KEYNOTE ADDRESS

# Complexity and Communication: Principles of In Situ Conservation

*Sharon Cather*

As the objectives of conservation evolve from remedial treatment to preventive intervention, new challenges emerge. This is particularly true in the field of in situ conservation, where the numbers, size, and widespread distribution of sites and buildings—coupled with the diversity of their ownership and use—compound the difficulties of problem solving and decision making. Recognition of past failures in conservation and of the present inadequacy of our understanding of both decay mechanisms and potential remedies should lead to far more caution. Problem solving needs to focus on disentangling complex effects from multiple causes. This requires a shift in funding away from treatment in favor of investigations of monitoring and diagnosis—a leap of confidence, as it requires a deferral of immediate, visible results in favor of long-term, intangible ones. Decision making depends on bridging the communication gap between a bewildering range of technical experts and the beleaguered nonspecialist administrators who still, remarkably, make all the main decisions about conservation. And this requires that conservation specialists provide candid, well-argued, and viable alternative options for addressing complex problems.

The inexorable trend toward increasing complexity in conservation has important implications. Current efforts to understand the nature of materials, the processes of deterioration, and the intricate relationships between effects and causes have led to a proliferation of the disciplines involved in conservation and a shift toward a scientific basis. These developments are both inevitable and desirable.

But what are the implications of this trend? Although there are many, this chapter will concentrate on just two. First, improved knowledge of materials and of decay mechanisms should have a direct bearing on principles and practices: we should be more cautious. Second, the results of multidisciplinary problem solving should be comprehensible to those outside the individual disciplines involved: we[1] should communicate better.

The discipline of conservation has evolved only recently. It has developed from the care of museum collections of fine art—that is, accumulations of discrete objects separated from their cultural and physical contexts; housed in structures in which the causes of deterioration can, to a greater or lesser extent, be controlled; and maintained where the objectives of treatment are narrowly and unilaterally defined, nearly always by the curators.

But conservation in situ (for the purposes of this discussion, the focus is on the conservation of wall paintings) is an altogether different matter. It demands a reassessment of the objectives and approaches borrowed from museums. Preservation of cultural property in situ differs fundamentally from care of collections in a variety of ways: in scale, location, ownership, and hence use; and—perhaps most problematic of all—in the complexity of monitoring, diagnosis, and intervention.

The scale of the problem is partly a matter of the actual size of individual "objects." The area of the paintings recently conserved on the cupola of the cathedral of Florence is greater than that of all the paintings in the National Gallery in London combined; yet even this vast project is in turn dwarfed by the magnitude of the paintings of the Mogao grottoes at Dunhuang.[2] The scale of the problem is also one of number. Overall numbers are difficult to assess, primarily because of the lack of adequate inventories of cultural property. In England, for example, a country not normally considered rich in mural painting, an inventory begun in 1980 and still ongoing has established that there are more than two thousand buildings with medieval wall paintings. Another problem that characterizes in situ conservation is location. Sites are always dispersed and often remotely situated, and the paintings themselves inaccessible. Moreover, the buildings are likely to be in use—often in a way that is inimical to the goals of conservation—and controlled by owners (private, institutional, corporate, ecclesiastical, or governmental) for whom conservation may not be a high priority.

The technical complexity of conservation in situ is obvious merely from a glance at the contents of this volume. There seem to be two principal reasons for this increasing complexity. First, through recognition of the persistent failures of treatment in the past, we have become more concerned with materials—both the original materials of objects and the materials applied to them. Second, we have realized that because of the risks to objects, the high costs, and the likely inadequacy of treatment, it is better to attempt passive or preventive rather than remedial measures. Neither understanding materials nor designing preventive conservation is easily accomplished, however; both require a firm scientific basis and a range of expertise.

Though all of these aspects of site-based conservation have significant implications, particularly with regard to planning and funding, this paper focuses on the multidisciplinary complexity and the consequent obligation of communication.

## Complexity

A single example may serve to demonstrate the present complexity of conserving wall paintings in situ. At Hardham, a remote church in the south of England, the paintings of circa 1100 are in perilous condition: the paint layer is being pushed off by salts (Figs. 1–5).[3] Because of the importance of these paintings, there is great concern over their deterioration and much pressure to conserve them, despite the fact that the paintings have been "conserved" five times since they were discovered 125 years ago. Although their condition is no doubt alarming, it has been alarming for many years. This is not an emergency; there is time for deliberation and planning. Therefore, what should be done? Moreover, who will decide?

While it is known that salts are crystallizing and pushing off the paint layer (Fig. 5), the first step before any intervention is even contemplated is to establish precisely what is happening and why—to define the effect and determine the cause. To study the salts at Hardham, the following areas of investigation would need to be carried out:[4]

**History**
A necessary preliminary to any program of investigation is documentary research to establish and assemble what may already be known about the paintings, the building, and any previous interventions.

**Present condition**
To determine the extent and state of the painting, to characterize the nature and distribution of decay phenomena, and to identify possible later additions requires in situ, noninvasive examination; graphic mapping; and photographic recording.

**Original and added materials**
From the perspective gained from a condition survey, the original, altered, and added materials should be investigated. This requires

- development of a strategy for both noninvasive and invasive investigation;
- sampling the full range of materials and stratigraphies; and
- analysis of pigments, binders, renders, consolidants, and coatings.

**Moisture survey**
Since the sources, transport, and behavior of salts are dependent on moisture—both as liquid water and water vapor—a full survey is required, involving

- investigation of the structure to determine the range of materials present and their thermal and hygral behavior, and to clarify the history of alterations to the fabric;
- investigation of the distribution of moisture in the structure, including core sampling to establish a three-dimensional model;
- examination and recording of heating and ventilation, and of rainwater disposal; and
- a minimum of one year of environmental monitoring of exterior and interior ambient temperature and relative humidity,

*Figure 1, left*
Hardham Church, England, exterior view from the north. This modest building of flint-rubble construction has been altered remarkably little since it was built around 1100.

*Figure 2, above*
Hardham Church, England, interior view toward the east. The original scheme of painting—Christological and hagiographical cycles—survives almost entirely intact, covering the walls of both the nave and chancel. From iconographical evidence, the painting has been shown to be of circa 1100 and, from architectural evidence, to be coeval with the architecture.

*Figure 3, above*
Detail of the *Annunciation,* Hardham Church, England. Almost uniquely for English medieval wall painting, the scheme at Hardham seems to have been painted predominantly in *buon fresco,* the orthodox palette only occasionally extending to pigments incompatible with fresco, as in the blue-green halos seen here.

*Figure 4, near right*
Detail of the *Annunciation,* Hardham Church, England. Both the separate *giornata* (plaster patch) for the head of the Virgin Annunciate and the thick impasto of the lime-white details are clearly visible. Although the green pigment from the halo has been analyzed as a copper chloride, it is not clear whether this is original or an alteration due to contamination with chloride salts.

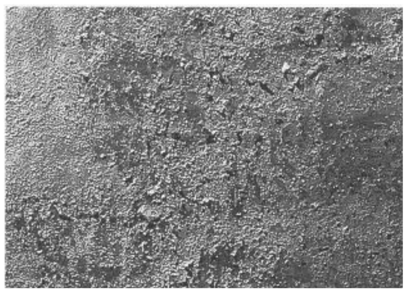


*Figure 5, above*
Detail of the *Last Judgment* on the west wall, Hardham Church, England. Soluble salts and organic coatings are responsible for the alarming deterioration shown here. The primary salt damage is from sulfation, while the various coatings applied in past treatments include size, varnish, wax, and soluble nylon.

and of interior surface temperature; followed by calculation of dew-point temperature and absolute humidity, and comparison with information on external weathering exposure and local climate.

**Salts**

Since salts, in the present case, are the most immediate cause of the deterioration, it is important to establish a clear understanding of their types and distribution in three dimensions in the structure. This requires

- mapping of the actual and apparent salt activity, ideally in different seasons;
- correlation of the salt activity with decay phenomena;
- development of a sampling strategy;
- sampling in three dimensions; and
- qualitative and quantitative analysis of the salts, including those in the building materials.

Although this condensed list could easily be much longer, it could not be much shorter without jeopardizing the likelihood of coming to reasonably satisfactory conclusions. To anyone involved in such an investigation—a phenomenological approach—it will be clear that the division into the categories listed here is for convenience. In practice, each area of study informs, defines, and directs the others. None can be carried out in isolation, and each must take account of the other. This is, of course, far more easily said than done. It also means that although there is a general sequence of investigations, a study cannot be strictly linear. There must inevitably be reexamination, resampling, and reevaluation throughout the process.

Such a diagnostic investigation would require the collaboration of a conservator, an art historian, a conservation scientist, and an environmental specialist, and—for some types of analysis—very probably additional conservation scientists. Yet Hardham is a relatively simple case. Others are far more complex: for conserving the wall paintings of Piero della Francesca at Arezzo, for example, several years and several million dollars were spent trying to answer such questions (Piero 1989).

## Communication

Remarkably, it is never these technical specialists who ultimately decide if conservation will actually be undertaken. They advise, they propose, but they do not decide. Such decision making is the province of others, of those charged with the care of the monuments and with the funding of that care. They are most likely to be predominantly art historians, archaeologists, or professional administrators. Therefore, the way results and conclusions of complex investigations are communicated to these decision makers becomes crucial. This conveniently leaves aside the equally difficult issue of how diverse specialists themselves will agree on their conclusions.

Returning to the example of Hardham Church, and assuming that after a year or two of intense investigations the various specialists have reached a conclusion, to whom is it then conveyed? Who will make the decisions? In this particular case—and, indeed, for wall paintings in any church still in use in England—there are a number of official bodies responsible. They are the parish church council (elected members of the particular church, who have legal responsibility for its care); the architect (appointed by the parish to provide overall supervision of the maintenance of the church and its contents); the diocesan advisory committee (a group of professionals that advises the chancellor of the diocese whether proposals that affect a church building or its contents should be approved—a group that, in this particular instance, includes a specialist wall-paintings adviser, though this is rarely the case); the Council for the Care of Churches (an advisory body of the Church of England that is responsible for commenting on proposals and for providing limited funding of conservation); and English Heritage (the national, government-funded agency that would probably be involved due to the importance of the paintings and the likelihood of being approached for funding).

This list is not particularly long, and is probably fairly representative of the range of bodies involved in most in situ conservation programs. Communication between technical specialists and those with the decision-making responsibilities has long been an issue, but the current trend toward passive and preventive conservation has inevitably complicated this process. The reason is fairly straightforward: intervention is not confined to the object itself. In the case of wall paintings, proposals for preventive conservation may include the use of a building (restrictions of visitor numbers, times and lengths of visits); alterations to heating, ventilation, lighting, and drainage; and specifications for building-repair materials and methods, and maintenance. Such proposals, which are both prescriptive and proscriptive, quite clearly cut across the competencies and responsibilities of other professionals such as site managers, architects, archaeologists, engineers, builders, and so on. Moreover, someone else—still not the conservation professional—must reconcile any conflicting interests and responsibilities.

There is one further difficulty with preventive conservation in situ that must be taken into account in this overall decision-making process: we have relatively little experience in predicting the effects of interventions for passive conservation in complex physical systems. Such effects will take some time to be manifest and may be difficult to interpret. Preventive conservation implies monitoring; that is, the measured assessment of the effects over time.

Monitoring has never been popular with those who fund conservation. A preference for clearly visible results—for before-and-after photographs—militates against it. In addition, we are not very good at monitoring; little experience has been accumulated, and few guidelines exist. The systems studied are ones in which there are too many variables and measurement is difficult.

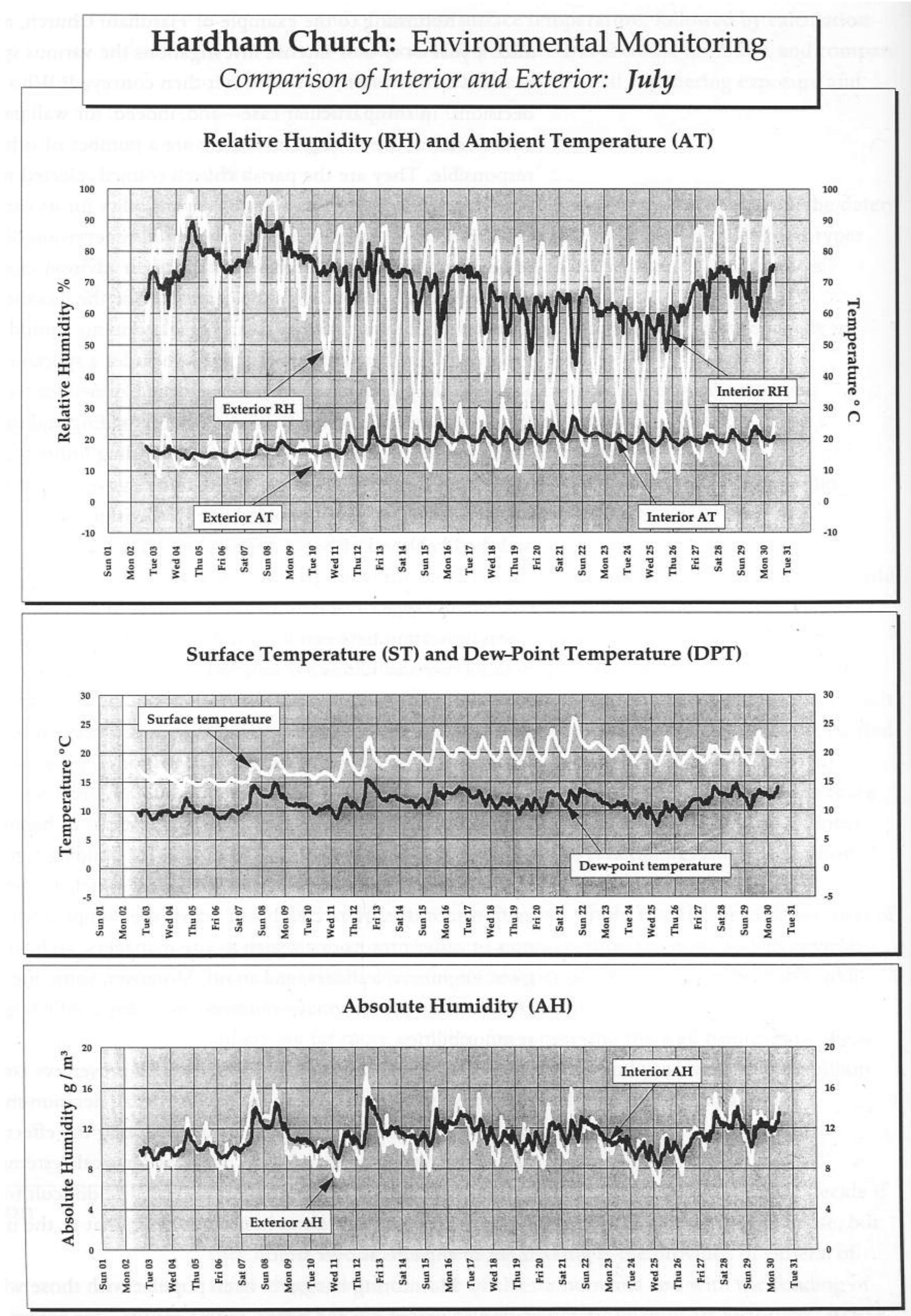



*Figure 6*
Hardham Church, England, comparison of interior and exterior environmental monitoring for July. Environmental monitoring was carried out to assess the role microclimate plays in activating decay mechanisms (salts and organic coatings). Measured parameters included exterior relative humidity (RH) and ambient temperature (AT), and RH, AT, and surface temperature (ST) at several interior locations. From these, absolute humidity (AH) and dew-point temperature (DPT) were calculated.[5]

What does this mean in specific cases? Returning once more to the Hardham example, results of investigations indicate that excessive ventilation has contributed significantly to salt crystallization by causing large shifts in both relative and absolute humidity (Figs. 6–8). Heating has played

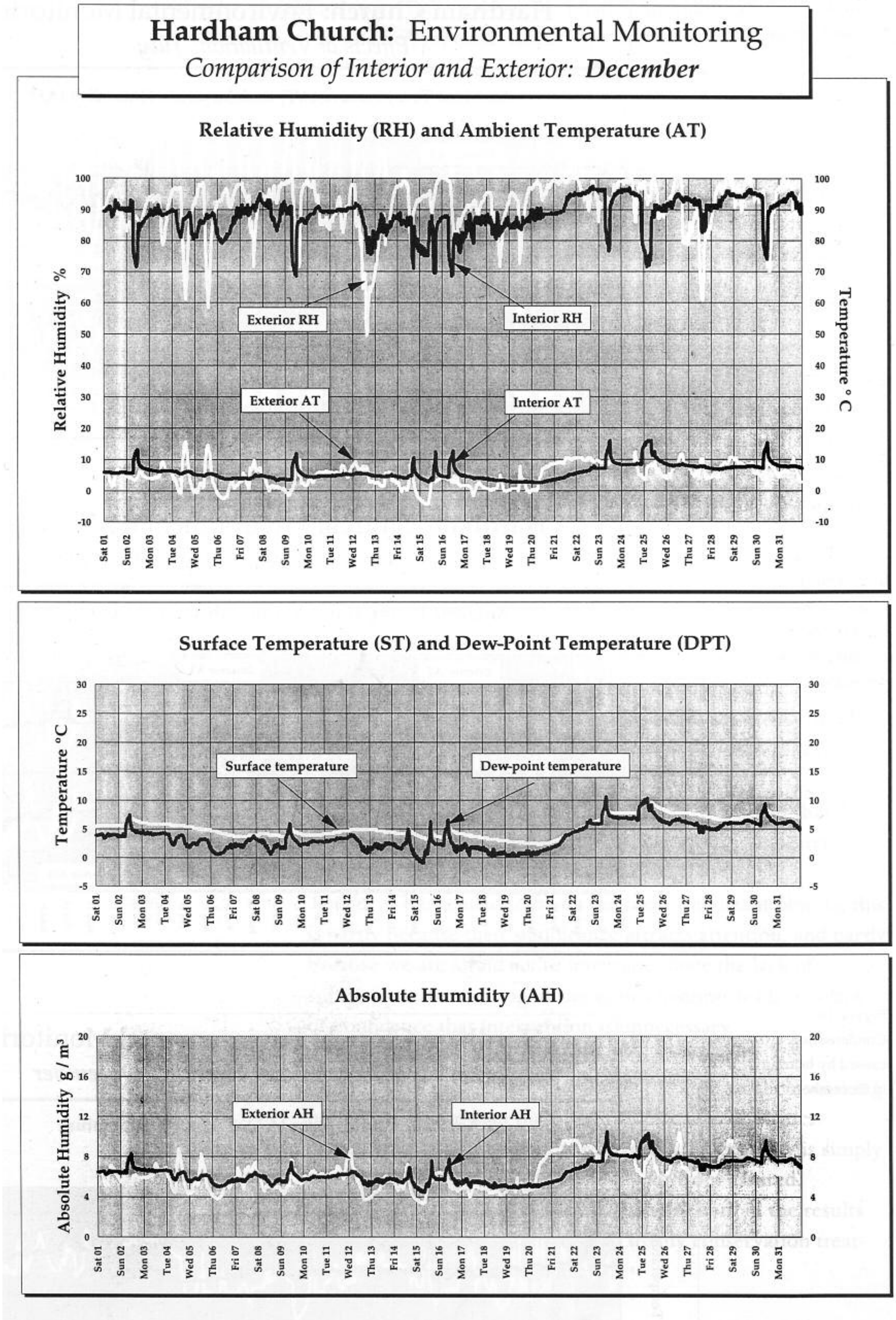



*Figure 7*
Comparison of interior and exterior environmental monitoring for December.

