden weaknesses resulting from small fractures, compression damage, and structural deterioration resulting from age. *E* values (modulus of elasticity) cannot be used to assess strength (resistance to bending) in the cross-grain direction. Tables of *E* values for timber only apply to bending at points along an axis parallel to the grain.[9]

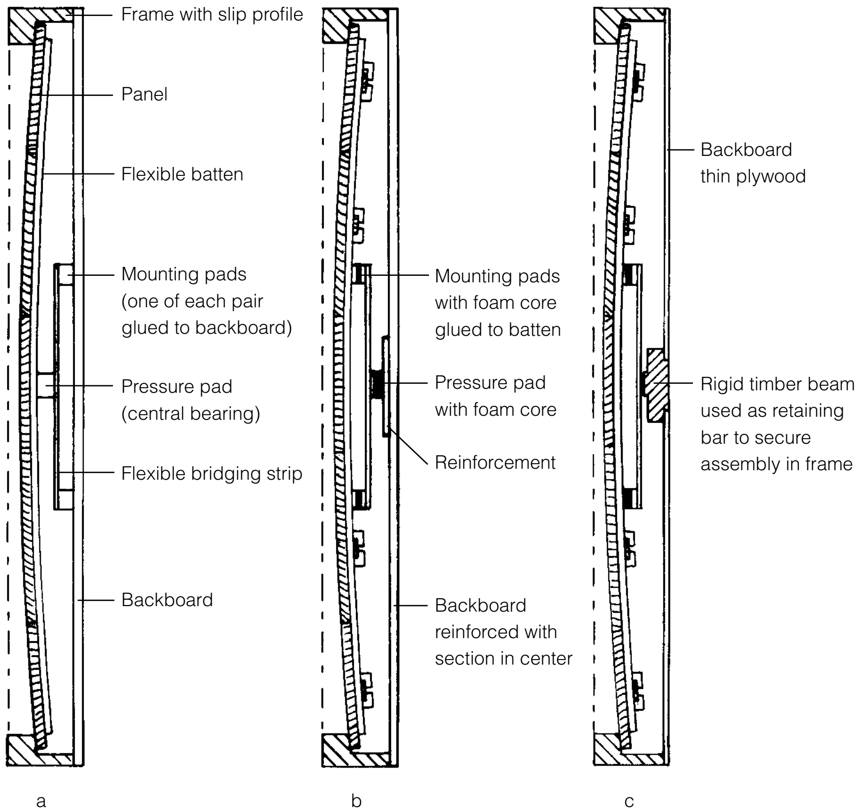


Figure 6a–c
The main stages in the development of an auxiliary support system. With an unattached support (a), when the backboard is removed, the spring bridges and battens joined to it come away, leaving the panel loose in the frame. With an attached support, in its earliest development (b), spring bridges are inverted and attached to battens. When the backboard is removed, the panel and secondary support remain loose in the frame. With an attached support, in its later development (c), the panel and secondary support are retained by a framing bar. When the backboard is removed, the panel remains secure in the frame.

Panel weight as a factor in evaluation

During the development of this type of auxiliary support, the first panel to be assessed had lines of weakness caused by fractures and worm damage, which made evaluation of its strength very difficult. Due to its areas of weakness, the panel was assumed to have little or no inherent strength. The intention of calculating a lattice flexibility was to find one that would provide the reinforcement to support the weight of the panel horizontally within a safe limit of deflection.

The known factors upon which a judgment could be based for the lattice flexibility were the weight of the panel and the change in curvature, monitored at the lower limit of RH that the panel might reasonably be expected to be subjected to in the future, measured at the outer long-grain edges of the panel as the dimensional deflection from the center. The panel weight, divided by twice the number of battens in the lattice, was taken as the load that, when applied to one end of a batten, would produce a similar deflection from the center as that previously measured in the panel. Tapered battens were then produced to give the specified flexibility. The result was that when the lattice assembly of battens was placed horizontally on a central support and the panel placed on top, the panel weight was adequately supported without the determined safe deflection being exceeded. The degree of rigidity of the support was therefore considered correct for reinforcement.

When the support lattice was completed and anchored to the panel, the assembly was evaluated in the vertical plane and found to give a satisfactory degree of restraint—it reduced the panel's previous curvature by about 30%. The panel could also be handled with much more confidence. It was not considered necessary to alter the lattice, and the project was completed by mounting the assembly in a tray with a spring-bridge support behind the lattice. The overall result appeared to be perfectly adequate even though the original design data were so limited.

This method of estimating the lattice flexibility has since been used successfully on other panels; therefore, although it may appear to be an arbitrary assessment, the results justify its use until a better method of calculation can be found.

Second Case Study: Support for a Panel with an Irregular Surface

Panels that have been cradled have frequently been thinned or have had some surface preparation to enable the cradle to be fitted. While such previous changes may have contributed to harmful effects suffered by the panel, they also make the attachment of another auxiliary support relatively straightforward.

Recently, conservation work was undertaken on a panel for which it was appropriate to use a flexible attached auxiliary support. The panel had not, however, been cradled or thinned, and consequently, the attachment of the support to an irregular surface presented some difficult problems.

Description

The seventeenth-century Flemish painting *Death of Orpheus,* by Alexander Keirincx and Roelant Savery,[10] measures 1.4 × 2.03 m; it is made up of six oak boards with doweled and glued horizontal joins. Early in its history, following some poor board rejoins, an attempt was made to flatten the panel. Four rigid poplar battens, each 100 mm wide, were glued into trenched rabbets across the grain of the boards. Shrinkage of the boards had then caused partial disjoins and some fracturing. In a misconceived attempt to prevent further damage, butterfly cleats were inserted across the board joins, while the cross-grain battens were left in place. These cleats were deeply recessed, with their grain perpendicular to that of the boards. As would be expected from these contradictory interventions, further damage had occurred in the form of fractures at the outer edges of the butterflies.

Some of the small butterfly cleats had been removed and even larger ones inserted, causing further fracturing. When the glued surface joins of the battens failed, the battens were reglued and their ends screwed to the outer edges of the panel. In one area on the bottom board, this had recently caused a severe fracture 35 cm long (Figs. 7–12).

At various times during these conservation attempts, areas of the boards had been crudely thinned, particularly where the large butterflies were inserted. Otherwise, the boards retained their original thickness, varying between 6 mm and 10 mm, with consequent steps of up to 4 mm at the joins. When the panel arrived for treatment, it showed signs of being highly stressed. When viewed from the front, it was concave, and some fractures were held open, indicating severe tension.

Before any structural work could be carried out, the panel was first kept in an environmental enclosure at 75% RH. When equilibrated, its profile indicated that much of the high stress was relieved. The battens, along with twenty-eight small butterfly cleats and five large ones, were then removed so that rejoins could be made. The recesses from which the

Figure 7
Alexander Keirincx and Roelant Savery, *Death of Orpheus,* seventeenth century. Oil on oak panel, 1.4 × 2.03 m. Private collection, Northumberland. View before cleaning and restoration, showing disjoins and fractures.

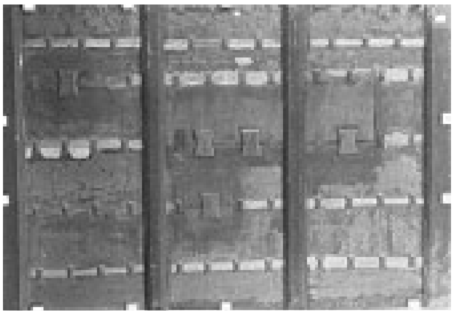


Figure 8
Keirincx-Savery, *Death of Orpheus.* The reverse before panel work.

Figure 9
Keirincx-Savery, *Death of Orpheus.* This detail before cleaning and restoration shows a recent fracture in the bottom board.

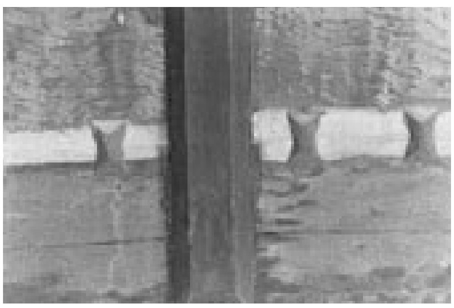


Figure 10
Keirincx-Savery, *Death of Orpheus.* Detail of the reverse before panel work, showing the end of a batten that had been reglued to the panel, a procedure that caused the fracture shown in Figure 9.

Figure 11
Keirincx-Savery, *Death of Orpheus.* Detail before cleaning and restoration, showing a board disjoin, with two lines of fractures below caused by small and large butterfly cleats.

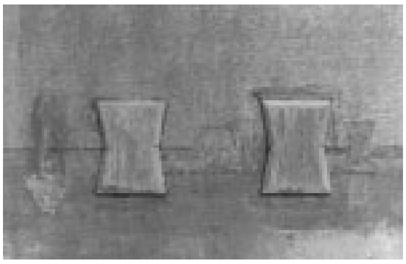


Figure 12
Keirincx-Savery, *Death of Orpheus.* Detail of the reverse before panel work, showing the cleats that caused the fractures shown in Figure 11.

cleats were removed were subsequently filled with shaped oak sections with their grain in the same direction as that of the panel. Other butterfly cleats that did not require removal were planed down flush with the panel's surface.

Difficulties of attaching a support to an irregular surface

After completion of all necessary structural repairs, the panel still presented a formidable combination of problems. There were many faults and lines of weakness. The panel was large and heavy, weighing more than 30 kg, but in some places it was very thin and its surface totally irregular. It was essential to provide reinforcement and to restrain the rapid response to variations in RH by warping, to which the panel was now prone (Fig. 13). To function properly, the secondary support would have to be in close contact with the panel surface.

One of the fundamental principles of the support design is that the calculated flexibility of the battens should not vary from one to

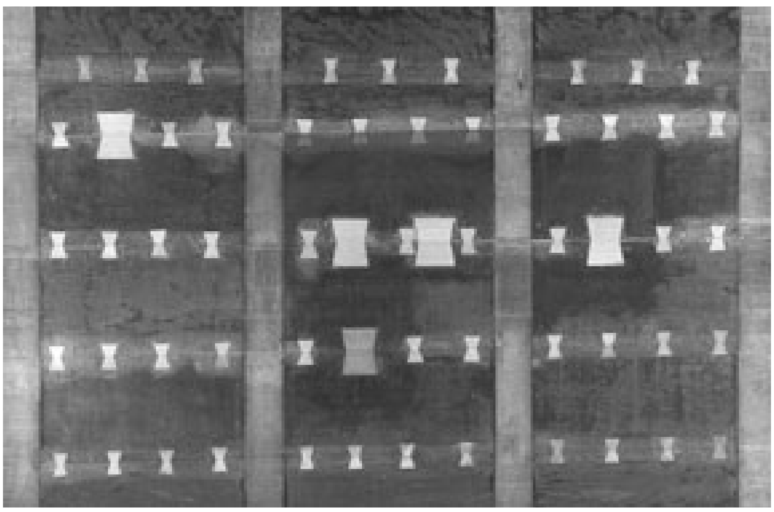


Figure 13
Keirincx-Savery, *Death of Orpheus.* The reverse after structural conservation.

another. This could not be achieved if the battens were individually shaped to the surface irregularities of the panel, a process that would create areas of rigidity and weakness in the battens. Initially, therefore, they were made identical—of uniform thickness and with a flexibility calculated to provide reinforcement. Calculations were made on the basis of using ten flexible battens, and it was decided to use one retaining strip on each of the six boards. Sitka spruce was again chosen as the most suitable timber from which to make the lattice.

With the layout for the main elements of the lattice decided, the panel was then laid facedown on a horizontal surface with support to maintain its camber established at 55% RH. The prepared battens were laid across it at the chosen spacing and weighted to deflect into contact with the concave back surface of the panel. With the top surface of the highest batten as a datum, the others were raised to the same level using suitable packers.

When all of the battens conformed to a uniform curved plane, the retaining strips were laid across the battens at the designated spacing. The retaining blocks, which had been prepared oversized (in terms of height), with slots already cut, were reduced in height and their bases shaped to suit the position in which they would be glued to the panel, with the slots aligned to engage on the retaining strips. This was a tedious process involving 132 blocks, but it was important that it be done accurately so as to ensure that the retaining strips would slide freely into place.

The packers supporting the battens were removed and replaced with a balsa thicknessing layer glued cross-grain to the underside of each batten. This layer was shaped to the surface profile of the panel. When completed, the addition of the balsa was found to have no measurable effect on the comparative flexibility of the battens. The battens were now all engaged by the retaining strips with a reasonably consistent contact over the irregularities of the panel surface.

To complete the support, the battens were linked together with two supporting strips to form a lattice, and an angle section of timber was produced to act as a support for the weak bottom edge of the panel. This angle was glued and doweled to the tips of the lattice, with bamboo pins cut from swab sticks as dowels.

Framing and retention

Now that there was an even surface alignment of the battens, the production and mounting of back springs was quite straightforward. The springs consisted of flexible bridging strips mounted centrally on each batten with Plastazote-foam-cored timber pads. The space available gave the springs a span of more than one-quarter of the batten length.[11] The use of pressure pads was unnecessary, as it was proposed to use a retaining bar that could bear directly against the bridging strips (Fig. 14).

With the auxiliary support engaged, the panel's restrained warp was monitored until stabilized at 55% RH, and the edge profiles of the panel were then recorded. A slip addition for the frame rabbet was made to follow the panel's profiles. Alterations were also made at the back of the frame to build up the rabbet. These alterations provided greater depth to accommodate possible increased curvature in the panel and support assembly of up to 30 mm.

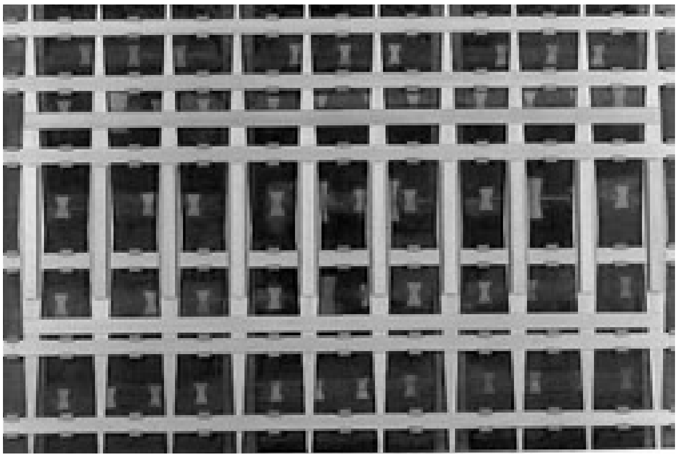


Figure 14
Keirincx-Savery, *Death of Orpheus,* reverse. The retaining blocks are glued in place; the flexible auxiliary support is engaged.

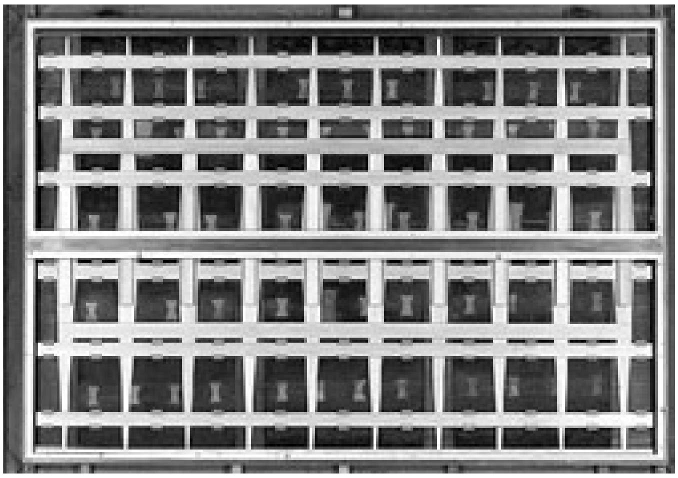


Figure 15
Keirincx-Savery, *Death of Orpheus,* reverse. The completed panel/support assembly is shown mounted in the frame, with the retaining bar in place.

A rigid timber beam, 100 × 30 mm in section, was then used across the back of the frame as a retaining bar to hold the panel/support assembly in place (Fig. 15).

Finally, the back of the frame was totally enclosed with two thin plywood sheets as backboard sections, fitted above and below the retaining bar. The backboards may be removed to allow inspection of the retained assembly without its being disturbed in any way.

An advantage of using this type of auxiliary support system is that it is one of the least intrusive methods of tackling problems such as those presented by the Keirincx-Savery panel. Most of the remaining original surface features have been preserved, and if at any time there is a suspicion that further problems are arising, conservators can gain access quickly and easily by removing the lattice, leaving only the retaining blocks attached to the panel. By themselves, these blocks are unlikely to have an adverse effect on the panel and do not preclude the possibility of further conservation work being carried out, after which the lattice could again be easily replaced.

Reducing friction on the supporting edge of heavy panels

When the panel work was completed, there still remained a framing difficulty to overcome. The Keirincx-Savery highlighted this recurrent problem of displaying large, heavy, horizontal-grain panels.

Even with the achievement of a flexible auxiliary support that will allow changes of curvature (although partially restrained) to occur in a panel, the whole object of the exercise will be defeated if the panel's supporting edge gets stuck and cannot move smoothly in the frame rabbet. With lightweight panels it has been common practice to use Teflon/PTFE pressure-sensitive adhesive tape to line the tray or frame rabbet, thus reducing friction against the load-bearing edge of the panel. With large, heavy panels, the reduction in frictional resistance achieved by Teflon tape may only be sufficient to prevent total jamming. Movement of the panel's bottom edge is still likely to be erratic, however, with sudden jumps occurring only when the warping stresses build up in the panel and exceed the frictional resistance imposed by its weight. Also, it is not uncommon to find environmentally responsive panels that have warped away from a slip profile and have become wedged at the back of the frame rabbet.

A solution to this problem of reducing friction, found suitable for the Keirincx-Savery panel, was simply to mount the bottom supporting edge of the lattice on bearings. Several bearing designs were investigated. Among them, linear slide bearings were found to be available with coefficients of friction as low as 0.003 (i.e., a force of 3 gm will move a 1 kg load on a horizontal surface). These bearings are high-specification devices for engineering applications and as a result are relatively expensive.

For the Keirincx-Savery panel painting, however, the type chosen were simple bearings known as Ball units that were found to work extremely well and are being considered for use on some even larger panels. A possible disadvantage of Ball units is that the minimum dimension below the panel needed to accommodate them is 20 mm, whereas with linear slide bearings it can be as little as 8 mm. Fortunately, the Keirincx-Savery frame was substantial enough for 20 mm deep recesses to be cut for the bearing to run in. Two Ball units were used, giving a combined specified load-bearing capacity of 50 kg. Polished 18-gauge stainless steel blanks were placed in the recesses as a running surface for the bearings. If adequate depth had not been available in the frame, then the thinner, more expensive type of linear slide bearing would have been considered (Figs. 16, 17).

Since completion of the restorations,[12] the Keirincx-Savery panel/support assembly, mounted in its frame, has been monitored at the

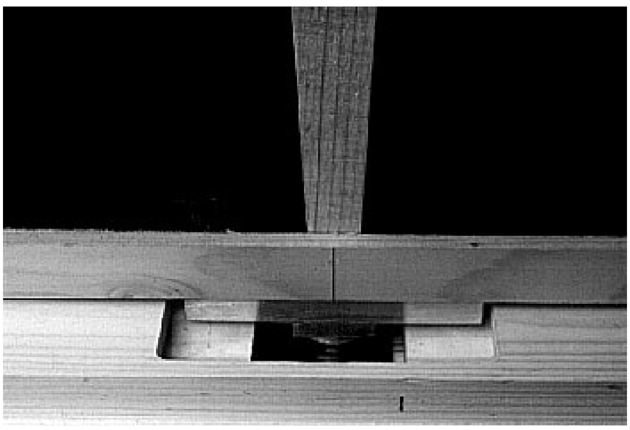


Figure 16
Detail of the vertical support bearing.

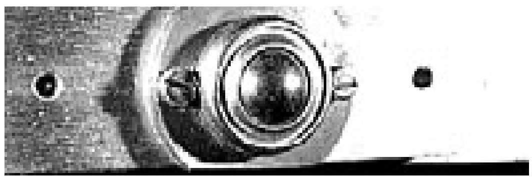


Figure 17
The support bearing seen from below.

author's studio. So far, the results of the structural conservation work look very promising. The efforts made to ensure the long-term stability of this panel painting will have likely been worthwhile (Fig. 18a, b).

Summary of the Principles of Calculating Batten Flexibility

When a secondary support is attached to a weak, responsive panel, it fulfills two functions. One is reinforcement, the other is restraint. Restraint is the function that is potentially damaging and also the most difficult to evaluate. It may be defined as the degree of rigidity required to resist the bending force of the panel. If the resistance is too high, the panel may be damaged.

A safe level of resistance could be calculated with basic engineering formulas if the panel's bending force can be found, but this calculation requires a figure for the modulus of elasticity (*E* value) across the grain of the panel. Approximate *E* values perpendicular to the grain may be derived from reference tables, but only for sound timber samples. For aged, stress-weakened, or damaged timber, these figures are not relevant and cannot be used. If the panel's strength cannot be estimated, then it is virtually impossible to calculate the rigidity of battens needed for tolerable restraint.

An alternative approach is to consider the problem from the point of view of reinforcement. This assessment can be made with the panel lying horizontally over a central beam, with the battens providing the rigidity necessary to support the panel's weight without it deflecting too far. Calculating reinforcement in this way is relatively easy, and the judgments involved are not too demanding.

In practice, it has been found that a support with a flexibility calculated for reinforcement also provides the safe level of restraint—a level that was difficult to determine by other methods.

If battens, which have been made up to the calculated dimensions with a uniform section, are now tapered in width from the center to the ends, their rigidity will decrease progressively away from the center. The bending force that the panel exerts on the battens also reduces progressively from the center to the outer edges. Therefore, the resistance to bending imposed by the battens on the panel will be balanced, producing an even restraint across the width of the panel. As a result, when the support battens are attached to the panel, the tension on all of the retaining blocks will be more equally distributed than if the battens were left as a uniform section.

The deflection calculated for point loading at the end of the batten will increase by about 50% after the batten is tapered. This increase does not constitute an error in the method of calculation, as it is compensated for by the actual load imposed by the panel's weight being uniformly distributed, so that a corresponding reduction in deflection is produced.

With this method of calculation for batten dimension, the support system has been applied to several panels that varied considerably in size, weight, thickness, and timber type. In all cases, the measurable reduction in curvature after the supports were engaged has been 30% or less. This level of restraint is judged to be below the threshold where damage is likely to be caused.

The support also provides a degree of reinforcement, enabling the panel to support its own weight and to be handled safely and with more confidence.

a

b

Figure 18a, b
Keirincx-Savery, *Death of Orpheus.* The general view (a) and a detail (b) show the painting's condition after restoration.

Conclusion

In general, before making a commitment to a detailed design, the panel conservator must amass all available information. It should be possible to specify the dimensional limits of movement of the panel that will determine tray depth, and so on; this can be done by monitoring movement. More information may be gained from assessing previous damage to the panel and painted surface, as well as from assessing conditions under which the panel may be kept in the future. Problems could also develop, especially in the ground and paint layers, when unrestricted freedom of response to environmental changes is allowed.

Sometimes the solution to the problems may be a compromise dictated by display requirements. There is little point in designing a microclimate box or a 15 cm deep tray that cannot be accommodated in an original frame or is unacceptable to the client for display purposes.

It is also worthwhile to consider a combination of ideas rather than a single solution. For example, it should be possible either to reduce or to slow down the response of a panel to environmental conditions with a choice of barrier or buffering techniques, and then to combine the chosen technique with a restraint or an auxiliary support. In addition, there is now a wide availability of technology that makes environmental control possible and more cost-effective in buildings where it would not have been considered previously.

It is not easy to generalize or adopt a standard practice when deciding which method to use. Every panel is different, and it would be incorrect to expect that an acceptable answer to one particular problem can be adopted as a principle for general use.

The fashionable answer among some nineteenth-century cradle makers was to thin, flatten, and restrain panel paintings so that they could be displayed like canvases. Today our views are different, and a lot of time is spent removing work that, when executed, was thought to follow the correct approach but that can now be seen to be damaging. To avoid falling into the same trap, today's conservators should adopt an open-minded approach and continually reappraise their methods and learn from their own experience and that of others.

Acknowledgments

It is the author's belief that many conservators might remain isolated from the benefits of an exchange of ideas if the opportunity to meet other specialist conservators were not made available. It is greatly appreciated that institutions such as the Getty Conservation Institute continue to provide these opportunities at an international level. The author would also like to express his appreciation to the British Standards Institute (BSI) for his use of material from a BSI publication.

Notes

1 Reference tables of the modulus of elasticity for timbers including Sitka spruce appear in Molesworth 1951:432–35.

2 Sitka spruce (*Picea sitchensis*), a softwood imported from Alaska and Russia, having consistent, reliable mechanical properties. It is used for structural framework in some light-aircraft construction (see Keen 1919).

3 Reference tables for modulus of elasticity from Molesworth (see n. 1) are given in lb in^{-2}; they have been converted into n mm^{-2} by multiplying by 0.0068947.

4 PVA Evo-Stik wood adhesive is generally the preferred choice for structural work. It is considered to have good long-term stability and flexibility, giving it higher shock resistance than animal glues, which may become brittle with age. Other adhesives used in these case studies were rabbit-skin glue, for replacement of butterfly cleats, and an impact adhesive containing toluene, for bonding Plastazote polyethylene foam to timber.

5 If board width is sufficient, it would be preferable to use three rows of slotted retaining blocks per board. This provides the best pattern of restraint against warp of each individual board. With narrow boards where space is sufficient for only one row of blocks, it is better to place them near the center line to avoid creating tension close to the board joins. It is not considered advisable to use the blocks to reinforce or span board joins, a practice that can frequently be seen with fixed-cradle members.

6 Teflon/PTFE skived tape, with a pressure-sensitive adhesive coating on one side, has been found to be the best of the range of PTFE products for reducing friction. A cheaper alternative recently found available is polyolefin tape. This is an ultrahigh molecular weight (UHMW) polyethylene material with a coefficient of friction comparable to PTFE. The pressure-sensitive rubber adhesive coating is more suitable for timber, and it also has improved mechanical characteristics, such as lower elongation and higher wear resistance to abrasion. As yet, it has not been in use in the author's studio long enough for full evaluation.

7 In the United Kingdom, this means that the panel has been stabilized at 55% RH.

8 Plastazote is a closed-cell, cross-linked polyethylene foam available in a number of densities. The one used as a core in the timber mounting pads is the low-density LD24.

9 Tables of values of modulus of elasticity of timber relate to data obtained from testing in a direction parallel to the timber grain. Figures do not exist for E values perpendicular to the grain. However, a useful reference can be found in a British Standards Institute (BSI) publication (1991:pt. 2, clause 11 ["Additional Properties"]): "In the absence of specific test data, it is recommended that, for tension perpendicular to the grain, torsional shear and rolling shear, values which are one-third of those parallel to the grain should be used. *For modulus of elasticity perpendicular to the grain, a value of one-twentieth (i.e., 0.05) of the permissible modulus of elasticity should be used"* (emphasis added).

Properties of Sitka spruce are given in table 11 of the BSI publication. Information for obtaining complete copies of the publication can be found in the "Materials and Suppliers" section below.

10 Alexander Keirincx (1600–1652) and Roelant Savery (1576?–1639). The painting depicts Orpheus, who could enchant the beasts, being attacked by the Thracian women.

11 A span of not less than one-quarter or more than one-third of the batten length has been found in practice to be a good dimension for which to aim.

12 Restoration of the painting was carried out at Lank Sanden Studio in London.

Materials and Suppliers

Ball units, Alwayse Engineering Ltd., Warner Street, Birmingham B12 0JG, England. (Large range of Ball transfer units available; the type in use are from the Solid Body Unit range.)

BSI Publications, BSI Customer Services, 389 Chiswick High Road, London W4 4AL, England.

Evo-Stik, wood adhesive, waterproof, or extra fast resin "W," Evode Ltd., Common Road, Stafford, England.

Linear-motion slide bearings, SKF Engineering Products Ltd., 2 Tanners Drive, Blakelands, Milton Keynes, MK14 5BN. (Small units are available in the standard slide range, RM series.)

Plastazote (a closed-cell, cross-linked polyethylene foam, REF LD 24), BXL Plastics Ltd., Mitcham Road, Croydon, Surrey CR9 3AL, England. (Distributed by Hemisphere Rubber Co., 65 Fairview Road, Norbury, London SW16 5PX, England.)

Polyolefin ultrahigh molecular weight (UHMW) polyethylene tape with a pressure-sensitive rubber adhesive (marketed as Polycohr), CHR Industries, Inc., 407 East Street, New Haven, CT 06509. (The European supplier is Furon CHR Products, P.O. Box 124, 7640 AC Wierden, Netherlands. Distributed in the United Kingdom by Polypenco Ltd., now part of DSM Engineering Plastic Products UK Ltd., 83 Bridge Road East, Welwyn Garden City, Hertfordshire AL7 1LA, England.)

Teflon/PTFE (polytetrafluoroethylene) tape with a pressure-sensitive silicon adhesive (marketed as Temp-r-tape HM series), CHR Industries (see information for polyolefin tape).

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Structural Conservation of Panel Paintings at the National Gallery, London

Anthony M. Reeve

The National Gallery, London, has a comprehensive collection of western European paintings from the thirteenth to the twentieth century. There are some one thousand panels in the collection, more than half of which are Italian and painted on poplar. The other main schools—Dutch, Flemish, and German—usually used oak. Other woods used include lime and beech (used by Lucas Cranach the Elder, for example), walnut or fruitwood (pear), and pine.

The National Gallery has mostly conventional panel structures of different types of wood with members glued together, mostly with animal glues, and usually with the grain running in the same direction as the joins. There are also some complex structures, of which Rubens's panels, such as *A View of Het Steen* (NG66) and *The Watering Place* (NG 4815), are prime examples (Brown, Reeve, and Wyld 1982) (Fig. 1).

Most of these panels have undergone some form of conservation work, ranging from crack repair to added buttons, battens, and cradles, or thinning and transfers. For the most part this work has been carried out prior to or at the time of acquisition by restorers abroad and in England.

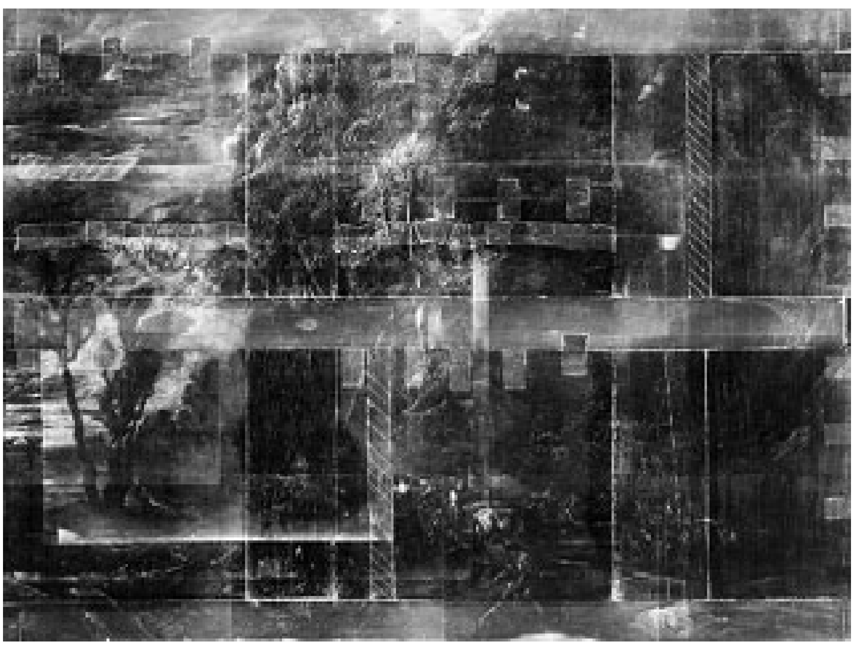

Figure 1
X ray of Peter Paul Rubens, *The Watering Place,* 1615–22. Oil (identified) on panel, 99.4 × 135 cm. National Gallery, London (NG 4815). The eleven panel members, as well as the buttons and battens, are seen before conservation treatment.

The National Gallery's Conservation Department, founded in 1946, initially occupied two converted exhibition rooms. Restoration studios built specifically for this purpose were opened in 1959. In theory, in-house restorers have carried out all the work on the collection since 1946. In practice, the records show that during the early years, there was still considerable structural work carried out by private restorers (Morrill is the most often mentioned). In 1949 (as described below in connection with balsa-wood buildup), Richard Buck came to the gallery from the United States with new ideas on panel work and transfer. In 1965 the gallery was still inclined to the removal of original wood, believing it would minimize the possibility of further movement; complete transfer was sometimes considered. Treatments of various kinds have been developed over the years, progressing to the present day. In looking back, one can see that some of the conservation treatments may not have been the most effective, although they were accepted practice at the time. The author has supervised all the structural treatments in the department since 1977.

This article contains a description of the methods used in the National Gallery at present. Where relevant, old methods and materials are discussed. As a general rule, every part of the original support is preserved whenever possible. Necessary treatments are designed to be as easily reversible as possible. Old methods and materials of conservation are not changed unless new ones can be shown to be more satisfactory.

The best environment for panels is considered to be 55% relative humidity (RH) at 21 °C; it is preferable to err on the side of higher, rather than lower, humidity. It is best never to move panels from these conditions if possible. The transport of panels from one country to another by aircraft and the exposure to a different, usually drier, environment have been prime causes of much panel movement and subsequent deterioration. Deterioration is even more pronounced if restrictive conservation has been carried out first. The location (e.g., church, country house, museum) of a panel greatly influences the types of treatment and materials necessary to carry out the best conservation.

Present Conservation Methods

Animal infestation

Any suspicion of worm or beetle activity should be treated to prepare the individual object for conservation, as well as to protect other objects from infestation. Various forms of treatment (gassing, oxygen deprivation, or liquid application) are suitable for particular problems.

Surface consolidation

Sturgeon glue, normally diluted to an approximately 5% solution, is commonly used with controlled-heat spatulas for conserving loose or blistered areas. If this proves unsuccessful, one may have to use a different adhesive to secure old flaking or impregnations. After surface consolidation of a painting that has previously been restored, it is usually preferable, where possible, to clean the painting to remove excessive fillings that might impede structural consolidation. Surfaces can often be improved where an old conservation treatment was not totally satisfactory.

Facing of the surface before structural consolidation work

Panels once consolidated on the surface are usually faced before any other treatment is carried out. Crack or join repairs are usually faced up to their edges. The facing should cover the surface entirely if structural or removal work is to be carried out on the back. The rationale for choosing a particular facing material and facing mixture depends on the surface, solubility, and condition of the painted layer and also on the structural work to be carried out. The materials commonly used include Eltoline tissue with Paraloid B72 or B67, or damar with a little wax. Occasionally, aqueous facing adhesives are used, but usually only for transfer treatment. If more than one facing has been applied and it is necessary to release or remove one or more of the facings, then the later layers should have different adhesives to ensure that the picture will always be protected. Where there are open cracks to treat, and protection is necessary, B72 or B67 is normally used first.

Removal of old nails or fixings and the treatment of cracks and joins

If normal methods of removing old nails or fixings are not adequate, heating the metal (which causes expansion and the ensuing contraction) may help.

Having used traditional clamping tools and experienced their limitations, the author designed a clamping table, which was manufactured by Willards of Chichester (Reeve 1990) (Fig. 2).[1]

The adhesive generally chosen for joining cracks is Cascamite, a powdered urea-diformaldehyde synthetic resin with a hardener. Its advantages are that it produces bonds that perform well when exposed to extreme dryness or dampness, or even when completely saturated in water. The aqueous quality of Cascamite allows softening and slight expansion of the edges of wood being joined. It also has the possibility of being used in dilute form for penetrating small closed cracks, or in thicker

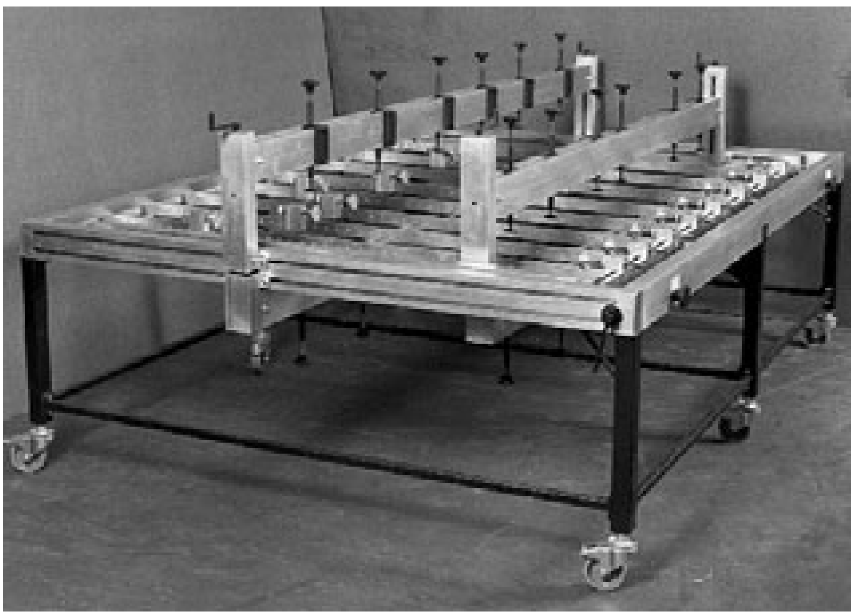

Figure 2
Clamping table for panel conservation.

concentration for open joints and wider cracks. If the cracks are over a few millimeters wide, rye flour can be added as a filler; if necessary, polyvinyl acetate (PVA) dispersions can also be used to reduce the brittleness. A wetting agent such as Oxgall can also improve adhesion when permeation is not sufficient. Cascamite has a two-hour or longer working time, making it very useful for working with the final alignment of deformations.

Cascamite is quite a brittle adhesive, although it is adequate to cope with the natural movements of a panel if joined and used properly. Subsequent applications are possible in inaccessible areas, so should difficulties arise, it will rebond very well. Also, changes in RH should not produce the same magnitude of dimensional change that proteinaceous glues undergo, and it is not susceptible to attack by microorganisms.

Where possible, Cascamite is applied to both sides of the join. If the join is partially sealed or only slightly open, the adhesive is applied along the join back and front alternately, and the panel is flexed sideways or up and down as much as the structure will allow without causing further cracking. This action creates an absorption of the adhesive and expulsion of the air. A dabbing movement on the surface can also be effective.

In some cases it may be necessary to use another adhesive. PVA dispersion emulsion (Resin W) is occasionally used; however, it is less easy to work with than Cascamite, as it has a rather short drying time of ten to fifteen minutes. The National Gallery's Scientific Department frequently reviews new materials in search of alternatives. For larger cracks, wood (preferably of similar age and type) may be inserted, with the grain running with the original.

A variant of a widely practiced method used initially for trying to correct warping and then for reinforcing cracks was used at the gallery for a while in the late 1950s and early 1960s. A V-shaped router was made and set to the desired depth to cut a groove along the line of the crack at the back of the panel, removing the original wood. Another tool was then used to produce a V-shaped wedge to fit into the newly cut channel, either in long straight strips or in short strips if the cracks were irregular. The idea usually behind this was to penetrate through to the back of the ground and to produce two new side surfaces to bond to the V-shaped wedge; this method is no longer used, however. In accordance with the ideal of preserving as much of the original wood as possible, cracks are joined edge to edge whenever feasible.

Cases involving insect attack or dry rot may require the removal of the original wood to consolidate the panel; however, this procedure has rarely been necessary on artworks in the National Gallery collection.

Figure 3
Multipurpose low-pressure conservation table with small warped test panel during moisture treatment.

Moisture treatments

After crack consolidation or release from previous restrictions (for example, removal of battens or a cradle), a panel may adopt a greater concave or convex warp. It may be possible to reduce the warp by exposure to moisture and relaxation under varying pressure over a period of days or weeks. The low-pressure conservation table, using circulated moisture under a controlled vacuum, is becoming an alternative for this treatment (Reeve 1984; Reeve, Ackroyd, and Wright 1988) (Fig. 3). This table and its use are described in more detail below, in the account of the panel treatment for Cosmè Tura's *Annunciation*.

Consolidation and impregnation of woodworm-affected areas

Where there are cases of woodworm attack, it is very difficult to consolidate the remaining wood, especially immediately behind the paint. The worst cases of this may eventually lead to the necessity for a transfer. Various materials have been tried in impregnation tests and evaluated for their efficacy in penetration and consolidation, with Paraloid B67 in white spirit found to be the most suitable. This material also could and would act as a moisture barrier, in preference to the old methods of applying Saran or hot wax. B67 and wood flour are used for infills of any large open wormholes or lost areas. Very large losses would possibly be infilled with wood similar to the original, with the grain running in the same direction as that of the original.

Moisture barriers

To create a moisture barrier by means other than impregnation with Paraloid B67 (for example), a layer of material preimpregnated with Beva 371 could be attached to the back of the panel with a warm spatula. This technique can also give extra support to the panel, reducing the need for further treatment.

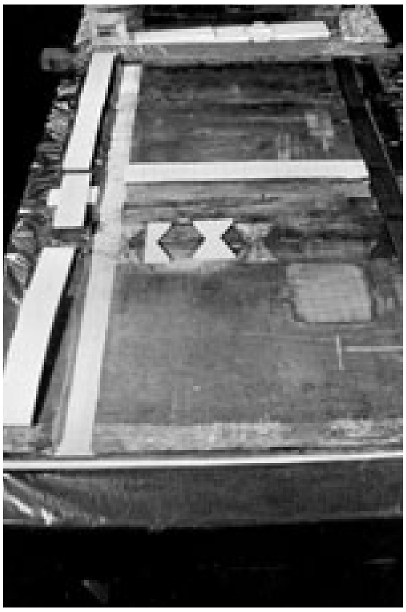

Figure 4
Zanobi di Benedetto Strozzi, *The Annunciation,* ca. 1450. Reverse. Tempera on panel, cut on all sides, 103.5 × 141.6 cm. National Gallery (NG 1406), London. On the back of the panel, infills of toned balsa are seen on the right side; balsa pieces ready for fitting are on the middle and the left side.

Infills of balsa wood

Where it proves necessary to remove restricting bars, battens, butterfly buttons, cradles, and so forth from the back of the panel, it is customary to infill with a material such as balsa wood (Fig. 4), cut to half its depth across the grain at 2.5 cm intervals to counter any tendency of its own to move, and usually running parallel with the grain of the original. Sometimes original chamfered sliding battens can be reduced a little, also cut halfway through at 2.5 cm intervals, and reused.

Panel trays

Where the original panel is in a state too fragile to support itself, either because of thinning or because of inherent weakness, it is often incorporated into a tray. The tray is a secondary support that has been used in the National Gallery for a long time, although its construction and materials have been improved and developed in recent years.

The panel tray consists of a backboard made up of Aerolam "F" board (aluminum honeycomb covered in a resinated fiberglass) with the internal edges cut back to allow the inset of a cedar strip (Brough and Dunkerton 1984; Dunkerton and Smith 1986), the purpose of which is to attach the panel tray to the outer oak frame, which is made to cap the front edges of the picture (Fig. 5). In a tray, the picture is completely supported at the back on blocks (minimum 6 mm thickness) of either Evazote (low-density polyethylene [LDPE] copolymer foam) or Plastazote (LDPE foam), with at least 3 mm of the same material under the oak strip that caps the sides and the edges. Evazote and Plastazote are available in different densities, and the strip of Evazote or Plastazote at the bottom of the tray frame supporting the picture should be of a higher density to prevent it from slipping down in the tray's rabbet.

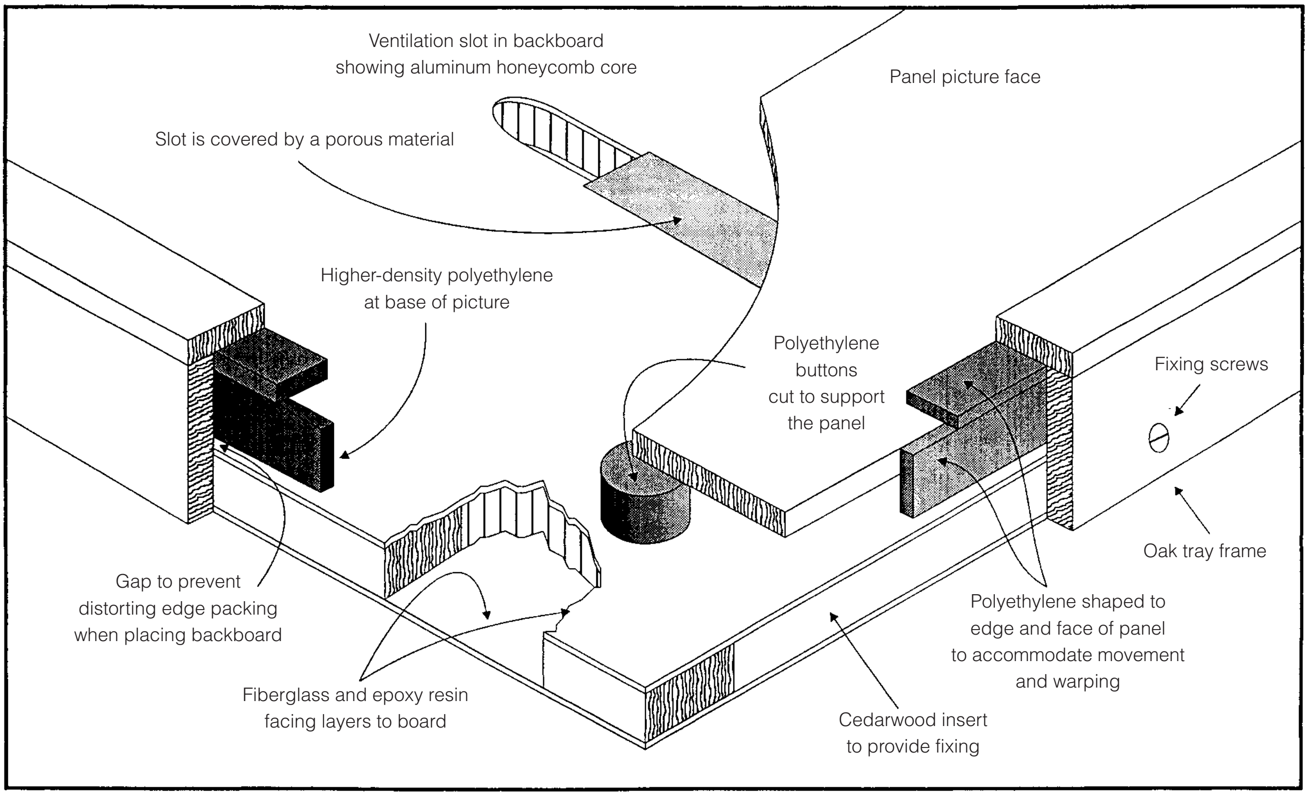

Figure 5
Construction elements of a panel tray.

The Evazote/Plastazote is shaped to accommodate potential panel warp. Only minimal rows of the foam blocks are used, to allow flexing of the panel during environmental changes. This, of course, may happen not only at the edges but anywhere across the width or length of the panel, depending on its structure: restriction of movement is kept to a minimum by this means.

The tray acts as a very substantial protection to a fragile panel, both in its frame and during handling. If the environments are expected to vary, slots can be cut in the tray backboard to allow greater freedom of air movement and to reduce the possibility of concave warp from the front. These slots should be covered with a porous material such as polyester net. However, it is essential to have enough movement available for the panel in the tray through use of blocks and edge slips that are sufficiently flexible. These trays can usually be accommodated in the original frames with a little adjustment, and the front edge of the tray can be toned or gilded to form the inner rabbet of the frame.

Balsa-wood buildup

Balsa-wood buildup is often necessary when, following the removal of a cradle or other veneered additions, a panel is too thin or weak for a tray. The most commonly cradled panels are on poplar and are often thinned to less than a third of their original thickness.

After a panel is released from a cradle and the cracks are consolidated, it usually adopts a convex warp when seen from the front and may also be too thin or too big to maintain a flat or near-flat conformation. After moisture treatment where required, it may prove necessary to attach a secondary support to the back, which will normally return the panel to its original thickness or even make it slightly thicker.

This procedure used to involve an updated and improved form of a method—the balsa-wood and wax-resin cement buildup—introduced from the United States by Richard Buck in 1949. This method has been described in the *National Gallery Technical Bulletin* (Smith, Reeve, and Ashok 1981) (Fig. 6). Since then, the method has been improved by the use of a different materials as an interleaf—impregnated with Beva 371 on both sides—between the original panel and the buildup, thereby preventing impregnation of the wax-resin into the original panel. Also, the balsa planks are all sawed halfway through at 2.5 cm intervals after the application of each layer, in order to reduce their strength (Fig. 7).

The application of the modified version of a balsa-wood panel buildup begins after moisture treatment or flattening, where necessary. New refinements of the method using the multipurpose low-pressure table are described in the case study below.

Transfers

Transferring a painting is the last resort and is considered only when the support or ground is no longer able to maintain the painting. Methods vary according to the problem. The only example carried out at the National Gallery in recent years was the transfer of *The Incredulity of Saint Thomas* (NG 816) by Cima da Conegliano (1459–1517), in which the following procedure was employed (Wyld and Dunkerton 1985).

After removal of the remaining wood and consolidation of the ground from the back, a reversible isolating layer of acrylic primer was applied, followed by a vinyl emulsion filler. An interleaf of finely woven white linen stretched on a loom was coated on both sides with a synthetic, heat-bonded adhesive (Beva 371) and attached to the reverse of the paint and ground. This was, in turn, attached to an aluminum honeycomb epoxy-coated fiberglass board (Aerolam "F" board), also coated with Beva 371. The author has found it more aesthetically pleasing to use a slightly textured surface for these supports; a flat texture seems to impose an unnatural smoothness.

Panel fittings

For support, early panels or fragments may need specially designed brackets of metal or other material, lined with polyethylene foam or velvet, so that no fixings are applied into the original panel. The security of the object must also be a consideration in the design of the brackets.

Frame fitting and exhibiting

A picture should be put into the frame against a soft surface of velvet or similar material to prevent scuffing of the edges. Panels that are warped need shaped polyethylene foam strips between them and the rabbet. In order for the foam strips not to become compressed at the base of the panels, they must be made of a higher density polyethylene or of balsa wood. Panels should be held in frames with as few fittings as possible, with adequate flexible polyethylene pads between the fittings and the panel. The fittings should also be placed at the ends of the wood grain only—at the top and bottom for vertical grains and at the sides for horizontal

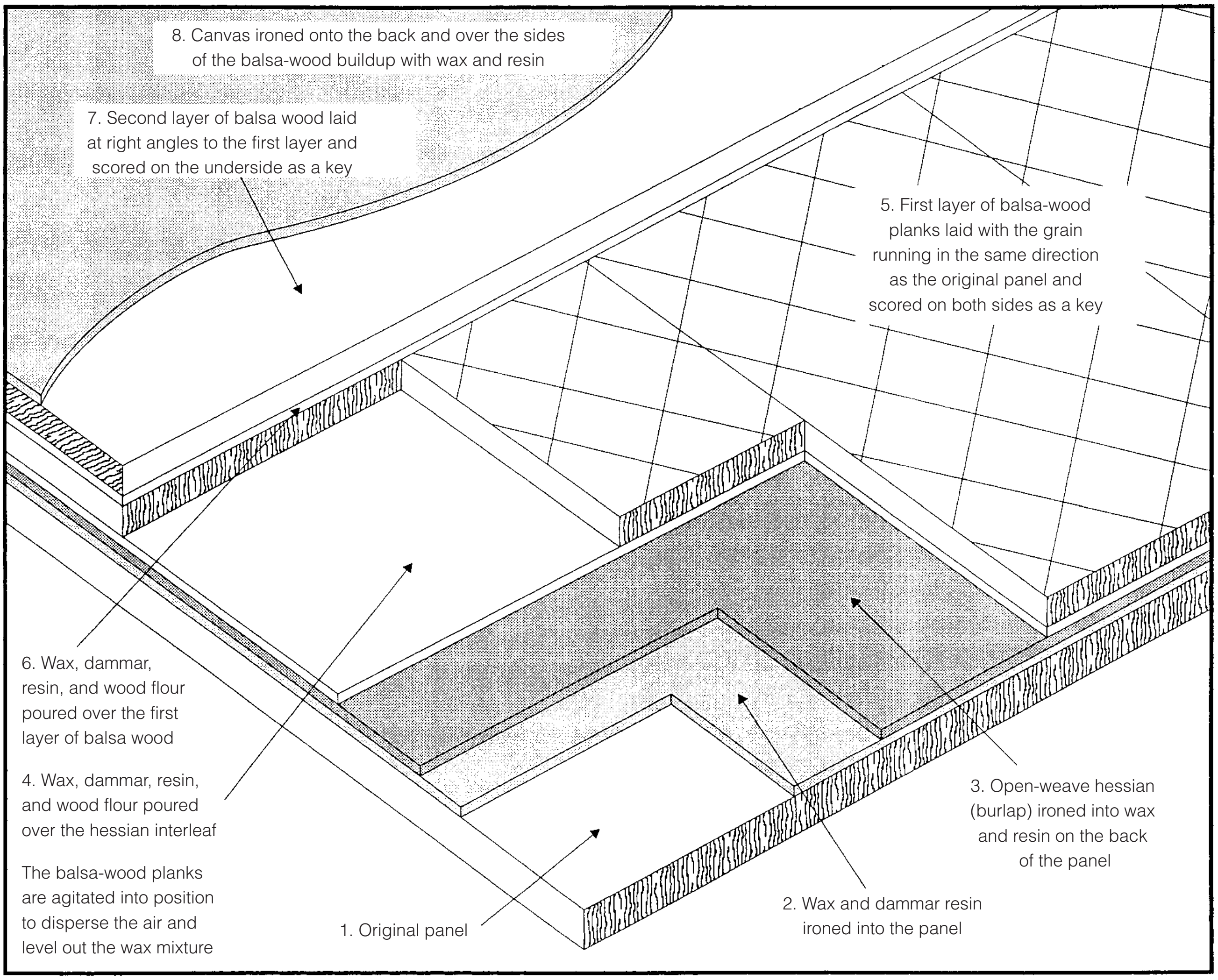

Figure 6
Diagram of the old method of balsa-wood buildup.

grains—and toward the center of the panel. The back of the frame should always project beyond the picture to prevent the panel from pressing directly against the wall. Also, a backboard of some sort helps to act as an environmental buffer and to prevent accidental damage.

When the panels are housed in an uncontrolled or fluctuating environment, it may be necessary to incorporate the panel and/or panel and frame—whether in a tray or not—into a vitrine (to assist in reducing the fluctuation of temperature and RH between the panel and surrounding air) or into a climate-controlled exhibition case.

Case Study: Treatment of a Painting by Cosmè Tura

This small (45 × 34 cm) panel is a fragment of the *Annunciation* by Cosmè Tura (1431–95), probably painted around 1480. The picture is on a poplar panel painted up to the edges and clearly cut all around. It was acquired by the National Gallery in 1874 and recorded to be in good condition. In 1915 the old parquet (cradle) was removed, and the breaks were reset (through the head in a vertical line and elsewhere). The panel was then veneered, and a new parquet was applied. In 1991 the picture was proposed for cleaning and restoration, procedures that were carried out by Jill Dunkerton. The structural work was done by the author and David Thomas.[2]

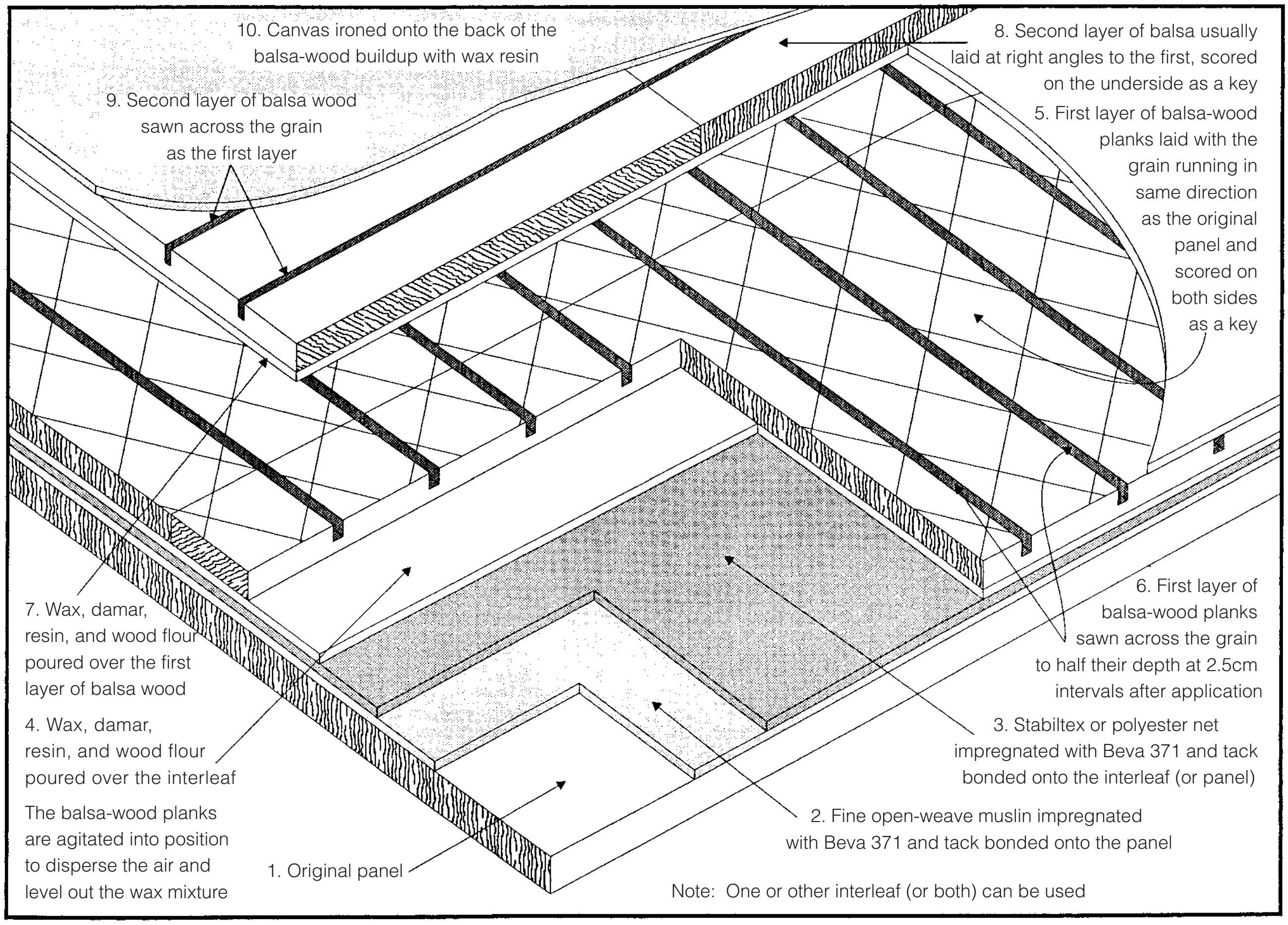

Figure 7
Diagram of the new method of balsa-wood buildup.

