met objectives

Due to the tenacity of organisms that infest and feed on works of art, and the damages they cause to the physical structure and visual character of their hosts, biodeterioration in museums is a recurring problem that needs to be addressed in a variety of ways. The Sherman Fairchild Center for Objects Conservation works actively with other museums and academic institutions in developing strategies for preventing, monitoring, and eliminating fungal and insect infestations that affect paintings, works of art on paper, textiles and three-dimensional objects in the collections of the Museum's seventeen curatorial departments. This issue of *met objectives* highlights some aspects of the Center's research and treatments, and serves as an invitation and appetizer to *Art, Biology, and Conservation 2002,* an international symposium to be held on June 13–15 at The Metropolitan Museum of Art.

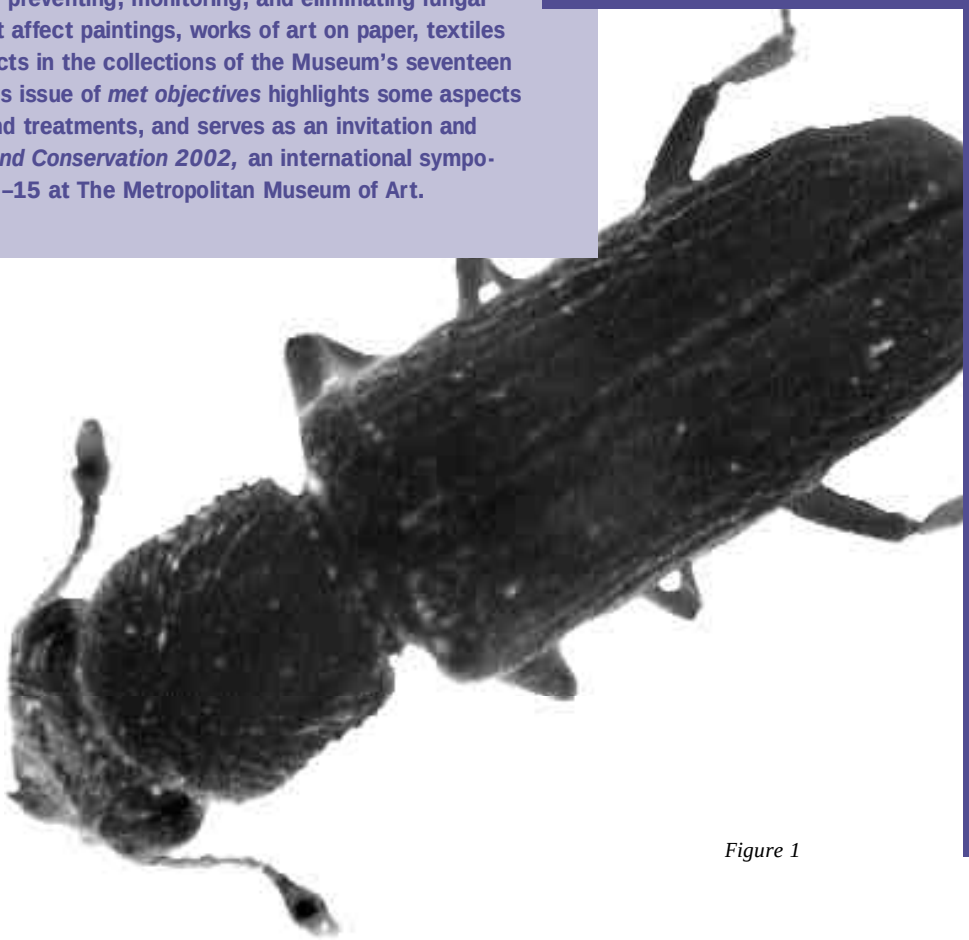

Figure 1

The Sherman Fairchild Center for Objects Conservation
The Metropolitan Museum of Art – Spring 2002
Treatment and research notes, Volume 3, No. 2

Biodeterioration in Museum Collections

Biodeterioration is the term generally used to describe the decay of culturally, historically, or economically significant materials that is caused by biological agents. In contrast, biodegradation refers to the breakdown of materials in nature. Microorganisms frequently damage stone and have been known even to attack metals, but as a rule, in museums as in nature, it is organic materials that suffer most from biological decay. Wood, ivory and bone, paper, leather, textiles, glues and sizes, as well as conservation materials, such as the silane compounds typically used to consolidate silicaceous stone, are all susceptible to biodeterioration. In addition to fungi, commonly known as mold or mildew, microorganisms that degrade cultural properties include bacteria, algae, and lichens, which are essentially symbiotic associations of algae and fungi. Mosses, ferns, plants, trees, and many kinds of animals, including humans, are responsible for various forms of biodeterioration as well, but the greatest threats to museum and historic collections are posed by fungi and insects (*Figure 1*).

Among the more than fifty thousand known species of fungi that provide the essential service of breaking down the earth's organic waste, several hundred have been found to cause damage to works of art. Fungi are assigned to a kingdom separate from that of plants because of their distinct morphology, and due to the fact that they derive energy not through photosynthesis but from nutrients absorbed from organic matter. The basic units of fungal morphology are the hyphae, tubular filaments that usually form radial networks called mycelia. When reaching maturity each mycelium

produces spores, reproductive cells that are formed either directly on the hyphae or in specialized fruiting bodies. Spores are dispersed in a variety of ways and are usually present in any non-sterile environment, although germination only occurs when both substrate and environmental circumstances are favorable.

Fungus-related problems typically result when collections are displayed or stored in areas lacking climate control, or following the failure of an existing system. In environments with a relative humidity greater than 80%, a period as short as three days is sufficient for spores to germinate and produce mycelia that can grow on or below the surface of an object. For especially hygroscopic materials even shorter exposures may initiate growth, and once removed from a humid environment, these materials can take weeks to dry out enough for fungal activity to cease. Many fungi are capable of sustaining growth in seemingly dry areas because they are able to transport water along their hyphae from regions that have a higher moisture content. So-called dry rot in wood is caused by one of the most destructive species of the Basidiomycetes family, *Serpula lacrymans*, which behaves in just this manner. Dry rot is easily recognized because the surfaces of infested specimens tend to crack across the grain and form well-defined cubes (*Figure 2*).

Many works of art enter collections already suffering the effects of biological decay. Stones from archaeological and other outdoor environments are often covered with a range of disfiguring and corrosive flora, and limestone and dolomite, in particular, are subject to attack by anaerobic bacteria that deposit by-products of their metabolic processes in the form of intractable manganese or iron-rich nodules (*Figure 3*). Fortunately, most microorganisms die when the objects are moved to a dry environment, or in the case of anaerobic bacteria, when the stones are excavated and exposed to air.