a role as well. Intermittent use has resulted in short, strong cycles of increased temperature; and, since water is produced as a by-product, temperature cycles are mirrored by increases in absolute humidity (Fig. 9). The resulting frequent episodes of condensation cause dissolution of the

*Figure 8*
Effects of ventilation in July.[6]

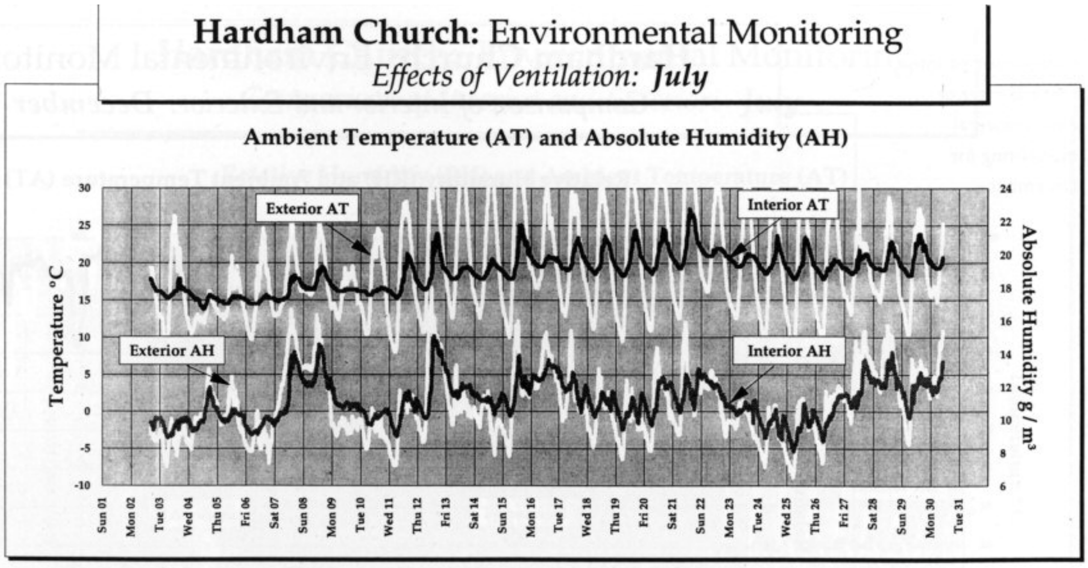



*Figure 9*
Effects of intermittent heating in December, indicating that heating was causing episodes of condensation.[7]

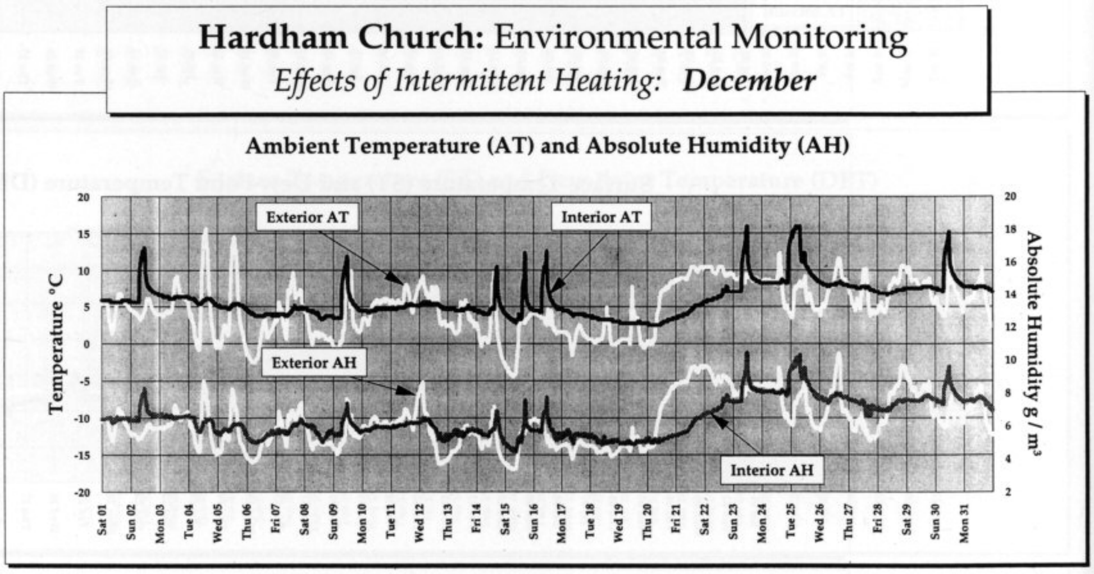
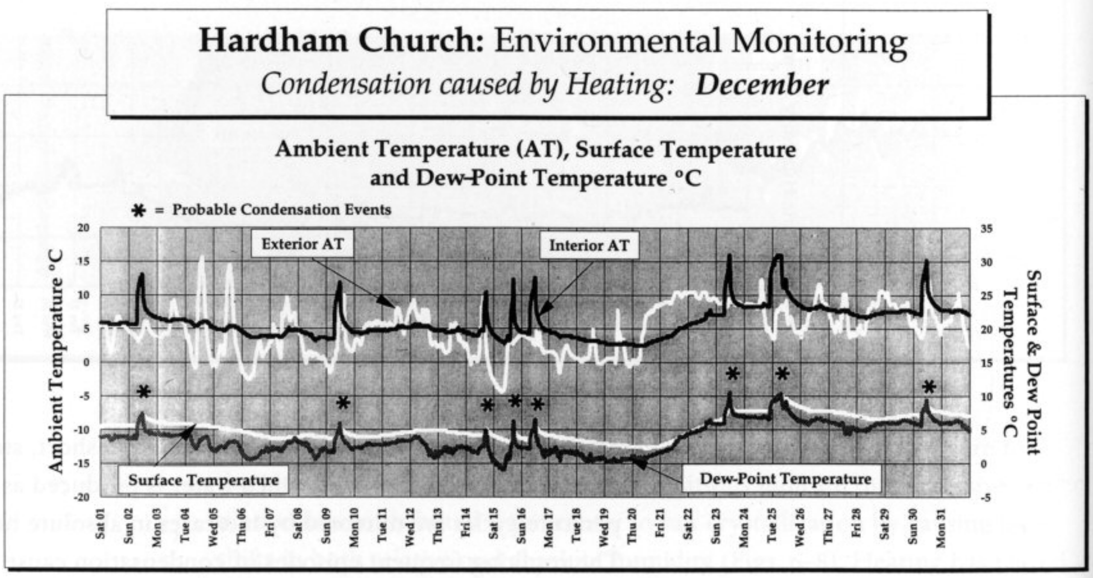



*Figure 10*
Condensation caused by heating in December.[8]



salts, which then recrystallize when the relative humidity falls (Fig. 10). What, then, should be proposed? Reduce the ventilation and change the heating—two separate variables that contribute to the overall environmental conditions.

This raises a number of questions: How can the effects be monitored? How long is it necessary to monitor, and how much will it cost? How certain can one be of the conclusions? During this period, what happens to the paintings that are in "alarming" condition? Finally, why should the decision makers believe us, since the decision to increase ventilation was itself the result of an expert proposal of some fifteen years ago?

To summarize, preventive conservation in situ is an enormously complex task, involving a wide range of conservation specialists who must reconcile their findings into coherent proposals to be judged by a separate group of professionals responsible for making the overall decisions. It should be added that in certain places and for certain monuments this problem has been overcome through the combination of these two groups into an overall, integrated administrative structure. However desirable, this rarely has been the case.

## Remarks

At the outset, it was asserted that we should be more cautious. The foregoing discussion of the particular difficulties of in situ conservation and the present limited state of experience in diagnosis, monitoring, and preventive measures should reinforce that assertion. But there are further compelling reasons for approaching such complex problems with caution:

- Past failures have led to frequent cycles of treatment that are not only harmful to the objects, but a waste of scarce resources.
- The focus has tended to be on the most important objects; this is partly because their significance attracts attention, and partly because we are afraid *not* to intervene, since the lack of sufficient understanding of decay mechanisms leads to a lack of confidence that intervention is unnecessary.
- Symptoms rather than causes tend to be treated.
- Materials continue to be selected on the basis of their working properties rather than their performance characteristics.
- For most treatments to porous materials, reversibility is simply a myth; and effective retreatability is far from assured.
- Conservation is far too subject to fashion, both in the results expected and in the materials used (many conservation treatments can be dated at a glance).

What, then, is needed? It is fairly easy to recite the list of conservation principles—reversibility, durability, compatibility, minimal intervention, and so on—but the focus at present is still on treatment. Until attention is redirected to the causes of deterioration, the cultural heritage will continue to be overtreated. We must be able to set priorities and target resources.

To be able to set priorities, we must first have a clear understanding of what we have. This means carrying out inventories and documenting condition. These steps must be the basis for any planned program of preservation, and they must be carried out jointly by art historians who understand the relative value of monuments and by conservators who can assess their condition. Then we must be prepared to undertake only the minimum treatment necessary to stabilize those objects that are at immediate risk. The temptation is always to do more.

To approach the overall task of conservation with caution, conservation specialists need to radically improve their methods of monitoring and diagnosis. This should be done jointly by scientists and conservators and would require a shift in funding away from treatment in favor of scientific investigation, since monitoring and diagnosis must be quantifiable. Although it is a common criticism of conservation that it has become too scientific, this is only true insofar as it is sometimes misguided. Much expensive analysis, investigation, and research is carried out without a clear understanding of its relation to genuine conservation issues or without an understanding of the specific questions intended to be answered. In general, however, there is too little recourse to the methods and tools that science can offer. The obvious exceptions are the highly prestigious projects—the Brancacci chapel; the tomb of Nefertari; Piero della Francesca at Arezzo; and, of course, the Mogao grottoes. Such major, costly, concerted programs are indispensable if conservation methods are to progress. Effectively, it is primarily such programs that push forward the boundaries of understanding of materials and their decay in complex physical systems.

And what of communication? It should be clear that if the complex problem solving of in situ conservation is to succeed, it must involve the cooperation of a range of professionals who can communicate with one another. We have been fairly bad at this, and scientists have been the worst. This may be largely a result of the shorthand methods scientists use and the nature of scientific data. Although these are necessary characteristics of the discipline, they can and should be interpreted for the nonspecialist. Everyone should insist on clarity and on an explicit statement of the relevance of any information to the specific problem under consideration. Finally, we have tended to manipulate decision making by artificially narrowing the options, by making single or very limited proposals. Those who are not specialists but who must make many of the most important decisions—whether to intervene, how to intervene, how much funding is available—should be aware of all the options. We should be more candid about the range of ways in which any given problem may be approached and be able to clearly set out the advantages and disadvantages of various options—the first of which, always, is to do nothing.

## Notes

1 By "we" is meant *all* those responsible, severally and collectively, for the preservation of our cultural heritage. The burden of responsibility must be shared among specialists and nonspecialists alike, among those trained in conservation and those who may encounter such responsibility only rarely.

2 There is an order of magnitude difference. While the immense Florentine program involved the conservation of some 3,800 $m^2$ of painting (Acidini Luchinat and Dalla Negra 1995:3), it has been estimated that there are more than 45,000 $m^2$ of painted surface at Dunhuang.

3 It is also being pulled off by the various coatings that have been applied—size, varnish, wax, and soluble nylon—and damaged by bat excreta, though even these problems are overshadowed by the salt deterioration. On damage to wall paintings from bat excreta, see Paine 1993.

4 The causes of deterioration of the paintings here have been the subject of an ongoing program of study by the Courtauld Institute, including extensive environmental monitoring. Within this project, investigation of the primary deteriogens—deliquescent salts and organic coatings—was undertaken by Alison Sawdy in 1993–94 (Sawdy 1994). Following this preliminary phase of investigation, further research funded by English Heritage is currently being undertaken on the various remaining issues, including biodeterioration, and potential treatment materials and methods.

5 To facilitate interpretation, and to improve communication with nonspecialists, several adjustments have been made in the way that the data are presented. Each page displays an entire month, with both the date and the day of the week, facilitating correlation with the use of the building. The data are presented in three charts: (a) exterior and interior relative humidity and ambient temperature, with the exterior values underlaid as the macroclimate "background"; (b) surface temperature (ST) and dew-point temperature (DPT) to indicate at a glance whether condensation is likely to have occurred—that is, if the DPT exceeds the ST; and (c) exterior and interior absolute humidity to indicate sources of any changes, whether from the external macroclimate or from internal sources. The three charts are aligned vertically so that an event or change in one parameter can be compared to its source or effect in another. For example, the large increase in temperature in the church on Tuesday, 25 December (Christmas day), can be traced in the two charts below as a condensation event (where the DPT exceeds the ST) and as a substantial increase in absolute humidity unrelated to the exterior value, which is actually falling.

6 Medieval buildings are typically efficient climate buffers. By isolating temperature and absolute humidity values in the presentation of monitoring data—as here for July—the effectiveness of this buffering can be assessed. It can be seen that the interior absolute humidity follows the exterior surprisingly closely, while the interior temperature varies less, but still more than one would anticipate. Comparing this behavior to the data for December (Fig. 7), it is clear that this "climate permeability" is a result of deliberate ventilation.

7 To demonstrate the role of gas-fired heating on this process, the temperatures and absolute humidities are compared and the scale of the axes adjusted to produce curves of similar amplitude. Each heating cycle results in a corresponding increase in the absolute humidity, clearly indicating the source of the additional water. The contribution of the parishioners can be discounted by examining the curve for Christmas, in which the size and duration of the change relates to heating rather than to the use of the building.

8 Condensation is notoriously difficult to monitor. The most usual way is, as here, to measure surface temperature and calculate dew-point temperature. To stress the relation between the heating of the church and resulting condensation, ambient temperature in this chart is compared to surface and dew-point temperatures. Each probable condensation event is marked with an asterisk and can be traced to heating in the curve above.

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# The Treatment of Two Chinese Wall Painting Fragments

*Cynthia Luk, Ingrid Neuman, James Martin, Cynthia Kuniej Berry, and Judy Greenfield*

Two unrelated Chinese wall painting fragments dating to the Ming dynasty have been the focus of independent study and treatment by two American regional conservation centers.[1] Structural deterioration of rendering layers required intervention to ensure the preservation of both painting fragments. In both cases, treatment decisions were based on technical examination; review of pertinent literature; and consultation with other conservators, conservation scientists, and specialists in Chinese wall paintings. Budgets and deadlines were practical considerations that affected the extent to which technical analysis and treatment could be undertaken. The following presents the construction and condition of these paintings and the rationale behind the materials and methods used for their treatment.

## *The Female Attendant*

In 1992, conservators at the Rocky Mountain Conservation Center treated a Ming dynasty wall painting fragment, *The Female Attendant,* which had been acquired by the Denver Art Museum in 1991. This piece has been attributed to the Shaanxi Province of northern China on the basis of historical and stylistic features.[2] Depicting a female wearing flowing robes and playing pipes (Fig. 1), the fragment was originally part of a larger wall painting in which such attendants may have flanked a central Buddhist figure. The painting's provenance and records of its detachment and restoration are unknown.

### Construction

Examination showed that the reverse of the painting fragment was attached to fabric scrim that was adhered with animal glue to a rigid plywood support. The ragged perimeter of the painting fragment was stabilized with plaster (not analyzed) that had been painted a purple-brown color. Paint loss had been inpainted, but not all losses were filled prior to retouching.

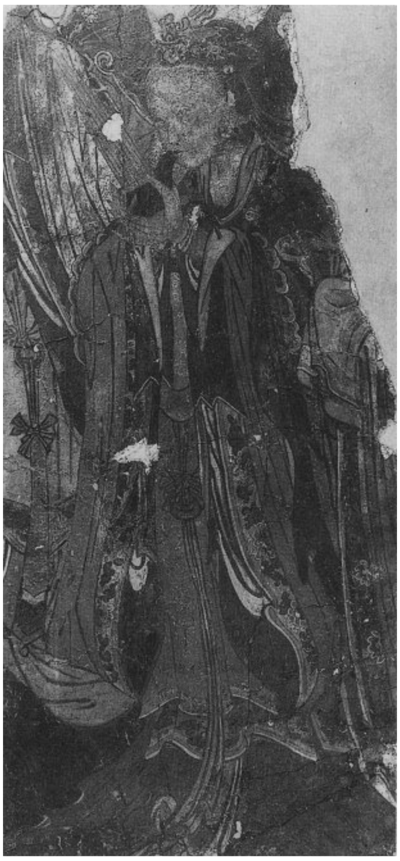

*Figure 1*
*The Female Attendant,* Ming dynasty, Shaanxi Province, People's Republic of China, 162 × 75 cm, after conservation. The Denver Art Museum.

Technical analysis revealed the presence of two rendering layers composed of dried earth material in a vegetable fiber matrix together with small fragments that appeared to derive from painted or decorated surfaces.[3] A single, white ground layer was observed in cross-section samples. Analysis revealed that the ground was composed of kaolinite and associated minerals. The thinly painted image consists of darkly outlined areas of red, dark green, blue, gray, brown, and ivory paint. Pigments identified in paint samples include red mercuric sulfide, red lead, ultramarine blue, yellow iron oxide, carbon black, calcium carbonate, calcined bone, and possible hematite. Details of the hair ornaments, jewelry, and edges of the costume were sculpted in relief and decorated with gold leaf applied over a fluorescent mordant (not analyzed). Infrared microspectroscopy detected the presence of protein in the ground and vermilion paint samples, possibly present as a binder.

## Condition

Major fractures extended through the rendering layers, and smaller cracks were observed in the paint surface, especially along the boundary between the painting and the less flexible plaster surround and fills. By probing the perimeter of the painting, examining two image areas where fills had been removed, and observing the amount of downward movement caused by gently depressing the surface, it was determined that the attachment between the scrim-backed painting and plywood was secure, except for a narrow band along the perimeter of the painting, extending no more than 7 cm from the edge.

The original appearance of the painting had been altered by the removal process, subsequent restoration, and deterioration of original and restoration materials. On later removal of the plaster surround, traces of bright-red and green paint were revealed, which suggested that light exposure, surface oxidation, or other environmental factors also may have contributed to the altered appearance of the painting.[4] The black outlines and some areas of the image had been reinforced by a later hand. Examination with ultraviolet light revealed the presence of a fluorescent surface coating that had been selectively applied, presumably as a consolidant, and that may have caused, or aggravated, paint flaking and loss. Accumulated surface grime obscured the condition of this coating.

