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This publication is primarily intended for the members of the Objects Specialty Group of the American Institute for Conservation of Historic & Artistic Works. Additional copies of this publication are available for purchase by contacting AIC.

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From the Poster Session:

FOREWARD

This is the 11th publication of *Postprints* published by the Objects Specialty Group (OSG) of the American Institute for Conservation (AIC). The OSG Session during the 2004 AIC Annual Meeting offered a series of 14 papers and one poster dealing with *Cleaning* that served to reinforce the General Session theme. The morning session and first half of the afternoon session consisted of lectures. The second half of the afternoon consisted of laser cleaning demonstrations and a series of presentations regarding various aspects of laser cleaning.

The papers are mentioned here grouped according to topic. Tarnowski's lecture introduced the theme of cleaning with her investigation of dust and the microbiological influence on the bonding of dust to surfaces. Various surface cleaning techniques were presented: Little and Wolbers illustrated the formulation of poultices for the cleaning of plaster statues; the contaminating influences of Groomstick in dry cleaning practices were examined by Moy; Calderaro presented an overview of the use of ultrasonic devices in cleaning. Various aspects of laser cleaning were presented by three speakers: Abraham illustrated the basic principles involved in laser cleaning; Dignard discussed the laser cleaning of feathers and presented a summary of the LACONA V conference (2003); Moreno examined the application of laser cleaning to wax objects. Roundhill and Hanna presented challenges involved with the cleaning of wooden Egyptian objects. Koob covered the cleaning of glass objects and Chang presented the cleaning of architectural reliefs associated with mural paintings. A DVD prepared by Arenstein from the Conservation Move Team of the National Museum of the American Indian (NMAI) was shown. Minderop, Podsiki and Norton discussed cleaning involved in the storage and moving of collections in The Field Museum. Edquist discussed the removal of hazardous materials from objects resulting from the 9/11 World Trade Center disaster. Of these 14 papers 10 are included in this publication in the order in which they were presented at the conference: Edquist; Tarnowski; Moy; Chang; Koob; Hanna and Meleka; Roundhill; Minderop, Podiski and Norton; Calderaro; Little and Wolbers. The poster by Whyte, Muros and Barack presented a project on a brick facade from Iraq.

First of all I wish to thank my predecessor, David Harvey (OSG Chair 2003-2004), for his invaluable assistance with the development of the 2004 OSG session and *Postprints*. Special thanks to all those who gave a paper, presented a poster or participated during the afternoon presentations. The 2004 OSG session was a great success! Many thanks to those who submitted their contribution for publication in this *Postprints* volume. Without you this publication would not have been possible! And finally, OSG and AIC are indebted to Virginia Greene for her invaluable service as OSG *Postprints* editor.

Alice Boccia Paterakis
OSG Program Chair 2003-2004

WHEN EVERYTHING IS PRESENT: RECOVERY OF OBJECTS FROM 9-11-01

Linda Edquist, Kathryn Makos and James Oakley

Abstract

The Smithsonian Institution's National Postal Museum and National Museum of American History were centrally involved with the recovery of objects of historic interest from the 2001 World Trade Center disaster site, Pentagon and Shanksville crash site. Environmental studies conducted on behalf of regulatory agencies identified numerous hazardous materials in the settled debris created from the collapse and subsequent fires of the WTC. Recovered objects slated for public display, loans or accession by the Smithsonian first underwent surface contamination identification, and decontamination by methods adapted from abatement industry standard practices. Evaluation of decontamination methods by statistical analysis of clearance samples proven to be effective in reducing available airborne concentrations of asbestos fibers (as the benchmark particulate contaminant) to below recognized clearance standards. Collections decontamination methods were developed by a team of experienced industrial hygienists, collections managers and conservators to satisfy the unique handling requirements of collections. Personal protective equipment and safe work practices were implemented in accordance with regulatory requirements and abatement industry best practices as well as measures necessitated by the unique nature of collecting for museums. The work completed on the objects collected and donated from the World Trade Center, Pentagon and Shanksville was a joint effort of museum curators, collection specialists, conservators and importantly an industrial hygienist at the Smithsonian to create a safe working environment for the staff handling these pieces now and in the future.

Introduction

Handling and processing collections have always been associated with certain health & safety risks, depending on whether hazardous materials were inherent to the object, or had been acquired during post-production treatment with pesticides or preservatives. In other instances, objects might have been contaminated as a result of building material deterioration, such as delaminating asbestos-containing sprayed-on ceiling insulation or lead-based paint, or contaminated in the aftermath of a natural or man-made disaster. Over the last several years, recovery of objects after such disasters has brought new challenges to the museum community.

In response to these challenges, the Smithsonian Institution (SI) has explored many related questions, such as: How do we document these historic events? What artifacts will best document the history to present and future generations? How can we define our role in the grieving and healing process? And just as importantly, what protocols can be developed to protect the collections and the staff handling them?

Background and initial on-site response

The Smithsonian Institution's National Museum of American History, Behring Center (NMAH) and National Postal Museum (NPM) were centrally involved with the recovery of objects of historic interest from the 2001 World Trade Center (WTC) and Pentagon disaster sites and Shanksville crash site. In the emotional aftermath of the Congressional mandate to use SI as the repository for artifacts from these sites, there was an initial lack of coordination among all parties involved. Some recovery occurred without the appropriate precautionary safeguards that were later instituted. The authors therefore would like to suggest considerations for other institutions and individuals who are now tasked, or may be confronted in the future, with the handing of objects from similar tragic events.

The focus of this article will be on those objects recovered from the WTC (Fig. 1), the Federal Building that housed the Church Street Post Office/mail sorting stations for the WTC buildings (Figs. 2, 3), and Pentagon.

Figure 1. Image of WTC, Ground Zero 11/19/01 from the roof of the Federal Building, Church Street Post Office building. Photo: L. Edquist.

In October of 2001, NPM was one of the first museums to be on site at the WTC. The NPM curator worked with the Postal Inspection Service to enter the Church Street Post Office and identify objects that were permitted to be collected. At this time, the work at Ground Zero was in the early stages of transition from rescue to recovery. The U.S. Occupational Safety and Health Administration (OSHA) had not yet secured the site for proper control of the potential hazards, the internal SI procedures for such a visit had not yet been established, and the Postal Inspection Service had not yet established requirements for cleaning and proper handling. Postal inspectors allowed selected objects to be removed by the curator and/or secured for later shipment.

When NPM collections management staff returned with the curator on November 19th, 2001, Ground Zero had been secured and material could not be removed from the site without the proper precautions required by OSHA By then, environmental studies conducted on behalf of regulatory agencies identified numerous hazardous materials in the settled debris created from the collapse and subsequent fires of the WTC. Materials with potential for significant adverse health risk included asbestos, fiberglass, cement and drywall dust, silica, heavy metals, dioxins and other organic particulate debris from burning plastic. This second visit with the Postal Service required that SI staff wear appropriate personal protective equipment (PPE) for a site

visit. At this time, the building was sealed and in the process of being decontaminated by a licensed company.

Figure 2. Curator Jeff Brodie inside of the sorting room in the Church Street Post Office. Photo: L. Edquist.

Figure 3. The interior of the sorting room in the Church Street Post Office. Photo: L. Edquist.

Between the October and November visits, several objects had been removed from Ground Zero to another Postal Service facility before decontamination was done. It was decided that the first step would be to conduct a preliminary cleaning of visible debris on-site in New York City prior to shipment to the SI, where the objects could be safely isolated and subjected to more thorough decontamination and testing. Wearing a half-mask, air-purifying respirator with P100 filters, full-body Tyvek coveralls, shoe covering, and nitrile gloves, Edquist used a HEPA-vacuum and wet-wipes to clean the interior and exterior of visible debris (Fig. 4).

After this preliminary cleaning, the objects were wrapped in multiple layers of 6-mil polyethylene for shipment. All PPE and wet-wipes (with the exception of the respirator), were bagged, labeled, and left at the site for disposal as hazardous waste by the Postal Service. (One cannot transport hazardous waste off the site of generation, and certainly not across state lines.)

Figure 4. Cleaning the Church Street mailbox before shipment to SI. Photo: SI, J. Brodie

Contaminant assessment

Upon return to SI facilities, the objects were carefully isolated, and the process of identifying the actual range of contaminants on these specific objects was begun, by the SI's Office of Safety, Health and Environmental Management, and HP Environmental, Inc, a consulting firm hired by the SI to assess the effectiveness of various cleaning protocols to be used (Fig. 5). Various techniques, including sample collection of bulk debris, wipe sampling and micro-vacuuming (collection of surface material onto a filter using a small battery-powered sampling pump) were used. Collections staff and conservators worked closely with the industrial hygienists involved with the project, as well as the curators, to determine if the sampling methods proposed might adversely impact the object or the exhibit intent for the object. For example, bulk debris might

Figure 5. Sample of the debris from the exterior of the Church Street mailbox. Photo: SI, NPM.

contain materials, shards, etc, that should remain as part of the object for historical reasons, or would be desirable for display to add to the impact of the story. Wipe samples typically require

a liquid solvent be added to the filter or cotton wipe. It is therefore necessary to specify whether water, alcohol or other solvents will be harmful to the object or its markings. Wipes and micro-vacuum samples also require surface contact and a bit of pressure. The preference may be to use bulk sampling if possible for an initial evaluation of what may be present. Without the data, it is necessary to make conservative assumptions about the degree and type of contamination, based on historical knowledge of the site identification.

Decisions on how these objects would be handled by staff or safely put on public display were based on an initial determination of contaminants present and the degree to which they could be released into the air or pose a skin hazard. For public display a test was made to stimulate air flow within a gallery, by creating an ambient air test chamber around the object. The test results would simulate if surface contaminants were present and could be made airborne. If so, then the object could not be installed in a public gallery in an open display, but would need to be safely enclosed.

Two object groups will be discussed to illustrate the processes and considerations involved in this type of recovery effort.

1. Objects which could be cleaned, based on health, conservation and curatorial concerns. Examples are the Postal Service outdoor receiving street mailbox from 90 Church Street, and a K-9 collar & harness (Fig. 6), which the conservators allowed to be altered and vigorously cleaned, and the industrial hygienists felt were capable of being thoroughly cleaned (i.e., objects of non-porous and robust material).

2. Objects which the curators did not want cleaned, e.g., a paper hole punch (Fig. 7), briefcase and doll (Fig. 9) from WTC; or could not be effectively cleaned.

Figure 6. K-9 dog collar from the Pentagon. Photo: SI, NMAH.

Figure 7. Paper hole punch from the WTC. Photo: SI, NMAH.

Bulk sample analysis from inside the Church Street receiving mailbox revealed the presence of chrysotile asbestos, crystalline silica, fibrous glass, cellulose, cadmium, lead, and zinc. Bulk sample analysis of the Rescue K-9 gear revealed a slightly different mix: asbestos, carbonates and soot, fibrous glass, plaster, glass shards, plant fragments, cotton fibers, insect parts, diatoms, fungus, pollen, and soil minerals. The only metals indicated on the bulk samples of the K-9 items were aluminum, iron and magnesium. Clearly most of these have potential for not only inhalation health risk, but object damage from a conservation point of view. The K-9 rescue items were also contaminated with a variety of semi-volatile organic phthalates, presumably as residual combustion products.

Treatment of objects that could withstand vigorous cleaning

Cleaning chambers were constructed according to standard abatement industry protocols, using multiple layers of 6-mil polyethylene, duct tape and spray adhesive (Fig. 8). Standard procedure for removing asbestos or lead-paint from a room interior would require room containment, with air exhausted through HEPA-filtered negative pressure air machines and an elaborate system of interlocked, multi-chambered entrances and exits. Smaller areas (such as steam pipes) might be enclosed in a polyethylene glove bag, exhausted through a HEPA-filtered vacuum cleaner. Objects to be cleaned, along with the required cleaning tools, were placed inside an oversized glove-box chamber. A HEPA-vacuum was inserted at the other end for filtered exhaust, with small make-up air intake slits made at the front to ensure that the containment would not collapse during use.

Figure 8. Cleaning chamber set up at SI. Photo: K. Makos

Once cleaning was completed, compressed air from a can (already inside the enclosure) was aggressively sprayed on the objects to loft any particles that remained (simulating any possible release during normal handling), and a sampling pump was activated to collect a specified amount of air from within the chamber (with the collecting filter media inside the chamber, connected by tubing to the pump outside the chamber)..

Results of asbestos clearance monitoring for the two Postal Service containment chambers indicated zero and 30 asbestiform structures (fibers or fiber bundles) respectively, per square millimeter of filter, identified by Transmission Electron Microscopy in accordance with

EPA/AHERA Method Appendix A to Subpart E, 40 CFR Part 763. According to 40 CFR Part 763 (primarily affecting abatement in schools), an asbestos abatement action is considered complete if air samples analyzed by the aforementioned method are less than 70 structures per square millimeter. Our samples met this criterion.

Cleaning and enclosure for objects that could not to be altered

For the objects that could not be altered, limited surface sampling was allowed, with results being similar to those described above for the other objects (asbestos and soot being of the greatest hazard concern). An uncleaned briefcase from the WTC was also covered with a variety of PCBs and polyaromatic hydrocarbon residues with dermal hazard potential, as well as a wide range of metal residues including aluminum, barium, chromium, copper, iron, lead, magnesium, manganese, nickel, potassium, and silver. It was therefore recommended that PPE, including respirator and chemical-protective gloves, be used at all times for future handling.

The briefcase was tested in the chamber, with low-velocity air passed over the surface to see if residual asbestos fibers could be lofted. Under conditions of gentle air flow, the resulting chamber air measurements did not detect any airborne asbestiform fibers. However, in the absence of more aggressive air testing (as specified in the standard AHERA method), it was still recommended that uncleaned objects (or objects that could not be aggressively cleaned and sampled), be displayed only in cases or enclosures. Other examples of objects which could not be cleaned are the paper punch in Fig. 7, and the doll in Fig. 9, both of which are displayed inside suitable enclosures.

Figure 9. Doll found at Fresh Kills site. Photo: SI, NMAH.

Maintaining the historical significance of an artifact has been an important ethical principle in conservation. The safety of those charged with object preservation must also be a part of the decision on the ‘historic appearance’ that may be desired. The decision was made that, if an object could not be vigorously and directly cleaned, and pass clearance testing with industry

referenced standards, then the object would have to be stored and displayed in an enclosure or some protected manner.

In addition to discrete protection, the object case itself needs to be appropriately labeled to alert future handlers of the potential for harm. This should include a notation in the accession records for the object.

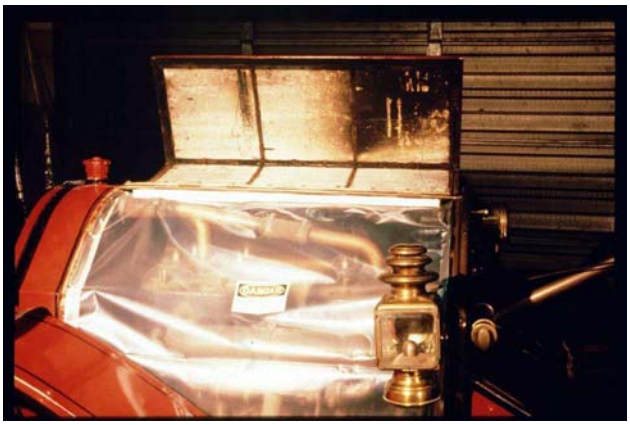

Figure 10. Truck engine covered and labeled as containing hazardous materials. SI, NMAH

Further discussion

What if you don't have access to environmental or regulatory resources and information? Much information will be available from the recovery site, through contractors, regulatory agencies such as the U.S. Environmental Protection Agency and OSHA, and local agencies with hazardous material regulatory responsibilities. The Project Manager should request all available information before any conservation recovery work is done.

In addition, before handling post-disaster objects purported to have been cleaned, the name of the company performing the decontamination should be obtained, as well as the clearance papers from the hazardous materials abatement contractor and their environmental monitoring consultants. Contracts with these companies normally specify that a report be provided.

Among the essential information would be the processes and regulatory (or state-of the-art) technical criteria used to clean and test the objects, whether further decontamination is needed, and whether special PPE precautions are still required for handling the material. All this information should then be included with the accession records.

A major lesson for cultural institutions in the wake of 9/11 and other disaster incidents is the absolute need for museums to expand emergency plans to include provisions for the safe recovery and decontamination of museum collections. Adequate response to such events requires two levels of training. The first level would be a limited number of staff possessing the training and equipment to safely enter contaminated emergency sites, not as first responders, but after the facility has been stabilized and the potential for chemical or biological exposures characterized.

This team would be responsible for planning and executing appropriate conservation actions, including oversight of contractors, cleaning of objects to be salvaged, and interaction with local authorities in the selection of effective decontamination methods posing the least hazard to the collections themselves.

There will then be a need for a team to continue with "post-emergency" response activities such as routine cleaning and restoration after the objects have been properly contained and removed from the emergency site to a controlled cleaning area. At this task level, staff would receive training in the handling of hazardous materials and the use of various types of personal protective equipment. This training is important for the safe handling of objects but it must be noted that the actual decontamination must be done by licensed and certified hazardous materials abatement workers with specialized training in hazardous materials removal and environmental surveillance.

The collection of artifacts that are to serve as the national remembrances of the tragic events of September 11, 2001, offered a challenge to the Smithsonian staff involved. The collecting was wrought with emotional and technical trials that had to be resolved to move forward as an institution. The authors hope that the lessons learned will benefit other institutions and individuals should they be unfortunate enough to have to document such a tragic event.

The most important lesson learned since 2001 was the necessity for all those involved in the recovery, care and display of these artifacts to work closely together for the protection of both the objects and the staff. Teams of curators, safety and industrial hygienists, conservators and collections managers must work cooperatively to develop procedures that will preserve the objects, protect the staff, and offer to the public a meaningful and lasting cultural heritage.

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STICKY MICROBES AND DUST ON OBJECTS IN HISTORIC HOUSES

Amber L. Tarnowski, Christopher J. McNamara, Kristen A. Bearce, and Ralph Mitchell

Abstract

This research investigated the role microorganisms play in bonding dust to surfaces. Non-biological mechanisms of dust adhesion include molecular dispersive forces, electrostatic interactions, and capillary condensation. In addition, dust adhesion may result from contact with sticky exopolymers produced by microbial biofilms. Biofilms are communities of microorganisms, which are present on all surfaces. Biofilms are held together by exopolymers, which are created as products of microbial metabolism. Layers of dust, microorganisms, exopolymers, and substratum form a complex system that makes it difficult to clean delicate surfaces in historic interiors. Dust samples were collected from Knole House at Sevenoaks in Kent, and from Blickling Hall in Norfolk, England. Plate counting and nuclear staining were performed to qualify and quantify the microbes. Dust samples plated onto nutrient agar culture plates yielded high numbers of bacteria. Investigation of microbial metabolism revealed that in controlled humid environments, microorganisms utilized dust components as the sole source of nutrition. Exopolymers visible under the microscope were produced within days. Solvent extractions of dust samples were analyzed with gas chromatography-mass spectroscopy (GC-MS) to identify the hydrocarbon and fatty acid components in the dust that serve as nutrition for microbes. While these English country estate homes are relatively removed from the typical sources of hydrocarbon nutrients that can support microbial growth, such as smog and heavy traffic pollution, sufficient nutrients remain in the dust. To illustrate the interaction of microbial activity on textiles, thin biofilm samples were examined with electron microscopy. Bacterial isolates displayed preferences for breaks and ends of wool or silk fibers. The analytical techniques used in this study are standard in the field of microbiology, and can be used to analyze housekeeping practices of historic house interiors and their contents.

1. Introduction

Biological colonization of outdoor sculpture, monuments, and architectural surfaces is a phenomenon that has been observed by conservators for years. Nutrients and moisture are available and renewed constantly in the outdoor environment, sustaining microbial growth on surfaces, which can eventually damage the substratum. The characterization and effects of biodeterioration on indoor art and heritage materials have been studied in recent years by microbiologists and conservators. These investigations have illuminated a variety of problems including fungal growth on cellulosic materials such as books and works of art on paper (Florian 1997; Hideo 1984; Szczepanowska 1994); deterioration of wool carpet and other textiles (Suwanarit 1995; Mahall 1982); and the susceptibility of paintings and silk to fungal growth (Seves at al. 2000). Fresco paintings, murals, and rock art in semi-closed environments have also suffered from biological attack. The closing of the Lascaux Caves to the public in 1963 serves as a reminder that biological bloom can be persistent and may require ongoing preventive measures (Ciferri 1999). These studies show that microorganisms can be problematic for objects

in both the indoor and outdoor environments. Since microorganisms can colonize almost any surface, no object is absolutely exempt from microbially-induced degradation (Gu et al. 2000 A).