As new acquisitions and incoming or returning loans of works made from organic materials arrive, it is important to consider their origin as well as their most recent whereabouts, since materials from certain geographical regions, and from damp environments in general, are more likely to be infested. Museums are also advised to isolate food preparation activities in areas distant from art storage facilities, to monitor the introduction of plants and wood products, such as packing crates, onto the premises, and to eliminate other possible avenues of entry for both insects and rodents.

Once inside, unwelcome guests often do not make their activities known until the damage they cause is quite severe. Many insects instinctively avoid light and populated areas (*Figure 4*), while others spend most of their lifecycles hidden from view. The larvae of some wood-boring insects, such as the furniture beetle (*Anobium punctatum*), may tunnel through objects for up to five years before becoming adults (*Figure 5*), only then to emerge on the surface, where evidence of their exit or their carcasses can be noticed. By this time, the eggs that assure a new generation have already been concealed inside a new host.

Even though insect and fungal infestations can be quite advanced by the time their detrimental effects are first noted, the careful and regular monitoring of works of art on display and in storage remains one of the most practical means of controlling

*Figure 1. (cover) The powderpost beetle (*Lyctus *sp.), a wood-boring insect active throughout the world.*

Figure 2. Dry rot on a specimen of archaeological wood dated to the second millennium B.C.

Figure 3. Stela with the cult servant Kenamun. Egyptian, said to be from Thebes, Dynasty 18, reigns of Tuthmose III–IV. Limestone, h. 44 cm, w. 32 cm. Gift of Edward G. Harkness, 1928 (28.9.6). Detail with Kenamun, illustrating disfiguring nodules deposited by anaerobic bacteria.

biological activity. An experienced eye can distinguish between holes in textiles that are the result of insect activity and those caused by wear. Sticky traps in strategic locations are sometimes used as indicators for the presence of crawling insects such as silver fish, and the metabolic waste products of both insects and fungi often have distinctive odors that reveal their presence even when they cannot be seen.

The role of environmental control in the management of biological problems in museums cannot be overstated. When collections are stored and displayed in suitably dry environments fungal growth can be largely avoided. Equally important are emergency procedures for quickly evacuating and processing large numbers of damp or waterlogged works of art. Air circulation is another factor, and even in the tropics, where the natural relative humidity encourages the growth of fungi, fans have proven useful in controlling infestations in collections. Both to facilitate air circulation and to avoid having pests traveling from neighbor to neighbor, works of art in storage should not be packed too closely together.

It is important that the collections be kept clean, as corpses left from past infestations provide nutrition for newcomers, just as fungal growths on paper, parchment, or leather are often accompanied by an influx of book lice that graze on the fungi. Insects generally prefer dirty textiles to clean ones, and those that typically eat wool or silk will also consume plant or even synthetic fibers if they are soiled. Dust, as well, is a source of nutrition and, because it is hygroscopic, can create zones of high humidity.

Museums and historic houses have traditionally looked to relatively ineffectual but benign household remedies such as mothballs or storage in cedar chests to control insect infestations in textiles. On the other hand, in ethnographic collections arsenic had been used widely until it was recognized how easily humans who came into contact with the objects treated could themselves be poisoned. Other biocides also were introduced in solid or gas form to combat both insects and fungal growth, but over time have been found equally unsuitable because of their potential to harm works of art and human beings. Currently, many museums effectively and safely employ non-toxic methods to control insect pests.

The Sherman Fairchild Center for Objects Conservation works with six other conservation departments to monitor the Museum's holdings for active infestations in an effort to prevent biodeterioration and to mitigate its effects. The articles that follow describe methods currently in use, and research for developing new procedures, that relate to several aspects of the Center's comprehensive approach to managing biological problems in museum collections.

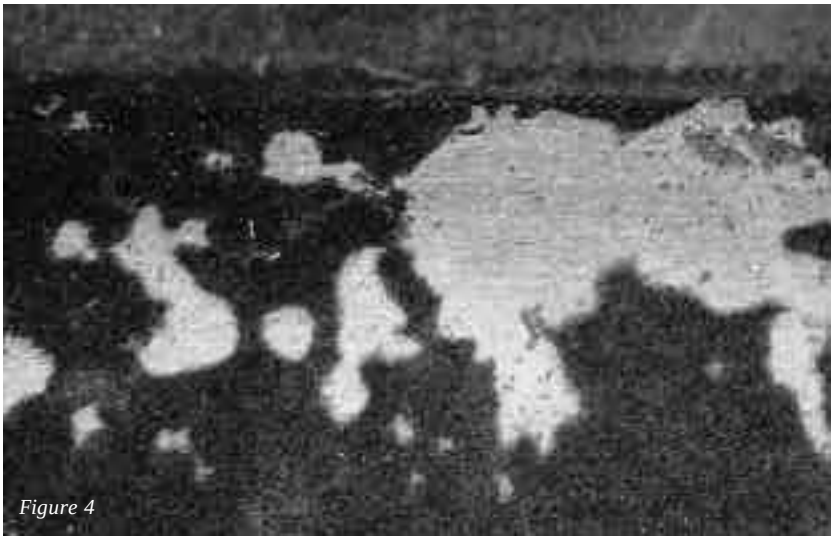
Figure 4

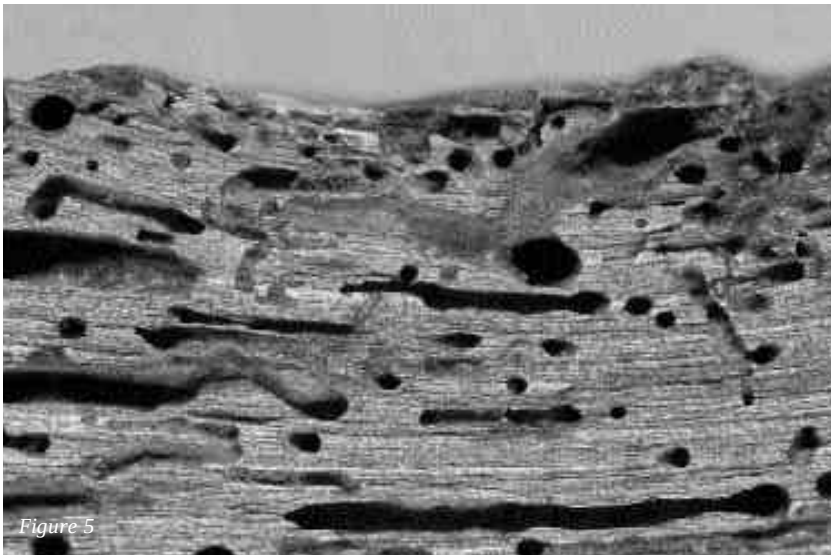
Figure 5

Figure 4. Moth damage to the woolen fabric lining of a closed compartment inside a nineteenth-century American card table.