Photographic examination by infrared and X ray was carried out to estimate the true condition of the remaining panel and paint (Fig. 8). Infrared photography showed that there was extensive restoration down the off-center vertical crack or join that runs vertically through the Virgin's face, as well as on some other, smaller areas of damage. The X ray showed a very worm-eaten panel, in which most worm channels seemed to have been filled with chalk, glue, and pigment. There were also several insets of a different wood in the complex vertical crack at the top and bottom edges. The original panel had been planed down to a thickness of no more than 2 mm. It was surrounded by thin oak strips, veneered onto mahogany, and cradled with oak sliding bars and mahogany fixed battens. The cradle had caused a slight concave warp on the length of the panel.

The painting's poor condition had been exacerbated by these past treatments, which were causing further cracking, blistering, and flaking. The painting was also covered with a very discolored varnish. Restorations covered original paint in some areas, and the surface was shown to be very uneven under raking light. In order to improve these panel defects, extensive panel treatment was proposed, involving the removal of all later additions.

After cleaning, the wooden inserts could clearly be seen from the front (Fig. 9). Under raking light, it was also clear how badly the surface had been affected, especially in the Virgin's face. Before facing, a tracing was made of all the major cracks and problem areas for future reference, as well as to relate the work to the back of the panel.

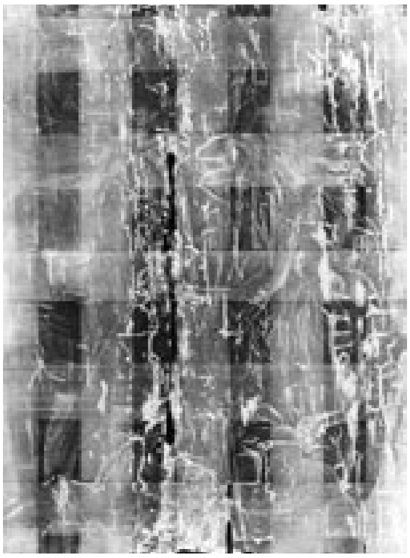

Figure 8, above
X ray before treatment of Cosmè Tura, *The Virgin.* Fragment of the *Annunciation,* 1475–80. Oil and egg (identified) on panel, 45.1 × 34 cm. National Gallery (NG 905), London.

Figure 9, right
Cosmè Tura, *The Virgin.* After cleaning and before panel treatment, the painting shows cracks, losses, and wooden infills.

First the picture was faced. With the goal of realigning uneven fragments of the picture adjacent to the cracks, different resins were used. The areas of paint 1.25 cm wide on either side of the main split were faced with small pieces of Eltoline tissue and Paraloid B72 in xylene. The pieces were shaped to support and protect the edges of paint along the split and some islands of paint and ground within the split, while allowing the split and other cracks to remain accessible. Two further complete layers of facing were applied over the whole surface with the Paraloid B67 in white spirit. This facing protected the painting during cradle and veneer removal, but when it was necessary to remove some parts during the crack conservation, it could be done without disturbance to the B72 facings.

The mahogany cradle was removed by the procedures of sawing across the glued battens at 2.5 cm intervals and chipping away with a gouge or chisel.

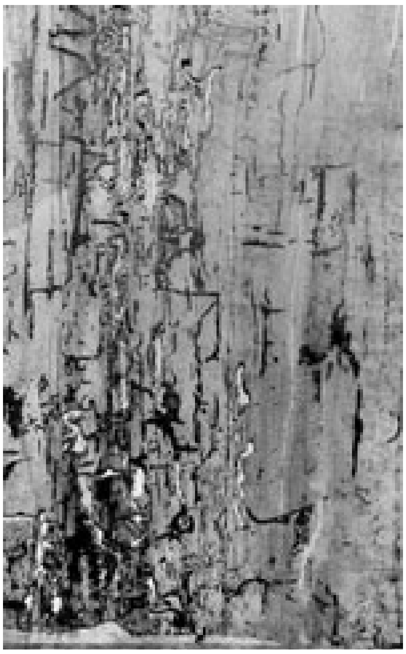

Figure 10
Cosmè Tura, *The Virgin,* reverse. The bottom right corner of the back of the panel shows worm damage exposed after the cradle and mahogany veneer were removed.

This treatment exposed a mahogany veneer approximately 5 mm thick, which was removed with hand gouges and scalpels. Once the mahogany was removed, the back of the thinned panel could be seen (Fig. 10). Many open cracks in the back of the panel had not been visible from the front. The procedure also exposed the many worm channels, seen in the X ray, that had been filled with pigment. The fillings were removed where necessary to enable realignment and securing of the cracks and old joins. In some areas where the fillings were removed, there was no panel fabric left, and the back of the original gesso was exposed. It is not certain when the picture was thinned: it could have been when the first cradle was applied, or possibly when the panel arrived in England. However, it is thought more likely to have been during the second intervention; during thinning, the panel collapsed in some of the worm-eaten areas, the infills of wood were applied, and a second orange putty was pushed in from behind around the new inserts next to the older white putty. These were now strengthened with dilute PVA (Vinamul 3252) in dispersion. Realignment of distorted parts was accomplished by softening and reopening some of the old joins and insets, gradually reweighting, drying, and gluing them into new positions while the picture was placed facedown.

Voids and worm channels were filled with thin layers of Fine Surface Polyfilla—a vinyl ester of Versatic 10 (Shell Resin)—PVA copolymer (Veo Va-PVA) with filler and thickener (Caley 1993). The mahogany insets and oak strips around the edges were left in place as a protection, but those along the top and bottom edges ran against the grain. Those insets were sawed through at 1.25 cm intervals to prevent any restriction. With all of the cracks glued and secured, the panel now took on a convex warp when seen from the front.

Because the panel was exceptionally fragile, it was decided that a balsa-wood buildup was necessary to provide support and stability. The panel was treated with controlled moisture to reduce the warp that had occurred after the removal of the additions and consolidation of the cracks and joins. In a departure from the traditional method of suspending the panel over damp pads, treatment was carried out on the multipurpose, low-pressure conservation table, hitherto used primarily for canvas treatments. The painting was placed faceup on the table and covered with Melinex (known in the United States by the trade name Mylar) (Fig. 11). A very mild surface vacuum was applied, and the table was warmed slightly to 30 °C. Room RH was raised from 55% to 75–80%. The air circulated in the area under and around the panel; humidification continued for about an hour.

The panel relaxed naturally, and as it did so, the surface vacuum was increased accordingly. When the panel had relaxed completely, humidification was turned off, the surface vacuum was maintained, and the excess humidity was drawn away from below with the built-in dehumidifier, bringing RH back to 55% while slowly reducing the temperature of the table to 21 °C. The dehumidifier was kept running at the same setting for several hours. The vacuum was then turned off and the panel left on the table until the next day, where it had flattened considerably, although it still had a slight frontal convex warp.

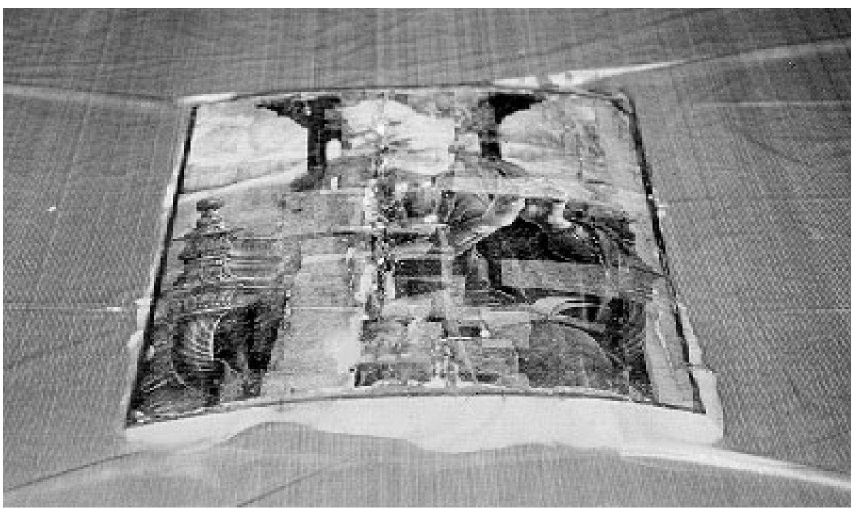

Figure 11
Cosmè Tura, *The Virgin.* Moisture introduction on the multipurpose low-pressure conservation table.

Further moisture treatment from the back was necessary, but a slower, more even drying process was desired. Therefore, moisture was sprayed onto the back with a pressurized fine-spray humidifier, and the panel was placed facedown on a Melinex interleaf. Fine linen canvas and then hessian (burlap) webbing were placed over the back to form a moisture-retention layer as well as an evacuation layer, which allowed a slower drying under a slight vacuum. The procedure, which was continued for a day with the dehumidifier, brought the room RH back to 55% at 21 °C. Afterward the panel showed a flatter plane.

Under raking light the uneven thinning of the original panel showed ripples and distortions. Two suitable interleaf materials were required. After the application of the first interleaf, the undulations in the panel were evened out with a filler and then isolated with a second interleaf before attachment to the balsa-wood buildup. A combination of muslin and then Stabiltex (a very finely woven polyester) was used. Fine muslin was prestretched on a strainer and coated on both sides with three coats of Beva 371. The panel was put facedown on Melinex over thick blotting paper on a board on the low-pressure table, and the strainer with the impregnated muslin was placed over the back. A sheet of silicone Melinex was placed over the Beva-coated area of the panel, the whole was covered in Melinex, and a vacuum was applied.

With a heated spatula, the muslin was then bonded to the back of the panel through the silicone. When it had cooled, the vacuum was released. Now the panel was attached and could be easily handled on the strainer.

During these treatments, the table was usually at about 30 °C; the table's built-in dehumidifier helped maintain the temperature by controlling the RH level. An overall infill of Fine Surface Polyfilla was applied on the back of the hessian webbing and sanded flat when dry.

A coat of Beva 371 was applied over the leveled layer of Polyfilla; a second interleaf was prepared by prestretching Stabiltex on a strainer and applying three coats of Beva 371 on both sides.

The first strainer on which the muslin and panel had been attached was detached. To make sure the painting had adopted a satisfactory surface, it was placed faceup on the board, with webbing under the muslin up to the edges of the panel, and covered with Melinex. A vacuum was then applied and the surface observed: the improvement was marked.

For the application of the Stabiltex layer, the painting was laid facedown on Melinex, and blotting paper and webbing were laid up to the edges of the panel over the visible edges of the muslin. The new strainer with the Stabiltex was laid over the painting; silicone was laid over the panel; and then the whole was covered in Melinex and a vacuum applied. The Stabiltex layer was then attached with a heated spatula.

The picture was then taken off the table and kept on the strainer in preparation for the next step, a balsa-wood buildup. Planks of balsa measuring 12.7 × 63 cm were prepared on the table. In this instance, it was decided to put two layers of balsa running with the grain of the original—as opposed to the normal practice of putting the first with the grain and the second against the grain. This variation was chosen because it was thought to reduce slightly the strength of juxtapositioning, as well as to reduce the chance of any restriction if the panel should move. The balsa wood in this instance was cut across the grain at 2.5 cm intervals to half of its depth, so

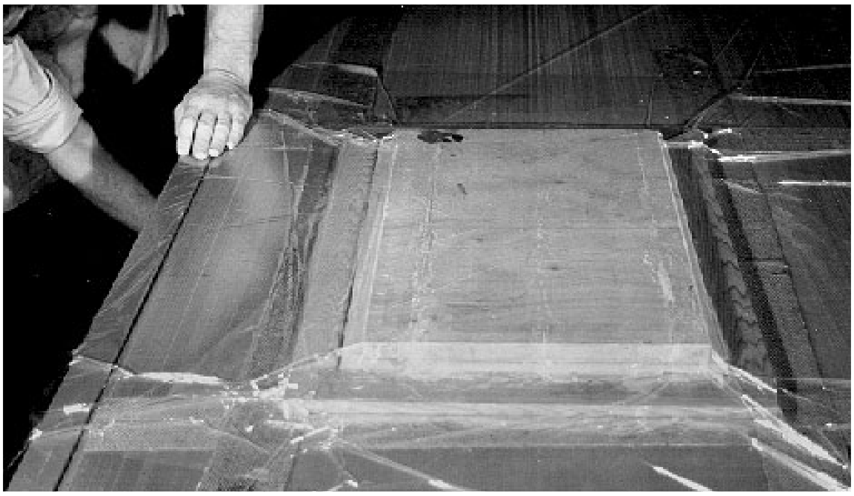

Figure 12
Cosmè Tura, *The Virgin,* reverse. Balsa-wood buildup on the multipurpose low-pressure conservation table.

that its strength was reduced before application. Both sides of the first layer and the underside of the second layer were scored to form a good key.

The panel was cut out of the strainer and placed facedown on Melinex and blotting paper. Webbing was then placed up to and around the edges of the original panel. A wooden frame was built up to the combined thickness of the panel plus the first layer of balsa wood. The purpose of this frame was to reduce the vacuum pressure on the edges so that there were no distortions in the even downward pressure on the balsa-wood layer. The heated wax-resin and wood flour cement were applied, and the first layer of prepared balsa wood put on. The second layer was

Figure 13
Cosmè Tura, *The Virgin,* after panel treatment and restoration.

applied immediately afterward. The wooden frame was placed around the edges of the panel; an overall vacuum was then applied and maintained for a few hours (Fig. 12).

The panel was released and the balsa wood trimmed back to the edge of the original. The sides were chamfered slightly and the interleaves turned around and attached by heated spatula to the sides and back. The sides and back were covered with a fine linen canvas attached by ironing with wax-resin, and trimmed back to the facing edges. Seen from the side and end, the panel now has a very slight frontal convex warp. Raking light photographs show a considerable improvement in the surface.

Subsequently, the holes in the picture were filled and the losses restored with Paraloid B72; the picture was then varnished with Larapol K.80 (Fig. 13).

Notes

1 The clamping table incorporates longitudinal sash clamps, together with vertical clamping above and below. All clamps can be moved into any position laterally and vertically. The apparatus has proved to be a great aid in the re-forming and rejoining of panels, especially those with complex splits, broken joins, and uneven distortions.

2 There is a further reference to the painting in *OPD Restauro* (1992) (Dunkerton 1993).

Materials and Suppliers

Aerolam "F" board, Ciba-Geigy, Duxford, Cambridge, CB2 4QD, England.

Balsa wood, Solarbo Ltd., Commerce Way, Lancing, Sussex, BN15 8TE, England.

Beva 371, Atlantis European Ltd., 146 Brick Lane, London, E1 6RU, England.

Blotting paper (for humidifying), Arcesso Conservation Materials, 194 Blue House Lane, Oxted, Surrey, RH8 ODE, England.

Brackets and mirror plates, Frank B. Scragg and Co., 68 Vittoria Street, Birmingham, B1 3PB, England.

Cascamite (urea-diformaldehyde adhesive and hardener), tool and hardware shops.

Clamps, Buck and Ryan, 101 Tottenham Court Road, London, W1P ODY, England.

Conservation tissue (previously Eltoline, now LX tissue, 100% manila hemp long-fiber tissue), Barcham Green and Co. Ltd., Hayle Mill, Maidstone, Kent, ME 15 6XQ, England.

Evazote, Zotefoams Limited, 675 Mitcham Road, Croydon, Surrey, CR9 3AL, England.

Gator foam, Dixon and Roe Ltd., Units I and II, Bricklayers Arms Estate, Mandela Way, London, SE1 5SP, England.

Gelatin, Thew Arnott and Co. Ltd., Newman Works, 270 London Road, Wallington, Surrey, SM6 7DJ, England.

Larapol K.80, BASF United Kingdom Ltd., Dispersions and Pigments Division, P.O. Box 4, Earl Road, Cheadle Hulme, Cheadle, Cheshire, SK8 6QG, England.

Linen canvas, Ulster Weavers, 47 Linfield Road, Belfast, BT12 5GL, Northern Ireland.

Mastic, damar, and wax, A F Suter and Co. Ltd., Swan Wharf, 60 Dace Road, London, E3 2NQ, England.

Melinex (Mylar), Preservation Equipment Ltd., Church Road, Shelfanger, Diss, Norfolk, 1P22 2DG, England.

Multipurpose low-pressure conservation tables, clamping tables for panel conservation, spatulas, and irons, Willard Developments, Industrial Estate, Chichester, Sussex PO19 2TS, England.

Muslin, Russell and Chapple Ltd., 23 Monmouth Street, London, WC2H 9DE, England.

Paraloid B67 and Paraloid B72, Lascaux Restauro, Alois K. Dethelm A.G., CH 83026 Bruttisellen, Switzerland; and Atlantis European Ltd., 146 Brick Lane, London, E1 6RU, England.

Paste glue (pearl glue), Brodie and Middleton Ltd., 68 Drury Lane, London, WC2B 5SP, England.

Plastazote, Zotefoams Limited.

Polyester net, John Lewis Partnership, 278-306 Oxford Street, London W1A, England.

Silicone release paper, Custom Coating and Lamination Group, Worcester, MA 01605.

Stabiltex (polyester multifilament), Plastok Associates Ltd., 79 Market Street, Birkenhead, Wirral, Merseyside, L41 6AN, England.

Sturgeon glue, Preservation Equipment Ltd.

Velvet ribbon, Barnett, Lawson, Trimmings Ltd., 16–17 Little Portland Street, London, W1N 5DE, England.

Vinamul 3252 (vinyl ethylene copolymer) dispersion, Atlantis European Ltd., 146 Brick Lane, London, E1 6RU, England.

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1982 Rubens's "The Watering Place." *National Gallery Technical Bulletin* 6:27–39.

Caley, T.

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Some Rejoining Methods for Panel Paintings

Al Brewer

Breaks in panel paintings frequently require conservation treatment. Generally, panel paintings are rejoined to improve the integrity of the image while preserving the object as a whole. Common problems include joint failure, splits, and a perceived necessity to improve joint alignment. Also, the support may need to be strengthened to forestall deterioration or to prevent the need for reinforcement by other means that may prove more damaging in the long term. In some cases, the option of not rejoining may be preferable.

Though a specialized approach may be recommended for the rejoining[1] of panels, it is not always possible. The following discussion and outline of general considerations might prove helpful in cases where a conservator who seldom encounters the necessity of rejoining finds there are no other means available. Three cases exemplifying panel rejoining methods used at the Hamilton Kerr Institute (HKI) are described. Each case represents a particular rejoining problem and the specific treatment methods and apparatus employed.

Detailed descriptions of rejoining procedures are not common in conservation literature, although various types of apparatus have been mentioned (Hermesdorf 1953; Kozlowski 1962; Glatigny 1989; Reeve 1989). Discussion in the section below entitled "Smaller Apparatus" gives a basic rationale while providing foundation information for the following sections. Finally, some disadvantages of the last apparatus, for treating panels vertically, are discussed. Better methods are continually evolving, so those described should not be taken as a fixed approach.

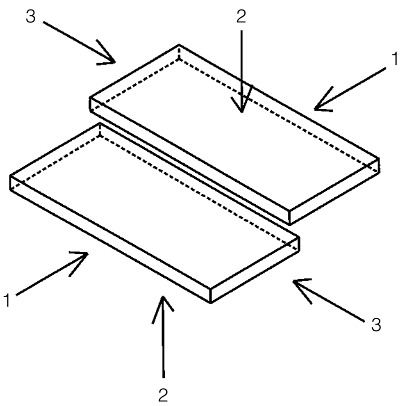


Figure 1
General direction of application for the types of pressures (indicated by arrows) used to rejoin panel paintings: (1) joining pressure, (2) out-of-plane alignment pressure, and (3) in-plane alignment pressure.

Joining Pressure

The pressures applied to rejoin a panel may be divided into two basic types according to their purpose and orientation in space (Fig. 1). The first type, *joining pressure,* as referred to in this article, is usually directed from the opposite edges of the panel, and thence, roughly, through the panel's plane and perpendicular to the line of the intended joint. This is usually done with bar clamps, though other possibilities exist, such as windlass-type straps, air or hydraulic pressure, and other mechanical devices. The use of bar clamps to rejoin a significantly warped panel can make pressure application difficult. Therefore, it is generally not an ideal method. The panel may bend into a greater warp, risking breakage, damaging the contact area of the joining surfaces, and negating careful alignment.

The second type of pressure, *alignment pressure,* may be subdivided into two categories. *Out-of-plane* alignment describes pressure applied roughly perpendicular to the general plane of the panel to bring the two sides of the joint to the same level.[2] *In-plane* alignment describes pressure applied parallel to the joint axis, primarily to bring the elements of the image into register on either side of a complete disjoin. In-plane alignment can usually be achieved by maintaining the position of the two panel members carefully by hand during the rejoining procedure. More control may be necessary with smooth-faced disjoins, where slippage is more likely under pressure.

The amount of joining pressure required is determined by the panel's condition. In most cases, much less pressure is used than would be needed for a construction joint. Panel paintings do not require high pressures: pressure should be just enough to bring the joint faces snugly together. If correctly chosen and applied, the glue fills slight gap variations. Too much pressure is dangerous: it can distort the panel and joint, increasing the possibility of damage to the paint and the structure of the wood.

In fact, some conservators prefer not to apply any pressure during rejoining to avoid initiating stress. Of course, depending on environmental conditions following treatment, joints made without the application of pressure still undergo some internal stress. The use of pressure may also be defended for the following reasons: (a) pressure can be beneficial to a good glue bond, and (b) a poorly aligned joint is usually difficult to putty and retouch satisfactorily, especially when a panel painting has a pristine, glossy surface. Therefore, the application of modest pressure to achieve a better joint and alignment may be worth considering.

Approaches to Rejoining

Various systems of wedges and screws with pressures borne by rigid beams have been developed to control alignment pressures. Weights can consist of loosely bagged sand or metal pellets, for example. With practice, such methods can be used with considerable success, though there are usually drawbacks. For one thing, the bulkiness of some apparatus interferes with access and control. Moreover, the careful setting of wedges can be frustrating and tedious and cannot be quickly and easily reproduced if the panel members need to be moved prior to gluing. Sophisticated, ready-made joining tables that address many such problems, however, can be purchased.

Another approach to rejoining uses (usually) V-shaped wooden inserts that are glued into channels cut along the line of splits or disjoins.[3] This method will not be discussed here in detail (see Bergeon 1990; Uzielli and Casazza 1994; see also Uzielli, "Historical Overview," and Rothe and Marussich, "Florentine Structural Stabilization Techniques," herein).

Precautions and Suggestions

The rejoining procedure is often technically demanding. For example, although there is a choice of adhesives that vary in ease of reversibility, the difficulties inherent in reversing a dried joint usually involve considerable risk to the structure of the painting, making it desirable to "get it right the first time." For this reason, control and access are important.

Even the simplest rejoining cases may prove stressful to practitioners—this author being no exception. The critical nature of the procedure demands a purposeful, well-planned approach, the necessity of which can become immediately apparent after the glue has been applied and the joint brought together—a moment when the unforeseen tends to occur. Contingency measures should be planned beforehand. It is important to rehearse the procedure "dry" (without glue) up to the stage of pressure application.

It is also important to consider how well a painting's condition can accommodate the rejoining procedure. Relevant factors are the condition of the ground and paint layers, whether the layers tend toward flaking, the solubility and reactivity of the adhesive and its components, and the wood's strength and degree of warp. Weak, porous, water-based animal-glue grounds, for example, might distort or flake during manipulation.[4]

A panel can sometimes be pressured into alignment, but inherent weaknesses could initiate further splits immediately or in the future. The type of panel wood is an important factor. The more flexible woods, such as poplar, may accommodate greater distortions from pressure without failing.[5] Accepting less than perfect alignment may be the best alternative if further treatment might overstress the panel and painting.[6]

Gluing procedure varies from case to case. Generally, old glue is thoroughly cleaned from complete disjoins, which are then aligned and separated slightly. After glue is applied to both joint faces, the joint is pressed together with relatively low pressure. For more highly concentrated glues, the glue line may be thinned by "rubbing" (slightly moving one joint face back and forth against the other by hand or by small repeated turns of the clamps used to apply out-of-plane alignment pressure). One cannot usually produce a true "rubbed joint" because the joint edges would probably cease to move at a moment when the panel is in the wrong position. However, short of this, a thinner glue line—desirable for durability and a better match to the original joint—can be achieved. As splits must be positioned with greater care, rubbing is normally not possible. For splits, the closest joint is achieved by fitting the torn wood together exactly.

It is not necessary to replane joint faces to eliminate gaps, though some panels have been so treated. Inserts or gap fillers can be used instead. A replaned joint may be suspected if the image no longer registers where it crosses the joint. To identify and then treat this condition effectively, it is best—prior to structural work—to remove the varnish, retouchings, and putties that obscure the joint.

Where joint gaps do occur, fillers may be employed; these may be wooden inserts or part of the adhesive system. If there is an excessive gap and wooden inserts can be fitted effectively without the removal of original wood, they are the preferred choice because they use a thin glue line, which increases durability. Thinner glue lines are more flexible and therefore able to move with the surrounding wood. In contrast, a glue-saturated filling compound is more likely to force the surrounding panel to comply under stresses.

Rejoining and gap filling of joints must be considered in conjunction with preservation of the original panel wood. Some conservators prefer to replace the original wood with wooden inserts, usually V-shaped in section, whose good fit should result in a more complete and thinner bond line than that achieved by rejoining the original wood unaltered. The joints (for two new joints are created) can be made as sound as technical skill, patience, and materials will allow. Again, because the glue line can be made thin and, therefore, more flexible, joint strength and durability should be better.

However, if sufficient strength can still be achieved, it may be preferable to leave the original wood intact at a disjoin or split to preserve its established relationship with the painted side. Many breaks can be rejoined adequately without removal of the original panel wood. If a panel breaks again in the same area, the original wood can still be repaired or even, as a last resort, replaced. Compromise may be required when insect damage is a factor. In any case, it is probably better to avoid or minimize the loss of original wood support.

Longer joints are difficult to rejoin in one procedure. Glues have limited "open times," during which they are sufficiently liquid to allow effective manipulation. With a larger joint, a step-by-step closure may be advised. The use of insert methods would allow this possibility. The choice of a method, or a combination of methods, is a question of judgment.

Access and Preparation

Access to both sides of a panel, especially the painted side, is desirable in order to assess the effects of the procedure, promote easy glue application and removal, judge the relative position and angle of the two parts being joined, control the degree and direction of pressure for alignment and rejoining, and allow the placement of pressure where it will be most effective.

There are disadvantages in having access to the back only—a limitation that can occur, for example, when the panel is treated facedown on a table surface. The primary drawback is that it is impossible to judge the alignment of the paint surface because it is not visible. This is especially important if the painting has been previously misaligned and the panel subsequently thinned, because the plane of the back surface cannot be relied upon to ensure realignment of the plane of the painted side. The original paint surface usually provides the best basis for alignment.

Access to the true, original paint surface is desirable so that the painting's integrity can be respected during the procedure. Old putties may have been imperceptibly "ramped" to disguise previously misaligned joints so that neither local alignment nor the general plane of the painting surface can be judged with accuracy.[7] Judgment of the general plane is a particularly subtle exercise that demands thorough familiarity with the panel's surface conformation.

In addition, overlying nonoriginal layers (i.e., putty fragments falling into the joint) can obstruct closure. This usually occurs when all other preparations have been made and the glue has been applied. If a partial disjoin is bridged by such layers and disjoins further during treatment, then original paint on either side of the joint may stick to the overlying layers and be dislodged.

Apparatus for Rejoining Panels

This article describes three types of apparatus used by the author at HKI to glue disjoined or split panel paintings. One is relatively simple in construction and suited to smaller panels. The other two were built for larger panels.

One advantage of the first type is its ease of quick assembly and disassembly. The other two types are more elaborate structures, but they

Figure 2
Screw clamps. One is attached to a double-thickness length of right-angled-section metal.

can be taken apart and rebuilt to suit most larger panels or be customized for a particular situation. All three designs require a degree of thought and planning in their application. However, they are relatively inexpensive, given the control and flexibility they allow in the gluing process.

All of the designs utilize a type of screw clamp, sometimes known as a hold-down clamp, to provide pressure (Fig. 2).[8] The screw clamp is mounted on a sufficiently rigid beam, usually of right-angled-section metal that is fixed in relation to the panel.[9] The spatial arrangement of the clamp and beam determines the general direction of pressure. The clamps are used primarily to achieve the desired alignment of joints in relation to the general plane of the panel, that is, to reduce "steps." They can also be used instead of bar clamps to provide joining pressure—for example, where greater directional control is desired.

The screw clamp can be attached to any suitably thick piece of stock. The thumbscrew of the attachment device may be snugged securely in position with pliers. The clamps are small enough to be placed closely together, and they can be moved to any desired location along the mounting beam. The screw shown can be adjusted through a length of about 20 cm. The circular swivel foot piece can be modified by padding or by the attachment of shaped pieces with various contact areas and rigidities in order to spread the applied pressure as desired.

Smaller Apparatus

Case description

A seventeenth-century panel painting[10] was treated structurally for splits from a cradle locked by glue that could not accommodate the painting's response to environmental fluctuations. The panel consists of two planks joined parallel to the grain near the center. The grain is oriented vertically with respect to the image. Two splits had occurred since cradling, shown by the lack of glue or varnish in the splits. The splits were stepped to a small degree.

Order of rejoining

The panel, which was almost as thick as it had been originally, had been cradled unnecessarily. The cradle was removed to permit access for rejoining and to serve as a preventive measure against further splitting. The extent of splitting was small, with the splits closed at both ends.

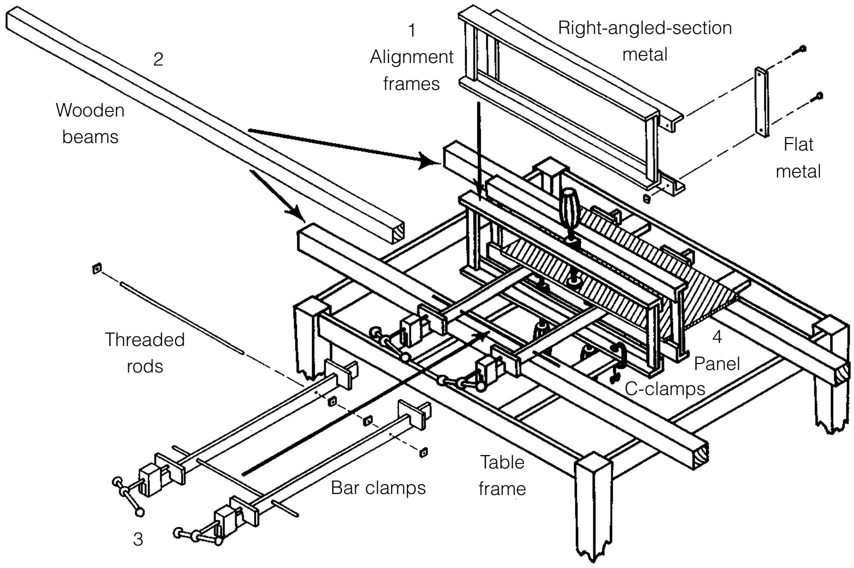


Figure 3
View of the smaller rejoining apparatus, in which the order of assembly is as follows: (1) build and attach the alignment frame(s) to the table crossbars; (2) place two parallel wooden beams on either side; (3) join the bar clamps with threaded rods and place on the wooden beams, through the alignment frame(s); (4) position the panel and adjust supports, clamp positions, and pressures. (To simplify the diagram, only one panel member is shown in position, and the bar-clamp stops are not padded.)

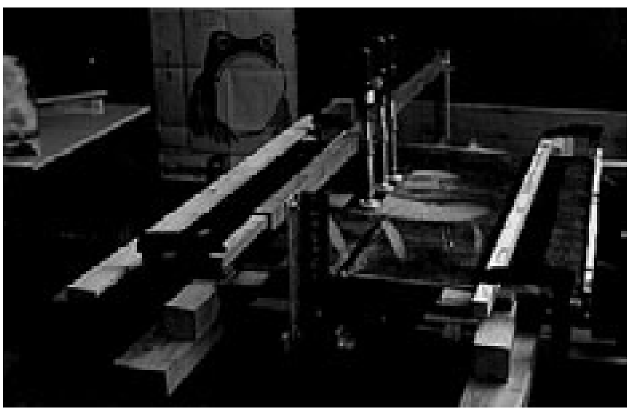
In panels with multiple splits, some running the entire length of the panel, it is preferable to rejoin each section first. This is partly because it becomes more difficult to control the procedure as the size of each section increases. Joining pressures must be directed over increasingly greater spans, and sections with unconsolidated weaknesses, especially larger sections, are more difficult to manipulate than those that have been consolidated.

Apparatus description and application

Construction

The apparatus is supported by a table frame with crossbars (Figs. 3, 4a, b). In order of assembly, a single alignment frame is made first from two equal lengths of right-angled-section aluminum, for lightness and sufficient rigidity. The aluminum lengths should be cut at least 50 mm longer than the dimension of the panel that is parallel to the intended joint. The lengths, which determine the maximum size of panel that can be treated, are drilled at each end and bolted together with two shorter lengths of flat metal to make a rectangular frame. Two such frames, one for each side of the joint, may be necessary to achieve sufficient control of joint alignment perpendicular to the panel plane.

Figure 4a, b
Cornelius Janssens (or Johnson), *Portrait of the Third Earl of Moray,* seventeenth century. Oil on oak panel, 807 × 640 × 7 mm thick. Private collection, Scotland. HKI treatment no. 1475. A view (a) of the rejoining procedure shown from above an end-grain edge. Note the restraining bars to the left and right of the alignment frames, attached with C-clamps to spacer blocks and the table frame below. A view (b) from underneath the middle of the panel shows the alignment frames and six screw clamps fixed to the table crossbar with C-clamps.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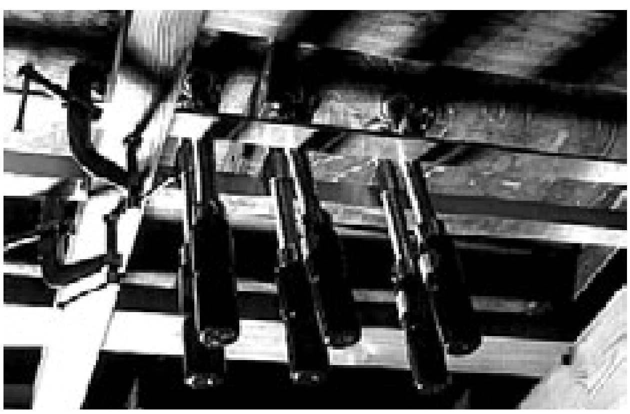
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The screw clamps will be attached to the angle-sectioned beams above and below the panel joint so that they are on either side and in line with it. First, however, the alignment apparatus is positioned approximately and the bottom beam clamped to the table crossbars with small C-clamps, which stabilize the apparatus.

Next, two straight wooden beams, of about 50 × 50 mm in cross section, are placed on each side of the alignment frame(s). These may be clamped to the table crossbars. Then, depending on the panel size, at least two bar clamps are laid across the wooden beams and through the rectangular frames. The beams above the lower set of screw clamps support the bar clamps and the panel. The top surface of the bar-clamp rail should lie in the middle of the alignment frame(s). This arrangement defines the panel position in relation to the clamps.

For stability, all the bar clamps may be joined by some relatively rigid means so that they are parallel to one another. In the diagram, two standard threaded steel rods serve the purpose, passing through stop holes and fixed with nuts to either side of each bar clamp. Fixing the clamps together rigidly prevents accidental slips and provides a secure base for the panel. Depending on the panel shape and the angle of the joint relative to the panel edges, the clamps can be positioned at angles to the panel edges rather than placed strictly perpendicularly.

Prior to placement of the panel in the apparatus, the effective contact area of the stops of the bar clamps is extended and padded. A length of relatively rigid bar (e.g., a strip of wood) is placed against the line of bar-clamp stops at each panel edge. A thin balsa plank or strip of card is placed between the rigid bar and the panel edge.

These two pieces distribute the pressure more evenly along the entire panel edge. The batten spreads the point pressures of the stops, and the padding conforms to local irregularities. The padding material can be carved or sectioned to apply pressure to the strongest surface while it avoids weaker areas. The lengths of batten and padding are cut slightly shorter than the respective panel edge. To permit judgment of curvature during the procedure, they are positioned to allow sighting along the end-grain edge of the panel.

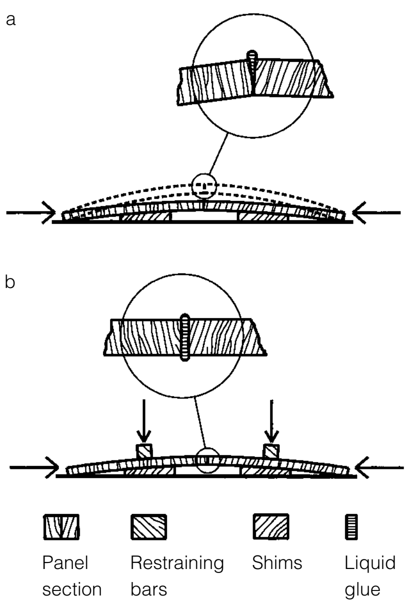


Figure 5a, b
Views of the end-grain edge of a warped panel, with the curvature supported by shims from below. Under joining pressure (indicated by arrows), when the panel is unrestrained (from above) from buckling (a), the joint aligns poorly and a gap is created between the joint faces, which will not be well bridged when the glue shrinks and dries. Padded restraining bars above the panel surface (b) redirect the joining pressure through the joint. The joint faces then meet more squarely and squeeze glue evenly from above and below, indicating a better joint configuration.

Panel manipulation before rejoining

Before glue is applied, a dry rehearsal of the alignment procedure is conducted. To bring both sides together squarely, it is critical to respect the panel's curvature during rejoining. Otherwise, a poor joint usually results, with interruptions of the inherent contours of the panel surface at the joint. If the panel is weak or warped, it should be supported in a state of curvature that minimizes the bending stresses imposed by its own weight. This can be done by placing wooden shims at intervals beneath the panel which are cut to fill the gap between the panel back and the bar clamps (Fig. 5).

The panel is then slid horizontally, painted side up, onto the bar clamps and through the rectangular void of the alignment apparatus until the intended joint is approximately aligned with the line of screw clamps.

Convex warps (viewed from the painted side) often promote buckling when joining pressure is applied. Inherent warp and excessive side pressure increase the tendency to buckle. This pressure can be redirected through the panel toward the desired direction and across the intended joint by the positioning of restraining bars above the panel.

In general, the restraining bars are placed parallel to and approximately halfway between the joint and each parallel panel edge. The bars may be made of padded wooden strips of sufficient rigidity. They should barely contact the panel surface or lie slightly above it. Spacer blocks are placed beneath each end of the bars, and the ends are clamped.

If necessary, the alignment frame is repositioned, after which the screw clamps are lightly snugged to the panel surface. The foot pieces are isolated from the panel and glue with a release film[11] and padded, if necessary, with small pieces of mount card or blotting paper. Glue should not contact the card or paper, as it could seep beneath and damage the painting.

Out-of-plane alignment of the joint edges is usually best attained with the least number of screw clamps and with the least pressure applied at the least number of pressure points. The conservator determines the arrangement by trial, repositioning the clamps until the desired effect is achieved. The procedure is usually to move each joint edge alternately, and about equally, until alignment is achieved. One edge should not assume all the strain. Many splits and disjoins realign with ease when the simplest appropriate arrangement of pressure points is used.

Out-of-plane alignment and the best overall curvature may be determined by several methods. These include (1) passing of the fingertips across the joint, (2) repeated passing of the palm across the general area of the joint, (3) use of raking light cast across the joint from both sides, (4) sighting of panel edges at the ends of joints (if appropriate), (5) checking the gap with backlight, and (6) use of raking light or backlight, with straight edges placed over the joint.

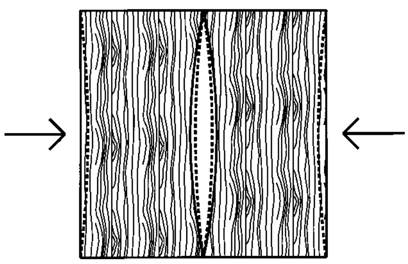


Figure 6
The effect of even joining pressure (indicated by arrows) on a disjoin with a central gap (exaggerated). The dotted lines show movement of the panel under pressure as it bends in-plane.

During use of these techniques, the joining pressure is tested, a process that previews how the panel shape will change under the anticipated pressure. Alignment pressure may have to be adjusted slightly in accordance with a shape change, and further precautions may be necessary. For example, thinner panels may bend in plane when joining pressure is applied to a joint that is gapped in the middle (Fig. 6). The joint edges contact near each end while the gap is reduced. This type of bending increases as joining pressure is concentrated across the gap. It may occur if the padded bars are not sufficiently rigid—a deficiency that causes pressure concentrations where the bar-clamp stops make contact.

To control these effects, it may be necessary to shim the curved edges of the panel (Fig. 7). Very small movement can have a significant effect on final alignment and bond strength. Shims can be used to concentrate joining pressure to close or reduce slight joint gaps.

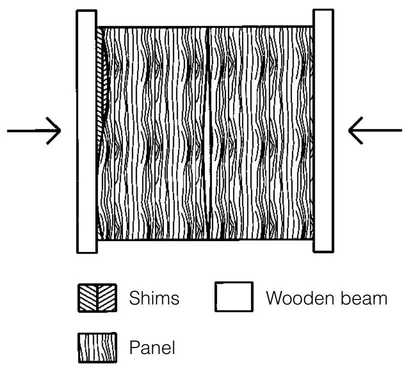


Figure 7
Shims placed in gaps along an uneven edge, left, spread the joining pressure (indicated by arrows) evenly along the joint.

Glue application and rejoining

After successful completion of the dry rehearsal discussed above, the conservator can proceed with the application of glue and the actual rejoining. To allow access to the joint for gluing, the top right-angled-section beam(s) and screw clamp(s) may be entirely removed from above the panel, or a bolt may be removed from one end only and the beam(s) hinged up and away. Alternatively, each top screw clamp could be backed off the panel—a maneuver that may be preferable and wastes little time during repositioning after or during glue application. The bottom clamps provide a sufficiently fixed datum if the panel is relocated exactly. Another option would be to mark each screw's position with an ink line across the screw thread and screw housing, back off the clamp, apply the glue, and turn the screw back to the mark. For most joining procedures, any disruption of the panel's position relative to the screw clamps necessitates minor readjustment when the joint is finally brought together.

Depending on the joint, the glue can be applied with the entire panel removed from the apparatus, or, if the joint consists of two pieces, one piece can be positioned and clamped in place while the other piece is moved slightly away to create a sufficient gap. The open structure of the apparatus allows considerable access for brushes and fingers.

Next, the glue is applied. Care and ingenuity must be used for partial disjoins, especially splits with both ends closed. An excess of glue is worked into the break, preferably from the panel back. Methods to increase glue penetration include finger pressure, slight flexing of the joint edges, suction, positive air pressure, and use of a syringe or a spatula. For better wetting of the joint faces, a more dilute glue may be applied first, then a more concentrated glue. The highest practical concentration should be used to avoid "starving" the joint,[12] a condition that can occur with glues that shrink or dry by moisture or solvent loss or with glues that are partially absorbed by porous woods.

To produce as complete a joint as possible, it is sometimes better to leave a sufficient line of excess glue on the back of the panel only, since glues that dissolve or disperse in water or solvent usually shrink into the joint. Any outstanding dried glue is then removed to the level of the panel surface.

The clamps are reset, and joining pressure is applied lightly in small increments, with alignment readjusted if the joint slips. The aim is to maintain alignment while forcing excess glue out of the joint in equal measure from the front and back of the panel. This indicates that the joining faces are meeting squarely.

If joining pressure is directed nearer to the front or back of the panel, a gap may result toward the opposite side. This occurs, for example, when a buckling deflection is induced in a panel with an inherent warp (Fig. 5). The chances of making a starved joint can be reduced by a slight increase in overall pressure in two or three stages during the initial drying period. In this way, shrinkage and absorption of the glue are countered by a reduction of the joint gap.

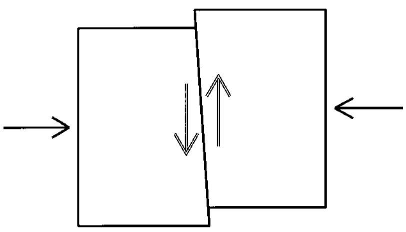


Figure 8
Slippage movement (indicated by vertical arrows) induced under joining pressure (indicated by horizontal arrows). This type of slippage occurs when the axis of the joint is not parallel to the panel edge(s) and therefore is not perpendicular to the applied pressure.

It may be necessary to readjust the alignment screws intermittently between successive increases of joining pressure. This is especially true for thin, flexible panels and for disjoins, where movements are more likely. Disjoins, because they are usually straight and smooth, are often prone to slippage as joining pressure is applied (Fig. 8). Joint slippage can occur imperceptibly, long after the final pressure settings have been made and well into the initial setting stages of the glue. It is necessary to check the alignment repeatedly in all directions until the glue is set to ensure best results.

After the glue has dried, pressure mechanisms are released in the order opposite to which they were applied during the gluing procedure (first the bar clamps, then the alignment screws). The bar clamps are backed off in small increments, in the order and to the degree in which they were applied. Any unexpected movements or sounds may signal a critical weakness. If the alignment screws are released before the bar clamps, then critical support may be removed prematurely from the joint area, and the panel may buckle.

Larger Apparatus for Treating Panels Horizontally

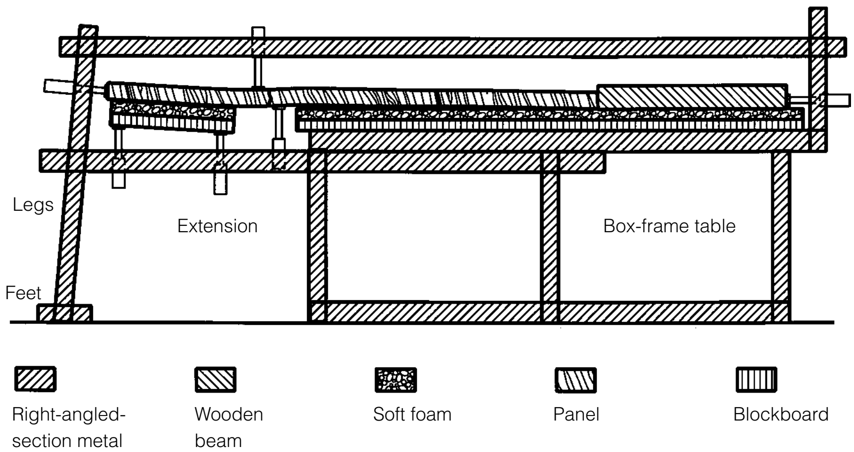
Case description

This apparatus was constructed in 1988. The method follows the principles described in the previous section. Screw clamps are arranged by some means around the panel to provide joining pressure. Alignment pressure is applied perpendicularly to the panel plane.

A more extensively damaged panel[13] of larger dimensions than the one discussed above necessitated construction of a more versatile combination of support table and rejoining apparatus. It was necessary to remove battens to gain access to splits and to insect-damaged wood. The panel required interim support until all the splits were glued and an auxiliary reinforcement applied. As the restraining battens were removed and the splits glued, it was expected that the panel conformation would vary accordingly, so that the interim support would have to be made adjustable to panel warp. Again, right-angled-section girders were used for construction.

Apparatus description and application

A main table was constructed that could, as work proceeded, support the panel's changing curvature across the grain direction and also provide a framework from which joining apparatus could be applied (Fig. 9a, b). The



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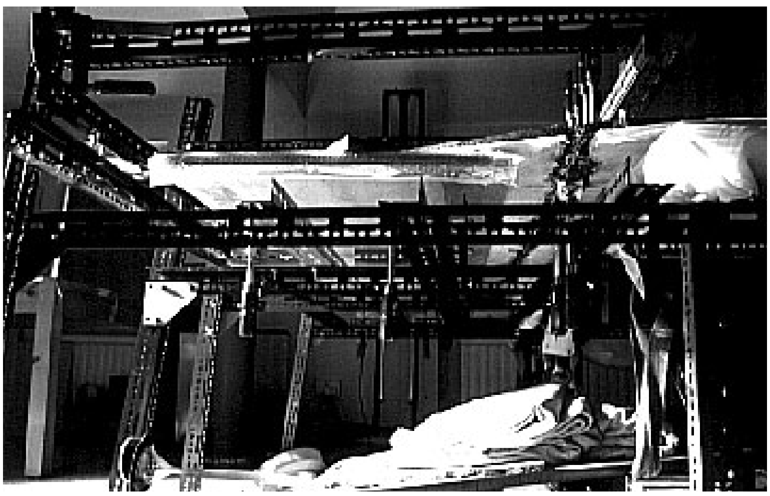

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Figure 9a, b
Drawing of an apparatus for rejoining larger panels, consisting of a table with extension, shown in elevation (a) from the end-grain edge of the panel. Note the angle adjustment of the extension, which accommodates the panel's curvature, and the turnscrews on the left, which are angled so as to direct joining pressure through the panel plane, thereby reducing buckling tendency. A view from below (b) shows the same end of a large panel during the rejoining of a split. The panel is facedown, and the facing is removed only in the area surrounding the split.

table consisted of a box frame of metal girders supporting a top of 25 mm (1-in.) thick blockboard panel fastened with screws from below. A layer of soft, 15 mm thick polyurethane foam sheeting[14] was laid on top, and a release film was secured over the foam.

The main table was extended to accommodate the panel and joining apparatus during gluing procedures. A side edge of the panel was projected over the table edge to expose the split being treated at both the front and the back of the panel. The panel's projected edge was supported by an extension, separated from the main table with a variable gap. The gap allowed access from above and below to the area to be glued. Girders, nested double for sufficient rigidity, were attached to the table frame. Screw clamps could be positioned to apply pressure in any direction for alignment and rejoining.

As work progressed toward the center of the panel, it became necessary to project an increasingly large portion of the painting, supported by the table extension. The extension consisted of a padded panel lying on four upturned screw clamps, which were attached to the girders of the extension frame. The extension girders, in turn, were attached to and extended from beneath the main table. They were of sufficient length to double the main table's width when fully projected.

The padded extension panel was thus made adjustable for angle, height, and distance with respect to the main table. These factors permitted adjustment of the panel's plane to conform with varying warp or to achieve various angles for gluing. Eventually, as more of the painting was projected, it became necessary to reinforce the projected girder ends with footed vertical girder legs that rested on the floor.

As rejoining proceeded, an inherent convex warp[15] became apparent when the panel was viewed from the painted side. The legs could be angled to direct the joining pressure in order to align it with the panel warp. Because the panel was facedown, pressure was directed at a slightly downward angle, in line with the panel's curvature, to prevent buckling.

Batten removal and rejoining began from one side-grain edge and was continued toward the center.[16] After half of the panel was consolidated, it was turned 180° horizontally to treat damages to the other half. For each split the battens were removed from above and to a point just before the next split. The exposed split was then aligned and glued.

Splits occurred at various angles in relation to the panel edge and roughly parallel to the local grain. The direction of any split could be followed closely by the screw-clamp positions, since the girders to which they were attached could be bolted at any angle in the horizontal plane. The top girder(s), with clamps attached and set, could be unbolted at one end and pivoted away from the split for the application of the glue, then repositioned quickly for the application of joining pressure—much as was done with the smaller apparatus.

In such a large rejoining mechanism, the beams that support the alignment apparatus are often not sufficiently rigid, especially when pressure must be applied in the middle of a large panel. Rigidity may be increased by bolting two lengths of girder together in the most useful configuration. Nested T or U sections may be constructed. U sections will allow screw clamps to be placed in parallel lines. Any thickness of timber could also be screwed or bolted to a girder to increase rigidity.

The entire apparatus can be taken apart quickly and easily, and the parts can be stored in a relatively small space or used for another purpose. Several other modifications can be made to the system, depending on need and limited only by imagination.

Larger Apparatus for Treating Panels Vertically

Case description

The treatment of a large eighteenth-century panel[17] suggested another rejoining method. The panel had been thinned. Rigid steel edge strips had been screwed into the end-grain edges of the horizontal planks, preventing movement of the panel across the grain during humidity changes. The resulting constraint caused considerable disjoining, partly because of poor environmental control.

The panel could have been treated horizontally, as in the case described above. However, a more compact apparatus was used to provide access and to make efficient use of studio space. Vertical orientation of the painting is also advantageous because it allows easier access to both sides than if the panel were oriented horizontally. Another benefit is that some aspects of cleaning, filling, and retouching can be conducted in tandem with the structural work if both sides of the panel are almost completely exposed.

Apparatus description and application

A frame/trolley constructed of a metal girder with six wheels for mobility was converted to a temporary support during treatment.[18] A padded ledge was affixed to the trolley bed, and the panel's longest edge was laid onto it, so that the panel planks were vertical with their backs facing outward. Two silicone paper strips placed beneath the lower panel edge reduced friction to allow warp movements. The topmost edge (a side edge of the panel) was supported with a padded length of girder. Thus, the panel was positioned for rejoining, back outward, as if on an easel.

Joining pressure was applied with polyester webbing straps fitted with ratchet-uptake mechanisms. This type of strap, available in various lengths, is typically used to tie down loads for haulage. The principle is similar to that of a windlass-type tourniquet. Such tourniquets can be manipulated to create a greater variety of pressure options than are possible with bar clamps.

Two straps (rather than one) were used. They were joined end to end to encircle the panel—a method that achieved one line of pressure. This method was used because the ratchet mechanism, if it were located on only one side of the panel, would cause unequal tension on each side because of friction at each end of the panel due to strap pressures. The resulting constraint produces a bending pressure toward the uptake side. However, when there is a ratchet on each side, pressure can be applied equally or unequally, as desired.

The joining pressure of the straps was applied to the panel edges through rigid end blocks, made from lengths of padded wood bolted into girder lengths. At each end of the panel, a strap was run through a slot in the girder and around the girder and the outside of the block. Each ratchet was loosely suspended from such an end block, then positioned to bear against the block when pressure was applied. Slings of cord or webbing were used to suspend the end blocks and ratchets from the top retaining bar of the support frame, where the bar projected beyond the borders of the painting. Thus the line of pressure could be directed at any desired height. The slings also prevented accidental damage that could have resulted if the end blocks had contacted the panel painting.

For longer splits or disjoins, it was necessary to use two or more strap pairs to concentrate the pressure across the entire panel. The number and the location of straps and the lengths of the end blocks determined the location and distribution of pressures.

Alignment was achieved with screw clamps and girder lengths, as discussed for the previous case. In this case the girders were placed on either side of the panel with their longest axes vertical and parallel to the joints or splits. The clamps could be repositioned to adjust alignment. Then, the girders could be unbolted at the bottom and pivoted away on either side of the panel to provide access for glue application. The bars could then be rebolted in virtually the same position, with only slight adjustments to the alignment clamps being necessary.

Each disjoin was treated consecutively across the panel. As work progressed, the girders and clamps were moved to the adjacent disjoin.

There were major disadvantages to the vertical apparatus. For one thing, access to the lower edge was limited—a problem that could be overcome by an improvement in design. Moreover, if a painting is especially heavy and if movement (from changes in moisture content, for example) occurs during treatment, the resulting friction would impose constraint. Another drawback of the vertical apparatus is that gravity can adversely affect the flow of adhesives and consolidants. The vertical orientation can make it difficult to control tools in such procedures as using chisels to fit wooden inserts into areas of severe insect damage, especially toward the lower edge. One final caution is that the vertical orientation can be used only in cases where the paint is secure or well faced, or there may be losses due to flaking.

Acknowledgments

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Notes

1 In this text the term *rejoining* refers to the gluing of either splits in the wood support or joints that have failed, or *disjoined,* due to a glue line being too weak or deteriorated. The term *joint* is used more generally and refers to the line where two wood members meet or would meet, whether the joint is intact, disjoined, or split.

2 The joint edges are displaced such that one edge is above and the other is below the general plane of the panel. Such misalignment is sometimes called a *step* or *stepping*.

3 The method described in this article utilizes specialized apparatus to rejoin a particular break in a single gluing procedure. In contrast, the insert method usually rejoins segments of a disjoin in sequential steps so that the joint is treated with successive gluing procedures. The insert method generally avoids the use of joining pressure as defined in this article.

4 Generally speaking, most water-based glues used for rejoining are removed easily from a paint surface while they are still moist. It is important to remove them as soon as possible after they contact the paint, since paint losses can result from swelling or solvent effects. Also, strong hygroscopic glues that expand and contract, such as animal (collagen) glues, though soluble when dry, can easily detach underlying paint (see Mecklenburg 1982:figs. 9, 11). Because even a thin remnant of such a glue can detach paint, it should be thoroughly and immediately removed from the paint around the joint.

5 This characteristic has probably been the salvation of many poplar panels subjected to stressful framing and reinforcement structures.

6 Like many conservation considerations, the determination of what constitutes overstress in the manipulation of a panel painting is generally a matter of judgment, based on experience and common sense.

7 Rather than leaving one side of a joint higher than the other, an earlier conservation might have graded a putty or filler between the two levels. Such a grade, or ramp, is often a sign of inaccurate rejoining or of a break that has been superficially treated without structural work.

8 The screw clamp's potential was suggested to the author by Professor I. S. Hodkinson of Queen's University, Kingston, Canada, where it was applied for this purpose. The first apparatus used at HKI was designed and built in winter 1987. See Materials and Suppliers below, for the supplier of the hold-down clamps used in this apparatus.

9 This is also known as *slotted angle* and is found in various forms in laboratories in many countries.

10 Cornelius Janssens (or Johnson). *Portrait of the Third Earl of Moray,* seventeenth century. Oil on oak panel, 807 × 640 × 7 mm thick. Private collection, Scotland. HKI treatment no. 1475.

11 Polyester (polyethylene terephthalate) film.

12 A condition in which insufficient glue remains in the joint after drying.

13 Marco Palmezzano, *The Mystic Marriage of Saint Catherine,* 1537. Oil and egg tempera on poplar (visual identification) panel, 2560 × 1805 × 20 mm thick. Signed and dated. Property of the Marquess of Northampton. HKI treatment no. 1302. (See Brewer, "Practical Aspects," herein, and Brewer 1994.)

14 The foam was used as a thin padding to distribute the weight of the panel. Use of a hard surface, which would have concentrated the weight on too few points over the warped panel surface, would have risked damage to the paint during the relatively long treatment period.