## Treatment

Structural stabilization of the unstable rendering layers was the primary objective of treatment. The plaster surround and two large interior fills were removed mechanically. A 2.5% (w/v) solution of methylcellulose in water was used to consolidate the exposed edges of the painting. Of the wide range of consolidants tested for consolidation, the methylcellulose solution imparted sufficient cohesion to the layers while causing minimal changes in the visual appearance of the rendering and adjacent ground and paint layers.

A 50% (w/v) solution of Acryloid B-72 in acetone, bulked with an equal volume of glass microspheres,[5] was selected to reestablish adhesion and fill voids between the fabric scrim and plywood support. Of the materials tested, the B-72-microspheres mixture was selected for its adhesive and bulking properties and its ease of reversibility with a heated spatula. The mixture was injected beneath the lifting perimeter of the painting. The edges of the rendering were then coated with an isolating layer of a 5% (w/v) solution of Acryloid B-72 in xylene before losses were filled. The perimeter of the painting was enclosed with Poly Filla bulked with macerated blotting paper and toned with pigment to approximate the color of the rendering layers.

The presence of accumulated surface grime and the discolored, selectively applied surface coating altered the color balance, clarity, and contrast of the image. Cleaning tests for the removal of these materials were conducted using a variety of aqueous and nonaqueous cleaning systems (including solvent gels and chelating agents); however, the friable paint surface was found to be sensitive to mechanical abrasion from dry cleaning methods and aqueous cleaning systems. The uncoated red and green areas were particularly vulnerable to aqueous systems, which were only partially effective in removing accumulated grime. Moreover, the porous structure of the paint resulted in rapid penetration of aqueous and nonaqueous cleaning systems and prevented removal of gel cleaning systems that might otherwise have been used to restrict penetration. Selective removal of grime from coated areas, and subsequent reduction of coatings, was considered but rejected as a treatment option. A sable brush and microvacuum were used to remove standing grime from the surface, but embedded grime and the degraded coating were left intact. Removal of these materials has been postponed until sufficient time and funding is appropriated for a more thorough investigation. The original strip molding was reattached to the edges of the plywood support, and the painting was exhibited horizontally under a Plexiglas vitrine on a temporary basis pending further investigation.

## *Bearer of Good Wishes*

From 1992 to 1995, conservators at the Williamstown Art Conservation Center treated a Chinese wall painting fragment, *Bearer of Good Wishes,* in the collection of the Memorial Art Gallery of the University of Rochester, Rochester, New York. The painting fragment was given to the museum by a private donor, and nothing is known about its provenance. Attributed on stylistic grounds to the late Ming dynasty, the piece depicts a figure standing against a background of clouds (Fig. 2). The figure holds a scepter, known as a *ju-i,* representing a Bearer of Good Wishes, the name by which the painting is now known.

### Construction

Following its removal from a wall, the rendering layers were backed with a fabric scrim that was subsequently attached to a rigid support consisting of cardboard and plywood layers. The perimeter of the painting fragment was secured with plaster, assumed to be plaster of paris but not analyzed. Technical analysis revealed the presence of two rendering layers composed of dried earth materials in a vegetable fiber matrix.[6] The color of the upper rendering layer is gray, and the lower is yellow ochre. Mineralogical analysis showed that the layers are composed of similar minerals: quartz and muscovite mica with lesser amounts of hornblende, biotite mica, alkali feldspar, limestone, iron oxide, calcium particles (salt not determined) occurring in clusters and as individual grains, and trace chlorite. Analysis also revealed the presence of a white ground layer of calcium carbonate and gypsum and subsequently applied preparatory layers containing quartz, calcite, muscovite, lead pigment, and coccolithic calcium carbonate. Particle size analysis indicated that the majority of particles composing the rendering layers were between 1 and 2 μm in diameter. The thinly painted image is dominated by areas of red and green with blue, yellow, orange, black, gray, and cream, outlined in carbon black. Pigments identified in paint samples included lead white, calcium carbonate, yellow iron oxide, carbon black, red mercuric sulfide, smalt, indigo, malachite, and possible hematite. Binder characterization was not performed.

## Condition

The desiccated rendering layers were cracked and separating from the rigid support, especially along the boundary between the fragment and the plaster surround. More localized areas of severe cupping of the paint and ground layers also were observed. Later removal of the plaster surround revealed the deteriorated state of the rendering layers (Fig. 3). It was suspected that ambient vibration had caused the rendering layers to powder and that gravity had caused this powdered material to settle to the bottom edge of the painting, leaving voids between the rendering and fabric scrim. This was confirmed by probing the perimeter of the painting and gently depressing the paint surface.

The surface of the painting had been significantly altered by liberal application of fillers and overpaint—a crude enhancement of the black calligraphic drawing so essential to Chinese painting—and the presence of fingerprints in the paint and ground layers, presumably left by a past restorer during a consolidation attempt.

## Treatment

The primary treatment objective was physical stabilization of the rendering layers and their attachment to the underlying support. The plaster surround was removed mechanically. Removal of the rigid supports that prevented consolidation from the reverse was considered but rejected as too invasive to the object. Instead, stabilization of the rendering layers by means of grouting was favored (Fig. 4).

A 20% (w/v) solution of polyvinyl butyral (PVB) in equal parts acetone and ethanol, with addition of one part gilder's whiting and one

*Figure 2*
*Bearer of Good Wishes,* Ming dynasty, Taoist wall painting fragment, ca. 1600–1650, 201 × 82 cm, prior to conservation. Memorial Art Gallery of the University of Rochester (86.117).

*Figure 3*
*Bearer of Good Wishes* (shown in Fig. 2), cross-sectional detail of original rendering layers and added modern support layers prior to conservation.

*Figure 4*
*Bearer of Good Wishes,* after conservation.

part glass microspheres[7] (to two parts PVB), provided the desired properties of an adhesive and gap-filling material. In preparation for grouting, loose aggregates were removed from the edges of the painting; and the exposed rendering was consolidated using a syringe application of a 5% (w/v) solution of PVB in equal parts acetone and ethanol.

The grouting mixture was delivered by syringe from the perimeter of the painting while the painting was positioned on edge at an angle of 60–70° from horizontal. Ethanol was first injected into the rendering layers as a wetting agent to encourage the PVB grout to fill the voids. The grout was injected along the elevated edge of the painting, which encouraged inward flow. Viscosity of the grout was adjusted by addition of solvent. The painting was returned to horizontal and weighted for at least twenty-four hours; the operation was then repeated along the opposite side of the painting. Four complete grouting cycles were required to fill the voids, thereby stabilizing the rendering layers. Finally, the edges of the rendering were treated with a PVB filler composed of the 20% stock PVB grout, small additions of kaolin and fumed silica, and ethanol as needed to form a workable putty.

A variety of consolidants were tested for insecure areas of the matte paint surface. Two consolidants showed satisfactory results. A 5–10% (w/v) solution of Ethulose in water—applied by brush, faced with a Japanese tissue, and weighted overnight—left no discernible tide lines or darkening of the paint surface. Better results were observed using a 5% (w/v) solution of Acryloid B-72 in xylene, applied in a glove-bag enclosure, according to a technique published by Hansen, Lowinger, and Sadoff (1993).[8] In this method, the atmosphere within the enclosure was saturated with xylene vapor for forty-five minutes prior to consolidation. In this xylene-saturated enclosure, a 5% (w/v) solution of Acryloid B-72 in xylene was locally brushed over insecure areas. This process was repeated several times until the paint surface was consolidated. In some areas, curling and lifting paint was brought into plane by application of gentle pressure from a heated spatula over a silicone-release Mylar polyester sheet. Care was taken not to burnish or compress the paint film.

Sensitivity of the paint to mechanical and solvent abrasion precluded the use of many aqueous and nonaqueous systems, gel systems, and chelating agents for removal of accumulated grime and overpaint. Standing dirt and grime were removed with a kneadable eraser called Groom/stick. Additional dirt and grime were removed using a 25% (v/v) solution of water in ethanol (with 2% v/v diacetone alcohol) from the few stable areas of the paint surface using cotton swabs or pads. These areas included the headdress, which contained a thick, well-bound layer of malachite. Otherwise, no attempt was made to remove embedded grime or degraded surface coatings. Selected overpaint and overfills were removed using a 20% (v/v) solution of water in ethanol. Later reinforcement of the black calligraphic lines could not be safely removed but were later muted using thin glazes of retouching.

Retouching was limited and was carried out using Flashe 1300 colors. Exact color matching was avoided; instead, a compatible tone was used that would visually unify the area of damage and would be clearly distinguishable from adjacent, original paint. Losses that exposed white ground were not filled, leaving subsequent inpainting recessed. Losses that exposed the gray rendering layer were not compensated.

Before treatment, the piece had been framed and exhibited as an easel painting; however, this manner of exhibition was reconsidered in favor of exhibiting the work as a fragment of a larger wall painting. To increase rigidity, a maple-wood surround was fitted to the plywood supports.[9] Gaps between the painting and surround were filled with PVB putty, and diluted putty was painted onto the maple over an isolating layer of shellac. The putty was applied in four layers over a period of several days to reduce cracking and shrinkage, then sanded to the level of the maple surround. Multiple layers of neutral-gray latex paint were applied to unify the background, which was recessed from the painting by one-quarter inch (0.635 cm).

## Discussion of Both Painting Fragments

Although the Chinese wall painting fragments described here are unrelated by geographical and historical origin or restoration history, each has been visually and structurally altered over time and through human intervention. Surface examination and technical analysis provided an objective basis for evaluation and implementation of treatment materials and procedures. Budgets and deadlines limited the extent to which technical analysis and treatment could be undertaken. Conservators of *The Female Attendant* operated under a low budget with an impending exhibition deadline. By contrast, the budget for technical analysis and treatment of *Bearer of Good Wishes* was significantly higher. Moreover, *Bearer of Good Wishes* was treated over a two-year grant period that was easily extended when it became necessary. In consideration of the fragile condition of these works and the limited resources for research and treatment implementation, treatment of these paintings was restricted to stabilization of the renderings, consolidation of the paint surface, limited removal of grime, and minimal compensation of damage.

### Stabilization of the renderings

In the treatment of both paintings, reattachment to the supports and filling of voids were favored over more comprehensive consolidation. Several factors influenced these decisions. First, an overall consolidation of the rendering layers would have required removal of the plywood backings, an approach that was considered too invasive and potentially damaging. Second, generalized application of a consolidant could have penetrated and adversely affected the saturation or reflectance of paint layers. Third, by exhibiting the paintings horizontally or at an incline, the need for more extensive consolidation was avoided.

Selection of the materials and methods used to reattach the rendering layers and fill voids was based on the severity of detachment and testing of a variety of adhesives on test blocks (acrylic and PVA resins, acrylic dispersions, and cellulose ethers). While the rendering layers in *The Female Attendant* were detaching locally along the fragment's perimeter, those in *Bearer of Good Wishes* were detaching more generally and crumbling to fine powder and coarse aggregates. Testing demonstrated that Acryloid B-72 bulked with glass microspheres was an appropriate adhesive filler to remedy the edge delamination observed in *The Female Attendant*. By contrast, polyvinyl butyral bulked with glass microspheres proved an appropriate grouting material for *Bearer of Good Wishes*—the material proved successful on mock-ups and in the treatment of other wall paintings (Hanna, Lee, and Foster 1988). Further, the high molecular weight of the polymer decreases penetration into the rendering layers.

### Consolidation of paint surface

Considerations in the selection of consolidants for the paint surface of each painting included adhesive strength, workability, aging properties, and effect on surface appearance after drying. Subtle differences in the quality and condition of the paint surfaces accounted for the different choice of materials and methods of application. Methylcellulose provided sufficient adhesive strength without altering the reflectance or saturation of the paint surface on *The Female Attendant.* Equal success was achieved on *Bearer of Good Wishes* using Acryloid B-72 in xylene, applied in a glove-bag enclosure saturated with xylene vapor.

## Removal of grime, coatings, and restoration

The friable, porous, water-sensitive condition of the paint surface prevented safe and uniform removal of embedded grime, coatings, and restoration. Aqueous and nonaqueous solvent systems could not be used safely on either painting, except in a few locations on *Bearer of Good Wishes.* The porosity of both paint surfaces prevented adequate clearance of gelled or thickened cleaning systems. Porosity and the underbound structure of the paint on each piece raised questions concerning the use of chelating agents, which might have resulted in removal of certain pigments. Soft brushes and a microvacuum were used to remove standing grime from the surface of *The Female Attendant,* while use of a Groom/stick kneadable eraser was permitted on *Bearer of Good Wishes.*

Another important consideration in cleaning was an uncertain knowledge of how the surface had altered, how the painting might have originally appeared, and how the paintings would be further altered through cleaning. Lacking sufficient resources for further investigation of the chemical composition of the surface layers, removal of coatings, overpaint, and embedded grime from *The Female Attendant* was not attempted; the rationale for this decision is aptly underscored by Mora, Mora, and Philippot (1984): "The removal by cleaning of all non-original materials does not restore the work to its original state, i.e. the state in which it was left by the artist on completing the original work. It simply reveals the present state of the original materials."

Under the guidance of the curator, selected overpaints were removed from *Bearer of Good Wishes.* These sites were selected based on the likelihood that original design elements obscured by the overpaint might be recovered. In the course of treatment, overpaint removal did reveal greater complexity in the cloud formations and slight differences in some decorative elements.

## Compensation

The extent and degree of compensation performed was determined by the visual condition of the paintings and discussion between conservators and curators. Given that coatings and restoration were not removed from *The Female Attendant,* retouching of the image was not considered an appropriate option. Compensation was restricted to application of a Poly Filla surround and fills that were toned with raw sienna and red ochre dry pigments blended to match the color of the exposed rendering layer.

By contrast, previous restoration had compromised the visual intention and subtlety of *Bearer of Good Wishes* to such a degree that more extensive compensation was proscribed by the curator. Paint losses revealing white ground were toned with a neutral color that approximated but did not match the adjacent color fields. Paint and ground loss that exposed the rendering were not compensated. The crudest reinforcement of black outline that could not be removed safely was muted with thin glazes. Flashe 1300 colors, a type of vinyl emulsion-based paint, was selected for retouching because of its matte appearance on drying and its synthetic composition.

### Rehousing

Choices of rehousing reflected exhibition needs, tempered by conservators' recommendations and cautions. *The Female Attendant* was temporarily exhibited at the Denver Art Museum as a work under investigation, reframed with wooden edge molding, and presented horizontally under a Plexiglas vitrine. The wooden frame for *Bearer of Good Wishes* at the Memorial Art Gallery was not reused; rather, a neutral, recessed surround was fashioned, and the painting was exhibited approximately 10° from vertical. The painting was installed in the museum's permanent Asian collection.

## Acknowledgments

The authors wish to acknowledge the assistance of numerous colleagues who contributed to the examination, technical analysis, and treatment of the paintings: Candace Adelson, Richard Brown, Thomas Hopen, Pam Martoglio, Chris Stavroudis, Richard Wolbers, and Williams College for use of the Cambridge Stereoscan scanning electron microscope. For assistance in preparing this text for publication, the authors thank Beth Greenfield Tulipan.

## Notes

1 Examination and treatment of the Denver painting was undertaken by Cynthia Kuniej Berry and Judy Greenfield at the Rocky Mountain Conservation Center. Examination and treatment of the Rochester painting was undertaken by Cynthia Luk and Ingrid Neuman at the Williamstown Art Conservation Center. Technical analysis was performed by James Martin at the Williamstown Art Conservation Center, except as noted.

2 Attribution was made by Julia White, associate curator of Asian arts, Denver Art Museum.

3 Technical analysis involved examination of layered and particle samples using reflected visible light microscopy, polarized light microscopy, fluorescence microscopy, and scanning electron microscopy with energy-dispersive X-ray spectrometry. Infrared microspectroscopy was provided by Pam Martoglio at Spectra-Tech, Inc., Shelton, Conn.

4 The possibility that some surface discoloration or darkening may have resulted from chemical alteration of pigment, especially vermilion or lead-based pigments, was considered. Definitive analysis to identify such alteration products was precluded by time constraints and was a factor in the decision not to clean the painting.

5 The glass microspheres used were soda-lime borosilicate glass manufactured by 3M Specialty Additives.

6 Technical analysis involved examination of layered and particle samples using reflected visible light microscopy, polarized light microscopy, fluorescence microscopy, and scanning electron microscopy with energy-dispersive X-ray spectrometry. Mineralogical analysis was provided

by Thomas Hopen and Richard Brown of MVA, Inc., Norcross, Ga., using polarized light microscopy, scanning electron microscopy with energy-dispersive X-ray spectrometry, and analytical electron microscopy.

7 The glass microspheres used were Scotchlite Glass Bubbles.

8 The technique involves the application of a stable thermoplastic resin solution in a chamber saturated with the solvent in which the resin is dissolved. Acryloid B-72 and polyvinyl acetate have been used successfully under such conditions. Hansen's method differs from past uses of solvent-saturated environments in that the object is placed in the chamber *prior to,* rather than *after,* the application of solvents. This induces further penetration of the resin solution without increasing solution viscosity at the surface, thus encouraging efficient wetting of the pigment particles and even distribution of the resin solution.

9 A supporting maple-wood frame was constructed by Hugh Glover, conservator of furniture and wooden objects, Williamstown Art Conservation Center, and was installed around the existing plywood backing of the wall painting. The design and materials described here were chosen for their strength and easy reversibility. The frame was sized to snugly fit the plywood backing and to sit below the surface of the wall painting. Four maple battens were screwed into the back to trap the plywood backing. Screws were also used to fasten the battens to the maple frame as well as the plywood backing. The areas of the spandrels were filled with plywood. Three lengths of 1-inch (2.64 cm) aluminum channel were screwed to the plywood backing within the recess created by the new framing.

## Materials and Suppliers

**Acryloid B-72** is a copolymer of ethylmethacrylate/methacrylate (70/30) produced by Rohm and Haas, Philadelphia, PA. Acryloid B-72 is also known as Paraloid B-72.

**Ethulose** is a water-soluble cellulose ether composed of ethyl hydroxyethylcellulose. The ethulose used was obtained from Conservation Materials, Ltd., Sparks, NV 89431.

**Flashe® 1300** colors are water-soluble matte colors manufactured by Lefranc and Bourgeois, LeMans, France, using a vinyl emulsion binder.

**Groom/stick** is described by the manufacturer (Picreator Enterprises Ltd., London) as a processed, kneadable, natural rubber that is free of moisture, solvents, and chemical additives.

**Methylcellulose** is a water-soluble cellulose ether. The material used was obtained from Gaylord Brothers, Syracuse, NY.

**Poly Filla** is a synthetic compound of calcium sulfate with cellulose filler manufactured by LePage Ltd., Bremalia, Ontario, Canada.

**Polyvinyl butyral** is a polyvinyl acetal. The PVB used is marketed as Mowital B60H, and is available from Hoechst, Charlotte, NC.