In this study, the approach was to investigate possible biological causes of severe dust adhesion to delicate objects inside historic houses. In March of 2002, conservators of the National Trust of England and researchers at the University of East Anglia commenced a three-year interdisciplinary study to examine soiling processes on sensitive materials in historic properties [1]. Although a regular cleaning program is instituted in the houses of the National Trust, typical techniques for dust removal had in many cases become ineffective. This was especially true for sites with long winters and high humidity, like Knole (Lithgow 2004). The strong dust adhesion was suspected to be a result of environmental and biological factors. Using an approach combining microbiology and conservation, the role sticky biofilms play in dust adhesion was investigated.

1.1 Adhesion as a biological phenomenon

Biological adhesion of microbes to surfaces is of the result of factors such as electrostatic forces, bacterial attachment structures, and the production of sticky polymers ('exopolymers') produced as a product of bacterial metabolism. Communities of microbes held together by exopolymers are called biofilms, and while the biofilm is primarily composed of polysaccharides, the exopolymer may contain proteins, nucleic acids, humic acids, lipids, and other carbohydrates (Roldan et al. 2003). Biofilms may include various microorganisms like bacteria, fungi, algae, and lichens (Flemming 2002; Varnam 2000). Investigations of microbial colonization on stone sculptures and fresco paintings exposed to the environment have revealed that a diverse community of microorganisms are able to colonize a surface, not just one type of microorganism (Albertano et al. 1991). Although some biofilms can serve as a protective patina, many microorganisms also produce acids as products of metabolism. For example, oxalic acid excreted from microbes has been observed to cause pitting and exfoliation on stone and glass (di Bonaventura, et al. 1999; Dornieden, et al. 2000).

Adhesion of dust particles is affected by factors such as the dynamics of molecular dispersive forces, electrostatic interactions, and capillary condensation (Phenix et al. 1990). Additionally, dust in itself is a key transporter of bacteria and fungal spores (Yoon et al. 2000), and a discussion of dust adhesion on non-sterile surfaces should therefore include consideration of the effects of biological adhesion [2]. Bacterial adhesion to a surface occurs when electrostatic forces, cell structures, and natural polymers bind the bacteria to a surface and work is required to separate them. Bacteria are able to adhere only after van der Waals and electrostatic forces bring the bacteria very close to a surface. When microbes sense short-range interactions with a substratum, there is a physiological response resulting in a modification of the cell surface leading to adhesion; the type of interaction with the surface depends upon the bacterial species present and the surface physicochemistry (Mozes et al, 1991). Although medical and environmental research is mainly focused on biofilms at solid-liquid and liquid-air interfaces, aerophytic biofilms can exist at solid-air interfaces (Gu et al. 2000 B). In this environment, the bacteria in the exopolymer matrix sequester nutrients from the substratum by excreting enzymes (Marshall 1996). Biofilms can form from just a few bacteria; the underlying bacteria multiply,

exude polymer, and die, while new ones are perpetually deposited on top from falling dust. The biofilm can grow on and around the dust particles, strongly securing themselves and the dust particles to surfaces.

1.2 The nature of dust

Indoors, microbial nutrition is dependent on available surfaces and dust particles. The term *dust* includes solid or liquid particles and aerosols. Indoor dust contains organic and inorganic soil particles tracked in from shoes of visitors, fibers from clothing and carpets, hair, dead skin cells, insects, salts and pollutants (Macher 2001). In Knoll House and Blickling Hall, the chief components of the dust were determined under magnification to be textile fibers, insect remains, and particles like quartz (see results). The wide range of nutrients is sufficient for bacterial and fungal growth. Because the contents of dust brought in from the outdoors will vary throughout the year, it is impossible to fully characterize the contents of the dust in a quantitative manner that represents the full picture. It is usually in a state of flux with direct relationships to other variables, such as the seasonal climate and precipitation, pollution, redeposition of particles from cleaning, admission of external air, and visitor numbers (Yoon et al. 2000). While the amounts of dust and dust contents vary, so do the microorganisms that survive from dust nutrients. Microbial population numbers indoors can equal or exceed the numbers found outdoors in common soil, which is 10 million per gram, including up to 10,000 different species (Ogram and Sharma 2002). Additionally, over 1.5 million fungi are estimated to exist on earth, only 80,000 of them are known, and about 1800 discovered and named every year (Bennett et al. 2002). Therefore, the investigation focused on the biological community as a whole, instead concentrating on the identification of individual species. The basic method for characterizing a biofilm community used here is to examine the environment and available nutrients.

2. General history of the case study sites

Two historic properties were selected for dust sampling. The first site was Knole in Sevenoaks, which lies 25 miles southeast of London. Knole is a Tudor mansion set in a 1000-acre deer-park, used for the deer-hunting activities of the Archbishops of Canterbury in the 15th century. Knole's history of royal ownership includes Edward VI and Henry VIII. It was given by Queen Elizabeth I to the Sackville Family in 1586. Vita Sackville West, friend of Virginia Woolfe, lived in Knole. Both Vita and Knole provided the inspiration for Woolfe's classic novel *Orlando.* Knole was given to the National Trust in 1947 (Brady 1839; Sackville-West 1958). Today Knole is home to a fine collection of art and furniture. Paintings by Van Dyke, Gainsborough, Holbein, and Reynolds, decorate the walls above 17th century royal Stuart furniture. Dust samples were gathered in two rooms: the Brown Gallery, and the Venetian Ambassador's State Bedroom.

Likewise, dust was collected from the Peter the Great Room in Blicking Hall. Blickling Hall is an early 17th century icon of England's Jacobean style country houses. It stands in the countryside of Norwich, inland from the sea by about 22 miles. It is surrounded by 4,777 acres of woodland, parkland, brick cottages, and farmland (National Trust 1987). Sir Henry Hobart owned Blickling during the reign of King James I, and rebuilt the house in 1619, replacing the earlier settlement that dated back to the first millennium. Throughout history the ownership of

Blickling changed many hands to include prominent figures and families, including Sir John Fastolfe, who was used as fertile material for a comic character by Shakespeare. Fastolfe sold the house to Sir Thomas Boleyn, so Blickling later became the accepted birthplace of Anne Boleyn. The house is also legendary because many of the original contents, gardens, and park remain preserved together, unlike other country houses that eventually lost their components due to high taxation. Blickling Hall was given to the National Trust of England in 1940, by the founder of the Country Houses Scheme, Philip Kerr, the 11th Marquis of Lothian. Philip Kerr (1882-1940) is famous for his political career, as he drafted the preface to the Treaty of Versailles in 1919 and helped unite America and England during World War II (National Trust 1987). Blickling's 18th century room furnishings include rare books and tapestries, furniture upholstery, and state bed textiles. The microorganisms harvested from dust collected at Blickling and Knole were used as the investigative biomaterial.

3. Experimental

Vacuum cleaner bags were collected from two rooms in Knole, between June of 2001 and October of 2003. Three bags were collected from the Venetian Ambassador's bed: the upper right valance area, the upper left valance, and the foot valance. These are referred to as dust samples A-C, respectively. In the Brown Gallery in Knole, dust sample D was collected from the crewelwork chair covers. Sample E was collected from the seats of furniture in the Peter the Great Room in Blickling Hall in November of 2003. The contents of individual vacuum-cleaner bags were stored in sterile containers at 5° C. Particulate matter in the dust samples were analyzed with light microscopy to identify the majority of the dust components.

3.1. Enumeration of microorganisms

Dust from samples A-E were diluted with sterile deionised water and inoculated onto nutrient agar plates. The plates were incubated for 10 days at 28˚C and 65% relative humidity (RH). The colony-forming units (CFU's) were counted.

The culture plate method is only a rough estimate of colonies able to grow on a particular medium. Total numbers of microbes in samples were counted by staining with a nuclear dye. Triplicate solutions of dust samples A-E were prepared for counting by diluting weighed amounts of dust into sterile deionised water and formaldehyde. Samples were concentrated by filtration (15 kPa vacuum) onto 0.22 μm pore size black polycarbonate membranes (Whatman Track-Etch Nucleopore with 0.2 μm pore size). This process trapped the microbes on the filter membranes, as bacteria and fungi are generally 2 to 4 μm in size or larger. Bacteria and filter membranes were stained with 4', 6-diamido-2-phenylindole (DAPI) and rinsed with deionized water (Gustashaw 1991). Filter membranes were air dried by vacuum suction and mounted onto glass slides, secured with Cargille non-drying immersion oil. An Olympus BX 60 epifluorescent microscope was used to view and count the cells on each filter.

3.2. Dust as microbial nutrition

To examine how microbes utilize dust for nutrition, the bacteria producing the most exopolymer in each dust sample were selected from the culture plates, and isolated as pure cultures by transferring cells from the culture plates with a sterile loop to tryptic soy broth (TSB). Cultures were agitated at 32 ºC for 24 – 48 hours at 100 rpm. Cells were harvested from the solution by centrifugation, separating the pelleted cells from the TSB. The bacteria were resuspended in sterile deionized water. The bacteria were centrifuged a second time, the water was decanted, and bacteria were transferred to a sterile glass slide. An average of 6.4 µg of dust in 100 µg of sterile deionised water was added to each slide as the sole nutrient source. The slides were placed in sterile petri dishes containing a moisture reservoir of 100 µL of sterile deionised water. The culture plates were sealed with Parafilm wax to create a microchamber at a constant humidity. Each microchamber was incubated for 48 hours at 32°C. Bacteria on the slides were Gram-stained, which helped to make the bacteria visible under magnification, and to differentiate between gram (+) and gram (–) bacteria by their outer cell wall chemistry (Bartholomew 1958). The bacteria were visible under 1000x magnification (using a 100x oil immersion lens). Imaging was assisted with the SPOT RT Color version 3.0.4 software program connected to an Olympus BX 60 microscope.

3.3. Electron Microscopy analysis

The effect of microbial activity on textiles was examined. The process of placing culture isolates and dust on slides in a culture plate microchamber was repeated, and included several individual sterilized fibers of wool and silk. Modern wool and silk replica textile used to replace curtains, seat upholstery, and wall-hangings in the Peter the Great Room of Blickling Hall served as a substratum layer for microbial growth. Slides made from dust samples B, C and E were incubated at 28˚C and 65% relative humidity for 9 days. They were examined in a FEI Quanta 200 Environmental Scanning Electron Microscope (ESEM). This method allowed the biofilm to remain intact, as the sample preparation method did not require dehydration.

Biofilms were cultured with sterile textile fibers and dust in a microchamber a second time as described. Sterile Thermanox plastic cover slips (10.5 x 22 mm, NUNC Brand Products) served as the substratum for biofilm formation instead of glass slides. After incubating at 31˚C and 100% humidity for 8 weeks, biofilms were visible on and around textile fragments. The biofilms were fixed overnight in 3% formaldehyde solution and dehydrated in a progressive series of ethanol and water solutions (from 40% ethanol to 100% ethanol in increments of 10%). Samples were prepared for the SEM with an Argon-ion sputter deposition system (Desk II Sputtering Unit, Denton Vacuum) after critical-point drying (Autosamdri-815, Tousimis). Samples were examined in a LEO (Zeiss) Field Emission Gun Scanning Electron Microscope (SEM). The sample preparation method may have caused distortion or loss of the biofilm during the dehydration process, but allowed for better resolution at higher magnification.

3.4. GC-MS

Gas chromatography-mass spectroscopy was used to determine the soluble components in the dust that may serve as microbial nutrition. Two extractions were performed on dust sample D. To extract hydrocarbons, 0.0216 g of the dust was placed onto Whatman GF/F 0.7 µm filter paper and 1.5 mL of 98.5% pure hexane (85% n-hexane) was passed through. A total of 30 µL of the extraction was used for GC-MS analysis. For extracting other compounds, 1.5 mL of a 1:1 solution by volume of sterile distilled water and ethanol was passed through 0.0582 grams of dust, using the same Whatman filter type. 15 µL of the extraction solution was used for GC-MS. Both samples were analyzed by GC-MS on a HP 6890 GC System with a HP 5973 Mass Selective Detector and a HP 6890 Injector. The oven was heated from 50° C to 250° C with a rate of 13° C/min. Results were compared to the ChemStation Software database (Agilent Technologies).

To verify the ability of bacterial and fungal isolates to grow on hydrocarbons such as those identified in dust samples using GC-MS, bacterial and fungal isolates were inoculated into a minimal salt medium [3] containing 1% sterile filtered kerosene (n C6 – n C16 alkanes). The kerosene was passed through a syringe with a glass filter size 0.22 µm to remove existing bacteria and other particles. Twenty-eight isolates were inoculated into the medium and shaken at 100 rpm for 106 days. Ability to grow using kerosene as the sole carbon source was assessed visually (i.e., increased turbidity of cultures resulting in an opaque appearance).

4. Results

Informal visual analysis by light microscopy revealed the major components of the dust samples to be textile fibers, insect remains, quartz, and other glass-like particles.

4.1. Enumeration of microorganisms

Numbers of bacteria in dust samples were determined using plate counts and DAPI staining. The average numbers of viable colonies of bacteria determined by plate counting were 3.52×10^6 CFU/gram of dust for Knole, and 1.03×10^6 CFU/gram of dust for Blickling. Numbers of CFU were variable among samples, with the highest numbers of CFU observed in samples A and E (Table 1). Numbers of bacteria determined using DAPI staining were one to three orders of magnitude greater than the plate counts, but numbers were much more similar among samples: Knole averaged 2.25×10^8 bacteria per gram, and 1.64×10^{10} for Blickling.

Dust sample	Sample Location	CFU's/g dust (colony count)	Bacteria/g of dust (DAPI count method)
A	Venetian Ambass. Bed, Knole	1.36×10^7 ($\pm 1.3 \times 10^7$)	2.36×10^8 ($\pm 5.7 \times 10^7$)
B	Venetian Ambass. Bed, Knole	1.23×10^5 ($\pm 4.5 \times 10^4$)	1.83×10^8 ($\pm 3.0 \times 10^7$)
C	Venetian Ambass. Bed, Knole	1.56×10^5 ($\pm 6.9 \times 10^4$)	1.13×10^8 ($\pm 1.6 \times 10^7$)
D	Brown Gallery, Knole	1.55×10^5 ($\pm 5.4 \times 10^4$)	3.67×10^8 ($\pm 7.1 \times 10^7$)
E	Peter the Great Room, Blickling Hall	1.03×10^6 ($\pm 5.9 \times 10^5$)	1.64×10^{10} ($\pm 7.7 \times 10^9$)

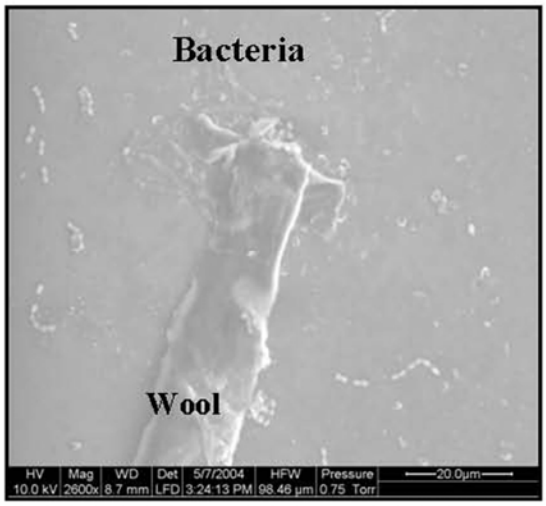
Table 1. Numbers of bacteria in dust samples from Knole and Blickling Hall (Mean± se, n = 3).

4.2. Dust as microbial nutrition

After 48 hours of incubation at 30˚C, the microbes adhering to dust particles were visible with transmitted light microscopy with a 100x oil immersion lens. Half the samples had produced exopolymer visible without magnification, and the other half demonstrated initial stages of biofilm growth. Gram's Stain was used to determine the variety of gram (+) and gram (-) bacteria present in the dust samples, and to render the cells visible. In the dust samples analyzed, the dominant microbial species was bacteria. It was also evident that bacteria appeared to be adhered to the surfaces of dust particles

4.3. Electron microscopy results

It was evident from the ESEM micrographs that microbes prefer to colonize on breaks or ends of the fibers (see Fig. 1). Individual isolates have definite nutritional preferences for either the dust, the wool, or the silk fibers. Isolates from dust sample B preferred the dust particles, and trails (or elongated colonies) of bacteria lead from one dust particle to the next (Fig. 2). Isolates from dust sample C preferred silk and did not agglomerate on wool. In this example, stringy exopolymer exuded by bacteria (larger than the fimbrae or flagella which would be 2 or 3 nm in length, not 2 or 3 μm), is also visible (Fig. 3). Isolate E from Blickling Hall demonstrated a much higher bacterial population and preference for both types of textile fibers (Fig. 4). In Figure 5 from isolate E, the stringy polymer is visible on the silk. Intact biofilms from dust samples D and E were examined with SEM. Figures 6 and 7 demonstrate clusters of bacteria and polymer can cover fibers completely. In all examined biofilm slides, the presence of exopolymer was sufficient to secure the dust particles to the textile fibers and to the glass, even long after the biofilms were dehydrated for two weeks at 50% RH and below. Overall, observations of microbial activity were similar for ESEM and SEM (Figs. 6 and 7).



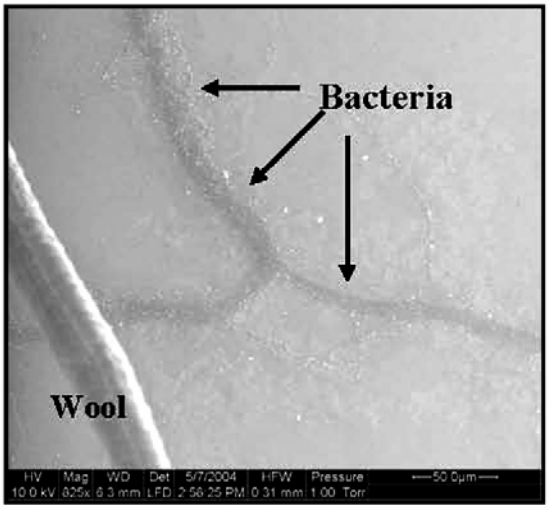
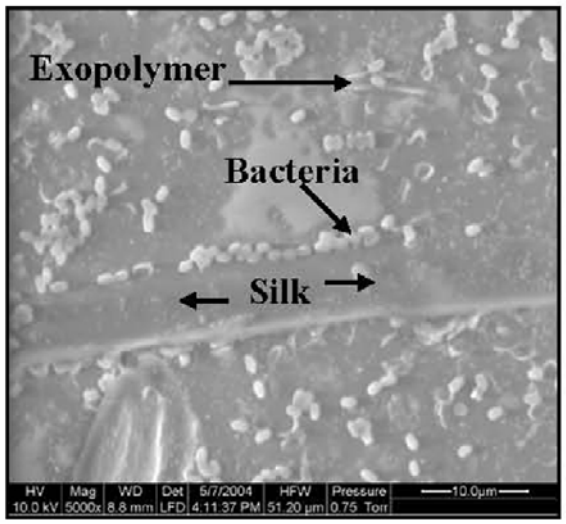


Figure 1 (above left). Isolate bacteria B with microbes colonizing on the ends of the fiber. The scale bar in the bottom right of the black information panel is 20.0 µm. ESEM micrograph.

Figure 2 (above right). Isolate bacteria B (from Knole) has little affinity for the wool fiber. The darker 'trail' of microbes leads to dust particles. The scale bar is 50.0 µm. ESEM micrograph.