15 A curvature typical of substantially thinned panels.

16 See the author's discussion of the removal of reinforcements from large panels (Brewer, "Practical Aspects," herein).

17 Anton Raphael Mengs, *Noli Me Tangere,* 1771. Oil on walnut panel, 2915 × 1785 × 20 mm thick. The Warden and Fellows of All Souls College, Oxford. HKI treatment no. 73.

18 See Brewer, "Practical Aspects," Figures 7, 9a, 9c, herein.

Materials and Suppliers

Hold-down clamps, Trend Machinery and Cutting Tool Ltd., Unit 'N', Penfold Works, Imperial Way, Watford WD2 4YY, England.

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The Framing of Wooden Panels

Ian McClure

This article considers the problems encountered in the framing of panel paintings in cases where some movement in response to fluctuations in ambient levels of relative humidity (RH)—either in short-term cycles or longer-term, seasonal cycles—is anticipated. The panels considered here are those that can be handled without further reinforcement and that can accommodate some movement without buildup of stress, as well as panels that have support systems that move with the panel and require a rigid frame to enclose and protect them. Particularly sensitive panels—those that are at risk from conflicting tensions in the structure or those weakened by agents of degradation—should always receive further structural treatment or climate-controlled enclosures.

In this article the frame itself is regarded as an auxiliary rigid support. The methods used to construct a frame for a painted panel illustrate several principles: different materials may be employed according to availability; the panel must be able to expand, contract, and warp in response to changes in RH; and in some instances, simple, unobtrusive modifications are made to the frame. The systems described here are the result of experience gained during the fitting of panels for display in places where the environment cannot be precisely controlled, such as in private collections, or in situations where small, unsupported panels have been prepared for transport and display in temporary exhibitions.

The rate of response to fluctuations in RH will vary depending on the thickness of the panel, the type of wood, the cut of the planks from which the panel is made, and the degree of sealing of the reverse of the painting and the endgrain. The framing should also take into account the amount of movement the panel is likely to produce within the range of RH levels in a given environment, and the space for that movement should be built into the frame rabbet.

Notably, the number of articles that discuss framing panels is relatively small; this situation may reflect the fact that framing often falls outside the jurisdiction of the conservator of paintings. With the growing popularity of large-scale traveling exhibitions and with their accompanying risks, however, it is essential to review and evaluate the principles behind framing methods—and perhaps arrive at some comprehensive guidelines.

A historical survey of the framing of panels[1] could start with integral frames, where the frame is carved from the same panel on which the painting is executed, such as the portrait of Emperor Charles V, attributed to the Master of the Magdalen Legend and painted at the beginning of the sixteenth century (Fig. 1), or a large, complex altarpiece where the molding of the frame is securely attached, sized, and gessoed along with the panel. An example is the San Pier Maggiore altarpiece by Jacopo di Cione, most of which was removed from Florence and is now in the National Gallery, London.[2] While there is evidence (such as the fixing of battens at only one point on each vertical plank of the painting) that altarpieces were constructed to allow small movements,[3] it seems likely that the relative stability of environmental conditions[4] within the church or chapel mitigated the buildup of tension and stress, which could result in cracking and splitting. Elements of the San Pier Maggiore altarpiece, however, were probably glued, dowelled, and nailed together with battens—procedures that produced a very rigid structure to counter the artwork's size and weight.

In northern Europe, panel and frame construction tended to be more sophisticated than in the south, and frames were routinely designed to allow movement of the panel.[5] For example, the wings of the Oxburgh Altarpiece, produced in an Antwerp workshop around 1530, have the panels fitted, unglued, into grooves in the frame molding. Despite allowances for movement, large altarpieces of this type are known to have suffered from structural failure due to flaws in their original construction. For example, it has been suggested that modifications had to be made to the wings of van Eyck's Ghent Altarpiece, as the wings proved to be too heavy (Verougstraete-Marcq and Van Schoute 1989:78). In the case of the Oxburgh Altarpiece, structural failure was a result of a restoration that was based on a misunderstanding of the principles behind the original construction. The free expansion and contraction of the panel in its frame had produced a gap between the *malrand* (paint edge) and the frame edge. This was filled and retouched—restorations that proceeded to restrict the panel's movement and cause splits in the panel and tenting and flaking in the paint layer (McClure and Woudhuysen 1994:20–23). The rigidity of the

Figure 1
Master of the Magdalen Legend (attrib.), *Emperor Charles V,* early sixteenth century. Oil on oak panel with integral frame, 34.3 × 23.8 cm. Fitzwilliam Museum, University of Cambridge (2309).

Figure 2
Antwerp school, Oxburgh Altarpiece (right wing, outer side), ca. 1530. Oil on oak panel, 226 × 114 cm. National Trust, Oxburgh Hall, Norfolk, England. In the lower right corner is a bolt that was inserted later.

Figure 3
Florentine school, *Virgin and Child,* early fifteenth century. Tempera and oil on poplar panel, 84.5 × 45.2 cm. Fitzwilliam Museum, University of Cambridge (1987).

frames of the wings was further weakened by the fitting of brass bolts and keeps in the nineteenth century (Fig. 2).

By the mid–eighteenth century, the movement of paintings from their ecclesiastical settings into private collections and museums had begun. Complex altarpieces were broken up and installed in new, fashionable frames, losing in the process not only cultural context but also, in many cases, structural soundness. For example, the context was obscured in a small *Virgin and Child,* painted in Florence in the 1420s and now in the Fitzwilliam Museum, Cambridge, when the arched top was squared off with a wooden addition decorated with gilded *pastiglia* work, so as to fit a rectangular frame, presumably for display in a secular setting (Fig. 3). A portrait of a man by Memling, originally part of a diptych, depicting a donor and presumably the Virgin and child (part of the Bearsted Collection, Upton House, National Trust), now has a nineteenth-century ornate Gothic frame fitted inside a shadow box. Traces of the original malrand survive, as do traces of gilding from the original, integral frame.

There seems to be no evidence that panel paintings were ever fitted with a regard for expansion, contraction, and warping of the panel support before the twentieth century, with the exception of double-sided elements of altarpieces in northern Europe. Even such a grand altarpiece as Carlo Crivelli's *Madonna of the Sparrow,* probably commissioned in the 1490s (National Gallery, London), has developed cracks as a result of its original construction. The altarpiece is largely intact, although the central panel has been thinned and cradled. The predella panel, a single horizontal plank painted with three separate scenes, was securely nailed in with nails of differing lengths. One nail subsequently caused a horizontal crack (Smith et al. 1989:32, 37, fig. 7).

The method of nailing panels rigidly into frames seems to have become generally employed as soon as frames were recognized as separate from the paint support. It is not uncommon to find panel paintings in British private collections that have been secured in this way and left undisturbed for generations. A pair of early-seventeenth-century portraits of Edward Altham and Elizabeth Altham, from Kingston Lacy House in Dorset, England, now owned by the National Trust, survive in their original frames and have received little, if any, structural conservation measures. Pinned tightly at regular intervals around the edges, the panels, each formed of three vertical oak planks, have been unable to move in response to changing levels of RH. A joint in each panel has failed. In the portrait of the man, the detached section of the panel was simply pinned at a later date with nails of later construction (Figs. 4, 5). At some time before the 1730s, in common with a large number of paintings in the collection, the panels were painted on the reverse with a red, probably ochreous, paint.[6] This paint layer runs into the split and over the back of the frame, suggesting that the joint had already failed by 1730, as a result of wide fluctuations of RH possibly caused by relocation of the painting; perhaps it was removed to a less well buffered area of the house, such as the attic or servants' quarters, when the style of the portraits became unfashionable or the significance of the sitters was forgotten. The depth of the rabbet of the frame is only about 2 mm greater than the average 6 mm thickness of the panels, indicating that no space for movement was allowed for by the frame maker.

A seventeenth-century view of a church interior after Neefs, from Grimesthorpe Castle in Lincolnshire, has horizontally aligned planks (Fig. 6). The panel has a history of structural failure, as the uppermost join has opened and has been reglued while misaligned. This initial failure

Figure 4, below
British school, *Portrait of Edward Altham,* 1617. Oil on oak panel, 78.8 × 63.5 cm. National Trust, Kingston Lacy House, Dorset, England. The condition before treatment is shown; the frame is original.

Figure 5, below right
British school, *Portrait of Edward Altham*. Reverse before removal from the frame.

Figure 6
Dutch school, *Church Interior,* mid–seventeenth century. Oil on oak panel, 89.2 × 120.8 cm. Grimesthorpe Castle, Lincolnshire, England.

was followed by the present failure of the lower join; on both occasions these failures were caused by the rigid fixing of the panel into the frame. Regular nicks on the sides of the reverse of the panel, cut for fixings, can be seen (Fig. 7).

An unthinned panel of approximately 1540, *Portrait of a Man with a Watch* (Science Museum, London), attributed to the Florentine painter Maso di san Friano, has regular V-shaped nicks along the top and bottom of the reverse of the panel where nails have secured it to the frame. There is no evidence of similar fixings along the sides. The panel has developed a convex warp, greatest in the center of the panel, between the dovetailed battens, set into channels (Fig. 8).

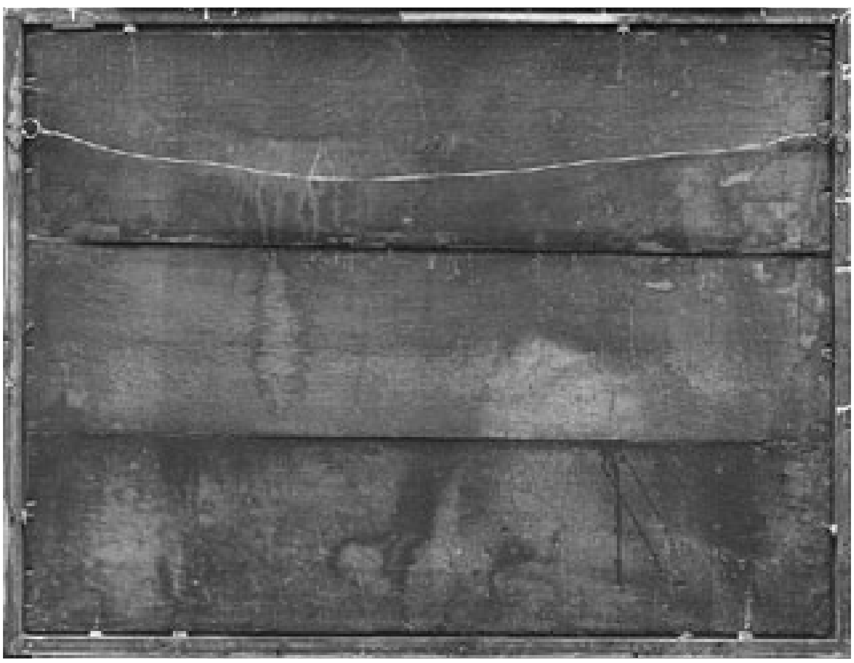


Figure 7
Dutch school, *Church Interior*. Reverse before removal from the frame.

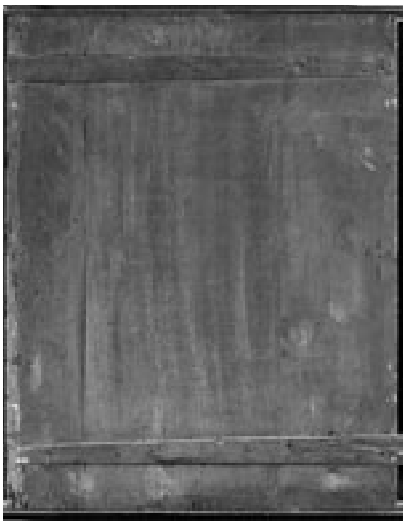


Figure 8
Maso di san Friano (attrib.), *Portrait of a Man with a Watch,* mid–sixteenth century. Reverse. Oil on poplar panel, 117 × 92 cm. Science Museum, London.

The correction of the tendency of panels to develop convex warps when exposed to low ambient levels of RH is probably one reason for the increasing popularity of cradling from the mid–eighteenth century into the first half of the twentieth century. A panel would be thinned by the introduction of moisture and become very responsive to flattening. A cradle would then be attached, to restrain the panel in plane. In this way, the visual disturbance caused by a gap between the frame rabbet and the picture surface could be corrected. By the mid–nineteenth century, panels were routinely thinned and cradled, and even as late as the 1960s the desirability of a flat picture plane was cited as a reason for major intervention.[7] Today it is generally accepted that panel paintings should be allowed to assume a natural warp at a given RH and that the frame should be adjusted to suit such movement.

The principles behind early-twentieth-century solutions to the problems of framing panels hardly differ from those we recognize today. In 1936 in the National Gallery of Scotland, the wings of the Trinity Chapel Altarpiece relied on the provision of a microclimate enclosure, the exterior of which served as the frame (Cursiter 1936:109–16). In 1940 the International Office of Museums recommended, among other urgent concerns, the use of steel springs in framing panels to allow movement and added the proviso that they should be removed for transport (International Office of Museums 1940:80, 81, n. 58, 59). In 1955 George Stout, as part of the survey of panel treatments instigated by the International Council of Museums Commission for the Care of Paintings, illustrated examples of frames causing splits in panels and of panels causing the breaking of frames. Several systems for fitting panels were illustrated, including a system for supporting a panel with unglued cracks.[8] In 1965 Straub recommended the use of flexible strips of sprung steel to allow warping. This apparatus could be combined with a backing to provide protection against shock and to act a buffer against changing climatic conditions (Straub 1965). Similarly, in 1978 Goetghebeur recognized the use of the picture frame to support panels and suggested the use of sprung steel strips to allow movement (Goetghebeur 1978). In 1982 Ranacher largely repeated Straub's recommendations (Ranacher 1982:147); the same year Vöhringer described a framing system for a sixteenth-century panel which supported the panel in the center and allowed movement at the edges by means of a leaf spring held in place by a U-section metal bracket and adjusted by a threaded bolt (Vöhringer 1982:fig. 9). In 1988 Dunkerton and coworkers described the widening of the groove of a later double-sided frame housing the wings of an altarpiece by Martin van Heemskerck (Dunkerton, Burnstock, and Smith 1988:20). Low-density foam was fitted in grooves on both sides of the panel to allow some movement. Hermesdorf, in 1989, described a system of suspending the panel on aluminium strips attached to the frame. Wooden buttons, normally reinforcing reglued joins and splits, had slots cut in them that fitted over the aluminum sections (Hermesdorf 1989:267–69). The use of roller bearings attached to the base of a support for a large panel with horizontally aligned planks and running on tracks on the bottom rabbet section of the frame significantly reduces static friction between the panel base and frame, allowing the panel to move in response to changes in RH (see Bobak, "A Flexible Unattached Auxiliary Support," and Marchant, "Development of a Flexible Attached Auxiliary Support," herein).

These methods reflect the current belief that panel paintings should be allowed to move, perhaps within limits, to adopt greater or smaller curves in response to changes in ambient RH. Observation of particular panels under varying levels of RH can reveal a surprising degree of warping over a short period of time. For example, in 1987 the Hamilton Kerr Institute, in Cambridge, England, treated an early-sixteenth-century poplar panel, *The Adoration of the Shepherds,* attributed to the Master of Santa Lucia sul Prato. The panel, measuring 169 × 162.5 cm, had been thinned to 1 cm and was heavily cradled. After the cradle was removed and the splits were reglued, the panel developed a convex warp of 3 cm across its width at an RH of about 55%. A reduction or increase of 10% produced an increase or reduction of the warp by 1 cm in just two hours. Rigid fixing of the panel in its frame would have inevitably produced rupture of the wood or of the glued joins.[9] Stout, in describing a formula to calculate the force required to constrain and flatten a warped panel temporarily straightened by moisture, gave a formula to calculate the force required to rupture the panel; that formula could then be used to calculate a safety margin in framing (Stout 1955:158–59). In practice, however, evaluation of the force required for the panel to deflect the frame fixings seems only recently to have been assessed. In 1991 Mecklenburg and Tumosa produced computer models of cracked and uncracked oak panels rigidly fixed into their frames and assessed their resistance to splitting. An uncracked oak panel measuring 76 × 102 × 1.27 cm thick could be split by fluctuations of RH between 70% and 10%. When a cracked panel of similar dimensions is subjected to strain, much less force is required to extend the cracks (Mecklenburg and Tumosa 1991:187ff.). Thinned poplar panels, often weakened to a far greater extent than oak by boring insects, are likely to split under much lighter loads.

The author has not found any assessment of the force exerted either by flexible spring fixings, commonly used to secure panel paintings, or by malleable brass fixings, which might be expected to distort under loading, thereby preventing undue stress to the panel or elastic foam of a known density (Plastazote and Evazote of a density of 50 kg m^{-3} are commonly used).[10] However, a simple experiment demonstrates that the force required to deflect a particular fixing is much greater than might be expected. Two commonly used sprung-steel fixings and four brass fixings of different dimensions were screwed to a length of wood. Holes (or in the case of one spring fixing, a hook) were provided to attach a spring balance. The force required to raise a fixing by 1 cm was observed. The length of each fixing, which affects the moment of the force generated, was not assessed. The spring fixings required a loading of 0.8–1.4 kg to deflect them 10 mm from an unstressed position. A force of 2.8 kg was required to move the three smaller malleable brass strips 10 mm; a force of 1.8 kg was required to move the largest brass fixing, a result that reflected the increasing moment as the length increased. Foam blocks of varying density require an often-underestimated force to compress the foam to accommodate a warp. For example, three foam blocks, 3 cm cubes cut from Evazote of 50 kg m^{-3} in density and set in line at 10 cm centers under a strip of wood, required a weight of 7.3 kg to compress the blocks by 5 mm. Two identical blocks at 10 cm centers under the same wooden strip required a weight of 5.5 kg to compress them by 5 mm. A single foam block under the wooden strip required a weight of 2.7 kg to compress it by 5 mm. The force exerted by the metal fixing devices described above, when the panel moves against them, could in many cases come close to or exceed the rupture strength of the wood, especially when the wood is weakened by splits or degraded by woodworm damage, and when glued joints are embrittled by age. It is doubtful that any calculation could be devised to give a value for the elasticity of the wooden panel at right angles to the grain—there being so many variables and features peculiar to each panel. It seems that framing systems that exert minimal restraining force at the edges and parallel to the wood grain are least likely to cause damage. A framing system to achieve such a goal would have to be designed on an individual basis, with the construction and inherent stresses of each panel, as well as its display and travel requirements, taken into account. It is an important consideration that systems that hold the panel while allowing maximum movement often provide insufficient support when the panel is moved.

Three case studies illustrate techniques employed at the Hamilton Kerr Institute. The first, the framing of a small panel of three vertical planks, the *Portrait of Elizabeth Altham,* has been mentioned above. The second is the framing of the large altarpiece *Noli Me Tangere* by Anton Raphael Mengs, with horizontally aligned planks; the frame of that work required considerable strengthening. The third is an altarpiece, attributed to Pietro Gerini, which had been reframed in the nineteenth century. Even though the frame was causing splitting in the three panels, the client wished the altarpiece to remain unchanged in appearance after treatment.

Portrait of Elizabeth Altham

The 1617 panel, one of a pair of seventeenth-century portraits, was in its original frame of oak painted black and partly gilded. The joints of the panel had opened. After gluing, the panel was observed to assess the maximum curvature it would develop. It became slightly convex at an RH of 50%. It was decided to increase the depth of the frame rabbet from 8 mm to 18 mm. Strips of dimensionally stable spruce were cut and angled to the outside edges of the frame to make the addition inconspicuous. Strips 25 mm in width were mitered, stained dark, and attached with screws to the back of the frame. (The use of glue was rejected as less reversible.) The addition is not visible when the frame is hanging, and only a slightly larger gap between frame and wall is evident. The panel fitted quite closely to the rabbet, which did not require any addition of shaped sections to follow the panel's curvature. Rabbets can be adjusted to remove the gap between the sides of the panel and the frame edge, which can be visually distracting, especially where light can be seen between the picture frame and the wall. However, a curved rabbet can itself restrict movement if the panel is subjected to higher RH levels; in such a case the sides of the panel across the grain will press against the outer edge of the rabbet and the nearest top and bottom fixing points, exerting pressure on weak areas and joins. The panel must be able to assume a less convex profile; this is facilitated either when space is left for movement at the edges or when the central fixings are designed to compress, allowing the panel to move away from the frame rabbet in the center. Compressible curved additions to the rabbet could be made. However, any material that can be accurately shaped and that presents a visually acceptable surface, such as Plastazote or Evazote, is likely to be too rigid to conform to changes to the configuration of the panel.

The panel was then fitted in the frame. The central vertical plank was set on a thin, 15 mm strip of hardwood. This raised the lower edges of the panel away from the bottom edges of the frame, allowing free movement. Small blocks of Evazote, with the bottom edges shaped to align with the chamfered edge of the panel, were cut. A groove was cut in the top of the blocks to position the brass fixing strip and prevent the foam block from accidentally falling out. The brass fixing strip was bent at a right angle at its end to retain the block. It was then screwed to the base of the frame addition and curved to hook over the back edge of the addition so that it could not be twisted out of position. These fixings were placed toward each edge of a central plank (Fig. 9).

Noli Me Tangere by Anton Raphael Mengs

The structural conservation of this large painting is described elsewhere (see Brewer, "Some Rejoining Methods," herein). Even after an auxiliary support in the form of battens was applied to the reverse, it was felt that the frame should supply further support. As the weight of the panel itself is estimated to be about 100 kg and the planks are horizontally aligned, it was decided to modify the system designed by Ray Marchant for a painting by Alexander Kierincx and Roelant Savery (see Marchant, "Development of a Flexible Attached Auxiliary Support," herein). This system would reduce the friction between the bottom edge of the panel and the frame by attaching roller bearings to the panel, locating them in slots in the depth of the frame rabbet. The existing frame originally had no rabbet, and so later additions were removed, and a new back rail, 19 cm in depth, was made to accommodate the panel and batten system and a movement of about 2 cm in either direction. This back rail was glued and screwed to the back of the frame for maximum strength and painted to match the sides of the frame. The lower ends of the four battens supporting the picture were then fitted with inserts, so that an L-shaped aluminum section could be bolted on to support the weight of the panel when upright. A pine spacer shaped to counter the angled edge of the panel due to the convex warp was fitted between the base of the panel and the aluminum section to spread the weight of the panel evenly. The L-shaped aluminum

Figure 9
British school, *Portrait of Elizabeth Altham,* 1617. Reverse. Oil on oak panel, 79 x 63.5 cm. National Trust, Kingston Lacy House, Dorset, England. Modifications to the original frame are shown.

section protruded in front of the panel by 5 mm to enable the block holding the roller bearings to be set in the line of the center of gravity of the panel. The blocks of aluminum were bolted to a strip of 6 mm aluminum, which was bolted in turn to the L-shaped aluminum section to increase rigidity. The bearings run in the slots cut in the bottom rabbet of the frame, which are lined with stainless steel strips to prevent the bearings from denting the wood and locking the system. When upright, the panel rests on the bottom edge of the frame and against shaped rabbets on either side. The panel is held in the frame across the center by two horizontal battens resting on the panel battens and attached to the frame by bolts and compression springs to allow some movement in the event the panel should assume a less convex profile (Figs. 10, 11a, b).

Triptych attributed to Pietro Gerini

When received for treatment, the three elements of the triptych—a central single poplar panel of the Madonna and child, flanked by panels of two vertical planks with arcading attached above—were held together by three battens screwed to each panel in turn (Hamilton Kerr Institute 1984) (Figs. 12, 13). At the front, the decorated base was screwed to the lower edges of the panel. This rigid construction, probably made in the late nineteenth century in France, as the provenance suggests, had caused the opening of splits in the left and right panels and two splits in the central panel. The two columns separating the wings from the center were contemporary with the rest of the frame.

The components of the altarpiece were dismantled. The battens were unscrewed and the columns and pilasters gently prized off. A new framework to hold the panels was constructed from pine, stained to be unobtrusive, and then sealed with polyurethane varnish to reduce dimensional change in the structure (Fig. 14). The frame's base was adjusted with balsa-wood spacers to hold the three panels at the correct alignment (Fig. 15). Each outside panel was attached by the base of the support and by a shaped brass strip fixed to the back of the framework at the upper rail. The central panel was similarly attached at the base and attached by steel hooks to existing original fixings in the panel above the pilasters. Two vertical strips of wood were placed over the joins between the central panel and the outer panels and were held in place by stainless steel bolts

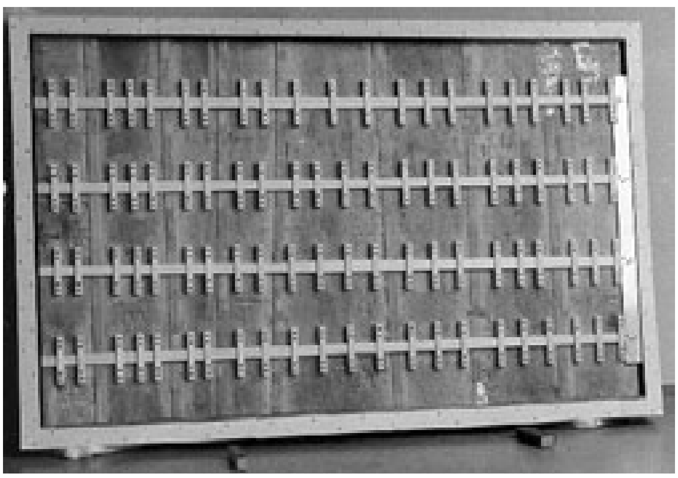
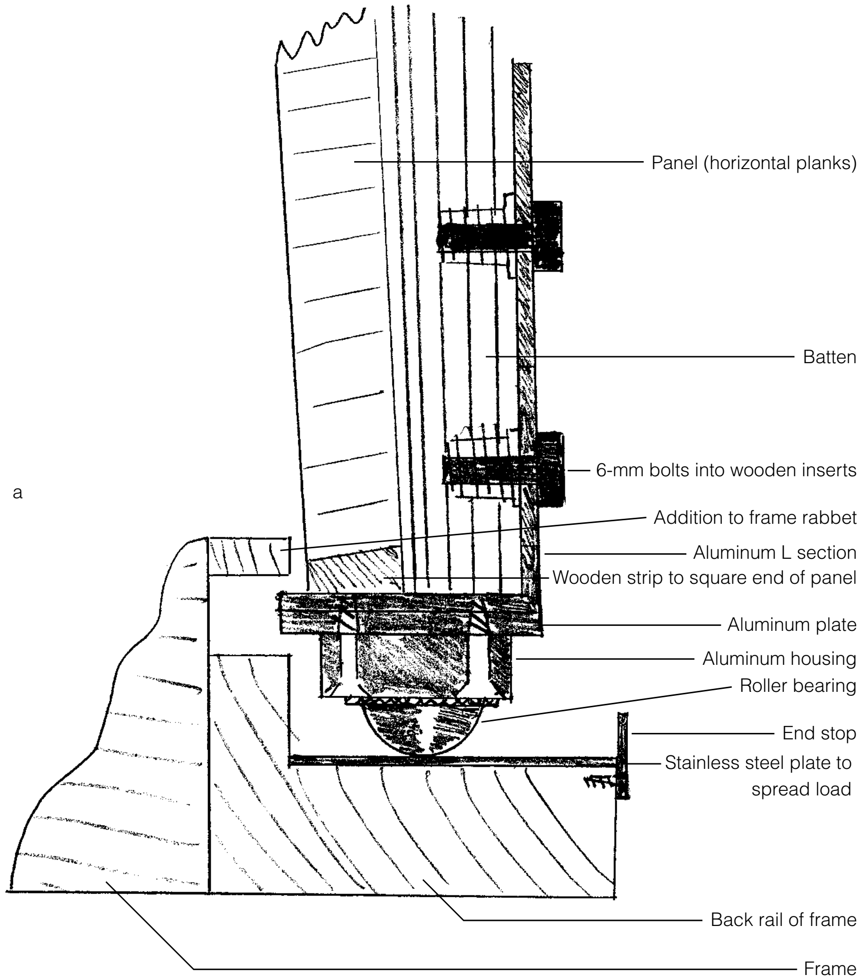


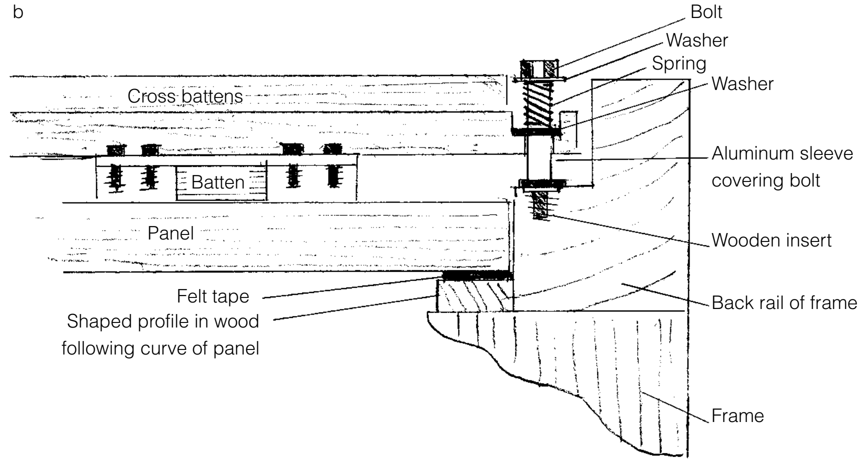
Figure 10
Anton Raphael Mengs, *Noli Me Tangere,* 1771. Reverse. Oil on walnut panel, 291.5 × 178.5 cm. All Souls College, Oxford.

Figure 11a, b
Anton Raphael Mengs, *Noli Me Tangere.* Diagram of (a) roller bearing fixings, and (b) sprung framing battens.

a



b



that passed through the gap between the three panels and that were bolted to the framework with provision for adjustment. The three panels were thus held and supported without any restriction to their movement.

To comply with the client's wishes, the nineteenth-century columns and base were put back. The decorated base was attached to the base of the framework, the bases of the columns at each end were

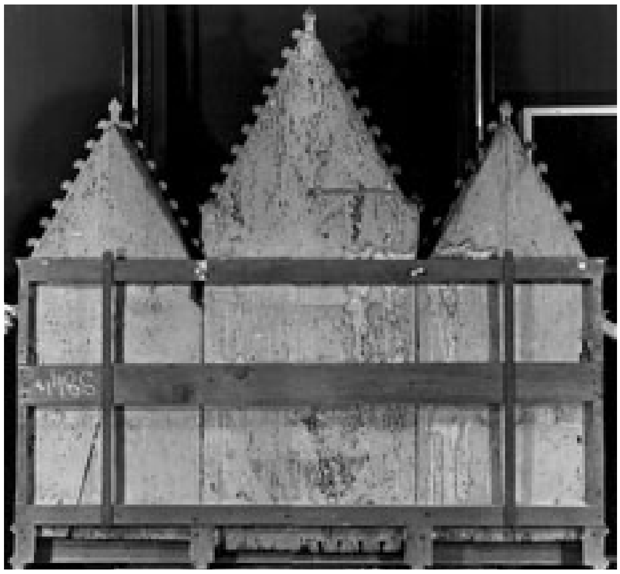


Figure 12, above
Pietro Gerini (attrib.), *Triptych*. Acqueous medium on poplar panel, 165 × 180 cm. Private collection. The condition before treatment is shown.

Figure 13, above right
Pietro Gerini (attrib.), *Triptych*. Reverse before treatment.

Figure 14, below
Pietro Gerini (attrib.), *Triptych*. Reverse after treatment.

Figure 15, below right
Pietro Gerini (attrib.), *Triptych*. Diagram of the framework.

lengthened, and the pilasters above the spring of the arches were refixed (those on either side of the central panel to that panel only). The sides of the framework were chamfered to echo the shape of the columns, and new central columns were made to cover the strips supporting the panels on either side of the central panel. The columns, slotted behind the capitals and held in place at the bottom by a thin base plate screwed onto the base of the framework, were prepared and gilded to match the rest of the framing elements. The reframed altarpiece differed only in minute detail from its previous appearance—yet the panels were unrestricted, and the frame could be easily dismantled and reassembled (Fig. 16).

It is hoped that these examples demonstrate a valid and flexible approach to the framing of panels. The solutions devised here are not presented as models to be copied but, rather, as proposed methods that can be adapted and improved.

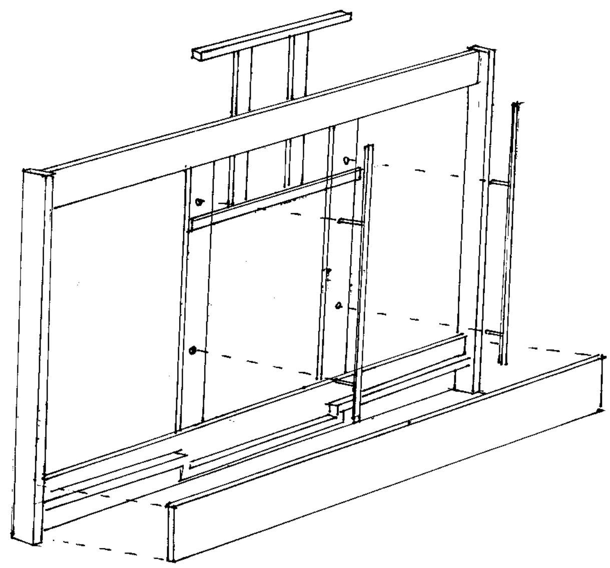


Figure 16
Pietro Gerini (attrib.), *Triptych*. The condition after treatment is shown.

Acknowledgments

The author is grateful to Kathryn Hebb for her help with this article, as well as to Ray Marchant for his help and advice.

Notes

1 For a well-illustrated history of frame styles, see Grimm 1978. An important study of Dutch frames in the seventeenth century is van Thiel and Kops 1984.

2 National Gallery, London, cats. 569–78. A full account of the technique and construction of the altarpiece can be found in Bomford et al. 1989, especially 156ff.

3 For a succinct account of the construction of early Italian altarpieces, see the introduction by Bisacca and Kanter in Newbery, Bisacca, and Kanter 1990:11–30. See also Cämmerer-George (1966) for illustrations of altarpiece construction.

4 See Lacey 1970:65–80, for a study of the environment in Kings College Chapel, Cambridge, before the installation of the large panel of *The Adoration of the Magi* by Rubens. The considerable buffering effect of the stone is assessed, as are the effects of low-level winter heating, which contributed to an annual fluctuation of mean levels of RH between 55% and 70%, with very slow rates of change.

5 For a detailed account of Flemish altarpiece construction, see Verougstraete-Marcq and Van Schoute 1989:78, where the problems encountered with the original design of the wings of the Ghent Altarpiece are discussed.

6 A list of paintings mended and cleaned by George Dowdney in 1731 survives. The linings of several of the Lely portraits were eighteenth century and had been coated with red paint on the reverse, presumably as a moisture barrier. See Laing 1993:107–31, especially n. 18.

7 For example, Helmut Ruhemann's comment on the "semi-transfer" of the *Nativity* by Piero della Francesca, "which did not leave the picture quite flat nor absolutely stable" (Ruhemann 1968:161, n. 2).

8 Stout 1955:figs. 22–24. For fitting panels in frames, see figs. 50, 52, and 53.

9 See Hamilton Kerr Institute 1987, where the work is attributed to the school of Ghirlandaio. The painting is in a private collection.

10 Plastazote is a low-density, cross-linked, closed-cell polyethylene foam. Evazote is a low-density, cross-linked, closed-cell ethylene vinyl acetate foam.

Materials and Suppliers

Brass fixing strips of various sizes, J. Shiner and Sons, 8 Windmill Street, London W1P 1HF, England.

Plastazote and Evazote, BXL Plastics, ERP Division, Mitcham Road, Croydon, Surrey CR9 3AL, England.

Roller bearings, Always Engineering, Warner Street, Birmingham, B12 0JG, England.

Self-adhesive acrylic felt tape (for lining rabbets of frames), George B. Tewes Co., Western Felt and Fiber, 323 South Date Avenue, Alhambra, CA 91803.

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Practical Aspects of the Structural Conservation of Large Panel Paintings

Al Brewer

A SUBSTANTIAL PROPORTION of paintings treated at the Hamilton Kerr Institute (HKI) in Cambridge, England, have been on wooden supports. This article uses examples to show the underlying causes and mechanisms that determine treatment decisions in practice.

General Considerations

Scales of damage and treatment constraints

Large panels have sufficient weight and size in the cross-grain dimension[1] so that a number of considerations arise that are generally less significant in smaller panels. Greater damages are found—breaks of greater number and length and larger areas of biological deterioration—with corresponding treatment implications. Liters of (usually toxic) consolidant may be needed for a large volume of insect-damaged wood, requiring large-scale application methods and large-capacity fume extraction. Thus, treatment methods are scaled accordingly and should be made as efficient as possible, while, of course, being subject to conservation demands.

Structural stabilization concerns for large panels must be balanced with restrictions in time, cost, and methodology. The greater logistics generally make treatment more difficult, demand more time and appropriate methods, and therefore increase total costs. Satisfactory results may require a complex treatment and some ingenuity.

Environmental considerations and wood movement

Environmental conditions are constantly changing, however slightly, so that panels of wood are *constantly* moving in response to changing moisture content (MC).[2] Depending on the panel structure, such *wood movement* may be relatively small or slow, and therefore not easily perceived. Generally, larger panels change MC more slowly, although movement may still be relatively fast, especially for thinner panels. Even when housed with the best environmental controls, panel paintings are unlikely to reach a stable equilibrium moisture content (EMC) with level moisture gradients and cessation of movement.

Relative humidity (RH) should be as stable as possible during treatment. Total *lateral* movement (across the wood grain and in the plane of the panel)[3] and *warp* movement (perpendicular to the panel plane) vary directly with the panel's dimension across the grain.[4] The location

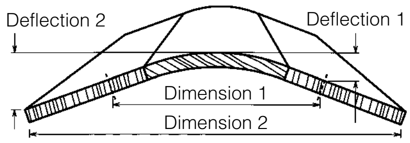


Figure 1, above
A panel, consisting of three planks, viewed from slightly above one end of the planks. A greater cross-grain dimension would "magnify" the deflection of the middle plank in the diagram. This is shown as the difference between deflection 1, for a smaller panel of dimension 1, and deflection 2, for a larger panel of dimension 2.

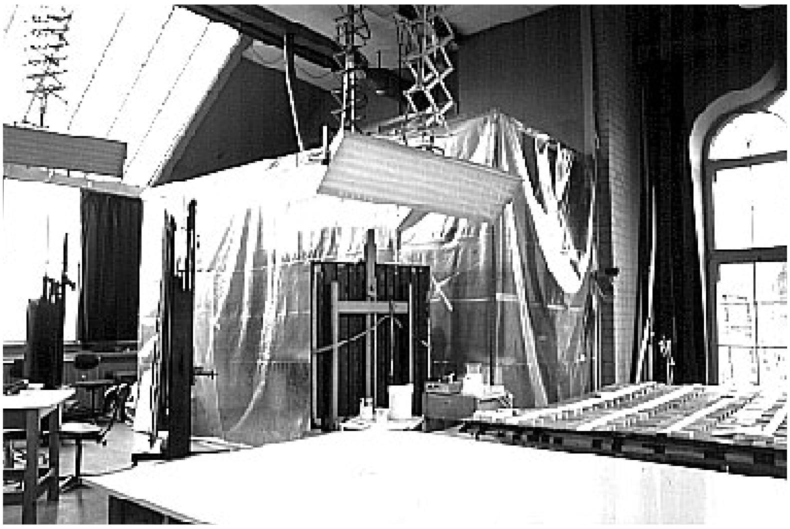


Figure 2, right
A tent enclosure for treatment of a large panel, built to sustain RH and temperature at approximately the same levels as in the panel's normal environment.

of warp-prone areas is also a factor. For example, planks cut tangentially are more prone to warp movement. If a warp-prone area is located toward the middle of a panel, the movement will be transmitted to the panel's (longitudinal-grain) edges so that the overall deflection may be somewhat greater than that of the central plank (Fig. 1).[5] Since this is an angular relationship, deflection of the panel edges may be almost instantaneous, especially for larger, thinner panels that are more flexible and therefore more responsive.[6]

Treatment RH should be similar to that of the panel's normal or destined location (Fig. 2). If not, after the panel is relocated there will be further movement opposing any restraints imposed by rejoining, reinforcement, or framing. Effective treatment should lessen potential stresses in the painting structure as much as possible.

Proportional increase in total wood movement has other implications for panels of larger cross-grain dimensions. The development of end-grain splits or checks is well-known in the drying of commercial oak timber, especially larger sections. This is partly due to much higher moisture permeability through end-grain, where oak's large-diameter vessels play a part, than through side-grain surfaces.[7] A similar phenomenon seems evident with respect to wood movement in oak panel paintings where cyclic compression sets and tensions provoke end-grain fractures (Desch 1956:93–95) and disjoins. These effects are proportionally greater in wider planks. Like oak, walnut has relatively high density and large vessels. Figure 3 shows a joint between wide walnut planks that had parted several times, developing an ever-increasing gap, evident from the stratigraphy of three or four putty layers.[8]

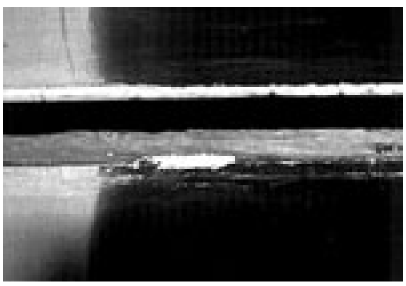


Figure 3
A gap in a joint toward one end of the adjoining planks shown after several strata of overlying nonoriginal layers and putty were removed. Since disjoining, the plank edges had developed a step that had been subsequently abraded to the same level. The length of joint shown is about 300 mm.

Structure of larger panels

Structure determines many aspects of conservation. Tree species that grow larger and yield larger planks have usually been used in large panels. White poplar (*Populus alba* L.), oak (*Quercus* spp.), and Scots pine (*Pinus sylvestris* L.) are examples. Large panels are sometimes made from relatively small planks, as in some of Rubens's larger landscapes (Brown, Reeve, and Wyld 1982).

Some unusual woods may be found. Raphael's *Transfiguration,*[9] painted on cherry wood (*Prunus arium* L.), is a very large panel (Mancinelli 1990:150). Italian panels are usually associated with white poplar (Bomford et al. 1989:11), linden (*Tilia* spp.) (Klein and Bauch 1990), and perhaps willow (*Salix* spp.),[10] so a very large panel of cherry is unusual.

Figure 4a–c shows an Italian painting on white poplar consisting of six vertical planks cut to a round top. Though it seemed slightly heavy, the wood density is within poplar's rather broad range (Jobling 1990:66). This panel would originally have been about 40–50 mm thick. Poplar has been justly preferred for large panels because of its high strength-to-weight ratio, ease of tooling and preparation, and moderate movement (Lincoln 1986:221).

In rare examples, one or two large planks may suffice for a support. Figure 5a, b shows a painting by J. M. W. Turner on a single mahogany plank. Its "sister" painting is similarly constructed.[11] Both panel paintings remain in extremely good condition, which is not unusual for sound mahogany panels[12] in a near-original state—that is, unaltered by thinning, cutting down, and so forth. Neither is restrained by an auxiliary support. If excessive, such restraint can be detrimental, particularly for larger panels. Movement of mahogany is small (Lincoln 1986:159), an advantage for preservation. With radially sawn planks and sound preparation, such panel paintings tend to be durable.

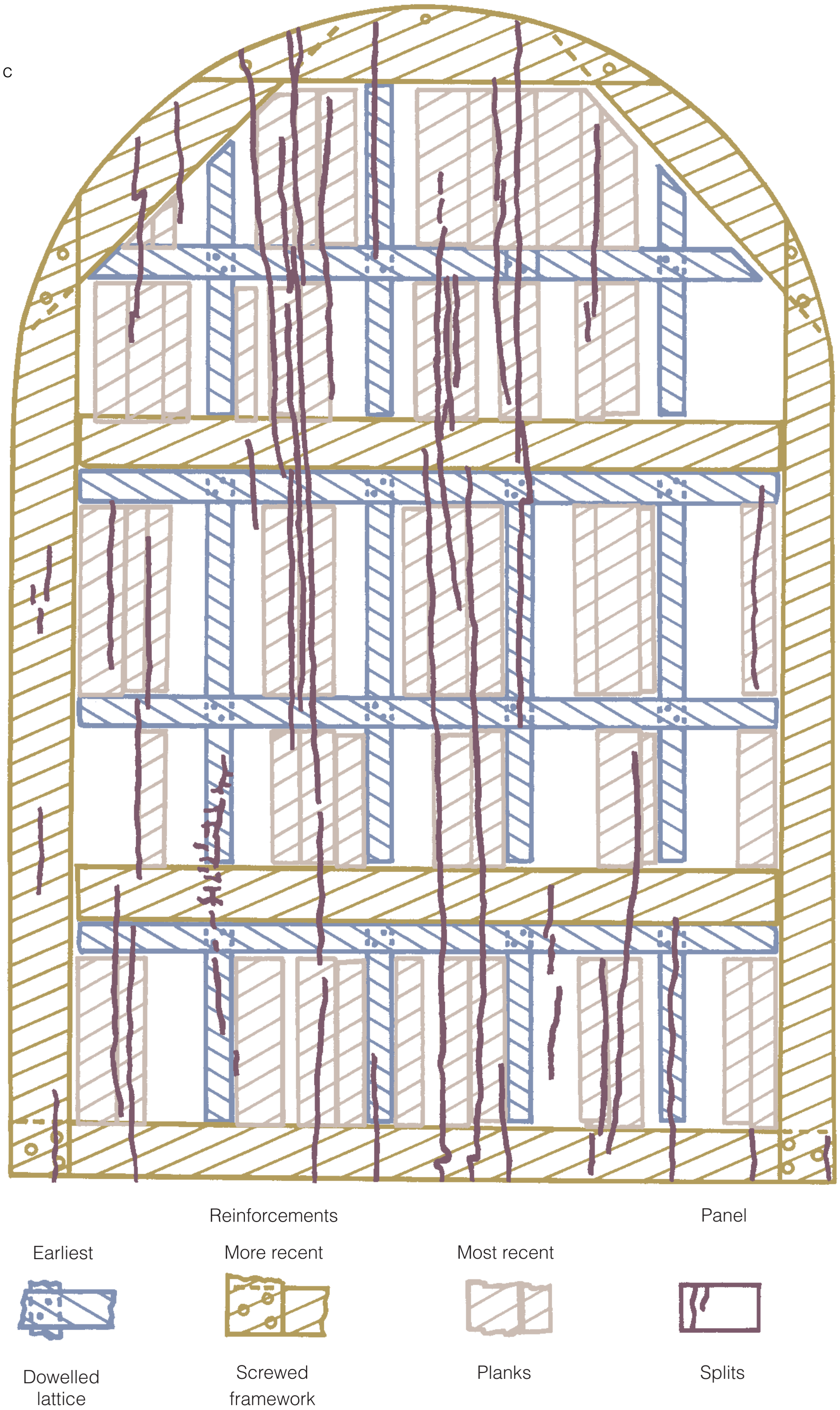
In "portrait" format, vertical planks are a more structurally sound arrangement than horizontal planks. Generally, rectangular panels have

Figure 4a–c (4c on next page)
Marco Palmezzano, *The Mystic Marriage of Saint Catherine,* 1537. Oil and egg tempera on poplar panel (visual identification), 2560 × 1805 × 20 mm thick. Property of the Marquess of Northampton. Before treatment, front with frame rubs along the curved edge (a); back (b); and a diagram of reinforcements and splits viewed from the back (c). Some splits were initiated or aggravated by screw tips protruding from the framework and into the panel back in the lower right corner, and especially by a cross-grain insert at the middle of the bottom edge, where the splits zigzag abruptly.

a


b

c

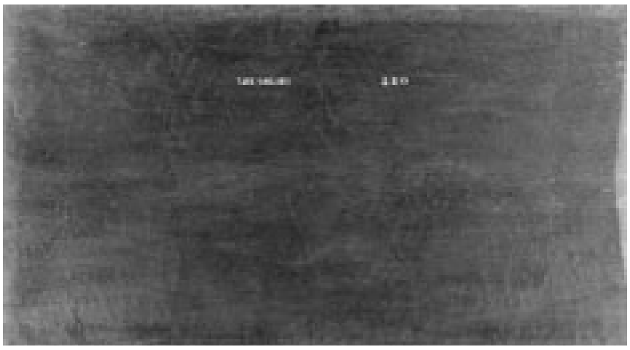


planks joined parallel to the longer edge, decreasing the work necessary for assembly.[13] *The Visitation*[14] by Tommaso Manzuoli (Keith 1994) and the *Transfiguration* by Raphael are both large by any standard. Most of the vertical planks of the Manzuoli are extended and consist of two planks joined end to end. In contrast, the planks of the Raphael are remarkably long, and they are not extended.

Large panels in portrait format with horizontally disposed planks are more prone to structural problems. Greater and more concentrated weight and greater warp movement provoke damage. For example, a large panel by Vittore Carpaccio,[15] though still of approximately original

Figure 5a, b
J. M. W. Turner, *Story of Apollo and Daphne,* exhibited 1837. Oil on mahogany panel, 1100 × 1990 × 10 (bevel) to 20 mm (middle) thick. Tate Gallery, London. Front (a) and back (b) of a large panel consisting of a single mahogany plank.

a



b

thickness, shows considerable joint damage. Despite these observations, Figure 6a–c shows a painting by Rubens in King's College Chapel, Cambridge, that has planks joined horizontally in portrait format. It is in very good condition. The oak planks are of original thickness; this has preserved the original joint surfaces and minimized wood movement so that the panel has remained flat overall.

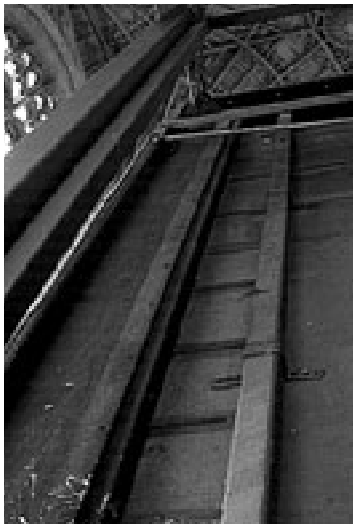
In "landscape" format, horizontal planks perform better. Joint strength is increased by greater surface area, and the panel's center of gravity is lower.

Handling of larger panels

In combination with greater weight, *the ratio of cross-grain dimension to thickness* is usually large enough to give larger panels a greater tendency to bend when handled or inadequately supported. In other words, for a constant thickness, panels that are larger across the grain become more prone to bending and subsequent damage. All panels bend when handled, though bending is not always perceived. Sound panels may withstand considerable bending stress.

Restraint considerations are more acute for larger panels, because of greater total movement, greater potential leverages, and weight effects. Restraint of moisture-dependent movement, such as that imposed by restrictive framing or reinforcement structures, can increase stresses. A statically restrained panel may be under considerable stress. Momentum—also a greater factor when heavier panels are handled or transported—should be

a



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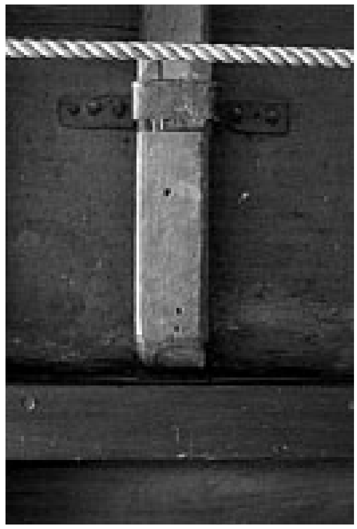


c

Figure 6a–c
Peter Paul Rubens, *The Adoration of the Magi,* seventeenth century. Oil on oak panel, 3280 × 2465 mm; original thickness unknown. King's College, Cambridge. Front (a); one of three vertical battens of the original auxiliary support (b); and an original iron cleat (c). Note the channel cut in the batten (c) to allow panel movement across the grain (vertically); the upper horizontal line is a joint. The panel has been maintained in a large interior space under relatively stable conditions. Disjoins along the side edges extend relatively short distances inward and stop near or at the first vertical battens. They had been treated with inserts or bridges. The battens, which are of relatively small rectangular section, do not appear to have caused excessive restraint, since the nailed cleats remain relatively unaffected.

considered in relation to potential stresses, whether a panel is restrained statically or allowed to move more freely.

Common sense should dictate precautions in handling. People with experience in panel structural work tend to rely on a "sense of feel" when handling a panel or judging its strength. This sense is probably a combination of experience, touch, and a keen attention to and awareness of the physical nature of the object. Inexperienced or careless handlers may be overconfident or, conversely, too cautious.

Therefore, when larger panels are moved, it is better to have at least one person present who is experienced in handling such objects. Two or more people are needed to move larger panels any distance. Coordination is important, because it is difficult to sense and maintain a constant share of the weight. A person on one corner of the panel may allow that side to droop, thereby causing a dangerous bend or twist.

Most wood is much weaker in the cross-grain direction. Strength in axial tension is up to fifty times greater than in tension perpendicular to the grain (Tsoumis 1991:162). If a panel is moved toward the horizontal, its weight should not be supported only at the side-grain edges[16] or only at the middle of the end-grain edges. In the first situation, the weight causes sagging of the middle. In the second, the sides sag. In both cases, the panel must be structurally sound (i.e., no major defects) to withstand cross-grain bending safely. To support and balance weight better in the stronger axial-grain direction, greater support should be given along the end-grain edges, primarily at about one-quarter to one-third the distance from each corner. Further support may help decrease stress.

Panels in a vertical position are usually handled by the sides, which are usually the longitudinal-grain edges. This happens with larger panels because people must usually stand at the sides to lift. If the panel is tipped to lie horizontally, then the grip can be shifted to a better position at the end-grain edges to avoid the bending stresses discussed above.

If it is necessary to move a large panel from one edge to another, it is safer to lower it to a horizontal position and then to raise it again onto the desired edge rather than to "cartwheel" the panel from one edge to another. When leaning a large panel away from a vertical position, it is also important to stop the bottom edge from sliding out. Weight directed at an angle to the floor can cause uncontrollable slides.

The greater mass of larger panels creates greater inertia, so rapid movements increase the likelihood of bends and twists. Twists or torsions cause stresses from many angles and are probably the most dangerous possibility (Gordon 1978:chap. 12). In describing the twisting of plates in relation to thin wooden panels, Bodig and Jayne have noted that a body in pure torsion is in a state of pure shear stress that is concentrated at the upper and lower surfaces (Bodig and Jayne 1982:165). Essentially, when a plate sustains a twist, one pair of diagonally opposite corners are forced closer together, while the other two corners are forced further apart. Boxlike structures or diagonals resist these distortions more efficiently, and they have been employed in some original reinforcements (Marette 1961:pls. 22, 23; Castelli and Ciatti 1989:142–43).

Twists can occur even with seemingly robust auxiliary supports, such as thick battens. The additional weight of the auxiliary support can increase the danger, as it is usually supported to some degree by the panel itself. A thicker panel resists bending and torsion better.

It is usually better to carry large panels with the grain held vertically. They should rest on an end-grain edge and lean slightly away from the painted side. During handling, great care should be taken if panels are laid horizontally or on a longitudinal-grain edge. The momentum of movement is transferred more dangerously to a horizontal panel, while buckling may occur in the latter case. Over longer distances, well-supported trolleys alleviate stresses on panels and bearers (Fig. 7). It is important to have the route clear and to have the panel's destination prepared for both breadth *and* height.

Temporary auxiliary supports

It may be useful to build a temporary auxiliary support[17] if a large, weakened panel is to be moved frequently or treated extensively. Designs can be tailored accordingly.

Figure 7
A large panel being transported on a custom-built trolley, attended by qualified personnel (1987).

A Flemish oak panel of original thickness had two nonoriginal metal battens screwed to the back (Fig. 8a–c). Not surprisingly, the panel developed splits and disjoins. A chalky, weak ground, combined with restrained wood movement, had caused tented flaking and losses. The battens were removed to prevent further damage while the painting awaited treatment.

To remove the battens, the panel was laid horizontally for better control. There was concern that release of the battens might cause a sudden warp movement and precipitate further flaking. A temporary framework was built to allow the panel to assume an unrestrained shape, as well as to provide support, improved access, and secure handling (Fig. 8d).

Wood may be preferred for such temporary supports, since a basic framework can be built quickly and easily. An adjustable, reusable, and therefore economical alternative was built from wood and right-angled-section metal girders, slotted for bolted assembly.[18] A smaller honeycomb-core panel was bolted to the middle of the framework to preserve some access from below and to decrease twist.

Adjustable levelers, made from machine bolts threaded into brass plates, were attached to the framework crossbars in a regular pattern (Fig. 8e). The levelers were turned against flexible wooden battens that conformed to the panel back. As the metal battens were removed, the levelers were periodically readjusted to maintain contact as the panel changed shape. Fortunately, little movement occurred in this case, but the screws were readjusted periodically as the panel equilibrated.

This type of metal girder can be used for several purposes, such as the trolley shown in Figure 7, which was later used as a "trolley easel" to support a large panel for treatment. The pair of rubber wheels at one end swiveled. A central pair was fixed to roll parallel to the longer trolley axis to allow easy maneuvering in any direction.

Mobility of such temporary supports is useful, especially in a busy studio where large paintings must be moved often to allow photography, passage of other large paintings, and so forth. For stationary support, either the wheels were blocked, or the base was elevated slightly onto wooden battens or bricks. More rigidity could be had by doubling the girders or by adding more structure.

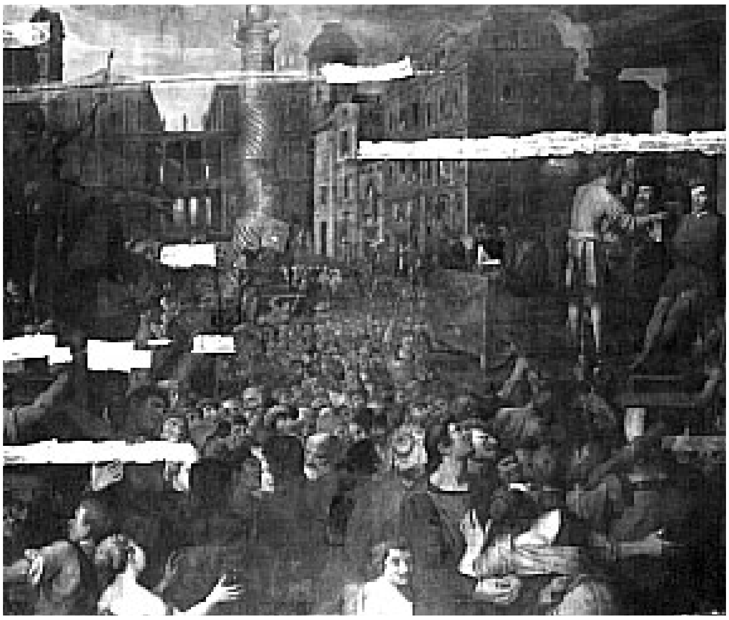
Two Examples of Large Panels

The structure and treatment of two large panels will be compared and contrasted because they show an instructive range of differences in period, place of origin, materials, construction, changes over time, deterioration, and conservation interventions. Their similarities show much about the structural behavior of large panels. An attempt has been made to relate the need for treatment, and some available treatment options, to the causes of deterioration. Some points specific to each case are included to emphasize the individuality that bears on treatment decisions. Though neither panel is typical, their mechanisms of change are similar to other cases. The paintings are referred to by the artists' names.