Figure 5. Tunneling produced by wood-boring insects.

Figure 6. Andrea del Sarto's Borgherini Altarpiece (The Holy Family with Infant Saint John) *(MMA 22.75) in a sealed plastic enclosure. A similar set-up is suitable for both FTIR-based monitoring of respiration and anoxic treatments using argon gas.*

Anoxic Control of Insect Infestation

Many works of art are vulnerable to attack by insects, and even in museum environments it proves impossible to prevent collections from becoming infested, due to the flow of objects and people into galleries and storage facilities. Wooden objects, textiles, prints and drawings, books, and paintings on panel or canvas are among the works, made entirely or in part of organic materials, most in danger of infestation. Fumigants of various kinds have been used in the past to treat infested objects, and museum records regarding insect control document many unfortunate applications of inappropriate compounds.

Fumigants are volatile chemicals that actively interfere with life processes such as respiration or digestion. These biocides are usually highly reactive, and it is now recognized that many of the commonly used fumigants not only affect the organisms targeted, but also have the tendency to alter physical properties of the materials used in the manufacture of the works they infest. Methyl bromide, for example, breaks the sulfur bonds in proteinacious materials and rubbers, while sulfuryl fluoride and ethylene oxide, respectively, can shift the colors of pigments and get trapped inside lipid-containing materials such as leather and parchment. In addition, if sufficient care is not taken, fumigants are harmful to people and to the environment in general, which is why the use of many has been restricted or prohibited by law.

Alternative, non-toxic techniques have been explored in recent years, and treatments based on exposure to carbon dioxide, heat or cold, or radiation of various wavelengths are currently used in a number of museums. Similar to biocides, these techniques have potential dangers, since they too can affect physical properties of materials through chemical reactions, or due to mechanical stress caused by temporary but extreme environmental changes.

Robert J. Koestler is Research Scientist at the Sherman Fairchild Center for Objects Conservation, where he has worked since 1981. Prior to this, he ran the Interdepartmental Laboratory Facility in the American Museum of Natural History for eight years. In 1985 he received a Ph.D. in cell biology from The City University of New York. His fields of specialization include electron microscopy and biodeterioration in museum collections. At the Metropolitan Museum his primary responsibilities include conducting and supervising research on biological problems and the development of monitoring and treatment strategies.

In 1990, scientists at the Sherman Fairchild Center for Objects Conservation started testing a method for the control of insect infestation based on the exposure of objects to an anoxic environment. The basis of this technique is the simple fact that the prolonged absence of oxygen makes any aerobic life impossible. The actual treatment consists of isolating the infested object in a closed container and replacing the air inside with an inert gas, which results in the suffocation of the insects (*Figure 6*). Since inert gases are by definition non-reactive, and therefore non-toxic and non-flammable, this technique is extremely safe. At the Metropolitan Museum more than two thousand art objects made of a wide variety of materials have been treated with this method, and to date no alterations in their appearance has been discerned.

The airtight enclosure required for this treatment can be either a hard-walled chamber or a soft-walled capsule. For several reasons the latter is being employed at the Fairchild Center, where bags of any size and shape are custom-made using a oxygen-barrier, plastic film that can be heat-sealed. The ability to configure these bags to the shape of any object saves on the volume of gas required, resulting in both lower construction and operating costs, as compared to those of a permanent hard-walled chamber. Another advantage of the plastic enclosures is the ease with which they can be assembled on site, allowing the treatment of objects that cannot be moved because of their size, complexity, or structural instability.

Once the bag is prepared and the object encapsulated, the air inside is replaced with a humidified, inert gas until the oxygen concentration drops below five hundred parts-per-million, or 0.05%. This anoxic environment must be maintained for several weeks to terminate all insect life. The plastic used for the capsules is not entirely impermeable, as it does allow the slow exchange of gases, which results in a daily increase in oxygen concentration of twenty to fifty parts-per-million per square meter of surface area. A slight overpressure reduces leakage of air into the enclosure, and oxygen scavengers that bind free oxygen by means of a chemical reaction, also help to maintain a low concentration of oxygen. Temperature, relative humidity, and the oxygen level inside the capsule are measured initially and once the desired conditions have been established there is usually no need for verification.

Inert gases that have been used to control insect pests in museums include helium, nitrogen, and argon, each of which has certain advantages and disadvantages. Helium has been employed to preserve both the Declaration of Independence and the United States Constitution for more than forty-five years, although the intent in this case is not limited to preventing insect infestation. In fact, helium is used primarily to create an environment that inhibits oxidization of the paper and ink of these treasured documents. The construction of the display cases was considered a minor engineering feat, since helium, due to its small molecular size, diffuses very easily through most types of barriers. Besides the high cost of building enclosures that can contain helium, the gas itself is the most expensive of the three mentioned.

Least expensive is nitrogen, which has been used for insect control in food storage silos for decades. For the treatment of art objects, however, this gas has several drawbacks. Although under normal conditions it is considered to be non-reactive, nitrogen is not truly inert, and can be used as a source of energy by anaerobic microbes and some insects. Since nitrogen is lighter than oxygen, it rises to the top of an enclosure while the residual oxygen sinks, making it difficult to maintain a sufficiently anoxic environment near the bottom of the bag, where the object under treatment usually rests.

Argon, like helium, is truly an inert gas, but it is cheaper and more easily contained. Unlike nitrogen, argon is heavier than oxygen, so the latter tends to rise to the top of the sealed capsules, away from the object. This may account for the fact that insects in anoxic environments maintained with argon die 25–50% more quickly than those exposed to nitrogen. For all of these reasons argon is the gas of choice for insect control

The biodeterioration research described in this issue of met objectives *represents the cooperative efforts of conservators and scientists in the Metropolitan Museum and with colleagues in several other institutions. Rob De Salle, Curator of Invertebrate Zoology, American Museum of Natural History, has generously contributed his expertise to the fungal genome project, as well as use of the research facilities in the Molecular Systematics Laboratory, where he is Co-Director. Preliminary stages were carried out at Rutgers University with the kind assistance and support of Douglas Eveleigh, Professor of Microbiology, who with Fernando Nieto, a former research fellow in the Sherman Fairchild Center and currently Chairman of the Department of Biology at Old Westbury College, has been instrumental in developing the program for testing commercially available enzymatic products on samples from fungi-infested Tiffany drawings. The effects of enzyme treatments on the fungi and the paper substrates are evaluated with Raman spectroscopy and FTIR by Silvia A. Centeno, Associate Research Chemist at the Museum, and with scanning electron microscopy by Mark T. Wypyski, Associate Research Scientist at the Fairchild Center. Franc Pohleven, Assistant Dean of the Biotechnical Faculty, University of Ljubljana, and doctoral student, Crtomir Tavzes, are working with the Center to develop anoxic treatments for the control of fungal growth.*

continued from previous page

at The Metropolitan Museum of Art, and it has come to be used for that purpose in many other institutions.