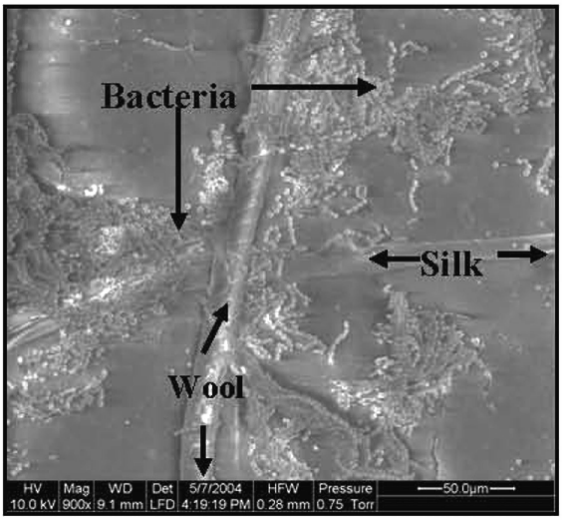
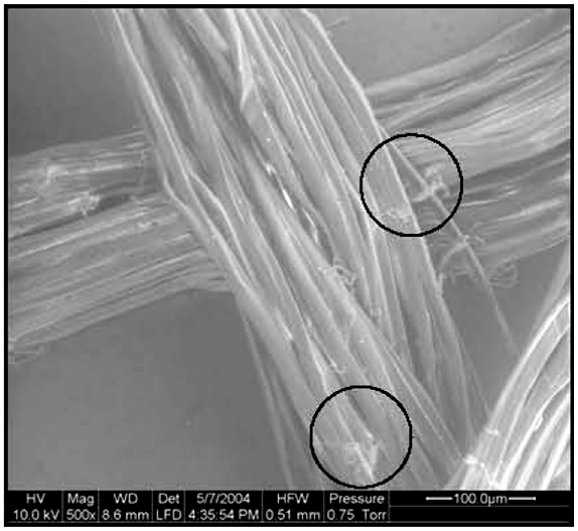


Figure 3 (above left). Isolate bacteria from dust sample C (from Knole) clusters on the surface of the silk. The scale bar is 10 µm. ESEM micrograph.

Figure 4 (above right). Isolate E (from Blickling) shows an abundance of bacteria adhering to both wool and silk present in the sample. The wool fiber has scales and lies vertical. The silk fiber lies horizontally. The scale bar is 50 µm. ESEM micrograph.



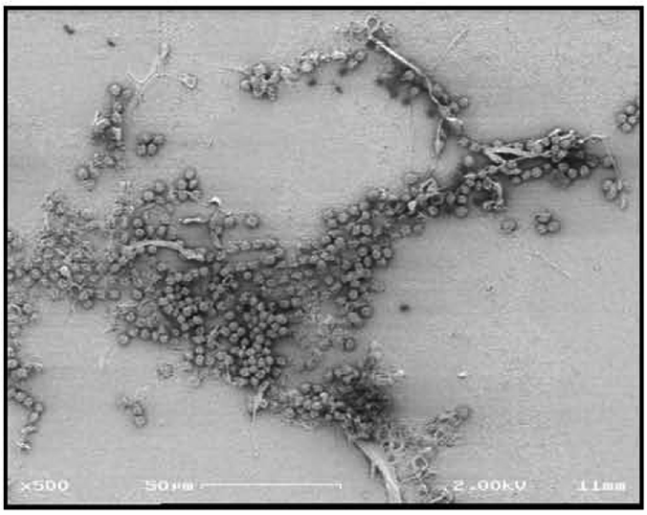


Figure 5 (above left). Isolate E (from Blickling) has formed stringy-looking trails of polymer (indicated with circles) over and around the silk. The scale bar is 100 µm. ESEM micrograph.

Figure 6 (above right). Fibers covered with microbes and polymer, isolate bacteria from dust sample D. The scale bar is 50 µm. SEM micrograph.

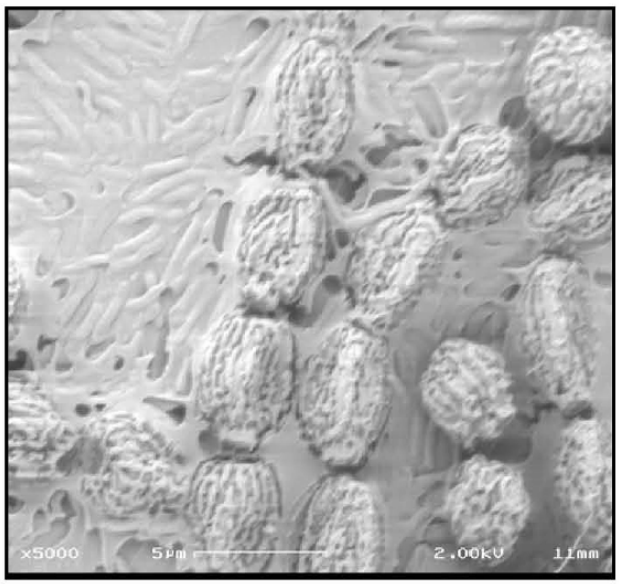


Figure 7. Exopolymer and microbes from isolate bacteria from dust sample D. The fibers are no longer visible because the biofilm has covered them. The scale bar is 5 µm. SEM micrograph.

4.4. GC-MS

The compounds identified from the hexane extraction included diphenyl ether (commonly used as a textile flame retardant and pesticide) and pentaethylene glycol (an anti-icing agent in petroleum, $C_{10}H_{22}O_6$). There were heavy hydrocarbons from fuel combustion and motor oil as well: octadecane ($C_{18}H_{38}$), eicosane ($C_{20}H_{42}$), and heptacosane ($C_{27}H_{56}$) (CambridgeSoft Corp. ChemFinder 2004; Potter et al. 1998; see Fig. 8).

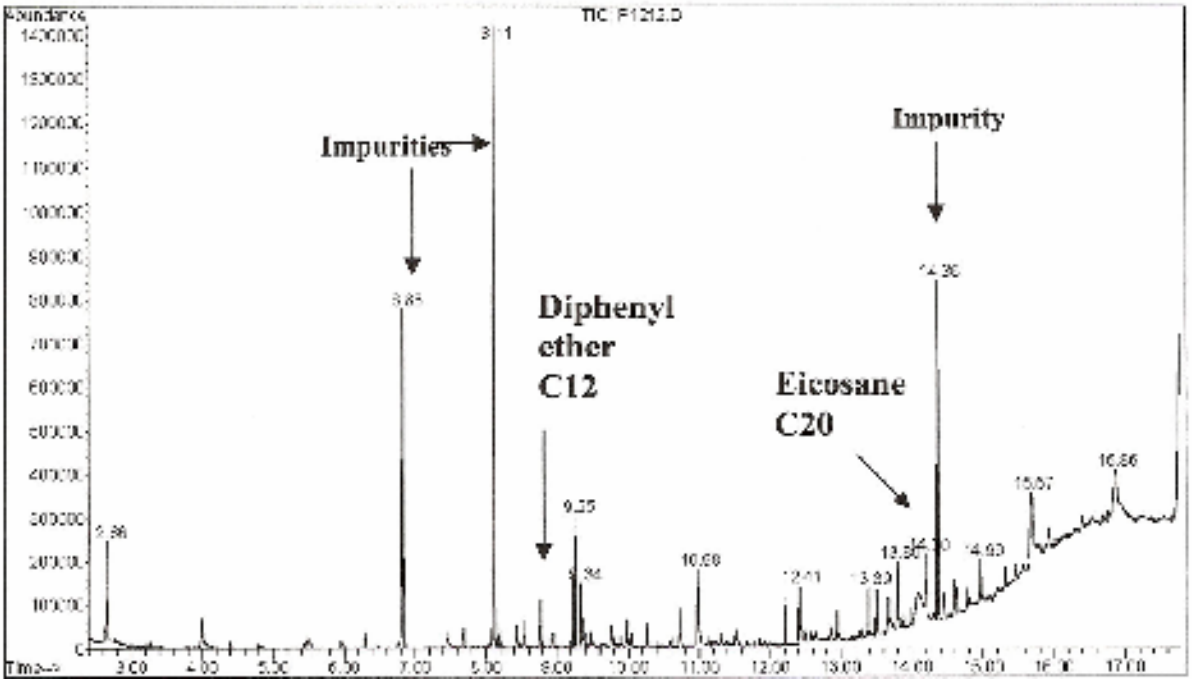


Figure 8. Chromatogram for the hexane extraction of dust sample D (Brown Gallery, Knole).

The 1:1 ethanol and water extraction yielded many fatty acids and chemicals: dimethylamine (C_2H_7N), 1H-Pyrazole ($C_3H_4N_2$), 4,5-dihydro-1-phenyl, acetic acid (ethanoic acid, $C_2H_4O_2$), octanoic acid ($C_8H_{16}O_2$), propanoic acid ($C_3H_6O_2$), and 1,2-benzenedicarboxylic acid, butyl ($C_{16}H_{19}O_4$). Although there could be many sources for these chemical compounds, these compounds had specific probable sources in common: insecticides, pesticides, herbicides, and fungicides. Chemicals commonly used in textile manufacturing and processing were also identified: glycerin ($C_2H_4O_3$), hexanoic acid ($C_6H_{12}O_2$), and adipic acid (hexanedioic acid, $C_6H_{10}O_4$) (Merck Index 1996; CambridgeSoft Corp. ChemFinder 2004, Washington State U., 2002; PAN Pesticides 2004; Nettles 1983; Canadian C.O.H.S. Cheminfo 2004; U.S. EPA 2004). These are likely from the textile fibers in the dust (see Fig. 9).

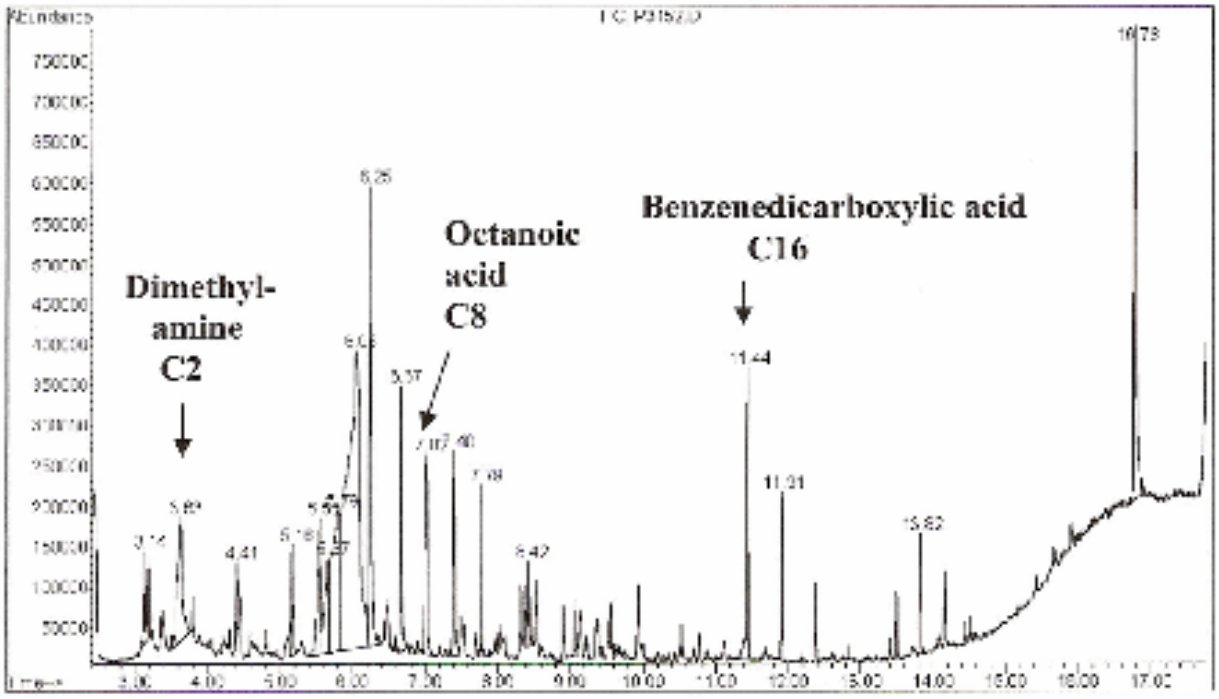


Figure 8. Chromatogram for ethanol and water extraction of dust sample D (Brown Gallery, Knole).

Of the 28 isolates in 1% kerosene and minimal salt solution, 82% displayed bacterial growth and 11% displayed fungal growth (Table 2). All of the fungal specimens grew from isolates harvested from Blickling Hall dust samples, and no fungal growth was observed in kerosene innoculated with dust from Knole. This confirmed that the hydrocarbons in the dust samples provided nutrients for microbial growth.

Dust sample	Sample Location	Percent growth
A	Venetian Ambass. Bed, Knole	50
B	Venetian Ambass. Bed, Knole	80
C	Venetian Ambass. Bed, Knole	100
D	Brown Gallery, Knole	86
E	Peter the Great Room, Blickling Hall	100

Table 2. Percent of isolates able to grow using kerosene as the sole energy source.

5. Discussion

These techniques illustrated that microorganisms play a role in dust adhesion. The prevention of dust adhesion due to microbial polymers in biofilms may be achieved by three-step process: identification of the microbial community and it's environment; sanitation and cleaning; and prevention of new biofouling (Flemming 2002). The experiments described offer a model for achieving step one, identification of the microbial community. Collecting the vacuum cleaner bags allows for later investigation of the dust contents and the microbial population. Other models of collecting dust for examination include glass slides and sticky samplers (Yoon et al. 2001).

Characterizing the biological community in the dust revealed information on the type and population of microbes present. However, the two methods used to quantify the microbial population are not flawless; counting CFU's reflected only microbial colonies that were able to grow on a specific pure culture plate media. The dust on the objects at these two sites does not represent pure culture media, but could be a much more complex nutrition scenario. The DAPI stain method causes all microbes present (and sometimes other matter) to fluoresce and be counted; naturally the numbers will be higher with the DAPI method. Although imperfect, the methods do allow for valuable comparisons. High populations may signal that there are problems on the microscale level occurring on the dusty surface of an object. Non-commonalities and new developments in the dust can alert the conservator to possible risk for the objects due to the microbial activity observed. The polymers generated in combination with the dust can be difficult to remove with time; surfaces may eventually be damaged by prolonged contact with acids produced by metabolism. The degree of wool and silk textile deterioration due to prolonged exposure of dust particles and microbes remains unknown, as it would be unique to each set of historic house variables (i.e. dust accumulation, humidity levels, microbes present, available nutrition, etc.).

In the case of Knole, the compounds found in the dust by GC-MS analysis may indicate that past use of the permethrin-based insecticide 'Constrain' on the floorboard and wall interfaces may have left a residue that microbes can utilize for nutrition (Bullock 2004; Cornell University Extoxnet 2004). Further analysis on this issue would be beneficial for collections subjected to pesticides.

The other compounds found in the samples provided nutrition for biofilm growth, and microbial exopolymers were able to secure dust particles to textile fibers in a high humidity environment in a short period of time. Housekeeping practices like vacuuming cannot address or remediate this problem after a biofilm is established. Traditional means of sanitation and cleaning (step 2) can be employed along with new and innovative methods (Madigan et al. 2003). Although washing is avoided until necessary with historic textiles, one of the benefits of washing is removing dust and bacteria. Detergents effectively disrupt the outer protective lipid and protein membranes of bacteria (lysing), and detergents help break the bonds of exopolymer adhesion. Stable materials not affected by exposure to alcohol and water could be wiped or sprayed with an application of 80% ETOH in distilled and deionized water after routine cleaning, which can lyse most kinds of

bacteria (Helenius et al. 1979). When washing is not safe for the textile or affected object, testing known or innovative methods for remediation can be a fruitful source of alternatives to cleaning.

Frequent housekeeping may help to avoid formation of compacted dust and biofilms formation, but is not necessarily the only prevention strategy. When thinking in terms of controlling microorganism growth, the obvious solution is careful humidity control and application of biocides; but this may not deter bacteria as they exude *more* polymer when under stress conditions, and can fix oxygen from sources other than water. Stress conditions include periods of low humidity and nutrition following periods of high humidity with nutrition. Biocides have also not proven to be an effective means to control bacteria, because the biofilm matrix prevents deep penetration into the community of the biocide, and because bacteria can alter their genetic expression to be less susceptible to the biocide (Flemming 2002; Roldan et al. 2003). Regular sanitization and cleaning are preferable to the use of biocides that are increasingly restricted by the government.

Ultimately, prevention involves the development and implementation of a monitoring program where the dust components, microbial population, and humidity levels are evaluated together determine essential relationships. Avoiding even short spikes in humidity can slow or prevent the initial growth of biofilms. Yoon and Brimblecombe have monitored and analyzed dust in museums, and have found correlations between dust deposition and visitor numbers, the proximity of visitors to the objects, and local climate cycles (Yoon et al. 2000, 2001). Prudent preventive practice may include the addition of dust monitoring to an established program of temperature and humidity monitoring and pest management.

6. Conclusion

The study illustrated the nature of the relationship between bacteria and dust particles. The experiments have shown that the microbes in the dust samples are mainly bacteria with a population equal to or higher than outdoor soil samples. Bacteria create a sticky exopolymer as a result of metabolism that adhere dust and textile fibers together. Biofilms can grow from dust on textiles in laboratory conditions in 48 hours. The adhesive and selective nature of bacteria to dust and textiles was illustrated with electron microscopy. Sources of nutrition were identified with GC-MS and are likely deposits from petroleum combustion, textile processing, and localized use of pesticides. Since the interactions between biofilms and historic textiles remain largely unknown, amassing and comparing data on microbial growth on sensitive surfaces would be helpful for evaluating the frequency and adequacy of any cleaning program. Prevention of biofilm formation would ease the degree of difficulty in cleaning delicate objects and reduces exposure to acids excreted by microorganisms. Prevention is achieved with an understanding of the nutritional cycle and eliminating sources of microbial nutrition whenever possible, accomplished by limiting sources of dust and instituting regular cleaning. The study highlights the fact that perfecting strategies and methods for monitoring and preventing indoor biofilms on historic objects, as well as effective remediation measures, remains worthy of further investigation.

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Endnotes

1. The three-year project (2002-2005) was organized by Helen Lloyd of the National Trust of England, and Dr.YH Yoon and Professor Peter Brimblecombe of the School of Environmental Sciences at the University of East Anglia, Norwich, UK.

2. There is disagreement in the scientific literature about the effect surface roughness has on bacterial adhesion. This is very important when examining bacterial adhesion of dust to textiles because textile surfaces can be rough or smooth, like comparing silk to wool. The variance in observations and conclusions is largely due to the technique used to examine this phenomena (Hilbert et al. 2003).

3. Rohan's Miminal salt media: 0.22 g $(NH_4)_2SO_4$, 1.20 g K_2HPO_4, 0.23 g $MgSO_4 \cdot 7\ H_2O$, 0.23 g dihydrate $CaCl_2$ in 1 L distilled sterile H_2O.

Suppliers

4',6-diamido-2-phenylindole (DAPI):
Sigma-Aldrich. P.O. Box 14508, St. Louis, Missouri 63178. Tel.: 1-800-325-3010.
https://www.sigmaaldrich.com.

DIFCO Nutrient Agar culture plate media, Tryptic Soy broth media, and Gram's stain:
Becton Dickinson and Company, Sparks, Maryland 21152. Tel.: 1-800-675-0908. Worldwide to the US: 1-410-316-4000.

Thermanox Plastic Coverslips (NUNC Brand Products):
VWR, West Chester, Pennsylvania 19380. Tel.: 1-800-932-5000.

References

Albertano, P., L. Luongo, and M. Grilli Caiola. 1991. Ultrastructural investigations on algal species deteriorating Roman frescoes. In *Science, technology, and European cultural heritage.* Proceedings of the European Symposium, Bologna, Italy, 13-16 June 1989. Ed. N.S. Baer, C. Sabbioni, and A.I. Sors. Oxford: Butterworth-Heinemann Ltd. 501-504.

Bartholomew, J. W. and H. Finkelstein H. 1958. Relationship of cell wall staining to Gram differentiation. *Journal of Bacteriology* 75: 77.

Bennett, J.W., K.G. Wunch, and B.D. Faison. 2002. Use of fungi in biodegradation. In *Manual of environmental microbiology*, 2nd edition, eds. C. J. Hurst et al. Washington, D.C.: ASM Press. 960-971.