Figure 9a–c shows a painting by Anton Raphael Mengs (1728–79) on walnut (*Juglans regia* L.) that was completed in 1771 for the chapel of All Souls College, Oxford.[19] The use of wood of a relatively high density is slightly puzzling for such a large panel and, moreover, one that would have had to be transported from southern Europe.[20] Though the painting is now about half its original thickness, its original weight may be estimated to

Figure 8a–e

Ambrosius Francken I, *The Judgment of Zaleucus,* late sixteenth century. Oil on oak panel, 1795 × 2165 × 20 mm thick. Fitzwilliam Museum, Cambridge (inv. 781); HKI treatment no. 137. A large panel of original thickness, damaged by attached (non-original) metal battens, which restrained wood movement: (a) front, faced, before treatment; (b) back before treatment; (c) detail of back, showing metal batten and one split; (d) temporary reinforcement of metal frame and honeycomb-core panel, to decrease twist; (e) in one corner, an adjustable leveler bears on a flexible wooden batten, against which the panel was laid.



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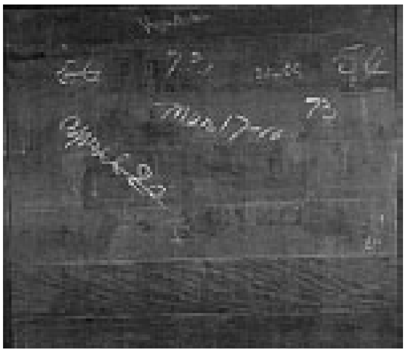

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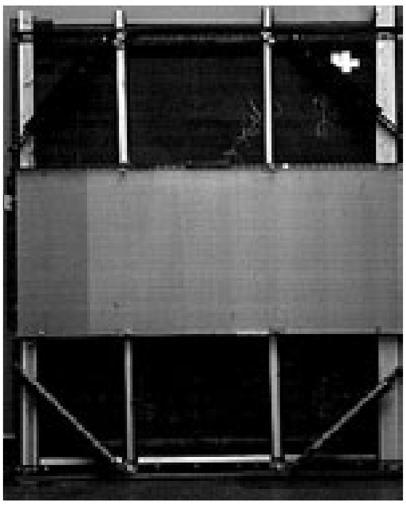

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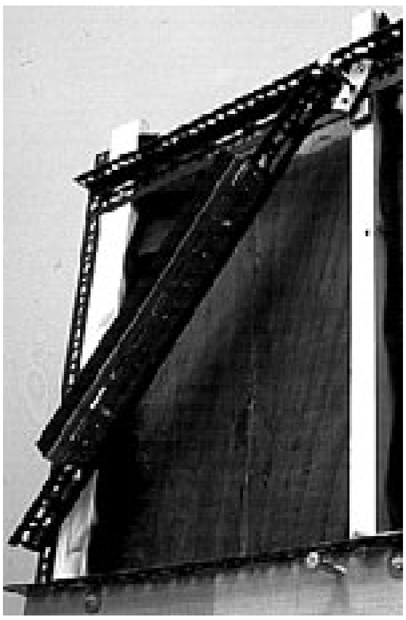

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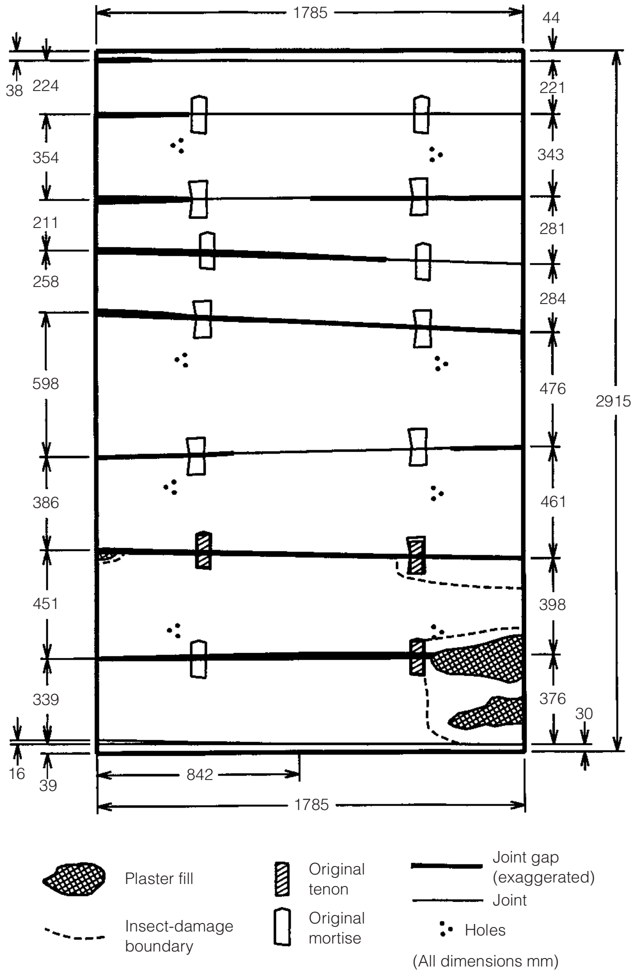
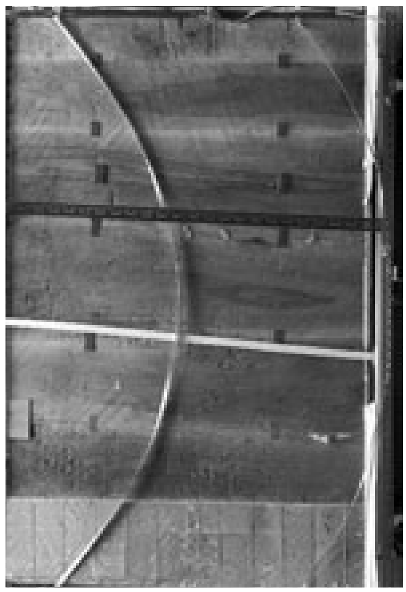


d

Figure 9a–d
Anton Raphael Mengs, *Noli Me Tangere,* 1771. Oil on walnut panel, 2915 × 1785 × 20 mm thick. All Souls College, Oxford. A large panel treated while lying on a side edge on a mobile temporary support: (a) front, before treatment, showing disjoins; (b) the front upper right of the panel, seen in top-raking light; (c) back during treatment, showing the last planks of the previous balsa laminate reinforcement (bottom) and the panel surface, damaged by thinning. The exposed mortises, the two remaining original tenons, and areas of insect damage and plaster filler can also be seen. Note the ratcheted polyester straps used to apply pressure during rejoining, and the vertical angle-sectioned beam used with veneer hold-down clamps to apply alignment pressure. A diagram of the panel construction (d) shows the tapered planks joined in reverse orientation and the irregular gaps (exaggerated) that developed after the panel disjoined.

b



c

have been about 140 kg.[21] Painted in portrait format, the substantial remaining weight and reduced thickness have had serious consequences.

The most recent conservation treatment, carried out in the 1960s, included thinning and reinforcement with a balsa laminate similar to that described by Lucas (1963). Subsequently, metal strips were added around all edges. Many of the panel's original joints later parted, presenting a precarious structure and dismembering the image both literally and figuratively. Structural damage made reappraisal of the painting's condition necessary as well, despite its recent restoration.

In contrast, a painting of 1537 by Marco Palmezzano (ca. 1458–1539) (Fig. 4a–c) with a lower-density poplar construction (briefly described above) arrived with the image greatly obscured by darkened varnish layers and surface dirt.[22] Weakened in areas by insect damage, this panel had also been thinned to about half its original thickness, which weakened it further. A lattice of wood had then been glued to it, probably before it left Italy.[23] Undulations and compression damages attested to poplar's high capacity for bending and distortion under mechanical stress. Fortunately, the painting exhibited sound technique, a great advantage for structural conservation.[24]

Both panels were assembled with casein glue. The joints of the Palmezzano had remained intact under stress, while the weaker, fibrous wood had parted into disconnected intermittent splits. Under stress, the stronger and more rigid walnut of the Mengs had remained relatively intact, while the joints had parted in the glue layer. These differences in fracture characteristics were due in part to the varying restraints imposed by the auxiliary supports. The wood of both paintings had fractured preferentially in insect-damaged areas.

More than thirty splits had developed throughout the Palmezzano, mainly from movement-restricting battens glued to the back. Some splits were older, with putties and aged varnish in the gaps, while others were obviously recent, with freshly exposed and fractured ground.

What factors led to deterioration of these panel paintings? Both panels may be examined more closely to understand the effects of structure, age, and past treatments on their condition.

Supports

The Mengs consists of six broad walnut planks arranged horizontally with respect to the image and joined in reverse orientation (Fig. 9d).[25] The bottom consists of two additional pieces: a narrower plank at the extreme edge, joined to a narrow, wedge-shaped strip. The wedge was used to square the bottom edge in relation to the taper of the lowest broad plank. At the extreme top edge, there is a similar narrow plank but no wedge.

Evidence shows that the panel was originally about 40 mm thick, twice its current thickness. The mortises and loose tenons had been uncovered by modern tools during the most recent thinning. The mortises had been chiseled into the joint faces to within 8 mm of the front of the panel[26] so that if originally centered, they would have left the same thickness of 8 mm at the back. The tenons[27] were not butterfly inserts, set into sockets cut into the panel back, as a superficial assessment of the exposed panel back might suggest. Thinning had also exposed remnants of original nails driven into the top and bottom edges, probably to secure the strips. These would have been driven near the center line of the original edges.

One of two original rectangular beech wood (*Fagus sylvatica* L.) inserts, visible on the front, had been exposed in an empty mortise at the back (Fig. 10a, b). The insert had been used to replace a wood defect. The adhesive did not appear to be casein, as was used to join the planks, but animal glue.[28] Where visible within the larger gaps, the joint faces had been inscribed with shallow Xs, either for adhesive tooth (which seems unlikely) or perhaps to ensure adequate glue pickup from the brush.

From the evidence then, the procedure for joining was as follows: the joint surfaces were planed; regular Xs were carefully inscribed into each surface and mortises were chiseled; one end of each tenon was glued with casein into one of the mortises of one plank;[29] the same glue was applied to both joint surfaces and to the protruding tenons; the planks were pressed firmly together and possibly rub-joined,[30] since the glue lines are relatively thin and do not appear to have dried in a "starved" condition. After drying, the desired height dimension was achieved, and the edges were squared with narrower strips, nailed and glued to top and bottom edges. The sides were trimmed square and straight.

Similarly, the Palmezzano would have been about twice its current thickness. Again, as with the Mengs's tenons, poplar dowels were used to maintain rough alignment during assembly, and then the edges were finished. Thinning had exposed some dowels. Also similarly, long spikes remained that would have been driven straight, and with evident skill, near the original midline of the side edges.

Insect damage

Larger panels have proportionally greater expanses of insect-prone wood. Practical construction from whole planks would have favored greater plank widths. For economy and practicality, critical edges of sapwood were sometimes left in longer planks, partly because the transition line between heartwood and sapwood is irregular for some types of wood used for panels, such as the walnut and poplar used here.

Nearly every plank of the Palmezzano had variable, discontinuous lengths of damaged sapwood.[31] In more central, critical areas, the damaged

a b

Figure 10a, b
Anton Raphael Mengs, *Noli Me Tangere*. On the back, an original beechwood insert (a) in the walnut panel can be seen through an exposed mortise. The same insert viewed from the front (b) before treatment and in top-raking light.

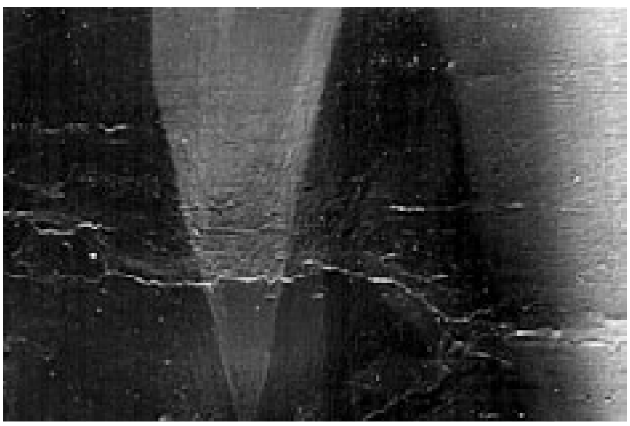
wood was replaced with inserts of linden wood to within 2–3 mm of the ground. No obvious adverse reactions to consolidation or wood replacement appeared after three years of observation. The apparent stability may partly be due to poplar's ability to accommodate stresses because of its resilient, fibrous, low-density structure.

Intermittent areas of damaged sapwood also occurred along some joints in the Mengs. Large wood losses had occurred at the bottom left corner (viewed from the front) (Fig. 11a, b), and plasterlike fills had been made, extending through the panel's thickness.[32] The paint overlying the surrounding damaged wood had blistered into foldlike undulations in some areas. This damage was probably a result of compression from the panel's weight, possibly aggravated by setting and swelling of the wet plaster. Despite these adverse effects, the plaster was strong and well keyed. Its contact surface was well dispersed, which probably helped to spread stresses.

Intermittent insect damage occurred over the remainder of the panel, but in general this damage was not a serious structural threat and required no treatment. However, the substantial loss at the bottom corner, covering nearly one-third of the panel's width, represented weakness in a vulnerable area. Thinning had concentrated the entire panel weight onto a narrower cross section, one-third of which was weakened by insect damage. Some provision for added strength was considered necessary to provide adequate support and prevent further loss and damage to the large area of paint overlying the damaged wood. Walnut inserts were fitted.[33]

Interactions of thinned panels and nonoriginal auxiliary supports

Obviously the Mengs was a heavy panel while still in its original state. Display, handling, and transport called for adequate reinforcement. Horizontal joints could be advantageous, since gravity would tend to keep them together in compression. Standing vertically, however, destructive



a

b

Figure 11a, b
Anton Raphael Mengs, *Noli Me Tangere*. Top-raking light shows an insect-damaged area in the lower left corner of the front, surrounding a plaster fill. Note the undulations, probably from compressive strain from the panel's weight. The same area seen from the back (b) in normal light.

bending stresses would be more likely, imposed by considerable leverages. Any warp from a flat plane would promote buckling. Such a buckling tendency would pose a long-term bending stress across the joint axes, a condition greatly exacerbated by thinning.

Evidence of a previous, perhaps original reinforcement exists as eight sets of three holes each, spaced at regular intervals across the panel back (Fig. 9d). It was unknown what form this reinforcement would have taken. Had documentation of the panel back prior to the recent thinning been available, it may have provided evidence to help with subsequent treatment decisions.

By contrast, the structure of the Palmezzano is more logical. The chosen wood is lighter, with the planks disposed vertically. Thus, the wood bears weight in a more natural orientation, analogous to its mechanical role in a living tree. With the grain vertical, buckling would be a negligible concern, even with the panel half its original thickness. Therefore, weight does not combine with movement across the wood grain to threaten the Palmezzano's structure as much as in the Mengs.

The Palmezzano had no evidence of original auxiliary support.[34] At least four different types of battens had been applied at various times over the long period since the panel was last thinned. Finally, remedial action took the form of short planks glued over developing splits, including old stretcher members taken from paintings on fabric. Eventually the panel became choked with stopgap solutions. These additions induced severe distortions, splits, and compression damage concentrated in the panel's center. Centralized damage occurred because overall reinforcements tended to concentrate bending stresses toward the middle. This factor then combined with tension and compression stress overall caused by restraint of lateral movement.[35] The pattern of splits shows how stresses were interrupted over the cross-grain battens (Fig. 4c).

Also, putties (or fills) had been applied to splits that had not first been rejoined. This and subsequent wood movement caused compression stress and distortions in the adjacent paint. Such disfiguring damage is neither easily nor totally reversible. It is better not to put fillers into surface cracks if effective structural work is not done first to underlying splits.

For both panels, attempts to flatten and reinforce them have instead tended to weaken them further. Such treatment efforts are examples of excessive, damaging measures that have been used to meet reinforcement requirements of some large panels, as well as to serve aesthetic purposes. The resulting deterioration of paintings *with* supports shows that those requirements must be better understood, and they must be achieved with better methods that maintain the integrity of the panel painting.

The consequences of thinning a large panel can be critical, mainly because a heavy weight must then be supported by a structure made relatively weak while still allowing for adequate wood movement under variable conditions. It is worth examining the motivations for thinning, which have particularly serious implications for preservation of larger panels. In general (and leaving the question of transfer procedures aside), panels may have been thinned for several reasons, including:

1. the mistaken belief that thinning reduces the tendency to move and warp in response to changes in MC (the reverse is true);[36]

2. to flatten and smooth the back surface, a procedure usually followed by the attachment of battens or laminates to restrain the panel in a flattened state;
3. to lighten the panel for easier handling or transport (which may also have the opposite effect because of increased fragility);
4. simply to take action.

It could be tempting to lighten large, heavy panels such as the Mengs. From a strictly practical viewpoint, sheer size would be reason enough for cutting away some wood to provide a flat surface to more easily fit a new auxiliary support. To respect and conserve the *entire original object,* however, it is possible, for example, to build up an even surface of balsa wood for battens to bear upon (Buck 1962) without removing original panel wood to achieve the same purpose. The three remaining reasons cited above for thinning are unjustifiable with respect to preservation.

The most recent thinning of the Mengs panel appears to have been directed at obtaining a flat surface to allow adhesion of relatively large balsa planks. The use of power tools is evident from the parallel kerf marks of a circular saw, power-planer blade marks, gouge marks chipped deep into the irregular walnut grain, localized rasp marks, and other damages.

Despite the large scale of work that seems to justify the use of power tools on larger panels, the use of manually controlled hand tools is preferable. Some power tools are "double-edged swords" that can speed work but also easily outstrip the intention and control of the user.[37] A higher speed of treatment, for whatever reason, should not endanger the painting. In this regard, responsibility for the *rate* of treatment and its effects extends beyond the conservator to all custodians of cultural property—administrators, curators, dealers, and owners.

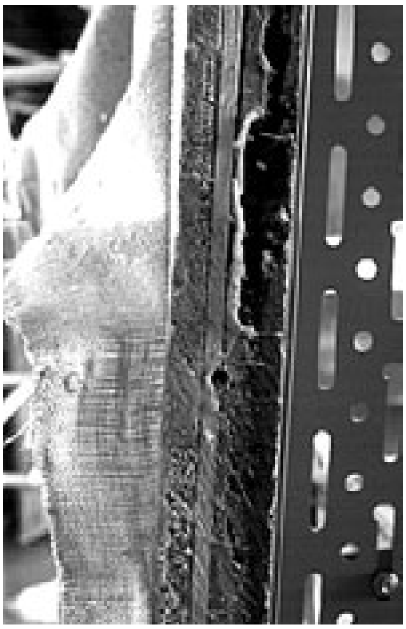


Figure 12
Anton Raphael Mengs, *Noli Me Tangere.* Screw holes in the panel edge where metal reinforcement strips were attached. The panel is on the right. Note the layers of balsa/wax-resin and fabric laminate and the saw marks in the panel where the balsa was carelessly trimmed.

In an effort to prevent buckling of the Mengs, strips of slotted metal had been screwed into the edges of the panel and balsa laminate (Fig. 12). Obviously, even though cross-laminated, balsa did not prove sufficiently rigid to prevent buckling when the panel was upright. The metal edging provided a relatively rigid outer framework that met the immediate reinforcement need but that had serious consequences for the painting.[38]

Unrestrained, the panel would expand and contract as a unit, the top moving upward and downward with changes in MC. With such a large panel, lateral movement across the wood grain could be on the order of 50 mm, if fully equilibrated over a 30% change in RH.[39] However, the entire panel could not move as a unit. Instead, the planks were individually constrained to expand and contract around the wood screws at each end. At lower humidities, the panel would contract across the grain, and either the wood had to split or the joint adhesive had to give way, depending on whichever was weaker. Though casein is normally a strong adhesive, the walnut wood was stronger, even across the grain, so the joints failed in tension across the adhesive layer. They probably opened catastrophically, as zippers sometimes do, especially if the panel was subjected to relatively rapid and large changes in RH.[40] One joint near the center of the panel had completely parted.

Environmental history affects the stress distribution in wooden panels.[41] Seasoned planks develop a particular stress distribution before being assembled. Once the planks are joined, grounded, and painted on one side, a *different* overall stress distribution develops that depends on environmental interactions. With larger panels, the total (elastic) stress in the panel structure is accordingly greater.[42]

For the Mengs, the combination of thinning and disjoining appeared to have reduced the physical equilibrium of the individual planks. Once disjoined, they responded to the internal stress with deformation. The plank edges at the joints, originally parallel, became contoured to the irregular grain direction of their respective planks. Thus, the joint gap varied by millimeters along some disjoined sections (Fig. 9d), and the joint faces no longer met continuously or squarely. Such potential damage from wood's reaction to stress release should discourage the thinning of panel paintings.

During the rejoining process, wood inserts were fitted to the gaps so that no original wood was removed.

Treatment considerations

Planning is important for any large panel treatment. The order and choice of treatment steps should be logical in relation to the treatment as a whole and should not foreclose later treatment options. The greater scale of treatment for large panels usually makes backtracking difficult and costly. A cautious, considered approach, in which each stage is tested, should be adopted.

As an example, radiographic examination of the Palmezzano did not reveal enough of the condition of the wood, prior to treatment, to ascertain the full extent of damage, since the battens were obscuring the panel wood. The possibility that the panel might require extensive wood replacement was anticipated with a more thorough facing than the panel's apparent condition warranted. Halfway through a batten or cradle removal, with splits all around, one cannot easily move a large panel to apply a facing that should have been anticipated earlier.

Photodocumentation is important for the back of the panel, as well as the front.[43] It is therefore necessary to have larger panels disposed so that necessary photography can be done at any treatment stage. Even with the best photographic resources, adequate space is required for the necessary distances and angles. Also, large panels invite strong lighting, especially for overall photographs, so heat effects should be considered (Wolters and Kühn 1962). Short-duration electronic flash units have a less drying effect than the heat associated with continually lit tungsten lamps.

Though not easily achieved, relatively constant humidity should be maintained to minimize stresses from warping movements during treatment. Rejoining can take days for larger panels because thicker joints and less-absorbent, higher-density woods require longer drying periods.

It is sometimes better to allow sufficient time for the panel structure to equilibrate during treatment, to avoid stress that might precipitate damage. When the Mengs was rejoined, for example, the balsa reinforcement was removed in stages between which the exposed panel was allowed to equilibrate to a more stable curvature (prior to rejoining) unimpeded by restraint caused by the reinforcement or its moisture-barrier effect. If rejoined before equilibration, joints could fail again prematurely.

It is possible to manipulate humidity to facilitate some procedures. Larger panels especially can bind or "lock" sliding reinforcements because of greater total movement and rigidity. It may be possible temporarily to raise or lower the humidity slightly in order to loosen sliding members of cradles for easier removal, for example.[44] This procedure could prevent greater stress to the painting from unnecessary tool work.

Structural treatments of large panels make great demands on a conservator and can take a long time. Assuming that they have equal abilities, one conservator usually takes at least twice as long as two, and the demands on stamina are doubled. A team benefits from improved safety and morale, and its members can help one another in making decisions, thereby achieving quicker and better results.

Access and control

Easy access is an advantage for structural work. Access is more difficult with larger panels since the conservator must move around the panel. If the panel is horizontal, the conservator must find some means of reaching the work area, which is often in the middle of the panel. It is important to establish a comfortable position, since the work may be of long duration or require sustained precise and safe manipulation of tools (Fig. 13).

Horizontal support of such a large, thin, heavy panel as the Mengs presents some problems with regard to treatment procedures and stress distributions in the panel during extensive, prolonged structural work. Concern arose that warp movement would be restrained by the panel's own weight if it were laid horizontally, causing detrimental bending stress.

It is difficult to judge the effect of such warp restraint, especially in larger panels. For example, it was anticipated that once the balsa and wax-resin were removed from the Mengs, a different curvature would ensue. Laid horizontally, the panel would almost certainly have warped away from a table surface. The suspended weight would have caused bending around the supporting fulcrum(s), with a risk of breakage at the weakened joints or in worm-damaged areas. Therefore, it was considered undesirable to treat such a panel horizontally before adequate structural consolidation was achieved.

Alignment and rejoining are generally more difficult for larger panels than for smaller ones. Suitable temporary supports and apparatus must be available for operations such as rejoining. The approach must

Figure 13
The conservator, left, kneeling on a bridge used to gain access to the back of a large panel laid horizontally for structural treatment of the wooden support.

meet the relative complications of treatment and may also take advantage of the panel structure itself.

Based on these considerations, the Mengs was placed on a side edge with silicone paper and a length of pine batten beneath. The main reason for standing the panel vertically was to make access to both front and back possible during structural work. This approach (which is not a new concept) is practical in some cases.[45] To minimize restraint and allow the panel to adjust position, it was occasionally lifted slightly at one end.

The relatively straightforward rejoining problem of the Mengs was especially suited to a vertical orientation. The Palmezzano, in contrast, had a high number of fragmented splits and generally more complicated treatment demands, which made a horizontal orientation preferable. A padded support table and rejoining apparatus were designed and built to allow all-around access and control.

Ideally, to improve access and stabilize the panel before rejoining, all moisture barriers and restraints, including unnecessary and nonoriginal glue layers,[46] may be removed to allow the entire panel structure to stabilize. This measure may not always be possible with larger panels, where equilibration may have to be limited to the general area surrounding the wood to be treated. It would have been difficult to treat either panel safely with all previous restraints removed, though such a proposal would be more feasible for smaller panels (Brewer 1994b).

In some cases, advantage may be taken of the immobilizing effect of previous reinforcements during their removal to maintain some structural stability while rejoining large panels. Working from the proper top of the Mengs, the balsa laminate and most of the wax-resin were removed from each successive plank pair to be rejoined, leaving the remainder still covered and the next disjoin still bridged for stability. Each freshly exposed plank pair was then left undisturbed for at least one week to allow some equilibration of the panel's curvature before rejoining. This approach maintained greater stability while allowing adequate joining pressures to be applied without disrupting the remaining disjoins.

Battens were removed similarly from the Palmezzano (Fig. 14). This was done by working across the panel grain and reducing the battens

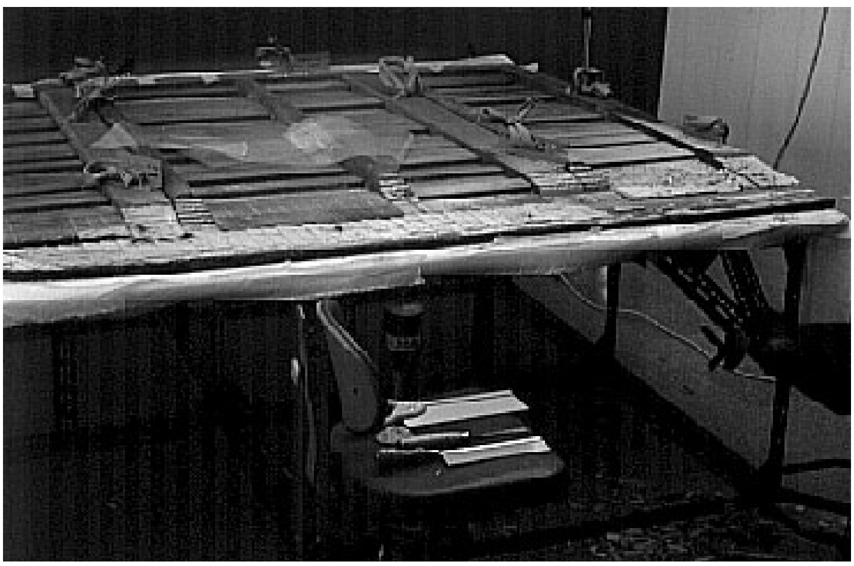


Figure 14
Marco Palmezzano, *The Mystic Marriage of Saint Catherine.* The panel laid facedown on a padded table during the initial stages of removal of the previous reinforcements. The tools are on the chair. Note that the removal was begun from a side-grain (nearest) edge and progressed across the panel grain.

in a step-by-step manner while leaving them intact over and beyond the next split. For larger panels, which may tend to move substantially on release, a cross-grain direction of removal may be adopted. The panel can move and warp more freely across the wood grain, with less chance of twist than if removal proceeded irregularly or from an end-grain edge. A hand-pressured chisel (no mallet) and a dovetail saw were the only tools used.

Curvature effects and rejoining of larger panels

The convex warp (viewed from the painted side) in many panel paintings is largely due to the development of compression set (Buck 1972:2), as shown by both panel examples.[47] Both were rejoined with respect to the set warp assumed by the planks after removal of the reinforcements. Several methods might be considered to reduce such warp and maintain the panel in a safer, more planar configuration. Though usually done for aesthetic reasons, this would also lessen the panel's tendency to buckle under its own weight if the planks are disposed horizontally.

In the author's opinion, set in the wood of panel paintings is not practically reversible as yet, especially in larger panels, because most methods involve extensive intervention to the wood or have uncertain long-term effects.[48] Raising the ambient humidity provides only a temporary reduction in warp, because the effect of set warp in a panel equilibrated to one humidity returns if the panel is placed in a higher humidity and allowed to fully equilibrate. The impression of an apparent reduction in warp from raising ambient humidity is especially evident with larger panels because of their greater total movement. However, most observers do not have the opportunity to monitor long-term changes in larger panels under controlled environmental conditions until an equilibrium curvature is established.

Other methods of warp reduction are possible. As the Mengs required extensive rejoining, V-shaped inserts could be used in the joints to counter the curvature of the planks and achieve a relatively flat panel (Fig. 15). This method has been used for panels of all sizes, sometimes for aesthetic reasons. However, a gentle overall curvature may be less disruptive to the appearance than the resulting "washboard." Photographs before and after structural treatment of the Palmezzano, in raking light, may be compared in this respect (Fig. 16a, b).

Insertion of wedges for the purpose of flattening the panel may be considered as a last resort, whether for structural or aesthetic purposes. Acceptable flatness is partly an aesthetic concern, of course. In general, however, it may be preferable to respect the current overall curvature, as determined by the original panel structure and aging effects, to preserve intact joints and the painting in unaltered form. Panels that are partially disjoined or split, such as the Mengs, would require either breaking the remainder of the fractured area, with serious risks to the overlying and adjacent paint, or inserting wedges into the parted areas as desired. Additional stress would be imposed on the remaining intact joint or sound wood as flattening pressures were applied. From an ethical standpoint, such an option for flattening is more practical and possibly more acceptable for a complete disjoin.

For both panels, the above options for flattening would all involve protracted and serious risks. Finally, breaking of a partial disjoin having original, intact paint above is an important ethical issue. In consideration of these points, the set warp and its ramifications were accepted in the

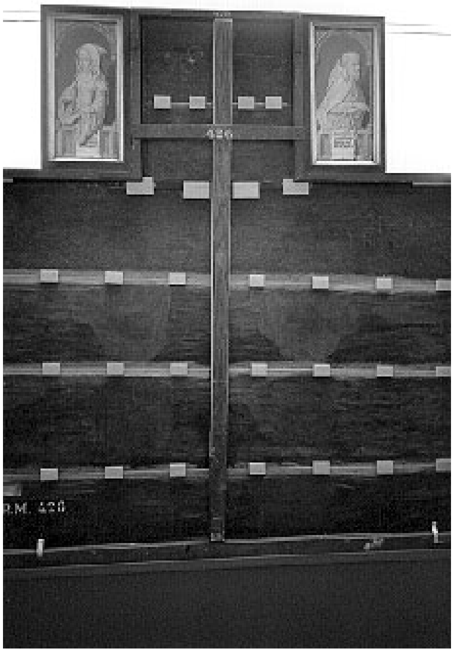
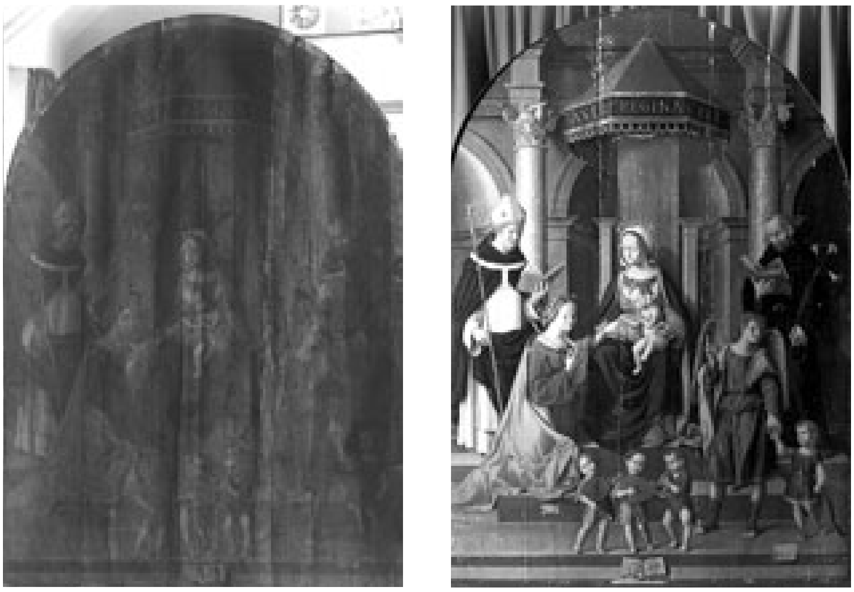


Figure 15
South Netherlands, *Triptych of the Holy Family and the Trinity,* ca. 1510. Oil on panel, 1500 (center) × 1500 × 15 mm thick (visual estimates). Wallraf-Richartz-Museum (INV WRM416), Cologne. An altarpiece consisting of oak planks rejoined with V-shaped inserts of oak, probably to reestablish an overall flat plane after the planks developed set convex warps (viewed from the front).

Mengs and the Palmezzano, and they were conserved within the limitations of their current structure and condition.

Though disjoins in smaller panels may be glued and rejoined in one operation using appropriate apparatus, larger breaks take more time, so that glues tend to set, or "go off," earlier than desired. The procedure must be well prepared if time is a factor (see Brewer, "Some Rejoining Methods," herein).

Alternatively, using inserts, the conservator may rejoin a long joint progressively by working along it in discrete stages.[49] If this method is used, it is important to ensure correct alignment in all three dimensions from the beginning. If the relative positions of the joint faces have been incorrectly aligned and fixed in the early stages of rejoining, they may



a b

Figure 16a, b
Marco Palmezzano, *The Mystic Marriage of Saint Catherine.* The painting, in raking light on the left, before structural work (a) and after structural work and before retouching (b).

converge or diverge as the other end of the joint is approached. Slight corrections may be made by bending softer woods back into alignment at later stages, but some distortion and stress are then built in as well.

Auxiliary support of larger panels

Despite such rare examples as the Turners mentioned above, larger panels generally have substantial reinforcements (Fig. 6b, c). A higher ratio of cross-grain dimension to thickness becomes a greater concern with large panels of higher wood density. The structural implications can be greater for certain panel structures, such as those with horizontal planks. Even with sound joints, the Mengs tended to buckle under its own weight if stood on its bottom edge. Most of the wood was sufficiently sound and strong to withstand even quite severe bending stresses, but the joints will always be weaker.[50] When there is already a set warp, buckling tendency worsens as the panel warps further out of plane because of humidity fluctuations. Such fluctuations would aggravate buckling even if the panel were relatively flat at a particular humidity.

So, with reference to these concerns, the final and most challenging difficulty, as with many large panels, was supporting the Mengs in an upright position without restricting movement too greatly. The disjoins, the inadequate balsa laminate, and especially the metal edge strips were no surprise considering the panel's structure, weight, and thinned state. The critical point, however, is that a relatively rigid form of reinforcement is necessary nonetheless for such large, thin, heavy panels, and the panel structure must be sufficiently sound to take potential stress without rupture.

The Palmezzano is also a good example of a large, thin, weakened panel requiring overall reinforcement of a specialized type. Internal fractures remain in many panels after structural treatment, partly because they are difficult to detect, even with radiography, especially in fibrous, lower-density woods such as poplar.

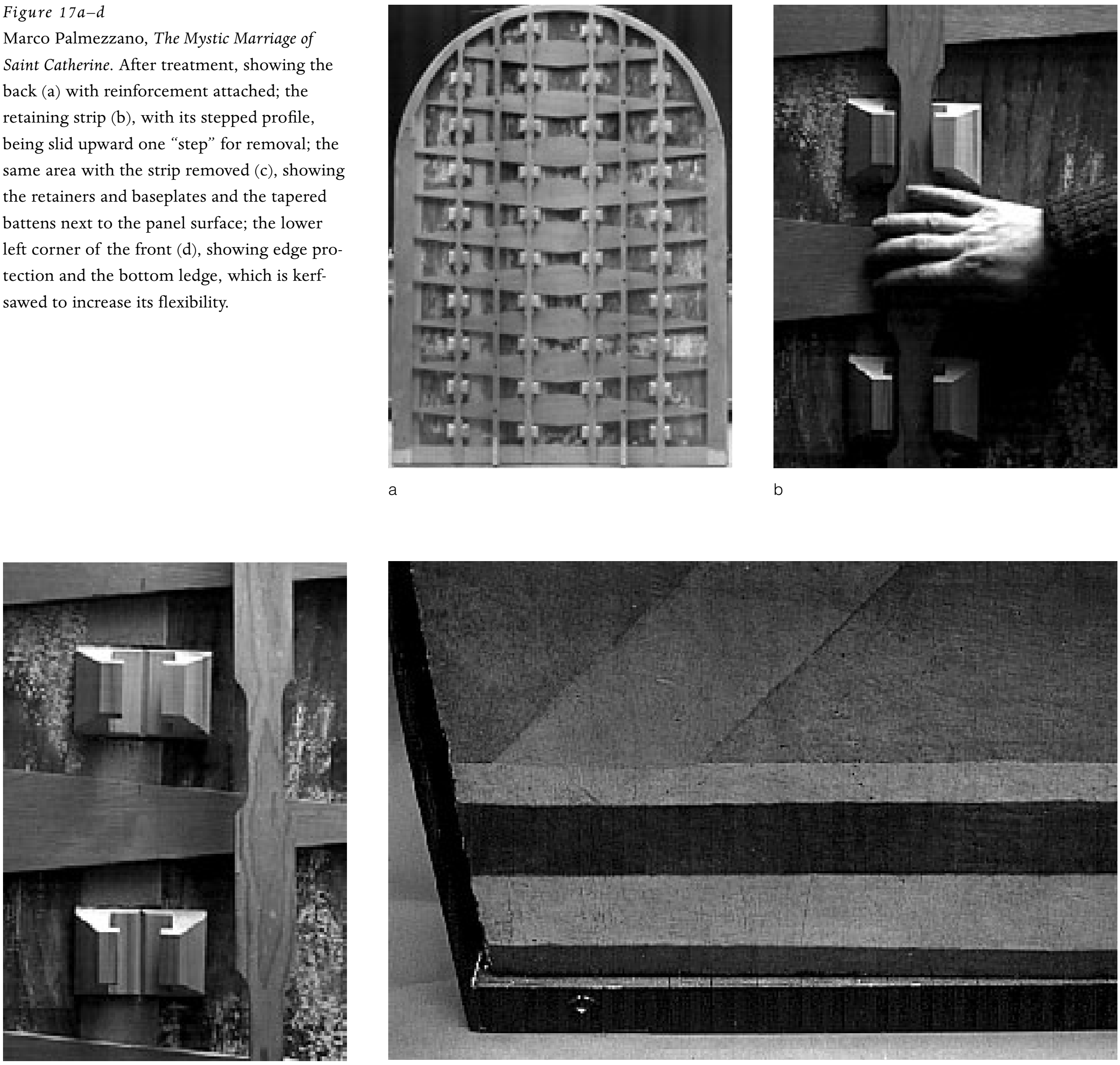
The inherent weaknesses of panels such as the Palmezzano cannot be overemphasized. A sympathetic but effective auxiliary support is necessary in such cases. Truly satisfactory reinforcement designs with proven effectiveness are still being sought for panel paintings of this nature, as evidenced by the increasing amount of literature on new and modified reinforcement designs.[51]

When this article was written, an auxiliary support was being designed and tested for the Mengs. It is therefore not presented here. However, an auxiliary support applied to the Palmezzano is described. The support was designed to allow greater movement, reduce the risk of further splits and damages, and give adequate reinforcement.

The design is based partly on those developed at the London studio of the HKI (Fig. 17a–c) (see Bobak, "A Flexible Unattached Auxiliary Support," herein; Marchant, "Development of a Flexible Attached Auxiliary Support," herein; Brewer 1994c). So far it is the largest version that attempts to realize the main principle of tailored flexibility. Horizontal tapered battens and a peripheral frame were constructed from Sitka spruce (*Picea sitchensis* [Bong.] Carr.), and oak uprights were attached to the horizontal battens to form a supporting lattice. The horizontals were dovetailed into the peripheral frame for strength during handling. The peripheral frame extended beyond the edges of the painting, and a surrounding border of thick card projected up to 5 mm in front of the paint surface (Fig. 17d), to protect the painting edges from careless handling and frame rubs (see Fig. 4a for damage from frame rubs).

The lattice was assembled with aluminum-reinforced joints and various fasteners of brass and stainless steel. It was made as lightweight as possible and was thinly constructed to facilitate framing. Because of its prototypical nature, it had to be capable of disassembly to any stage, a characteristic it retains. The battens were made of equal thickness and then tapered to adjust their flexibility to the panel's strength and potential movement. The bottom ledge of the peripheral frame was kerf-sawed for flexibility. Both battens and ledge were steam-bent to approximate the panel's overall deflection when equilibrated to about 60% RH.[52]

To attach the lattice, four vertical retaining strips were cut and positioned at regular intervals across the panel back. The strips were slid through retainers of poplar that were glued to the panel back. Potential stresses on the retainers were spread locally with baseplates of poplar.



a b c d

Figure 17a–d
Marco Palmezzano, *The Mystic Marriage of Saint Catherine*. After treatment, showing the back (a) with reinforcement attached; the retaining strip (b), with its stepped profile, being slid upward one "step" for removal; the same area with the strip removed (c), showing the retainers and baseplates and the tapered battens next to the panel surface; the lower left corner of the front (d), showing edge protection and the bottom ledge, which is kerf-sawed to increase its flexibility.

The choice of positions for the retainers was based partly on a regular distribution across the panel and partly on the location of relatively flat gluing surfaces.

Normally, the removal of sliding battens from a panel requires a space of twice the batten length. The required space was twice the panel's height in this case and made a modified means of removing the retaining strips desirable. It was possible to narrow the strips at intervals equal to the vertical distance between the retainers. This allowed the strips to be placed directly against the lattice battens (Fig. 17b, c) and between the retainers; they were then slid down and engaged in a functional position.[53]

Built thus, the structure provided adequate reinforcement while it was still flexible enough to bend with warp movement. This reduced the risk of restraint of lateral movement by friction and locking. It protected the edges against mishandling and accidents. While attached, the structure still permitted examination of much of the panel back. Most of the structure could be quickly removed to access all of the back surface except beneath the retainers. The retainers could be removed mechanically with relative ease because low-density wood was used. The glue used to attach the retainers could be easily swelled with water and removed with spatula and swab.[54]

Since the structural work was completed, the panel has been monitored for at least two years to determine the effectiveness of the reinforcement and other aspects of the treatment. Due to RH variations, changes in deflection at the middle (in relation to the side edges) have been measured at up to 30 mm—about half the deflection that was observed under a similar RH range when the panel was structurally consolidated but not reinforced. The two central retaining strips have shown increased friction as the panel has become more convex (viewed from the front), but lateral movement has not been excessively constrained, as occurs frequently with more rigidly battened or cradled panels of this nature.[55] The panel appears to be adequately reinforced and moves without any obvious detrimental effect.

Framing, hanging, and transit

Old wooden panels are continually subject to movement—probably nearly as much as when they were first painted (Buck 1952; Laurie 1967:55; Klein and Bröker 1990; Mecklenburg and Tumosa 1991). Therefore, allowance should be made in the frame for *potential* panel movement. Of course, excessive frame restraint would negate any capacity of the panel's reinforcement structure to allow for movement. Considerations related to the frame retention of panels are similar to those relating to auxiliary support. Many paintings do not remain in a relatively constant, well-controlled environment. Passive controls are not always sufficient, and active controls can malfunction in even the best-maintained buildings.

Therefore, an allowance must be made by sizing the frame rabbet for cross-grain expansion of the panel wood. Otherwise, a "bound-in-frame" condition occurs as the panel expands to press on the rabbet's outer walls. Also, it is important that framing not restrict warping movement with overly rigid retention. These stresses can easily break the panel or the frame (*Museum* 1955:159–60). Of course, competent framers allow space in the rabbet to avoid this possibility, but the degree of panel movement can be underestimated, especially in larger panels.

Whether or not they are framed, large heavy panels are probably better supported on a plinth or base rather than hung. In either case, but certainly if they are hung, a strong, rigid frame is an advantage for the protection of a larger panel—and not simply during handling. The panel painting by Mengs arrived in such a frame. In contrast, the framing of the Palmezzano was inadequate and detrimental.

When it arrived, the Palmezzano had a shallow, flimsy frame that was hung from the panel—instead of the sensible reverse arrangement that has the panel hung by its frame. The weight of both was concentrated on the panel by screw eyes set into one of the half-round battens of oak that made up the horizontal members of the glued lattice.

Large panels, especially, should not be hung from such reinforcements, because the weight is thereby converted to internal stresses on the panel wood. The weight of the panel, battens, and frame had put such a torque on the surrounding panel wood that a cross-grain tear was induced. This probably occurred slowly, over a period of years, since the thick overlying ground and paint layers, though broken, show considerable plastic deformation. Larger panels should be framed sturdily and be hung from the frame—certainly not the reverse. In consultations with the owner and professional framers, it was determined that a more suitable frame was urgently needed because of inherent weakness and the dangers of mishandling.

Though sufficiently strong, the rabbet of the Mengs frame was not deep enough to allow for any warping movement of the panel, so that the panel was, in fact, retained too rigidly. Before treatment this factor was rather immaterial because the metal edge strips allowed little movement in any direction. After conservation, though, the rabbet could be deepened, padded, and possibly profiled where it contacted the front to allow for inherent warp and potential movement. Rabbets shaped to the contour of the painted surface, or camber, at the panel edges help to spread the surface of contact between panel and frame, reducing localized stresses and friction. Abraded varnish and paint are more likely on larger framed panels because of greater movement and resulting friction. Profiling may also help aesthetically to decrease large visible gaps from the larger panels' greater warp movement.

During transit, larger panels should be supported to minimize the effects of weight on bending. Low-density foam may be secured around the panel to minimize bending from weight or shock loads while allowing some wood movement. Since a packing system can seldom conform to large changes in panel shape, the environment—RH, shock, and vibration, in particular—should be controlled, especially for large, thin panels (Mecklenburg and Tumosa 1991:190; Michalski 1991:241). For the transport of larger panels, reputable art professionals well versed in the proper precautions may be preferred. They should be accompanied by a qualified conservator, if possible.

Acknowledgments

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Notes

1 Transverse grain direction.

2 Changes in MC and moisture gradients in wood are the primary causes of wood movement. Skaar (1988:chap. 4) reviews the topic thoroughly. See also Panshin and de Zeeuw (1970:206).

3 Of course, wood movement as a proportion of cross-grain dimension (percent of movement across the grain) remains the same, no matter what the panel size.

4 This statement refers mainly to the changes in dimensions and shape that accompany an RH change prior to equilibration. Dimensions and shape at equilibrium also depend on such things as the proportion of tangential to radial wood, the set of the wood cells prevailing from past conditions, and the presence of preparation and paint layers that may influence mechanical restraint and the rate of moisture permeability.

5 The effect will be less if such a plank is positioned closer to the panel's longitudinal-grain edges.

6 For example, as RH rises, the uncoated panel back usually swells first in response to a rising MC. The expansion is resisted by the remaining panel thickness, which has not begun to swell. If that remaining thickness is less rigid, such as in thin panels or in woods of lower density, the force of swelling at the back will cause a deflection, producing a concave warp when viewed from the front. For the same wood density, thicker panels will be more rigid and therefore have greater resistance to the effect of the swelling.

7 Longitudinal permeability may be 1,000–10,000 times greater than transverse permeability (Panshin and de Zeeuw 1970:217).

8 Determined by microscopic examination of a cross section.

9 Raffaello Sanzio, *Transfiguration* (1517–20). Oil on cherry-wood panel, 4100 × 2790 × 45 mm thick (average). Vatican Museums.

10 Marette (1961:65–67) gives a frequency distribution by wood type.

11 Not shown, J. M. W. Turner, *The Opening of the Wallhalla, 1842,* exhibited 1843. Oil, wax, and resin on mahogany panel, 1130 × 2010 × 10 (bevel) to 20 mm (middle) thick. Tate Gallery, London (inv. N00533).

12 See an early use of American mahogany (*Swietenia* spp.) in two paintings attributed to Rembrandt's studio of the 1640s (Bruyn et al. 1989:668–78). Though not particularly large paintings, they are both on single planks and are therefore "large" examples in that sense. Moreover, the planks are from the same tree, and show rather "wild" (very irregular) figure, making them even more unusual.

13 The number of joints is smaller and the clamping spans are shorter and therefore less awkward.

14 Tommaso Manzuoli, *The Visitation,* ca. 1560. Oil on poplar panel, 4090 × 2485 × 45 mm (original thickness). Trinity Hall, Cambridge, England. HKI treatment no. 194.

15 Vittore Carpaccio, *Saint Thomas Aquinas Enthroned between SS. Mark and Louis of Toulouse, Adored by a Youthful Donor; (above) Virgin and Child with Angels,* 1507. Oil on poplar (?) panel, 2640 × 1710 × 30–40 mm thick (visual estimate by author). Staatsgalerie, Stuttgart (inv. 136).

16 Edges roughly parallel to the axial, or longitudinal, grain direction.

17 The panel itself is usually called the *primary* support, or simply the support. A *secondary,* or *auxiliary,* support may be defined as an original or later structure applied to the panel, whether attached or not, to provide overall reinforcement.

18 Also known as slotted angle, such girders are found in various forms in laboratories in many countries. They can usually be acquired in various flange widths.

19 HKI treatment no. 73. The painting is on a thin glue-based ground. The glue appears to be casein, judging from the color, hardness, relative insolubility, and swelling characteristics of a

ground drip at the edge. It is interesting to note, in relation to the origins of this panel, that Mengs was in a transition period at the time this painting was commissioned, having just arrived in Rome from Madrid via Florence (Roettgen 1993:30–32).

20 Such considerations did not stop others from using heavy woods for panels that were commissioned from afar. Though Rubens may be cited as an example, oak was the standard panel wood in northern Europe, so lighter woods would not have been commonly used there. Lighter woods, mainly softwoods and poplar, were more common in Spain and Italy, and therefore it is curious that walnut was used here.

21 Based on a density of 640 kg m^{-3} from Lincoln (1986:27).

22 Marco Palmezzano, *The Mystic Marriage of Saint Catherine,* 1537. Oil and egg tempera on poplar panel (visual identification), 2560 × 1805 × 20 mm thick.

23 The earliest reinforcement lattice was glued to the thinned panel with casein, an adhesive common in Italian panels of that period (Marijnissen 1985:65) and less likely to be found as a panel adhesive in northern Europe in the same period. This observation was subsequently strengthened by research, kindly shared with the author by P. Balch. Known as the Calzolari Altarpiece, the painting was commissioned for the Church of S. Agostino in Cesena, near Palmezzano's native Forli. The painting had been moved to the Ercolani collection in Bologna by 1776. Cavalcaselle saw it in England in 1860, stating that it appeared "damaged [and] comes from the Ercolani in Bologna" (*Quest'opera non molto bella e danneggiata pervenne alla Raccolta Ercolani di Bologna*) (Grigioni 1956:575). Therefore, it seems likely that the earliest lattice and some related damages are at least 120 years old, or probably nearly twice that age.

The lattice was constructed and then glued *as a unit* to the thinned, flattened panel. This was evident from the dowelled cross-halving joints of the lattice, exposed during removal. The dowels were set into tapered holes and finished flush on the unexposed side of the lattice.

24 This technique included a thick gesso ground and a combination of oil and tempera paint.

25 Most planks were cut to the taper of the tree trunk for minimal waste, and the topmost end of one plank was positioned beside the bottommost end of its neighbor.

26 Interestingly, the cutting direction caused by the bevel of the panel maker's chisel resulted in a distinctly butterfly-shaped profile in many of the mortises, when viewed from the back. Thus, it is now possible to mistake the mortises for original insert sockets of the butterfly type, with inserts set in from the back, a technique seen in some panels.

27 Loose tenons, probably of holm oak (*Quercus ilex* L.) were used to align the plank edges during assembly. Regarding origins, both woods could be found in Italy and Spain at the time. In Spanish panels, walnut is found mainly in panels from the regions of Navarre and Castille (Marette 1961:68). It is possible that the panel was constructed in Spain, the painting begun there by Mengs and finished after his move to Rome.

28 This observation was not tested chemically.

29 The tenons were fitted very loosely, with at least a 3 mm gap all around. Before the joining, the tenon glue may or may not have been allowed to dry. It is interesting that the fit is quite free, with little contact area, suggesting that the tenons were more for alignment in assembly than for joint strength.

30 The surfaces are rubbed together to thin the glue line until the increasing adhesive strength makes further rubbing very difficult. For such large planks, this might have been done with mallet blows at the plank ends while joining pressure was applied.

31 Consolidation of one damaged edge has been presented in a previous article (Brewer 1994a).

32 The filler, harder than plaster of Paris, had keyed well into the surrounding damaged wood. It had swelled on setting, a characteristic of plaster of Paris (Gettens and Stout 1966:253).

33 After a thorough facing of the area, wood inserts of similarly grained European walnut were applied to the Mengs. Only insect-damaged wood was removed, to within 2–3 mm of the ground, as with the Palmezzano. Though the wood was sized with Paraloid B72, the use of water-based glue caused considerable swelling of the higher-density walnut, which then tended to delaminate from the back of the weakened casein ground. It was then necessary to remove the remaining wood to the ground, which was strengthened with a thin size, and the inserts were directly fitted.

This approach seemed to work well, though the original wood-ground interface was lost. Epoxy fillers, which would not swell the wood so much, were considered, but penetration and flow are hard to control. Also, most cured epoxies are mechanically intractable to the movement of surrounding wood. They are also too efficient as moisture barriers, and adhesion of other glues is limited (Skeist 1977:chap. 26). Rather than the epoxy, something like a strong, flexible, two-part polyvinyl acetate or a tough acrylic, soluble in organic solvents, might be more suitable. The behavior of the wood of the Mengs was in critical contrast to that of the fibrous, lower-density wood of the Palmezzano, which swelled less from the same glue and did not transfer the swelling detrimentally. There was no apparent effect on the strongly adhered gesso ground of the Palmezzano.

34 It would likely have been two or more dovetail-section tapered battens, set into matching grooves in the panel back, typical for such panels (Marette 1961:pl. 14, no. 56).

35 Such cross-grain battens, if not fitted carefully to a panel's surface, are usually glued to the high spots only. Aside from the inherent restrictions on transverse wood movement from any glued restraint, the *intermittent* attachment also helps to localize and concentrate tensions due to restraint of differential movements of the two components. Consequently, splits are multiple and are distributed accordingly.

36 The greater tendency of thinned panels to move and warp in response to changes in MC is due partly to steeper moisture gradients and partly to the decrease in panel rigidity. Lucas (1963:166) referred to this, perhaps in a slight understatement, as a loss of "constructional strength." See note 6, above, for a partial explanation.

37 The classic horrifying scenario of knots being pulled out along with the paint by power routers is sensational but entirely possible. Vibration is another concern.

38 The more informed choice of balsa makes it unlikely that those who applied the balsa reinforcement also attached the edge strips.

39 This estimate is based on movement of 1.8% (average of 2.0% tangential and 1.6% radial) over an RH range of 30–90% at 25 °C (Building Research Establishment 1975:6).

40 See Gordon's absorbing discussion of "critical Griffith crack length" (Gordon 1978:chap. 5, esp. 98–105).

41 Because wood is viscoelastic, seasoning establishes a general stress distribution, but it does not make timber free from stress.

42 An example of the effect of "releasing" elastic stress is seen in the warp that may immediately develop as oak planks are sawn from thicker timber that has already been dried to EMC. (These stresses are sometimes called *tensions*.) Paintings on oak, if recently disjoined, will sometimes show variable gaps that may be partially or wholly due to the same reason.

43 Adequate photodocumentation of the condition and potential identifying features of the panel back is an advantage for treatment. Examination and photography with other light sources, such as infrared, may also reveal important historical or conservation-related information that future events may obscure or destroy.

44 Water should not be applied directly to the panel wood because it increases the risk of compression set at the back, with a subsequent tendency to greater set warp.

45 Other larger panels have been treated in a vertical position. One example is the *Pietà de Villeneuve-lès-Avignon* (1454–56) by Enguerrand Quarton (Louvre INV RF1569), also painted on a walnut support (Bergeon 1990:35–38).

46 Animal glue, for example, can form a substantial restraint.

47 Warp from this cause is modified by movement deriving from the cuts of the planks and by any restraint caused by applied layers and by joints.

48 Some effects of flattening by water application have been noted. Flattening with moisture and pressure over an extended time to induce wood plasticization and a tension set in opposition to an existing compression set has been discussed lucidly by Buck (1963 and esp. 1972). Though these elements were discussed theoretically, the practical application and consequences were not conclusive. Regarding "slippage" and flattening, Buck states that his conclusions about slip-

page at the molecular level in panels restrained flat by balsa laminates must remain theoretical "until an occasion arises to remove the balsa backing from one of the panels and to observe the actual behaviour." (Buck 1972:11). Observations and an attempt to accomplish this process under similar conditions have not convinced the author that flattening can be achieved by higher MC and pressure alone. Gordon (1976:143) asserts that heat is the principal agent for bending wood. Other key elements, however, are time and whether the desired effect can be achieved within a *practical* treatment period. A combination of heat and moisture applied over an extended period would subject most panel paintings to considerable risks.

Chemical methods, through vapor exposure or impregnation (for example, see Wolters 1963), either interfere physically with the moisture response of the wood or alter the chemical nature of the wood. Both results alter the nature of the panel painting structure in ways that have not been tested over long periods. Again, the risks seem prohibitive. The effects and effectiveness of flattening methods should probably be investigated with controlled studies.