The application of this anoxic method represents a major improvement in the safe treatment of works of art that are infested with insects. The Sherman Fairchild Center for Objects Conservation is now working closely with the University of Ljubljana to test the use of inert gases for the control of fungal infestations as well. Preliminary results show the potential of argon to inhibit regeneration of fungal hyphae. Spores, however, are not affected by exposure to anoxic environments and remain viable even after prolonged treatment.

The Detection of Biological Activity

Signs of insect infestation are observed regularly in the day-to-day handling of works of art in museums. The damage varies greatly, from exit holes or small amounts of frass to the structural failure of entire objects, but in many cases the newfound evidence represents a past rather than active infestation. Frass may be dislodged through vibration of objects on display, in storage, or in transit, and sections that are structurally unstable due to infestation can collapse suddenly while an object is being handled. Whenever insect damage is noted, it is the responsibility of conservators and conservation scientists to assess whether the infestation is indeed active, and to decide on the appropriate measures to be taken.

A non-destructive technique for the detection of biological activity, developed in the Sherman Fairchild Center for Objects Conservation, is based on the measurement of gaseous by-products of respiratory processes. Since aerobic life forms produce carbon dioxide and anaerobic microbes generate methane, increasing levels of these gases in a closed container demonstrate the presence of living organisms. Using Fourier transform infrared spectrometry (FTIR), a prototype monitoring system built in 1992 was able to resolve fluctuations of ten parts-per-million in the concentration of carbon dioxide. The improved system currently in use can detect increases of less than two hundred parts-per-billion, cutting down the time necessary to confirm biological activity from three days to approximately four hours (*Figure 7*).

This same technique has been employed to establish how long objects need to be contained in an oxygen-free environment to effectively end all life, whether present on the surface or concealed within. Earlier studies provide data obtained only from trials with insects in containers or in small pieces of "artificially" infested wood. In practice, the period of exposure to an anoxic environment necessary for the successful treatment of an actual object depends on many factors, such as its size, the nature of the host material, its moisture content, and temperature, as well as the species and the life stages represented. Since the values of many of these variables cannot be determined for each individual work of art, the length of an effective treatment can only be established empirically. The FTIR respiration monitoring-system has been used to measure the carbon dioxide emitted by insects before and after treatment of a large and varied group of infested objects. On the basis of the data obtained, works of art are now treated with argon for a period of three to four weeks, which has shown to be effective in eliminating all life stages of insects. RK

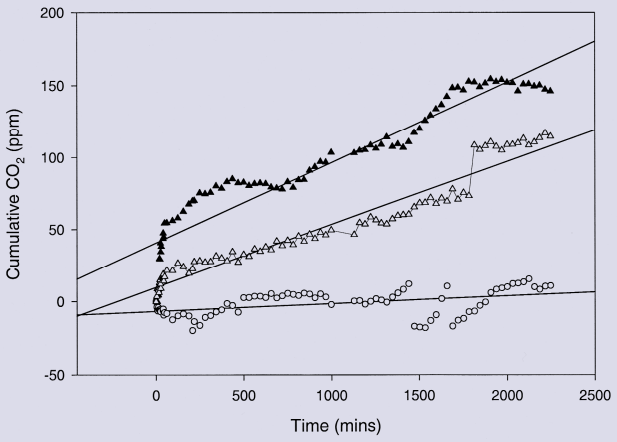

Figure 7

Figure 7. Carbon dioxide concentrations within a closed container measured over a period of three and a half days, representing the accumulation of respiration by-products of twenty ground-dwelling termites (Reticulitermes sp.). In the uppermost plot the diurnal cycle of activity can be recognized. In a subsequent run, corresponding to the middle plot, the activity of the termites is reduced because their environment has become drier. The third plot reflects equipment background variations.

The Conservation of Tiffany Drawings

Among the more colorful works receiving treatment in the Sherman Fairchild Center for Works on Paper and Photograph Conservation are some four hundred drawings originating from the studios of Louis Comfort Tiffany (1848–1933). Comprised mainly of preliminary sketches, more polished, colored pencil renderings, and presentation drawings executed for prospective clients, this body of work reflects the many stages of Tiffany's designs, from conception to completion. Domestic and religious interiors and their furnishings—stained glass windows and lamps, glass mosaic fonts (*Figure 8*) and mantel pieces—as well as jewelry, textiles, and other types of decorative objects are represented. The collection provides scholars with opportunities to study the development of Tiffany's extensive oeuvre and the work of his studio artists, and helps to document their significant contributions to American design, craft, and technology. The presentation drawings, in particular, are skillful in their application of transparent and opaque watercolors, using glaze and scumbling techniques to create the illusion of light filtering through brightly colored glass or reflected by lustrous, iridescent surfaces.

The collection presents significant and challenging conservation issues. Some relate to inherent weaknesses in the original presentation materials such as highly acidic wood-pulp secondary supports, and ornately cut window mats, which often bear the signature of Tiffany himself. More serious damages are due to prolonged exposure to water following an accident that occurred before the works were accessioned by the Museum in 1967. Soaking and uncontrolled drying caused delamination of the paper substrates and left behind tide lines, soil deposits, and even a small population of long dead, but formerly voracious insects. Most devastating and difficult to treat, however, are the effects of extensive fungal infestation. Multi-colored growths disfigure as much as twenty percent of the surface area of many drawings, visually disrupting delicate and precise renderings and their subtle tonal harmonies. Fungi are responsible for structural damage to the substrates as well; a myriad of microscopic hyphae reside between and within the paper fibers, and the secretion of fungal enzymes has led in some areas to the complete disintegration of the paper.