Brady, J. H. 1839. *The visitor's guide to Knole.* London: Printed by and for James Payne. 9.

Bullock, L. 2004. Personal communication. Preventive Conservation Advisor, The National Trust, 36 Queen Anne's Gate, London, SWIH 9AS England.

CambridgeSoft Corporation, ChemFinder online database. http://chemfinder.cambridgesoft.com. Accessed 04/29/2004 and 08/03/2004. Records 84-7-2, 101-84-8, 124-40-3 and 4792-15-8.

Canadian Center for Occupational Health and Safety, Cheminfo online database. www.intox.org. Accessed 04/29/2004. Record number 491.

Ciferri, Orio. 1999. Microbial degradation of paintings. *Applied and Environmental Microbiology* March: 879-885.

Cornell University, Extoxnet, Extension Toxicology Network online database. http://pmep.cce.cornell.edu/profiles/extoxnet/metiram-propoxur/permethrin-ext.html. Accessed 8/03/04. Pesticide Information Profile: Permethrin.

di Bonaventura, M.P., M. del Gallo, P. Cacchio, C. Ercole, and A. Lepidi. 1999. Microbial formation of oxalate films on munument surfaces: bioprotection or biodeterioration? *Geomicrobiology Journal* 16:55-64.

Dornieden, T., A. A. Gorbushina, and W.E. Krumbein. 2000. Patina: physical and chemical interactions of sub-aerial biofilms with objects of art. In *Of microbes and art: the role of*

microbial communities in the degradation and protection of cultural heritage, ed. O. Ciferri et al. New York: Kluwer Academic/Plenum Publishers. 105-119.

DuPont, Uses of DuPont Methylamines online database. www.dupont.com/methylamines/uses.html. Accessed 4/29/2004.

Flemming, H. C. 2002. Biofouling in water systems – cases, causes and countermeasures. *Applied Microbiology Biotechnology* 59:629-640.

Florian, M.-L. 1997. *Heritage Eaters.* London: James and James.

Gu, J.-D., T.E. Ford, and R. Mitchell. 2000 (A). Microbial degradation of materials: general processes. In *Uhlig's Corrosion Handbook,* ed. R.W. Revie. 2nd ed. 349-365.

Gu, J.-D., T.E. Ford, D.B. Mitton, and R. Mitchell. 2000 (B). Microbial degradation of polymeric materials. In *Uhlig's Corrosion Handbook,* ed. R.W. Revie. 2nd ed. 439-460.

Gustashaw, KM. Chromosome stains. In *The ACT Cytogenetics Laboratory Manual, Second Edition,* edited by M. J. Barch. The Association of Cytogenetic Technologists, Raven Press, Ltd., New York, 1991.

Helenius, A., D. R. McCaslin, E. Fries, and C. Tanford. 1979. Properties of detergents. In *Biomembranes, part G: biogenesis: biogenesis of mitochondria, organization, and transport.* Methods in Enzymology, vol. LVI, ed. S. Fleischer. 734-749.

Hideo, A. 1984. Microbiological studies in the conservation of paper and related cultural properties. Part I. Isolation of fungi from the foxing on paper. *Science for Conservation* March 23: 33-39.

Hilbert, L. R., D. Bagge-Ravn, J. Kold, and L. Gram. 2003. Influence of surface roughness of stainless steel on microbial adhesion and corrosion resistance. *International Biodeterioration and Biodegradation* 52:175-185.

Lithgow, Katy. 2004. Personal communication. Conservation Advisors Manager, The National Trust, 33 Sheep Street, Cirencester, Glos., GL7 1RQ England.

Macher, J.M. 2001. Review of methods to collect settled dust and isolate culturable microorganisms. *Indoor Air* 11:99-110.

Madigan, M. T., J. Martinko, and J. Parker, eds. 2003. *Brock biology of microorganisms,* 10th ed. New Jersey: Pearson Education , Inc., Prentice Hall. 706-707.

Mahall, K. 1982. Biodegradation of textile fibers as seen under the microscope – actual case histories. *International Textile Bulletin* 4: 280, 285-288, 291-292.

Marshall, K. 1996. Adhesion as a strategy for access to nutrients. In *Bacterial adhesion: molecular and ecological diversity,* ed. M. Fletcher. New York: Wiley-Liss, Inc. 59-87.

Merck Index, Encyclopedia of Chemicals, Drugs, and Biologicals, 12th edition. 1996. S. Budavari et al, ed. New Jersey: Whitehouse Station. 10-11, 547, 1236, 8141.

Mozes, N., P. S. Handley, H. J. Busscher, and P. G. Rouxhet, ed. 1991. *Microbial cell surface analysis*. New York: VCH Publishers, Inc. 7-9.

National Trust, 1987. *Blickling Hall*. Great Britain: The National Trust. 5-8, 48-49, 69, 89.

Nettles, J. E. 1983. *Handbook of chemical specialties: textile fiber processing, preparation, and bleaching*. New York: John Wiley & Sons. 192, 254-256, 337-340, 369-374.

Ogram, A. and K. Sharma. 2002. Methods of soil microbial community analysis. In *Manual of environmental microbiology,* 2nd edition, eds. C. J. Hurst et al. Washington, D.C.: ASM Press. 554-563.

Pesticide Action Network North America, PAN Pesticides online database. http://www.pesticideinfo.org/Detail_ChemUse.jsp?Rec_Id=PC37117. Accessed 04/29/2004. Record: Propanoic acid mixed with acetic acid – pesticide use statistics for 2002.

Phenix, A. and A. Burnstock. 1990. The deposition of dirt: a review of the literature, with scanning electron microscope studies of dirt on selected paintings. In *Dirt and Pictures Separated. Papers given at a conference held jointly by UKIC and the Tate Gallery, January, 1990,* ed. V. Todd. London: UKIC, 11-18.

Potter, T. L. and K. E. Simmons. 1998. *Composition of petroleum mixtures: total petroleum hydrocarbon criteria working group series*, volume 2. Amherst, Massachusetts: Amherst Scientific Publishers. 5,10,14-17.

Roldan, M., E. Clavero, and M. Hernandez-Marine. 2003. Aerophytic biofilms in dim habitats. In *Molecular biology and cultural heritage*, ed. C. Saiz-Jaminez. Lisse: Swets and Zeitlinger. 163-169.

Sackville-West, V. 1958. *Knole and the Sackvilles*. Kent: Ernest Benn Limited. ix, 23, 38, 50.

Szczepanowska, H.M. and W.R. Moomaw. 1994. Laser stain removal of fungus-induced stains from paper. *Journal of the American Institute for Conservation* 33: 25-32.

Seves, A.M., M. Romano, T. Maifreni, S. Seves, G. Scicolone, S. Sora, and O. Ciferri. 2000. A laboratory investigation of the microbial degradation of cultural heritage. In *Of microbes and art: the role pf microbial communities in the degradation and protection of cultural heritage,* ed. O. Ciferri, P. Tiano, and G. Mastromei. New York: Klewer Academic/Plenum Publishers. 121-133.

Suwanarit, P. 1995. Role of microorganisms in the deterioration of woolen carpet. In *Biodeterioration of cultural property 3: proceedings from the 3rd international conference on biodeterioration of cultural property, July 4-7, 1995, Bangkok, Thailand,* ed. C. Aranyanak and C. Singhasiri. Bangkok: Office of Archaeology and National Museums, Conservation Science Division. 701-718.

U.S. Environmental Protection Agency, Federal Register Environmental Documents online database. www.epa.gov/fedrgstr/EPA-PEST/2003/January/Day-13/p615.htm. Accessed 04/29/2004. Record: Propanoic acid, and its calcium and sodium salts.

Varnam, A. 2000. *Environmental microbiology*. Washington, D.C.: ASM Press. 10-11.

Washington State University. Fact sheet for vinegar/acetic acid recommendations. http://oregonstate.edu/dept/nurseryweeds/weedspeciespage/acetic_acid_factsheet.pdf. Accessed 4/30/2004.

Yoon, H. Y., and P. Brimblecombe. 2000. Contribution of dust at floor level to particle deposit within the Sainsbury Center for Visual Arts. *Studies in Conservation* 45: 127-137.

Yoon, H. Y., and P. Brimblecombe. 2001. The Distribution of soiling by coarse particulate matter in the museum environment. *Indoor Air* 11: 232-240.

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GROOMSTICK: A STUDY TO DETERMINE ITS POTENTIAL TO DEPOSIT RESIDUES

Sara A. Moy

Abstract

The use of kneadable eraser products for dry surface cleaning on works of art is a common practice adopted from paper and book conservation, but questions as to their suitability consistently arise with the availability of each new product. Since the 1960s testing has attempted to address whether erasers and other related dry cleaning materials leave residues when applied to works of art. While many products have been found to be inappropriate for use on artifacts, the viability of Groomstick, a vulcanized rubber of cis-1,4 polyisoprene has not previously been conclusively established.

This paper reviews past studies conducted on a variety of kneadable rubber products with a focus on the author's investigation of Groomstick and its potential to contaminate surfaces.

1. Introduction

The potential for eraser products to damage surfaces during dry cleaning has been a concern since the 1960s, as they may disrupt the surface and/or leave traces of the eraser behind. The question of whether erasers used to remove loose contaminants and other superficial matter would leave any harmful residues in paper was addressed in 1966 when the Library of Technology Program of the American Library Association commissioned the McCrone Associates to study 17 book cleaning materials. Of the 17 cleaning materials, only one was the kneadable type, Absorene wallpaper cleaner, a starch-based pink putty. Based on microscopic evaluation and accelerated aging tests of paper cleaned with them, all cleaning materials evaluated were deemed safe for use, including Absorene (Horton 1969). It was presumed that residues left behind from some of these dry cleaning products would even be beneficial if remained on the paper (Walter C. McCrone and Associates 1966).

2. Kneadable rubber products

2.1 Wallpaper cleaner

Subsequent study on Absorene and Sheffield's, the European equivalent wallpaper cleaner, advised that all eraser materials be removed from the surface of the paper to avoid the possible long-term destructive effect of the residues or crumbs, as they were found to be tenacious once they had dried (Banks 1969). It was postulated that some of these materials could be regenerated with a little water (Horton 1969), and that further solvent or wet-cleaning methods applied to the paper would cause the residues to dissolve or to swell, and to penetrate further into the paper matrix (Moffatt and Laver 1981).

2.2 Silly Putty

Silly Putty is a pink dough sold primarily as a children's toy. It has been classified as a kneadable material whose main component is silicon with the presence of titanium, colorants and traces of iron and chloride (Moffatt and Laver 1981). It is oily in nature and if left on a sheet of white paper for a day was found to flow down into the matrixes of the paper, making it impossible to remove and causing an oily pink discoloration (Moffatt and Laver 1981). It has been suggested by Cowen (1986) that colored materials are inappropriate and should be avoided, as they may become trapped and visible on the surface of an object.

2.3 Kneadable erasers

Several other kneadable eraser products have also been studied. They include the Artist Rubber manufactured by Faber Castell Corporation, Kneaded Rubber 1224 by Eberhard Faber and Rowney Kneadable Putty Rubber by Daler-Rowney. In the late 1960s these kneadable rubber erasers were described as the gentlest of all erasers, however further investigation has shown them to abrade surfaces to a greater extent than block and powder erasers (McInnis 1980). The chemical composition of these putties has been identified as polyisobutene rubber with calcium carbonate (AIC Books and Paper Group 1992; Moffatt and Laver 1981). Trace elements include chloride, sulfur, titanium, magnesium, aluminum, silicon, potassium and carbon black (AIC Books and Paper Group 1992; Moffatt and Laver 1981). It has been found that Kneaded Rubber 1224 left behind a gummy residue on Mylar film (Hueber 1985). Small residual crumbs of Artist Rubber and Kneaded Rubber 1224 have been detected in paper fibers (Pearlstein et al. 1982). The presence of sulfur in Kneaded Rubber 1224 was found to tarnish silver coupons when the rubber was left in contact (Moffatt and Laver 1981). Only the Rowney Kneadable Putty Rubber had no corrosive affect (Thomsen and Shashoua1991).

It has been suggested that kneadable erasers could transfer oils from the fingers and dirt to the eraser and then to the object during cleaning (Cowan 1986). This was not evaluated until 1988, when the British Museum launched a study to evaluate soiled Kneadable Putty Rubber and its potential ability to transfer dirt onto clean substrates. They found that heavily soiled Kneadable Putty Rubber imparted detectable organic residues. These residues were attributed to the contaminated eraser (Thomsen and Shashoua).

3. Groomstick

Groomstick, another kneadable rubber product, is described by the manufacturer (Picreator Enterprises) as a "Processed kneadable rubber, extraordinarily absorptive and retentive. Permanently Tacky, non-hardening, clean to handle. Gentle, non-abrasive, non-staining cleaner of paper and archival materials. Dry-cleaner and de-greaser of hands and many other smooth or carved solids. 'Ever-lasting' service life" (Picreater Enterprises Ltd 1999) (Fig. 1).

Figure 1. Groomstick.

Like other kneadable products, Groomstick has also been studied for its ability to impart itself on to substrates. The first study of Groomstick appeared in 1981 by CCI (Moffat and Laver 1981). The Analytical Research Services division at the Canadian Conservation Institute, using x-ray primary emission spectroscopy in a scanning electron microscope, identified the material as vulcanized cis-1, 4-polyisoprene containing titanium dioxide and traces of calcium, Al, Si, K, Fe, Cl, and sulfur

This study found that Groomstick left no detectable residues and did not cause any tarnishing to silver. A subsequent study conducted in 1991 by the British Museum (Thomsen and Shashoua), also found that Groomstick, when fresh, did not to impart itself onto substrates. Unlike the study conducted at CCI, tarnishing was found on silver coupons when the rubber was left in contact. They also concluded that that soiled Groomstick, like Kneadable Putty Rubber contaminated clean surfaces. In a study carried out in 1995 (Caldararo), substrates that were cleaned with Groomstick were thermally aged in order to detect observable color changes on cleaned surfaces. It was observed that aged substrates treated with Groomstick produced a yellow/brown residue on paper. A milky whitish-gray film was observed on sandpaper and a reflective surface was detected on black mat board.

4. Experiment

In 1999, a study was designed to evaluate (1) the application of Groomstick under a variety of temperatures; (2) the application of aged and artificially aged Groomstick; (3) the application of soiled Groomstick to evaluate its potential ability to transfer soil onto clean substrates; and (4) examination of surface change in artificially aged substrates cleaned with fresh Groomstick.

4.1 Substrates

Drawing from previous experiments performed on dry cleaning materials, five substrates were selected for this experiment. These were:
• Whatman's # 1 chromatography paper number 1 basis weight 87g/m2, thickness 0.16 mm applied on felt side
• Potassium bromide discs, 1.750g (=/- 0.015g), pressed at 25 tons
• Bueler plain waterproof silicon carbide discs metallographic grinding paper, grit-P200
• Whatman's 100% borosilicate binder free glass micro fiber filters, 25mm circles
• Whatman's flexible chromatography paper, PE SiLG/UV, 250μm layer on a flexible polyester back.

The latter two substrates were added to provide a broader range of surfaces in addition to its potential to be analyzed with little spectral interference.

4.2 Instrumental analysis

Scanning electron and binocular microscopes were used for visual examination for the detection of residues (See Appendix A). Elemental analysis included Energy-dispersive X-ray analysis (EDXA) in the SEM to detect inorganic trace elements which are contained in the Groomstick and Fourier Transform Infrared Spectroscopy (FTIR) to detect organic composition, namely the functional groups found in natural rubber, *cis*-1, 4-polyisoprene. Backscattered images taken from the SEM and elemental analysis using EDXA were performed on uncontaminated (control) substrates and compared with those being tested. Spectra of the possibly contaminated surfaces, uncontaminated substrates and Groomstick were obtained from FTIR. These spectra were compared so as to identify any deposited residues.

4.3 Groomstick applied at varying temperatures

The manufacturer of Groomstick advises that the product should be stored under room temperature and between polyethylene sheets (Picreater Enterprises Ltd 1999). Despite these instructions, it has been found that many conservation laboratories store their supply in the refrigerator. This is possibly due to the nature of natural rubber, *cis*-1, 4-polyiosprene, which has a very low glass transition temperature, enabling it to flow at room temperature. Refrigerated Groomstick would be less tacky than an un-refrigerated supply. A less sticky material would be less likely to attach to the surfaces that are being cleaned.

4.3.1 Temperature selection: Discussion

The exposure of test samples of Groomstick to varying temperatures was performed in order to determine whether or not this would have any impact on potential eraser residues deposited. Realistic temperatures of 9˚C (refrigerator temperature), 23˚C (room temperature), 30˚C and

40˚C, a potential temperature in some countries and an unrealistic temperature of 50˚C were selected.

4.3.2 Observations of Groomstick applied at various temperatures

It was expected that Groomstick when applied above room temperature would leave residues on the surfaces of the substrates. With the exception the flexible chromatography paper, it was observed through visual, elemental and FTIR spectroscopy that no contamination was found on any other surfaces. It was however observed that applying Groomstick at temperatures above 30˚C resulted in a more elastic and tacky product.

4.4 Aging

4.4.1 Heat aging – Discussion

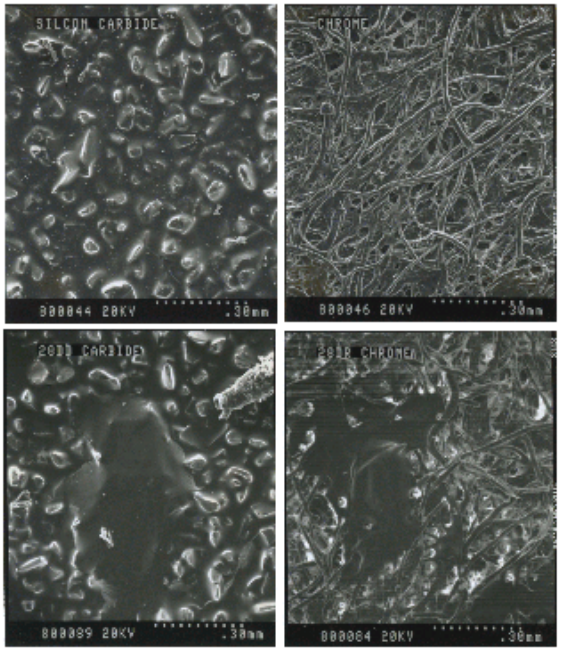
Groomsick is advertised as having an "'Ever-lasting' service life" (Picreater Enterprises Ltd 1999). In general, natural rubbers do not have good long-term chemical stability as they are susceptible to oxidation. Fig. 2 shows samples of Groomstick of unknown age, with typical signs of oxidation. Degradation of vulcanized rubber may result in tackiness and/or pastiness, discoloration and presence of an outer film.

Figure 2. Groomstick samples of unknown age showing typical signs of oxidation.

Following German standard (DIN 53508) for aging soft vulcanized rubber, test samples of Groomstick for thermal aging were exposed to the action of dry heat at 70˚C for 24, 48 and 72 hours and 7, 15 and 28 days.

4.4.2 Observation of thermally aged samples

It was observed that large visible clumps of all thermally aged Groomstick were found on all flexible chromatography paper. Groomstick thermally aged for 28 days, left residues on both Silicon Carbide and #1 chromatography paper. The residues of Groomstick found on silicon carbide paper could not be detected under the binocular microscope, but were easily discernable under the SEM at x100 magnification (Fig. 3). Qualitative analysis using EDXA identified the presence of titanium on both silicon carbide and Whatman's #1 chromatography paper. Silicon was also detected on the chromatography paper (Fig. 4).