49 One method of rejoining uses wood inserts glued into V-section channels that are cut into the panel back along the split or disjoin (Uzielli and Casazza 1994:21; Bergeon 1990:22).

50 Recall that even the strong original joints of casein parted—rather than the surrounding walnut wood.

51 See, for example, the increasing frequency of articles on this subject in the journal *OPD Restauro* (1986–93).

52 This is a recommended average RH level for wooden objects (Thomson 1978:85).

53 Another possibility to facilitate the use of such long battens or similar strips for large panels is to construct the retainers from base blocks, glued to the panel, and a removable retaining plate screwed or bolted to threaded metal inserts in the blocks.

54 Evostik Resin W, a virtually 100% polyvinyl acetate resin, applied as a dispersion (Howells et al. 1993).

55 As a warp ensues, a panel that is more flexible than a reinforcing batten, for example, performs like a flexible reinforcement, so that the proper roles are reversed. Rather than the batten bending to conform to the panel's warping movements, the panel's warp is bent back on itself to conform to the reinforcement. Thicker panels, being more rigid (other things being equal), increase the friction against rigid reinforcements. When the friction exceeds the tensile strength of the panel, the panel will break from the stress. Bending in panels involves stresses of a more complex nature than can be discussed further here.

Materials and Suppliers

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Paraloid B72, Conservation Resources (U.K.) Ltd., Pony Road, Horspath Industrial Estate, Cowley, Oxfordshire, England.

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A Renaissance *Studiolo* from the Ducal Palace in Gubbio

Technical Aspects of the Conservation Treatment

Antoine M. Wilmering

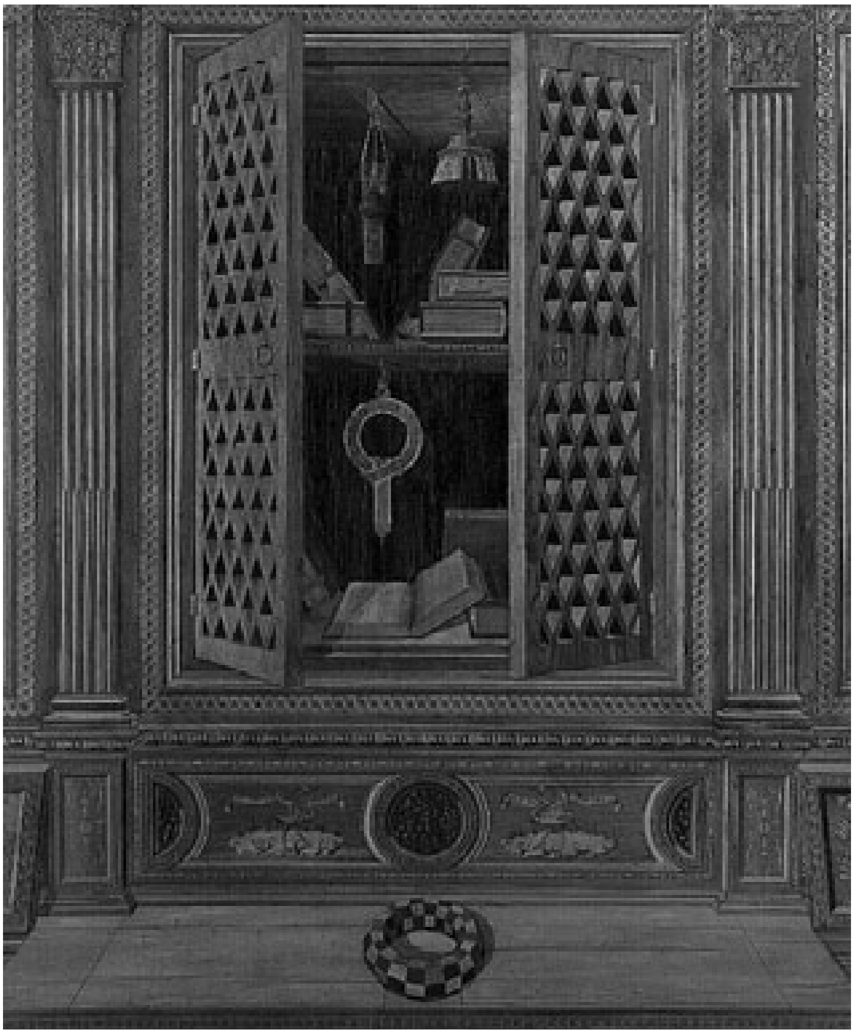
I saw a group of students huddled before a painting. Their noses were almost, but not quite, touching the panel and the soon-to-be practicing conservators were eagerly scanning the surface. Out of curiosity I approached the group and asked them what the problem was. They started commenting on the craquelure, the pigments used, retouches, etc. It was all technically quite sound. I asked them if they would mind stepping back about four feet. Somewhat reluctantly they complied, and then I asked them what they saw. There was silence. I repeated the question. One of the students finally ventured, "A painting." "Of what?" I asked. "An angel on a hill." Exactly. The panel in question was Flemish, some school piece of Thierry Bouts perhaps. A delicate, svelte angel in a white, billowing gown holding a sword aloft stood triumphant on top of an emerald-green hillock. A magical, jeweller's landscape with winding, dusty roads, Brussels Sprout-like trees, pilgrims and horsemen threading their way through the sun-drenched countryside, and a many-turreted castle receded into an azurite infinity beyond the hillock. This meant nothing to them as far as I could tell. The students had not started their examination by considering the painting as a work of art, but as an object, a thing, with ailments. There was no sympathetic attention and they may just as well have been looking over a used car. If students are not taught first to experience works of art as objects capable of providing us with aesthetic pleasure, they will never be able to apply their technical knowledge and craftsmanship in such a way that the integrity of the work and its tradition are totally respected.

—M. K. TALLEY, "UNDER A FULL MOON WITH BB: BUILDING A 'HOUSE OF LIFE'"

THE FURNITURE CONSERVATION STAFF at the Metropolitan Museum of Art, New York, has completed the conservation treatment of the Gubbio *studiolo,* after more than a decade of work.[1] This essay provides a summary report of some technical aspects of the conservation treatment of the intarsia support panels.[2] The studiolo is a splendid example of a Renaissance study; it was built between about 1477 and 1483 for Federico da Montefeltro's ducal palace in Gubbio, Italy. Federico da Montefeltro (1422–82), duke of Urbino, was a wealthy and important patron of the sciences and the arts in the fifteenth century. He commissioned numerous works of art for his palaces, including many intarsia works and two *studioli:* one for his main ducal palace in Urbino, which still exists in situ, and the other for his palace in Gubbio (Remington 1941; Winternitz 1942; Cheles 1991; Bagatin 1992; Raggio 1992). The painter, engineer, and architect Francesco di Giorgio Martini (1439–1502) directed the expansion of the ducal palace at Gubbio, which started in 1476 or shortly thereafter. The new Renaissance palace that emerged housed the studiolo, which also must have been designed and executed under Francesco di Giorgio's supervision. The studiolo, which was probably used as a small room for study or education, has an irregular ground plan of about 13.7 m^2 and consists of intarsia wall paneling that originally extended from a tiled floor to a height of 2.8 m. The intarsia panels create the illusion of an elegant interior with a trompe l'oeil bench and wall cupboards containing, among other things, books, musical instruments, Federico da Montefeltro's coat of arms, his armor, and, in the central panel, the Order of the Garter (Figs. 1, 2). A set of panel paintings attributed to Justus of Ghent (active ca. 1460–80) or Pedro Berruguete (ca. 1450–1505) depicting the liberal arts is believed to have been mounted above the intarsia panels (Davies 1955:45–53).[3] A spectacular gilded and polychrome painted coffered ceiling had been mounted at 5.3 m high, supported by an equally rich decorated cornice. A Latin phrase reflecting Federico's humanist background appears in carved and gilded letters in the frieze above the intarsia panels. The Latin text,[4] which very likely refers to the paintings, reads:

Figure 1
Studiolo of Federico da Montefeltro, duke of Urbino, from the ducal palace, Gubbio, as displayed in the Metropolitan Museum of Art, New York, in the 1950s. The floor, modeled after the fifteenth-century original (ca. 1477–83), and the window surround are modern reconstructions.

Figure 2
Detail of the central wall panel of the Gubbio studiolo during conservation treatment. The panel is constructed with various irregularly shaped matrix sections. Each door, for example, is one matrix section. The genius of the intarsiatori can be seen in the sophisticated play between light and shadow, as well as in the intricate details of the writing utensils pouch and the Order of the Garter.



ASPICIS ETERNOS VENERANDE MATRIS ALVMNOS
DOCTRINA EXCELSOS INGENIOQVE VIROS
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SVPPLIC]ITER FLEXO PROCVBVERE GENV
IVSTITIA PIETAS VINCIT REVERENDA NEC VLLVM
POENITET ALTRICI SVCCVBVISSE SVE.
(Menichetti 1987; Raggio 1992)

See how the eternal students of the venerable mother,
Men exalted in learning and in genius,
Fall forward, suppliantly with bared neck and flexed knee,
Before the face of their parent.
Their reverend piety prevails over justice and none
Repents for having yielded to his foster mother.[5]

Guidobaldo da Montefeltro (b. 1472), Federico's only son and second duke of Urbino, died in 1508 without an heir. From 1508 to 1631 the duchy belonged to the House of the della Rovere; when that line ended the duchy fell into the hands of the Papal States. At that time, around 1631, many of the artworks—including paintings, the books from Federico's famous library, and other portable objects—were removed from the ducal palaces. The paintings were removed form the walls of the studiolo in 1673 and taken to Florence (Raggio 1996). It was not until the end of the nineteenth century, however, when a local family owned the ducal palace, that such major architectural fixtures as chimneypieces, door surrounds, and decorative ceilings were removed. In 1874 the studiolo was bought by Prince Filippo Massimo Lancellotti. He had the studiolo dismantled (except for the paintings, which had already been removed) and moved to his villa in the hills of Frascati, near Rome. The first major restoration of the studiolo took place before it was installed in Lancellotti's villa.[6] A note discovered in one of the studiolo's doors confirmed the restoration and dated its completion to September 1877. In 1937 the German art dealer Adolph Loewi purchased the studiolo from the Lancellotti family. Loewi's workshop in Venice executed the second restoration (Fig. 3).[7] In 1939 the Metropolitan Museum of Art purchased the studiolo and displayed it until 1967. The current conservation campaign started in 1987 with a rotating team of conservators, conservation fellows, and students. The project was completed in April 1996 and the room opened to the public in May 1996; the exhibition included a didactic presentation about the history and conservation treatment of the room.

The Intarsia Panels

The Gubbio studiolo was commissioned, designed, and skillfully executed during the height of the Italian intarsia tradition, which started in the middle of the fourteenth century and lasted roughly two hundred years. From the second quarter of the fifteenth century onward, the *intarsiatori* applied linear perspective (the representation of three-dimensional space on a plane surface) in their work and soon were given the honorary title *i maestri della prospettiva,* "the masters of perspective" (Ferretti 1982). The Florentines in particular had mastered the technique of creating a perfect

Figure 3
The Gubbio studiolo in the workshop of Adolph Loewi in Venice in 1938 or 1939, shortly after the restoration of the room had been completed. The configuration of the panels is not accurate. This staged setting of the studiolo was intended to show as much of the room as possible to prospective buyers.

trompe l'oeil image with naturally colored woods. The workshop of Giuliano da Maiano (1432–90), who was a woodworker, architect, and one of the most celebrated intarsiatori of the fifteenth century, probably produced the intarsias of the Gubbio studiolo (Raggio 1992). The three-dimensional illusion of the panels results from the application of the rules of linear perspective combined with a thorough understanding of the delicate play between light and shadow. The extremely skillful craftsmanship of the woodworkers is best illustrated with some intarsia details that reveal the precision and subtleties of the inlay (Fig. 2).

Intarsia Technique in the Fifteenth Century

A basic form of intarsia is called *intarsia a toppo:* repetitive, geometric decorations created by inlaying complicated, often symmetrical patterns into a walnut substrate or matrix. The designs were often simple. The woodworkers laid them out with measuring tools such as rulers, squares, and compasses. The more elaborate intarsia images required design drawings and cartoons. Generally the painters, who often collaborated with woodworkers on other projects as well, supplied the designs and cartoons for figurative intarsias. Alessio Baldovinetti (1425–99), for example, supplied a cartoon for the Nativity panel, which Giuliano da Maiano executed for the new sacristy of the Duomo of Florence (Haines 1983).

The steps of creating an intarsia panel are not known to have been recorded; however, examination of the various intarsias suggests that some were made as follows: The intarsiatori first cut the wood sections to be inlaid according to a design or cartoon. They used saws, planes, adzes, chisels, and knives to form these approximately 5 mm thick sections, or tesserae, into the desired shapes. The next step was to outline, cut, and excavate the matrix wood (usually walnut), so that the various tesserae could be inlaid into the excavated areas. The intarsiatori typically used a shoulder knife, first, to set the outline of the areas to receive the inlay and, second, to remove the wood with gouges down to the depth of the first knife cuts. They next made a new series of knife cuts along the same outline and removed more wood down to a depth of about 5 mm. Once the matrix wood was ready for inlay, the intarsiatori secured the tesserae into the matrix with hot protein glue or cold casein glue. After this initial round of inlay, they planed the surface until it was level. By then, a basic design could be recognized. The use of the shoulder knife caused the walls of the excavated wood to taper slightly, creating a very tight-fitting inlay—much tighter than that achieved with later marquetry techniques. The matrix often formed part of the image and therefore, in many instances, remained partly visible after the work was completed.

The intarsiatori further inlaid the panel to create finer detail, adding rounds of inlay until satisfied with the final image. They cut slightly less deeply after each round of inlay, and each time they planed the surface of the wood. No known cartoons for intarsias have survived, a fact that suggests that the cartoons were cut and used during the intarsia-making process.[8]

The intarsia panels from the Gubbio studiolo were made using these techniques. Locally available woods such as walnut (*Juglans* spp.) in various shades, pear (*Pyrus* spp.), mulberry (*Morus* spp.), bog oak and brown oak (*Quercus* spp.), spindle tree (*Euonymus* spp.), cherry (*Prunus* spp.), and others were part of the "palette" of the woodworkers. These woods provided a variety of colors and shades, as well as the different grain and texture so essential in creating the extraordinarily intricate intarsia images. One colored wood stands out as unique among the more common wood colors. It is a green wood, stained by the fungus Chlorociboria (Blanchette, Wilmering, and Baumeister 1992). The wood is stained in the forest, when dead trees or branches become infected by this particular fungus. The intarsiatori were quite familiar with this phenomenon, and the use of green wood can be seen, for example, in some of the inlaid book covers and in the feathers of the small parrot in the Gubbio studiolo.

In the Gubbio studiolo the intarsiatori assembled the various matrix sections to form a full- or half-height wall panel. They then nailed the matrix, sections from the front, to a backing of poplar support panels, with handwrought nails (Fig. 4). The nails pierced the back of the support, and their tips were bent over and driven back into the wood. The intarsiatori then concealed the nail heads with a piece of inlay. In many instances they predrilled the location for the nails to prevent the wood from splitting.

Approach to Conservation

The conservation treatment of the Gubbio studiolo has proceeded along two paths. One proved to be a fairly straight lane, while the other is best described as a rugged trail with narrow passes, fallen trees, and rewarding scenic views. The straight lane involved preserving the structural integrity of the room, including such work as stabilizing the wall panels and ceiling construction and consolidating loose inlay and flaking paint. The rugged trail was more challenging to tread; it involved the aesthetic decisions necessary to preserve the visual integrity of the extraordinary fifteenth-century Renaissance room. These aesthetic decisions could be made only in relation to a virtual mental reference collection of similar intarsia works, as well as paintings, illuminated manuscripts, drawings and prints,

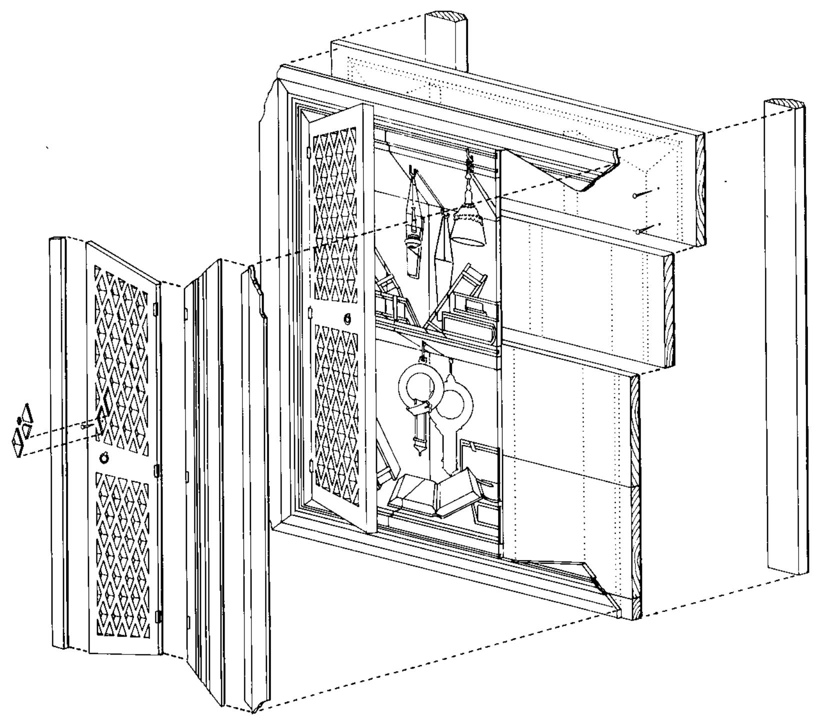


Figure 4
Exploded drawing illustrating how the various matrix sections form half a panel (in this case panel 7 top). Each matrix section is nailed to the support panel, and the nails are typically hidden beneath the intarsia. Each support panel originally had one or two vertical battens for strength. Only one original batten remains, at the bottom of panel 6, the model for shaping those in the drawing.

architecture, furniture, and other decorative arts. All of these were products of a unique moment in European history, rich in humanist interests, scientific pursuit, and artistic expression. During this vibrant time of curiosity and imagination, a historic consciousness emerged that was not only new to a whole generation of nobility but also new to middle-class merchants and artisans. Human and architectural proportions and nature were studied in depth, as were such abstract subjects as volume, color, light, and perspective.

Therefore, we cannot simply talk about the preservation of a room with intarsia wall panels and a polychrome ceiling that happens to have been built at the end of the fifteenth century. The studiolo, constructed at the height of the Italian Renaissance, was designed with great deliberation, every component serving a purpose, and even the seemingly casual placement of the tesserae was carefully considered. The studiolo strongly reflects the zeitgeist of the Renaissance. During the current conservation treatment, the goal of maintaining the integrity of the intarsia wall panels and polychrome ceiling has been at least as important as the physical preservation of the material. The aesthetic pleasure that Federico and his son Guidobaldo da Montefeltro must have felt upon entering the studiolo is what we should be able to feel today. As Talley says, no object should be considered solely as "a thing, with ailments." His description at the beginning of this article of the generic Flemish landscape painting as a "magical, jeweller's landscape" captures the essence of every work of art (Talley 1992).[9]

With these aesthetic considerations foremost, the conservation treatment of the Gubbio studiolo has proceeded; requirements have ranged from cleaning, consolidating, and retouching the intarsia and polychrome paint to fabricating complicated replacements for both the intarsia panels and the polychrome ceiling components. The focus of this article is the treatment of the supports of the intarsia panels and the coffered ceiling.[10]

The main concept of the conservation treatment can be summarized as follows: to preserve and restore the fifteenth-century character of the studiolo. All the original elements of the room were to be conserved[11] and the nineteenth- and twentieth-century restorations kept, where possible. These later restorations were respected as part of the history of the studiolo; even so, they were replaced in areas where the initial fifteenth-century intention of the intarsia panel had been misinterpreted, and the restorations had consequently disfigured the image. The intarsiatori executed original intarsia panels with a sophisticated sense of the delicate play between light and shadow and with a superb eye for detail. Today the aged wood still displays more contrast and a warmer tone scale than many of the later restorations, which have discolored—competing with, rather than complementing, the fifteenth-century elements.[12] Much of the treatment, therefore, consisted of integrating past restorations to bring out a coherence that had been compromised, within the intarsia panels and between the intarsia panels and the polychrome elements. New additions were kept to a minimum, and where possible they were made reversible. Unfortunately, the polychrome paint of the ceiling elements had sustained considerable damage over time, and the later restorations had badly discolored and flaked. These previous restorations were, therefore, completely removed. This removal prompted extensive repainting, which was possible because of the repetitive decorative pattern of the ornamentation.

Condition of the Intarsia Panels

The intarsia panels, and indeed the entire room, had sustained damage from the studiolo's four-hundred-year tenure at the Gubbio palace, especially in those years when the palace was neglected and abandoned. The ducal palace housed a candle factory near the end of the nineteenth century. Paul Laspeyres, who saw the studiolo in its original location in 1873, described it nine years later as being in a "severely deteriorated state."[13] The Lancellotti and Loewi restorations had aged, and many of their interventions had become visible. Woodworm infestation had substantially deteriorated the supports, and they had lost structural strength.[14] In areas, the back panels and matrix sections had separated, and in a number of locations, the inlay was loose and protruding from the matrix sections. Also, many of the restorations were discolored. In some instances wood replacements had been selected without respect for either grain direction or the proper species. Thin rosewood (*Dalbergia* spp.)[15] veneer, for example, was used to restore areas that should have been restored with brown oak or bog oak.

Treatment of the Intarsia Panels

The intarsia images were cleaned with a variety of gentle cleaning emulsions containing hydrocarbon solvent, water, and soap.[16] A thin layer of 7.5% shellac was applied to the surface to saturate the wood colors and serve as a retouching varnish.[17] Intarsia elements that had become detached were reglued with traditional warm protein glue (hide glue). Discolored restorations were toned with either watercolor or dilute Golden acrylic color to create a balance with the aged fifteenth-century intarsia. Missing elements were replaced with wood, which was carefully selected with a concern for the proper species and for similarity in texture, grain direction, hue, and density.

A few of the intarsia images had no back supports and needed elaborate intervention to restore their structural strength. The state of each detached intarsia varied from panel to panel. Some panels had no remaining hardware at all, while in others the original nails had been clipped, and stubs ranging from 0.5 to 1.0 cm in length protruded from the back of the matrix sections. The intarsia panels that still possessed their original supports had survived well over the last five hundred years because of the flexibility inherent in the original nailing system. Therefore, it was of particular importance to restore the original nailing system in each of the damaged panels. A number of solutions were devised to ensure that the original "pull," or force of the nails, in each panel was approximated as closely as possible. Most boards had little, if any, planar distortion, or warping. Existing splits and gaps were not filled or otherwise treated, since the panels were in equilibrium with the matrix sections, and it was important to avoid introducing any new forces.

The most effective solution to restoring the original nailing system in the damaged panels was also the simplest, as those nails where a stub of about 1 cm had been left could be cut with a positive thread. Solid brass extensions were then fabricated;[18] they were hollow on one end, which was tapped with a negative thread to fit the threaded nail stub. The other end of the brass extension was cut with a thread that could be used to fasten it with a washer and nut to the back of the new support (Figs. 5–8).

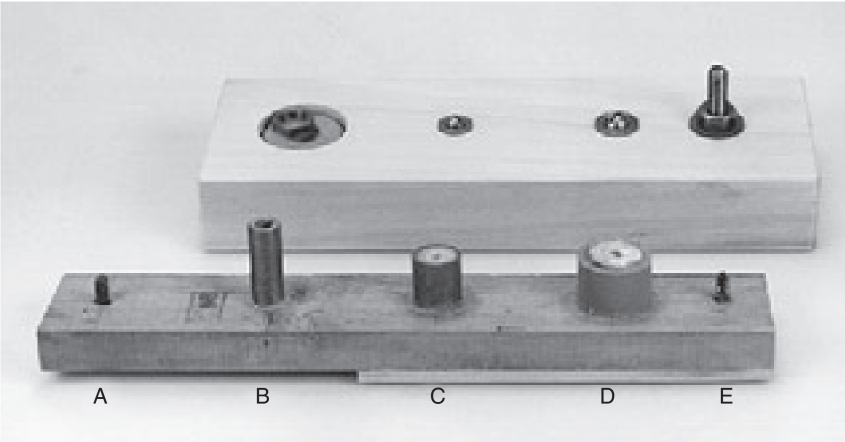


Figure 5, above
Test and demonstration model of a variety of attachment systems considered for the intarsia matrix sections and the new poplar support. From left to right: (a) an imitation of a clipped nail; (b) a short notched nail extended with a threaded tube glued with epoxy resin onto the stub; (c) and (d) small round pieces of wood glued with hide glue to the matrix, with their grain in the same direction as the matrix sections, protected from splitting by small collars; and (e) a nail stub cut with a thread and fitted with a brass extension.

Figure 6, above right
Detail of Figure 5 showing the two most frequently used attachment systems (d and e).

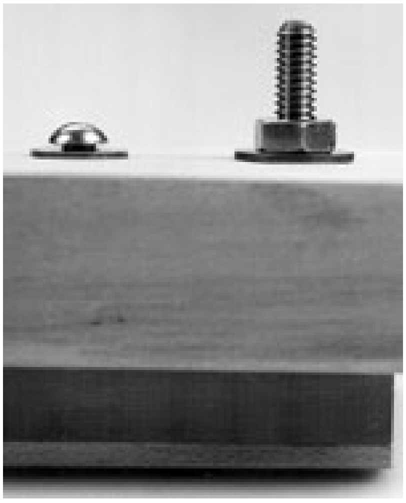


Figure 7
Detail of Figure 5. A poplar board is attached with the systems shown in Figure 6.

Figure 8
Side view of the attachment of the poplar board show in Figure 7 (attachment system e). From left to right: the end of a threaded brass extension, the poplar support, the walnut matrix with a remaining nail stub, and a strip of inlay.

Some nail stubs were too small (shorter than 0.5 cm) to be threaded and therefore needed a different extension system. A hollow piece of threaded brass, similar that used by electricians, was secured to the nail stub with carvable epoxy resin (Araldite AV 1253/HV 1253). Before the resin was applied, the wood surrounding the nail stub was isolated with a thin layer of protein glue. The nail stubs were notched and degreased for better adhesion with the epoxy resin. After being secured to the matrix sections, the brass extensions were fastened to the supports by washers and nuts (Fig. 5).

A third method was necessary in areas where the nails had been removed completely. Small round cylinders of wood, measuring about 1.6 cm in diameter and 1.4 cm high, were glued to the matrix sections next to where the nails had been removed. This was done to approximate as closely as possible the original forces in the intarsia panel. The grain of

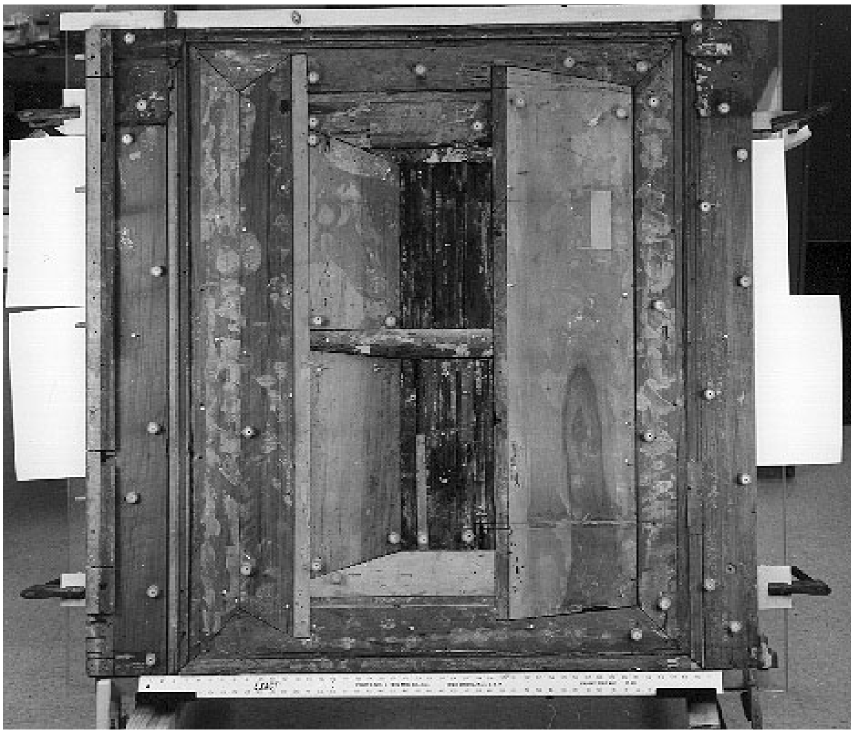


Figure 9
Reverse of panel 8 top. The separate matrix sections are clearly visible. Remaining nail stubs have been threaded, and wooden cylinders, with their collars, have been put into place.

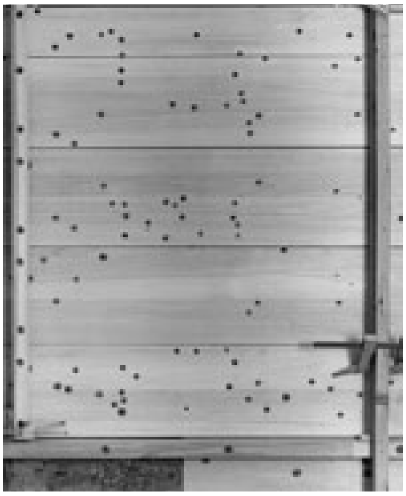


Figure 10
Reverse of panel 8 top. The new boards have been attached with a combination of attachment systems (d and e—see Fig. 5).

Figure 11
Proper front side of the new support of panel 8 top. This side of the support has been shaped to accommodate irregularities in the matrix sections, thus ensuring that the front of the panel (matrix and inlay) produces a level surface.

the wood cylinders was placed in the same direction to match each matrix section. The cylinders were glued to the matrix section with hot protein glue.[19] A plastic collar was glued around the cones with Araldite to prevent the wood from splitting, because the supports were attached to the cylinders by screws (Figs. 5, 6, and 9).

Cottonwood (*Populus* spp.) was selected for the new support panels, to match as closely as possible the original Italian black poplar and its properties. The wood was purchased air-dried in Louisiana and stored in the conservation studio for two years prior to its use. The new boards, which were mostly sawed in semiquarter direction, were abutted to approximate as closely as possible the width of the original boards. The fronts of all new boards were meticulously shaped to match any irregularities of the matrix section backs. This ensured that the matrix sections had level surfaces once the new supports had been installed (Figs. 10, 11).

One board in panel 9–10 top had to be removed from the support because it was too deteriorated to provide adequate structural strength for the intarsia panel (Figs. 12, 13). X radiographs confirmed extensive woodworm tunnels that former restorers had filled with stucco, a plasterlike material (Fig. 14). The board was removed, as much as possible in one piece, so it could be kept and stored separately from the studiolo. The remaining nails[20] attaching the matrix to the support were straightened, and the entire board was lifted from the matrix sections. Two pieces of cottonwood, cut to the size of the old board, were glued together to make a new board. The old nails were reused—but not in the traditional manner, which might have broken them. They were cut with a thread so that they could be fastened with a washer and nut through the new board. Where necessary, additional round sections of wood were glued to the matrix sections, in close proximity to the old nails, to ensure that there were ample areas of attachment. The new board provided enough strength

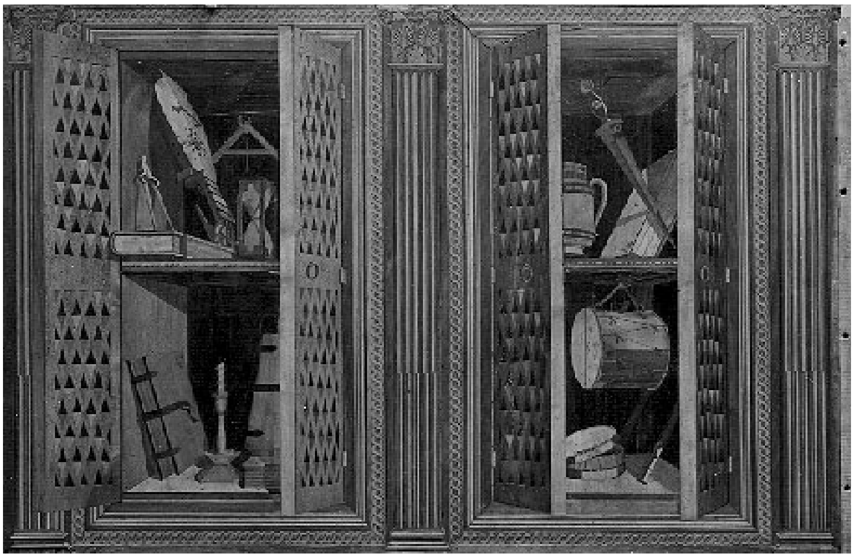


Figure 12
Panel 9–10 top. The panel has been photographed on one of the specially designed project worktables. The working surface of the tables can be tilted vertical (as shown) to allow proper viewing of the work in progress.

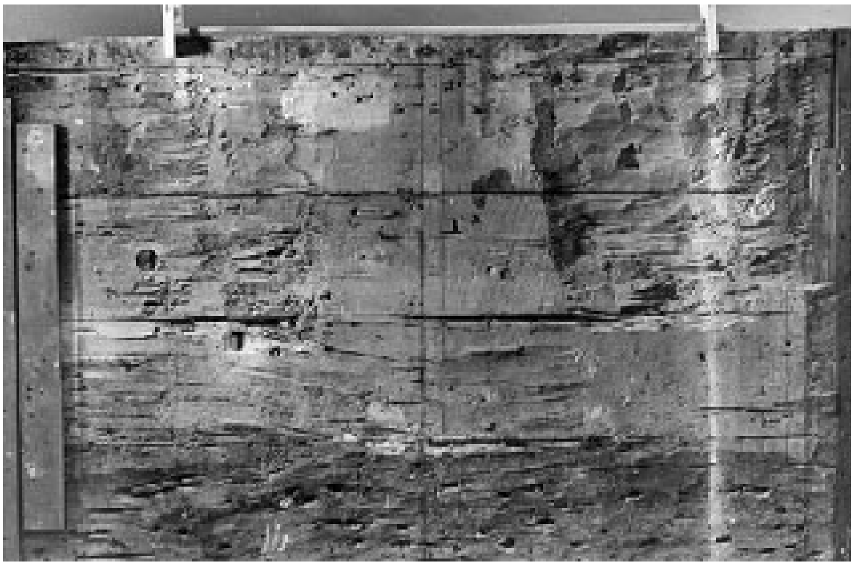


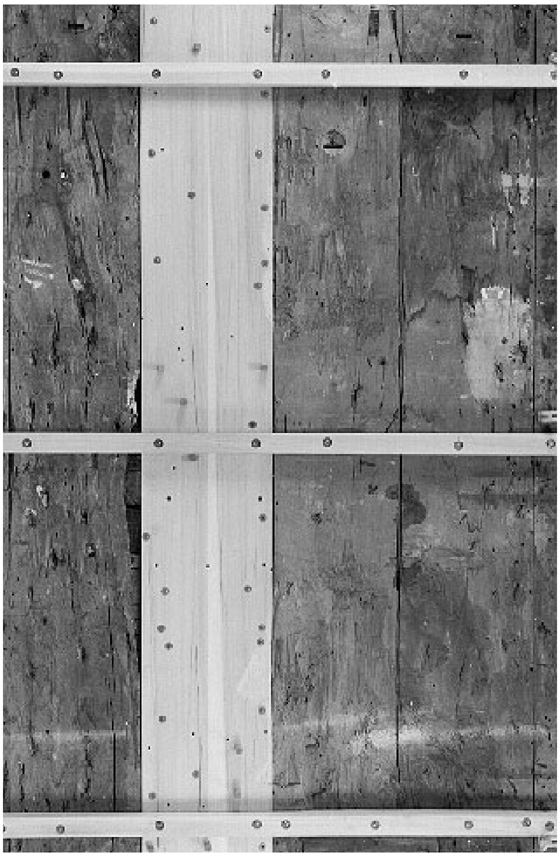
Figure 13
Reverse of panel 9–10 top. The second board from the bottom was too deteriorated to provide adequate support.

a

b

Figure 14a, b
Reverse of panel 9–10 top. The deteriorated board has been removed, and the remaining nails piercing the matrix sections have been straightened (a). The X radiograph (b) reveals the extensive stucco fills, which, combined with the deterioration, were the main reason for the removal of the board.

Figure 15
Reverse of panel 9–10 top. The new board is in place, and new battens have been attached. The substantial damage to the lower board was not treated; the gap in the center was filled, however, with sections of balsa placed without adhesive.



to the intarsia panel so that none of the adjacent boards, which had fragmentary deterioration at the sides, required removal (Fig. 15).

Ceiling and Polychrome Elements

The polychrome coffered ceiling, in keeping with fifteenth-century practice and similar to the ceiling in the Urbino studiolo, had been constructed from poplar (*Populus* spp.) with very little wood joinery but with an abundance of handwrought nails (Figs. 16, 17) (Luchinat 1992:23–27; Rotondi 1973).

The nailing system of the ceiling contributed to the fairly well preserved structure of the ceiling components. Areas of extensive former woodworm infestation, however, needed conservation treatment. The ceiling had been restored and expanded with fir, although the original wood was poplar. The nineteenth- and twentieth-century polychrome restorations were badly discolored and flaking, while the fragmentary remaining fifteenth-century paint was fairly well preserved under a layer of grime.

Treatment of the Ceiling and Polychrome Elements

The infested areas of the ceiling components needed to be treated in order to preserve the ceiling and to ensure safe display at a height of 5.3 m. Consolidation with synthetic resin was considered but not executed because this plan would have substantially increased the weight of the ceiling. Instead, a mechanical system was devised to support the infested areas from above the polychrome hexagons. Steel plates of the proper shape were welded to a 20 cm piece of threaded steel.[21] These plates were mounted above the hexagons, with their thread through the backing. The nineteenth-century beams bore the weight by means of smaller aluminum crossbars.

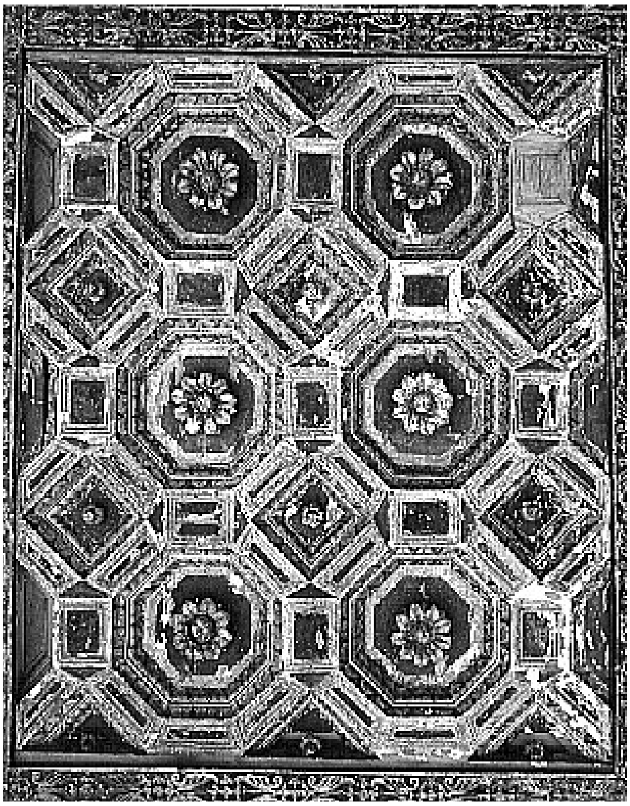


Figure 16
View of the small ceiling from the window niche during the conservation treatment. This portion of the ceiling was almost entirely repainted in the nineteenth century. The decorative borders, with their fifteenth-century gilding and azurite paint, are mostly original.

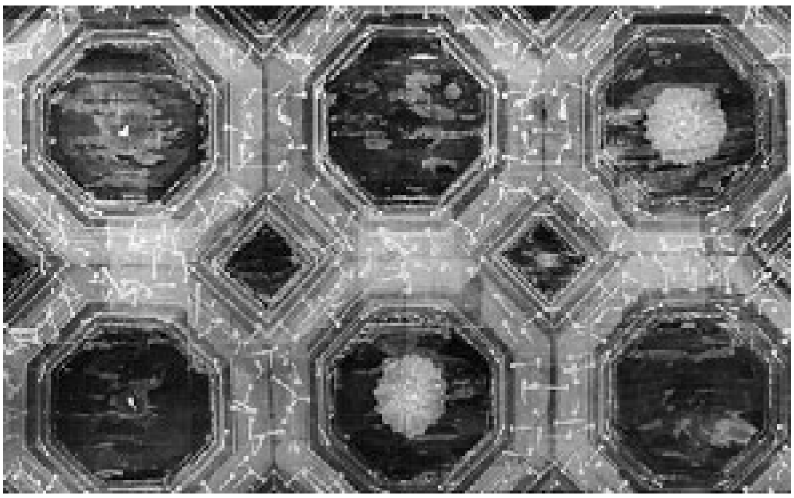


Figure 17
X radiograph of the ceiling of the window niche, showing the absence of joinery and the abundant use of nails. The fifteenth-century paint has survived only fragmentarily, as can be seen, for example, in the octagons, which have dark "islands" of slightly denser original paint.

The original fifteenth-century paint was consolidated with fish glue and the surface lightly cleaned with saliva. Most of the nineteenth- and twentieth-century restorations were removed with either a methylcellulose gel or an acetone gel, according to which binding media was used in the later restorations. A new ground of gesso was applied after the wood had been prepared with glue size. The decorative elements were repainted with gouache and dry pigments in Arkon P90 resin[22] as a binder. New gilding was applied in the traditional manner. All new inpainting was executed to match the aged, original fifteenth-century paint.

Through the conservation treatments discussed above, this Italian Renaissance masterpiece has regained some of its former glory (Figs. 18, 19).

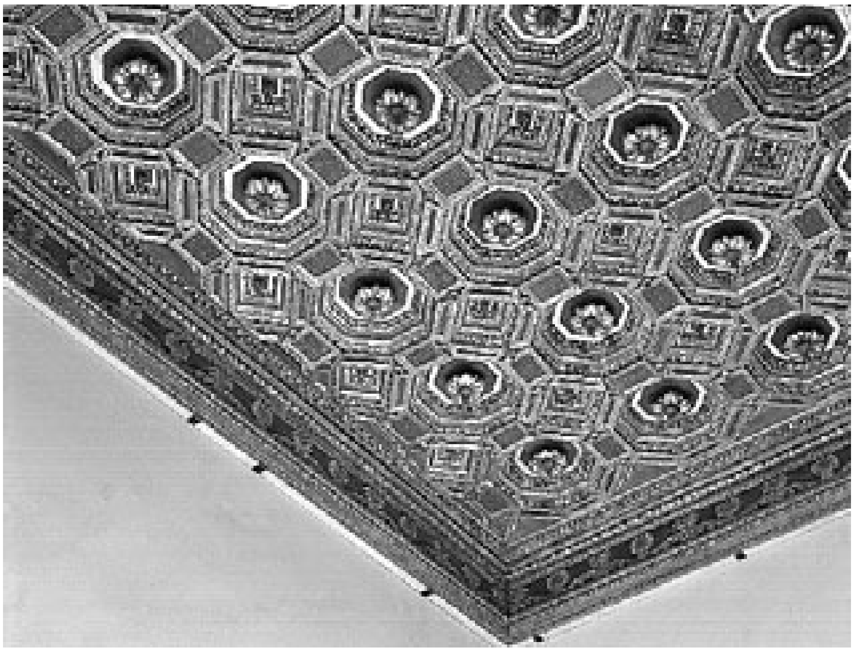


Figure 18
Main ceiling of the studiolo after conservation treatment.

Figure 19
The Gubbio studiolo after conservation treatment.

Acknowledgments

The author dedicates this article to Charles D. Wright and John Kitchin, retired chief conservation officers of Furniture and Woodwork at the Victoria and Albert Museum, London, and to Bertus F. Boekhoff, retired senior furniture conservator at the Historical Museum of Amsterdam, for so kindly and generously handing him the tools of his profession.

The conservation treatment of the Gubbio studiolo could not have been achieved without the support, advice, and interest of a number of key players. The author would like to express his gratitude to Olga Raggio, Iris and B. Gerald Cantor Chair of the Department of European Sculpture and Decorative Arts, for her guidance and continuous support of the conservation treatment of the Gubbio studiolo. He is grateful to Tony Frantz, conservator in charge of the Sherman Fairchild Center for Objects Conservation, for his trust and encouragement during the many years of conservation work. He also owes a great debt to George Bisacca, conservator at the Sherman Fairchild Center for Paintings Conservation, who generously shared his vast knowledge of Italian intarsia, woodwork, and technology. Over the years a number of conservators, conservation fellows, and students have been part of the Gubbio conservation team. The author would especially like to thank and acknowledge Susan Klim, formerly associate conservator, and Mechthild Baumeister, associate conservator, as well as John Canonico, Rudy Colban, Mark Minor, Fred Sager, Pavol Andrasko, Albert Neher, Dennis Degnan, Ralph Stoian, Birgitte Uhrlau, Carmen Chizzola, John Childs, Jack Flotte, Susan Müller-Arnecke, Constanze Doerr, Ann MacKay, Anke Tippmann, Henriëtte Bon-Gloor, Carole Hallé, Perry Choe, Hong Bae Kim, Amy Kalina, Stephanie Massaux, and Jacqueline Blumenthal for their valuable contributions to the project and for their excellent and skilled conservation work on the Gubbio studiolo. He also sincerely thanks Bruce Schwarz and Bob Goldman of the Metropolitan Museum's photo studio for their superb photography and print work.

Notes

1 At the time this paper was presented in spring 1995, the conservation treatment was in progress; it has since been completed. The room opened for exhibition in May 1996.

2 A *Metropolitan Museum of Art Bulletin* on the Gubbio studiolo authored by Olga Raggio and Antoine M. Wilmering was published in spring 1996 to celebrate the studiolo's reinstallation. Olga Raggio is the Iris and B. Gerald Cantor Chair of the Department of European Sculpture and Decorative Arts. A major book on the subject is being prepared by the same authors; it is scheduled for publication by the Metropolitan Museum of Art in 1998.

3 Two paintings of the set, *Music* and *Rhetoric,* have been preserved at the National Gallery in London. Two more paintings, *Astronomy* and *Dialectic,* were preserved up to World War II at the Kaiser Friedrich Museum in Berlin. The liberal arts were commonly, although not exclusively, grouped as seven in the *trivium* and *quadrivium.* It is unknown whether any more paintings of the group exist.

4 The Latin text had suffered losses over time and was restored on several occasions. In the various descriptions by Dennistoun (1909), Laspeyres (1882), and Gabrielli (late sixteenth century), published in Menichetti (1987), different losses and discrepancies are apparent.

5 The author is grateful to John Marincola, associate professor at Union College, Schenectady, New York, for his suggestion for a missing section in the Latin inscription, as well as for his suggestions for the translation of the text, which is partially based on the *Codice Gabrielli* cited by Menichetti (1987), Nachod (1943), and Laspeyres (1882). The translation is taken from Raggio (1996).

6 Paul Laspeyres, a German architectural scholar who visited the ducal palace in 1873, mentions that Prince Lancellotti purchased the studiolo for L 7,000 and that it had been thoroughly restored (Laspeyres 1882).

7 The author is grateful to Mrs. William J. Robertson, who shared much information on the restoration of 1937. She was eighteen years old at the time the studiolo was at her father's workshop, and she recalls having been involved in the restoration of the incomplete Latin text. The workshop operated separately from Adolph Loewi, but according to Mrs. Robertson, it executed all restorations for the firm.

8 Intarsia making typically involves a design drawing from which cartoons on paper are produced (Haines 1983). These cartoons are suitable for transferring the design onto the wood. In this process the cartoons are cut into smaller pieces and glued to the wood surface. This technique allows the intarsiatori to cut accurately along the outline with woodworking tools to produce properly shaped tesserae. The technique, in which the cartoons are destroyed, is practiced today by marquetry cutters (Ramond 1989).

9 The author owes a great debt to M. Kirby Talley Jr. for kindly allowing him to reproduce the passage quoted at the beginning of this article (Talley 1992).

10 See note 4 above.

11 Some elements—for example, one of the boards of the support panel opposite the studiolo's entrance—had to be replaced because they no longer provided adequate structural strength.

12 The natural wood colors would have been richer, and the designs of the intarsia panels would have had more contrast in the fifteenth century. Wood owes much of its color to the gums and deposits it contains. Light-colored woods generally have fewer of these materials than darker colored woods. During aging, two factors play a role in the change of a wood's color. First, the gums and deposits tend to fade, much as do natural textile dyes. Second, the main components of wood, cellulose and hemicellulose, bleach upon aging, while lignin darkens. Thus, the aging process causes the wood colors to draw together in tone and display a less vivid chroma.

13 "Noch sah ich dasselbe, wenn auch im Zustande arger Verwahrlosung im Jahre 1873" (Laspeyres 1882:77).

14 No signs of active woodworm infestation marked any of the panels or ceiling components. It is very likely that the panels and ceiling were fumigated around 1937–39.

15 South American rosewood would not have been available in Italy in the third quarter of the fifteenth century. Small quantities of tropical woods may have been available through the trade routes in Africa and Asia. It is unlikely, however, that these precious woods would have been used in secondary areas in the intarsias (Baxandall 1986; Meilink-Roelofsz 1962; Origo 1985).

16 The mildest cleaning emulsion consisted of 600 ml Shellsol 71, 100 ml water, and 0.75% Brij 35, a nonionic soap. The author is grateful to Richard Wolbers, associate professor in the Art Conservation Department at the University of Delaware, for his advice in making this emulsion. Where necessary, a slightly stronger cleaning agent (composed of 445 ml benzene, 40 ml oleic acid, 15 ml triethanolamine, and 500 ml water) was used.

17 A 7.5% shellac solution was preferred to a B72 solution, because the shellac provided fuller color saturation for proper evaluation of the intarsia images. It formed a base for inpainting some of the nineteenth- and twentieth-century restorations. It also protectively coated the wood surface during consolidation in case of glue spillover.

18 The brass extensions were fabricated by Gerard Den Uijl, supervising maintainer of the machine shop at the Metropolitan Museum of Art.

19 A high-quality protein glue with a strength of about 640 g was used. It is a very pure glue, possessing a high shear factor and no additives, made to the specifications of William Monical, violin maker and restorer. The author is grateful to Stewart Pollens, associate conservator of the Department of Musical Instruments at the Metropolitan Museum of Art, for advice about this glue and its properties.

20 Many nails had already been removed, probably by the Loewi restoration of 1938.

21 The stainless steel plates were made by Gerard Den Uijl, supervising maintainer of the machine shop at the Metropolitan Museum of Art.

22 Arkon P90 is a synthetic resin that dissolves in Shellsol 71. It is a very stable resin and has little tendency to cross-link, or discolor, when mixed with a small quantity of Tinuvin 292, a UV inhibitor (Rie and McGlinchey 1990).

Materials and Suppliers

Araldite AV 1253/HV 1253, Industrial Sales Association Inc., 39 Henry J. Drive, Tewksbury, MA 01876.

Arkon P90 resin, Conservation Support Systems, P.O. Box 91746, Santa Barbara, CA 93190.

Brij 35, Sigma, P.O. Box 14508, St. Louis, MO 63178.

Golden acrylic, Golden Artist Colors Inc., 188 Bell Road, New Berlin, NY 13411.

Shellsol 71, Shell Solvents, 200 Pickett District Road, New Milford, CT 06776.

Tinuvin 292, Conservation Support Systems.

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Microclimate Boxes for Panel Paintings

Jørgen Wadum

Probably there is no construction that suffers more seriously as a result of the movement of wood than the paint on a painted panel.

—R. D. BUCK, 1952

IN A POORLY CLIMATIZED MUSEUM or during transit, it is crucial to control continuously the moisture content of humidity-sensitive objects such as wood, fabric, and paper.

The use of microclimate boxes to protect vulnerable panel paintings is, therefore, not a new phenomenon of the past two or three decades. Rather, it has been a concern for conservators and curators to protect these objects of art at home and in transit since the end of the nineteenth century. The increased number of traveling exhibitions in recent years has heightened the need to protect paintings during circulation (Thomson 1961; Mecklenburg 1991).

Departures from the usual climatological surroundings may cause swelling or shrinkage of a panel, resulting in cracks, splits, and cleavage of the support or between the support and image layers (Stolow 1967). Early research in packing has covered some aspects that are used as criteria for the microclimate boxes (Stolow 1965, 1966, 1967).[1] Although there may not be an "ideal" relative humidity (RH) for museums, it is evident that some objects require, or would benefit from, separate microenvironments, regardless of the chosen RH set point (Erhard and Mecklenburg 1994).

The use and design of microclimate boxes have been evolving since 1892. These boxes may be divided into three broad groups: those using an active buffer material to stabilize the internal RH, a more recent box containing no added buffer material, and, in recent times, boxes with an altered gas content. Another concern is the appearance (aesthetics) of the box.

Wood as a Hygroscopic Material

The cross-grain instability of wood has been a perennial problem to artisans as it is in the nature of wood and wooden objects to seek an equilibrium between internal moisture content and that of the surrounding atmosphere (Fig. 1a, b) (Buck 1961).[2]

Examination of the hygroscopic behavior of various wood species shows that green as well as old wood responds to changes in humidity (Buck 1952, 1962).[3] The swelling and shrinkage of two panels was

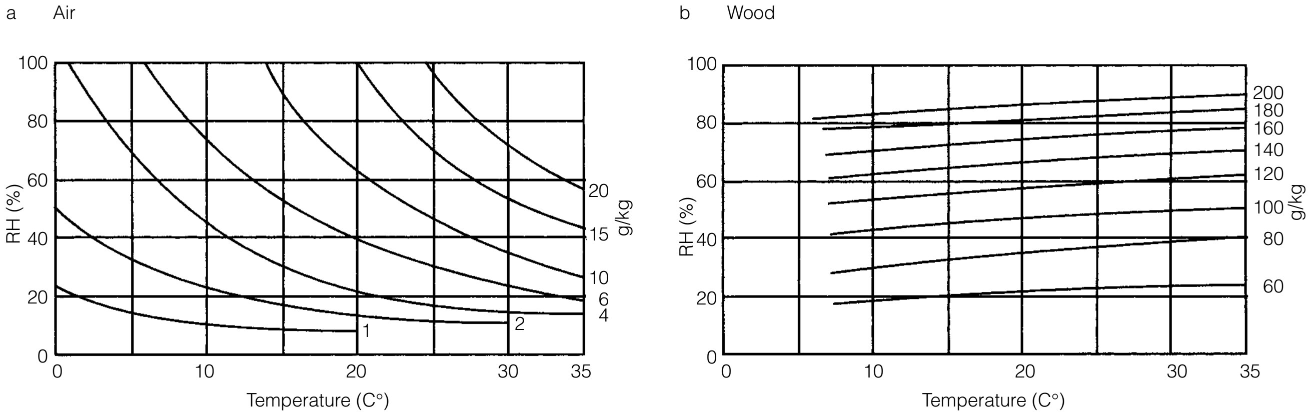

Figure 1a, b
Correlation between RH, temperature (°C), and grams of water per kilogram (g/kg) in (a) air, and (b) wood.

measured with strain gauges and recorded. The investigation showed that the movements of a new oak panel and a panel from the seventeenth century were analogous (Klein and Bröker 1990).

Experiments with beech (hardwood) and Scotch pine (softwood) demonstrated that the hardwood has a slightly higher moisture change rate than the softwood, and that the movement of beech samples was therefore larger than that of the Scotch pine samples (Stevens 1961).

The ratio of the area of exposed surface to the volume of the wood also influences the reactivity of the wood. Thin pieces of wood respond more quickly than thick ones, while small pieces respond more quickly than large pieces of equal thickness. When a panel is thinned, as is often done during the cradling process, the ratio of exposed surface to wood is sharply increased; therefore, the diffusion of moisture throughout the bulk of the panel and the response to changes in the atmospheric environment are accordingly accelerated.

It has also been demonstrated that the higher the temperature, the more rapid the rate of moisture transfer. A piece of wood comes to equilibrium about twice as fast at 24 °C as at 12 °C because the vapor pressure of water at 24 °C is twice as great as at 12 °C, if the RH is constant.

Finally, the greater the change in RH, the faster the rate of moisture transfer (Buck 1961, 1979).

The preparation of a panel before the painting process must also be considered (for a discussion of historical techniques, see Wadum, "Historical Overview of Panel-Making Techniques," herein). The size and ground may contain hygroscopic materials, such as glue, that also react to changes in RH and temperature.[4]

The behavior of a number of materials found in traditional paintings has been analyzed under the stress of temperature fluctuations and varying RH (Buck 1972; Mecklenburg and Tumosa 1991). Another important result of climatological fluctuations is the changing stiffness of painting materials and mediums in traditional paintings (Michalski 1991).

Changes in RH produce measurable changes in the dimensions of a panel. Research has also shown that paintings change dimensionally as a consequence of temperature, independent of a change in RH (Richard 1991). However, bearing in mind that the thermal expansion of a panel enclosed in a case is small, the conservator should concentrate on keeping the moisture content of the wood constant and thus ensure dimensional stability of the panel.[5] The unanimous advice given by various authors holds that a narrow range of temperature and RH change is advisable for the preservation of a panel painting.

Microclimate

Thomson's studies on the different properties related to RH variation with temperature in cases containing wood set the standards for the field (Thomson 1964).

Calculations show that equilibrium moisture content (EMC) is more relevant than RH, since in the microclimate box, the ratio of wood to air will exceed 1 kg of wood per 100 l of air, a ratio that is critical to controlling the humidity of the wood.[6]

Stolow, in particular, provided much useful information and experimental data on tests on enclosed packing cases (Stolow 1965).[7] Stolow, Thomson, and Padfield were primarily interested in stabilizing RH at a constant temperature (Thomson 1964, 1977; Padfield 1966; Hackney 1987). Apart from Thomson's calculations and experiments showing the RH and temperature changes within cases, as well as the relationships between them, Padfield's contribution to the understanding of the phenomena inside small closed areas must be regarded as part of the standard literature.

If much wood is present, its moisture content determines the RH of the entire volume of the microclimate box. It has been emphasized that the diffusion of water vapor through the case materials and through stagnant air in gaps should be kept in mind when a hermetically sealed case is created (Padfield 1966; Brimblecombe and Ramer 1983). Padfield remarks that water vapor diffuses through air almost twice as fast as oxygen and nitrogen and very much faster than dust particles.[8]

Objections have been raised about the exhibition of objects in almost-closed containers, because of the danger of condensation forming on the glass or object when the temperature suddenly falls. However, Padfield's calculations and experiments confirmed that the stabilizing effect of absorbent materials, such as the wooden panel itself, prevents condensation. Padfield concludes that the conservation of wooden objects in rooms that are heated but not air-conditioned often demands an artificially raised RH in individual showcases. To this end, he recommends using saturated salt or a solution of sodium bromide to stabilize the RH of a showcase.