**Scotchlite Glass Bubbles**, 3M Corp., St. Paul, MN.

**Soda-lime borosilicate** glass manufactured by 3M Specialty Additives, St. Paul, MN.

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# Paintings on Silk and Paper from Dunhuang at the British Museum

## Conservation Methods

*Lore Erwine Fleming*

The paintings and sketches from Dunhuang are among the most important treasures of the British Museum. The paintings, along with other items, were discovered by a Taoist monk around 1900 in a sealed repository next to Cave 17 at Dunhuang (see map, page xiii). Mark Aurel Stein (later Sir Aurel Stein), the British archaeologist, explorer, and orientalist, visited Dunhuang in 1907, having heard of the existence of a great library (Stein 1987; Hopkirk 1985). After some delays, he obtained several thousand items from the repository, which were then sent to England and India. India received three-fifths of the items and England two-fifths—the proportions reflecting their relative levels of sponsorship for Stein's journey. The British Museum's share included prints on paper, paintings, drawings, and sketches on paper (Fig. 1), scrolls of stencils, banners, booklets, paper flowers (Fig. 2), a paper valance, and, of course, paintings on silk (Fig. 3).

The paintings on paper and silk in the museum's collection date from the eighth to the tenth century C.E. (Whitfield and Farrer 1990), and

*Figure 1*
Sketch of camel, detail. 30.5 × 84.5 cm (British Museum 1919-1-1-077).

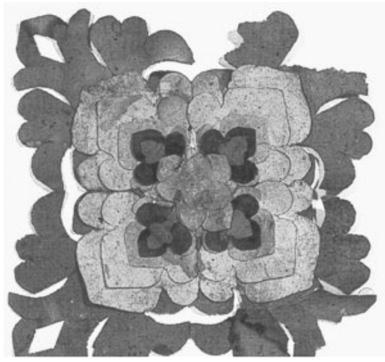

*Figure 2*
Paper flower. 16 cm diameter (British Museum 1919-1-1-0230).

*Figure 3*
Banner, *Avalokitésvara with Suryagarbha Candragarbha and Maitreya Bodhisattvas.* 61 × 58 cm (British Museum 1919-1-1-059).

their condition varies from small fragments to almost complete works of art. Many of the temple banners and Paradise paintings in relatively good condition were repaired in antiquity by the technique of affixing strips of paper manuscripts to the backs and resewing the silks. In contrast, many of the paintings on silk were in poor condition, being mere crumpled bundles of fragments. Tasks required for their modern conservation were flattening of the fragments, assembly of the fragments into more complete images, and consolidation of the assembled images into a suitable format for storage and display.

## Conservation of Works on Paper

Damage to the works of art on paper from Dunhuang has been caused by handling, insects, or dampness through the years. Because of these degradations, many paintings now consist of fragments, which can sometimes be consolidated and mounted to compose one image again. The paper carrying the image is usually quite robust; in these cases the holes and lacunae are filled with matching paper, often supported from the verso with a lighter paper, which is 3 mm larger than the missing area and attached with paste to the back of the original behind the repair.

The paper preferred for these repairs is a fairly heavy, long-fibered mulberry paper, handmade in Japan (Barrett 1983; Hughes 1978), which matches the characteristics of the old Chinese paper. (It has not been possible to match these characteristics with a modern Chinese paper.) The fine paper used on the verso may be a handmade *tengujo,*[1] or something slightly heavier if the original is very fragile. These strong, flexible, and transparent Japanese papers are attached with gluten-free wheat starch paste.[2] The repair is toned to a matching background color with watercolors.

Sometimes the damage is more extensive, and the whole object is in very poor condition (Fig. 4). The verso of *The Arhat Kalika as Monk* shows problems caused by some old linings and repairs, probably made while the artwork was in use in Dunhuang—although these interventions no doubt saved the painting from disintegration. When all the old repairs were removed, the piece was very fragile and required extensive repairs and a new lining. These repairs were achieved with the Japanese technique

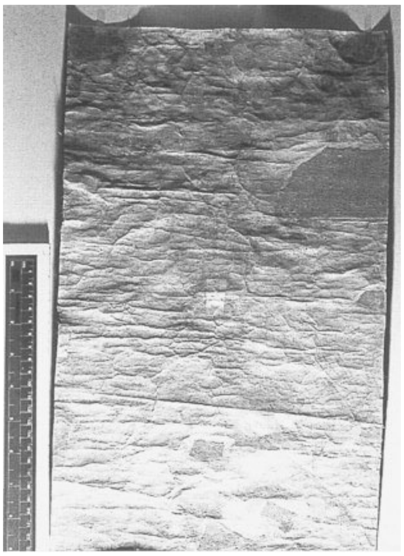

*Figure 4*
Verso of *The Arhat Kalika as Monk,* showing the poor condition of the painting. 43.5 × 26 cm (British Museum 1919-1-1-0169*).

of relaxing the painting with water, brushing it flat, and applying pasted lining paper. The weight and fragility of the original determine the choice of lining paper (Koyano 1979). In this case it was fairly heavy.

The design of the image is never restored. In the British Museum, the ethic of conservation calls for the repair to be clearly visible to scholars without being too intrusive to viewers when the object is on exhibition (Fig. 5).

Pigments employed by the original artist sometimes cause problems for the conservator. For example, the green pigment verdigris (basic copper acetate) can hydrolyze, becoming acidic and "burning" holes in paper (Fig. 6). The new supporting paper on the verso is placed behind any remaining verdigris to hold the area and prevent further loss, and the lacunae are filled in as before and left a neutral tone. The area of verdigris is also deacidified by localized brushing with magnesium bicarbonate in a solution of Klucel G (hydroxypropylcellulose) as recommended by Banik, Stachelberger, and Wächter (1982). The magnesium bicarbonate stops the attack of the copper acetate on the paper by neutralizing free acid, and the cellulose encapsulates the pigment grains, separating them from the paper fibers and preventing the access of moisture that leads to hydrolysis.

Problems can also arise when lead-containing pigments have been used, such as white lead carbonate and a red oxide of lead ($Pb_3O_4$), as they blacken in the course of time by reaction with hydrogen sulfide from the atmosphere (Fig. 7). This blackening is treated with a local application of hydrogen peroxide in diethyl ether, which oxidizes the exposed surface layer of the blackened pigment to white lead sulfate (Daniels and Thickett 1992).

*Figure 5*
*Dharmatrata,* showing repairs. 41 × 29.8 cm (British Museum 1919-1-1-0168*).

*Figure 6*
*Talisman of the Pole Star,* showing loss of paper caused by degradation from verdigris pigment. 42.7 × 29.7 cm (British Museum 1919-1-1-0170).

*Figure 7*
*Avalokitésvara,* showing blackened red lead pigment. 49.8 × 29 cm (British Museum 1919-1-1-0159).

Stains are the most difficult to treat. They could have been caused by lamp oil, candle wax, food, or dirt. Washing often puts the image at risk, and there is no guarantee that these stains will respond. Some prints were washed and yet are still stained, so it is sometimes better to accept the stains as part of the history of the work of art.

## Conservation of Works on Silk

Many of the paintings on silk consisted of bundles of crumpled fragments that had fortunately been stored in solander boxes since their arrival at the British Museum in 1908 (Fig. 8) (Whitfield 1982–85). The late Alfred Crowley, a conservator in the Department of Conservation from 1967 to 1990, spent several years treating fragments by floating them on a pool of water on glass to relax and flatten them, and then drying them between sheets of blotting paper. The colors were absolutely fast and totally unfaded. The other astonishing fact was that although these paintings on silk were fragmentary, each small piece of silk was strong enough to be handled. Some fragments had been stuck onto paper in the past—possibly by a desperate British Museum conservator shortly after 1908. This very crude method of conservation no doubt prevented the loss of many of the small pieces of silk.

*Figure 8*
Bundles of silk fragments before conservation.

When the design of the fragments could be seen, it was possible to assemble them into larger pieces with curatorial help. Even with gaps in a painting, it was possible to visualize most of the image. Conservation consisted of toning a long-fibered Japanese mulberry paper to a suitable background color with organic pigments such as *yasha*[3] and lining the fragments that belonged together, after they were carefully positioned in relation to one another and moistened face down on a facing paper.

They are lined using a technique that hinges the lining into its correct position on the workbench in relation to the fragments before pasting. The silks are placed in their correct position on a rayon facing paper, and the lining is positioned dry. One centimeter of the lining edge is pasted to the bench to act as a hinge. The lining paper is then turned back and pasted, turned onto the verso of the fragments, and brushed down. For larger paintings, it is sometimes a four-handed job to place the lining in the correct position without disturbing the fragments.

The adhesive used is a 1:1 mixture of ten-year-old wheat starch paste and fresh paste (Winter 1984; Wills 1984). Aging paste is stored in a cellar in large ceramic pots, and one potful is made every year (Fig. 9). The mixed paste is much softer than fresh paste, with greater flexibility. Gluten-free wheat starch is always used.

For one painting, the borders were in relatively good condition so that the size of the original was known (Fig. 10). Several very large pieces of the painting were found, but there were still very large gaps. Because of the size of this painting (208.5 × 202.5 cm), Crowley had to build a bridge of wooden planks, positioned a few centimeters above the painting, which he moved along so that he had access to each area during the lining process. After the lining had dried, the whole painting was slightly moist-

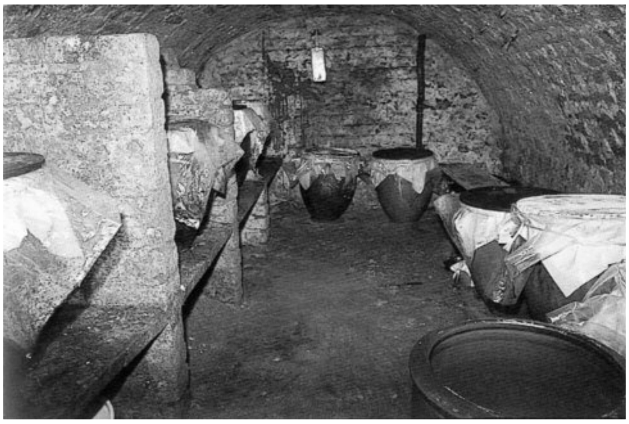

*Figure 9*
Cellar with jars of aging paste. One jar is made per year.

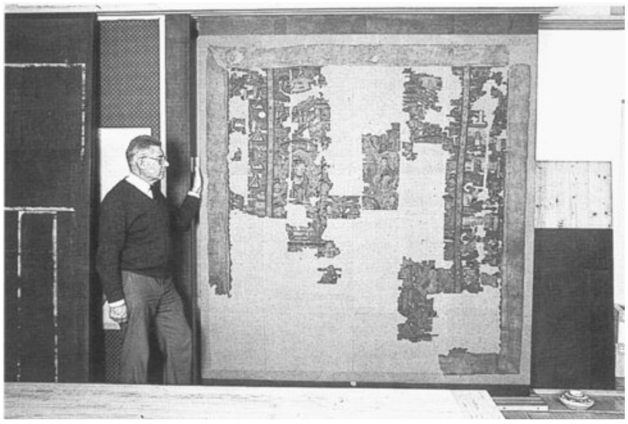

*Figure 10*
Conservator Alfred Crowley with a large painting consisting of fragments. 208.5 × 202.5 cm.

ened and placed on a drying board for several months (Webber and Huxtable 1985). During this period more fragments were found; it was then possible to place these in their correct positions from the front.

## Mounting

Small paintings and sketches on paper are inlaid in European paper of a suitable weight made to British Museum specifications.[4] One method is to pare the inner edge of the inlay and overlap about 3 mm over the edge of the verso of the original or its lining. Another method is to cut the inlay aperture 1 mm larger than the original and attach the painting with 3 mm wide strips of Japanese paper. The aperture of the mount can then show the whole object safely without danger of damage to the edge (Fig. 11). The corners of the mount are rounded, the sides are sanded, and the board is thick enough to hold an adjacent mount away from the surface of the painting while in storage in a solander box. The mounting board is acid free and also made to British Museum specifications. An interleaving tissue is placed in each mount during storage. The small silk paintings are mounted in exactly the same way as the small paintings and sketches on paper.

Larger paintings on silk are mounted on panels made either in a similar manner to drying boards or made of Tycore.[5] The decision as to which panel to use depends upon the size of the paintings, the smaller ones usually going onto Tycore. The wooden trellis is made with "woven" joints so that the trellis does not warp (Webber and Huxtable 1985). The wood used for the core has to be resin free and straight grained, without knots; it cannot be a wood that will stain paper when wet or cause the paper to become acidic. *Liriodendron tulipifera* has been found to have these characteristics. Before the painting is attached, the core is covered with eight layers of paper—a process that creates air pockets (Koyano 1979).

The verso of *Buddha with Cintamani-cakra and Vajragarbha* has a floral decoration that was obviously intended to be shown through a

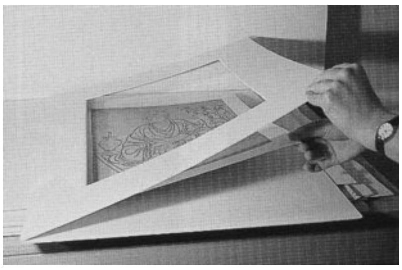

*Figure 11*
Mount with inlaid sketch.

*Figure 12*
Verso of *Buddha with Cintamani-cakra and Vajragarbha,* showing floral decoration behind wooden trellis. 81.8 × 74.7 cm (British Museum 1919-1-1-071).

trellis. Because the flowers were not evenly spaced, each window had to be carefully measured for the trellis to re-create the original effect (Fig. 12). The painting and the trellis are held unglazed in a frame.

The work of sorting the fragments is ongoing; the museum expects to bring the whole collection into good condition over the next few years.

## Acknowledgments

The author would like to thank Andrew Oddy, Keeper of the Department of Conservation at the British Museum, for his assistance in editing this paper.

## Notes

1 *Tengujo* is made from the finest long kozo fibers. It is silky and very fine—sometimes only 0.03 mm thick—but strong, porous, and flexible (Hughes 1978).

2 Gluten is the protein content of wheat starch; it is a hard and brittle solid when isolated and dry. Because the adhesive for conservation should remain flexible, it is important to exclude gluten.

3 The water from boiling alder cones.

4 Paper from cotton or rag fiber, with neutral pH and low hygroexpansivity, both across the grain and with it.

5 Tycore is a panel of rigid, acid-free board with a honeycomb center. It is 15 mm thick and can be framed if desired.

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# Conservation Treatment of Two Ming Dynasty Temple Wall Paintings

*Eric Gordon*

The Birmingham Museum of Art in Birmingham, Alabama, has in its collection two Buddhist temple wall paintings (Figs. 1, 2) from the Ming dynasty. Based on their iconography, these paintings were titled *The Pure Land of Amitabha* and dated roughly to the fifteenth century. In many ways, these mural pieces are distinctive; yet in construction, style, and composition, they show characteristics found in many other temple wall paintings. This article discusses the recent conservation of the murals, which combined traditional and modern treatment methods.

The Birmingham paintings are thought to be the two outside panels of what must have been a much larger composition. It is not known where the paintings originated. In style, they are closest to paintings from Fahaisi in the Beijing area. No inscriptions or graffiti are present, and the quality of the work is high, which suggests that the murals are from an important temple in a major city.

*Figure 1*
*The Pure Land of Amitabha,* fifteenth century. Gilding, paint, and gesso on plaster, 3.20 × 1.61 m. Right panel, after treatment. Birmingham Museum of Art (1987.34).

*Figure 2*
*The Pure Land of Amitabha,* 3.20 × 1.61 m. Left panel, after treatment. Birmingham Museum of Art (1987.34).

The two paintings form an architectural unit: a complete interior wall. Each panel is approximately 3.20 × 1.61 × 0.14 m and weighs nearly one metric ton ($10^3$ kg). Because of their great weight and size, the panels were not removed from their crates after shipment to the conservation studio. After the lid of the crates was removed, exposing the elaborately painted front surfaces, the murals were examined, tested, and treated on the painted side only.

One of the most distinctive features of these paintings is that they were not cut into small blocks to facilitate removal from their original locations and transport to the West. Most likely because of their fairly compact size, the paintings were moved as a whole from their original temple location, and the backings were kept intact.

## Technique

*The Pure Land of Amitabha* mural has a complex structure (Fig. 3). It appears that a heavy wooden, inner framework runs the length and width of the mural in a large grid. This latticework is covered with a plasterlike material containing long, hemplike fibers that run throughout the plaster. The plaster is then covered with a fairly coarse, long-fibered hemp or strawlike material. This layer is loosely adhered with plaster; however, it is distinct from the plaster beneath it. On top of this hemplike layer is a fine but loosely woven, off-white fabric. This fabric provides reinforcing for the finer plaster support. The plaster or light-colored clay on top of this fabric is off-white or slightly gray, and it is finer in composition than the underlying plaster wall. The finer clay or plaster contains short-fibered hemp and finer silica particles. In cross section, one can see numerous, very thin layers of increasingly finer clay built up to the paint layer.

In general, the paint layer is very thin and has a transparent quality. Black outlines are blocked in with various colors. On close inspection,

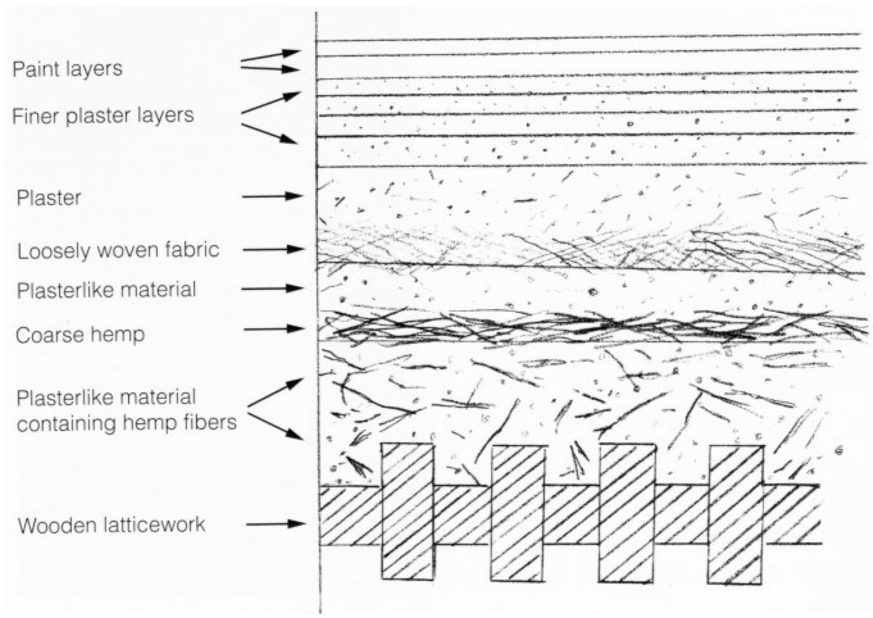


*Figure 3*
Schematic diagram of wall painting structure.

one can see an underdrawing in different colors in some areas. The paint appears to have been applied in washes of various opacities. Blacks and dark greens are more opaque and were applied in layers. The greens, most likely malachite, were not ground as finely in order to maintain their rich color. Pigments were not analytically identified; however, the palette is similar to the other Chinese wall paintings, such as those at the Royal Ontario Museum that were examined at the Canadian Conservation Institute and described by Gordon and Phillimore (1984).