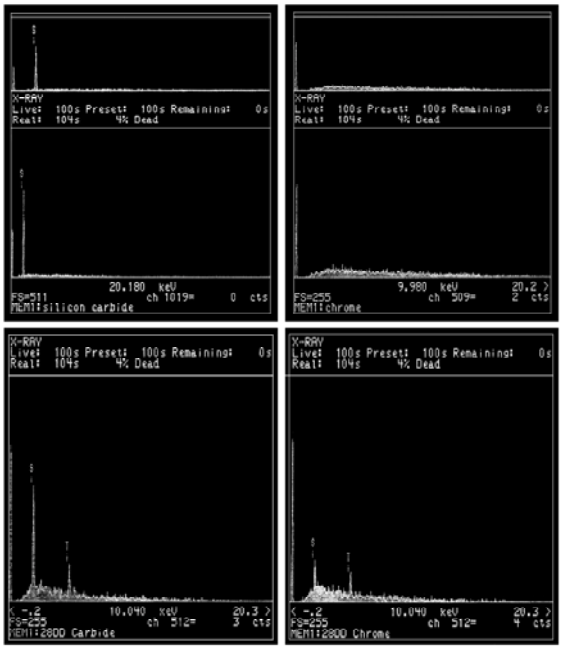


Figure 3 (left). Observation of thermally aged Groomstick. SEM photomicrographs (clockwise from upper left): Silicon carbide control (100x); chromatography paper control (100x), applied by tamping; 28 days heat-aged on chromatography paper (100x), applied by rolling; and 28 days heat-aged on silicon carbide (100x), applied by tamping.

Figure 4 (right). Observation of thermally aged Groomstick: EDXA spectra (clockwise from upper left) Silicon carbide control; chromatography paper control; 28 days heat-aged on chromatography paper, applied by tamping; 28 days heat-aged on silicon carbide, applied by tamping.

4.4.3 Light aging: Discussion

Like the heat aged samples, Groomstick samples for accelerated light aging, following British Standard Institution (BS 1006:1990) for *Color Fastness to Artificial Light: Mercury Vapor Fading Lamp Test,* were exposed for 24, 48 and 72 hours, and 7, 15 and 28 days (BS1006:1990). Additionally, Groomstick pieces were aged under natural light on a windowsill and dark-aged at room temperature in a cupboard at 23ºC for 28 days.

4.4.4 Visual observation of light-aged samples

It was found that all artificially light-aged Groomstick produced a skin-like film. There were no significant changes found with the dark aged sample. Groomstick exposed to 28 days of natural light had the same physical appearance as the sample that was artificially light-aged for 7 days (Fig. 5).

Figure 5. Left, Groomstick exposed to 28 days of natural sunlight; right, Groomstick control.

4.4.5 Observation of application of light-aged samples

Dark-aged Groomstick did not impart itself onto the test substrates, however all light-aged samples with the exception of the glass filter paper contained residues (Fig. 6). The Groomstick was found to be too tacky for the glass filter paper, pulling surfaces away. Clumps of Groomstick and transparent and/or translucent reflective films were observed with the aid of a binocular microscope, and some of the residues were visible without magnification. Traces of titanium and silicon were consistently detected using EDXA; absorption peaks containing functional groups including alkanes, double bonds and OH, typical of vulcanized rubber, were found on the FTIR spectra of all potassium bromide discs, indicating the presence of Groomstick (Fig. 7).

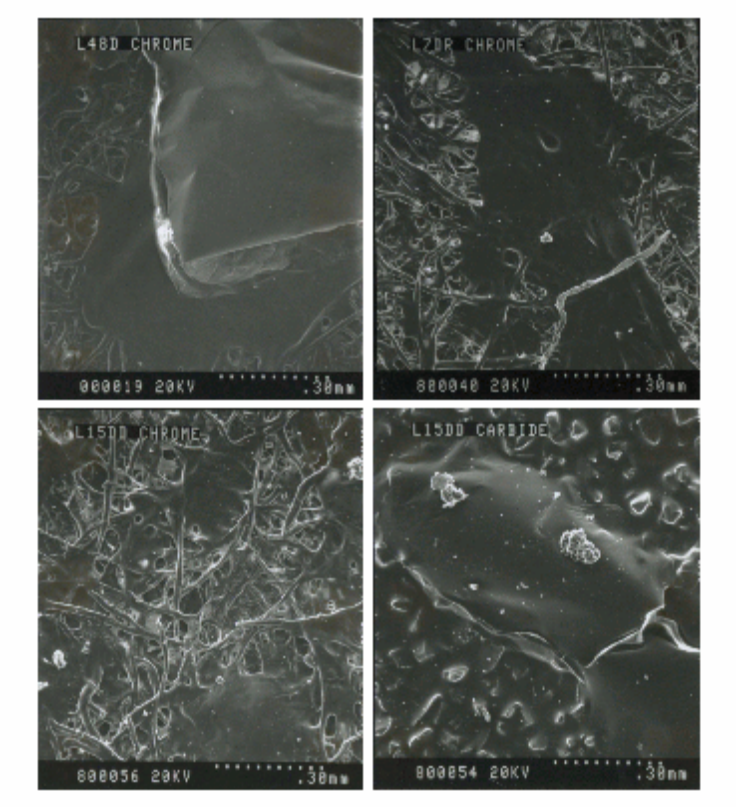


Figure 6. Observation of light-aged Groomstick. SEM photomicrographs, clockwise from upper left: 48 hours of artificially light-aged on Whatman's #1 chromatography paper (100x), applied by tamping; 7 days of artificially light-aged on Whatman's chromatography paper (100x), applied by rolling; 15 days of artificially light-aged on silicon carbide (100x), applied by tamping; 28 days of naturally light-aged on Whatman's #1 chromatography paper (100x), applied by tamping.

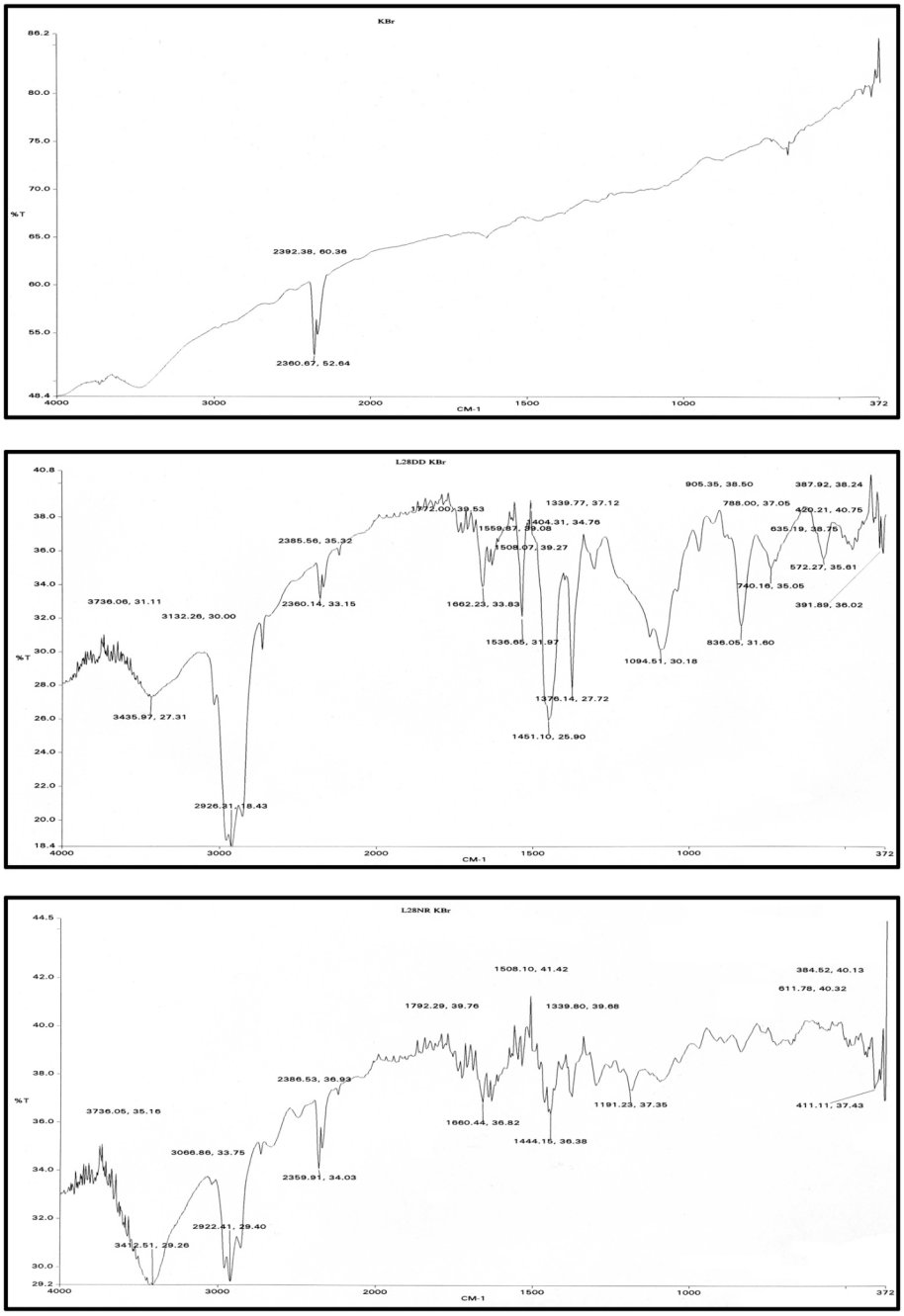


Figure 7. FTIR spectra of light-aged Groomstick. Top: KBr control, Middle: spectrum of 28 days artificially light-aged sample on KBR disc, Bottom: spectrum of 28 days naturally light-aged sample on KBR disc.

4.4.6 Groomstick of unknown age

No preparation was required for the Groomstick pieces of unknown age labeled no. 1 and no. 2

4.4.7 Observation of samples of unknown age

It was found that sample no. 2 of unkown age resembled Groomstick that was artificially light aged at 28 days.

Sample no. 2 of unknown age also imparted the same type of residues on the test substrates as Groomstick that had been artificially light-aged. Sample no.1 of unknown age did not appear to leave residues. It was also observed that the Groomstick samples of unknown age had functional groups found on the FTIR spectra similar to the artificially light-aged samples. Due to the control panel malfunctioning during analysis, trace elements could not be determined on EDXA.

4.5 Selected particulate matter

Four types of particulate matter were selected to contaminate erasers: (1) mold *Aspergillus niger*, commonly found in temperate climates on museum objects derived of cellulose, plant materials and other organic materials; (2) soot obtained from the interior surface of a glass candleholder; (3) lanolin (hydrous wool fat), often found in hand creams and lotions, was selected to imitate oily residue that might be found on bare hands; and (4) dust obtained from a nearby air-extraction unit.

4.5.1 Observation of substrates cleaned with Groomstick contaminated with particulates

Dust, soot and mould were transferred from Groomstick to substrates. Dust was found on the surfaces of substrates having a topography. Soot was observed on the flexible chromatography paper and KBr discs (Fig. 8). Peaks found on the soot spectrum were found on contaminated substrates. Mold was observed upon application with the naked eye on most substrates. Contaminated mold substrates undetectable with the naked eye were confirmed under high magnification and FTIR spectroscopy. The transfer of lanolin on substrates could not be determined conclusively on visual examination or through FTIR analysis.

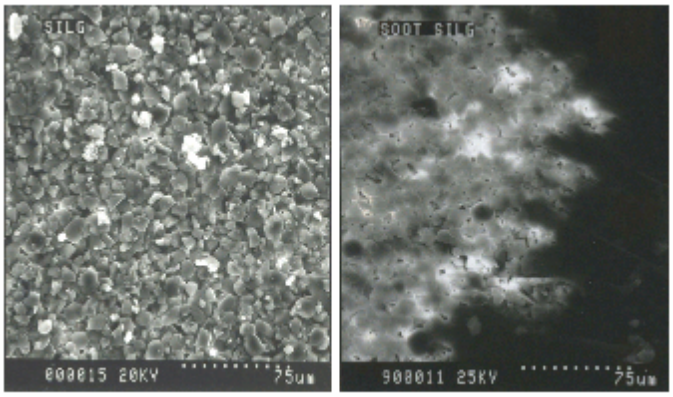


Figure 8. Left, Flexible chromatography paper control (400x), Right, soot observed on the flexible chromatography paper (400x).

4.6 Observations of aged test substrates following application of fresh Groomstick

No Groomstick oxidization residues were found on aged test substrates, with the exception of the flexible chromatography paper. This was the only substrate with residues that were visible during the application of Groomstick. The clumps that remained after aging appeared as yellow/brown rings around the gray mass of Groomstick.

5. Review of test substrates

It should be noted that the glass filter paper and flexible chromatography paper might not have been the ideal testing substrates. The surface of the glass filter paper lifted too easily, clinging to the Groomstick when applied, and it was readily disrupted on handling. All applications of Groomstick, even when fresh, had a marked tendency to stick to the flexible chromatography sheets.

6. Conclusion

The Groomstick investigation carried out in this project showed fairly conclusively that it has the potential to leave residues behind. However, the nature of the deposited residues will vary.

We can conclude that Groomstick is temperature dependent, as its ability to 'tack' to a surface increases with a rise in temperature. This is especially noticeable with surfaces that have topography. The rougher the surface, the more likely the warmer Groomstick will stick to it. Smooth surfaces, such as the pressed KBr, were less likely to retain a residue, as there is nothing for the Groomstick to grab or hold on to.

Despite the slight changes in working characteristic found in thermally aged Groomstick, only the substrates with irregular surfaces retained residues, and only after 28 days of heat aging. In contrast, with both artificial and natural light aging residues were found on both irregular and smooth surfaces even at 24 hours of exposure. It is unclear how much dark aging will actually affect Groomstick. Given its potential to degrade quickly in light, the product should be stored where exposure to light is minimal.

Soiling held in Groomstick has a great potential to transfer on to cleaned surfaces. It should be noted that if Groomstick is used to remove superficial matter, it should not be reused. However, the finding in this study that Groomstick has the potential to leave residues behind does not preclude its use for the cleaning of artifacts. What should be considered is temperature at which it is applied. Clearly, the suitability and efficiency of this product and its application must be evaluated on an object-by-object basis. In the end, Groomstick is worthy of remaining in our toolbox but the conservator’s judgement is always paramount.

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References

The American Institute for Conservation of Historic and Artistic Works, Books and Paper Group Eighth Edition, March 27, 1992.

Banks, P. N. 1969. Paper Cleaning. *Restaurator* 1:1, 5-6.

British Standards Institution. 1990. BS 1006:1990. *Color Fastness to Artificial Light: Mercury Vapor Fading Lamp Test.* London: BSI.

Caldararo, N. 1995. A Note on the Use of Groomstick on Paper. *Archives et Bibliotheques de Belgique* 66:1-4, 83-94.

Cowan, J. 1986. *Technical Bulletin No. 11: Dry Methods for Surface Cleaning of Paper*. Ottawa: Canadian Conservation Institute.

Horton, C. 1969. *Cleaning and Preserving Bindings and Related Materials.* Chicago: American Library Association. 64.

Hueber, R. P. 1985. *Investigation of Document Cleaning Preparations* (unpublished). National Archives and Record Administrations (NARA), NNPD, cited on p. 21 of *The American Institute for Conservation of Historic and Artistic Works, Books and Paper Group* Eighth Edition, March 27, 1992.

McInnis, K. 1980. Study 2: Dry Cleaning of Paper. *I.I.C.M.Bulletin, June 6, 1980*. 43-52.

Moffat, E. and M. Laver. 1981. *Erasers and Related Dry Cleaning Materials* (unpublished). CCI Analytical Report ARS. No. 1738, File No. 7034-20-3, October 20, 1981.

Pearlstein, E. J., D. Cambelli, A. King and N. Indicator. 1982. Effects of Eraser Treatment on Paper. *Journal of the American Institute for Conservation* 22:1,1-13.

Picreater Enterprises Ltd. Groom/Stick Paper Cleaner. Printed product literature enclosed with product when obtained in 1999.

Thomsen. S. and Y. Shashoua. 1991. Evaluation of Kneadable Rutty Rubber as a Mechanical Cleaning Agent for Ceramics and Paper Surface. Unpublished. The British Museum Conservation Research Section report 1991/45.

Walter C. McCrone Associates. 1966. The Report on Testing Book Cleaning Materials (unpublished). Report to the Library Technology Project No. 50, July 1966.

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Appendix A

A. Methods of Analysis and Examination

The purpose of this appendix is to provide an overview of the methods of analysis used during the project for the examination of residues Groomstick. The capabilities of each technique and the specifications while running the equipment will be presented.

A.1 Stereomicroscope

The Vickers Stereomicroscope with a built-in illumination consisting of a pair of x10 eyepieces and objective lens providing a x20 magnification was utilized for the initial examination of the substrates tested.

A.2 Scanning Electron Microscope – Energy Dispersive X-Ray Analysis

The Hitachi Model S-570 scanning electron microscope, equipped with a Mamiya camera was employed for examining and photographing all substrates, tested and untested. A beam of electrons at 20 kV is directed at the sample striking the atoms presented on the surface to approximately 30mm and 75μm in depth. Detecting the resulting secondary electron or backscattered electrons creates images.

Energy dispersive X-ray analysis, the analytical facility on the SEM was used to detect inorganic elements contained in Groomstick, which may have imparted on the substrates tested. The samples are bombarded by electrons or x-rays; the x-rays emitted are characteristic to the elements presented. The intensity will depend on how much of those elements are present. No bonding information is provided.

A.3 Fourier Transform Infrared Spectroscopy (FTIR)

Organic functional groups were identified on tested and untested substrates using the Perkins Elmer 2000 Fourier Transform Infrared Spectrometer. The FTIR is a form of absorption spectroscopy that is concerned with the vibrational molecules. When a sample is placed in a beam of infrared radiation, the sample will absorb radiation at frequencies corresponding to molecular vibrational frequencies. Different functional groups will absorb at characteristic wavelength. Diffusive reflectance was employed as this provided little or no sample preparation. Substrates were placed on the plane mirror, at a resolution of 4 cm-1 and scanned 50 times and set to infrared region of the electromagnetic spectrum: 400cm-1 to 372cm-1.

THE MATERIALS AND TECHNIQUES OF RELIEF ELEMENTS IN JOHN SINGER SARGENT'S *TRIUMPH OF RELIGION* MURALS

Angela Chang

Abstract

Recent conservation of John Singer Sargent's *Triumph of Religion* mural cycle (1890-1919) at the Boston Public Library included a significant objects conservation component to treat over 600 relief elements included in the mural design. This paper discusses Sargent's sculptural materials and techniques and highlights one cleaning treatment demonstrating an intention to balance relief elements with their surrounding murals. Completed in January 2004 by the Straus Center for Conservation, this conservation project provided a unique opportunity to study the artist's experimental sculptural materials and techniques. On most of the sixteen marouflaged canvases, Sargent applied decorative relief elements to highlight areas of the design, to animate the surface, and to help incorporate the painted murals into the surrounding architecture. Ranging from low relief to near sculpture in-the-round, the relief materials included painted and gilded plaster, papier-mâché, metals, wood, glass, and Lincrusta-Walton (a nineteenth-century wall covering material). Although Sargent was known almost exclusively as a portrait painter prior to creating the murals, it is thought that he did execute these sculptural details himself. Unlike the complex condition of the oil-painted canvases affected by past restorations, the relief elements appeared largely untouched. Structural problems in many of the relief elements revealed the experimental design and inexperience of the artist with sculptural materials. Treatments focused on stabilizing materials and mounting, and removing heavy grime and dust. This large-scale project required a multi-disciplinary approach to stabilize and clean the mixed media compositions, while considering the surrounding architectural ornaments and lighting created by the artist.

Introduction

John Singer Sargent considered his *Triumph of Religion* murals at the Boston Public Library to be his most important work. Commissioned by the library's architects McKim, Mead and White to decorate the Special Collections Hall, Sargent spent twenty-nine years, 1890-1919, creating his murals and the space in which they were presented. Now called Sargent Hall, the barrel-vaulted room is adorned with sixteen oil-painted canvases filling the upper reaches of the room, gilded architectural moldings, massive wooden bookshelves, a decorative paint scheme, and bronze light fixtures, all designed by the artist (Fig. 1). The murals, mounted with the marouflage technique using a lead white and oil adhesive, depict the history of Western civilization as a progression of religious ideas, beginning with ancient deities and culminating in a modern belief in spiritual individuality. Sargent painted two other mural cycles, one at the Museum of Fine Arts, Boston, and the other at Widener Library at Harvard University, but the *Triumph of Religion* was the most ambitious.

Figure 1. Sargent Hall, southeast view. Photograph courtesy of Bill Kipp 1999.