Toishi describes the common belief that a closed package containing a large quantity of wood dries out when the temperature is raised, even though the wood gives out moisture to balance the dryness of the air. He counters, however, that the quantity of moisture vapor released from the wood when temperature rises is generally so great that it increases the RH (Toishi 1961).

Stolow describes the relationship between EMC and RH, as well as the variations in RH and temperature in sealed cases containing wood. A case at 20 °C with an initial RH of 50% will increase to 53.5% RH when the temperature is increased to 30 °C. If, on the contrary, the temperature were lowered to 10 °C, the final RH would be 46.5%. If the case were not sealed or the air volume were very large, however, he recommends that the internal RH be stabilized with silica gel (Stolow 1967).

To this end, Weintraub tested five different types of silica gel (Weintraub 1981; Stolow 1967). The tests showed no direct relationship between the actual moisture content of a particular sorbent and its relative ability to control the RH of a showcase.[9]

Miura examined sorbents for their static and dynamic characteristics, to estimate their ability to buffer RH changes in a showcase (Miura 1981).

Wood heated to 30 °C lost 2% of its moisture content, which the silica gel or Art-Sorb could easily absorb in order to maintain the RH at stable values (Hackney 1987; Kamba 1993; Wadum et al. 1994).

Microclimate Boxes: 1892–1994

"Sealing a show-case to prevent diffusion and convection and to resist, or deform under, pressure changes up to 0.5 mb would very much reduce the leakage of air and be a major contribution to the conservation of a wide variety of art objects," Padfield wrote in 1966. This concept, as shall be seen, has been a concern since the end of the nineteenth century.

In deciding the ways and means of creating a microclimate, the conservator should consider the following questions (Cassar 1984, 1985):[10]

- What are the requirements of the object, based on its environmental history?
- What is the climate in the gallery where the microclimate case is to be placed?
- What are the functions of the microclimate? Is it to act as a stabilizing, dehumidifying, or humidifying factor to the object?
- What will be the materials used for constructing the display case?[11]

The importance of using inorganic materials, such as glass and metal, in constructing the case cannot be emphasized enough (Padfield, Erhard, and Hopwood 1982). However, the buffering material can be either organic (wood, paper, textiles) or synthetic or natural derivatives (Nikka pellets, Kaken Gel, zeolite clay, silica gel, Art-Sorb) (Weintraub 1982).[12]

Thomson's recommendation of 20 kg of silica gel per cubic meter for buffering purposes in exhibition cases has been regarded as a good starting point (Thomson 1977), but in certain circumstances, the same result may be achieved with less. Recent research, however, questions the recommendation of using any buffering material at all in microclimate boxes (Wadum et al. 1994).

Display materials also influence the buffering ability of a display case and should therefore be chosen carefully. They should all be conditioned before installation. Conditioning hygroscopic materials may require up to one month's exposure to the desired RH before the equilibrium wished in the microclimate environment is achieved (Fig. 2a–c).

Microclimate boxes with added buffers

Even though most authors thought that wood itself could be used as a buffer, there was often a tendency to add an extra buffer to stabilize the internal RH of the microclimate box.

In 1933 a patent appeared for the use of salt-hydrate pairs as regulating substances in cases and picture frames. The humidity should be controlled through a low rate of air exchange, so that all the entering air passes over certain salt-hydrate pairs. In this way, one salt may absorb moisture from air that is too humid, while the other salt will conversely release moisture if the air is too dry (Wilson and Barridge 1933). Shortly thereafter, in

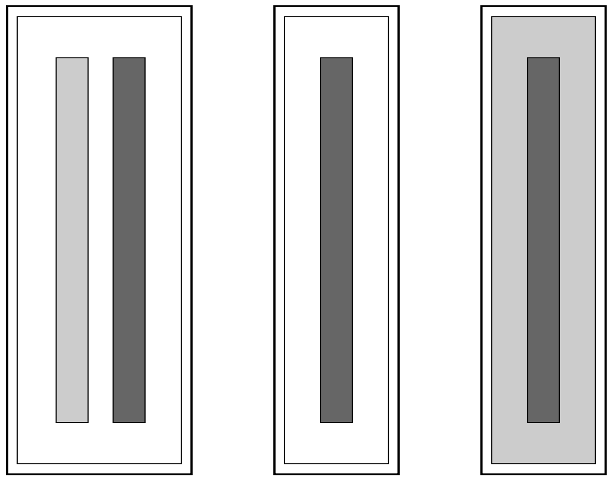

Figure 2a–c
Three main principles behind the construction of a microclimate box: (a) a box containing a panel painting and buffer material; (b) a box containing only a panel painting; and (c) a box containing a panel painting and an altered gaseous content.

1934, MacIntyre published test results to show that RH in a poorly sealed display case is still more stable than the RH in the surrounding room. He further demonstrated that the hygroscopic panel, frame, and fabric lining of the case would improve this stability so that even with a 1 mm gap around the glass base, a fairly constant RH could be maintained during the week of monitoring (MacIntyre 1934). The results were applied to an air-conditioning system for Mantegna's cartoons at Hampton Court Palace.

In 1934 Constable proposed an alternative to buffers. The idea was to feed conditioned air into the frame (or case) by means of pipes; however, this was dismissed at the time on the presumptions of bulk and inconvenience (Constable 1934). The idea was nevertheless put into practice approximately fifty years later (Lafontaine and Michalski 1984).[13]

In 1936 Curister enclosed a panel painting attributed to Hugo van der Goes. Salts were kept in trays within the base of the double-glazed standing vitrine, which was capable of keeping a stable RH indefinitely, provided the exchange rate with the exterior was not too great.[14] Small glazed openings were made at the top of the cases, through which enclosed hygrometers could be monitored. Before the construction and assembly of the microclimate box, the wood used in the construction of the cases and frames was carefully seasoned and conditioned in an atmosphere of the agreed moisture content. During the most difficult climatological months, the sealed cases showed a stable internal RH of 55%.

More than twenty-five years would pass before a new description of a microclimate box for a panel painting appeared (Sack 1963–64). Sack describes how a controlled environment was made for a panel painting and kept stable during a low winter RH of 12–28%. A large sealed wooden case with a double glass door was constructed that held pans containing a saturated solution of magnesium nitrate hexahydrate. A small fan distributed the conditioned air to all areas within the case. In this manner, the RH was held stable between 50% and 52%.

Shortly after, Stolow published his aforementioned studies of the humidity and thermal properties of a sealed case (Stolow 1967).[15]

If the elements (case and painting) are in equilibrium with the environmental RH and temperature when the case is sealed and then subsequently placed in another environment, a new equilibrium will develop within the case after a certain time.[16] Thus the sealed case—when tightly packed with conditioned wood and similar hygroscopic or moisture-sensitive components—can maintain reasonable RH control over temperature changes.

There are two instances to which the above conditions do not apply and where more complicated formulas must be used. The first arises if the case is not tightly packed; the second occurs when the internal air volume is relatively large compared with that of the humidity-sensitive materials. If the air volume is very large, the moisture properties of the internal air dominate the relationship between RH and temperature; in this case an increase of temperature will cause a decrease of the RH, and vice versa. Stolow advises that silica gel be used to stabilize the RH, as the response of the gel to temperature is negligible.

Based on the studies of Thomson and Stolow, Diamond's 1974 article on a "micro-microclimate" gave the first description of a microclimate box for a panel painting on display. A sixteenth-century French portrait from the school of François Clouet was placed in a showcase. It appeared that with a maximum fluctuation of temperature in the galleries of 11 °C, the RH should vary by less than 4%.

Accordingly, a hardwood box was constructed and fitted at the front with glass, which was puttied to make an airtight seal. A chipboard back was made. This procedure yielded a box of approximately 13.7 l volume, containing about 220 g of wood (picture and frame), which, according to Thomson's figures, should have produced a near-stable environment. The wood of the case was left uncoated so that it could play its part in absorbing and giving off moisture. The whole box was conditioned for two weeks to 55% RH (±5%) and 20 °C (±2 °C).

The fact that the picture showed signs of distress very soon after being treated suggested either that it was sensitive to changes of RH of less than 4% or that the design of the box was faulty.

The construction of a completely airtight box was impossible, due to finances. Therefore, a buffer was chosen to reduce the RH fluctuations. The principles involved were those laid out by Stolow (1966). The box was fitted with panels of silica gel held in a grid. The grid was crucial, as it spread the silica gel over the largest area possible within the box.[17] The open box and all its materials were left for four weeks to reach equilibrium in a stable environment.

The environment was controlled with a small hygrometer and was stable around 41% RH (±4%) over two months. Variations inside the box were no greater than 5%, so the box was considered a safe container for the painting.

The box protected the painting from considerable fluctuations of approximately 20% during this period. Thus, only minor changes in RH took place inside.

The same year Toishi and Miura described how the *Mona Lisa* from the Louvre was exhibited for fifty days in the Tokyo National Museum (Toishi and Miura 1977). Throughout the run of that exhibition, the painting was enclosed in an iron case equipped with a double-panel glass window and lined with a 75 mm layer of glass. To maintain a stable RH of 50%, zeolite was placed in the case. The zeolite was found to be capable of absorbing various gases such as sulfur dioxide, hydrogen sulfide, ammonia, carbon dioxide, and formaldehyde. The zeolite had been brought to a humidity equilibrium in air at 60% RH (Kenjo and Toishi 1975).

Probably the most-cited contribution on controlling microclimates was written by Thomson in 1977. He derived a formula with experimental support to predict the RH changes inside an unsealed exhibition case that contained a buffer such as silica gel. The formula showed that a well-constructed case (containing about 20 kg silica gel per cubic meter of case volume) should constrain seasonal humidity variation within reasonable limits and, in some climates, make air-conditioning unnecessary. The practical solution recommended by Thomson was to make a showcase of non-moisture-permeable materials and snugly fitting closures, possibly gaskets.

For RH conditions above 50%, silica gel offers little advantage over wood, as its *M* value is about the same.[18] However, at lower RH values silica gel is the best buffer.

In this article Thomson does not take fully into account the change of temperature; his focus is mainly on the RH changes. Tests of the half-time of the case were made under constant temperature levels. Also, the tests were conducted only with silica gel, not with other buffer materials, such as wood.

The leakage rate for the case is important. Thomson refers to important studies by Padfield on the problem of diffusion through various materials (Padfield 1966).[19]

Sack and Stolow (1978) reported that in a case designed in 1963 to exhibit a German panel painting in the Brooklyn Museum's main entrance lobby (an area of the museum with a particularly erratic climate), a saturated solution of magnesium nitrate hexahydrate proved to be effective in controlling the RH at 50–52%.

In another situation, a similar box served to control the microclimate around a painting on a thin wooden panel. This microclimate box was constructed to protect a fine Fayum panel on loan to the Brooklyn Museum. The intention was to design a case as airtight as possible to preserve the required level of RH, independent of external variations. The Fayum painting (44.5 × 28.5 × 0.2 cm thick) was painted on thin wood. The wood had been bent to conform to the double convex contours of the original mummy case.[20]

It was decided to enclose the Fayum painting in a case kept at a constant RH of 50%. Preconditioned silica gel would serve as the RH stabilizing agent in the case. The case consisted of an outer display box and an inner, airtight, metal-and-glass chamber. Inside the case, a wooden frame was covered with fabric containing the preconditioned (50% RH) silica gel, with the painting secured 4 mm in front of the silica gel panel. A section of paper-strip RH indicator was placed in the corner of the case to allow continuous monitoring of the internal RH. The painting flattened considerably from its convex warp while sealed inside this case.

Although the case was almost airtight, a very slow moisture exchange with the exterior could still occur over time. This possibility made it necessary to recondition the silica gel annually. Since it was time-consuming to remove, recondition, and replace the silica gel, a second panel was made. Kept under secure airtight conditions, it could be installed as a replacement to the "worn-out" panel, which would be reconditioned and readied for the next annual replacement.

Acclimatization of two large (922 l) vitrines of air containing five icons was carried out to attempt the difficult task of stabilizing the gallery environment at 50–60% RH (Schweizer and Rinuy 1980). To keep the environment stable, the recommended amount (20 kg m^{-3}) of silica gel was placed in a honeycomb tray and covered with a nylon screen. With the screen facing the interior, the tray formed the back of the case. The results showed that the temperatures in the gallery and showcase were approximately the same at all times. In contrast, the RH within the cases remained stable despite changes of 44–74% in the RH outside the showcases. Evaluation of the amount of silica gel actually required to keep the RH level stable in the vitrine led to a recommendation of 10–15 kg m^{-3}—almost half of what Thomson advised. It was also noted that the conditioning of the silica gel should be at an RH value 5% higher than what was actually desired in the case.

At the Sainsbury Centre for Visual Arts at Norwich, England, the use of a mechanical system dependent on electricity was considered impractical to assess RH control employed within showcases (Brimblecombe and Ramer 1983).[21] The use of a saturated salt solution, which is most effective when auxiliary support is provided by an electric fan, presented the same drawbacks as the fully mechanical system. The use of silica gel enabled the creation of a self-sufficient system without the need for electrical support.

To monitor the mechanism of air exchange between the interior and the exterior of the case, an experiment was designed using a tracer-gas method to monitor the concentration of various gases over time within a standard-sized display case.[22] Padfield's indication that the air-exchange process occurs essentially by diffusion was confirmed (Padfield 1966). Additionally, Thomson's studies showing that the exchange of air within a display case—and hence water-vapor variation—occurs exponentially were also verified (Ramer 1981, 1985).

The conclusion reached, based on a calculation of the hygrometric half-time, was that Thomson's recommendation to use 20 kg m^{-3} of silica gel was valid.

The diffusion of air is the primary cause of RH variation within showcases; therefore, good construction of cases is essential (Ramer 1981, 1985).

Also in 1981, a number of case histories about controlled-climate cases were presented by Stolow (1981). One such case involved a large panel painting and its predella by Neri di Bicci. The acrylic case enclosing the panel was relatively small in air volume compared to the object volume, having only slightly larger dimensions than the artwork to allow for maximum buffering action of the silica gel. The estimated weight of the panel and the predella was 250 kg. After consideration of the panel painting and the supporting materials (i.e., fabrics, wood), it was deemed necessary to place inside the case approximately 200 kg of conditioned silica gel, which was held in place by a screened panel covered with linen fabric.

With the past environment of the panel painting considered, it was decided to establish a slightly higher-than-average RH (45%) within the case. The EMC of the silica gel was periodically tested during the conditioning procedure to verify, via sorption curves (isotherms), that the 45% RH operating level had been reached.

Electronic probes were considered to monitor the interior of the case, but because they are costly and require frequent calibration, they were abandoned in favor of paper RH indicators. After one year of operation, it was shown that the internal RH level had been kept at a fairly constant 40–43% RH, despite wide variations in the gallery climate.

A further example of a specific microclimate box is to be found in a description by Knight of the Tate panels in the Church of All Hallows

Berkyngechirche by the Tower (Knight 1983). A box was made of Perspex (known in the United States by the trade name Plexiglas), with a sheet of aluminum as a backing board. Steel brackets attached the box to the wall, thus leaving an air gap between the back plate and the wall.

Recommendations by Stolow and by Sack and Stolow provided the basis for the humidity-control requirements of the box (Stolow 1977; Sack and Stolow 1978). Silica gel was placed in the box in small narrow trays that could be individually removed for reconditioning. After installation, a small hygrometer showed that the interior RH was maintained at a level of 56–58%.

The variation in RH in an experimental exhibition case that was intentionally not sealed or airtight was monitored over two years (Schweizer 1984). The RH of the surrounding room varied considerably (20–70%), but the RH inside the case, which contained silica gel, maintained acceptable stability (40–58%). This type of box, therefore, would prove very useful in regions with hot summers and cold winters. The amount of silica gel required was based on Thomson's formula of 20 kg m^{-3}.

Also in 1984, a microclimate box was presented by Ramer for a seventeenth-century panel painting from the Netherlands (Ramer 1984). The goal was to create—with a more aesthetic design than previous microclimate boxes—a humidity-controlled display case for the painting that covered both the panel and frame. The new microclimate box was to be fitted into the extended rabbet of the picture frame, making this the first occurrence of its kind since the late nineteenth century (Simpson 1893) (see the section below entitled "Microclimate boxes that alter the gaseous content").

Practical requirements demanded a low maintenance level and easy recharging of the silica gel humidity buffer. The RH requirement within the case was 55%. The silica gel amount was determined according to Thomson's formula of 20 kg m^{-3}.

The microclimate box was made of inert materials (e.g., aluminum), and the glazing at the front was composed of 5 mm polycarbonate sheeting (Lexan). As in previous designs, the tray of silica gel could easily be remounted and reconditioned. The box was designed by B. Hartley, A. Southall, and B. L. Ramer.

Thirteen Fayum mummy portraits and a panel painting of Saint Luke by Simone Martini, all housed in the J. Paul Getty Museum in Malibu, California, were placed in special cases that had a higher humidity than normally maintained in the paintings galleries (Rothe and Metro 1985). An absolutely airtight microclimate box was constructed, with care taken to make sure that it wasn't too visually overpowering.[23] The case consisted of three basic sections: a back panel, a front bonnet (vitrine), and a silica gel container. Art-Sorb was selected as the buffer in accordance with comparative performance statistics published by Weintraub and Miura (Weintraub 1982; Miura 1981).

For the Simone Martini panel, 4 kg (dry weight) of Art-Sorb was placed in the gel container and conditioned in a humidity chamber to 66% RH. This amount is four times greater than recommended by Thomson (1977) for a case of this size. The showcase had been on display since March 1983 in a temperature- and RH-controlled gallery. The RH in the gallery was always 14–16% lower than the RH inside the case.

The same construction was used for the Fayum portraits, except for the back panel, which was replaced by a Formica panel. The silica gel container was made out of birch with a silk-screen fabric stretched over the front and back. The gallery used for this display is open to the outside environment during public hours, a factor that influenced the RH, which ranged from a low of 37% to a high of 68% during the test period. During the year, the temperature ranged from 20 °C to 27 °C. The mummy portraits required cases that were capable of maintaining an ideal environment of 50% RH, with minimal or no fluctuations. After observation of the hygrometers in the cases, it was ascertained that the RH never varied more than 2%. Thus, it was not necessary to recondition the Art-Sorb for two years. Because the cases were constructed of Plexiglas, the objects were clearly visible and could be lit from the outside without any apparent change in temperature.

Dissatisfaction with the microclimate boxes previously used by the Kunsthistorisches Museum, Vienna, led Ranacher (1988) to present a slightly different idea.[24] In his concept, silica gel could be renewed without dismantling of the box, and an electronic device enabled convenient external checking of the internal environment (Mayer 1988). The back and sides of the box were made of wood to aid in stabilizing the internal moisture content. The front of the box consisted of a Plexiglas hood, which was mounted on the frame of the backing board. The frame of the painting on display would be mounted over a hole in an internal wooden board covering the backing of silica gel. The amount of buffer material (7 kg m^{-3}) was determined by Ranacher's own experimentation, not chosen according to previously recommended high values of 10–20 kg m^{-3}, or recommended low values of 1–2 kg m^{-3} as recorded by Miura in his laboratory tests (Miura 1981). The ratio used in Vienna had previously been proved adequate for maintaining a stable RH of 50% within a microclimate box that hung in a gallery having temperature fluctuations of 14–23 °C. The built-in electronic device for monitoring RH and temperature levels was invisible to the public. Personnel could read the electronic data by plugging in a wire at the bottom edge of the box.

At the United Kingdom Institute for Conservation conference, Cassar and Edmunds individually presented microclimate boxes designed to fit within the frame of the painting, similar to those presented by Ramer in 1984 (Cassar 1988; Edmunds 1988). Cassar enclosed a panel painting in a buildup of the original frame, which permitted the manufacture of a glazing (Perspex) and backing. The environment of the box was kept at a stable RH through the presence of an Art-Sorb sheet placed behind the painting. Edmunds constructed a closed box with low-reflection glass at the front and with Perspex sides and backing. A Perspex grid containing conditioned silica gel crystals in small sacks could be stored behind the panel painting. A hair hygrometer and, later, Grant Squirrel Data Loggers were used to monitor the box interior and surrounding environment. The data showed that the inside RH remained stable for a considerable period at various ambient conditions without recalibration of the silica gel. Cassar also reached the same conclusion.

Bosshard and Richard also recognized the disadvantages of microclimate boxes that enclosed both the painting and its frame (Bosshard and Richard 1989). A box enclosing only the painting was developed and widely distributed by Johnson and Wight in the beginning of the 1980s in California.[25] This box was further refined, in conjunction with an empirical trial with the Thyssen-Bornemisza Collection, to become a standard-climate vitrine. This new microclimate box was flat and could, therefore, be fitted into the frame of the painting (Bosshard 1990). With low-reflection glazing, the box could hardly be seen. The rabbet of the frame often had to be extended to make room for the box, but in situations where this action was not desirable, the sides of the vitrine could be made of a thinner metal foil instead.

Art-Sorb granules were preferred to Art-Sorb sheets, as the gel is more reactive in absorbing and desorbing moisture. The inside of the box was made according to the specifications: one-third panel, one-third silica gel, and one-third air.

Because RH always drops after the box is closed, the Art-Sorb was conditioned to a RH of 3% higher than desired. A paper RH meter was placed in back, making it possible to check the RH inside the box at any time. Foam rubber on the silica gel frame pressed the painting forward to the front of the box. At present, more than fifty-eight panel paintings—on loan or in the Thyssen-Bornemisza Collection—are kept in these vitrines.

Simultaneously with the empirical trial in the Thyssen-Bornemisza Collection, Mervin Richard carried out lab tests at the National Gallery in Washington (Richard 1993). The results showed that the thicker the walls of the box, the greater its stability. The interior RH depends on the amount of the buffer material, and the greater the difference between RH outside and inside the case, the quicker the inside will change to a new equilibrium.

Thomson recommended 20 kg m^{-3} of silica gel. As the Art-Sorb in this case was deliberately over the requirements of the air volume, "overkill" was established. Richard proved with his climate chamber that a temperature change of 10 °C resulted in a change of about 2% RH inside the box, depending on its size and capacity to absorb the temperature change.[26]

In 1990 a microclimate box to be fitted within a frame was constructed in the Mauritshuis, The Hague, largely following the concepts of Ramer, Bosshard, and Edmunds (Wadum 1992).[27] The glazing was, however, always a layered safety glass that enabled the box to travel with minimum risk.[28] At first the box included silica gel or Art-Sorb sheets to stabilize its internal RH during display and transit (Wadum 1993).[29] Between the glazing and the front of the painting, in the rabbet, a grid was placed along all four sides allowing convection of the air from front to back and vice versa.

Small built-in microprocessor loggers monitored the RH and temperature from the time of installation until the painting was returned after loan.[30] The printout showed that the RH stayed stable within 2%, despite temperature fluctuations of more than 10 °C.

Simultaneously with the Mauritshuis, the Rijksmuseum in Amsterdam was also developing a microclimate box. This box, a low-budget variant, was initiated and constructed by Sozzani, who needed a simple, easy-to-mount box to fit into the frame (Sozzani 1992). The box was constructed of safety glass that was mounted and sealed in the rabbet of the frame. Behind this, the painting was mounted in the usual way. Thin wooden battens were built up on the back of the frame, allowing enough depth in the rabbet for the insertion of a sheet of Art-Sorb behind the panel. The stainless steel backing sealed off the box with airtight gaskets.

The primary advantage of this type of box is that the rabbet never has to be extended, a requirement that would be undesirable in many situations. The previously used microclimate boxes from California required some manipulation of the frame.[31] The Rijksmuseum boxes also proved effective when monitored with humidity indicator strips or small hygrometers, all of which indicated a stable RH within the boxes in the museum environment.

Extensive studies undertaken by Richard have confirmed that temperature changes affect panel paintings much faster than do RH variations (Richard 1994). Although he concludes that silica gel has no effect on the temperature changes, he nevertheless recommends that the gel remain in use for microclimate boxes. Drawing on the assumption that virtually all microclimate boxes leak, Richard states that silica gel plays an important role in stabilizing the RH in display cases used in unsuitable environments for extended periods.

Microclimate boxes without added buffers

A more recent approach to the construction of microclimate boxes relied on the hygroscopic behavior of the wood panel itself as a stabilizing factor within a small volume of air. Such boxes were not kept at a stable RH through added buffers but instead maintained their own internal moisture equilibrium at changing temperatures.

A critical approach to the consistently recommended use of a moisture buffer in small display cases was presented by Ashley-Smith and Moncrieff (1984). Their experiences in the Victoria and Albert Museum in London showed that the silica gel in a showcase neutralizes the short-term RH fluctuations but does not compensate for seasonal changes. Ashley-Smith and Moncrieff concluded that for wooden showcases, silica gel gives poor results in relation to the time and expense required to purchase, prepare, and handle it, as well as to design and build showcases to accommodate it. They stated that an ordinary showcase without silica gel fares nearly as well—or as poorly—in reducing short-range fluctuations. The same conclusions were drawn in reference to some old-fashioned walnut cases in the Royal Ontario Museum, Toronto, that proved remarkably effective in slowing moderate fluctuations of RH (Phillimore 1979). For best results, a well-sealed case made completely of metal and glass or plastic is usually essential (Brimblecombe and Ramer 1983). However, for the Victoria and Albert Museum, wooden case vitrines serve in themselves as useful, additional buffers (see Cassar and Martin 1994).

Also in the early 1980s a special type of microclimate box was created by Padfield, Burke, and Erhard (1984). A cool-temperature display case was made for a vellum document placed in a close-fitting airtight container. The document required a stable temperature of ±16 °C, some six degrees cooler than the gallery, and an RH of 40–50%. The box maintained a nearly constant RH after cooling; however, special care was necessary to minimize temperature gradients. The case performed satisfactorily for one year with no change in internal moisture content.

The simplest method possible was chosen for displaying this document. It was sealed inside a thin, airtight container that was cooled by means of the Peltier effect.[32] The refrigeration system of the box consisted of two coolers at the bottom of the aluminum tray holding the microclimate box.

A close-fitting, airtight enclosure has many advantages for the temporary exhibition of flat pieces of vellum or paper. It can be designed to maintain a nearly constant moisture content and a safe RH. At room temperature, paper contains thousands of times more water than an equal volume of air does. In a sealed box full of paper, therefore, it is the paper that controls the RH of the surrounding air, if both are of the same temperature.

Based on the psychrometric chart, it was obvious that a container holding more than 1 g of paper per liter of air has a reasonably stable RH as the temperature varies (a rule of thumb that, incidentally, holds true over the whole range of ambient temperature). This conclusion applies only to a slow temperature change imposed uniformly to the paper and box.

It is important to remember that absorbent material such as paper or silica gel only functions as an RH buffer if it is at the same temperature as the air or object to be buffered. To buffer for eventual air leakage of the sealed box, extra paper was enclosed in the box to increase the buffering capacity.

Apart from using inert material for the inside of the box, a further precaution against air pollution involved using paper containing calcium carbonate to absorb acid gases.

In 1987 Hackney warned against enclosing buffering materials such as silica gel in small, sealed environments. He underlined, as have authors before him, that the equilibrium of silica gel or similar buffers is not dependent on changes in temperature (Stolow 1965, 1967; Thomson 1964, 1977; Weintraub 1982). On the contrary, hygroscopic materials such as wood were characterized by relative equilibrium, showing a higher RH at higher temperatures, and vice versa.

Despite these developments, the creation of microclimate boxes continued with added buffers such as silica gel or Art-Sorb (as discussed above in the section entitled "Microclimate boxes with added buffers"). The tradition continued, under the influences of guidelines laid out by the authors mentioned above, to keep the internal RH stable under all circumstances.

Richard reported in 1991 that in closed cases, falling RH levels caused by temperature decreases should not cause alarm, noting that several publications have emphasized that it is not beneficial to maintain stable RH levels for hygroscopic works in transport if temperature changes are anticipated at the new location. If, for example, a painting were moved from 50% RH and 20 °C into a very cold gallery, a lower RH must be maintained if the EMC is to be kept constant within the object.

Users of microclimate boxes seemed fairly reassured by the stable RH values produced through the use of added buffers such as silica gel or Art-Sorb. However, considerations regarding the effects of temperature fluctuations on the wood of the enclosed panel developed into an extensive test program set up by the Mauritshuis, The Hague; the Central Research Laboratory for Objects of Art and Science (CL), Amsterdam; and the Rijksmuseum, Amsterdam (Wadum et al. 1994).

The tests at the CL demonstrated that buffering material should be avoided in small microclimate boxes. Otherwise, fluctuations in the temperature would initiate a breathing process between the non-temperature-reactive silica gel or Art-Sorb and the panel.

Boxes made of inert material proved effective in maintaining stable environments for the hygroscopic material inside. A box made of an inert front and back, but placed in the wooden rabbet of the frame, also provided effective maintenance against fluctuations of 10–30 °C. Long-term (i.e., more than eight hours) low or high temperatures were not tested. RH fluctuated between 30% and 70% without any influence on the interior climate. The boxes were well sealed to prevent leakage.

The Mauritshuis microclimate box now uses polycarbonate sheets as a backing; because buffer material is not used, the reverse of the painting is left visible so that the courier or other museum staff can examine it without removing it from the microclimate box.[33]

Dimensional movement of different types of wood in closed cases, with and without silica gel, was studied by Kamba (1993). He states that the dimensional change of the wood inside the box without silica gel was less pronounced than that of the wood in the silica gel–buffered case. Kamba's studies thus confirmed the results from the tests at the CL, in which an equilibrium between wood and the surrounding air at different temperatures was attained without added buffers.

For these reasons the most recent microclimate boxes for panel paintings at the Mauritshuis and the Rijksmuseum are now made without any added sorbent material. The buffering role of the panel itself is regarded as sufficient for the small, enclosed environment of a microclimate box. However, care is taken to ensure stable temperatures around the microclimate box, whether it is on display in the gallery or in transport (Wadum et al. 1994). To this end, the research at the CL also showed that maintaining an open air space of 2 cm or more between the microclimate box and the wall increases considerably the stability of temperature within the box (see also Ranacher 1994). Thermally insulated transit crates may maintain a relatively stable temperature inside the microclimate box on long journeys (Fig. 3a–d).

Microclimate boxes that alter the gaseous content

Apart from one very early foray, the use of microclimate boxes with an altered gaseous content has become popular only in the last decade. This new interest arose from the need to reduce the deteriorating effects of oxygen.

The first known attempt to make a microclimate box was in 1892 in England by Simpson, to protect a painting by J. M. W. Turner in the Victoria and Albert Museum (Simpson 1893). The characteristics—tailored to fit the specific painting—of this sealed, airtight box were very similar to a modern microclimate box. Simpson's box was even intended to be fitted into the original gilt frame and hung in the usual manner. The front was composed of glass; the back comprised glass, metal, or other materials. In Simpson's box, nozzles were placed at the bottom for attachment to an exhauster, which could extract air from the box to create a vacuum around the picture.

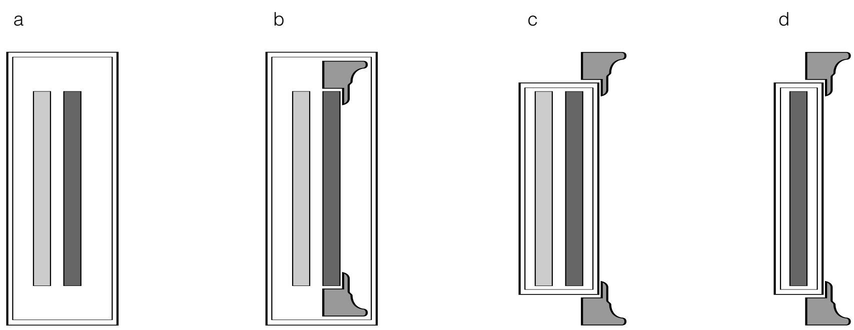

Figure 3a–d
Four main types of microclimate boxes: (a) a box containing a panel and buffer and no framing, (b) a box encapsulating a framed panel and buffer, (c) a framed box containing a panel and buffer, and (d) a framed box containing only a panel.

Simpson concludes his description by asserting that the color of the picture in the box would be hitherto immune to light, sun rays, dampness, or other damaging external influences.[34] Indeed, time has shown that the Turner painting is in excellent condition to this day; until the present, the box has not been opened. Although hardly subject to vacuum for very long, Simpson's box represents the first attempt to create an altered gaseous content around the object enclosed in the microenvironment.

The first inert gas display case was described by Byrne (1984). An effigy figure from Easter Island was placed in a round Plexiglas tube acting as a display case. The ends were sealed with Plexiglas disks fitted to the tube. Silicone rubber served as a gasket. The tube was 20 cm in diameter; its walls were 6.3 mm thick. To avoid the presence of water vapor around the effigy figure, the tube was charged with nitrogen gas to exclude oxygen and moisture. A modified aneroid barometer monitored the pressure within the case and confirmed the presence of a stable charge of nitrogen gas. Four years later the case showed a loss of pressure, so nitrogen gas was added again. A humidity indicator strip was placed in the case, and future recharging with nitrogen was accomplished by first bubbling the gas through a water bath.

The use of Ageless as a means of generating low-oxygen atmospheres for the treatment of insect-infested museum objects is discussed by Gilberg (1990). Ageless is a type of oxygen scavenger that is described by the manufacturer to be a mixture of finely divided moist iron, (ferrous) oxide, and potassium chloride, a combination that rapidly absorbs atmospheric oxygen. The oxygen concentration in a microclimate box can be reduced to less than 0.05% as the introduced Ageless quickly reacts with any oxygen leaks. Ageless can also reduce the oxygen concentration in a closed environment to less than 0.01% and can maintain this level indefinitely, depending on the permeability of the packing material.

Ageless is available in different package sizes that correspond to the amount of oxygen to be scavenged (for example, Ageless Z-200 is capable of absorbing the 200 ml of oxygen contained in 1 l of air). Ageless-Eye is an oxygen indicator in tablet form that changes color in relation to the absence or presence of oxygen. Tests in which insect-infested objects were kept at 30 °C and 60% RH resulted in convincingly stable, low oxygen levels and stable RH.

Ageless is being used to prevent deterioration of rubber, which becomes brittle as a result of ultraviolet light, ozone, and oxygen (Shashoua and Thomson 1991). After some rubber objects in the British Museum, London, were sealed in bags, the oxygen was reduced; an investigation into the deterioration rate of the objects showed positive results.

Further investigations on the uses and reactions of Ageless were undertaken at the Getty Conservation Institute to develop hermetically sealed, inert, gas-filled display and storage cases (Lambert, Daniel, and Preusser 1992).

No matter how well cases are designed and constructed, some air can always enter. If their value as oxygen-free chambers is to continue, the leaking cases must be reflushed with nitrogen or some other inert gas. After the original flush, the oxygen-free life span of the case can be greatly extended by an oxygen scavenger placed in the case. Calculation of the approximate lifetime of a case is obtained by dividing the oxygen-absorbing capacity of Ageless in the case by the leak rate per day.

The Getty Conservation Institute studies were conducted on packets of Ageless-Z in boxes, in which RH-conditioned nitrogen was produced by control of the mixing ratio of dry nitrogen obtained from the cylinder, to humidified nitrogen—the result of dry nitrogen bubbling through water at room temperature (Byrne 1984). The test chamber was initially flushed with nitrogen until the oxygen reached the 1000–9000 ppm range. At this point Ageless was rapidly inserted and the test chamber hermetically sealed. The RH inside the chamber was maintained at 52% with saturated salt solutions (magnesium nitrate). This research showed that Ageless reacts rapidly and thoroughly with oxygen in a sealed case that is filled with an inert gas, and that has an optimal RH above about 50%.

Sealed cases filled with inert gas prevent the oxidation of the objects placed therein. In small flexible containers with little air content, Ageless can perform well in spite of slight warming. It is hazardous, however, to place Ageless in a large rigid case containing air because of the heat produced and also because of the risk of implosion when the oxygen (20% of air) is removed. A sealed case filled with an inert gas should have flexible bellows attached, to compensate for temperature and pressure fluctuations in the museum atmosphere.

A slight color change in cinnabar, litharge, and sienna has been observed on objects in nitrogen-filled sealed cases (Toshiko 1980). There is good evidence, however, that a nitrogen atmosphere retards the fading of watercolors.

The Getty Conservation Institute, as well as Gilberg and Grattan, concluded that Ageless is a rapid and efficient oxygen scavenger (Gilberg and Grattan 1994). Its use in an inert, gas-filled, hermetically sealed display case with a moderate leak rate should maintain the oxygen content at a very low level for several years. An environment with an RH of 53% or above is recommended. Both the level of the oxygen content and the interval after which an Ageless-equipped case will require a replacement and flushing can be readily predicted if the case leakage rate is known.

Measuring Devices

There are many devices for measuring RH; they range from aspiration and sling hygrometers to thermohygrographs, dial hygrometers, cobalt salt strips, and data loggers of various kinds. Thomson and Brown have described the pros and cons for a number of devices, showing how unreliable they can often be, either because of an instrument's poor accuracy or lack of calibration or because of mistakes made by the person manipulating the instrument (Thomson 1981; Brown 1994). Suggestions for the monitoring of showcases include a special built-in sensor with digital readout or a printer (Mayer 1988). A number of small measuring devices have also been used to keep track of activity inside the microclimate boxes.

Diamond placed a small Edney dial hygrometer inside the box, after checking it for accuracy against a sling psychrometer. Diamond's microclimate box covered both picture and frame, so the hygrometer could be placed flat at the bottom of the vitrine, enabling the viewer to monitor the environment from the front of the box (Diamond 1974).

The vitrines used by Rothe and Metro of the J. Paul Getty Museum had been tested with small thermohygrographs from Pastorelli and Rapkin (Rothe and Metro 1985).[35] They were not as accurate as much larger and more sophisticated thermohygrographs but were, in this instance, proved to be reliable, since they provided warning about air leakage. According to Rothe and Metro, the only evident disadvantage is a necessity for frequent monitoring because no printout (that can be read later) is produced.

Paper RH indicators with impregnated bands of cobalt salts change from pink to blue in relation to the ambient RH. This type of indicator has been used by most modern authors, and a thorough investigation into their effectiveness has indeed proved them to be reliable and long lasting (Daniels and Wilthew 1983). A reference color against which to compare the RH values on the strips is recommended.[36] As dial RH measuring instruments have hair, paper, or special plastic sensing elements, they need frequent recalibrating; strips, in contrast, are not altered over time.

Placement of the cobalt strips next to the painting within the vitrine is necessary to obtain an accurate reading. Since this is aesthetically not a very pleasant solution and distracting for spectators, other placements have been explored. The cards have often been placed on the back of the boxes, but microclimate boxes that fit within the frame can only be monitored when the painting is turned, a procedure that requires much time-consuming and unnecessary handling of the object in order to track the changes in the microclimate box.

When daily monitoring of a microclimate box and its painting is not feasible, a continuous record of activity is possible only with small data loggers. Inspired by the National Gallery in Washington, D.C., the Mauritshuis began monitoring the RH and temperature within microclimate boxes using ACR data loggers (Wadum 1992).[37] The small logger was mounted behind the panel on the inside of the backing lid of the microclimate box, with its communication socket in the frame of the vitrine. This method allowed for initialization of the logger inside the box without its being opened. When the painting was traveling, the courier made backups of the logged RH and temperature after arrival at the destination museum.[38] Then, a new interval of logging (typically around three months) was set for the loan period to follow.[39] The courier and the registrar could then evaluate the transit period and eventually arrange for improvements before the return of the painting. These small loggers make it possible to keep a complete record of a specific painting's climatological history, starting from the moment of installation.[40]

Aesthetics

Discussing the aesthetics of microclimate boxes can initiate a heated dialogue between most curators and conservators, as well as among the public. Most people would probably prefer being close to an object of study, without having the feeling of looking into a vitrine. Paintings in vitrines seem remote—the vitrine forms a barrier between the spectator and the artwork.

As previously discussed, microclimate boxes have developed from vitrines hanging on the wall, enclosing painting and frame inside, to small boxes placed behind and within the frame. This evolution clearly reflects the goal of distracting the spectator as minimally as possible. De Guichen and Kabaoglu once made an ironic list of recommendations regarding the optimum manufacture of a showcase (de Guichen and Kabaoglu 1985). Almost all of their "guidelines" could also apply to the microclimate boxes (to wit: one suggestion, to "be sure to display the locking mechanism prominently," reflects the assembling screws or painted backing boards that make a disturbing impression on many a microclimate box).

During the installation of a painting in a microclimate box, dust can become a nerve-racking nuisance ("Avoid sealing the showcase too tightly, because exhibits always look better when covered with a uniform coat of dust," de Guichen notes). Many microclimate boxes on display do show small specks of dust on the inside of the glass, and cleaning them out is impossible without dismantling the whole box, a practice usually acceptable only when the box has returned to the controlled environment of the lending museum.

The protective Perspex or glass is another main issue. Many microclimate boxes recall de Guichen's "helpful" suggestion to "polish the glass of your showcase to a mirror finish." Any glazed painting, particularly a darker one, reflects at certain viewing positions. Perspex has the most reflective qualities; coated and low-reflection glass can reduce the amount of reflection to a minimum. In some instances, detection of the protective glass in front is impossible without specific inspection (Saunders and Reeve 1993).

The small (366 × 257 mm) François Clouet picture that Diamond placed in his microclimate box is aesthetically and physically delicate (Diamond 1974). It has an extremely finely wrought rosewood frame inlaid with silver and mother-of-pearl, "clearly not the sort of thing you just put in a box and screw to the wall," he states. The proportions of the box, as well as the color and texture of its lining, were thus critically considered in the design; ultimately, the museum agreed that the picture actually benefited from its more aesthetic installation, as well as its new, larger presence on the gallery wall.

This particular approach for a small picture has also been used in the display of fragments of altarpieces on gallery walls. These so-called shadow boxes not only serve as buffers but also enhance the object's physical presence.

Rothe and Metro state that microclimate boxes should not be too visually overpowering, since their main function is to protect the painting (Rothe and Metro 1985). Rothe and Metro's Perspex box for the Simone Martini also covered the painting's original, inseparable frame; the box around the Fayums—which, for obvious reasons, do not have frames—could, of course, only be of a showcase type. Here the objects became, in a sense, archaeological fragments; without the microclimate boxes, the visitor would not have the opportunity to view these fragile objects.

With a microclimate box covering both the painting and the frame, the vitrine does not have to be built to fit the panel painting exactly. Rather, it can be made in standard sizes, allowing reuse for another painting at a later date. Disadvantages include the high reflection factor of Plexiglas and the fact that some viewers find the box aesthetically displeasing.

Ramer, however, suggested that to fulfill aesthetic requirements, the microclimate box around his Netherlandish painting should be fitted into the extended rabbet of the picture frame (Ramer 1984). The box in this case "pretends" not to be present, leaving the viewer's attention focused on the painting. Most of the more recent constructors of microclimate boxes (i.e., Cassar, Edmunds, Bosshard, Wadum, Sozzani) included these considerations, preferring small, narrow boxes made to fit behind the frame.

The use of low-reflection glass of low iron content (which takes the green out of normal glass) has limited the amount of disturbance to a minimum.

Conclusion

Encapsulating panel paintings in microclimate boxes in this manner reinforces the protection and care of our cultural heritage, benefits that promote an increased willingness by museums to lend their most vulnerable panel paintings.

It would be wrong, however, to suggest that all problems can be overcome by fitting a panel painting in a microclimate box. More secure microclimate boxes with better seals against leakage have yet to be made. Also, the problem of adequate thermal buffers when a painting is on loan has not, in many instances, been satisfactorily handled. The level of shock or vibration to which a paint film and its carrier are exposed during transit still begs further definition: a better solution to this trauma must be found. Correct acclimatization in historic buildings and museums also requires much more research and attention, if the dimensional movement of painted wood that is displayed or stored is to be stabilized.

Acknowledgments

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Notes

1 Standards for sealed transport cases of wood painted with water-resistant paint, or lined on the inside with a nonpermeable water-resistant membrane, are given by Stolow (1965). The standards include precise volumes for wood and silica gel in the cases.

For maximum thermal insulation, a case should have thick walls, high thermal capacity, small thermal conductivity, and small surface area (Stolow 1967). Stolow gives examples from air transit, in which hulls of planes may reach temperatures of −40 °C, or in which hulls have no pressure correction, and therefore, at low pressure, air escapes the box. Upon a plane's return to earth, air again enters because of the higher pressure, and this air may be of an undesired climatological condition. Therefore, cabin-pressure control and temperature control during air transit are important factors to take into account.

2 Buck concludes that while good moisture barriers may almost completely insulate a panel from short-cycle humidity variations, they may nonetheless be surprisingly ineffective against seasonal cycles. For recent studies on moisture buffers applied on panel paintings, see Brewer 1991.

3 Buck suggests that the larger fluctuations in RH in the United States could be the reason for a tendency to cradle panels more often in the United States than elsewhere (Buck 1962). He further demonstrates that a cradled test panel that was kept in a heated, dry room for several months showed shrinkage of roughly 1.4% in its width, with the members of the cradle sticking out at the sides. Buck invites rheologists to communicate with restorers to learn about the laws that govern the flow and deformation of materials.

4 The addition of hygroscopic material (having the same quick response as gelatin) at the rear of the canvas and the sealing of the reverse by a loose lining would help reduce the rate of response of the glue. Glazing with acrylic and a backboard creates further enclosure for the original object and thus provides protection from unwanted reactions to temperature changes (see Hackney 1990).

5 Investigation of thermal properties of transport cases is important when traveling exhibitions are on the move. During travel, the cases may be exposed to unforeseen temperature conditions, and the use of thermal linings can offer significant protection and permit greater RH stability within the cases (Stolow 1966).

It is also possible to maintain constant moisture content of soft-packed paintings by controlling temperature, provided that the moisture barrier used as a wrapping material (polyethylene) is well sealed (Saunders, Sitwell, and Staniforth 1991).

An early example of polyethylene as a tight wrap for paintings coming from Europe to Canada is recorded by Thomson (1961).

6 When wood and other moisture-containing materials are heated, they give off moisture. At the same time, heated air can hold more moisture; so together the wood and the air reach a new equilibrium. In an empty case of nonabsorbent material such as glass or metal, a rise in temperature will cause a fall of RH, and vice versa. In a case holding a quantity of wood, the situation is reversed: a rise in temperature will cause a rise in RH. When wood gets hotter, it will give up moisture unless the surrounding RH rises. In a closed case, the RH will indeed rise because of the moisture given off by the wood, and the two tendencies will counteract each other. At median humidity, wood contains about twelve times as much moisture as air, volume for volume. Therefore, wood or other cellulosic materials will have the dominant effect on the interior of a small microclimate box.

Thomson showed in practical experiments that a ratio of 120 g wood per 100 l air achieves a constant RH at changing temperatures (Thomson 1964). The change of RH will not exceed about one-third of the temperature change (°C) and will be in the same direction—provided that there is no entry of outside air of a different RH into the case. For ratios greater than 1 kg of wood to 100 l of air, the standard curves for wood equilibrium may be used.

7 Based on the rather dramatic climatological changes occurring in Canada, Stolow demonstrates his findings on different forms of small environments within packing cases (Stolow 1967). It is seen that a sealed case is capable of maintaining a certain level of RH when it contains wood or similar cellulosic materials preconditioned to the desired level. The use of silica gel permits exposure to even greater external temperature changes while it retains the same RH control.

8 The diffusion coefficient of water vapor through air is about 0.24 $cm^2\ sec^{-1}$ (Padfield 1966). This is about twice the coefficient of the other gases found in air. The coefficient for diffusion through wood is about 1.2×10^{-4} cm^2/sec for water vapor, and 0.75×10^{-4} cm^2/sec for carbon dioxide (see Stamm 1964). This means that 1 m^2 of wood allows as much air to diffuse as 3 cm^2 of hole through it, and it leaks water vapor as fast as a 5 cm^2 hole.

9 Weintraub introduces a number of tools for determining which sorbents will be most efficient within a specific RH range (Weintraub 1981). In the 1978 International Council of Museums Conference on Climatology in Museums, there was a general consensus that a sorbent should be temperature independent and have as large a surface area as possible (e.g., powdered silica gel).

10 As a consequence of the many different types of microclimate vitrines being introduced by various authors, Cassar proposed standardization of symbols to be used in classifying the more commonly used types of case construction designs (Cassar 1984).

11 Many woods (especially British and European oak) give off organic acid vapors, which can accumulate and harm many types of objects, including those of metal, marble, materials such as mother-of-pearl and shell, and paper and textiles, in cases where the exchange of air between inside and outside has been reduced to a minimum. All adhesives, adhesive tapes, and sealants used should be tested for stability to ensure that none give off harmful vapors.

12 The choice of the right sorbent is essential and should be considered together with the RH level required for the specific object. Therefore, it is essential to consider the isotherms for the different kinds of sorbents before a decision is made.

13 The RH-control module designed to service a number of display cases is based on a mechanical system combined with a buffering agent such as silica gel (Lafontaine and Michalski 1984). A plastic tubing system distributes the well-conditioned air to a number of display cases, relying on an air exchange in the display cases of a certain amount per day. Air in the display cases equipped with this humidity-control module should be supplied at a rate of at least double the natural leakage. One RH-control module can thus control many display cases. The conditioned air enters the cases through the tubes and leaves again via natural openings that permit leakage. There is no active temperature control—the module passively follows the room temperature. The system, therefore, works only if none of the cases is cooler than the control module.

14 The salts used were hepta- and hexahydrates of zinc sulfate, which are at equilibrium in an atmosphere of 55% RH at a temperature of 15 °C (Curister 1936).

15 Stolow gives as an example a case for which the wood and silica gel are both 1000 g and the RH is kept stable (Stolow 1967). Even a smaller ratio of gel to wood would have a stabilizing effect, buffering the internal RH against temperature changes. If silica gel is used, it should be packed in a way that gives it as large a surface area as possible.

16 The change of RH is somewhat more than a third of the imposed temperature change, and in the same direction as the change (e.g., if the initial RH were 50%, the temperature 20 °C, and the case exposed to 30 °C, the resulting RH would be 53.5% RH; if the case were exposed to a temperature of 10 °C, the final RH would then go to 46.5%).

17 Stolow recommends a silica gel granola, not exceeding 3 mm, spread out thinly over as large a surface as possible. He also advises the use of a dry weight of silica gel at least double the weight of the material to be protected (Stolow 1966). In the box discussed, 450 g of silica gel was used.

18 The *M* value is the "specific moisture reservoir" (moisture gain in g/kg for a 1% rise in RH).

19 Theoretical and experimental research at the Canadian Conservation Institute has shown that if gaps at the top and bottom seams of a case are smaller than 0.3 mm, the leakage rate of the case will be less than two air changes per day (Michalski 1985).

20 Previously the panel underwent conservation treatment as follows: The reverse was covered with Saran F-300 (a copolymer of vinylidene and acrylonitrile, soluble in methyl ethyl ketone) and a layer of glass fabric, in an effort to stabilize the panel. Prior to this treatment, it was noted that there was a dark, water-soluble layer (skin-glue sizing perhaps) between the paint film and the wooden support. Four other Fayum portraits (two painted in encaustic, two in a water-soluble medium) were examined, and it was concluded that the intermediate layer between paint and wood was indeed very hygroscopic. The Saran and glass fabric on the reverse side of the Fayum on loan may have altered the warpage pattern, as the panel developed a pronounced concave configuration.

21 The museum display cases used in the Sainsbury Centre and their exchange of water vapors are being evaluated. The hygrometric half-time is calculated, as is the half-life for water diffusion in the cases. The better sealed the case, the longer the half-life (Brimblecombe and Ramer 1983).

22 A large amount of nitrogen was passed into the case, via the screw hole where the Perspex top was secured. Increasing the concentration of nitrogen acted to deplete the oxygen level to approximately half its normal value. Immediately after the introduction of the nitrogen, a small volume of carbon dioxide was added, which increased the carbon dioxide level of the air in the case to about ten times its normal value. The following day, small samples of gas were extracted and injected into a gas-liquid chromatograph in order that the oxygen and carbon dioxide content might be determined. In this way the gradual loss of carbon dioxide and the invasion of oxygen could be monitored. The half-lives for the exchange of oxygen and carbon dioxide gases with the display case were calculated to be 2.3 and 2.7 days, respectively.

23 The case was designed in collaboration with Helmuth Guenschel, Inc., Baltimore, which actually built the case.

24 Ranacher's concept was based on the microclimate boxes from the Philadelphia Museum of Art (Ranacher 1988).

25 This box was made by the California company of G. F. Wight Conservation, following the principle laid out by Bosshard and Richard.

26 This result is explained by the specific characteristics of Art-Sorb, which according to Bosshard desorbs or absorbs different amounts of humidity depending on temperature. However, contradictory reports by several authors as to the nature of the silica gel or Art-Sorb emphasize its stability despite changes in temperature (Richard 1991).

Richard tested two vitrines of different size: one with an RH of 50%, the other with an RH of 30%. After three months the RH in the small vitrine had decreased to 1%, the large vitrine to only 0.5%. This result proves that the half-time will be around two years for the less sealed of the two. Both tests were made in empty vitrines. It is concluded that the climate would have been even better with the panel inside, as the hygroscopic material would help stabilize the microenvironment. During transit the same benefit was recorded: 16 °C fluctuations in the vehicle but only 2 °C fluctuations in the box. RH fluctuations of 45% were recorded in the vehicle, but only 1% were recorded in the box, as it was kept in a well-insulated transport crate.

27 The box was made as a joint project with the Museum Boymans–van Beuningen, Rotterdam, which had the skilled technical staff required for its production. Nicola Costaras, Luuk Struik

van der Loeff, and Carol Pottasch all contributed to creating this first box, which was designed by André van Lier (Wadum 1992).

28 The safety glass used for the first model was Noviflex; at present the thinner and less-costly Mirogard Protect Magic, Low-Iron, is used.

29 A method later found not advisable (Wadum 1993).

30 ACR data loggers from ACR Systems, Inc., were used. They were typically set at measuring intervals of 30 seconds during transit and at 10 minutes throughout the duration of the loan.

31 See note 25 above.

32 The Peltier effect describes the absorption or emission of heat when an electric current passes across the junction of two dissimilar conductors.

33 The microclimate boxes were initially made by Smit Mobile Equipment B.V., Oud-Beijerland, the Netherlands; they are now produced by the technical staff of the museum, according to the most recent manual.

34 The author is indebted to Susannah Edmunds at the Victoria and Albert Museum for information on this early microclimate box.

35 Pastorelli and Rapkin Ltd., London, was taken over in 1983 by M and T Precision Instruments Ltd., Enfield.

36 The Humidical Corp. type card no. 6203-BB seemed to satisfy most users.

37 The author is indebted to Sarah Fisher, National Gallery of Art, Washington, D.C., for sharing her information on measuring devices.

38 Shock monitoring may also constitute part of the recording of a painting in transit. The most recent literature on this topic can be found in Mecklenburg 1991, in which several authors deal with the subject. The author has had fruitful discussions on this topic with David Saunders of the National Gallery, London.

39 The logging interval during transit would often be 30 seconds; the interval during exhibition would generally be 10 minutes.

40 With regard to the investigation into the performance of humidity sensors, M. Cassar is conducting a comparison of ten different sensors for stability, drift, and long-term performance. This work in progress will provide valuable information for the assessment of measurements obtained by study of artifacts on display or in transit.

Materials and Suppliers

ACR data loggers, ACR Systems Inc., 8561 - 133rd Street, Surrey, British Columbia, Canada V3W 4N8.

Ageless, Ageless Z, Ageless Z-200, Ageless-Eye, Mitsubishi Gas Chemical Co., Mitsubishi Building, 5-2 Marunouchi 2-chome, Chiyoda-ku, Tokyo, 110 Japan. (Different types of Ageless are available depending upon the water activity (WA) of the packaged commodity: AgelessZ WA ≤ 0.85%, Ageless A-200 indicates that 200 ml of oxygen can be absorbed. Ageless-Eye is used as a color-changing oxygen indicator.)

Art-Sorb, Fuji Silysia Chemical Ltd., 6th Floor, YH Hisaya Building, 13-35, 1-Chome, Izumi, Higashi-Ku, Nagoya-Shi, Aichi-Ken, 461 Japan.

Edney dial hygrometer, Edney 2 in dial hygrometer (ref. PH2P), M and T Precision Instruments Ltd., Queensway, Enfield, Middlesex EN3 4SG, U.K.

Grant Squirrel Data Loggers, Grant Instruments Ltd., Barrington, Cambridge CB2 5QZ, U.K.

Humidical Corp. type card no. 6203-BB, Humidical Corp., 465 Mt. Vernon Avenue, P.O. Box 464, Colton, CA 92324.

Kaken Gel, Kaken Pharmaceutical Co. Ltd., 2-28-8 Honkomagome, Bunkyo-ku, Tokyo, Japan.

Lexan, General Electric Plastics, Old Hall Road, Cheshire M33 2HG, U.K.

Mirogard Protect Magic, Low-Iron, Deutsche Spezialglas AG, (DESAG/Schott), Postfach 2032, 31074 Grünenplan, Germany.

Nikka pellets, Nippon Kasseihakudo Co. Ltd. (Nippon Activated Clay Co. Ltd.), 7th Floor, Daisan-Azuma Bldg., 1, Kandahirakawacho, Chiyoda-ku, Tokyo, 110 Japan.

Saran F-300, Dow Plastics, 2020 Willard Dow Center, Midland, MI 48674.

Squirrel, Eltek Ltd., 35 Barton Road, Haslingfield, Cambridge CB3 7LL, U.K.

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Technical Considerations for the Transport of Panel Paintings

Mervin Richard, Marion Mecklenburg, and Charles S. Tumosa

Over the years, panel paintings have suffered damage from a wide range of causes—accidents, natural catastrophes, improper handling, dramatic environmental changes, and misguided conservation treatments. Once damaged, panel paintings can be difficult to repair. Due to this risk, many museum professionals and collectors are hesitant to transport panels unless absolutely necessary. Some institutions have even adopted policies that forbid their loan. In the United States, panel paintings are not indemnified by the Arts and Artifacts Indemnity program, a government program that provides insurance for international exhibitions designated as being in the national interest.

Indeed, some paintings on wood supports are very fragile and should not be transported or loaned to other institutions. Even the most ideal packing case cannot protect a painting in very poor condition. Many panel paintings are very stable, however, and can be safely packed and transported.

A thorough technical examination of panel paintings considered for loan is probably the most crucial aspect of the loan process. This examination is especially useful if condition and treatment records have been maintained for many years. Paintings that have recurring problems such as flaking paint are poor candidates for loans, unless the cause of the insecurity of the paint is clearly understood and controllable.