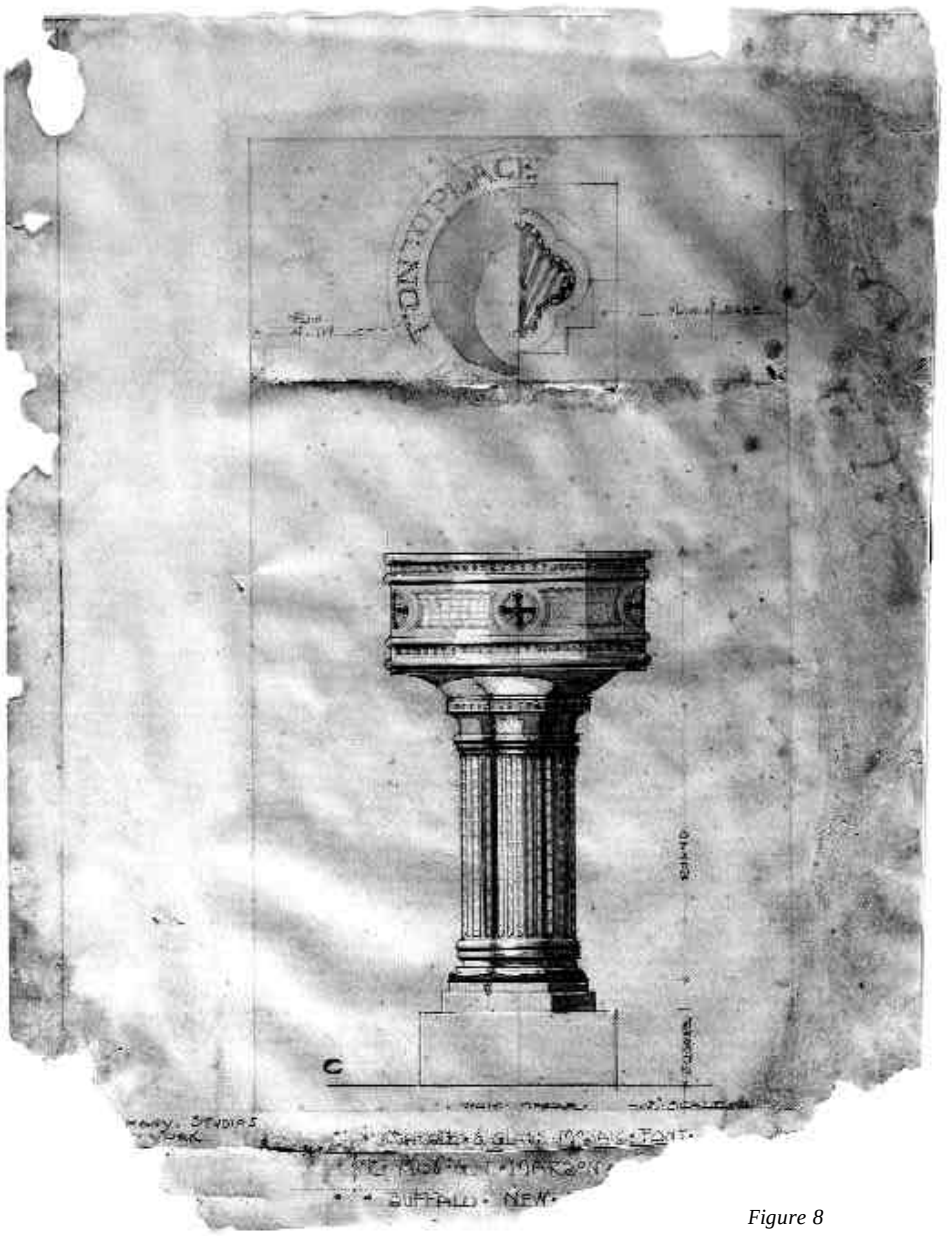

Figure 8

Figure 8. Design for marble and glass mosaic baptismal font. Tiffany Studios, 1902–1918. Watercolor, gouache, and graphite pencil on paper, 15⅝ x 11¼ in. (39.0 x 29.8 cm). Purchase, Walter Hoving and Julia T. Weld Gifts and Dodge Fund, 1967 (67.654.233). The paper has been subject to both fungal and insect infestation.

In order to prepare the drawings for study, publication, and exhibition, a preservation initiative was established by Alice Cooney Frelinghuysen, Anthony W. and Lulu C. Wang Curator of American Decorative Arts, and conservators and conservation scientists in the Museum and several other institutions have joined in an effort to mitigate the effects of the fungal infestation. While conservation measures intended to resolve some of the many problems in evidence are under way, a full analytical program, designed to characterize and identify the fungi and to develop new methods of removing them from paper substrates, draws on recent advances in microbiology and includes the testing of purified enzymes to treat infested works of art.

On close inspection the disfiguring fungal growths on the Tiffany drawings can be resolved into a variety of forms (*Figure 9*). Discrete, fluffy patches of white, brown green, or yellow fungi are present as superficial growths that cover broad areas, while smaller black spots clearly penetrate through to the reverse of the paper substrates. Visibly weakened areas of the paper are often associated with large, diffuse, gray stains. At magnifications of 90–200X these features can be examined in greater detail, allowing the fluffy, superficial growths to be recognized as masses of reproductive hyphae covered with a profusion of spherical, asexual spores called conidia, each measuring between two and five microns in diameter (*Figure 9a*). Under magnification the localized, dark spots appear as networks of very fine, pigmented, vegetative hyphae (*Figure 9b*), while the diffuse gray stains consist of countless black conidia, five to ten microns in diameter, clustered in twisting strands (*Figure 9c*). The degree of paper deterioration observed is consistent with the presence of cellulose-degrading fungi, "second colonizers" that follow the arrival of more adventitious species.

The potential of spores to generate new growth, and the health hazards they pose to curators, conservators, and other museum employees who have occasion to handle works infested by fungi, necessitates vigilant hygiene. The superficial fungal growth on each drawing is removed using an industrial vacuum cleaner outfitted with a high efficiency particulate air (HEPA) filter and variable speed control. The smallest amount of suction is adequate to remove dry spores and hyphae from the surface, and vacuuming can be carried out under a stereomicroscope when the growth extends into especially vulnerable areas. The use of a translucent polyethylene transfer pipette—trimmed, smoothed, and inserted into the end of a vacuum micro-attachment—minimizes damage to the image and the paper, and allows the conservator to monitor what is actually being removed. To reduce cross-contamination, this operation is carried out on sheets of newsprint paper that are discarded after each work has been treated. It is essential that conservators protect themselves while carrying out this operation, and the use of goggles, latex gloves, and respirators with 3M™ P100 filters (or equivalent), which remove 99.97 % of all airborne particles larger than 0.3 microns, is recommended.