The viewer's experience was of utmost concern to the artist. Visitors entered the tall, narrow hall (84 feet long, 23 feet wide, 26 feet high) from a staircase along the east wall. The lower edges of the murals were located almost 18 feet from the floor. Supplementing natural light from three skylights, Sargent added six electrified bronze sconces of his own design mounted below the murals, creating a dramatic effect within the cavernous room. Ornate gilded architectural moldings reflected light around the murals and complemented gold details on their surfaces. Sargent further enhanced his mural design with the application of relief elements on the painted canvases. Ranging from low relief to near sculpture in-the-round, the relief materials included painted and gilded plaster, papier-mâché, metals, wood, glass, and Lincrusta-Walton. These elements emphasized details of the design and animated the surfaces with light effects. Sargent's experimental mixed media approach was highly unorthodox, particularly for an artist who had never previously exhibited sculpture.

Questions about whether Sargent executed this work himself were addressed by his close friend and architectural consultant, Thomas Fox, who stated that "Not only all the finished work itself, but all the preliminaries both mechanical and artistic he preferred to do himself alone… There was no squaring off and laying in on canvas by assistants, neither was there any enlarging by pointing up from a small model of any full size sculptural work" (Fox, n.d.). Sargent's own comments in 1894 revealed his meticulous approach: "I must add that an essential feature of the work is the use of ornament in relief of which there is a considerable amount and which would have to be adjusted to the canvases by myself before they are [nailed] to their place..." Over a 29-year working period, Sargent developed his skills in adapting sculptural materials: he experimented with various materials for similar effects, he changed media to solve aesthetic and technical problems, and he improved the effectiveness of layering these media onto his murals.

Sargent's four installation phases in 1895, 1903, 1916, and 1919 demonstrated a marked progression of this development.

In January 2004, the Straus Center for Conservation completed a 15-month project to stabilize and clean the Sargent murals, as well as to consult on other aspects of restoring the Hall (Fig. 2). These included improving environmental conditions and reinstating Sargent's decorative paint scheme and lighting plan. The six-member team of conservators and conservation scientists worked in consultation with an advisory committee of Sargent scholars, other conservators and conservation scientists, and a curator, who met throughout the project to discuss treatment issues and review results. One prevailing concern was achieving a balanced cleaning for these varied surfaces. While the cleaning of the paintings was complicated by past restorations, the relief elements were in better condition, having endured minimal intervention.

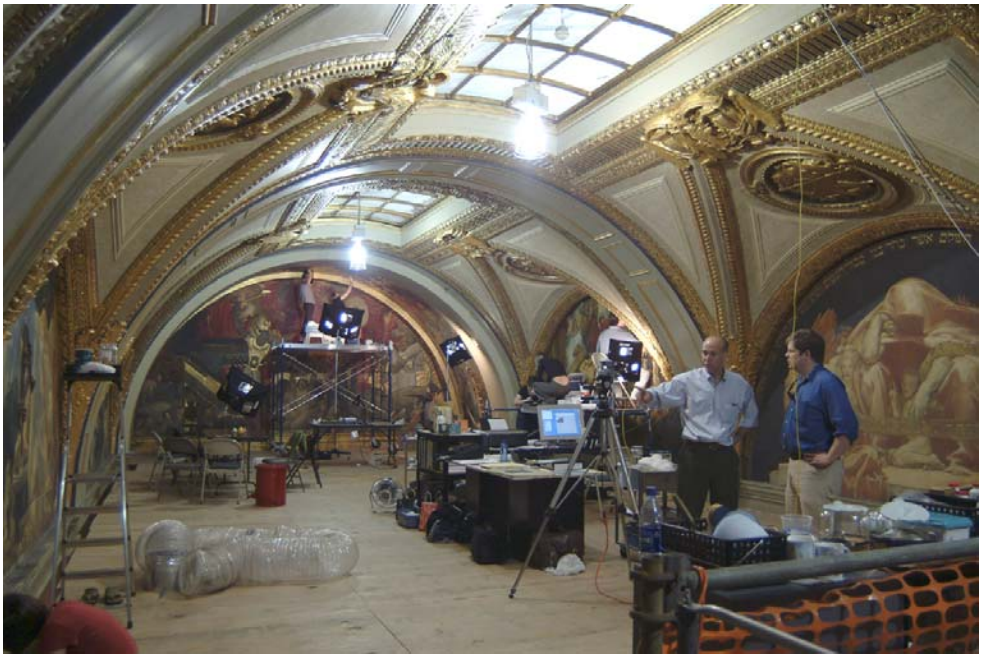

Figure 2. Staging for 2003 conservation treatment.

This project provided a unique opportunity to study Sargent's experimental sculptural materials and techniques. Observations made about the artist's methods in applying relief elements follow, with a subsequent discussion of a cleaning of plaster relief intended to maintain an appropriate aesthetic balance with its surrounding mural.

Early Experimentation with Sculptural Materials

Sargent painted his murals in his London studio and made many adjustments after their installation at the library. The first of four installations occurred in 1895 and included the lunette,

frieze, and vault at the north end of the hall, entitled *Israelites Oppressed*, *Frieze of Prophets*, and *Pagan Gods*, respectively (Fig. 3). For these murals, Sargent rendered specific forms and identifying accoutrements in cast plaster (Figs. 4, 5). While they appeared similar, these elements varied in their composition, quality of casting, and method of attachment.

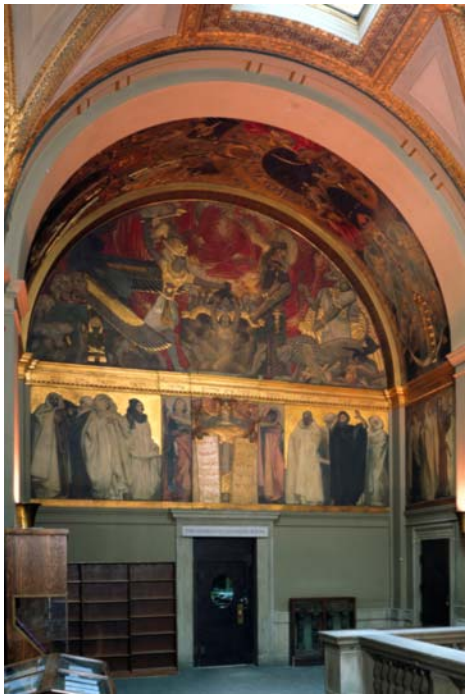

Figure 3. Sargent Hall, north view. Lunette, frieze, and vault installed in 1895. Photograph courtesy of Bill Kipp, 1999.

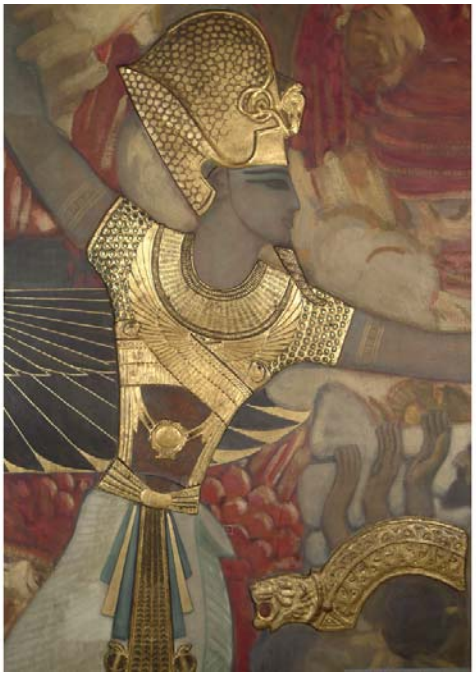

Figure 4 (left). *Israelites Oppressed*, detail. Pharaoh figure. Gilded and painted plaster relief elements.

Figure 5 (right). *Israelites Oppressed*, detail. Genie figure. Gilded and painted plaster relief elements.

Both lime plaster and Plaster of Paris were used in different consistencies, and various bulking agents such as horsehair were added. The verso of some plaster elements had a smooth, even surface suggesting the use of a thin, poured plaster, while others exhibited a lumpy texture with fingerprints from pressing a thick mixture into a mold (Fig. 6, 7). The most complex cast from this installation was the life-size Moses at the center of *Frieze of Prophets* (Fig. 8). This figure appeared to have been first modeled in clay or plasticene on a wooden board, before being cast in plaster. Sargent employed the plaster surface as another support for paint and gold. On Moses' tablets, the plaster surface was treated with a paint or ground layer followed by toning and oil paint layers.

Figure 6 (left). *Israelites Oppressed*, verso of plaster element with a smooth, poured texture.

Figure 7 (right). *Israelites Oppressed*, verso of plaster element with a lumpy, pressed texture.

Figure 8. *Frieze of Prophets*, detail of Moses figure in painted and gilded plaster.

For almost all of the relief elements, surfaces were gilded, toned, and/or painted. Gilding techniques included oil and water gilding, gold paint, and toned aluminum and silver leaf.

Sargent reinforced many plaster elements with armatures or backing materials. Some broad or long and narrow elements such as the sections of the serpent and the bows in *Pagan Gods* were cast with iron wire armatures. In several instances, the expansion of the armature as it corroded caused structural damage to the plaster (Fig 9, 10). Other elements were reinforced with backings made of paper, fabric, or perforated metal sheets. In his most unusual and elaborate combination of materials, Sargent painted and layered painted fabric, plaster, and metal sheet in a cast form to depict the lions surrounding the pagan god Moloch (Fig. 11).

Figure 9 (left). *Pagan Gods*, detail of archer and serpent with bows and serpent in cast plaster.

Figure 10 (right). *Pagan Gods*, detail from archer's bow showing back of bow with damage from armature.

Sargent's application of so many variations in media and techniques in these early murals demonstrated his experimentation with adapting sculptural elements into his mural design. Other examples include cut-glass "jewels" mounted in ready-made brass bezels adorning the pagan goddess, Astarte, in *Pagan Gods* (Fig. 12). Around Moloch, the rays of the sun were made from silver-gilded wood beading, probably manufactured for framing. Segments of wood beading were cut and attached with small nails. The rays terminated in 50 water-gilded, carved wood hands.

The quality and condition of numerous elements pointed to the artist's inexperience with sculptural materials. The quality of the plaster casts varied, with many pieces exhibiting warping and cracks. Other structural damage resulted from the methods of attaching the plaster elements to the murals. A great variety of nails and fasteners were used, often causing significant breaks and cracks in the brittle plaster. In some cases, nails appeared to be hammered in without pilot holes. Sargent left some of this damage as is; in other cases he added more nails to secure the fragments in place. Other fastening methods included nail heads and bent nails used as brackets,

and twisted and looped wires.

Figure 11. *Pagan Gods*, Moloch figure. Gilded details in relief, including sun (oil gilded plaster), rays (silver gilded wood), hands at end of rays (water gilded wood), and lions (painted and gilded plaster backed with fabric or metal sheeting).

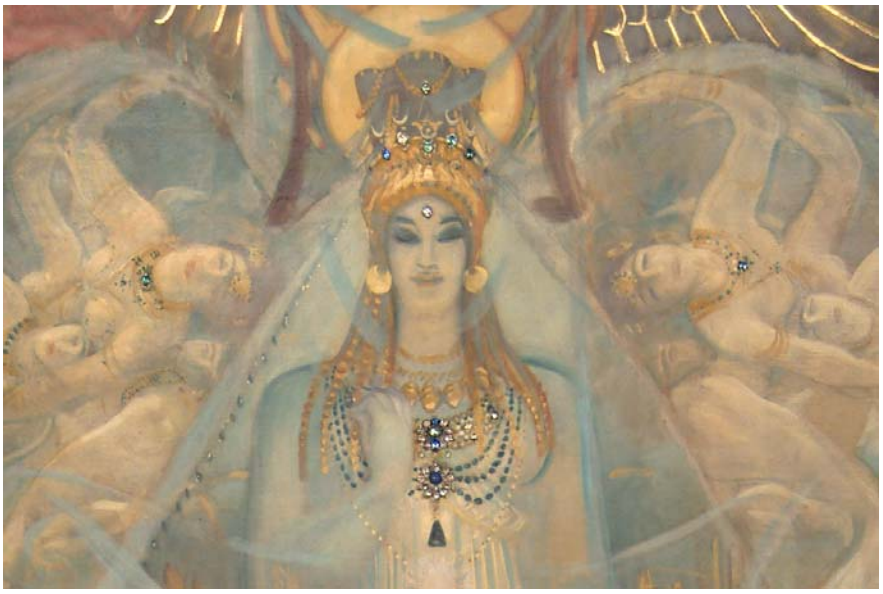

Figure 12. *Pagan Gods*, Astarte figure, detail. Glass "jewels" mounted in brass bezels.

A Shift from Plaster to Papier-mâché Techniques

In the second installation of the murals in 1903, Sargent completed the *Dogma of the Redemption* panel and *Frieze of Angels* on the opposite end of the Hall (Fig. 13). The Byzantine-style ensemble focused on the *Crucifix* sculpture with Christ flanked by Adam and Eve bound by a red cloak. The overlapping on the cornice by the sculpture from above and the angels' wings from below demonstrated Sargent's interest in physically incorporating the murals into the architecture. Sargent created the painted plaster *Crucifix* in consultation with his friend, sculptor Augustus Saint-Gaudens, and the help of his plaster molder in London.

Figure 13. Sargent Hall, south view. Lunette, *Crucifix*, and frieze installed in 1903. Vault installed in 1916.

Crucifix was first formed in clay or plasticene, and then cast in six sections (Fig. 14)**.** Sargent painted the surfaces with thin glazes of color, leaving areas of the plaster showing through as highlights. Areas depicting flesh were painted directly onto the plaster, whereas red and gilded areas were first sized with glue.

In the surrounding mural, Sargent shifted from plaster to papier-mâché as his primary relief material. With papier-mâché, Sargent rendered the faces and hands of the Trinity figures, the orphrey, and the instruments of the Passion held by the angels (Figs. 15-17). These elements were built up in a mold with two or three plies, coated with a shellac-like glaze, painted, and gilded. With papier-mâché, Sargent eliminated many of the problems he encountered with plaster in the previous installation. The light, flexible material took a sharp impression of fine details, and the thin casts blended well into his paintings. Flat borders were cast as part of the elements, allowing a generous tacking edge.

Figure 14. *Crucifix*. Executed in painted and gilded plaster with an iron halo.

Figure 15 (left). *Dogma of the Redemption*, detail. Trinity face in painted papier-mâché.

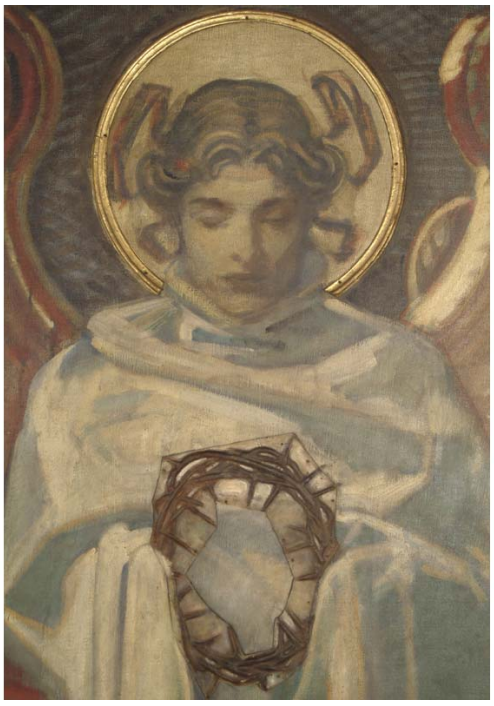

Figure 16 (right). *Frieze of Angels*, detail. Angel with halo and crown of thorns in painted papier-mâché.

Figure 17. *Frieze of Angels*, detail of relief elements in papier-mâché.

Lincrusta-Walton

In his third installation in 1916, Sargent completed the south vault above *Crucifix* and connected the ends of the hall with three lunettes on each the east and west walls. Abandoning plaster and papier-mâché almost completely, Sargent added Lincrusta-Walton to his repertoire of materials.

Lincrusta-Walton, a nineteenth-century commercial English wallcovering material, was invented by the creator of linoleum, Frederick Walton in 1877, at the height of a Victorian interest in domestic furnishings and a taste for decorative wallpaper. It offered an affordable imitation of fancier wallcoverings such as tooled leather, plaster, or ceramic tile, and was touted for its washability. Lincrusta was manufactured using a paste of linseed oil, gum, resins, wood pulp, and zinc oxide spread onto a canvas or paper backing and machine-embossed with iron or steel rollers (Fig. 18).

This process created an inexpensive material that could reproduce intricate designs in low relief. The surface could then be painted, stained, or gilded (Woods 1994). Lincrusta is still manufactured in England with the same nineteenth-century processes.

In a shift from using relief elements to depict specific elements in his mural design to applying them to broader, undefined areas, Sargent boldly incorporated Lincrusta-Walton into his murals to create lighting effects. Fragments of Lincrusta used by Sargent were embossed with "SUNBURY WALL COVERING", referred to its manufacturing site at Sunbury-on-Thames (Lynn 442). He chose a corrugated pattern depicted in Figure 18 and trimmed pieces to fit small details, borders, and broad fields of the composition (Fig. 19). He gilded and painted these elements before and after affixing them to the surface with a glue-paste lining adhesive and brads. Hanging Lincrusta involved soaking, pasting, and tacking the edges to prevent them from curling. Sargent oriented the Lincrusta pattern either diagonally, or horizontally. In discussing

illumination in 1915, he indicated that his use of Lincrusta to alter lighting was experimental: "…I have been working with the idea of a small quantity of light, and not direct light from the sky but reflected from below… I have been using a ribbed material for my gilding, in order to catch this light…" (Sargent, Mar. 19, 1915, 2, letter to Josiah Benton) This effect, ultimately created with bronze light fixtures designed by Sargent, combined with the variable light from the skylights to create shimmering details in the murals.

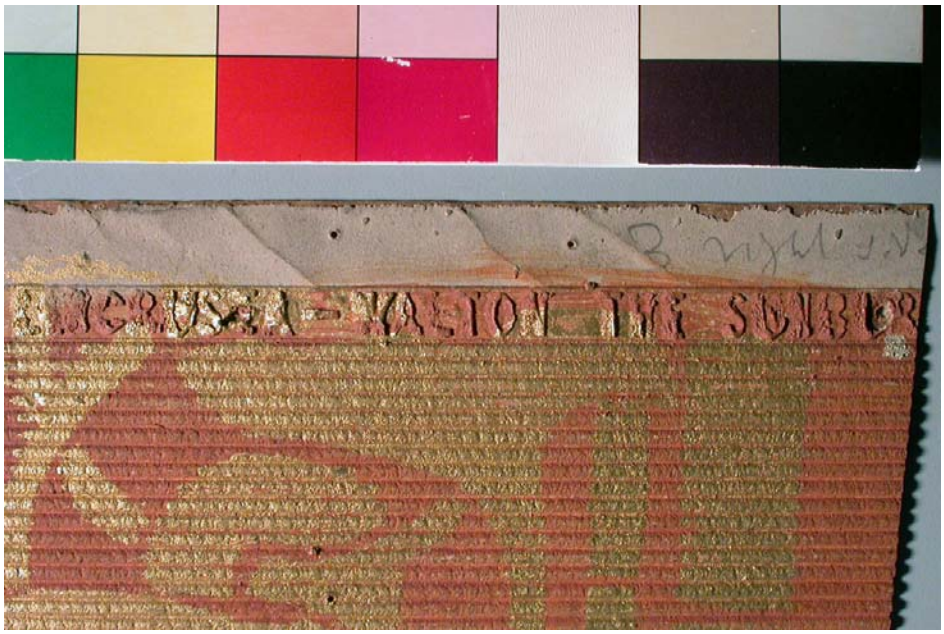

Figure 18. Lincrusta-Walton, detail of edge showing layers: paper backing; white, undecorated Lincrusta-Walton mixture; and embossed, painted, and gilded layer.

Figure 19. *Messianic Era*, installed in 1916. Sections of trees, banners, and foreground in painted and gilded Lincrusta-Walton.