There are four environmental conditions that should be considered when evaluating any painting for possible loan: relative humidity (RH), temperature, shock, and vibration. The overall safety of a painting during transit is gauged by any expected response to these conditions; this response must then be evaluated in terms of what the painting will be able to withstand and what protection the proposed transport is able to provide. For example, a very fragile painting might suffer impact poorly, and no packing condition would be able to provide the protection needed to ensure safe transport. If this is the particular case, transport of the painting is not recommended. However, if the painting can sustain moderate fluctuations in RH and temperature (factors easily controlled during transport), and the panel can safely resist the anticipated levels of shock and vibration, then the panel is a more likely candidate for loan.

There are several things to consider about the painting itself when contemplating a possible loan, including the following: the size of the painting, its materials and construction, the condition of the design (paint and ground) layers, and the condition of the wood supports. Small paintings usually present fewer difficulties than large paintings, since they are lightweight, easily moved, and frequently made of a single piece of wood. Large panels are heavier and more subject to bending moments during handling operations, because of their own weight and width. Bending or flexing can also result from impact and vibration, which will increase the stress throughout the panel and have particularly adverse effects on poorly glued joints and existing cracks in the wood.

Considerable anecdotal evidence shows that some panels have been exposed to extensive environmental fluctuations for years without apparent damage, while others subjected to similar conditions have suffered. Some paintings have remained stable for centuries, probably only because their environment has also remained relatively stable. If subjected to a different environment, the same paintings might rapidly develop problems.

Until recently, the only way to verify and observe this effect was to change the environment to see what occurs. Obviously, this test can prove destructive: damage has been reported when paintings have been moved from relatively damp churches to drier and better-controlled environments in museums or private homes. Similar problems also have developed when central heating systems without humidification have been installed in buildings that were normally cold and damp. These reports have led institutions to become cautious when considering the advisability of lending a panel painting. Lenders to exhibitions frequently require that borrowers maintain environmental RH levels closely matching the conditions where their paintings are exhibited.

Battens or cradles have often been added to the reverse of panels, either to reinforce the panels or to reduce warping. Usually such restoration treatments have limited success and often lead to additional problems, since these devices tend to restrain RH- and temperature-related movement in the cross-grain direction of the panel. This restraint can lead to excessive stresses (either compressive or tensile) if the RH or temperature significantly deviates from the conditions present when the battens or cradle were applied.

The issue, then, lies in assessing the effects of changes in temperature and RH, as well as the events of impact and vibration on panel paintings, and recognizing the limitations of controlling these factors during transport. The typically short duration of transport usually precludes chemical damage to paintings, but occasionally biological problems, such as mold growth, arise. For the most part, determining the risks inherent to the transport of a panel painting is an engineering problem that requires a knowledge of the mechanics of artists' materials. This particular discipline is an important part of the authors' current research, and a summary of materials' behavior is a significant focus of this article.

RH and Moisture Content

All the materials typically found in panel paintings are hygroscopic; they adsorb water when the RH increases and desorb water when the RH decreases. These materials include the wood supports, hide glues, gesso and paint layers, and varnishes. When these materials are unrestrained, changes in their moisture content result in expansion and contraction. It should be noted that panel materials respond differently to the gain and loss of water vapor. Oil paints and gessoes show relatively little dimensional response to moisture, for example, as compared to pure hide glue or to wood cut in the tangential direction. Wood cut in the radial direction shows about one-half of the dimensional response of wood cut in the tangential direction (U.S. Department of Agriculture 1987). The dimensional response of wood in the parallel-to-grain direction is 0.05–0.08% of that in the tangential direction. In the tangential direction, some woods (e.g., cottonwood [*Populus* spp.] and white oak [*Quercus* spp.]) can swell as much as 7% when subjected to changes from 5% to 95% RH. Other woods (e.g., spruce [*Picea* spp.] and mahogany [*Swietenia macrophylla* sp.]) swell only 3.5% under similar conditions. The rate of dimensional change with respect to RH is usually called the *moisture coefficient of expansion* and is cited in units of strain per percentage RH (mm/mm/% RH). It is of critical importance to recognize that free-swelling dimensional changes are stress-free strains. It is only when under restraint that hygroscopic materials subjected to RH changes develop stress-associated strains. These are called mechanical strains, in the truest sense of the word.

A coefficient of expansion is often considered to be a constant; however, the moisture coefficients for these materials are not only variable but highly nonlinear as well. In Figure 1, the moisture coefficients for four materials are plotted versus RH. These materials are a fifteen-year-old flake white oil paint, gesso with a pigment volume concentration of 81.6%, hide glue, and a sample of white oak in the tangential direction. In this plot, the longitudinal direction of the white oak (or of any wood) would factor almost along the zero line. In Figure 1 all of the materials have very low rates of dimensional response with respect to RH in the 40–60% range. Outside this range the wood and glue show dramatic increases in the rate of dimensional response with respect to RH, and there is a significant deviation of the wood and glue responses in relation to the paint and gesso responses. This mismatch in the coefficients is indicative of the source of most of the problems associated with environmental changes. Wood in the longitudinal direction responds much less to the environment than do the paint and gesso, which essentially means that different responses are occurring to the painting's layers in the two perpendicular directions of the panel. The responses of the materials to RH can be studied either alone or as part of a composite construction.

A material that is allowed to expand and contract freely can be repeatedly subjected to a fairly wide RH range without damage. In addition, woods (e.g., white oak) show a dramatic hysteresis when the unrestrained dimensional response is measured over a very large range of humidity. The increasing RH path tends to stay lower than the decreasing RH path; therefore, if the measurements are taken at 25–75% RH, the increasing and decreasing paths are almost the same.

A structural problem arises when either full or partial restraint is present. This restraint can result from defects such as knots in the wood, cross-grain construction (often found in furniture), or battens that are attached to the reverse of a panel. If battens and cradles restrict the dimensional movement of the wood, stresses and strains develop perpendicular to the grain with changes in RH. Internal restraint can develop when the outer layers of a massive material respond more quickly than the interior layer.

Research has shown that there are reversible levels of stress and strain. In the case of a fully restrained material (white oak in the tangential direction, for example), some changes in RH can occur without ill effect to the wood (Mecklenburg, Tumosa, and Erhardt 1998). Organic materials (i.e., wood, paints, glue, gesso) have *yield points,* which are levels of strain below full reversibility and above permanent deformation. Measured by an axial mechanical test, the initial yield points for woods, paints, and glues are approximately 0.004. These materials can, however, harden under strain, a process that creates substantial increases in their yield points. For a brittle gesso found in a traditional panel painting, the yield point is approximately 0.0025. If gessoes are richer in glue, both their yield points and their strains at failure increase significantly. The magnitudes of yield points do not appear to be appreciably affected by RH, but generally the strains to breaking will increase parallel to increases in RH. Finally, RH- and temperature-related events are biaxial and triaxial events. This means that yielding can occur at significantly higher strain levels than axial testing would indicate. In this article, the lowest axially measured strain level of 0.004 will be used for all materials except gesso, which yields at 0.0025. These yield points will be used to determine the maximum allowable RH fluctuations in panels. This approach is a fairly conservative one to assessing the effects of RH and temperature on panel paintings, and it should be considered accordingly. It also should be noted here that while materials yield at strains of 0.004 or greater between 35% and 65% RH, strains of 0.009 or greater are necessary to cause failure. The strains at failure in seriously degraded materials are often lower because the process of degradation usually reduces strength. When the magnitude of the failure strains approaches that of the yield strains, the materials of the panel painting are considered fragile and probably difficult to handle, as they will break in an elastic region rather than plastically deform.

Response of restrained wood to RH: Tangential direction

Research has shown that the moisture coefficient of a material can be used to calculate the RH change required to induce both yielding and failure strains in a restrained material (Mecklenburg, Tumosa, and McCormick-Goodhart 1995). Equation 1 shows how these mechanical strains can be calculated as a function of RH. Using this equation, the strain change ($\Delta\Sigma$) for any RH change can be calculated by integrating from one RH point to another as

$$\Delta\Sigma = \int \partial \, d\mathrm{RH} \qquad (1)$$

where: $\partial = d\Sigma / d\mathrm{RH}$, the moisture coefficient of expansion.

The yield point for white oak is about 0.004 at all RH levels, and its breaking strains increase with increasing RH. These strain values are shown in Figure 2. The failure strains are small at a low RH and increase dramatically as RH increases.

With the information from Figures 1 and 2 and Equation 1, it is possible to develop a picture of the effects of RH on the strains of white oak fully restrained in the tangential direction. This is a hypothetical example of the worst condition possible; fortunately, few objects in collections are actually fully restrained. The plotted results of calculations made using Equation 1 are shown in Figure 3. In this plot, the calculated results show what would occur if white oak in the tangential direction were restrained at 50% RH, then subjected to RH changes. A decrease to approximately 33% RH would result in tensile yielding of the wood. Further decreasing, to 21% RH, could cause the wood to crack. Increasing the RH from 50% to approximately 64% would cause the wood to begin

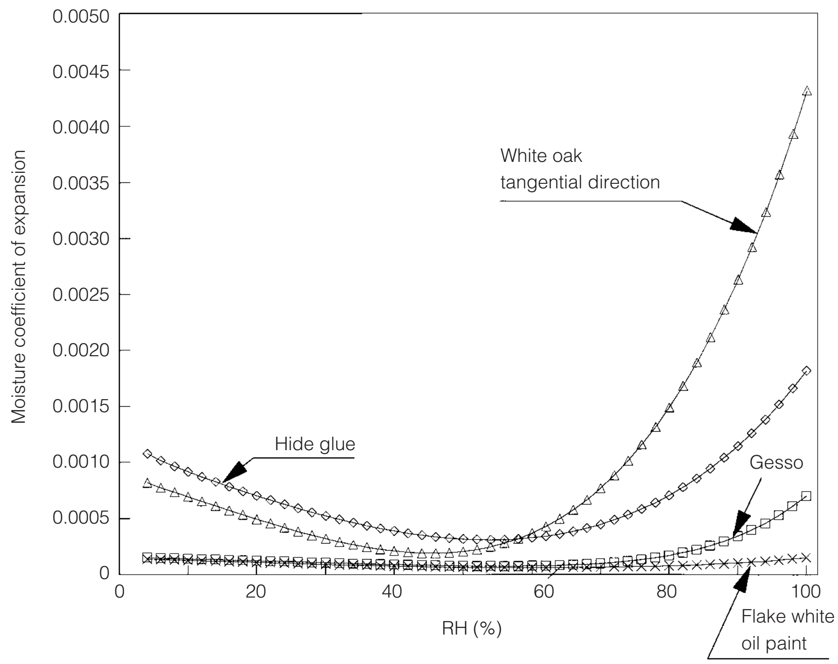


Figure 1
Moisture coefficients of expansion versus RH for four materials: white oak in the tangential direction, hide glue, gesso, and fifteen-year-old flake white oil paint. The radial-direction coefficient for white oak is approximately one-half of the tangential, and the longitudinal-direction coefficient is about one-tenth of the tangential. The swelling rate is the lowest in the midrange RH levels.

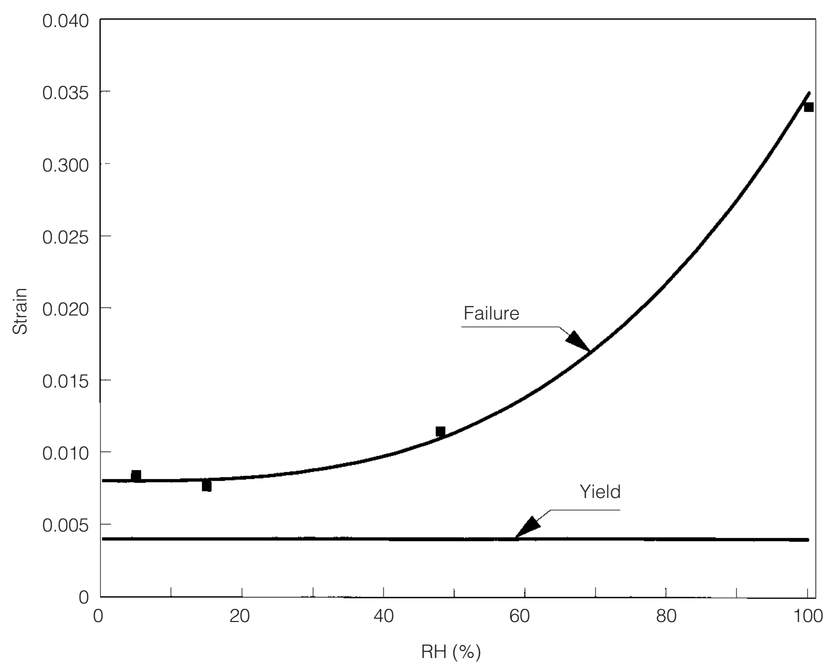


Figure 2
Measured yield and breaking strains of tangential-direction white oak versus RH (axial tensile test).

compression yielding. As long as the RH remains between approximately 33% and 64%, the wood can respond dimensionally without its structure being altered. However, if the RH increases above approximately 64%, *compression set* may occur, which is a permanent deformation of the wood. Compression set also re-initializes the wood to a new, higher RH environment, causing the wood to behave like one acclimated to a higher RH.

The plots in Figure 4 were obtained by recalculating Equation 1 for the fully restrained white oak panel, now acclimated to 70% RH (the circumstances under which the panel acclimated to a higher ambient RH are irrelevant—it does not matter whether the painting has always been maintained at 70% or whether it was temporarily stored in a damp location).

Figure 3
Calculated reversible RH range of fully restrained, tangentially cut white oak versus ambient RH. A yield value of 0.004 was used as the limiting criterion in both tension and compression. The values of the dotted lines are for stress-free wood that has been fully equilibrated to 50% RH.

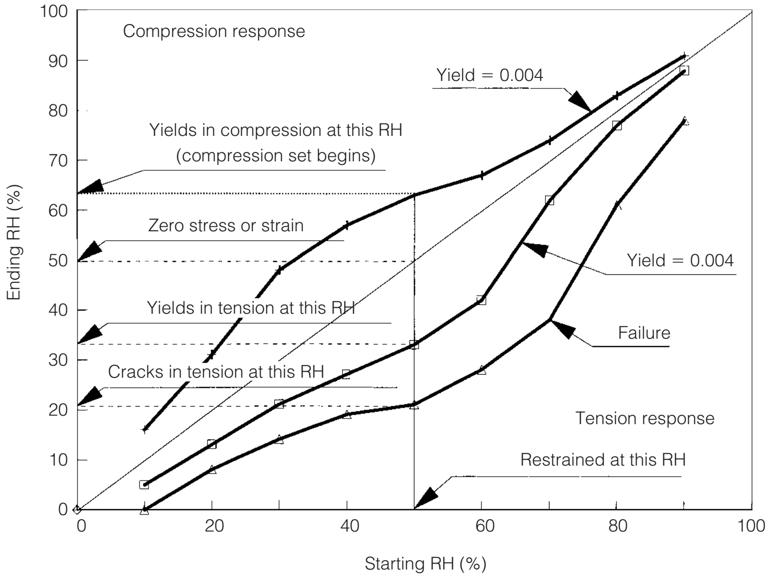
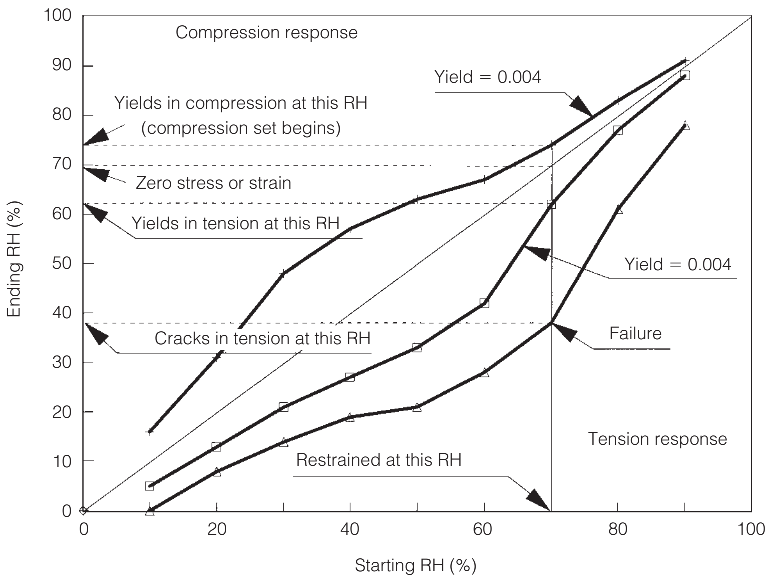


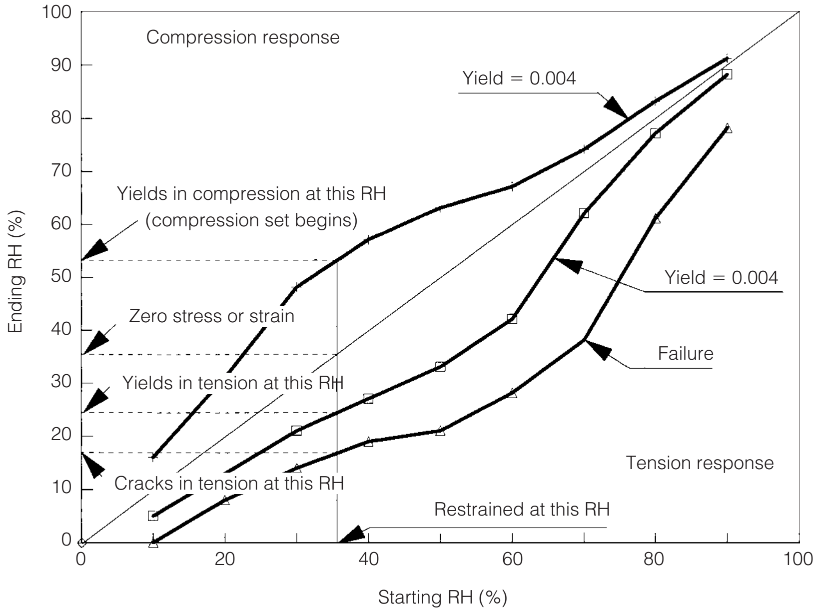
Figure 4
Calculated reversible RH range of fully restrained, tangentially cut white oak versus ambient RH. A yield value of 0.004 was used as the limiting criterion in both tension and compression. The wood has been fully equilibrated to 70% RH. The allowable RH range has been severely reduced in comparison to wood equilibrated to 50% RH.



A problem becomes apparent when desiccation of the panel is attempted. A drop from 70% to 62% RH causes tensile yielding, and a drop to approximately 38% RH can cause cracking of the wood. Increasing the RH to approximately 74% induces yielding in compression. The panel cannot tolerate the much larger variations in RH that are possible with a panel equilibrated to 50% RH, as seen in Figure 3. This narrow range of RH must be considered when evaluating the risks of lending panel paintings acclimated to high RH.

In the past, some panels have been treated with water or large amounts of water vapor in an attempt to flatten them. Battens or cradles

Figure 5
Calculated reversible RH range of fully restrained, tangentially cut white oak versus ambient RH. A yield value of 0.004 was used as the limiting criterion in both tension and compression. The wood has been fully equilibrated to 36% RH. The allowable RH range is still fairly broad, but it has been shifted to lower values.



were often attached to the reverse while a panel was still wet. The effect of this treatment was to restrain the panel while it was still acclimated at an extremely high RH. As the panel dries, the adhesive hardens, and the point of full restraint could easily have a moisture content equivalent to acclimation of the wood at 75% RH. If this is the case, this panel will yield in tension at around 68% RH and could quite possibly crack at approximately 45% RH. If a restrained panel were to be subjected to a flood (such as occurred in Florence in 1966), the simple act of drying would be almost certain to cause wood-support damage unless all of the restraint were removed before drying.

Figure 5 shows the results of RH fluctuations on a typical white oak panel restrained and equilibrated at 36% RH. In this case the panel will yield in compression at approximately 53% RH and in tension at 25% RH. The effect is to simply ensure that the reversible environment for the painting support panels is changed to a lower RH.

For comparison purposes, the moisture coefficient of expansion for a 100-year-old white oak sample was measured in the tangential direction. This measurement allows for a comparison of the strain development in new and aged oak. Figure 6 shows that when the same yield criterion (0.004) is used, the 100-year-old oak appears to be able to sustain slightly greater RH variations, particularly at the extreme ranges of the RH spectrum. Many other woods used as painting supports have less dimensional response to moisture than white oak, so their allowable fluctuations will be significantly greater, even in the tangential grain direction.

Response of restrained wood to RH: Radial direction

The moisture coefficient of expansion in the radial direction is about one-half that of the tangential direction. If a wood panel support is made so that the two primary directions of the wood are longitudinal and radial, the panel can sustain significantly greater variations in humidity than if a primary direction were tangential. Figure 7 shows a comparison of the

Figure 6
Calculated reversible RH range of fully restrained, new, tangentially cut white oak versus ambient RH, compared to 100-year-old oak. A yield value of 0.004 was used as the limiting criterion in both tension and compression. It is assumed that the wood has been fully equilibrated to 50% RH.

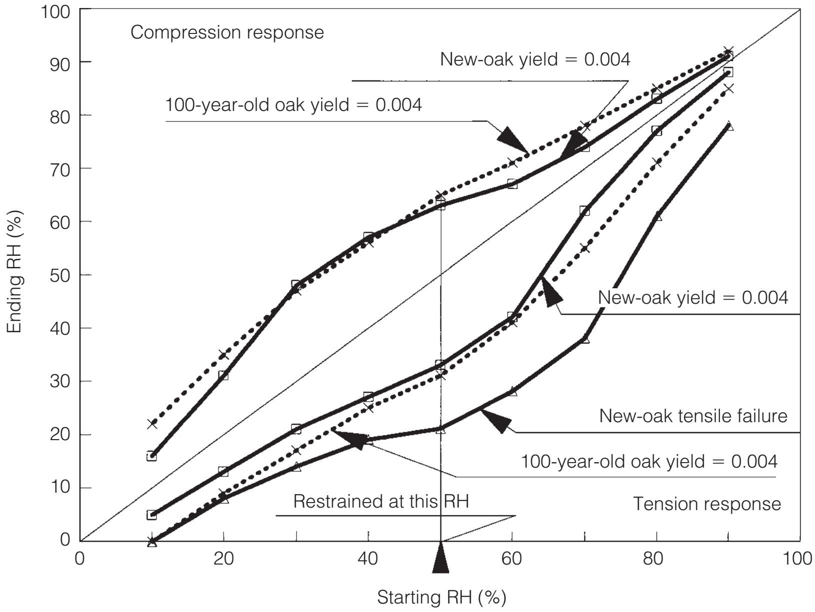
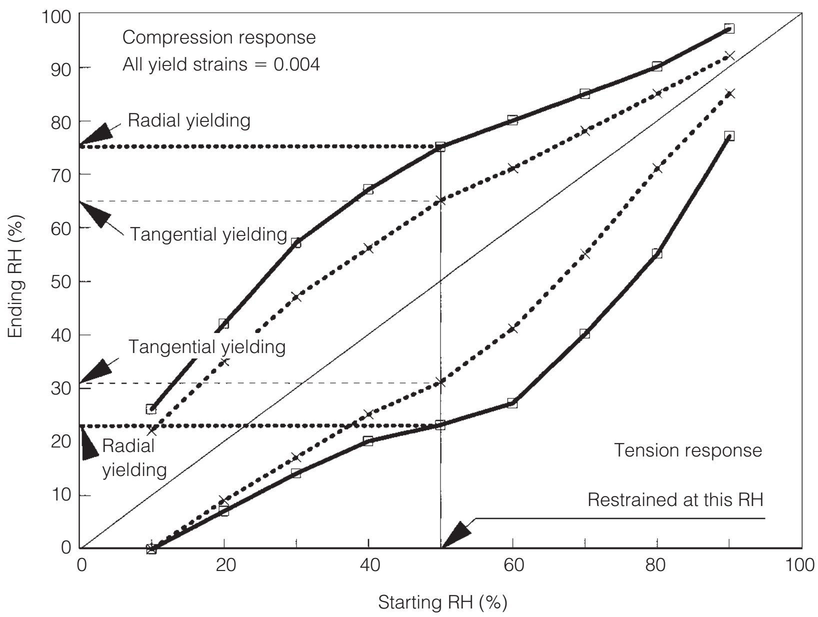


Figure 7
Calculated reversible RH range of fully restrained, 100-year-old, radially cut white oak versus ambient RH, compared to 100-year-old tangentially cut oak. A yield value of 0.004 was used as the limiting criterion in both tension and compression. It is assumed that the wood has been fully equilibrated to 50% RH. The significant increase of allowable RH in the radial direction demonstrates the advantages of preparing panel supports in that direction.



calculated RH changes required to reach yield in both the radial and tangential directions for 100-year-old white oak. If it is assumed that the panels had been restrained at 50% RH, the RH change required to cause yielding in tension is a decrease to 31% in the tangential direction and to 23% in the radial direction. An increase in RH to 65% would cause compressive yielding in the tangential direction; an increase in RH to 75% would cause compressive yielding in the radial direction. Because of its substantial increase in the allowable changes in RH, radial cutting is an important consideration for woods that are to be acclimated and restrained at high RH. In Figure 8 the restrained panels are shown as equilibrated to 70% RH. In the radial direction the wood would be capable of sustaining a drop to

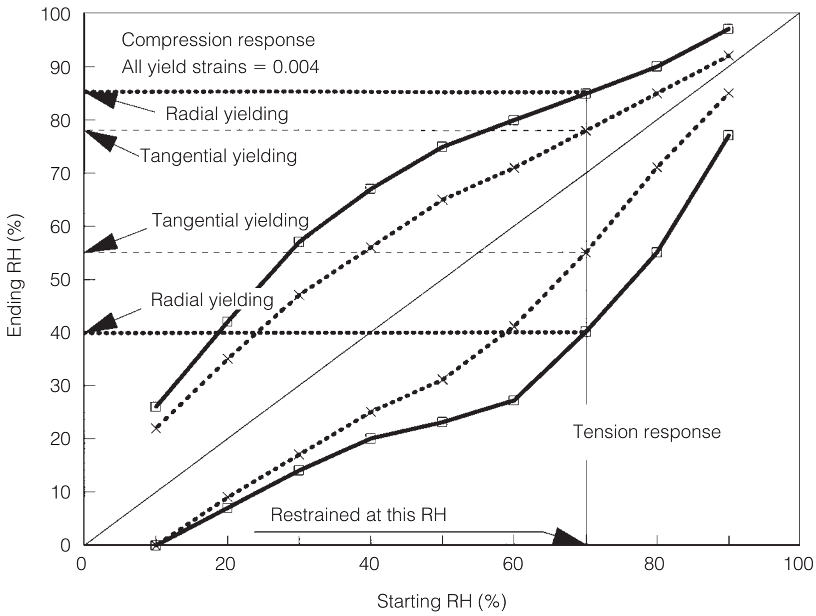


Figure 8
Calculated reversible RH range of fully restrained, 100-year-old, radially cut white oak versus ambient RH, compared to 100-year-old tangentially cut oak. A yield value of 0.004 was used as the limiting criterion in both tension and compression. It is assumed that the wood has been fully equilibrated to 70% RH. The significant increase of allowable RH in the radial direction demonstrates the advantages of preparing panel supports in that direction. This consideration is particularly important in the case of panels equilibrated to high RH levels.

40% RH before yielding in tension, and capable of sustaining an increase to 86% RH before compression set begins. In the tangential direction, the panel is restricted to a range of 55–79% RH. The implications of these results are clear: panels cut in the tangential direction present a significantly greater risk of movement, particularly if acclimated to a high RH. In contrast, restrained panels cut in the radial direction are low risk, even if they have been acclimated to 70% RH.

The above examples help illustrate the response of wood to RH. Knowledge of the history, wood type, treatment record, and grain orientation of a panel painting is highly useful in helping to determine its potential risk from changes in RH and its subsequent potential for safe travel. This study used the extremes of conservative yield criteria and assumptions of worst-case full restraint.

Response of the design layers to RH

Until now, only the wooden panel has been discussed. However, it is also important to examine other components of the panel, such as gesso and oil paint layers. Since paint and gesso have very similar dimensional responses to changes in RH over most of the RH range, similar effects will occur when these layers are considered as coatings on panels that are both restrained and unrestrained (i.e., without battens, cradles, or framing techniques).

The primary difference between the two materials is that paint will be assumed to yield at a strain of 0.004 and gesso at a strain of about 0.0025. Therefore, while gesso and paint do have similar dimensional responses to changes in RH, the gesso will yield sooner to those changes than will the paint. As was seen with the wood, once paint or gesso is beyond the yield point, nonreversible strains occur. Depending on the environment to which the panel is acclimated, damage can be anticipated if the equilibrated RH deviations are well in excess of those causing yielding. Since not all paintings have gesso layers, the following comments will distinguish between the effect of RH on panels having both gesso and paint layers and the effect on panels having paint directly applied to the wood.

Unrestrained wooden panels in the tangential direction exhibit substantial dimensional fluctuations with RH changes. If the swelling coefficients of expansion of all materials applied to the wood panel are the same as those of the wood, then RH variations will induce no stresses in the attached layers. If the swelling coefficients differ, mechanical stresses and strains will develop as a result of RH changes. For example, in the longitudinal direction of a panel painting, the wood is minimally responsive to RH. The paint and gesso coatings are responsive, but the wood restrains these layers from shrinking and swelling with changes in RH. In the tangential direction, however, the wood is much more responsive to RH variations than the gesso or paint. The responsiveness of the wood also creates stresses and strains in the design layers. In effect, the wood is overriding the response of the design layers.

The mechanical strains in the paint and gesso layers can be calculated using Equation 2. This equation can be used for any material applied to any substrate, provided the substrate is substantially thicker than the applied layers. (To check this equation, assume that the coefficient of expansion for the substrate is zero; Equation 2 would then simplify to Equation 1.) Equation 2 is

$$\Delta\Sigma_p = [(1 - \int\alpha_s \, d\text{RH}) - (1 - \int\alpha_p \, d\text{RH})]/(1 - \int\alpha_s \, d\text{RH}) \qquad (2)$$

where: α_s is the swelling coefficient of the substrate, which is thick relative to any attached layers; and α_p is the swelling coefficient of the coatings, either flake white paint or gesso. In our examples white oak is the substrate.

Response of the design layers to RH: Panels cut in the tangential direction

In Figure 9 the calculated mechanical strains for flake white oil paint and gesso (calcium carbonate and hide glue) on an unrestrained white oak panel are plotted versus RH. The paint, gesso, and wooden support panel are considered to be equilibrated to 50% RH, with initial stresses and strains of zero. The strains are plotted versus RH in both the tangential and longitudinal directions of the wooden panel support. In the longitudinal direction, the wood acts as a full restraint to the applied coatings (paint and gesso), and strains remain low over most of the RH range. The oil paint and gesso are minimally responsive to moisture—for the paint, the plot shows that it is possible to desiccate from 50% to 8% RH before tensile yielding occurs. Compressive yielding in the paint occurs when the RH is raised from 50% to approximately 95% (note that the paint is yielding, not breaking). However, in the gesso (which yields at a lower strain), the range for acceptable RH is narrower. In this case, tensile yielding will occur at approximately 19% RH, and compressive yielding at approximately 83% RH. This indicates that fairly large RH variations can occur without yield in the design layer. However, it is well known that cracks do develop perpendicular to the grain of the wood, indicating that the stresses and strains are parallel to the grain. This study shows that these cracks do not usually occur as a result of moderate RH changes. Drops in temperature are more likely to cause these types of cracks, as will be discussed below.

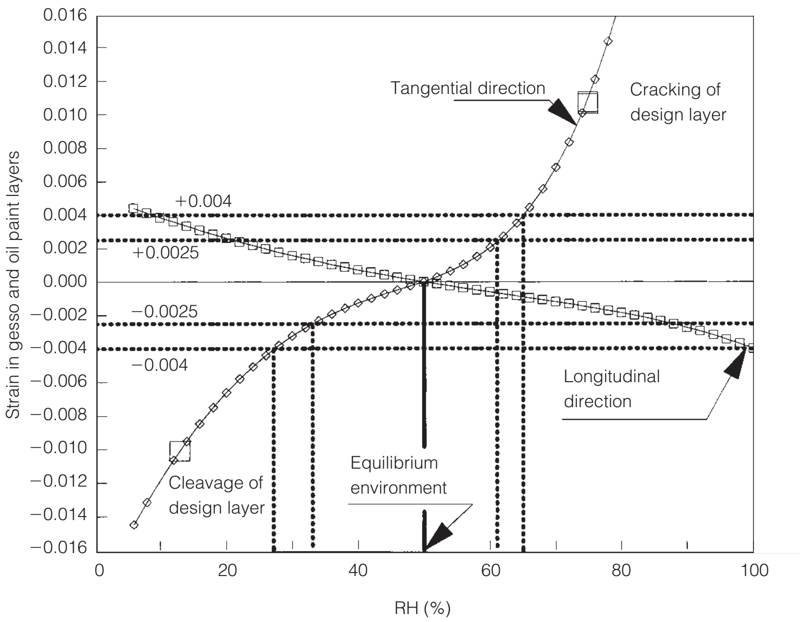


Figure 9
Calculated strains in gesso and flake white oil paint applied to an unrestrained, tangentially cut white oak panel versus RH. The panel painting is assumed to be equilibrated to 50% RH. Both the gesso and paint have fairly large allowable RH fluctuations, even in the tangential direction of the wood.

As it responds to the moisture changes, the wooden substrate significantly affects the mechanical strains in both the paint and the gesso layers. The strains of the design layers actually become compressive with desiccation, because the wood shrinks at a greater rate than either the paint or gesso—the gesso yields at 33% RH, and the paint yields at 27% RH. Further desiccation from the yield points causes permanent deformation in both layers. If the desiccation continues below 15% RH and the gesso ground is not firmly attached, crushing may occur, and cleavage ridges will develop parallel to the grain.

Raising the RH above 50% causes a different problem. At approximately 62% RH, the gesso begins to yield in tension; at about 65% RH, the paint begins to yield in tension. At about 75% RH or above, strains in the design layer can be high enough to induce cracking in a brittle gesso layer. This cracking of the gesso can subsequently crack the paint film applied above it. These cracks appear parallel to the grain of the wooden support panel. If no gesso layer is present, paint cracking would not begin until well above 85% RH.

Diagrams similar to that in Figure 9 demonstrate the response of gesso and paint layers attached to the panel when they are equilibrated to RH levels other than 50%. Figure 10 shows the calculated resulting strains developed in the paint and gesso when the panel painting has been equilibrated to 64% RH. Tensile yielding in the paint now occurs at about 43% RH (higher than when the painting was acclimated to 50% RH). At 53% RH the gesso yields in tension. A 14% variation (50–64% RH) in the equilibrium environment will have a major effect on the dimensional response of the panel. This panel is to some degree restricted to a narrower and higher environment, as compared to a panel equilibrated to 50% RH. If, however, the equilibrium environment is higher (e.g., about 70%), greater differences will occur in the response of the panel to the environment. This is illustrated in Figure 11, which shows the calculated strains of the design layers applied to a panel equilibrated to 70% RH. Under the condi-

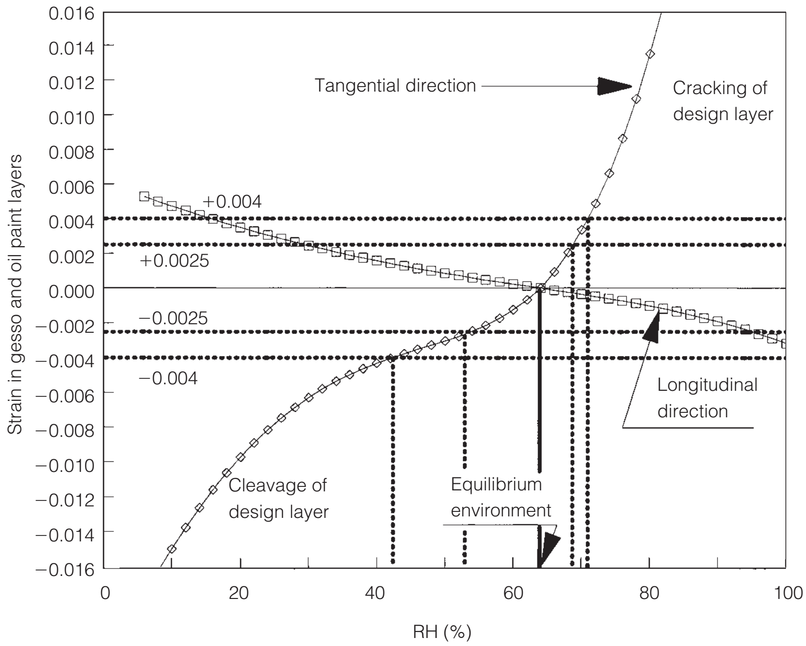


Figure 10
Calculated strains in gesso and flake white oil paint applied to an unrestrained, tangentially cut white oak panel versus RH. The panel painting is assumed to be equilibrated to 64% RH. The paint still has a fairly large allowable RH fluctuation, even on the tangentially cut wood, but the gesso is now confined to a more restricted RH range.

tions in this example, the gesso layer will yield with a drop in RH from 70% to 64%, and the paint will yield when the RH drops to 60%. Crushing or cleavage of the design layer could occur at about 35% RH if the gesso ground is not sound. A panel equilibrated to a high level of RH will suffer some permanent deformation if subjected to the well-controlled environments found in many institutions. In addition, a smaller increase in RH, (6–8%), is needed to cause tensile yielding when compared to a panel equilibrated to 50% RH.

How realistic is the example above? At such a high RH level, there is a strong potential for biological attack that should be observed and noted. For a panel's RH to equilibrate to a high annual mean, RH levels during the more humid periods of the year must also be high. Evidence of

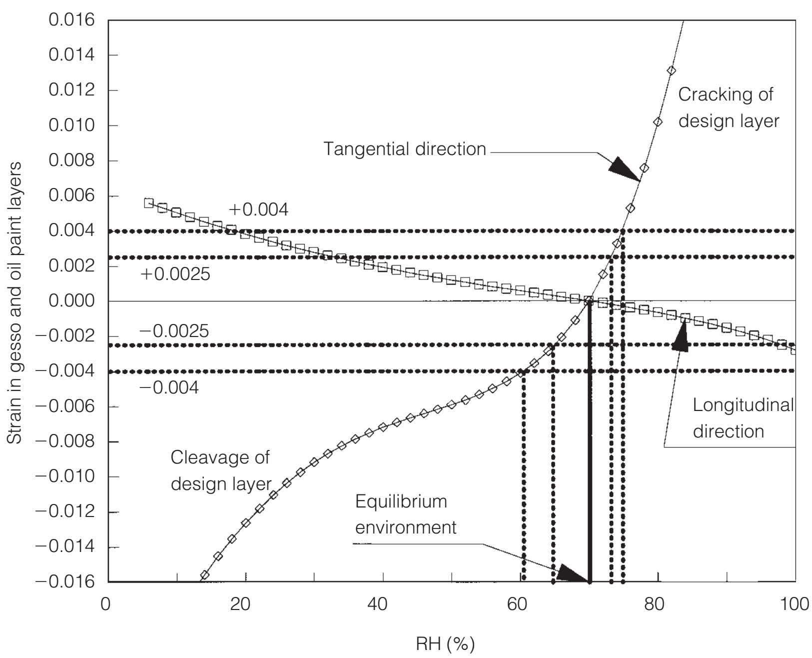


Figure 11
Calculated strains in gesso and flake white oil paint applied to an unrestrained, tangentially cut white oak panel versus RH. The panel painting is assumed to be equilibrated to 70% RH. Both the gesso and paint are now confined to a very restricted RH range in the tangential direction. This painting would be at serious risk if subjected to low RH levels.

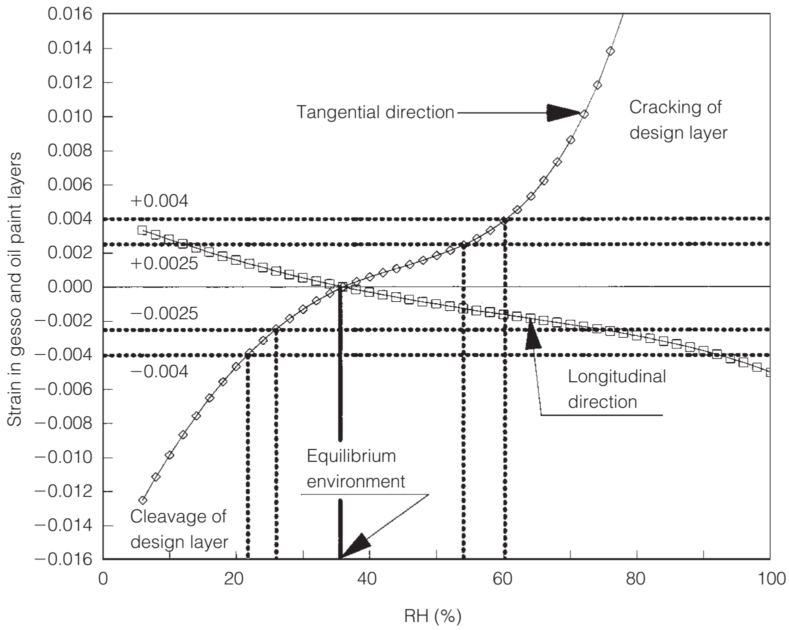


Figure 12
Calculated strains in gesso and flake white oil paint applied to an unrestrained, tangentially cut white oak panel versus RH. The panel painting is assumed to be equilibrated to 36% RH. Both the gesso and paint have large allowable fluctuations of RH, even in the tangential direction. This painting would not be at risk unless it were subjected to RH levels above 55%.

mold damage could be an important indication that a panel painting may have equilibrated to an excessively high humidity and therefore is a less-than-suitable candidate for shipment.

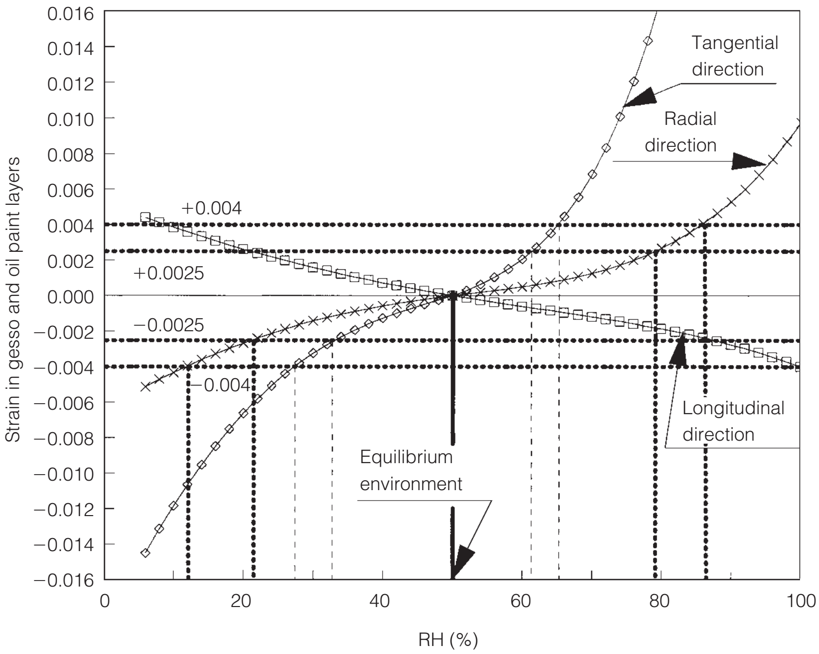
If a panel painting has equilibrated to an environment lower than 50%, the RH changes needed to cause yielding are not significantly affected. Figure 12 shows the calculated results for a painting equilibrated to 36% (rather than 50%) RH. Note that with a 14% downward shift in the equilibrium environment, only about a 6% downward shift in the RH is necessary to attain compressive yielding in both the gesso and the paint layers. The panel painting equilibrated to this low-RH environment can still sustain significant deviations in the mid-RH range without yielding. In addition, the painting has to drop to 26% RH for yielding in the gesso to occur, and to 22% RH for yielding in the paint to occur.

Response of the design layers to RH: Panels cut in the radial direction

Paintings executed on radially cut wooden panels are at reduced risk during transport, and the layers applied to such panels are far less likely to suffer RH-related damage. Figure 13 illustrates the different responses of the design layer to the unrestrained movement of white oak. In the longitudinal direction, there is little difference between tangentially and radially prepared panels, and the strains in the gesso and paint layers are similar to those shown in Figure 9. (As before, the assumed yield strains are 0.004 for the paint and 0.0025 for the gesso.)

In a panel cut in the radial direction and acclimated to 50% RH, gesso shows compressive yielding at 22% and shows tensile yielding at 79%. In a panel cut in the tangential direction, the gesso shows compressive yielding at 33% RH and tensile yielding at 63% RH. If there is no gesso layer, the paint film attains compressive yielding at 13% RH and tensile yielding at 86% RH. These RH values are not substantially reduced from the RH yield points of the paint in the longitudinal direction. The

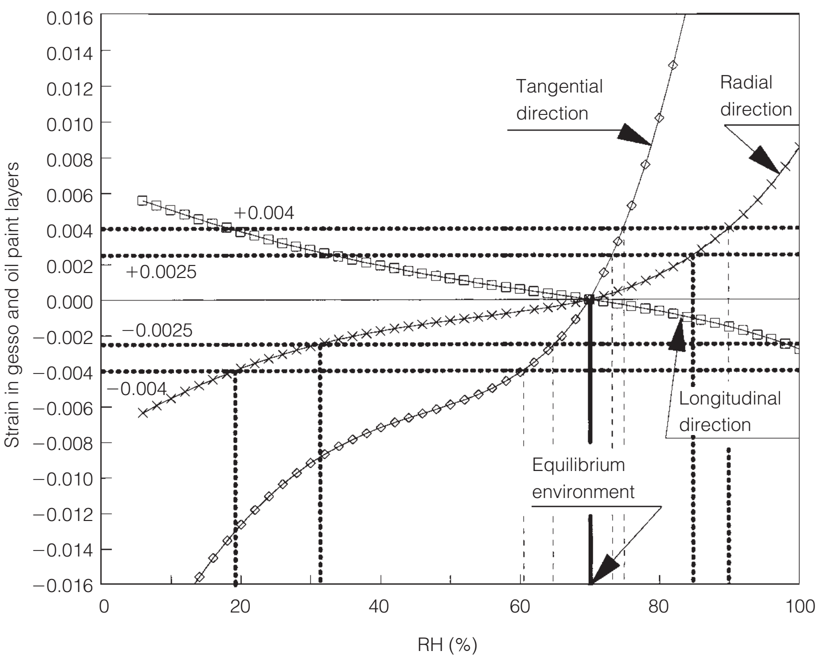
Figure 13
Calculated strains in gesso and flake white oil paint applied to unrestrained, radially and tangentially cut white oak panels versus RH. The panel paintings are assumed to be equilibrated to 50% RH. Both the gesso and paint have large allowable fluctuations of RH, even in the tangential direction, but the radial direction shows a significant increase in the allowable fluctuations over the tangential cut.



difference is that with desiccation, the paint and gesso experience compression in the cross-grain direction and tension in the longitudinal direction, while increases in humidity induce the opposite reaction. Both the wood and the design layers are more stable on a radially cut panel.

Of significant interest is the response of the design layers that have been applied to radially cut oak and equilibrated to a high RH. In Figure 14, the calculated strains in the paint and gesso layers applied to radially cut oak and equilibrated to 70% RH are given. When desiccation occurs, compressive yielding occurs in the gesso at 32% RH and in the paint at 19% RH. Upon equilibration to 50% RH, tensile yielding in the gesso occurs at 85% RH and in the paint at 90% RH. This is a sub-

Figure 14
Calculated strains in gesso and flake white oil paint applied to unrestrained, radially and tangentially cut white oak panels versus RH. The panels are assumed to be equilibrated to 70% RH. Both the gesso and paint have very small allowable fluctuations of RH in the tangential direction, but the radial direction shows a significant increase in the allowable fluctuations. Where the tangentially cut panel is at risk when equilibrated to high RH, the radially cut panel can still sustain large RH fluctuations.



stantial improvement over the strains that developed in the design layers that were applied to tangentially cut wood. Panels cut tangentially and equilibrated to a high RH are at serious risk if desiccated. Panels cut radially are at considerably less risk, even when desiccated and equilibrated to a high RH. For example, paintings on plywood panels that are made entirely of restrained, tangentially cut wood fare poorly when exposed to RH fluctuations, as compared to paintings on radially cut panels, whether restrained or not.

The equilibrium RH of a panel painting's environment establishes its risks for transport. Knowing the equilibrium RH allows for the development of environmental guidelines for both the transit case and the new, temporary exhibition space. Tangentially cut panels acclimated to high RH are at risk. This risk can occur when warped panels have been flattened with moisture before the addition of battens or cradles. In such instances a warped panel is often thinned, moistened on the reverse, and finally attached to battens or a cradle to forcibly hold the panel flat. As a result, considerable tensile stress can build up as the wood dries, since the battens or constricted cradles can restrict the return to warpage.

When panels are thinned, there are other consequences. Decreasing the thickness reduces the bending stiffness of a panel and makes it more flexible. The reduction in stiffness is inversely proportional to the cube of the thickness of the panel (Weaver and Gere 1965:115–17). This thinning makes the panel prone to buckling when restrained. At a high RH, a panel with a locked-in cradle is subjected to high RH-induced compressive stresses in the spans between the cradle supports, and because of the cradle, such stresses are not uniform. They cause out-of-plane bending or buckling of thinned panels.

It is important to assess whether a panel's movement is restricted—an assessment that may be difficult in some cases. Panels with battens or cradles that have locked up by friction present higher risks for transport if they are cracked or if the panel has equilibrated to a very high RH environment (Mecklenburg and Tumosa 1991:187–88). In addition, research suggests that an unrestrained panel with a gesso layer equilibrated to a high-RH environment is at greater risk of damage upon desiccation than is a sound (free of cracks), restrained panel. This risk occurs because the gesso layer is subject to compression cleavage when an unrestrained panel contracts from desiccation. Almost all the panel paintings of the fifteenth- and sixteenth-century Italian Renaissance have gesso grounds. This gesso layer and the wood panel itself should be considered the crucial components when the movement of such paintings is contemplated.

In contrast, oil paintings on copper supports seem to have fared well over the centuries. Research shows that oil paint responds only moderately to changes in RH, particularly if extremely high RH levels are avoided. Additionally, copper is dimensionally unresponsive to RH fluctuations. The combination of these two materials results in a painting that is durable with respect to changes in atmospheric moisture.

Contemporary panel paintings having wooden supports and either acrylic or alkyd design layers may also be analyzed in relation to the criteria discussed above. Figure 15 shows the coefficients for swelling of alkyd and acrylic emulsion paints compared to those of oil paint. All of these paints have dried for fifteen years or more under normal drying conditions. Both the alkyd and the acrylic emulsion paints are much less dimensionally responsive to moisture than is oil paint. When acrylic paints are

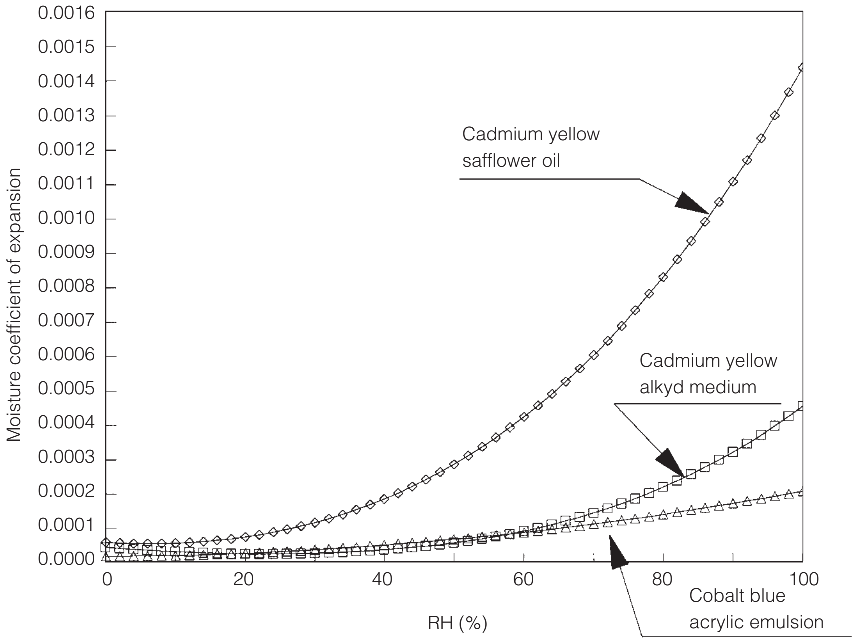


Figure 15
Moisture coefficients of expansion versus RH for oil, alkyd, and acrylic paints. The dimensional responses of the alkyd and acrylic paints are substantially lower than those of the oil paint.

applied to a wooden panel, RH changes have very little effect in the longitudinal direction of the wood. In the tangential direction, the movement of the paint is almost totally dictated by the movement of an unrestrained wooden panel. However, the RH change needed to develop yield in alkyd or acrylic paints will be approximately 2–3% less than the change needed for oil paint on wooden panels because the moisture coefficient of expansion of the oil paint is higher.

Control of transport RH

RH levels may also vary during transport, but fortunately this problem can be solved with proper packing. Since the RH levels in trucks depend largely on weather conditions, the RH inside even an air-conditioned truck may be very high on a hot, humid day. If the weather is very cold, the RH in the truck may be low because of the drying effects of the cargo-area heating system. At high altitudes, the RH in a heated and partially pressurized aircraft cargo space is always low—often as low as 10–15%. Panel paintings exposed to this extreme desiccation for the duration of an average flight could be damaged. This desiccation can be avoided if the painting is wrapped in a material that functions as a moisture barrier (wrapping of panel paintings is discussed further below).

Temperature Effects

The dimensional response of wooden panels to temperature variations has been largely ignored by many conservators, because temperature has been considered to have a much smaller effect on wood than has RH. This precept holds true if one considers only the relative dimensional response of wood to temperature as compared to its response to moisture. It would take a change of several hundred degrees in temperature to induce the same dimensional change in wood that can be caused by a large change in RH. Panel paintings are rarely exposed to such temperature extremes, and they are usually exhibited or stored where temperature variations are relatively small. The problem, however, is not so much the response of the

Table 1 Thermal coefficients of expansion of selected painting materials

Material	Thermal coefficient of expansion
White oak—longitudinal	0.0000038/°C
White oak—tangential	0.0000385/°C
White oak—radial	0.00003/°C
Oil paint	0.000052/°C
Gesso	0.00002/°C
Hide glue	0.000025/°C
Copper	0.000017/°C

wood as it is the response of the gesso and paint layers. Therefore, when the effects of temperature are considered, it is also necessary that the mechanical properties of the different paint media, as well as their dimensional responses, are understood. In the temperature ranges most likely to be encountered, the thermal coefficients of expansion for the materials found in panel paintings can easily be considered as constants. Some values for these materials are given in Table 1.

To determine the effect of temperature on paint or gesso applied to different substrates, it is again possible to use Equation 2. Note that changes in temperature will change the moisture content of materials even when the ambient RH is held constant. At a constant RH, heating will desiccate materials somewhat, and cooling will increase their moisture content. The following discussion does not take these effects into account. Figure 16 plots the calculated mechanical strains of flake white oil paint directly applied to panels in the longitudinal, tangential, and radial directions of the wood, and to a copper panel as well. Because the thermal coefficient of expansion of the paint is greater than the thermal coefficient of wood in any direction, the paint responds to drops in temperature by developing tensile strains. The wood's shrinkage in the tangential and radial directions relieves a considerable amount of the paint strain, since the coefficients in these directions more closely match those of the paint. In the longitudinal direction of the wood, the coefficient is the smallest and strain relief to the paint the lowest. Hence, the greatest mechanical strain increase in the paint occurs in the direction parallel to the grain of the wood. As the temperature drops, the paint may pass through its glass-transition temperature (T_g). At this approximate temperature, the paint undergoes a transition from ductile to very brittle and glassy. Below T_g, the paint is very fracture sensitive and prone to crack under low stresses and strains. In this example, cracks could result when the strains reach levels as low as 0.002. In the longitudinal direction of a wooden panel painting, cracking occurs if the temperature drops from 22 °C to approximately −19 °C. A copper panel painting, however, requires a temperature drop to −35 °C to produce the same strain level.

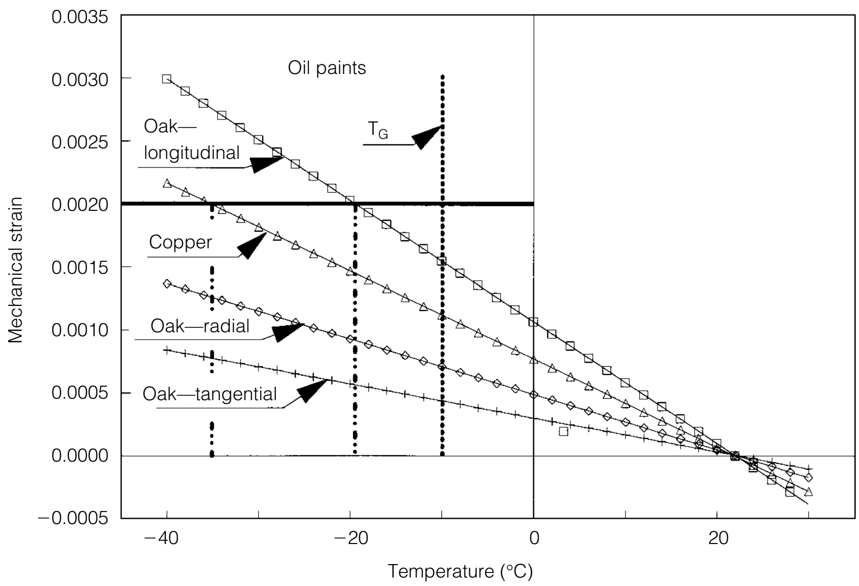


Figure 16
Calculated temperature-related strains in flake white oil paint when applied to white oak and copper. The paint strains in the longitudinal direction are the highest, and failure can most likely occur when the temperature drops below the glass-transition temperature (T_g). This type of failure results in cracks in the oil paint perpendicular to the grain of the wood.

Cracking in varnish and polyurethane coatings on wood has, in fact, been recorded when the temperature has dropped from 24 °C to −20 °C. In the radial and tangential directions of the wood, the temperature must drop to well below −50 °C to produce similar strains in the oil paint layers.

It is unlikely that cracks in oil paint layers could occur perpendicular to the grain of the wood because of RH variations. However, with regard to temperature, even moderate subfreezing temperatures can crack oil paint in this direction. Low temperatures are less likely to cause cracking of paint parallel to the grain, unless the wooden support panel is fully restrained from thermal movement during the temperature drop. As Figure 16 shows, oil paint layers applied to copper can survive a substantial drop in temperature. Note that resultant embrittlement of the paint layer is far more severe when it is exposed to low temperature at moderate RH than when exposed to low RH at room temperature.