While this treatment works well for removing superficial conidia and hyphae, it is not effective for extracting the embedded

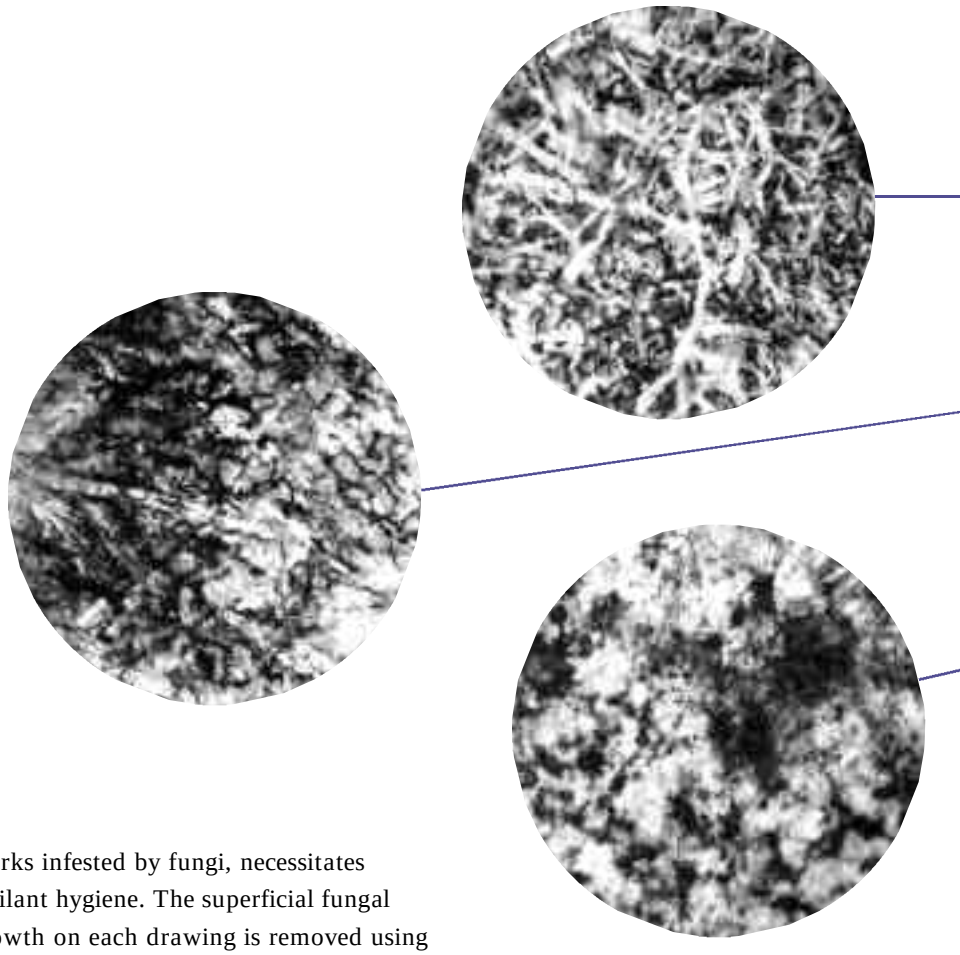

Figure 9. Design for square mosaic panel. Tiffany Glass and Decoration Company or Tiffany Studios, 1892–1918. Watercolor, gouache, and graphite pencil on paper, on secondary support, 15¾ x 17⅜ in. (44.3 x 44.1 cm). Purchase, Walter Hoving and Julia T. Weld Gifts and Dodge Fund, 1967 (67.654.53). Detail of mat and lower left hand corner of drawing, illustrating three types of fungal growth. At high magnifications, patches of fluffy, superficial fungi can be resolved as masses of reproductive hyphae covered with spherical conidia (a), black spots as vegetative hyphae networks (b), and diffuse, gray stains as clustered dark conidia (c).

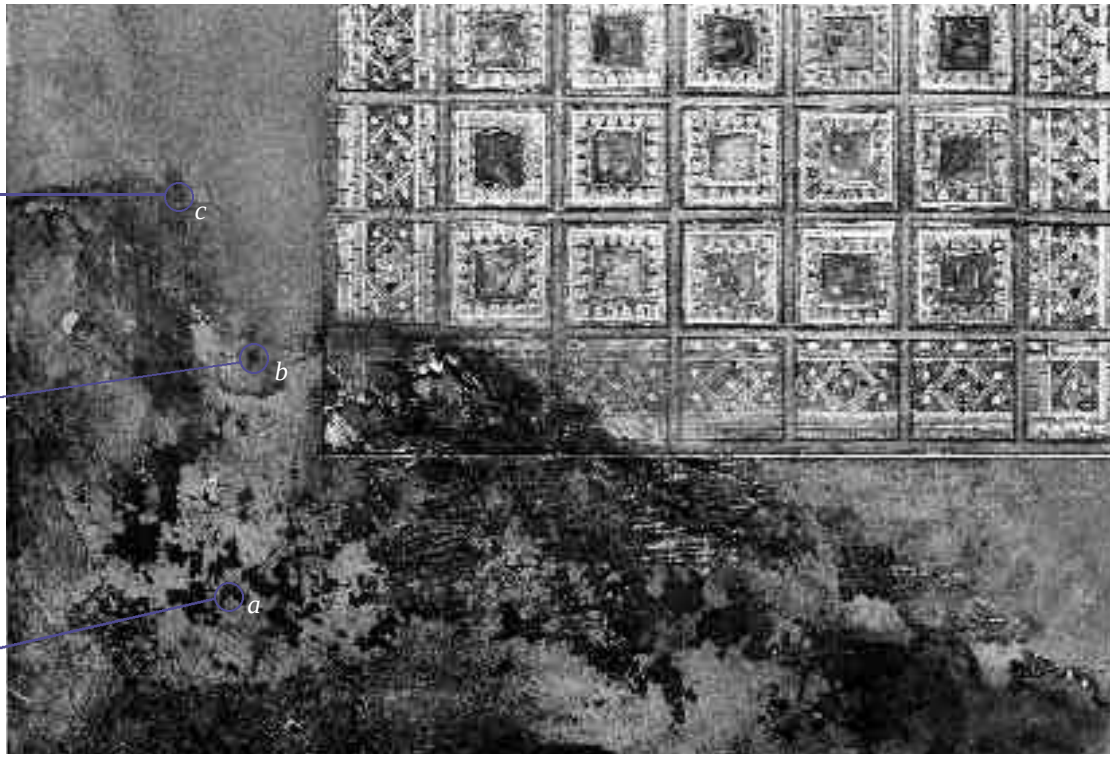

Figure 9

fungal tissue most destructive to the paper, and if pigmented, most disfiguring. Fungal cell walls are complex, layered structures comprised of natural polymers called chitins and glucans, interwoven in specific three-dimensional arrangements. Found within these layers are dark, granular melanins or melanin-like substances, called pigments, that are responsible for most of the stains caused by fungi. The hyphae are very fine and well dispersed, and their pigmented cell walls have proven impervious to conventional paper conservation treatments such as the localized application of aqueous mixtures, organic solvents, oxidizing bleaches, or reducing agents.