Experimentation with metal reliefs

In his third installation phase Sargent also installed relief elements made of various metals in addition to Lincrusta. A 1916 shipping inventory described some of these elements as "metal casts, galvano plaster," referring to the copper electrotypes, or galvanos, formed in a plaster mold. (Sargent gallery memoranda, 3, n.d.) Sargent probably did not execute such a technical process himself, but it is notable that he selected a working technique that afforded him control of an original that would be reproduced in fine detail.

In front of the Madonna, a panel of candlesticks measuring three feet high and four and a half feet wide was comprised of 28 pieces of copper in three sections: a stepped red base, a background panel, and numerous attached elements depicting the bases of the candlesticks. These pieces were all made of electrotyped copper (Fig. 20). The panel was plated with silver on the front and zinc on the verso, while the smallest elements depicting the base for the white crescent were plated with gold overall. The smaller elements were attached to the panel with fasteners resembling the brass clasps now used on mailing envelopes: a ribbon of metal soldered at the center with ends that laced through a hole and were flattened.

Figure 20. *Madonna of Sorrows*. Swords and candle "screen" (at bottom third) in painted electrotyped copper.

Figure 21. *Madonna of Sorrows*, detail. Candle screen verso showing columnar deposition pattern of electrotyped copper in raking light.

Columnar deposition of metal visible on the verso, reproduced details in repeating forms, and the purity of copper core indicated the use of an electrolytic process (Fig. 21). X-ray fluorescence (XRF) spectroscopy identified zinc plated on the back of the pure copper substrate, and silver or gold plated on some of the display surfaces [1]. The surfaces were painted or coated to continue the mural design and to accentuate the relief patterns.

The swords representing the Virgin's sorrows piercing her heart were thinly formed with a white metal and filled from the back with lead, presumably for reinforcement. Silver and tin were identified in the white metal with XRF, suggesting a silver-plated tin. Because only one small element of the swords could be safely removed for examination, their method of their manufacture could not be confirmed.

Sargent created a second, major relief element in gilded copper. The *Coronation of the Virgin*, a medallion four feet in diameter, was placed at the height of the curved vault above *Crucifix* (Fig. 22). Positioned in a recess in the vault amid architectural plaster decoration and papier-mâché panels, the medallion stood as its own architectural form, rather than embellishing a painted mural. It was formed in two joined sections, with a surrounding inscription band in the same medium. The copper sections were mounted with nails and staples. The manufacture of this element was not well understood, owing to its fixed placement.

Figure 22. *Coronation of the Virgin*, from *Mysteries of the Rosary* at the top of the south end of the Hall.

Cleaning Moses' Tablets in Context

The cleaning of *Frieze of Prophets* and its central plaster Moses relief demonstrated the challenges encountered in the 2003 conservation treatment in balancing the aesthetics of Sargent's complex *Triumph of Religion*. A careful interpretation of archival materials combined with consideration for the murals' current condition supported treatment decisions to reinstate losses in some areas, while reducing original toning in another.

Examination of archival images taken after the 1895 and 1919 installations showed the Moses tablets as the brightest element at the north end of the Hall, against the more muted *Frieze of Prophets* (Fig. 23). Comparison of these archival images with before-treatment images suggested that an original glaze on the gilded background of the frieze had since been removed in a previous restoration, creating a highly reflective background. The painted figures, even after cleaning, appeared to recede against the gold (Fig. 24).

Difficulty in cleaning the plaster tablets held by Moses also upset the appearance of the frieze. Cross-section examination of samples taken from the tablets confirmed that an original brown toning layer was present overall, including under the red-painted inscription. The layer was too thin to sample for media analysis. An initial surface cleaning with Shellsol® 340HT followed by a 1.5% tri-sodium citrate solution rinsed with deionized water removed wax residues and general grime (Fig. 25). Care was taken in cleaning the toned surface, which became sensitive after repeated passes of the citrate solution. After the initial cleaning, however, the tablets appeared dull in relation to the figures of the frieze as well as the reflective gold background (Fig. 26).

In consultation with the advisory committee, it was decided to reinstate the glazing in the gilded background and to reduce the original toning in the tablets to harmonize with the frieze. An umber-toned glaze (Golden MSA Conservation Paints) was applied in the background, and the toning on the tablets was reduced with the 1.5% tri-sodium citrate solution and rinsed with deionized water. The immediate effect was subtle, but it was enough to adjust the overall balance of the tablets, figures, and background (Fig. 27).

This treatment demonstrated the difficulty in balancing the cleaning of these multiple components with varying treatment histories and conditions. Close examination of archival images combined with an interpretation of the relief elements and murals as a whole helped to guide aesthetic treatment decisions.

Conclusion

Sargent adapted common decorative and architectural materials to add sculptural details to his highly original mural scheme. Like the signature impasto of his easel paintings, these details imparted texture and animation to his design through their added dimension and variable light effects. Bridging the murals with the architecture, the relief elements contributed to a theatrical presentation, emphasizing the artist's interest in the viewer's experience of an artistic ensemble.

Sargent was inventive and quick in adapting new materials and techniques. With each

installation, he demonstrated a marked progression in the integration of these ornaments, improving the quality of fabrication and the sophistication of his sculptural techniques. In his last installation in 1919, he added just two plaster relief elements to the *Church* panel. Instead of the bulky forms from his earlier works, these were relatively thin elements with a textile backing (Fig. 28). Their graceful execution pointed to Sargent's growth in understanding the nuances of cast plaster. His eagerness to experiment with the details of this monumental program yielded a remarkably modern work in mixed media.

Several factors complicated a thorough understanding of the murals' condition during the 2003 conservation project: both mural painting and sculptural techniques were unprecedented in the artist's oeuvre, and past restorations were poorly documented. A multi-disciplinary approach combined with a careful assessment of archival images and documentation was critical to balancing treatment decisions for the component parts of Sargent Hall.

Acknowledgements

The author is grateful for the collegial and enriching experience this project provided. Special thanks are due to Henry Lie, Gianfranco Pocobene, Glenn Gates, Teri Hensick, Narayan Khandekar, Philip Klausmeyer, Nancy Lloyd, Richard Mulholland, Kim Muir, Kate Olivier, Tony Sigel, Kate Smith, and Ruxandra Stoicescu from the Straus Center for Conservation. Thanks also to a constructive and supportive advisory committee: Mary Crawford-Volk, Ian Hodkinson, Sally Promey, Carol Troyen, and Richard Wolbers. This project received generous support from the Institute of Museum and Library Services and the Boston Public Library Foundation.

Suppliers

Golden MSA Conservation Paints:
Golden Artist Colors, Inc., 188 Bell Road, New Berlin, New York 13411-9527, USA

Shellsol® 340HT (now called Shellsol® D-38):
Conservation Support Systems, P.O. Box 91746, Santa Barbara, California, 93190, USA.

Endnotes

1. Areas were examined in situ using a Rontec ArtTAX mXRF Spectrometer equipped with an electronically cooled X-Flash detector, which contains a silicon drift detector and high-speed, low-noise electronics with a resolution of 160eV at a count rate of 10kcps. X-rays were produced by a low power tube with a molybdenum target. The beam was focused by polycapillary optics to a spot size of 70mm x 50mm. The analysis area was purged by a stream of helium. Analysis was carried out at 50kV for 200s. Bronk et al. (2001) have published a detailed description of this instrument:

Bronk, H., S. Röhrs, A. Bjeoumikhov, N. Langhoff, J. Schmalz, R. Wedell, H.-E. Gorny, A.

Herold and U. Wäldschlager. 2001. ArtTAX - a new mobile spectrometer for energy-dispersive micro X-ray fluorescence spectrometry on art and archaeological objects. Fresenius Journal of Analytical Chemistry 371: 307-16.

References

Chase, Frank. 1926. *Boston Public Library: A Handbook to the Library Building, Its Mural Decorations, and Its Collections*, Boston: Association Publications.

Crawford-Volk, M. 1998. Sargent in public. In *John Singer Sargent*, eds. E. Kilmurray and R. Ormond. Princeton: Princeton University Press.

Fairbrother, T. 1986. *John Singer Sargent and America*. New York & London: Garland Publishing.

Fairbrother, T. 1994. *John Singer Sargent*. New York: Harry N. Abrahms.

Fox, T.J. not dated. S. Sargent, 1856-1925: The man and something of his work. Unpublished manuscript. Boston: Boston Athanæum. SFC Box 4, Folder 12.

Gammell, I. 1977. A masterpiece dishonored. *Classical America* 4: 47-53.

Lloyd, N. 1999-2000. Reconstruction of Sargent's scale model for the *Crucifix*. Sargent at Harvard. *Harvard University Art Museums Bulletin* 7(1): 58-66.

Lynn, Catherine. 1980. Wallpaper in America. W.W. Norton and Company.

Kilmurray, E., and R. Ormond, eds. 1998. *John Singer Sargent*. Princeton: Princeton University Press.

Klausmeyer, P., and G. Pocobene. 2000. Resurrecting John Singer Sargent's *Triumph of Religion* at the Boston Public Library: issues for future conservation treatment. *AIC Paintings Specialty Group Postprints*: 27-43.

Promey, S. M. 1999. *Painting religion in public: John Singer Sargent's Triumph of Religion at the Boston Public Library*. Princeton: Princeton University Press.

Promey, S. M. 1997. Sargent's truncated *Triumph*: art and religion at the Boston Public Library, 1890-1925. *Art Bulletin* 79(2): 217-250.

Sargent, J. S. 1894. Letter to the President and Council of the Royal Academy of Arts, London. Clausen Papers. Archive, Royal Academy of Arts, London.

Sargent, J. S. 1915. Letter to Josiah H. Benton, Esq., President of the Trustees of the Boston Public Library. Boston Public Library Archives.

Sargent Gallery memoranda, n.d. Particulars of 10 cases decorations for insurance for shipment by Mr. J. S. Sargent, R.A., to Boston in Bond. Boston Public Library Archives.

Stewart, M., and K. Schauber, eds. 1999-2000. Sargent at Harvard. *Harvard University Art Museums Bulletin* 7(1).

Woods, C. 1994. Proliferation: late 19th-century papers, markets and manufacturers, Britain. In. *The Papered wall: history, pattern, technique*, ed. L. Hoskins. New York: Harry N. Abrams, Inc. 150-170.

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CLEANING GLASS: A MANY-FACETED ISSUE

Stephen P. Koob

Abstract

The removal of decades of cigarette smoke, grease and grime from handling, and more recently, pollution and off-gassing from improper storage cabinets, will contribute significantly to the prolonged stability of all glasses. In addition, glasses that are subjected to prolonged storage in high humidity (over 55% rH) will begin to hydrate and the alkali in the glass is brought to the surface. Unless this is removed, the alkali will eventually start to dissolve the silica in the glass.

There are numerous types of glasses, but the "silica-soda-lime" glasses make up approximately 90% of all types from antiquity to the present, from Roman vessels to modern window panes. These glasses are generally thought to be very stable, but they will slowly deteriorate (through weeping or crizzling) over decades and centuries of prolonged exposure to high humidity, grime and pollution.

Most glasses can be washed using a detergent and water, as long as the glass is sound and in good condition. Warm tap water can be used for the initial washing, followed by rinsing with deionized or distilled water. A dilute conservation-grade detergent is recommended, such as Synperonic A-7 or Triton XL-80N. Cleaners or detergents that contain perfumes or ammonia should be avoided. A simple washing, even once in the lifetime of a glass, will protect the glass for decades, if not centuries. Soft brushes and soft cotton toweling are recommended. Glass objects should never cleaned in a dishwasher, or with abrasive sponges or cleaners.

Introduction

There are many, many reasons to wash glass, the most basic of which is that the glass looks much better when clean (Figs. 1, 2). There are also many instances and situations when one should not clean glass, as in the case of severely weathered archaeological glass, where cleaning will remove the iridescent or opalescent weathering layers (Fig. 3). The primary reason not to remove the weathering on archaeological glass is the fact that glass deteriorates, or corrodes, or "weathers" from the outside in. If the weathering is removed, so is the original surface, including the details, decoration and information preserved in that surface layer (Smith 1999). The end appearance may be a glass with its original color, but since glass does not always corrode evenly, the result will be a glass with a severely pitted and etched surface, whose integrity has been compromised. Unfortunately, every museum and every time period have their own tastes, and until recently it was not unusual for archaeologists and curators to remove the weathering layers from glazed ceramics and glasses. However, this is not an acceptable practice today.

Figure 1. Dirty glass plate with paper label and masking tape (CMOG 59.4.279A).

Figure 2. Plate in Fig. 1, after washing.

Figure 3. Roman glass unguentarium with flaking weathering. Arthur M. Sackler Gallery, Smithsonian Institution (LTS1985.1.174.24).

Figure 4. Well-preserved glass bracelets from a 7th century BC tomb at Gordion, Turkey (Gordion Inventory G 162).

Some archaeological glasses do not even need to be washed, or can be safely washed, as they have no weathering, and come out of the ground looking like they were made yesterday (Fig. 4). Some modern studio glasses should never be washed as they have cold painted decoration (applied after the glass was made and cooled) or organic attachments (textiles, fur, wood, etc.). These pieces should be treated as other sensitive composite materials, e.g., ethnographic objects.

Cleaning

The first and most important point in cleaning glass is to know something about the glass. If the glass is sound and in good condition, it generally can be cleaned, or if the glass has been previously cleaned, it can be cleaned again. If there is some doubt, one should learn more about the glass. Most glasses are of a composition that are called silica-soda-lime glasses, with a very stable composition of approximately 70% silica, 20% soda (sodium carbonate, one of the most common alkalis used in the production of glass), and 10% lime (or CaO), which serves as a stabilizer. This composition makes up about 90% of all glasses, and has changed very little from ancient times to modern. Despite the many new types of glass being developed every day, most glasses from Roman times to modern window glasses have virtually the same composition. The glasses are strong, durable and can safely be cleaned.

Additional reasons for cleaning glass include the removal of accumulated dirt and grime, tapes, adhesive labels (see Fig. 1), old or yellowed adhesives or fills (Fig. 5), or to repair the results of a natural disaster (Fig. 6). In addition, almost any glass made before 1980 probably has some traces of cigarette smoke or nicotine on it. Smoking was so commonplace 25 years ago that it was even possible to smoke in most museums.

Figure 5. Yellowed adhesive and fill on a glass sculpture (CMOG 59.4.426).

Figure 6. Chandelier, damaged and mud-covered after the Corning flood of 1972 (CMOG 60.2.39).

Materials and Techniques for Cleaning

The removal of adhesives, tapes, and labels involve well-published conservation treatments (Navarro 1997), but basic cleaning is a different problem. Glasses that are in good condition and are not sensitive to water (see above), can easily and efficiently washed with soap and tap water. Ideally, washing should be done in a plastic sink (Fig. 7). Polypropylene sinks are available, and a standard size is 30” long x 24” wide x 8” deep, not counting the 24 x 30 inch drainboard (available from McMaster-Carr, see Suppliers). The sink should also have a long gooseneck faucet with wide handles, and even a separately plumbed sprayer. A supply of pure water is

required, and a simple solution to this is to place close to the sink a large polypropylene tank attached to a deionizing column (see Fig. 7).

Figure 7. Polypropylene sink, with sprayer on the left, deionized water tank on the right.

The large sink provides ample working space, so that even large glasses can be completely washed and rinsed. A plastic sink will not prevent glass from breaking if it is dropped heavily, but it will minimize the risk. Polypropylene is certainly better than stainless steel, where one tap against the side, even a gentle one, will break most glasses. If it is not possible to purchase a plastic sink, one should at the very least use a large shallow plastic bucket or tub inside a metal sink.

Gloves should not be worn when washing glass (or even handling most dry glass, with the two exceptions of acid-etched and most pâte-de-verre glasses, which are extremely sensitive to staining from oils). Glass is slippery even when dry; once covered with soap it is even more slippery. A conservation grade detergent should be used, such as Triton XL-80 (see Suppliers). The detergent should be diluted with water to approximately 15:1, but the dilution ratio is not critical. Other clear liquid detergents may be used, but one should avoid powdered detergents, and anything that has color, perfumes and/or ammonia.

Cleaning can be done, by rinsing, dipping, brushing, or swabbing. This depends on the shape of the glass, and how strong/stable it is. A Venetian goblet is probably best cleaned with soft toweling, either a cut-up 100% cotton diaper or soft paper toweling, both of which are even softer when wet. Brushes or small bits of cut-up sponges are also useful, as is a large curved bottle brush with very soft, natural soft bristles and a plastic handle (available from Fisher Scientific, see Suppliers). Alternatively, a soft paintbrush may be used, but one should be sure to tape over the metal ferrule. Straight brushes are more difficult to use, as one needs to keep the bristles aimed at what is being cleaned.

Cleaning should begin with warm tap water, brushing or swabbing with soap, followed by rinsing in tap water. The glass is then thoroughly rinsed in deionized (or distilled) water. A final

rinse in pure water is critical to complete cleaning, as there enough minerals (dissolved and undissolved) in tap water to create little white spots on the glass upon drying. The glass can then be lightly towel-dried, with soft, lint-free, paper toweling. Bottles and decanters, if they are narrow-necked, can be drained and then a small amount of acetone used for a final rinse on the inside. The acetone combines with any remaining water, and the bottle can be drained again, ensuring complete and even drying. The acetone/water mixture also dries faster than just water. Stoppers should not be re-inserted in a bottle or decanter until the bottle is completely dry. Even then, a small slip of thin acid-free mat board, or a small piece of thick Mylar should be inserted between the stopper and the bottle, to prevent a complete seal.

Cleaning and stability

How often should glasses be cleaned? The answer to that is "probably only once", perhaps for the entire lifetime of the glass. In a stable, controlled environment with the humidity around 45%, the glass will get dusty, but the dust can be vacuumed or dusted away. Glasses should never be washed in a dishwasher, or the glass will end up cloudy and etched in just a few years (Fig. 8). The extremely hot water (usually re-heated) and hot soap (a strong alkali) rapidly attacks the silica of the glass and within a few years glasses become irreversibly cloudy and etched (microscopically).

Figure 8. Modern juice glass after approximately five years of cleaning in a dishwasher.

Figure 9. Cloudy foot on a glass goblet, showing the initial stage of crizzling (CMOG 61.3.135).

The most serious problem involves the storage of glasses in an uncontrolled environment, including silica-soda-lime glasses, lead glasses, borosilicate glasses, and glasses with unstable or modified compositions. The terms “crizzling”, “weeping”, or “sick glass” are familiar to most conservators, and they refer primarily to the small group of 16th-19th century glasses that have unusually high alkali compositions, which have visibly begun to deteriorate since manufacture.

Crizzling can be categorized into several phases or stages. Initially the glass looks cloudy or hazy (Fig. 9), but the haziness will not wash off. The glass may also exhibit little white dots or even crystals on the surface if the humidity is under 45%. As soon as the humidity goes up into the upper 50s, all the dot or crystals become liquid, and sometimes the entire surface can be wet or “weeping” (Fig. 10). This is a result of the alkali in the glass leaching to the surface under high humidity conditions. Alkalies are extremely hygroscopic, and are naturally drawn to the surface of glasses, particularly if there is a compositional imbalance.

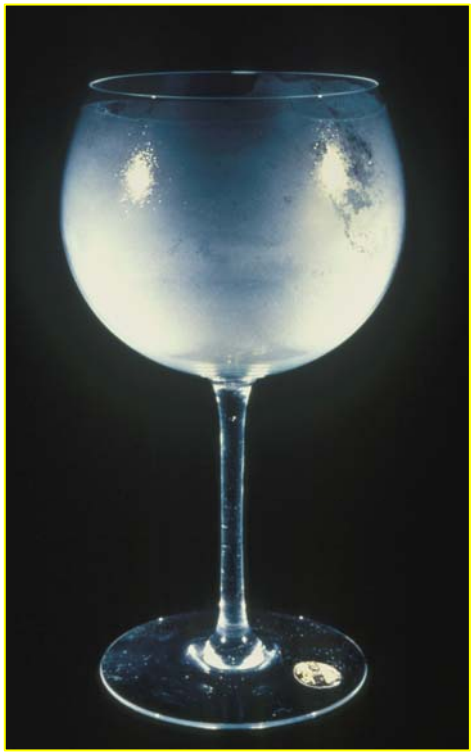

Figure 10. Wet, “weeping” wine glass (CMOG, no number).