Other paint media suffer embrittlement similar to that suffered by oil paint, but at higher temperatures. With alkyd paints, a T_g occurs at approximately −5 °C, while with acrylic paints, it occurs at approximately 5 °C. While unlikely, it is possible for the temperature inside packing cases to drop to 5 °C in the cargo holds of aircraft, on the airport tarmac, or inside an unheated truck. T_g should be considered the lowest allowable temperature for a safe environment, because embrittled materials are more vulnerable to damage.

The effect of temperature on gesso applied to wooden panel paintings is different from the effect of the same temperature on paint applied to wooden panels. In general, gesso has a low thermal coefficient of expansion that is higher than that of the longitudinal direction of white oak and lower than the oak coefficients in the radial and tangential directions. Figure 17 plots the calculated temperature-related mechanical strains in the three different grain orientations for a gesso coating applied to a white oak panel. First, the developed mechanical strains are minimal, even at −40 °C. In the longitudinal direction the gesso strains are tensile, and in the tangential and radial directions they are compressive. Thus, it

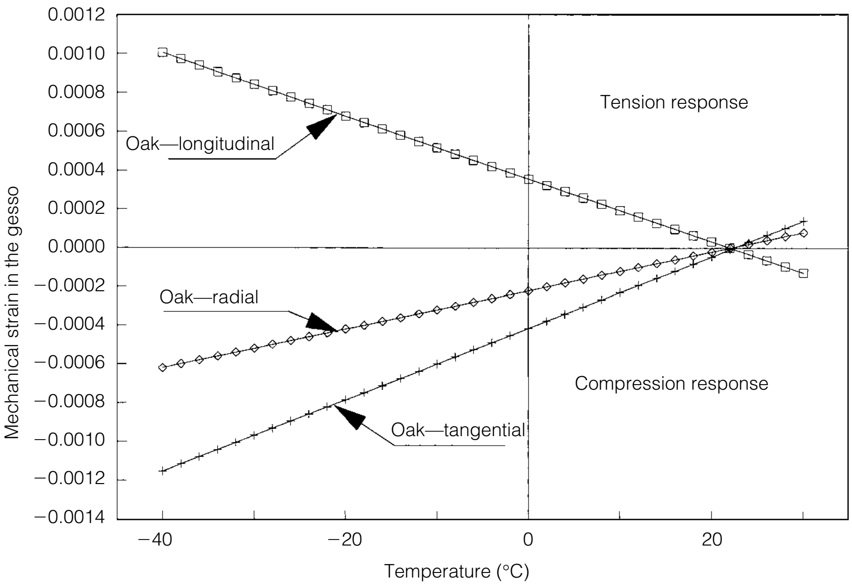


Figure 17
Calculated temperature-related strains in gesso when applied to white oak. The gesso strains in the longitudinal (tensile) and cross-grain (compressive) directions are never very high, and failure is not likely to occur, even if the temperature drops significantly.

appears that temperature has a significantly smaller effect on gesso than it has on oil paint.

In the panel itself, the most probable damage would occur in the tangential direction if the wood were fully restrained and subjected to a drop in temperature. The tangential direction has the highest thermal coefficient of expansion and the lowest strength. However, even in this direction, a drop in temperature from 22 °C to −40 °C causes a mechanical strain of only 0.00246, which is not a serious concern for wood.

Excessive heat can cause undue softening of paint and varnish layers and therefore is to be avoided. In the transport environment, temperature changes can be great enough to cause damage to the paint (and varnish) layers. Thus, precautions must be taken to avoid exposing panel paintings to extremes of hot or cold environments.

Temperature variations are inevitable in most transport situations (Saunders 1991; Ostrem and Godshall 1979; Ostrem and Libovicz 1971). Although variations are usually minimal during a local move in a climate-controlled vehicle, they can grow extreme during a long truck trip during harsh winter months. In the northern United States and Canada, for example, winter lows of −20 °C are typical, and temperatures of −40 °C are possible. These extremely low temperatures can cause damage to panel paintings and must be avoided.

In the summer, temperatures of 40–50 °C can be found in many parts of the world; because of solar heating, temperatures inside stationary vehicles can be even higher. High temperatures are less likely to cause cracking in panel paintings, since heat softens the paint. However, varnishes can become tacky at high temperatures, causing wrapping materials to adhere to the panel surface. The use of climate-controlled vehicles for transporting works of art is the best way to minimize temperature variations, but contingency plans should be made in case of mechanical problems with vehicles or with their climate-control systems. Should a problem occur, insulation in packing cases will slow the rate of temperature change inside packing cases, but for only a short while (Richard 1991a).

Temperature variations can also occur in the cargo holds of aircraft. Cargo holds of all modern commercial aircraft now have heating systems, however, and barring mechanical failure, the temperature should not fall below 5 °C. Acrylic paintings are at high risk at these lower temperatures, but sound oil paintings on panel are not.

Shock

In addition to environmental variations, handling can add sufficient stress to a panel structure to cause paint loss, propagate cracks, separate joints, and permanently deform its wood.

Shocks in the transport environment are derived from three basic sources: handling before a work is packed, handling of the packing case, and the motion of the vehicle carrying the packing case. Shock levels in trucks and planes are low if packing cases are properly secured to the vehicle. In contrast, handling operations "are generally considered as imposing the most severe loads on packages during shipment" (Marcon 1991:123). "Packaging designers have achieved reasonable success in preventing shipment losses due to shock by designing packages and cushioning systems according to the presumption that shocks received during handling operations will be the most severe received by the packages during the entire shipment" (U.S. Department of Defense 1978:9).

Because old panel paintings are fragile, the shock level to which they are exposed must be minimized. The *fragility factor,* or *G factor,* is a measure of the amount of force required to cause damage, and is usually expressed in Gs. Mass-produced objects are destructively tested to measure their fragility, but obviously this test is not possible with works of art. Until recently, no attempt has been made to determine the fragility-factor range for panel paintings. Instead, art packers have relied on estimates. Conservatively, a packing case should ensure that a panel painting is not subjected to an edge-drop shock level greater than 40 G. The edge drop, however, is not the greatest concern.

One of the most serious accidents can occur when a painting resting upright on the floor and leaning against a wall slides away and falls to the floor. Another possible accident involves a case toppling over. In both of these handling situations, a panel painting is at serious risk because of inertially induced bending forces applied to the panel. The bending stresses induced in a panel are potentially the most damaging, and the thinner the panel, the greater the risk. While a thin panel has a low weight (low mass), for a given action, the bending stresses increase as a function of the inverse square of the thickness of the panel. For example, consider a sound, 2.54 cm thick white oak panel painting measuring 100 cm in the direction perpendicular to the grain, and 150 cm in the direction parallel to the grain. If this panel painting is bowed and supported in a frame, it is very likely that the support is along the two long edges (Fig. 18). If this painting were to topple so that the rotation were along one of the long edges, there would be bending stresses in the wood perpendicular to the grain. These stresses can be calculated by first determining the effective loading on the panel that results at the time of impact. If the impact were 50 G, the maximum bending stresses would be approximately 4.66 Mpa. This stress is calculated by first determining the shear (Fig. 19) and bending (Fig. 20) resulting from the impact forces. White oak has a specific gravity of approximately 0.62, which means that it has a density of approximately 0.171 kg cm^{-3}. At 50 G, the density of the wood is 0.032 kg cm^{-3} along the impact edge and diminishes to zero at the rotating edge. For a 2.54 cm thick panel, the loading for every 2.54 cm of width of the panel at the impact edge is 0.032 kg cm^{-3}, and the loading tapers to zero at the other edge (Fig. 18). From the bending moment diagram, the bending stresses can be calculated from the equation

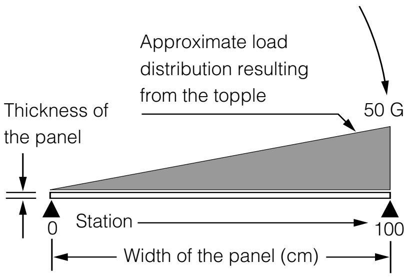


Figure 18
Approximate loading that occurs to a panel painting subjected to a 50-G topple accident. In this case, it is assumed that the panel is supported only along the two parallel-to-grain directions. It is always better to support the panel continuously around the edges.

$$\sigma = M_c / I \quad (3)$$

where: σ is the bending stress, in either tension or compression, at the outer surfaces of the panel; *M* is the bending moment calculated and shown in Figure 20; *c* is one-half the thickness of the panel; *I* is the second area moment of the cross section of the panel segment under consideration, and $I = bd^3/12$, where *b* is the width of the panel section, and *d* is the thickness of the panel.

The calculated bending stresses resulting from a 50-G topple impact to a 100 × 150 × 2.54 cm thick oak panel are shown in Figure 21. The maximum stresses are stationed approximately 58 cm from the rotating edge and reach 4.88 Mpa. This amount is slightly more than half the breaking strength of structurally sound oak in the tangential direction.

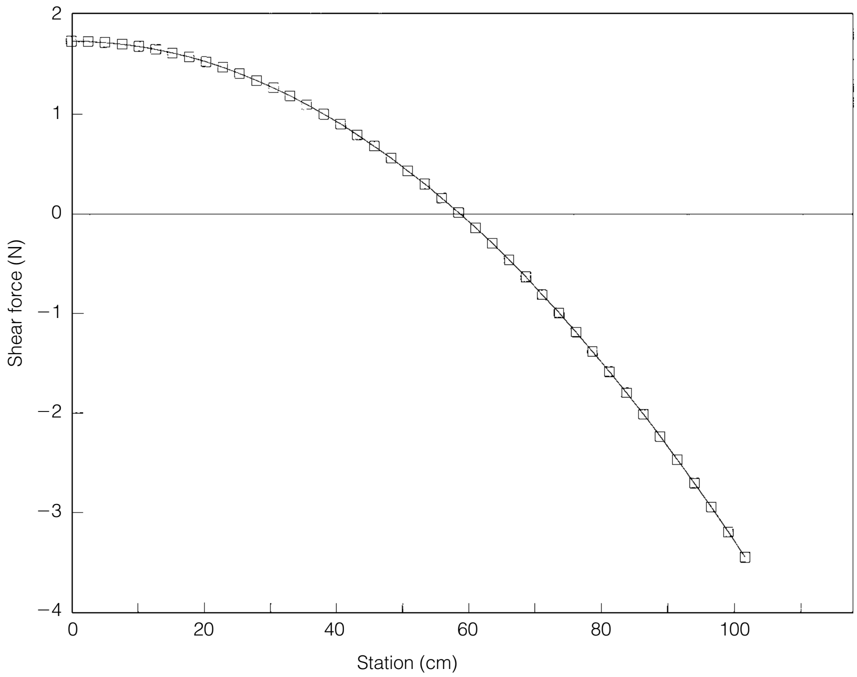


Figure 19
Shear in newtons (N) for a 2.54 cm wide strip of a 100 × 150 x 2.54 cm thick panel subjected to a 50-G topple accident.

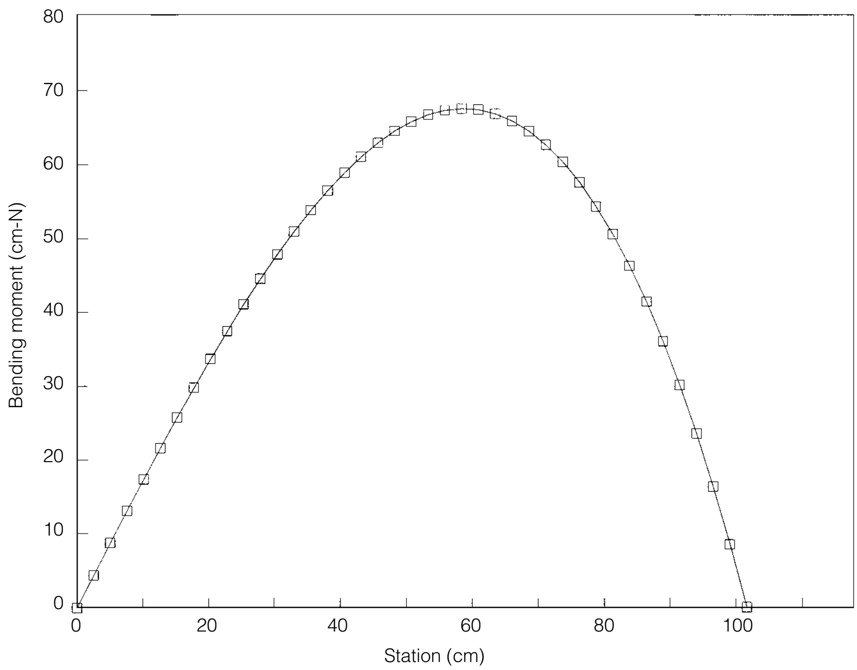


Figure 20
Bending-moment diagram for a 2.54 cm wide strip of a 100 × 150 × 2.54 cm thick panel subjected to a 50-G topple accident. The bending moments of panels subjected to topples can be quite high.

If the same event occurred to an oak panel 1.25 cm thick (with the other two dimensions the same), the bending stresses would be 9.8 Mpa. Even though the 1.25 cm thick panel weighs half as much as the 2.54 cm one, it incurs twice the stress. The measured breaking stress of white oak at room temperature and 50% RH is approximately 8.9 Mpa. The thinner panel will likely crack in a 50-G topple accident. The 2.54 cm thick panel would require a 100-G topple impact to crack it. If either panel were supported continuously around the edges, the risk of damage would decrease by a factor of five.

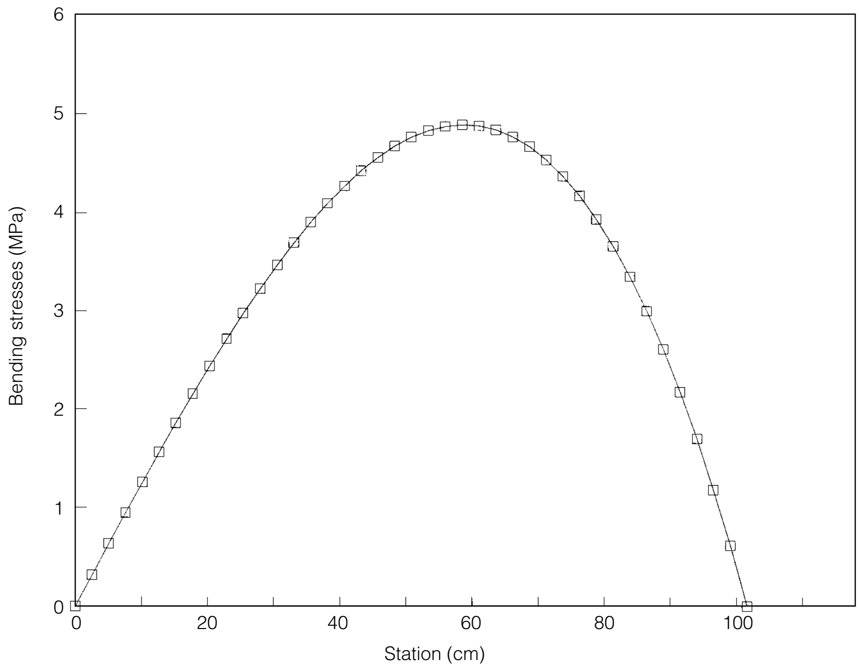


Figure 21
Distribution of the calculated bending stresses for a 2.54 cm wide strip of a 100 × 150 × 2.54 cm thick panel subjected to a 50-G topple accident. The bending stresses of panels subjected to topples can be quite high, and in this case they reach about one-half the breaking stress of oak in the tangential direction. Thinner panels are at even greater risk.

Figure 22 shows the calculated bending stresses of oak panels of different sizes and thicknesses subjected to 50-G topple impacts. These panels are assumed to be supported on the parallel-to-grain edges only, and the topple is a rotation of one of those edges. For this test, it is also assumed that there are no battens or cradles attached to the reverse, since they would provide a certain degree of bending protection.

Panels constructed of lighter woods such as pine (*Pinus* spp.; specific gravity, 0.34) will develop comparatively lower bending stresses when subjected to a 50-G topple impact. However, the strength of the

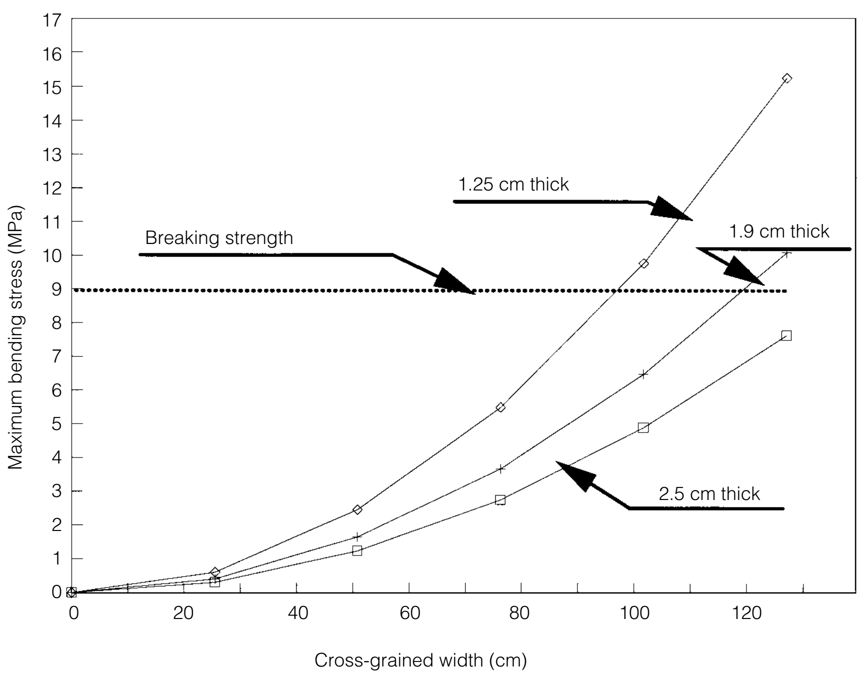


Figure 22
Calculated maximum bending stresses for white oak panels of different thicknesses and sizes when subjected to 50-G topple accidents. These stresses assume that the panels are supported only on the two parallel-to-grain edges.

lighter wood is also lower, and the result is that the risk of damage is greater than for denser woods. Figure 23 illustrates the results of the calculated bending stresses for different thicknesses of oak and pine panels of 100 × 150 cm subjected to 50-G topple impacts. The breaking stress of the pine in the tangential direction is only 3.10 Mpa. As was the case with white oak, the thinner pine panels are at greater risk, and the pine panels must be thicker than oak panels to prevent failure under the same topple conditions.

This implies that a single packing criterion is not sufficient for the impact protection of panel paintings. Larger and thinner panel paintings obviously need greater protection than those that are smaller and thicker. In addition, in this analysis it is assumed that the panel is sound, since existing cracks reduce the total strength. Panel paintings should be supported continuously around the edges in a way that allows them to expand and contract with RH and thermal fluctuations. Special care should be taken to prevent topple accidents; one way to do this is to pack more than one painting in a case, effectively increasing the width of the case and reducing the possibility of a topple.

Panel paintings in the size range of 100 × 150 cm will often be thicker than 2.54 cm, and those that are thinner are probably supported by either battens or cradles. Yet a 2.54 cm thick oak panel that is 125 cm wide or greater will fail in a 50-G topple. Based on this information, a 30-G maximum impact criterion for topple should be considered reasonable.

It should not be difficult to provide 30-G topple protection for larger panels. For one thing, the risk for an edge drop is much lower. It is fairly easy to provide 40-G protection for edge drop heights of 75 cm or less, using foam cushioning materials (the use of foam cushioning to reduce shock will be discussed below).

Vibration

The primary sources of vibration in the transit environment come from the vehicles used for transport. "Trucks impose the severest vibration loads on cargo with the railcar next, followed by the ship and aircraft"

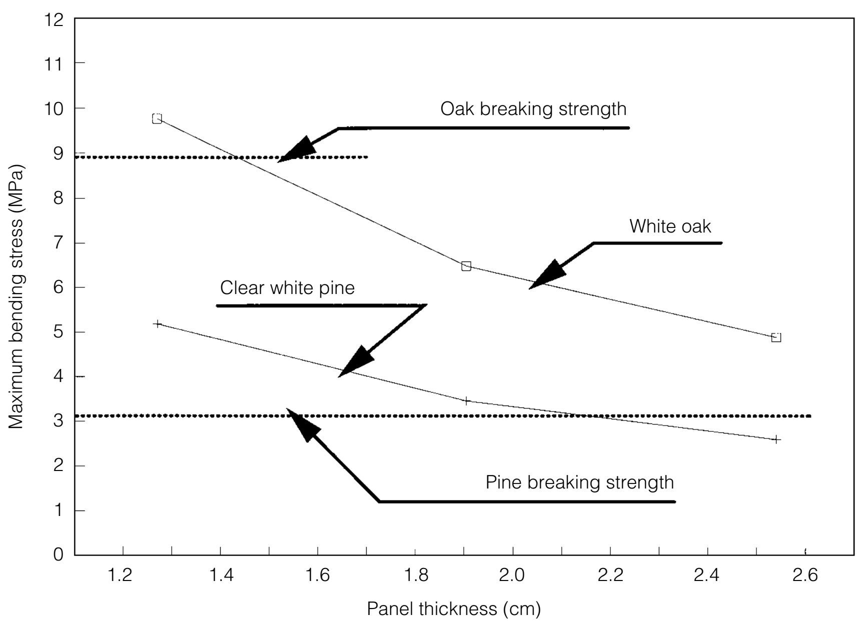


Figure 23
Calculated maximum bending stresses for 100 × 150 cm white oak and pine panels subjected to 50-G topple accidents versus panel thickness. These stresses assume that the panels are supported only on the two parallel-to-grain edges. Even though the pine is a lighter wood, because of its substantially lower strength, panels made from it are at serious risk in the event of a topple.

(Ostrem and Godshall 1979:29). In trucks, the main sources of vibration are the natural frequencies of its body, engine, tires, drive train, and suspension system. The properties of the road surface are also a factor. The vibration levels in vehicles are all relatively low and random in nature, as vehicles are usually designed for passenger comfort.

Low levels of vibration are unlikely to damage panel paintings unless sustained vibrations create resonant vibrations in the panel; the random nature of vehicle vibration makes this unlikely. In addition, the resonant frequencies of panel paintings are high, and those vibrations are easily attenuated by packing cases (Marcon 1991:112).

Packing Cases

There are many packing-case designs suggested for the transport of panel paintings. It is essential that all cases provide adequate protection against shock, vibration, and environmental fluctuations. Protection against the first two stresses is usually achieved through the use of foam cushioning materials. Although various cushioning materials are available for the transport of works of art, the most commonly used are polyethylene and polyester urethane foams. These foam products, along with polystyrene foam, can additionally function as thermal insulation. The proper use of these materials and information concerning the principles of case design are available in many publications (Mecklenburg 1991; Piechota and Hansen 1982; Richard, Mecklenburg, and Merrill 1991; Stolow 1966, 1979, 1987) and will only be summarized here.

Packing-case construction

Packing cases for panel paintings should be rigid to ensure that panels do not flex or twist during handling and transport. Rigidity can be accomplished by the use of relatively stiff materials and quality construction techniques. It is recommended that glue be used in the joinery of the cases because it increases the strength and stiffness of the joints. Case joints held together with only nails or screws perform poorly when dropped. "A case having edges and corners that are well-joined can have over ten times the strength and one hundred times the rigidity of a case that has corners and edges that are poorly joined" (Richard, Mecklenburg, and Merrill 1991).

Compared to single packing-case designs, double packing cases provide significantly better protection for panel paintings because an inner case adds rigidity to the structure. An inner case also increases the level of thermal insulation and reduces the likelihood of damage should the outer case be punctured by a sharp object, such as the blade of a forklift.

Figure 24 depicts a double packing-case design commonly used at the National Gallery of Art in Washington, D.C. The polyester urethane foam not only functions as a cushioning material but also provides thermal insulation. The entire case is lined with a minimum of 5 cm of foam, which proves adequate insulation for most transport situations if temperature-controlled vehicles are used. A packing case for a typical easel-sized painting has a thermal half-time of two to three hours (Fig. 25) (Richard 1991a). The foam thickness should be increased to at least 10 cm if extreme temperature variations are anticipated. However, thermal insulation only slows the rate of temperature change within the case: increasing the thickness of the insulation increases the thermal half-time to approximately four to five hours.

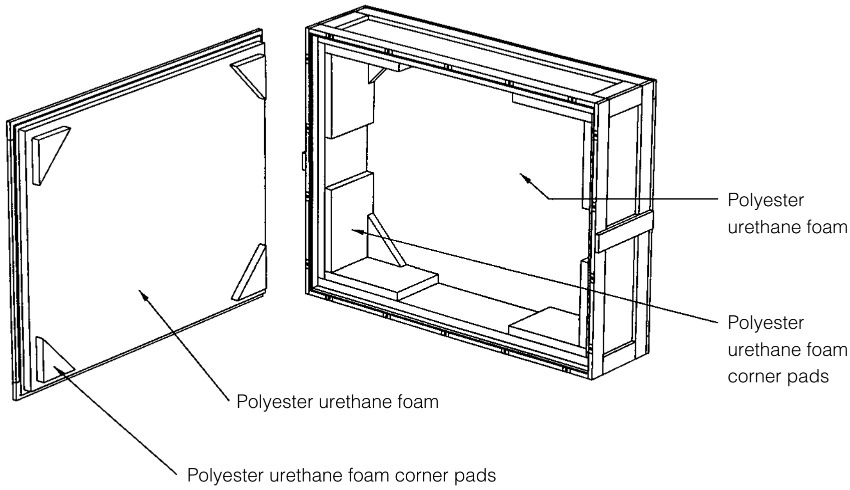


Figure 24
Interior view of the outer packing case of a double-case packing system.

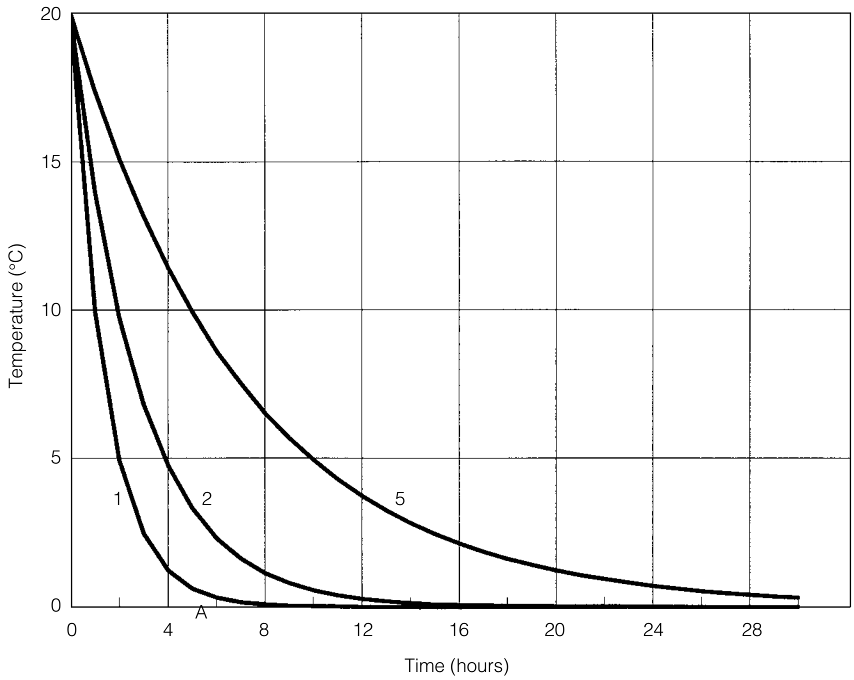


Figure 25
Thermal half-times for three different case designs. The cases were initially conditioned at 20 °C environment. The half-times shown are 1, 2, and 5 hours. Even for a well-insulated case (such as the 5-hour half-time example), little time is available before the case equilibrates to a new temperature.

When paintings are transported in extreme climates, the only way to maintain temperature levels that will not damage paintings is through the use of temperature-controlled vehicles.

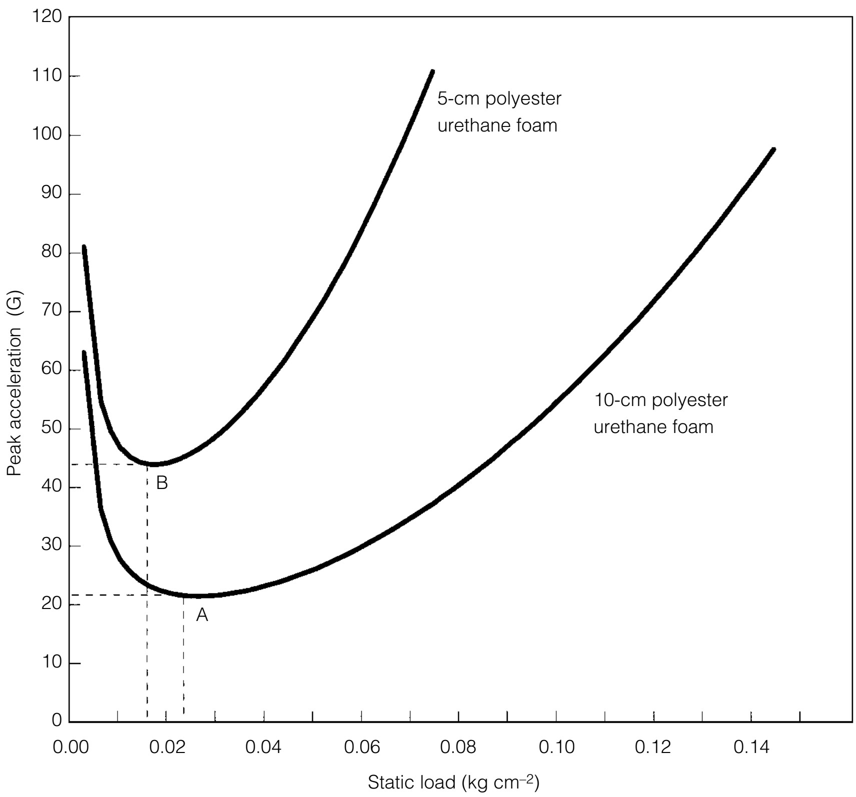
Foam-cushion design

In the packing-case design depicted in Figure 24, the polyester urethane foam provides shock protection for the painting. The painting should be firmly secured within the inner case. There are two procedures that are commonly used: (1) the painting's frame is secured to the inner case with metal plates and screws, or (2) the frame is held in place with strips of foam. Shock protection in a double case design is provided by foam cushions fitted between the inner and outer cases. When a packing case is dropped, the foam cushions compress on impact, allowing the inner case to move within the outer case. While the acceleration of the outer case is quickly halted on impact with the floor, the acceleration of the inner case is halted much more slowly. If the packing system functions properly, the outer case may sustain a few hundred Gs on impact, while fewer than 50 G are transmitted to the inner case and the painting inside.

It is easy to attain 50-G protection for panel paintings when packing cases are dropped less than 1 m. In fact, if careful attention is given to the proper use of foam cushioning materials, 25-G protection can be attained. The shock-absorbing properties of cushioning materials are provided in graphs known as *dynamic cushioning curves* (Fig. 26). These curves plot the G forces transmitted to a packed object as a function of the static load of the cushioning material. The curves vary with different materials, thicknesses, and drop heights. Dynamic cushioning curves for many materials are published in the *Military Standardization Handbook* (U.S. Department of Defense 1978). More accurate cushioning curves for specific products are usually available from the manufacturers. The use of these curves has been extensively discussed in several publications (Piechota and Hansen 1982; Richard 1991b).

Two cushioning curves for polyester urethane foam with a density of 33 kg m^{-3} are shown in Figure 26. Both are calculated for a drop height of 75 cm. Note that an increase in foam thickness dramatically effects the cushioning properties of the material. The lowest point on each curve corresponds to the optimal performance for a given thickness of the material. Therefore, as seen in Figure 26, the optimal static load for 10 cm thick polyester urethane foam is approximately 0.025 kg cm^{-2} (point A, Fig. 26). The static load is the weight of the object divided by the area in contact with the foam cushioning. At this static load, a painting packed with 10 cm thick cushions of polyester urethane foam will sustain a shock force

Figure 26
Dynamic cushioning curves for two thicknesses of polyester urethane foam. The curves show the distinct advantage of using the thicker material.



of approximately 22 G. If the cushioning in the packing case is 5 cm thick, then the optimal static load is 0.016 kg cm^{-2} and a force of 45 G would be anticipated (point B, Fig. 26). Because of the dramatic improvement in the performance of the 10 cm thick foam as compared to the 5 cm thick foam, it is highly recommended that foam cushions at least 10 cm thick be used in packing cases built for the transport of panel paintings.

It is not possible to predict the fragility of every panel painting accurately, although the methods described provide a good estimate for reasonably sound objects. Due to cracks and unseen defects, panel paintings will always be more—never less—fragile than calculated. Manufacturing companies that sell mass-produced items destructively test a few to ascertain their fragility. In this way, the company can design an adequately protective package at the least possible cost. While a small percentage of the items will be damaged, the expense incurred due to loss will be less than the cost of more complex and expensive packing cases. In the absence of accurate fragility information, it is recommended that packing cases provide at least 40-G protection for small panel paintings and 30-G protection for larger panel paintings. To provide optimal performance, the foam cushions should be at least 10 cm thick, and the static load on the foam should be calculated, using dynamic cushioning curves, to provide optimal performance.

Wrapping Materials for Paintings

Wrapping paintings in moisture-barrier materials is one way to control their moisture content during transport (Hackney 1987). Relatively thick polyethylene films that are well sealed with packaging tape usually work effectively. The quality of commercial polyethylene film materials varies considerably, however: the film is often made from recycled materials, and a low-quality film might result from the addition of grease, oil, chemical additives, and powders during the manufacturing process. Better moisture-barrier materials are available, but in ordinary transport situations, they provide few advantages over polyethylene sheeting, provided it is of high quality. It would be advantageous, however, to use the better materials when paintings are stored for many weeks in an environment having extremely high or low RH, or one having high concentrations of atmospheric pollutants.

Conservators and packers are often concerned that wrapping paintings in a moisture barrier causes condensation. Condensation problems can occur in packing cases containing large volumes of air relative to the mass and surface area of the hygroscopic materials inside. However, when a typical panel painting is wrapped in polyethylene, the volume of air is very small relative to the mass and surface area of the painting and frame. In this case, experimental evidence indicates that condensation will not occur unless a painting is acclimated to a very high RH level (at least 70%) and is exposed to a rapid and extreme temperature drop in a noninsulated packing case. The most likely cause of condensation is unpacking and unwrapping a cold painting in a warm room (those who wear eyeglasses have experienced similar condensation problems when they walk indoors on a cold winter day). This problem can be avoided simply by allowing several hours for the painting to acclimate to the higher temperature while it is still in the insulated case.

Wrapping paintings in polyethylene or an alternate moisture-barrier material is particularly important when there is uncertainty about the environment in which the packing cases will be stored. Most packing cases contain hygroscopic materials, and if they are stored in environments having an unusually high or low RH, they acclimate to that environment. Unless sufficient time (usually a week or two) is allowed for the cases to reacclimate to the proper RH before packing, inappropriate microenvironments may be created in the cases. Similar problems can occur when packing cases are constructed from wood that has not been acclimated to the proper RH; a moisture-barrier film surrounding the painting reduces the potential of damage from an inappropriate environment.

To improve the microclimate inside packing cases, buffering materials such as silica gel can be added. Additional buffering materials slow the variation of moisture content in the painting, should it be subjected to extreme variations of RH for an extended period of time. The greatest risk in adding silica gel to a packing case is the possibility of using improperly conditioned silica gel. Even if the gel is carefully conditioned by the lending institution, it is always possible that it has become improperly conditioned during the period when the packing cases were in storage. Therefore, if silica gel is used, it is essential that it be checked for proper conditioning each time it is packed.

Silica gel can also be used in a microclimate display case in which the painting remains during exhibition. A properly constructed display case provides a stable microclimate environment for a panel painting and is particularly useful when a painting is accustomed to an environment that the borrowing institution cannot achieve. A panel acclimated to 65% RH, for example, could be placed in a microclimate display case while on loan to a borrowing institution that can only maintain 35% RH during winter. It must be kept in mind, however, that mold growth can develop inside microclimate display cases acclimated to a high RH.

Hand Carrying Panel Paintings

Because of concerns about their fragility, panel paintings are often hand carried by courier during transit. In certain situations, there are advantages to hand carrying works of art. The work remains in the possession of the courier at all times—a situation not possible if works are sent as cargo on an aircraft. The painting will be subjected to smaller temperature variations if the courier is conscientious about time spent in unusually cold or warm locations. However, there are some risks associated with hand carrying works of art. It is important that the painting fit into a lightweight but sturdy case that is easily carried and small enough to fit in a safe location on an aircraft, ideally under the seat. Overhead compartments should not be used because the work could accidentally fall to the floor should the compartment door open during the flight. The case might be placed in an aircraft coat closet if necessary, but it must be secured so that no movement can occur.

Another risk with hand carrying works of art is theft. Carried materials of high value are a potential target for well-informed thieves. Although this is an extremely rare problem, it is a concern that nevertheless must be considered. While couriers may feel more secure because they are never separated from their packing cases, this proximity doesn't necessarily mean that the work is actually safer.

There are many ways to pack a panel painting for hand carrying on an aircraft. Metal photographic equipment cases have proved very successful. These cases come in various sizes and shapes, the smaller ones fitting conveniently under aircraft seats. The procedure for packing a painting in these cases is straightforward. The National Gallery of Art in Washington, D.C., often follows these steps: First, either the framed panel painting is wrapped directly in polyethylene and sealed with waterproof tape, or it is placed in an inner case that is wrapped in polyethylene. Unframed panels are always fitted into an inner case to prevent anything from touching the surface of the painting. The metal photography case is then filled with polyester urethane foam. A cavity is cut into the foam with a minimum of 2.54 cm of foam remaining on all sides. In this cavity, the wrapped painting or inner case is placed. In this procedure the polyester urethane foam functions as both cushioning material and thermal insulation.

Conclusion

Most panel paintings that are in good condition and free to respond dimensionally to environmental variations can be safely transported, as long as they are packed properly. However, there are circumstances when some paintings are at greater risk than others. Therefore, all panels should be carefully examined and an assessment should be made of RH- and temperature-related stresses that may develop from improper framing techniques or from restraint imposed by cradles or battens. Existing cracks in the design layers usually act as expansion joints, but cracks in panels can prove to be a potential problem, especially if the painting is subjected to impact.

It is also important to compare the RH levels where the painting normally hangs to the RH levels at the borrowing institution. If there is a large discrepancy in the RH, a microclimate display case could be used. Tables 2–4 summarize the relative RH-related risks for sample paintings of different construction and grain orientation. For example, Table 2 shows the risks of transporting a restrained, tangentially cut, white oak panel that has been equilibrated to 70% RH or higher.

Tables 3 and 4 show that it is potentially hazardous to ship a panel painting that has been equilibrated to 70% RH or higher and that has a gesso ground or paint directly applied to the wood—particularly if the wooden support is tangentially cut and not restrained.

To maintain stable moisture contents, paintings should be wrapped in moisture-barrier materials, provided they are not already conditioned to an unusually damp environment. Because condensation can occur when paintings acclimated to very high RH are transported in extremely cold weather, such transport could encourage mold growth.

Table 2 Maximum allowable RH ranges and relative risks for sound, uncracked, and restrained white oak panels in different grain orientations

Panel grain orientation	Equilibrium RH (%)	Allowable RH range to yield (%)	Relative risk
Tangential	36	25–54	medium
Tangential	50	33–63	low
Tangential	70	62–73	high
Radial	50	23–75	low
Radial	70	40–85	low

Table 3 Maximum allowable RH ranges and relative risks for well-attached gesso applied to unrestrained white oak panels in different grain orientations

Panel grain orientation	Equilibrium RH (%)	Allowable RH range to yield (%)	Relative risk
Longitudinal	50	20–86	low
Radial	50	22–79	low
Tangential	50	33–62	medium
Longitudinal	64	29–93	low
Radial	64	33–87	low
Tangential	64	53–68	high
Longitudinal	70	32–96	low
Radial	70	32–84	low
Tangential	70	65–73	very high
Longitudinal	36	12–75	low
Radial	36	15–71	low
Tangential	36	26–54	medium

Table 4 Maximum allowable RH ranges and relative risks for well-attached oil paint applied to unrestrained white oak panels in different grain orientations

Panel grain orientation	Equilibrium RH (%)	Allowable RH range to yield (%)	Relative risk
Longitudinal	50	8–95	low
Radial	50	13–86	low
Tangential	50	27–65	medium
Longitudinal	64	16–95	low
Radial	64	20–92	low
Tangential	64	43–71	medium
Longitudinal	70	17–95	low
Radial	70	19–90	low
Tangential	70	61–75	very high
Longitudinal	36	4–92	low
Radial	36	8–88	low
Tangential	36	22–60	medium

Table 5 Approximate glass-transition temperatures for selected paints

Material	Glass-transition temperature, T_g (°C)
Oil paint	−10
Alkyd paint	−5
Acrylic paint	+5

Temperature variations during transit should be minimized by use of climate-controlled vehicles and thermal insulation inside packing cases. Table 5 gives the typical glass-transition temperatures for three types of paint. However, paintings should never be subjected to temperatures as low as these values and, ideally, should stay above 10 °C.

Careful attention should be given to the selection and proper use of cushioning materials in the packing cases to ensure that paintings are not exposed to edge drops resulting in forces exceeding approximately 40–50 G.

For panel paintings, topple accidents can cause more severe damage than edge drops. The edges of panel paintings should be supported

Table 6 Topple-accident G levels required to break selected wooden panels cut in the tangential direction and supported along the two parallel-to-grain directions

Panel width (cm)	Panel thickness (cm)	Topple G at failure: White oak	Topple G at failure: Pine
127	1.25	29	19
127	1.90	44	28
127	2.53	59	37
102	1.25	46	29
102	1.90	69	44
102	2.53	92	58
76	1.90	82	52
76	1.90	122	77
76	2.53	163	103

continuously around the edges when in the frame and during transport. The panel must be free to move in response to changes in temperature and RH. See Table 6 for the approximate topple-accident G levels that will break uncracked panels of various dimensions and woods. This table assumes that there is no auxiliary support, such as battens or cradles attached to the panels, and that the wood is cut in the tangential direction. Woods cut in the radial direction are approximately 40% stronger than the examples provided in Table 6.

Low temperatures can severely reduce the effectiveness of foam cushions in reducing impact G levels.

Normally, transit vibration in panel paintings can be successfully attenuated by the foam cushions used to protect the painting from impact damage.

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Contributors

Odile Baÿ entered the paintings conservation department of the Louvre Museum to work on the Campana Collection in 1967; she was later appointed director of the department, which by then served all of the museums in France. She collaborated with the cabinetmaker René Perche until his retirement and then with his successor, Daniel Jaunard of the Atelier Claude Huot, until her retirement in 1989.

Ségolène Bergeon became a professor of physics in 1965 and a museum conservator in 1969. She joined the Service de Restauration des Peintures des Musées Nationaux in 1970, serving as director from 1981 to 1988. Her career has included work at the Villa Medicis and the International Centre for the Study of the Preservation and the Restoration of Cultural Property, Rome (ICCROM), and she became the president of the ICCROM Council in 1993. She is the author of several publications and has curated several conservation exhibitions.

George Bisacca is a conservator at the Metropolitan Museum of Art in New York, where he has worked since 1983, and holds an adjunct professorship at the Institute of Fine Arts, New York University. He trained in paintings conservation at the Palazzo Pitti with Andrea Rothe and Alfio Del Serra and specialized in the treatment of panel paintings with Renzo Turchi and Giovanni Marrusich of the Opificio delle Pietre Dure.

Robert A. Blanchette, Ph.D., is a professor in the Department of Plant Pathology at the University of Minnesota at Minneapolis St. Paul. He has written numerous scientific articles and reviews on degradation processes of living trees and wood products and has coauthored two books dealing with microbial degradation of wood. His current research involves biodeterioration of archaeological wood from terrestrial and aquatic environments, as well as the development of conservation methods for decayed wood.

Simon Bobak, conservator of paintings, currently works in London. He is a fellow of the International Institute for Conservation. He also holds the position of honorary chief conservator at the Hamilton Kerr Institute, Cambridge, England.

David Bomford, who is now senior restorer of paintings at the National Gallery, London, joined that institution as a junior restorer in 1968, after postgraduate research in chemistry; he was trained by Helmut Ruhemann. At the National Gallery, Bomford has worked on a large number of paintings and has lectured and published widely, especially on the study of European painting techniques. He was coorganizer and coauthor of the award-winning series of exhibitions and catalogues called "Art in the Making," on the subjects of Rembrandt, fourteenth-century Italian painting, and Impressionism, and he also served for ten years as editor of the international journal *Studies in Conservation*. In addition, Bomford serves as secretary-general of the International Institute for Conservation. In 1996–97, he was the first conservator to become Slade Professor of Fine Art at Oxford University.

Jacqueline Bret is an engineer and a physicist at the Institut de Physique et de Chimie Industrielles de Lyon. She holds an advanced degree from the Ecole du Louvre and is a research specialist with the Service de Restauration des Musées de France, Petite Ecurie du Roy, Versailles.

Al Brewer, a Canadian who learned much from his father with regard to forests, wood, and woodcraft, received a B.Sc. in forestry from the University of New Brunswick, in eastern Canada (1983), attended the Pennsylvania Academy of the Fine Arts for two years (1978–80), and received a master's degree in art conservation from Queen's University in Canada in 1987. Since then he has conserved easel paintings, specializing in panel structural work, at the Hamilton Kerr Institute, University of Cambridge, where he has also taught. More recently, he has concentrated on researching the effects of overall reinforcement structures on the preservation of panel paintings.

Ciro Castelli began work as a joiner in 1957, progressing to the position of cabinetmaker for a private company. In 1966 he began restoring panel paintings and wooden structures at the Fortezza da Basso's state-run laboratory, including paintings damaged in the flood of 1966. Now with the Opificio delle Pietre Dure e Laboratori di Restauro, Florence, Italy—where he has also been a teacher since 1978—he has restored important works by Masaccio, Giovanni del Biondo, Raffaello Sanzio, and Botticelli, among many others. As a consultant and restoration expert representing the public museums of Italy, Castelli has served on official delegations at international art meetings. His reports have appeared often in *OPD Restauro,* as well as in restoration catalogues and conservation congress transcripts.

Vinod Daniel received his M.Tech degree in chemical engineering in 1986 from the Indian Institute of Technology in Madras, India, where he worked on the rheological characteristics of polymer blends. He received his M.S. degree in physical chemistry in 1991 from Texas Christian University, where his thesis addressed diffusion in liquids. From 1991 to 1994 he was a senior research fellow in the environmental sciences division at the Getty Conservation Institute. His research involves museum cases, moisture buffers in display cases, nontoxic fumigation, and data acquisition. He is presently scientific officer at the Australian Museum in Sydney, Australia.

Gilberte Emile-Mâle completed advanced studies in art history at the Sorbonne. In 1950 she became head of paintings restoration at the Louvre Museum and served as head conservator of the Service de Restauration des Peintures des Musées Nationaux from 1971 until her retirement in 1981. She is the author of numerous articles on the history of the restoration of paintings.

Jean-Albert Glatigny, an art restorer, specializes in the treatment of wood supports. After studying cabinetmaking, he took four years' training at the Institut Royal du Patrimoine Artistique (IRPA), Brussels, in the polychrome sculpture and panel painting workshops. In addition to his restorer's activities at IRPA and abroad, he teaches at several restoration schools and participates in studies of works of art and conducts research on ancient techniques of woodworking.

Gordon Hanlon received his B.A. degree in biology from the University of York, England, in 1979. From 1980 to 1984 he was assistant curator of Road Transport and Agricultural Implements at the Museum of Science and Technology, London. In 1984 he started a four-year studentship at the Victoria and Albert Museum, London, specializing in the conservation of furniture and gilded objects. In 1988 he joined the J. Paul Getty Museum as an intern and is now associate conservator in the Decorative Arts and Sculpture Conservation department. He specializes in the conservation of gilded furniture.

R. Bruce Hoadley holds a B.S. in forestry from the University of Connecticut, as well as master's and doctorate degrees in wood technology from Yale University. He is currently a professor in wood science and technology at the University of Massachusetts at Amherst, where his principal teaching and research interests are the anatomy and fundamental properties of wood. His wood identification analyses have been included in catalogues of major collections, including those of the Metropolitan Museum of Art in New York, the Garvan Collection at Yale University, the furniture collection at the J. Paul Getty Museum, and the diplomatic reception rooms at the U.S. Department of State. He is the author of two books, *Understanding Wood* (1980) and *Identifying Wood* (1990), and of more than fifty scientific and popular articles relating to wood.

James S. Horns studied with Richard Buck from 1971 to 1974 at the Intermuseum Conservation Association at Oberlin College, in Ohio, where he received a master of arts degree in conservation. He was a paintings conservator at the Minneapolis Institute of Arts from 1974 to 1978 and at the Upper Midwest Conservation Association from 1979 to 1986. Since that time he has been a conservator in private practice in Minneapolis.

Claude Huot carries on a two-generation tradition of cabinetmaking, having practiced under his father, Georges Huot, whom he succeeded as director of his studio in 1962, and René Perche. An avid personal interest in airplanes and gliders has allowed him to become better acquainted with various uses of wood and its mechanical behavior, from the standpoints of both piloting and conserving aircraft made of wood and canvas.

Daniel Jaunard is a cabinetmaker and restorer of support frames for easel painting. He has previously worked with René Perche at the Atelier Claude Huot and is licensed by the Service de Restauration des Musées de France.

Peter Klein graduated with a degree in wood technology from the University of Hamburg in 1973 and received a doctoral degree, with a specialty in wood science, from the same university in 1976. From 1976 to 1978 he served on the staff of the university's Department of Wood Biology, and from 1979 to 1981 he was a visiting scientist at the Gemäldegalerie Berlin-Dahlem. Since 1981 he has served on the staff of the University of Hamburg's Department of Wood Biology. His research activities concentrate on wood biology and technology, wood conservation and preservation, and dendrochronology.

Frédéric J. M. Lebas studied at the Institut Suisse pour l'Etude de l'Art in Zurich; he later served as paintings and sculpture restoration assistant to Th. Brachert at the Germanisches National Museum, Nuremberg, and held a one-year fellowship to the Institut Royal du Patrimoine Artistique de Bruxelles. Since 1979 he has served as restorer of paintings and sculpture at the Museum für Kunst und Gewerbe, Hamburg.

Patrick Mandron is a graduate of the Institut Français de Restauration des Oeuvres d'Art. A cabinetmaker and restorer of support frames for easel painting, he teaches at the Sorbonne, Université de Paris I, in the Maîtrise des Sciences et Techniques de la Conservation des Biens Culturels. He is licensed by the Service de Restauration des Musées de France.

Raymond Marchant has a background in design engineering, carpentry, cabinetmaking, and furniture restoration. He has also worked for John Bull in London as a technician restoring metal sculpture. In 1989 he joined Simon Bobak in association with the Hamilton Kerr Institute (HKI), Cambridge, England. At the London studio of the HKI, he works on the structural conservation of panel paintings, and at the HKI in Whittlesford, Cambridge, he advises on the structural conservation of panel paintings.

Giovanni Marussich, who was born in Croatia, embarked on his professional life as a woodworker in 1948, and he immigrated to Florence in 1956. From 1962 to 1983 he was a wood conservator for panel paintings at the Fortezza da Basso, part of the Opificio delle Pietre Dure e Laboratori di Restauro (formerly the Soprintendenza alle Gallerie) in Florence. Since then he has done conservation on panel paintings for various institutions and has taught a course on wood conservation at the Museo de Arte de Catalunya in Barcelona. He has also been a consultant to the J. Paul Getty Museum. He is presently involved in a restoration campaign for war-ravaged paintings in the former Yugoslavia.

Ian McClure studied English literature at Bristol University and art history at Edinburgh. He became head of paintings conservation at Glasgow Art Gallery and Museum in 1978. In 1982 he was named assistant to the director at the Hamilton Kerr Institute, where he became director in 1983. He has written on various specific conservation projects and techniques, as well as on the history of conservation.

Marion Mecklenburg holds B.S., M.S., and Ph.D. degrees in structural engineering from the University of Maryland. He has worked for twenty years as a paintings conservator in the United States. In 1987 he joined the Conservation Analytical Laboratory of the Smithsonian Institution, where he is a senior research scientist and where for several years he was the assistant director for conservation research. He has also been an adjunct professor in the Department of Conservation at the University of Delaware, an assistant professor and director of the Fracture Mechanics Laboratory at the University of Maryland, and coordinator of the graduate program for material science at the Johns Hopkins University. His research interests include the mechanics of materials and the effects of the environment on the mechanical properties of materials.

Anthony M. Reeve is senior restorer at the National Gallery, London, where he joined the conservation department in 1963 and trained under Arthur Lucas, Helmut Ruhemann, and Louis Howard. He carries out all forms of conservation, cleaning, restoring, and structural work on all the paintings he conserves. Since 1977 he has been in charge of all structural work, research, development, and application of improved methods of conservation. He represents the fourth generation of picture restorers in his family.

Mervin Richard studied paintings conservation at Intermuseum Laboratory in Oberlin, Ohio, and joined the staff of the laboratory upon graduation. He then held positions as a paintings conservator at the Philadelphia Museum of Art and at the Winterthur Museum. Since 1984 he has been the head of exhibition conservation at the National Gallery of Art in Washington, D.C., where he is also the deputy chief of conservation. His research over the years has focused on the dimensional behavior of panel paintings and on the packing of works of art for transit. Richard has served as cochairman of the International Council of Museums (ICOM) Working Group for the Care of Works of Art in Transit, and as cochairman of the ICOM Working Group for Preventive Conservation.

Andrea Rothe has been conservator of paintings at the J. Paul Getty Museum since 1981. Born of German parents in Bolzano, Italy, he grew up in France and Spain during World War II. After the war he immigrated to the United States with his parents and attended school in North Carolina, New York, Florida, and Connecticut. After having been accepted into New York University's history of art program, he left with his parents for a trip to Europe. There an introduction by George L. Stout enabled him to begin an internship at the Uffizi Gallery in Florence that changed the course of his career. He worked first with a gilder, Rafaello Bracci, and then with the restorers Augusto Vermehren, Gaetano Lo Vullo, Leonetto Tintori, and Alfio Del Serra. He subsequently did internships with Hermann Lohe at the Bavarian State Galleries in Munich and with Josef Hajsinek and Franz Sochor at the Kunsthistoriches Museum in Vienna. After this period of training, he started working on contract for the Italian state in Florence, Naples, Urbino, Arezzo, and Siena. During this time he also became an assistant to Oskar Kokoschka at his summer academy, called the School of Vision, in Salzburg.

Ulrich Schiessl received a Ph.D. in art history from Ludwig-Maximilians University in Munich in 1978, and an M.A. in the conservation and restoration of easel paintings and polychrome sculpture from the Academy of Fine Arts in Stuttgart in 1981. Since 1983 he has been a professor in the conservation department at the Academy of Fine Arts in Dresden. He is a member of ICOM and an honorary member of the Swiss Association for Conservation and Restoration.

Arno P. Schniewind received B.S., M.W.T., and Ph.D. degrees in wood technology from the University of Michigan, Ann Arbor. He joined the Forest Products Laboratory, University of California, Berkeley, in 1956. Initially his specialty was the mechanical behavior of wood and wood-based materials, and he taught undergraduate and graduate courses and did research in this area. In 1982 he became interested in the application of wood science to the conservation of wooden artifacts, and he has since published a number of research papers on that topic. Since his early retirement in 1991, he has been professor emeritus and continues to be active.

Charles S. Tumosa has a Ph.D. in chemistry from Virginia Polytechnic Institute and State University. He has twenty-three years of experience running analytical laboratories and has spent his career examining and determining the character of materials. At present he is a senior research chemist at the Smithsonian Institution, where he works on the chemical and mechanical properties of cultural objects.

Luca Uzielli is a professor of wood technology and forest operations at the University of Florence, Florence, Italy. He specializes in the evaluation, restoration, and conservation of wooden artifacts, including supports of panel paintings, sculptures, and load-bearing timber structures of artistic and historical significance.

Zahira Véliz trained as a conservator of paintings at the Intermuseum Conservation Laboratory, receiving an M.A. from Oberlin College in 1978. She began working as a freelance conservator in Spain, collaborating extensively with the World Monuments Fund and the Royal Foundation of Toledo, and working in the conservation department of the Prado Museum in Madrid. She has taught at the Courtauld Institute, London, and at University College, London. Since 1990 she has been working privately in London and Spain, lecturing and writing on technical aspects of sixteenth- and seventeenth-century Spanish painting.

Jørgen Wadum received a bachelor's degree in art history from the University of Copenhagen in 1980. He graduated with his B.Sc. (1982) and M.Sc. (1987) in conservation from the School of Conservation, Copenhagen. He has worked as a freelance paintings conservator since 1983 and worked at Rosenborg Palace, Copenhagen, in 1987–88. In 1989 he was employed as a lecturer at the School of Conservation and at the University of Copenhagen. From 1990 to the present, he has been chief conservator of paintings at the Royal Picture Gallery Mauritshuis, The Hague. He is also the coordinator of the International Council of Museums Committee for Conservation Working Group on Scientific Study of Paintings: Methods and Techniques.

Philip Walker is a practical worker in wood with a special interest in the historical and contemporary use of tools and techniques of various trades and cultures. He has written and lectured widely on these subjects. In 1987 he was elected a fellow of the Society of Antiquaries of London. He is president of the Tool and Trades History Society, founded in 1983, which has members in eighteen countries worldwide.

Donald C. Williams has been a furniture restorer and conservator since 1972; his particular interests are in coating and adhesive materials. He received a B.A. in the technology of artistic and historic objects from the University of Delaware and joined the Conservation Analytical Laboratory (CAL) of the Smithsonian Institution in 1984 as furniture conservator. He later became senior furniture conservator. He is currently coordinator of education and training programs at CAL.

Antoine M. Wilmering received his training in furniture conservation under the aegis of the State Training Programme for Conservators in the Netherlands. He was awarded internships in the Historical Museum of Amsterdam and the Victoria and Albert Museum in London and received his certificate in Furniture Conservation from the Ministry of Culture in 1983. He was furniture conservator at Rijksmuseum Paleis Het Loo in the Netherlands before being hired in 1987 by the Department of Objects Conservation at the Metropolitan Museum of Art, New York, to direct the conservation treatment of the Gubbio studiolo. He is conservator at the Metropolitan Museum of Art and is responsible for overseeing the work of the furniture conservation staff in the Sherman Fairchild Center for Objects Conservation.

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