Alternative approaches are based on the ability of certain enzymes to break apart the cell walls of conidia and hyphae. While the development of advanced DNA extraction techniques for identifying fungal species and the manufacture of specific enzymes to destroy them is in progress (see *The Fungal Genome Project,* p.10), trials using commercially available enzymatic products are also underway. Some classes of enzymes tested by other researchers have been shown to permeate unpigmented fungal cell walls, but the presence of melanin appears to inhibit their penetration. One type of enzymes, ligninases, which are produced by white rot fungi, have been successful both in breaking down cell walls and, because they facilitate various oxidation and reduction reactions, in bleaching melanins.

Purified chitinases, glucanases, and lysing agents, in conjunction with two types of ligninases, will be applied to pigmented fungal material present on small samples of extremely damaged paper. The enzymes will be introduced sequentially and in combination, in aqueous baths, agarose poultices, and in alcohol solutions, in order to determine which system is the safest and most effective for treating works of art.

Infected and uninfected paper samples will be evaluated before and after treatment using a binary statistical method designed to quantify visual assessment by trained observers, as well as with colorimetry, scanning electron microscopy, and Raman laser microscopy. The latter two methods, along with Fourier transform infrared spectrometry and gas chromatography-mass spectroscopy, will also be applied to the study of melanins and other pigmented compounds present in the fungal cell walls, in an attempt to determine how they interact chemically with the paper fibers and with the artists' pigments.

Ann Baldwin is Assistant Conservator in the Sherman Fairchild Center for Works of Art on Paper and Photograph Conservation. Prior to joining the Museum in 1999, she was an NEA Fellow and then Project Paper Conservator in The Brooklyn Museum of Art. Ms. Baldwin received a B.F.A from the Rhode Island School of Design in 1987, and an M.A. in art history and Certificate in Conservation in 1998 from the Institute of Fine Arts, New York University. She has published articles on the testing of adhesives for use on oil paintings on paper, and on Robert Rauschenberg and artist's intent.

The Fungal Genome Project

As part of the initiative to study and conserve the Tiffany drawings in the Metropolitan Museum, newly developed molecular biology techniques are being used to extract genetic material from fungal growths, with the aim of identifying the species present and developing "designer" enzymes that can effectively and safely remove the disfiguring stains associated with them. The melanin-like substances responsible for some of these discolorations reside within the cell walls of fungi, while other stains are associated with by-products of the metabolic process. In both cases, even when the organisms are no longer viable, the stains persist. In order to effectively break apart and remove fungal tissue of any particular species it is necessary to be familiar with the structure of its cell walls. The first step in developing appropriate treatments for removing fungi from works of art, therefore, is to identify the fungal species present.

Samples of pigmented fungi removed from six Tiffany drawings were selected for classical microbiological assaying in order to see which species could be cultured. The trials were carried out for a period of four weeks using several different gel media in a high humidity environment. Unfortunately, culturing techniques often miss some fungi that are present in the sample material, for even though different media and environments can be chosen to optimize the growth of different species, not all fungi will flourish under laboratory conditions. Furthermore, the organisms sampled may be dead, and spores, if present, will not always germinate.

Because of the limitations of conventional culturing techniques, hyphae or conidia samples are now processed with molecular techniques designed to extract genetic material from biological specimens. The procedure for hyphae is to grind the tissue with liquid nitrogen and extract the DNA chemically using a proprietary kit. Once isolated, it is amplified using a polymerase chain reaction and sequenced. The fungi are identified by aligning the sequences with those of known species. Unfortunately, DNA often deteriorates after an organism dies, and for this reason it can be difficult to obtain good quality genetic material in sufficient quantities from the fungal hyphae alone. Intact DNA is more likely to be found in the conidia, but the extraction process is quite difficult because most spores have evolved strong defense mechanisms, including physically tough exteriors, to help them survive aggressive environments. A variety of chemical, biochemical, and physical procedures were tested to determine what methods, and in which order, might be used most effectively to obtain DNA from fungal spores.

At present, the extraction of DNA from hyphae and conidia from the six drawings is nearly completed. Thus far several species, including those belonging to the genera *Aspergillus, Penicillium, Fusarium,* and *Cladosporium* have been identified. Using existing literature it will be possible to ascertain the structural components of their cell walls, and with this knowledge in hand the production of enzymes designed to break apart these structures, allowing direct access to the melanins and other pigmented cellular components, can commence. These biomolecules will be tested for their efficacy and safety in the removal of fungal tissue from works of art, and if this approach proves successful, it may be possible to apply these new methods for the treatment of fungal problems on a wider range of materials.

Maria Pia Di Bonaventura is the L.W. Frohlich Research Fellow at the Sherman Fairchild Center for Objects Conservation. She received her Ph.D. in environmental science at the University of Florence in 1995 with a dissertation on the microbial synthesis of oxalates, and spent two years as a post-doctoral fellow at the University of L'Aquila, researching biomineralization processes of microbial communities living on architectural stone surfaces. She received a CNR-NATO fellowship at the MPA Institute for Materials Science in Bremen and a Marie Curie Research EU-Program fellowship to carry out research on the use of biocalcification processes for open-air stone conservation.