Another distinctive feature of these paintings is the raised, gold gesso ornamentation that lends a jewel-like, delicate appearance to the dark palette (Fig. 4). From cross sections, it appears that a fairly thick, gluelike material was applied to the sculpted plasterwork before the gold was applied. This application helped preserve the gold, making it harder and more impervious to water seepage and damage.

## Condition

The mural structure was of generally good condition and showed no serious damage (Fig. 5). The wooden framework and underlying plaster and hemp layers were in stable condition, although the loosely woven fabric layer had detached from the plaster wall and hemp in numerous areas, resulting in many scattered air pockets. There were three or four large cracks extending half the length of each painting from the bottom edge to the middle of each mural; however, there appeared to be no sign of loss of the support. The entire surface exhibited pronounced cupping with a large network crackle pattern. Underneath these cupped areas, the fabric was detaching from the plaster substrata.

Many small, scattered areas of loss in the plaster support were seen, primarily in the bottom third. The paint layer exhibited extensive flaking and losses, also in the bottom third, as well as in the blacks and

*Figure 4*
Right panel, detail, during cleaning.

*Figure 5*
Left and right panels, before treatment.

coarsely ground greens. This was most noticeable in the depiction of the so-called Wish-Granting Trees, where paint was not only lost but dissolved, displaced, and reformed into discrete pigment agglomerates in the lower areas of the painting. Water damage may have destroyed the cloud-like designs and the bottom 7–8 cm of the murals. These areas were quite faint and abraded.

Evidence of one minor early restoration treatment was found. In an attempt to consolidate flaking paint at some time in the past, a thin resin had been clumsily applied to some areas of cleavage toward the bottom of the paintings and around the platform of the Buddha in each one.

A thick layer of soot and surface grime covered both paintings. Because the paintings were porous and unprotected, dirt had penetrated the plaster due to water seepage and had stained and disfigured the paint layer, obscuring the images.

## Treatment

Because of the conditions described here, the paintings were not considered exhibitable or stable. The basic plan of treatment was to remove the soot and surface grime, as safety permitted, stabilize the cracks, readhere the support layers and flaking paint, set down the cupping, and reintegrate the paint layer to unify the pictorial image. The paintings were treated in a horizontal position; because the panels are relatively narrow, areas in the center could be reached.

As more extensive tests were performed, many other problems soon became apparent. The first of these was cleaning. Tests using dilute solutions, then progressively more concentrated ones were carried out with organic solvents and alcohols, mild soaps and detergents, and mixtures of ammonium and sodium bicarbonate with additives. None of these methods—which are typically used to clean paintings, including wall paintings—worked on these murals. The paint layer was soluble in water, and solvents seeped into the surface and did not remove the dirt or soot. The gold had a harder, more impervious surface and could be cleaned with saliva; however, saliva also solubilized the paint. Ideally, what was needed to clean the murals was a soap that could break through the soot, dissolved in a solvent that would not affect the paint layer.

With the help of Richard Wolbers from the Winterthur Conservation Program at the University of Delaware, a solvent-soap-gel system was developed to cut through the soot and grime without disturbing the paint. This solvent-based, detergent gel consisted of xylene (200 ml), benzyl alcohol (50 ml), Armeen CD (15 ml), Carbopol (2 g), and Triton-X (20 g). The gel was diluted further, after experimentation, with a small amount of Shellsol (a mixture of hydrocarbons). The solution was applied with a cotton swab and rinsed thoroughly with Shellsol. The paint layer was not affected, and the dirt and soot were partially removed (Fig. 4). The purpose of this step was not to remove all the grime covering the paint but to bring back a truer sense of the color relationships. This method solved the problem of grime and soot removal. Since this treatment, however, it has been noted that, in certain cases involving oil paintings, Triton-X can be difficult to remove completely during rinsing. No residuals were found on the murals in this case. Should this cleaning solution be used again, however, one might try eliminating the Triton-X and rinsing with xylene, which has a higher aromatic content than Shellsol.

Another cleaning step involved removing accretions and displaced paint. Water damage had caused some displacement of paint through the centuries. These flakes could not be saved or satisfactorily matched up to their original sites. Therefore, along with accretions, they were mechanically removed with a scalpel.

Actively flaking paint and gold areas that had not yet been cleaned because of their unstable condition were reattached with a synthetic adhesive applied with a small brush. Ethyl alcohol was first applied to an insecure area with a small brush or through a syringe, followed by a dilute solution of the synthetic adhesive Beva D-8 in water. Beva D-8 was chosen because it could sufficiently soften the paint and support layer but not dissolve it. Also, this solution allowed sufficient time for the adhesive to dry; so the area could be manipulated, if necessary—a feature that became useful in later steps. Any excess adhesive could be removed with acetone. Once the flaking areas were stabilized, they too were cleaned.

After the paintings were cleaned and the actively flaking paint reattached, consolidation treatment began on lacunae, branched areas of cleavage, and cracks. The same adhesive used to set down the flaking paint was used for these areas but in different concentrations. Whereas a very dilute solution had been brushed into the actively flaking areas, a thick, concentrated solution was injected into the interlayer cleavage.

To treat lacunae and large, branched areas of cleavage, ethyl alcohol was first injected through a syringe into an opening or crack, which served to open up the connecting network of cleavage and allow the adhesive to flow with greater ease. When the alcohol had completely evaporated, Beva D-8 was injected into the loss, filling the empty spaces and opening channels beneath the paint layer. After the consolidant had settled and started to set, silicone-release Mylar was placed over the area and cleavage was set down with a warm tacking iron (Figs. 6, 7). This greatly reduced the cupping. To ensure the adhesion of the layers and hasten the drying of the adhesive, a Thermofilm heat blanket and conformable weights (fine lead shot contained in fabric) were placed on top of the consolidated area. The heat blanket was controlled by a rheostat and set at a low heat.

Small areas of cleavage and cracks were treated in a similar manner, usually with a tacking iron and without the heat blanket. Small lacunae that appeared secure and had no prominent cracks or openings were not treated. This method of consolidation worked well on the paintings. Flaking and interlayer cleavage were stabilized, and cupping was greatly reduced.

At this stage, a 5% solution of Acryloid B-72 in xylene was brushed over the surface to further consolidate and harden the paint layer and saturate the slightly stained, water-damaged areas. Because the concentration was low, the B-72 did not change the texture, matte appearance, or any other aspect of the surface.

## Discussion

Approaches to filling and inpainting of wall paintings are varied. Whether one should leave a mural with natural and human damage left exposed, or restore losses to hide damage, is a subjective question. There are as many approaches to this question as there are wall paintings; which is as it should be, as the artwork itself should be the determining factor in deciding an approach. In the case of the Birmingham paintings, most of the paint losses were contained in specific, key areas, where loss of paint color contrasted greatly with the exposed clay, as in the areas depicting the Wish-Granting Trees. If left exposed, such losses would detract from the overall aesthetic unity of the murals. Therefore, the curator and

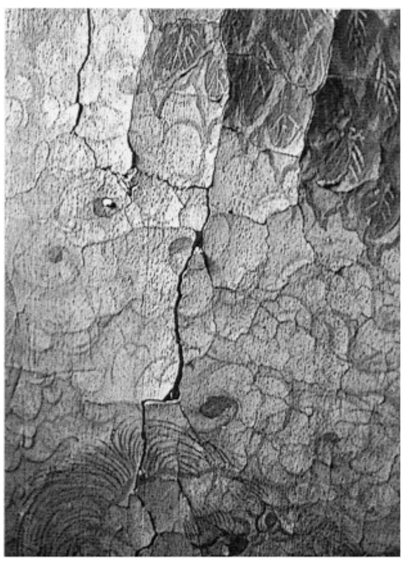

*Figure 6*
Right panel, detail, raking light, before treatment.

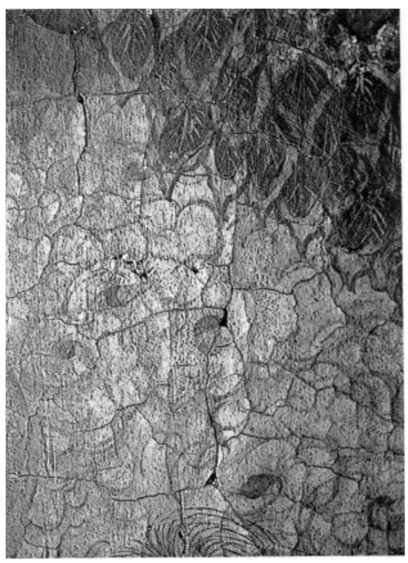

*Figure 7*
Right panel, detail, raking light, after setting down cleavage.

*Figure 8*
Left panel, detail, before inpainting.

*Figure 9*
Left panel detail, after inpainting.

conservator decided that the numerous losses should be toned to match the surrounding area, so a viewer looking at the mural from a standard distance would not be distracted by the exposed white clay. Only the most disruptive, deep losses in the clay support were filled with a pigmented, animal-skin glue and gesso putty with added polyvinyl acetate emulsion. Most of the cracks were left unfilled.

Inpainting was carried out in a synthetic medium with preground, tubed Lefranc and Bourgeois Restorer's Colors. Watercolors were eliminated as an option because if a decision were made to alter the retouching in the future, it would be difficult to remove without affecting—perhaps even dissolving—the original, water-sensitive paint layer. Lefranc and Bourgeois colors can be removed with very dilute solvents, such as mineral spirits containing low aromatic hydrocarbons, without affecting the original paint (Figs. 8, 9).

## Conclusion

Treatment of the two Ming dynasty murals at the Birmingham Museum of Art stabilized their condition and returned them to a more cohesive, tonally correct image. Materials used were reversible whenever possible, and applications of resins and adhesives were kept to a minimum.

## Acknowledgments

The author would like to thank Donald Wood, curator of Asian Art at the Birmingham Museum of Art, for his knowledge and support in this project.

## Materials and Suppliers

**Acetone AR**, Conservation Materials Ltd., 1165 Marietta Way, P.O. Box 2884, Sparks, NV 89431.

**Acryloid B-72**, Conservation Materials Ltd. (manufactured by Rohm and Haas Company, Philadelphia, PA).

**Armeen CD**, cocamine, Akzo Chemicals Inc., 300-T South Riverside Plaza, Chicago, IL 60606-6613.

**Benzyl alcohol**, Fisher Scientific, 1 Reagent Lane, Fairlawn, NJ 07410.

**Beva D-8**, Conservation Materials Ltd.

**Carbopol 954**, B. F. Goodrich Co. Chemical Group, 9911-T Brecksville Road, Cleveland, OH 44141.

**Ethyl alcohol**, Conservation Materials Ltd.

**Lefranc and Bourgeois Restorer's Colors**, Conservation Materials Ltd.

**Shellsol**, Odorless Mineral Spirits, Petroleum Naphtha NOIBN, Inland Leidy, 2225 Evergreen, Baltimore, MD 21216

**Thermofilm heat blanket** is a carbon-coated fiberglass enclosed in heavy Mylar. No wire elements run through it, and the amount of heat can be regulated by a rheostat. It is available from Canada Thermofilm Ltd., 8421 Keele St., P.O. Box 720, Concord, Ontario L4K 1C7, Canada.

**Triton-X 100**, Fisher Scientific.

**Xylenes AR**, Conservation Materials Ltd.

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**Gordon, E., and E. Phillimore**

1984 The treatment of two thirteenth-century Chinese wall paintings in the collection of the Royal Ontario Museum. In *Preprints of the Seventh Triennial Meeting of ICOM Committee for Conservation, Copenhagen, 10–14 September 1984,* 84.15.12–14. Paris: ICOM.

# Research on Protection of Ancient Floor Tiles in the Mogao Grottoes

*Gao Nianzu, Jia Ruiguang, and Wang Jinyu*

Located in the Mogao grottoes at Dunhuang are a wide variety of floor tiles made during medieval times in China. The floors of nearly fifty caves are lined with more than twenty thousand tiles of at least twenty different designs and patterns. These tiles were produced over the centuries, from the Northern dynasties (420–589 C.E.) to the Yuan dynasty (1271–1368 C.E.). The tiles made since the Tang dynasty (618–906 C.E.) are of the best quality. A great variety of tiles were manufactured during the Five dynasties period and during the Song and Western Xia dynasties. Taken together, these ancient floor tiles are an important component of Mogao grotto art.

In 1978, research on the protection of the floor tiles began. Abrasion damage, mainly caused by foot traffic, was identified as a problem. Because of the desire to maintain the design integrity of the ancient floor and to avoid intrusive visual elements, an overlaid walkway or other physical protection methods were not considered. Instead, various consolidants were tested as protective coatings. Results from two stages of experiments suggested that polyurethane coating and infiltration with traditional tung oil can increase the wear resistance of the tiles (Gao, Jia, and Wang 1993).

## Selection of Consolidants as Coating Materials

A consolidant that is to be used as protective material for floor tiles should be transparent, of suitable viscosity to penetrate the tiles, and sufficiently abrasion resistant to provide a durable coating. Two kinds of coatings were selected for testing: synthetic resins and raw tung oil.

Synthetic resins: Polyurethane resin was selected for its elasticity, durability, and wear resistance. For comparison, epoxy resin coating was also tested.[1]

Raw tung oil: This pale yellow oil extracted from the seeds of tung trees is quick drying and provides a strong, nonsticky coating. It has a density of 0.924–0.925 g $cm^{-3}$ and a melting point of 2–3 °C. Tiles permeated with raw tung oil are resistant to erosion by water and alkali, and to deterioration by light and the atmosphere. The "golden tile" used in many important ancient Chinese buildings was made by permeating tiles, after firing, with raw tung oil.

## Preparation of Samples and Testing of Consolidants

The equipment used to test the floor tiles were a road-abrasion testing machine, a high-pressure sandblasting machine, and a freeze-thaw testing machine.

Most of the testing samples were taken from the Meridian Gate of the Beijing Palace Museum during a renovation project. Fired during the Ming dynasty, these tiles are strong, dense, and homogeneous, as demonstrated by the consistency of the testing results. For comparison, the samples were treated with different consolidants in wear-resistance and freeze-thaw tests. Some tile samples taken from the Mogao grottoes were also treated and tested. These tiles were produced during the Tang and Song dynasties.

In preparation for testing, the sample tiles were precisely cut into 15 × 15 × 4 cm square pieces with perpendicular sides and flat surfaces to ensure good contact with the steel balls of the road-abrasion testing machine. The test pieces were oven dried to facilitate penetration of the consolidant and weighed before the consolidant was applied. Results are shown in Table 1 for the fifteen samples tested.

### Tests of polyurethane varnishes on Meridian Gate tiles

In the first part of the experiment (Table 1, samples 1–8), eight Meridian Gate tile samples were tested, each with a different polyurethane varnish. Fifty grams of consolidant with 42% solid content were applied to one side of each tile. The other sides were left untreated for comparison. The consolidants used in samples 1 and 2 were too viscous to penetrate the tiles. In samples 3–8, all the consolidants permeated the tiles and produced a dark, homogeneous, dull, nonreflective surface. Penetration of 1–2 mm was observed when cross sections of these samples were examined under ultraviolet radiation after treatment with aqueous sodium fluorescein. Abrasion tests were performed several days (usually more than fourteen) after the application of the consolidants.

### Tests of raw tung oil on Meridian Gate tiles

In the second part of the test, raw tung oil was applied to tile samples 9 and 10. Following the Chinese traditional methods of manufacturing "golden tiles," both coating and soaking techniques were tested. Abrasion resistance tests were performed after one year of hardening.

Coating method (sample 9): To facilitate the penetrability of raw tung oil, 20 parts of kerosene (by volume) were added to each 100 parts of oil. Fifty grams of the oil-kerosene mixture was applied to the surface of each tile.

*Table 1* Results of abrasion-resistance test results

| | | | Abrasion machine | | Sandblasting | | |
|---|---|---|---|---|---|---|---|
| Tile sample number | Consolidant | Surface condition | Abrasion (g) | Wear resistance[a] | Abrasion ($cm^3$) | Wear resistance[a] | Appearance after coating |
| 1 | Polyurethane floor paint | coated | 0 | | | | Partially reflective |
| | | uncoated | | | | | |
| 2 | Polyurethane floor varnish | coated | trace | | | | Partially reflective |
| | | uncoated | trace | | | | |
| 3 | Wet-fixation varnish (WFV) | coated | 3.2 | | | | Darker, dull, nonreflective |
| | | uncoated | 63.2 | 19.8 | | | |
| 4 | WFV + epoxy resin | coated | 3.3 | | | | Darker, dull, nonreflective |
| | | uncoated | 77.7 | 23.5 | | | |
| 5 | Forbidden City floor varnish | coated | 1.0 | | | | Darker, dull, nonreflective |
| | | uncoated | 74.7 | 74.7 | | | |
| 6 | Thermoplastic binder (TPB) | coated | 0.1 | | | | |
| | | uncoated | 88.4 | 884.0 | | | |
| 7 | TPB + consolidant | coated | 0.5 | | | | |
| | | uncoated | 99.9 | 200.0 | | | |
| 8 | SO-3 additive | coated | 1.7 | | | | |
| | | uncoated | 74.9 | 43.8 | | | |
| 9 | Raw tung oil coating | coated | 0.9 | | 1.66 | | Yellowish, dull, nonreflective |
| | | uncoated | 67.7 | 75.2 | 10.00 | 6.01 | |
| 10 | Raw tung oil soaking | coated | 0 | | 4.29 | | Yellowish, dull, nonreflective |
| | | uncoated | 109.9 | ∞ | 17.00 | 3.96[b] | |
| 11 | TPB | coated | 0 | | | | Dull, nonreflective, little change in color |
| | | uncoated | 94.8 | ∞ | | | |
| 12 | TPB | coated | 0.3 | | | | Dull, nonreflective, little change in color |
| | | uncoated | 119.7 | 399.0 | | | |
| 13 | TPB | coated | 1.3 | | | | Dull, nonreflective, little change in color |
| | | uncoated | 118.9 | 91.5 | | | |
| 14 | TPB | coated | 0 | | | | Dull, nonreflective, little change in color |
| | | uncoated | 42.1 | ∞ | | | |
| 15 | TPB | coated | 1.6 | | | | Dull, nonreflective, little change in color |
| | | uncoated | 116.3 | 72.7 | | | |

[a] Wear resistance = ratio of abrasion of uncoated surface to abrasion of coated surface.

[b] Only 34 g of raw tung oil was absorbed (normally, 50 g of raw tung oil was absorbed).

Soaking method (sample 10): Each test piece was placed in a tightly fitted cardboard frame that had been waxed with paraffin. Fifty grams of raw tung oil was poured onto each test piece and allowed to slowly infiltrate the tile.

All the consolidants used in both the coating and soaking techniques were absorbed completely by the tile samples. After treatment with tung oil, samples were observed to have a dull, homogeneous, nonreflective surface that was slightly yellowish in hue.

### Tests of consolidant on Mogao grotto floor tiles

In the third part of the experiment (samples 11–15), the same consolidant used in sample 6 on Meridian Gate tiles was applied to decorative floor tiles from the Mogao grottoes. Based on the first test results, this polyurethane consolidant, a Wang-brand thermoplastic resin, demonstrated a high degree of wear resistance. The Mogao tiles, produced during the Tang and Song dynasties, are not as strong and dense as those made for the Ming-period Meridian Gate; they contain more sand, less clay, and were fired at a lower temperature.

## Abrasion Tests

Abrasion test results for each tile sample are shown in Table 1. Using a road-abrasion testing machine (from the former East Germany) with a rotating steel ball, 40 kg top load was applied and rotated eighty times on the Meridian Gate samples (samples 1–10). Because they are of poorer quality, the Mogao tiles (samples 11–15), were tested under 20 kg top load and rotated forty times. The polyurethane consolidants used in samples 5–8 gave satisfactory results, especially in samples 6 and 7. These consolidants remarkably increased the wear resistance of the tiles (Fig. 1).

Even better results were observed for the tiles treated with raw tung oil (samples 9 and 10). There is almost no abrasion loss for sample 10 (Fig. 2), which was treated by the soaking method. The tung-oil coated and soaked samples were also tested in a sandblasting machine. The samples were placed at a distance of 20 cm from the spray nozzle and blasted with 6 kg $cm^{-2}$ of air pressure for fifteen seconds. These results demonstrated that treatment with raw tung oil can effectively increase the wear resistance of ancient tile.

The Mogao test pieces (samples 11–15) coated with the Wang polyurethane consolidant used in sample 6 also gave very satisfactory results (Fig. 3).


*Figure 1*
Sample tiles from Meridian Gate, Beijing Palace Museum, after abrasion-resistance testing; tile consolidated with polyurethane on the left and untreated tile on the right.

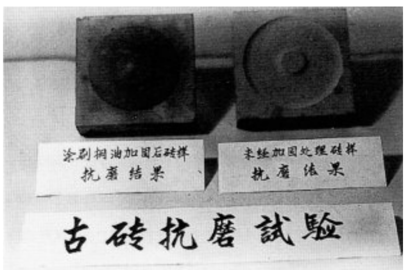


*Figure 2*
Sample tiles from Meridian Gate after abrasion-resistance testing with raw tung oil; treated tile on left and untreated tile on right.

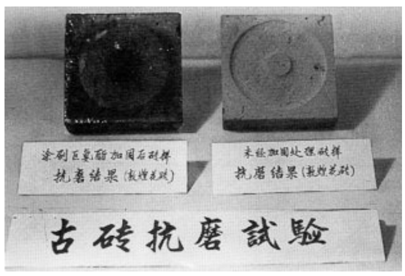


*Figure 3*
Samples of Mogao grottoes tiles after abrasion-resistance testing; tile consolidated with polyurethane on left and untreated tile on right.

## Freeze-Thaw Tests

Freeze-thaw tests were conducted on the tile samples from the Meridian Gate (samples 1–10), using the Wang polyurethane tested in sample 6. The tiles were divided into three groups: (1) untreated samples; (2) samples coated with consolidant on 50% of the total surface area (one face and half of the four sides); and (3) samples coated on 100% of the surface area.

The dry weight of each tile was measured after the coating had been applied and allowed to dry. The samples were then soaked in water for five days. After soaking, each tile was weighed again to obtain its water-absorption rate.

To test the freeze-thaw rate, sample tiles were placed in boxes containing sticks at the bottom for support, with four tile pieces per test box. Water was gradually poured into each box until the top surface of the tile was submerged by 1–2 cm. Each box was then placed in a solution of calcium chloride at −20 °C to freeze for three hours. After this freeze period, the test boxes were transferred to a water bath at 16 °C for three hours to thaw. Temperature change was recorded with a resistance thermometer in each box. Freezing temperatures ranged from −15.95 °C to −1.35 °C, with an average of −6.9 °C. Thawing temperatures ranged from 12.5 °C to 17.7 °C, with an average of 16.6 °C. However, the volume of water in each box was too high for the samples to freeze completely in three hours.

After 40 freeze-thaw cycles, the experiment was modified to ensure effective freezing of the samples. The number of tiles in the box was reduced from four to three, and the water level in the boxes was measured at 1–2 cm above the base, rather than the top surface, of the tiles. The freeze-thaw cycle remained at an interval of three hours. Freezing temperatures measured with the new experimental procedure ranged from −11.3 °C to −3.3 °C, with an average of −7.5 °C. Thawing temperature was from 17.5 °C to 13.4 °C, with an average of 16.5 °C. The experiments were terminated after 163 cycles. Table 2 shows freeze-thaw test results for the seven samples tested. Figure 4 shows deterioration of two tile pieces after 163 freeze-thaw cycles.

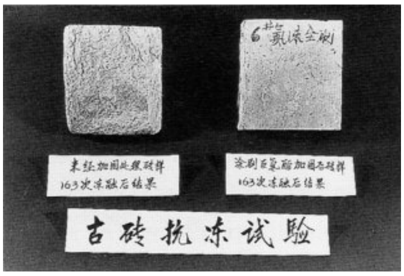


*Figure 4*
Polyurethane treated and untreated tiles after 163 freeze-thaw cycles. The untreated tile is on the left. The tile on the right was treated with the polyurethane used in sample 6 (Table 1).

## On-Site Experiments and Results

The authors began on-site experiments at the Mogao grottoes in September 1980. Tests were conducted at three representative sites: Cave 45 (Tang dynasty), temple ruins in front of Cave 130, and Cave 328 (early Tang dynasty).

Two different consolidants were applied: raw tung oil mixed with kerosene in a ratio of 9:1; and polyurethane (the one tested in sample 6) mixed with a thinner (toluene or xylene and butyl acetate) in a ratio of 1:1.

First the tiles were cleaned and photographs were taken before coating with the consolidants. The coating solutions were then mixed on the basis of the number of tiles to be treated and the amount to be applied to each piece of tile. After treatment, photographs were taken again.

Both raw tung oil and polyurethane were applied to the tiles inside Cave 45 and outside Cave 130, and only polyurethane was used in Cave 328.

Several tiles in Caves 45 and 328 were left untreated and partially coated for comparison, and only four rows of tiles in Cave 130 were treated.

Raw tung oil penetrated rapidly and was readily absorbed; it took only twenty-four hours for the tiles at the site to absorb the same amount of oil that was used in the laboratory. During application of the polyurethane, permeation gradually became more difficult because of the evaporation of the thinner, with only half the amount of consolidant penetrating the tiles at the site as compared with the laboratory test samples.

After more than ten years of observation of natural abrasion at the site, no further wear of the treated tiles has been observed, whereas obvious wear has been observed on the untreated tiles. Thus, results show that these two consolidants were ideal agents for the protection of floor tiles in situ.

## Conclusions

Compounds formed on the surface of tiles treated with polyurethane consolidants can improve the wear resistance of ancient tiles. Of these, the polyurethane used in samples 6 and 7 (Table 1) has produced the most outstanding results.

Results demonstrate that raw tung oil, a traditional material for the treatment of decorative tiles in China, is as effective as—and sometimes even better than—the best abrasion-resistant polyurethane consolidant studied in the testing project.

*Table 2* Freeze-thaw test results

| | | | | Weight change after freeze-thaw test | | | | | | | | | Appearance |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | After 40 cycles | | | After 100 cycles | | | After 163 cycles | | | |
| Tile sample number | Number of surfaces coated | Water absorption (%) | Initial weight (g) | Weight (g) | Weight change (g) | Percent of loss | Weight (g) | Weight change (g) | Percent of loss | Weight (g) | Weight change (g) | Percent of loss | |
| 1 | 0 | 13.8 | 1675 | 1672 | −3 | 0.30 | 1560 | −115 | 6.87 | 1380 | −295 | 17.61 | Tile surface (1–3 mm) peeled off after 70 cycles. |
| 2 | 0 | 14.3 | 1715 | 1720 | +5 | | 1710 | −5 | 0.29 | 1690 | −25 | 1.46 | Tile surface (1 mm) started to peel after 70 cycles. |
| 3 | 0 | 13.2 | 1890 | 1900 | +10 | | 1765 | −125 | 6.61 | 1655 | −245 | 12.96 | Tile surface (1–2 mm) started to peel after 60 cycles. |
| 4 | 1+[a] | 14.8 | 1680 | 1685 | +5 | | 1660 | −20 | 1.2 | 1620 | −60 | 3.57 | Untreated surface started to peel after 70 cycles. |
| 5 | 1+[a] | 14.5 | 1700 | 1710 | +10 | | 1710 | +10 | | 1690 | −10 | 0.59 | Untreated surface started to peel after 140 cycles. |
| 6 | 6 | 15.8 | 1650 | 1680 | +30 | | 1670 | +20 | | 1680 | +30 | | No deterioration observed. |
| 7 | 6 | 13.7 | 1705 | 1725 | +20 | | 1720 | +15 | | 1720 | +15 | | No deterioration observed. |

[a] One full surface was coated plus half of each of the adjacent four sides of the tile.

Even in regard to the poorer quality tiles at the Mogao grottoes, coating with consolidants has greatly improved their wear resistance. On-site experiments also suggest that consolidation can be easily carried out in the field and that use of either coating material satisfies a fundamental conservation principle of retaining the original appearance of materials.

In addition, polyurethane coating was shown to increase the ability of tiles to withstand freezing and thawing with less deterioration of the surface.

In March 1988, an evaluation team from the Unesco World Heritage Committee visited the Mogao grottoes for two days. Team members raised several issues concerning the conservation of the site and made a number of suggestions. The protection of the floor tiles was one of the items mentioned in their report (Unesco 1988: Item 94). They pointed out that replacing the floor tile with concrete would change the original grotto structure and would also disturb the microenvironment inside the cave. Environmental monitoring was suggested for caves with original floor tiles as well as for those with concrete floors. The report also proposed that the ancient floors be conserved by placing mats and other protective pads in areas that incur heavy traffic.

In accordance with the evaluation team's suggestions, environmental monitoring of caves with both types of floors are being conducted. As for floor mats or pads, it was felt that these may be useful for tile protection but would limit visitors' ability to appreciate the aesthetic tile patterns of the floors. The most suitable approach, therefore, is still to treat the tiles with consolidants and other protective coating materials.

## Note

1 Additional information was not available on the chemical nature and source or manufacturer of consolidants tested. Ed.

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# A Chinese Wall Painting and a Palace Hall Ceiling

## Materials, Technique, and Conservation

*Sally Malenka and Beth A. Price*

THE YUAN DYNASTY wall painting and Ming dynasty palace hall installed in the Philadelphia Museum of Art provide, as was the intent of their acquisition, impressive architectural settings for the display of Chinese objects. The development and implementation of a conservation treatment for the painted ceiling of the palace hall initiated a study of materials and techniques of Chinese architectural painting. Although the wall painting represents a different painting tradition, it offered a convenient comparison with a similar paint structure. The materials of both the wall painting and palace hall ceiling were studied using a complement of analytical methods: visible-light, fluorescence, and polarized-light microscopy (PLM), electron probe microanalysis (EPMA), X-ray diffraction (XRD), Fourier-transform infrared microspectroscopy (FT-IR), gas chromatography-mass spectrometry (GC-MS), reversed-phase high-pressure liquid chromatography (RP-HPLC), and wet-chemical testing.[1] The history, the technique and materials, and the conservation treatments for the wall painting and palace hall ceiling are described here.

## The Wall Painting

### History

The Yuan dynasty wall painting depicts an assembly of bodhisattvas, cosmic deities, civil and military guardians, and donors (Fig. 1). It was purchased by the museum in 1924 through George Crofts and Company in Tianjing, China. The wall painting was removed from a partially destroyed temple near Xinxiang in Henan Province (George Crofts and Co. 1924, 1925). It is now displayed in a gallery built from parts of a Ming dynasty temple.

### Technique and materials

The technique and materials of the wall painting are consistent with those published for other wall paintings (e.g., Gordon and Phillimore 1984; Hanna, Lee, and Foster 1988). Under magnification, an underdrawing for

*Figure 1*
Wall painting, Yuan dynasty (1260/80–1368). Width 4.5 m, height 2.8 m. Philadelphia Museum of Art, 1925-98-1. Given anonymously in memory of Langdon Warner.

the layout of the stylized imagery was visible along damaged edges. Folds of garments and lines on faces were not underdrawn but executed in black only after the color fields were painted.[2] The raised ornamentation on garments, jewelry, and attributes were produced before the fields were painted; gilding was one of the final steps.[3]

The range of effects, which are produced by techniques characteristic of a watercolor medium, is masterful. Volume is given to forms by the transition of a single color from dark to light. The texture of leathery skin on the mask of a guardian figure's belt is evoked with concentric circles of large and small dots of paint. Subtle shadows in flesh areas are created with dark underlayers or with black pigments added to white.

Cross-section analysis shows the painting to be composed of three distinct layers: a coarse render, a fine white preparation layer, and a paint or presentation layer. There is no evidence of repainting. A backscattered electron microscope image of a typical cross section is shown in Figure 2. Table 1 summarizes the pigments and grounds identified in these layers.

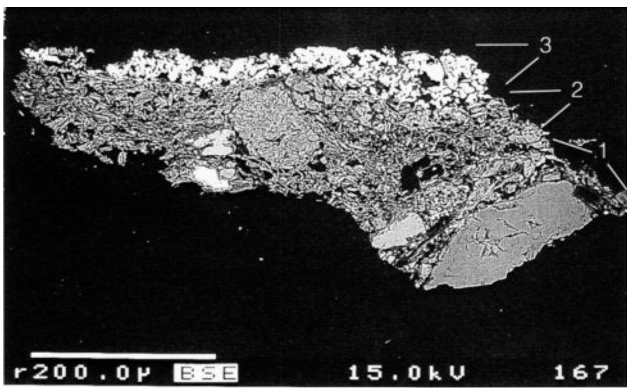


*Figure 2*
A backscattered electron microscope image from the Yuan dynasty wall painting showing (1) coarse render, (2) clay preparation layer, (3) red-lead paint layer.

*Table 1* Pigments and grounds identified in the Yuan dynasty wall painting.[a]

| Layer | Mineral name | Chemical formula | XRD-JCPDS # |
|---|---|---|---|
| Render | clay: | | [b] |
| | kaolinite | $Al_2Si_2O_5(OH)_4$ | [c] |
| | montmorillonite | $(Na,Ca)_{0.3}(Al,Mg)_2Si_4O_{10}(OH)_2 \cdot nH_2O$ | [c] |
| | quartz | $SiO_2$ | 33-1161 |
| | calcite | $CaCO_3$ | 24-27 |
| Preparation | clay: | | [b] |
| | muscovite | $KAl_2(Si_3Al)O_{10}(OH)_2$ | 21-993 |
| | biotite | $K(Mg,Fe)_3(Al,Fe)Si_3O_{10}(OH)_2$ | 2-45 |
| | quartz | $SiO_2$ | 33-1161 |
| Raised ornament | calcite | $CaCO_3$ | 24-27 |
| Paint | | | |
| red | red lead and/or | $Pb_3O_4$ | 8-19 |
| | vermilion | $HgS$ | [d] |
| blue | azurite | $Cu_3(CO_3)_2(OH)_2$ | 11-682 |
| green | atacamite and | $Cu_2Cl(OH)_3$ | 25-269 |
| | botallackite | $Cu_2Cl(OH)_3$ | 8-88 |
| white | lead white | $2PbCO_3 \cdot Pb(OH)_2$ | |
| flesh | lead white with | $2PbCO_3 \cdot Pb(OH)_2$ | 13-131 |
| | red lead and | $Pb_3O_4$ | 8-19 |
| | charcoal black | C | [d] |
| | lead white with | $2PbCO_3 \cdot Pb(OH)_2$ | 13-131 |
| | red lead and | $Pb_3O_4$ | 8-19 |
| | vermilion and | $HgS$ | [b] |
| | charcoal black | C | [d] |
| black | charcoal black | C | [d] |

[a] All samples identified by PLM and EPMA (except where noted by "d"); confirmation by FT-IR or XRD as noted.

[b] Identified by PLM and EPMA.

[c] Identified by PLM, EPMA, and FT-IR.

[d] Identified by PLM.

The coarse render consists primarily of clay, quartz, calcite, and fibers. The fine white preparation layer contains clay and quartz, with less iron than that of the render. The paint palette is restricted to a few colors.

Three kinds of organic media were detected (Fig. 3). Their identification was complicated by the impregnation of the painting with polyvinyl acetate (PVAc), which was detected in each of the layers. (See treatment description that follows.) All of the layers contained proteinaceous material.[4] In addition, there were trace quantities of conifer resin in the fine white preparation layer,[5] and a resin in the gilding mordant. Wax was found associated with the gilding layer.

## Conservation treatment of the wall painting

When the wall painting was removed from its original site, it was cut into eighty sections, backed with paper, and shipped to the museum (Fig. 4). The removal of the painting from its architectural situation initiated a series of decisions, within a Western paintings conservation tradition, as described here.

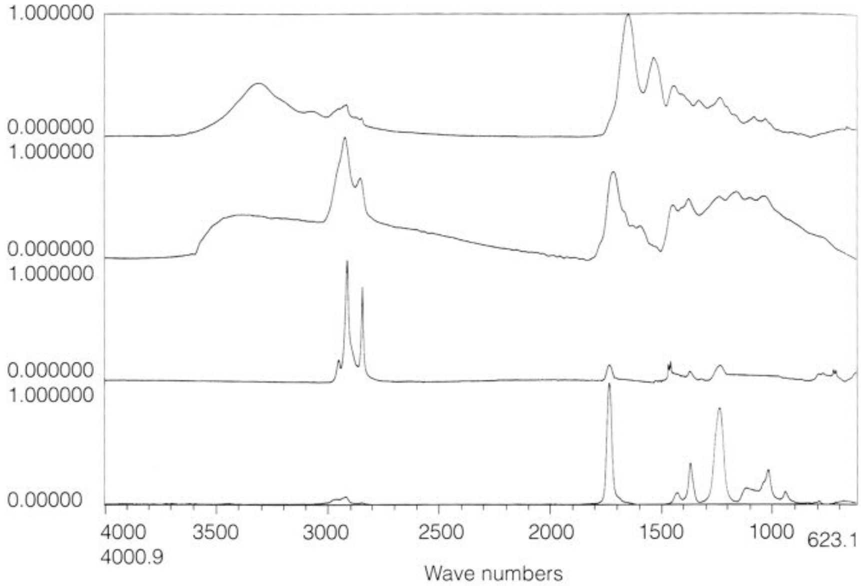


*Figure 3*
Infrared spectra from the Yuan dynasty wall painting (top to bottom): proteinaceous material in coarse render, resin in gilding mordant, wax associated with gilding, and PVAc from the 1930 restoration.