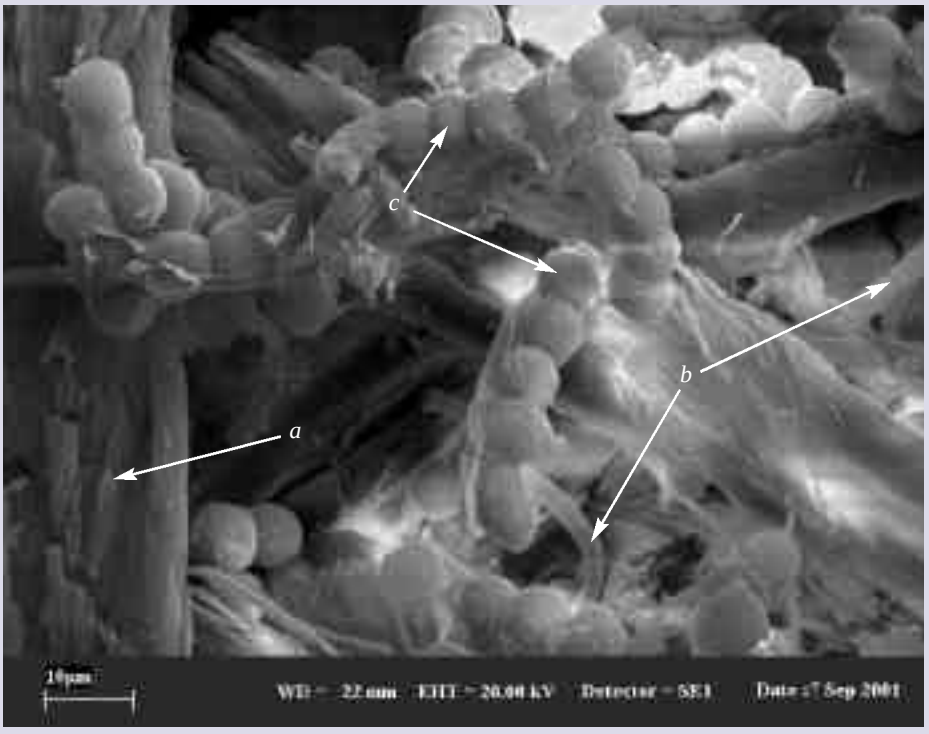

Figure 11. Scanning electron photomicrograph of fungal growth on paper, showing paper fibers (a), hyphae (b), and conidia (c).

The Stabilization of Insect Damaged Wooden Objects

Figure 12

Figure 13

Artifacts in ethnographic collections often suffer from extensive damage caused by wood-boring insects that over time can reduce large volumes of wood to hidden networks of sawdust-filled channels (*Figure 12*). Whereas the original surface survives as a thin shell and the object appears intact, these structurally weakened works are unstable and easily damaged in handling. Moreover, when surface loss does occur, the exposed cavities are distracting and can prevent the viewer from appreciating the artist's intentions (*Figure 13*).

A conservation treatment designed to counter these effects should focus therefore on both structural support and the visual integration of areas of loss. In the past, insect channels were filled with wax or epoxy, or with bulked adhesives such as animal glue thickened with sawdust or acrylic resin and glass microballoons, but none of these solutions have proven particularly satisfactory. In seeking more appropriate fill materials several factors need to be considered. Because wood damaged by insects is usually fragile, both the fluid component and bulking agent, if used, must be lightweight. Wood is a hygroscopic material, and not only is it easily stained, internal stresses introduced through the absorption of liquid media can further undermine its strength. Options for fill materials are further limited by the inaccessibility of some areas of loss. Perhaps the most important criterion is reversibility; it must be possible to apply the chosen materials in such a way that the fills may be safely removed in the future.

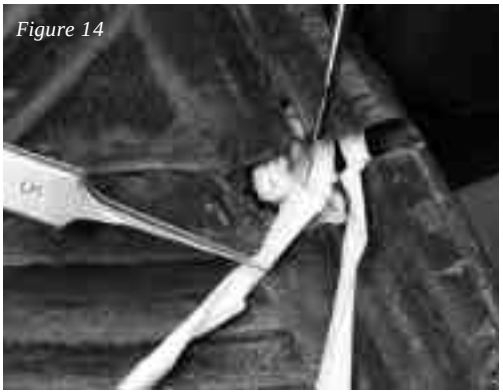

Figure 14

Several objects damaged by wood-boring insects were recently conserved at the Sherman Fairchild Center for Objects Conservation. The treatment devised makes use of a paper, chosen for its strength, charged with an aqueous medium that can safely be redissolved. The substance of the fills is a medium-weight Japanese tissue cut into long strips, ranging in width from one to three centimeters, dependent on the diameter of the tunnels to be filled. Twisting these ribbons along their entire length in corkscrew fashion adds bulk, while the fills remain lightweight. To minimize staining and stress on the original material, the amount of moisture introduced is limited by inserting the twists when they are nearly dry, yet still pliable. Although the fish glue solution used is relatively weak, the strips are still rigid enough when set to provide support.

Before the cavities are filled, any loose dust, soil, or insect frass inside should be removed, while the risk of leaving tide lines on the outer surfaces of an object can be reduced if they are cleaned. With the use of probes and forceps, the twisted strips are inserted into deep cavities and otherwise inaccessible spaces, conforming to any shape as they are eased inside (*Figure 14*). Large voids are filled in stages to allow each successive campaign to dry. When the Japanese tissue has been built up to just below the outer surface, different fill materials that more closely replicate the variety of surface textures seen on wooden objects can be applied, and inpainting completes the visual integration of the fills with the surviving original surfaces.

Figure 12. Bench. Mali, Dogon, 16th–20th century. Wood, iron, organic surface coating, l. 87.5 cm. Gift of Lester Wunderman, 1979 (1979.541.3).

Figure 13. Detail of Dogon bench (Figure 12), showing the extent of insect damage. The interior of the object has been entirely consumed, leaving a thin skin of wood and its surface coating.

Figure 14. Stabilization treatment in progress; tweezers and a microtool are used to coach twisted Japanese paper strips into a cavity.

Leslie Gat is Assistant Conservator at the Sherman Fairchild Center for Object Conservation. After receiving an M.A. in art history and a Certificate in Conservation at the Institute of Fine Arts, New York University in 1988, she worked at The Brooklyn Museum. In 1992 she established a private practice serving small institutions and private collectors. She is currently Guest Lecturer at the Institute of Fine Arts Conservation Center.

The treatments were carried out with Kendra Roth, Assistant Conservator.

The Sherman Fairchild Center for Objects Conservation provides for the preservation and technological study of ten curatorial collections in the Metropolitan Museum. The activities of the Center encompass the conservation of archaeological objects, sculpture, furniture, ceramics, and glass, as well as investigative research related to mechanisms of deterioration, preservation treatments, and historical technology. More than thirty professional conservators, scientists, and installers conduct their work in modern facilities located in the Henry R. Kravis Wing. These laboratories are equipped for a variety of analytical and investigative methods, including electron microscopy, X-ray spectrometry, X-ray diffraction, Fourier transform infrared spectroscopy, ultraviolet-fluorescence microscopy, metallography, and radiography. Areas of research that are of special long-term interest to the Center's staff include the development and testing of methods for the treatment of deteriorated stone sculpture, the development of safe and effective methods for the monitoring and control of biodeterioration, and the evolution of metalworking technologies throughout the world.

Staff members also serve as adjunct faculty at the nearby Conservation Center of New York University, and the Fairchild Center is the site of seminars and internships for students from this and other graduate programs. Postgraduate fellowships are awarded annually to conservators and other researchers from institutions in the United States and abroad.

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