The painting was examined, treated, and reassembled by George Stout and Rutherford Gettens in 1930 at the Fogg Art Museum at Harvard University (Stout and Gettens 1930, 1931).[6] A 5% solution of PVAc was sprayed on the front, and cracks and holes were filled with a mixture of clay, sand, and water; the surface was then brushed with a 20% solution of PVAc. The painting was faced with hide glue, paper, and muslin, and the back was scraped to a thickness of 1–2 mm. After the sections were lined with linen and treated with PVAc, they were held in a press for forty-eight hours[7] and then glued to five wood panels for gallery installation. Finally, the facing was removed with water, and excess PVAc was reduced with toluene.

*Figure 4*
Sections of the wall painting in China, circa 1925.

PVAc was a new material to conservation in the 1930s. Gettens himself became aware of it through publications in 1928 (Gettens 1935:16). The long-term properties of PVAc as a surface consolidant were unknown, but it compared favorably with alternative contemporary resins. PVAc was colorless and retained the matte surface quality of an aged and untreated painting (Gettens 1935:19, 26, 27).

Since its treatment, the wall painting has remained stable with no cleavage from the wood support. The ornamentation is flattened, and the entire painting is smooth and hard. On close examination of the surface, residual PVAc is soft and visible with entrapped dust and dirt. The saw gaps between cut sections were integrated with a toned fill but were not inpainted.[8] This choice, reflecting the collection history of the piece, remains the preference of the curator today. There are no plans at this time for additional conservation of the wall painting.

## The Palace Hall Ceiling

### History

The ceiling of the Ming dynasty palace hall is painted with conventional flowers of the four seasons, stylized dragons and clouds, and delicately rendered mythical animals (Fig. 5). The palace was located in Wangdoren Hutong in northeastern Beijing. According to oral tradition, it was built by a chief eunuch of the emperor Tianqi (1621–27) (Jayne 1929:27–28). At the end of the nineteenth century the Empress Dowager (1835–1908) confiscated the palace and gave it to her younger brother (Smith 1901:535–36). The hall was purchased in 1928 by Horace H. F. Jayne for the museum. From photographs of the palace in situ and in eyewitness accounts, the palace complex had been neglected and had fallen into ruin

*Figure 5*
Palace hall, Ming dynasty (1368–1644), circa 1621–27. Length 14 m, width 11 m, height 11 m. Philadelphia Museum of Art, 1929-163-1. Given by Edward B. Robinette. Note the side door in center of photograph; the installation of the hall as a museum gallery dictated a change in the position of the side doors that had led into two rooms not acquired by the museum.

(Roberts 1940:23). The palace hall is now the setting for furniture and precious objects from the Ming and Qing dynasties.

## Technique and materials

The ceiling is constructed of wood from a species in the red pine group, possibly *Pinus massoniana* (Miller 1992). Areas of design were first blocked out in large color fields, and then the painted decorations were successively applied. The design is formally arranged but loosely executed.

The wood is covered with a coarse render, followed by a fine preparation of dark or white layers or both. Cross-section analysis shows three major paint campaigns and numerous partial campaigns. Figure 6 illustrates a representative cross section. Three complete sequences were found on the ridge beam, which is the highest center beam. Most cross sections examined included the second and third campaigns or some variation of them. Table 2 summarizes the stratigraphy, pigments, and grounds identified in these layers.

In the earliest paint campaign on the ridge beam, green, blue, and red are found with raised and gilded ornamentation. On the main beams, the earliest campaign is red with raised and gilded ornamentation in a geometric pattern. This pattern is stylistically different from the cloud and floral motifs now seen on the main beams.[9]

The palette of the second campaign is narrower than that of the first and third campaigns. Blue, green, black, and white predominate. Only one section of red and one of yellow were found, and they may be associated with other partial repaintings.[10]

The third campaign is the current surface. A coarse render is followed by a preparation layer of white, blue, and yellow. The palette includes the colors of the second campaign. In addition, red lead was used extensively, and red and yellow lakes were found in the flower designs.

The use of malachite, azurite, and vermilion in the early campaigns, compared with the use of copper chloride greens, organic dyes, and red lead in later layers, may reflect the relative cost or availability of

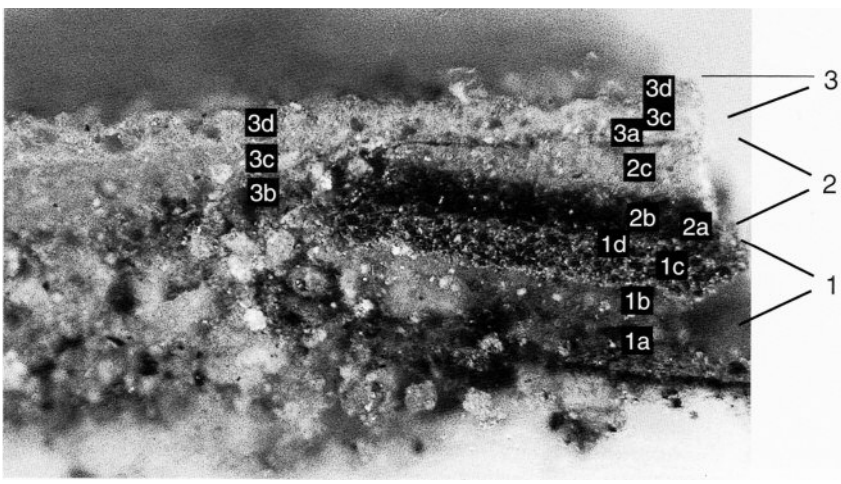


*Figure 6*
Cross section from the ridge beam of the palace hall (10× object ≈ 435 m thick). The cross section shows three paint campaigns. Campaign 1: (1a) coarse render, (1b) white preparation layer, (1c and d) blue and red paint layers. Campaign 2: (2a) coarse render, (2b) black preparation layer, (2c) green paint layer. Campaign 3: (3a) polysaccharide layer, (3b) coarse render, (3c) white, blue, yellow preparation layer, (3d) green paint layer.

*Table 2* Pigments and grounds identified in the paint campaigns of the Chinese palace hall ceiling[a]

| Layer | Mineral name | Chemical formula | XRD-JCPDS # |
|---|---|---|---|
| **FIRST CAMPAIGN** | | | |
| Render | clay | | [c] |
| | quartz | $SiO_2$ | [c] |
| Preparation | calcite | $CaCO_3$ | 24-27 |
| Raised ornament | calcite | $CaCO_3$ | 24-27 |
| Paint | | | |
| green | malachite and | $Cu_2(CO_3)(OH)_2$ | 10-399 |
| | atacamite | $Cu_2Cl(OH)_3$ | 25-269 |
| blue | azurite | $Cu_3(CO_3)2(OH)_2$ | 11-682 |
| blue | dye | | [d] |
| red | vermilion | HgS | 6-256 |
| **SECOND CAMPAIGN** | | | |
| Render | clay: | | [c] |
| | montmorillonite | $(Na,Ca)_{0.3}(Al,Mg)_2Si_4O_{10}(OH)_2{\cdot}nH_2O$ | [b] |
| | kaolinite (minor) | $Al_2Si_2O_5(OH)_4$ | [b] |
| | quartz | $SiO_2$ | [b] |
| | gypsum (minor) | $CaSO_4{\cdot}2H_2O$ | [b] |
| Dark preparation | clay: | | [c] |
| | montmorillonite | $(Na,Ca)_{0.3}(Al,Mg)_2Si_4O_{10}(OH)_2{\cdot}nH_2O$ | [b] |
| | kaolinite (minor) | $Al_2Si_2O_5(OH)_4$ | [b] |
| | quartz | $SiO_2$ | [b] |
| White preparation | clay: | | [c] |
| | muscovite | $KAl_2(Si_3Al)O_{10}(OH)_2$ | [b] |
| | quartz | $SiO_2$ | 33-1161 |
| Paint | | | |
| green | atacamite and/or | $Cu_2Cl(OH)_3$ | 25-269 |
| | botallackite | $Cu_2Cl(OH)_3$ | 8-88 |
| blue 1 | lead white and | $2PbCO_3{\cdot}Pb(OH)_2$ | 13-131 |
| | calcite and | $CaCO_3$ | 24-27 |
| | dye | | [d] |
| blue 2 | | | [e] |
| red | red lead | Pb3O4 | 8-1 |
| black | carbon | C | [f] |
| white | lead white | $2PbCO_3{\cdot}Pb(OH)_2$ | 13-131 |
| yellow | calcite and | $CaCO_3$ | 24-27 |
| | dye | | [d] |
| **THIRD CAMPAIGN** | | | |
| Render | calcite | $CaCO_3$ | [b] |
| | gypsum | $CaSO_4{\cdot}2H_2O$ | [b] |
| | quartz | $SiO_2$ | [b] |
| Preparation | | | |
| white, | calcite and | $CaCO_3$ | 24-27 |
| blue, | dyes | | [d] |
| yellow | | | |
| Paint | | | |
| green | atacamite and/or | $Cu_2Cl(OH)_3$ | 25-269 |
| | botallackite | $Cu_2Cl(OH)_3$ | 8-88 |
| blue | lead white and | $2PbCO_3{\cdot}Pb(OH)_2$ | 13-131 |
| | calcite and | $CaCO_3$ | 24-27 |
| | dye | | [d] |
| orange-red | red lead | $Pb_3O_4$ | 8-19 |
| black | carbon | C | [c] |
| white | lead white | $2PbCO_3{\cdot}Pb(OH)_2$ | 13-131 |
| red | red lake | | [d] |
| yellow | yellow lake | | [d] |

[a] All samples identified by PLM and EPMA (except where noted by [d]); confirmation by FT-IR or XRD as noted.

[b] Identified by PLM, EPMA, and FT-IR.

[c] Identified by PLM and EPMA.

[d] Dyes not included in study.

[e] Not conclusively identified: EPMA detected Si, K, Mg, minor Al, Fe, and no Co, Cu. $SiO_2$ confirmed by XRD.

[f] Identified by PLM.

these pigments. Also, large timbers were valuable; the ones in the palace hall may have been reused from another structure and may have an independent paint history.

In all layers, proteinaceous material was found to be the major organic phase.[11] In the coarse render, GC-MS detected trace levels of drying oil and minor quantities of conifer resin.[12] In the preparation and paint layers, minor quantities of conifer resin were also detected.[13]

An unpigmented layer between the second and third paint campaigns was characterized as a polysaccharide containing starch granules, possibly rice paste, with a minor oil component. This layer was probably applied to improve adhesion of the render of the third campaign. FT-IR of the gilding mordant layer detected a resin and proteinaceous glue, but this identification requires further investigation.

## Conservation of the palace hall

The paint layer is flaking primarily at the wood-ground interface; approximately 75%, or 307 $m^2$, of the ceiling requires some treatment (Fig. 7). In order to select appropriate adhesives for the treatment and to develop a comprehensive conservation strategy, a testing and planning phase was carried out.

Seven test areas representative of failed paint layers were selected. Written records and photographs documented the condition before and after treatment. A section in each test area was left untreated as a control.

The adhesives tested included acrylic resins (Rhoplex AC-33, Acryloid B-72, and Acryloid B-67); PVAc-derived polymers (Bakelite AYAF and AYAT, Butvar B90 polyvinyl butyral resin, Gelvatol polyvinyl alcohol, and BEVA 371); cellulose ethers (Methocel A4C and Klucel G); and proteinaceous glues (isinglass and gelatin). Solvents were selected to control working properties. Adhesives in water, ethanol, or mixtures of both were preferred because they softened the paint, allowing it to be returned to plane, and had low toxicity. The adhesives were introduced under and through the paint layer with a brush or syringe.

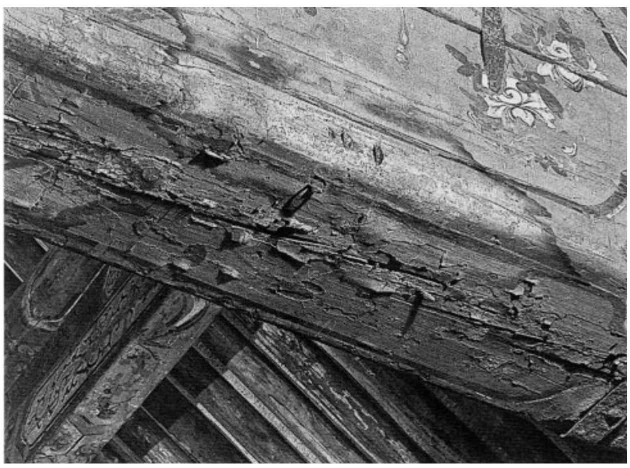

*Figure 7*
Ground-facing surface of a main beam from the palace hall illustrating the flaking and loss of paint.

The test areas were evaluated at intervals of one month and two years by assessing adhesion of the paint to the wood and visible alterations to the surface quality of the paint. Change in saturation of color or the matte quality of the paint was undesirable. It was found that many of the adhesives stained the wood and saturated the color, especially the layer of blue-dyed calcite and lead white.

Based on the test results, Methocel A4C (1–2% in 50/50 ethanol/water) and Klucel G (1–2% in ethanol, and 1–2% in 60/40 toluene/ethanol) (all w/v) were used for the treatment. Methocel A4C did not saturate the wood and paint layer, except for the blue colors; the adhesion was sufficient within the museum environment, which is maintained at approximately 21 °C and 50% relative humidity. Klucel G was the only adhesive tested that did not saturate the blue areas and was therefore used selectively, although in general Klucel G may be considered less stable than Methocel A4C (Feller and Wilt 1990:94–95).

The treatment procedure included removal of particulates on the surface with dry brush and vacuum, removal of particulates from behind the detached paint layer with a brush dampened with mineral spirits, injection of the adhesive with a syringe, and readhesion of the paint with a hot spatula. This procedure was modified as needed to suit the condition of the paint layer.

The project was scheduled to be completed at the end of 1996. A representative area will be left untreated for future materials analysis and as a reference for comparison to treated areas. Long-term care will include monitoring the adhesion in areas that were documented in detail, minimizing dust accumulation, and maintaining low light levels as well as a stable temperature and relative humidity.

## Conclusion

The materials of the wall painting and palace hall ceiling have many parallels, including a narrow palette, raised gold ornamentation, coarse and fine grounds, and proteinaceous binders with trace levels of conifer resins. The use of different materials over time in the palace hall might suggest a change in the cost or availability of particular pigments; studies of similar architecture would provide useful comparisons.

The materials analysis and the testing and evaluation of treatment options, including a review of previous treatments, were considered essential in developing and implementing the conservation treatment of the palace hall ceiling.

## Acknowledgments

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## Notes

1 Instruments used: Zeiss Universal Research polarizing microscope; Wild Leitz Laborlux S microscope; Cameca SX50 electron probe microanalyzer equipped with wavelength dispersive spectrometers (WDS) and Princeton Gamma Tech IMIX solid-state detector; Philips PW1729 X-ray generator equipped with a PW1840 diffractometer and Gandolfi cameras; Nicolet 510P FT-IR spectrometer bench and Nic-Plan microscope with a Spectra-Tech Micro Sample Plan with diamond windows; Fisions VG Trio 2000 MS equipped with a Hewlett-Packard 5850 Series II GC; Hewlett-Packard MS Engine with HP5890 Series II GC; and Waters Picotag amino acid analysis system.

2 A section of the painting that was not installed was examined by infrared reflectography. A brush stroke could be seen as a guide for the placement of the proper left eyebrow of the figure.

3 In contrast, Hanna, Lee, and Foster (1988:34) found the gilding below, not above, the painted decoration for a painting of three bodhisattvas from 1424, Shanxi Province.

4 Proteinaceous material was characterized by FT-IR: NH stretch 3309 $cm^{-1}$; amide II overtone 3078 $cm^{-1}$; amide I (CO absorption) 1657 $cm^{-1}$; amide II ($NH_2$ deformation) 1533 $cm^{-1}$ (Bellamy 1975:233, 250–57). Selected samples were confirmed by amino acid analysis. The amino acid composition of the paint layer included hydroxyproline and had a profile characteristic of an animal-skin glue (Halpine 1992). The coarse render contained other amino acids not accounted for by the animal-skin glue. It should be noted that hide glue was used for the facing as discussed in the treatment section.

5 GC-MS analysis in the selected ion monitoring mode (SIM) detected a molecular ion at mass 314 and the base peak at mass 239, suggesting the presence of methyl dehydroabietate, the methylated derivative of dehydroabietic acid, a diterpenoid present in conifer resins (Mills and White 1982).

6 Many wall paintings acquired by museums in North America and Europe were treated in a similar manner (e.g., Stout and Gettens 1932).

7 Two 2.54 cm diameter fragments of the painting were saved at this stage of the treatment. They are very rigid and glossy.

8 See Stout (1941:105) for a discussion of compensation, including examples from a Chinese wall painting.

9 It is unclear whether the first paint campaign on the main beams is contemporary with the first campaign on the ridge beam. For example, vermilion and gold are found in both; however, the sequence and composition of grounds are different.

10 These anomalous layers may reflect partial campaigns or a sampling bias.

11 See note 4. Amino acid analyses detected more than one proteinaceous material but included animal-skin glue.

12 The dicarboxylic acid methyl ester, dimethyl nonanedioate (azelate) molecular ion, was found with peaks observed at masses 185, 152, 111, 83, and 74, indicating the presence of an aged oil. Trace levels of methyl-7-oxo-dehydroabietate, an oxidation product of pine resin, were detected with peaks at masses 328 and 253 (Mills and White 1982).

13 GC-MS analysis of the preparation layer of the first paint campaign revealed the presence of abietic and pimaric acid methyl ester analogues. In nature, these compounds appear as the free

acids, with trace quantities of the esters occurring in a true bled conifer resin. Significant amounts of these esters may have accrued by pyrolysis of the wood in the collection or production process (White 1993).

## Materials and Suppliers

**Acryloid B-72, Acryloid B-67, Rhoplex AC-33**, Conservation Materials, Ltd., 1165 Marietta Way, P.O. Box 2884, Sparks, NV 89431 (manufactured by Rohm and Haas Company, Philadelphia, PA).

**Bakelite vinyl acetate AYAF** and **AYAT**, Conservation Materials, Ltd. (manufactured by Union Carbide Corporation/ Chemicals and Plastics, 270 Park Avenue, New York, NY 10017).

**BEVA 371**, Conservator's Products Company, P.O. Box 411, Chatham, NJ 07928; or Adam Chemical Co. Inc., 18 Spring Hill Terrace, Spring Valley, NY 10977.

**Butvar B90** polyvinyl butyral resin, Conservation Materials, Ltd. (manufactured by Monsanto Polymers and Petrochemical Co., 800 N. Lindbergh Blvd., St. Louis, MO 63167).

**Gelvatol** polyvinyl alcohol, Conservation Materials, Ltd.

**Klucel G**, Aqualon Company (A Division of Hercules), Wilmington, DE 19894.

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# The Conservation of Tempera Mural Paintings and Architectural Finishes

*Constance S. Silver*

The artistic patrimony of the Silk Road is all the more remarkable when one recalls that its monumental mural paintings and sculpture are derived primarily from Neolithic traditions that stem from simple clay-based technologies. For example, characteristic mud-brick construction, cut-stone masonry, and grotto surfaces were covered with mud renderings, upon which mural paintings and other decorative finishes were executed. Most of the pigments also contain clays. The paint media were obtained from plant gums, faunal glues, and other natural materials (Mora, Mora, and Philippot 1984:82–83).

Although separated by distance and culture, there are many mural paintings in the United States that share technical similarities with those of the Silk Road. The prehistoric and historic mural paintings of Native Americans of the Pueblo culture of the American Southwest are technically the closest. Classically Neolithic, they were painted with naturally occurring pigments in tempera media applied to mud and clay renderings. There are also tempera mural paintings in the Western tradition that date from the eighteenth, nineteenth, and twentieth centuries, although these are rarely executed on clay-based renderings. The following discussion focuses on minimum intervention—a key principle of modern conservation—for the treatment of monumental mural painting in tempera media, and reviews four recent case histories from the United States.

## Minimum Intervention in the Treatment of Tempera-Based Murals

The principal objectives of minimum intervention in the treatment of tempera-based mural paintings are the retention of original materials and their original optical qualities and the retention of the mechanical equilibrium of rendering, preparation, and paint. Consequently, modern synthetic materials of conservation, which generally differ radically from traditional materials, are employed only when there are no other practical options.

However, there are additional technical and philosophical reasons for minimum intervention. Mural paintings are inherently problematic for conservators because they are a component of generally complex building systems that include the architectural/structural support, the materials of preparation and paint layers, the ever-changing interior and exterior environments in which the structure and murals exist, and the impacts from human use and misuse. All elements of the system must remain compatible if the mural painting is to survive in an undamaged state. Unfortunately, it is quite easy for any building system to become destabilized, and it is impossible to predict when instability may occur. It is also acknowledged that many conservation treatments have proved unsatisfactory or incompatible over time, in spite of the best modern climate-control systems. In this regard, the porous nature of the component materials of the murals of the Silk Road, and of similar tempera-based murals, makes complete removal of any poorly performing conservation materials virtually impossible.

Thus, minimum intervention is physically prudent. It is also philosophically attractive because the murals of the Silk Road—like those of the prehistoric Southwest—are the material record of unique moments in human history. When these murals are infused with modern synthetic materials, they are changed forever—even if the treatment accomplishes its goals. The following case histories from three regions of the United States—the Southwest, the Central Atlantic, and the Northeast—illustrate the viability of minimum intervention for the conservation of tempera mural paintings (Fig. 1).

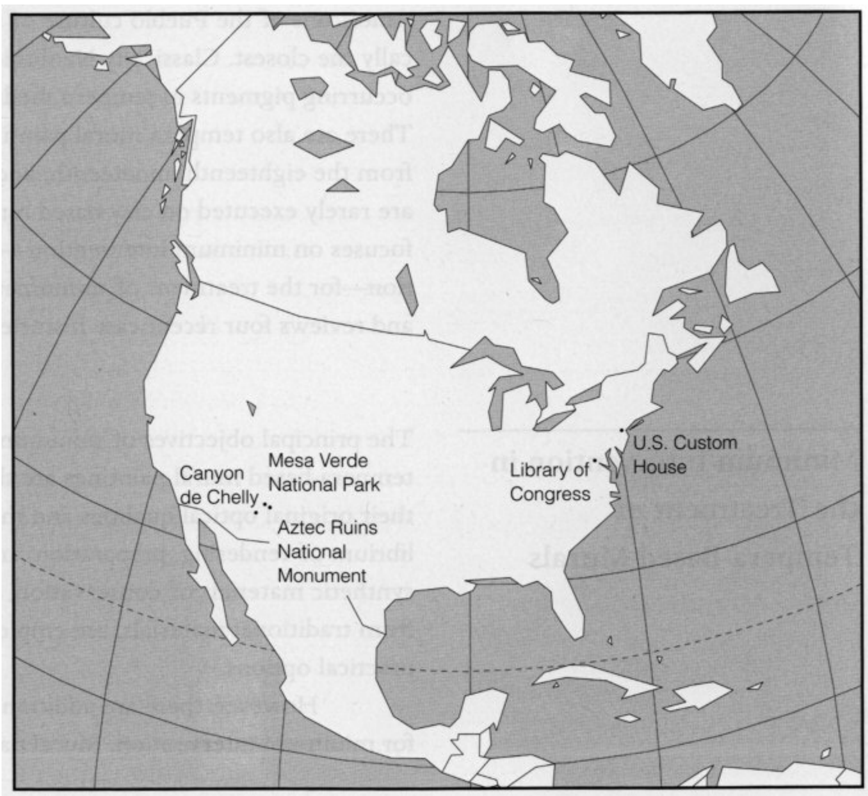


*Figure 1*
Map showing the location of the sites discussed.

## Prehistoric Mural Paintings and Architectural Finishes in the American Southwest

The prehistoric agrarian culture of the American Southwest culminated around 1250 C.E., in complex masonry villages constructed in huge caves, the world-famous cliff dwellings. By about 1350 C.E., the area had been abandoned by its prehistoric inhabitants, for reasons still unknown. Extensive paintings survive on the prehistoric architecture at such sites as Mesa Verde National Park, Colorado; and Canyon de Chelly, Arizona. Briefly summarized, the most complex architectural finishes are composed of a first rough coat of mud mortar applied directly to the masonry, and sometimes to the stone face of the caves. A second finish coat, of finer texture, was applied to the rough coat. This stratum is the surface for the painting. Often, a ground of white clay was applied in preparation for painting. The palette was simple, consisting of a small number of mineral pigments. The most outstanding mural paintings were executed in subterranean chambers called kivas, used for ceremonial purposes (Smith 1952).

In 1981, a field study was undertaken in Mug House Ruin, Mesa Verde National Park, a site administered by the National Park Service. The objective was to develop methods for the conservation of the architectural finishes and to test the conservation treatments in the field over several years. The research design was based on an observable fact: after eight hundred years in uncontrolled environments, in the absence of human contact, the murals had remained in remarkably good condition. Clearly, this "system" of architecture, architectural finish, and environment had proved itself compatible over many centuries. Where unaffected by human intervention, deterioration of the architectural finishes resulted largely from the fatigue and desiccation of the component materials over time. Therefore, modern materials of conservation were judged an option of last resort because they might introduce a destabilizing element into the generally stable system, in addition to changing the original materials' composition forever.

However, the murals of the subterranean kivas were actively deteriorating from human intervention: they had been excavated in the early 1960s and left exposed, the surface of the murals acting as the site of evaporation for groundwater moving through the masonry. Several conservation problems had developed and become very serious: detachment of rendering from the wall; delamination between strata of the rendering; friable rendering; flaking paint; efflorescence; root penetration; burrowing insects and rodents; and surface dirt.

It was posited that water would be an effective conservation material because of its capacity to relax and replasticize the brittle and deformed clay-based rendering and paint. This would permit compaction and cohesion of the delaminated strata of the rendering and their reattachment as a cohesive unit on the masonry. Water also enhances the bond between paint and rendering, perhaps also by reactivating any remains of desiccated original media that might still be present.

Pilot conservation treatments were carried out on one kiva and on one standing wall of Mug House in 1981 (Fig. 2) (Silver 1991). Briefly summarized, the treatment to stabilize rendering and paint entailed temporary attachment of supportive wet-strength tissue facings to the surface,

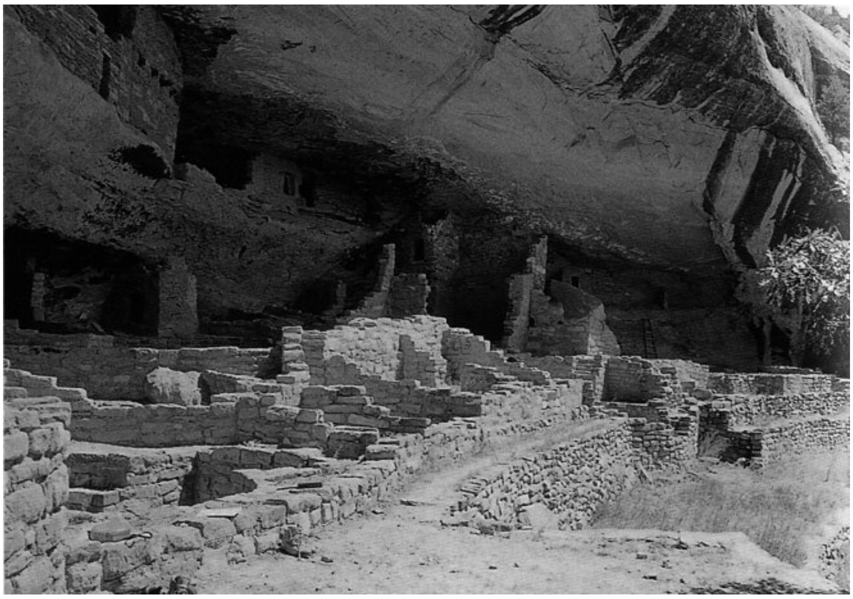

*Figure 2*
Mug House Ruin, Mesa Verde National Park, Colorado.

using water applied by brush. This was followed by spraying of water, until the rendering became malleable. A mixture of 50% water and 50% isopropyl alcohol was injected between the detached rendering and the masonry, followed by injections of diluted polyvinyl acetate emulsion.[1] The treated area, now a cohesive unit, was pressed back onto the plane on the wall and allowed to dry under pressure for twenty-four hours. The adhesive was the only synthetic material used in this treatment because no other practicable category of material was available. However, it was used as a thin stratum in discrete areas of detachment between the surface of the masonry and the rendering. No synthetic materials were infused into the fabric of the mural nor applied to its surface.

After nine years, the treated areas had remained stable. Based on these results, two comprehensive projects to conserve very unstable mural paintings were carried out at Aztec Ruins National Monument, New Mexico (Silver, Snodgrass, and Wolbers 1993). Aztec Ruins National Monument is a prehistoric site administered by the National Park Service. The first project was undertaken in 1990 to stabilize the mural paintings in Room 156, a roofed masonry structure (2.8 × 3.1 × 3.4 m high). Although roofed, there had been leaks—causing serious detachment of the mural paintings from the masonry walls—erosion, and considerable deposition of mud on the painted surfaces.

The murals were stabilized using the methods developed in 1981 during the pilot treatments at Mesa Verde National Park. However, Rhoplex AC-33, an acrylic emulsion adhesive, was substituted for polyvinyl acetate emulsion because there is some evidence that it will age better in the field. The mud was removed with various mechanical methods. The murals have remained stable.

The mural painting in Room 117 of Aztec Ruins National Monument was treated in 1992 (Fig. 3). Measuring about 1 × 1.3 m, it is located on a fragmentary wall that had been partially exposed to the ele-

*Figure 3*
Mural painting in Room 117, circa 1300 C.E., 1 × 1.3 m, Aztec Ruin National Monument, New Mexico.

ments since excavation around 1920. The mural, composed of horizontal fields of white and red paint, is unusual and important because many anthropomorphic, zoomorphic, and geometric forms were etched into the upper white field.

The mural had deteriorated and become very unstable due to its semiexposed position and to artificial and adverse changes in drainage patterns. The instability was exacerbated by the effects of heavy coatings of shellac and cellulose nitrate, which had been applied as consolidants in the past. These coatings were unsightly because they had consolidated dirt on the surface and had blanched (i.e., turned milky and opaque). More disturbingly, however, the coatings were contracting, causing the painted stratum to curl and detach from the mud rendering.

A treatment to remove the coatings was developed by application of solvent mixtures through Gore-Tex[2] and wet-strength tissue. The Gore-Tex appears to exert a poultice effect, drawing the dissolved coatings from the mural and depositing them on the tissue. However, laboratory examination showed that some adhesive remains fixed below the painted surface, again indicating that it is impossible to remove all consolidants from this type of porous material.[3] The murals were then stabilized with the treatment used in Room 156, mentioned above. The final step of the project entailed controlled backfilling as the only viable and cost-effective way to protect the mural from the elements.

## Tempera Mural Paintings by Candido Portinari in the Library of Congress

The Library of Congress in Washington, D.C., maintained by the architect of the U.S. Capitol, has recently been renovated and restored. On 12 February 1990, a frozen pipe ruptured above the Hispanic Reading Room. Water flooded the area above the room and soaked into the mural *Mining for Gold,* painted in 1941 by the Brazilian artist Candido Portinari (1903–62) in a tempera technique on a lime-based plaster (Fig. 4). According to his son, Portinari painted with Totain glue, a form of rabbit-skin glue still used today. Laboratory analyses confirmed the presence of rabbit-skin glue, but also suggested that egg albumen might have been used, as well, in a very limited way.[4]

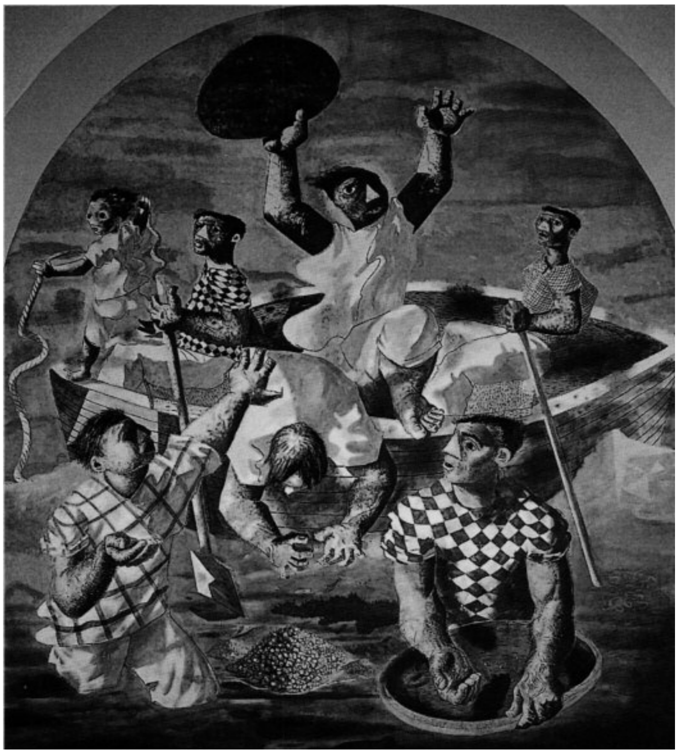

*Figure 4*
Candido Portinari, *Mining for Gold,* 1941, 5 × 6 m, Jefferson Building, Library of Congress, Washington, D.C.

Following the flood, the ambient conditions of the room and the water content of the mural painting were monitored. The relative humidity in the room stabilized about three weeks after the flood. The mural was allowed to dry slowly for several months. The flooded cavity wall was opened, and fans maintained circulation of air in the room and in the wall. Although the mural had been soaked, it remained remarkably stable as it dried. However, the paint did powder and flake in many areas. Salts composed of sodium sulfate, sodium chloride, and sodium carbonate effloresced in some areas.

A conservation treatment was carried out in April 1991. Salts were removed on a cotton swab moistened with saliva. Powdering paint was consolidated with rabbit-skin glue diluted 1:18 in water, and applied as a fine mist. Areas of lost paint were inpainted with pure powdered pigments in water. The mural painting has remained stable since treatment.

## The Murals of Reginald Marsh in the U.S. Custom House, New York City

One of the most outstanding cycles of mural paintings in the United States was executed in 1937 in the rotunda of the U.S. Custom House, New York City, by modern American master Reginald Marsh (1898–1954) (Fig. 5). The sixteen murals show alternate scenes of the port of New York as it appeared in 1937, with trompe l'oeil portraits of important historic explorers. Laboratory analyses were positive for protein, supporting archival documents that suggested that Marsh employed a tempera medium composed of pigments mixed in limewater and skim milk applied to a dampened lime plaster; however, Marsh's idiosyncratic technique has not been identified with complete certainty.

*Figure 5*
The murals of Reginald Marsh, painted in 1937 in the rotunda of the U.S. Custom House, New York City.

From 1937 until 1970, the rotunda was a busy office space. With the exception of heat in the winter, the environment remained uncontrolled. From 1970 until 1991, the building was abandoned and unheated, and the roof often leaked. Thus, when each mural was individually examined in 1990, preparatory to the renovation and reoccupation of the building, areas of powdering and flaking paint were anticipated and recorded. However, the overall stability of Marsh's rather odd and inherently fragile system of monumental painting within such poor ambient conditions militated against introduction of consolidants and fixatives that could prove destabilizing over time.[5] It was decided that Ethulose (ethylhydroxyethylcellulose) would be employed as the fixative. Although Ethulose is a modern synthetic product, it shares many properties and is compatible with traditional materials. An aqueous solution ranging from 1% to 1.5% in deionized water and ethanol 1:1 was applied by spraying. Moreover, like the highly diluted rabbit-skin glue used to treat the Portinari mural, Ethulose did not alter the optical quality of the colors.

## Conclusions

Tempera mural paintings that share many technical similarities with those of the Silk Road exist throughout the world. Two principal conclusions are drawn from the case histories discussed in this paper. First, although inherently fragile and sensitive to the environment, mural paintings executed in tempera media can remain stable over centuries, especially when protected from human intervention. Second, many problems of conservation can be treated effectively with minimal intervention, which avoids the introduction of potentially incompatible modern materials that change the character of the mural painting forever and may well prove deleterious over time.

## Acknowledgments

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## Notes

1 CM Bond M-1 PVA emulsion (see Materials and Suppliers) was used in a 20% dilution.

2 Gore-Tex (see Materials and Suppliers) is a polytetrafluoroethylene (PTFE) in sheet form. It has an unusual semipermeable nature that allows transmission of aqueous and nonaqueous liquids and vapors, while being inert and incapable of adhering to other materials.

3 In this case, the relative success of removal was determined by examining cross sections of the mural painting before and after treatment at 200× magnification. Before treatment, layers of shellac fluoresced conspicuously orange on and below the painted surface of the mural. After treatment, a very thin layer of orange fluorescence was visible just below the painted surface.

4 The analyses were carried out by the Conservation Science Department, National Gallery of Art, Washington, D.C. The conservation treatment was carried out by Christy Cunningham-Adams. Unpublished reports on this mural and its conservation are located in the Archives of the Architect of the Capitol, Washington, D.C.

5 The U.S. Custom House is under the jurisdiction of the General Services Administration. The project development was carried out by the author (for Preservar, Inc.), and the conservation treatment by Perry Huston and Associates and New York Conservation Associates. Scientific analyses were carried out by SciCom, Inc., Professor Richard Wolbers (University of Delaware), and Professor Frank Matero (University of Pennsylvania).

## Materials and Suppliers

**CM Bond M-1 PVA emulsion**, Conservation Materials, Ltd., 1165 Marietta Way, P.O. Box 2884, Sparks, NV 89431.

**Ethulose**, Berol Noble Inc., Meritt 8 Corporate Park, 99 Hawley Lane, Stratford, CT 06497.

**Gore-Tex**, Gore, Inc., 555 Papermill Road, Newark, DE 91714-9329.

**Rhoplex AC-33**, Conservation Materials, Ltd. (manufactured by Rohm and Haas Company, Philadelphia, PA).

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