Figure 11. Cracked Venetian goblet with advanced crizzling (CMOG 59.3.20).

“Weeping” then, is simply the high-humidity phase of a glass that is in the beginning stage of “crizzling”. Over many years (or sometimes it takes decades, or even centuries), the glass begins

to crack – microscopically at first, and then visibly to the naked eye (Fig. 11). Eventually, the cracking gets deeper into the glass until the glass is so structurally weak that it breaks (Fig. 12).

Figure 12. Structural failure of a severely crizzled glass goblet (CMOG, no number).

The primary cause of the deterioration is the high humidity, which over time leaches the alkali in the glass to the surface. If the high humidity is maintained over a prolonged period (year after year, decade after decade), the alkali can be seen as droplets, and eventually will pool or drip, thus creating the "weeping" phenomenon. If the alkali is not removed from the surface it will eventually attack the silica, thus freeing up more alkali, and causing the glass to develop cracks, or "crizzling". Fluctuations in humidity can result in the glass cracking further, and/or the droplets drying out and forming "salt crystals". The problem becomes worse if the glass is sealed in some manner and the moisture is trapped against one surface, such as in a stoppered decanter, where moisture trapped on the inside sets up a microclimate with a humidity approaching 100%.

Therefore, the leaching of alkali, or hydration of the alkali in the glass, and eventual cracking or crizzling of the glass, all occur as a result of the cycling between high and low humidity. Crizzling can occur on the interiors of glass vases, decanters, cover glasses for biological specimens, cover glasses or "crystals" of clocks and watches, on the inside cover glass of daguerrotypes, miniatures, prints and drawings. It also can occur underneath labels applied to glass, on the insides of thermopane windows, and even the original 1950's glass pane housings of the Declaration of Independence and Bill of Rights, recently redone for this very reason.

This deterioration phenomenon is most common in 16^{th}-19^{th} century glasses that have unstable compositions (usually low lime, high alkali), but given the examples above, it can also occur in stable glasses, owing to the microclimate created. Interestingly, the glass, or side of the glass, that is NOT exposed to high humidity (e.g., the outside of a decanter or the outside of a cover glass or clock crystal), generally does not show this problem, simply because air movement and occasional cleaning prevent it from happening. Current research (Eremin, et al., 2005, Grzywacz, et al., 1994), also indicates that the problem can be exacerbated by airborne pollutants, such as those found in wooden storage cabinets. Moderately low humidity, around 40-45% virtually

stops the weeping/crizzling, but this is difficult to achieve in private collections. The humidity should never be dropped below 30%, as glasses that have already begun to hydrate and crack will develop even worse cracking.

Some exceptions and problems continue to exist. Glasses with very poor compositions will require even more careful monitoring and climate-controlled storage. This is especially true of some enamels, which may suffer more from dehydration than from hydration (T. Weisser 2004). Weisser noted that the early Limoges enamels in the Walters Art Museum were especially sensitive to cracking at low humidity and that 50% might be better for preserving their transparency and condition (T. Weisser, 1998). However, unstable Venetian glasses of the 16th century have been seen to hydrate in The Corning Museum of Glass at just above 50%. More research is needed to identify the actual compositions of these unstable glasses so that we can better know at what conditions they are best stored. Glasses that show recurring hydration, evidenced by a slimy or slippery surface, and recurring cloudiness, may need washing, or at least rinsing, more frequently, possibly every 10-20 years.

The real reason to clean glass, therefore, is to keep it stable. Most clean glasses, if stored in a stable environment between 40-50 % RH, should remain stable indefintely.

Recommendations for Display and Storage of Glass Objects

Dr. Robert Brill, Research Scientist at the Corning Museum of Glass, recommends that glass be displayed and stored between 45 - 50 % RH, plus/minus 5%, with as little fluctuation as possible (Brill 1975; Brill, et al., 1998). He further recommends that the humidity should not go below 40% for more than 5 days, not below 35% for more than one day, and should never go below 25%. For glasses that already show signs of crizzling the storage should be maintained as close to 42% as possible, and as long as they are strong enough they should also be washed once, before going into storage. The humidity control is critical to the long-term preservation of glass. The temperature is not as critical, unless it affects the humidity, which it often can do in intense spotlighting. Rapid environmental changes should also be avoided.

The humidity is best controlled through the building's HVAC system. Controlling the climate in individual cases is not often practical or cost effective, especially for large collections. It would be virtually impossible to maintain appropriate humidity levels for individual cases in the Corning Museum of Glass, which has a collection of over 40,000 glasses. In addition, because air movement prevents the establishment of a high humidity microclimate, more air movement is recommended. This can be achieved through higher air-exchange in the HVAC system, or by individually installing fans at the tops or bottoms of cases. This will prevent any alkali build-up on the surface of a glass.

Conclusion

Cleaning is an important step in the long-term preservation of glass. Cleaning also enhances the appearance of glass, whether it is for personal pleasure, study and research, or museum display

(Figs. 13, 14). There are numerous types of glasses, but the silica-soda-lime glasses make up approximately 90% of all types from antiquity to the present, from Roman vessels to modern window panes. These glasses are generally thought to be very stable, but they will slowly deteriorate (through weeping or crizzling) over decades and centuries of prolonged exposure to high humidity, grime and pollution.

Figure 13. Glass sculpture (cf. Fig. 5) after adhesive removal, cleaning, repair and restoration (CMOG 59.4.426).

Figure 14. Chandelier (cf. Fig. 6) after cleaning and repair (CMOG 60-2-39).

Glasses that are subjected to prolonged storage in high humidity (over 55% RH) will begin to hydrate and the alkali in the glass will come to the surface. Unless this is cleaned off, eventually the alkali will start to dissolve the silica in the glass. In addition, the removal of decades of cigarette smoke, grease and grime from handling, and more recently, pollution and off-gassing from improper storage cabinets, will contribute significantly to the prolonged stability of all glasses.

Most glasses can be washed using a detergent and water, as long as the glass is sound and in good condition. Warm tap water can be used for the initial washing, followed by rinsing with deionized or distilled water. A dilute conservation-grade detergent is recommended, such as Triton XL-80N. Cleaners or detergents that contain perfumes or ammonia should be avoided. Soft brushes and soft cotton toweling are recommended; and glass objects should never be run through the dishwasher, nor cleaned with abrasive sponges or cleaners.

A simple washing, even once in the lifetime of a glass, will protect the glass for decades, if not centuries.

Suppliers

Polypropylene Lab sink:
McMaster-Carr Supply Company, 330-342-3330, (www.mcmaster.com) .

Triton XL-80:
Conservation Resources, 8000-H Forbes Place, Springfield, VA 22151,
1-800-634-6932, (www.conservationresources.com)

Fisherbrand flexible-handle brushes:
Fisher Scientific, 1-800-766-7000, (www.fishersci.com).

Acknowledments

The author thanks Dr. Robert H. Brill for his comments and recommendations regarding the stability and storage of glass.

References

Brill, R.H. 1975. Crizzling- A problem in Glass Conservation. In *Conservation in Archaeology and the Applied Arts, Stockholm Congress*. London: International Institute for Conservation. 121-134.

Brill, R.H., Hanson, B., and Fenn, P.M.. 1998. Some Miscellaneous Thoughts on Crizzling. In *Proceedings of the XVIIIth International Congress on Glass*. San Francisco: International Commission on Glass. On CD, not paginated.

Eremin, K., Cobo del Arco,C., Robinet, L., and Gibson, L., 2005. Deteriorating nineteenth and twentiethcentury British glass in the National Museums of Scotland, *Annales*, London: de l' Association Internationale pour l'Histoire de Verre 380-385.

Grzywacz, C.M., and Tennent, N.H. 1994. Pollution monitoring in storage and display cabinets: carbonyl pollutant levels in relation to artifact deterioration, in *Preventive Conservation, Practice, Theory and Research*, edited by Ashok Roy and Perry Smith, London: IIC 164-170.

Navarro, J. 1997. Removing paper labels from ceramics and glass. *The Conservator* 21: 21-27.

Smith, S. 1999. Opacity contrariwise. In *Reversibility, Does it Exist?* British Museum Occasional Paper Number 135, ed. A. Oddy and S. Carroll. London: The British Museum 135-140.

Weisser, T. 1998, 2004. Personal communications. Head of Conservation, The Walters Art Museum, 600 N. Charles Street, Baltimore, MD.

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PROBLEMS AND METHODS OF CLEANING: PRACTICAL EXAMPLES OF THE CLEANING OF WOODEN OBJECTS FROM EGYPT

Hany Hanna Aziz Hanna and Neveen Atef Meshrieky Meleka

Abstract

Much attention has been given to the treatment and conservation of some objects in churches, mosques and museums in Cairo, Egypt. Some of these objects are made of wood, including teak, cedar and pine, and are decorated with geometric patterns such as stars with animals, birds and floral designs as well as calligraphic inscriptions. They show a variety of techniques of construction and decoration, including paneling or joinery, gilding, painting, staining with shellac, incision and engraving and inlay with materials such as ivory, bone, shell and ebony.

These objects have been examined by scanning electronic microscopy (SEM), light microscopy, x-ray diffraction and IR spectroscopy (FTIR). Relative humidity, temperature, air and microbial pollution of the surrounding environment were also studied.

The different materials used in the manufacture and decoration of the objects displayed various forms of deterioration, resulting from the combined effect of environmental factors such as air pollution and relative humidity, etc. The deterioration includes (a) a high degree of soiling by particulate matter such as heavy dust and black carbon soot, mostly deriving from atmospheric pollution; (b) extensive alteration of original materials with lime plaster, plastic and oil paint, old paper of poor quality adhered with gum Arabic, and the use of modern nails; (c) damage by the modern application of coating materials that have undergone weathering.

In this paper the techniques used to recognize and identify the nature of these alterations, as well as the methods and the materials used for cleaning some of these objects, will be described.

1. The objects

Much attention has been given to the treatment and conservation of objects in churches, mosques and museums in Cairo, Egypt. Some of these objects are made of wood, including church sanctuary screens (*iconostasis*, pl. *iconostases*), *mashrabiyya* (wooden grilles used to cover windows or balconies), furniture, painted wood and structural timber. The screens, furniture and wood panels may display a variety of joints and include lathe-turned elements, incised or engraved designs, gilding, painting, staining with shellac and inlay.

Many of the objects are composed of numerous small interlocked pieces of wood. The designs include geometric patterns such as stars (see Figs. 18, 19) and crosses (Fig. 27) as well as animals, birds, floral designs and calligraphic inscriptions.

Identified species of wood include teak (*Tectona grandis*), cedar (*Cedrus libani*), sidder (*Zizyphus spina-christi*), oak (*Quercus robur*), beech (*Fagus orientalis*), sycamore fig (*Ficus*

sycamorus) and pine (e.g. *Pinus halepensis*). Inlaying materials include ivory, bone, shell (mother of pearl) and ebony.

2. Deterioration

The different materials used in the manufacture and decoration of the objects displayed various forms of deterioration, resulting from the combined effect of environmental factors such as air pollution, relative humidity, rain fall and precipitation, heat, light, fire, water, insects, fungi, rodents and birds.

In addition to breakage, cracks, holes, cavities, gaps, corrosion, abrasion, loose and lost pieces, the deterioration includes disfiguration and alteration caused by surface accumulation of particulates as well as old repairs, including:

1. A great deal of soiling by particulate matter such as heavy dust and black carbon soot, mostly deriving from atmospheric pollution.

2. Extensive alteration by human intervention, including restoration with lime plaster, cement, acrylic and oil paint, old paper of poor quality that had been adhered with gum Arabic, and modern nails.

3. Damage by the modern application of coating materials that have undergone weathering.

Examples of dirt accumulation and alterations are shown in Figs. 1-4.

Figure 1. Detail shows some disfiguration on the sanctuary screen (iconostasis) from the central sanctuary, dedicated to the Virgin Mary, at *El-Muallaqa* Church, Cairo [1].

Figure 2. Detail shows the high degree of soiling by particulate matter on one of the screens (*mashrabiyya*) in the *El-Amir Bashtak* palace.

Figure 3. Detail of damage to *mashrabiyya* No. 2979 in the Museum of Islamic Art in Cairo.

Figure 4. Detail of alteration on painted panels of the *Mar Bahnam* sanctuary at *Mar Mena* church in Cairo.

3. Testing and analytical work

Examination and testing have included the following:

1. Identification of wood and inlay materials using light microscopy. For example, teak wood (*Tectona grandis*) sections are shown in Figures 5-6.

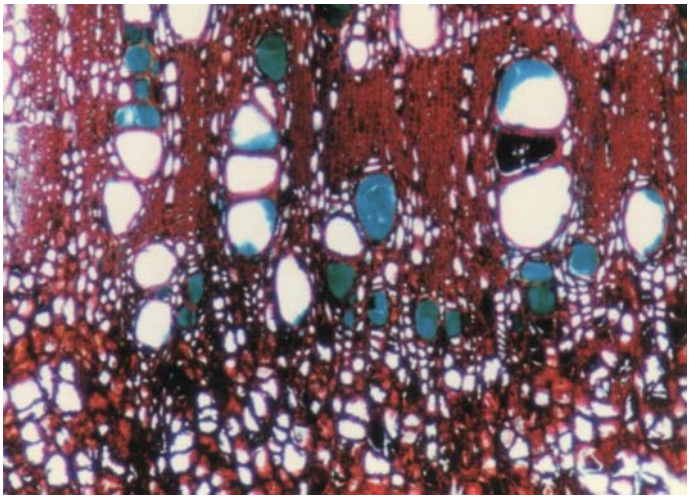
2. Scanning Electron Microscopy (SEM) showed damage to the surface layer of wood (which now appears white in color, see Figs. 7-8) as well as dirt which has accumulated in the fibers of the wood.

3. Wood samples showing evidence of fungal attack were placed in growth media in an attempt to identify the fungi. Two different species of soft rot fungi were obtained, one of which is *Phialophora verrucosa* (Fig. 9).

4. X-Ray diffraction together with examination using a mineralogical microscope have demonstrated that the deposits included carbon (C), calcite ($CaCO_3$), dolomite ($CaMg(CO_3)_2$), gypsum ($CaSO_4.2H_2O$) and quartz (SiO_2); and that the pigment minium (Pb_3O_4) had been used to coat the wood (Figs. 10-11).

5. Infra-red spectroscopy analyses (FTIR) was used to identify the various materials that caused stains and spots, such as gum Arabic, animal glue, oils and waxes, and demonstrated that animal glue was used as the binding material for pigments and as the adhesive for the inlays. Examples of waxes and waxy substances are shown in Fig. 12.

6. Temperature and relative humidity were recorded during 2003 in the areas surrounding many objects. The records demonstrated that the average variation in temperature over the year was 2-10 degC, and the change in RH 2-11%. These fluctuations are large enough to cause damage to the wood.



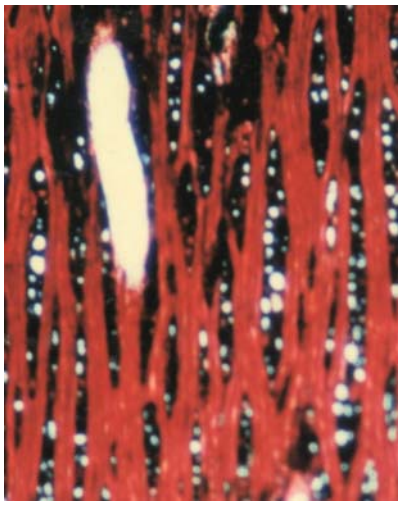


Figure 5 (left), 6 (right). Light microscopy photomicrographs of cross-section (Fig. 5) and longitudinal-section (Fig. 6) of teak wood (*Tectona grandis*) (x50).

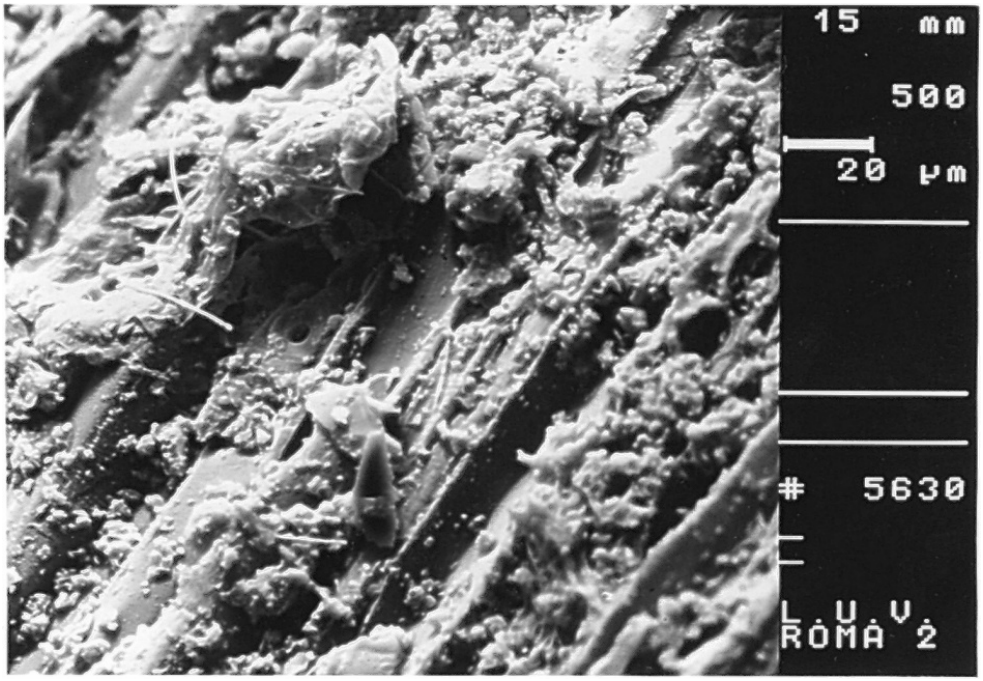


Figure 7. Scanning Electron Microscopy photo of cross-section of pine wood showing the damage in the xylem parenchyma and the dirt that accumulated in the wood (x500).

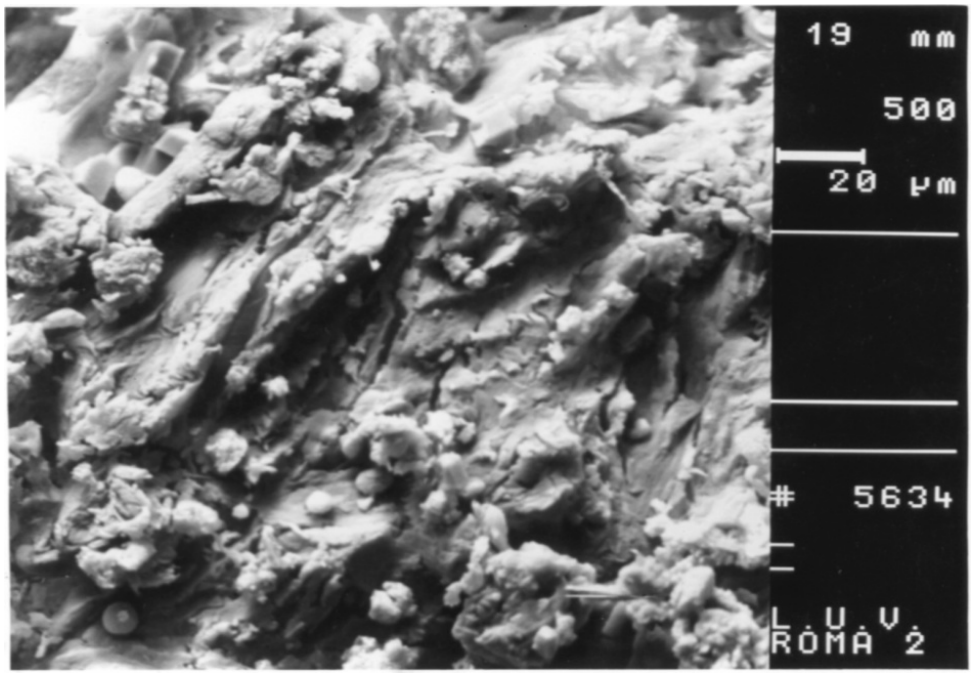


Figure 8. Scanning Electron Microscopy photo showing the damage to the surface layer of the wood, dirt and salt crystals (x500).

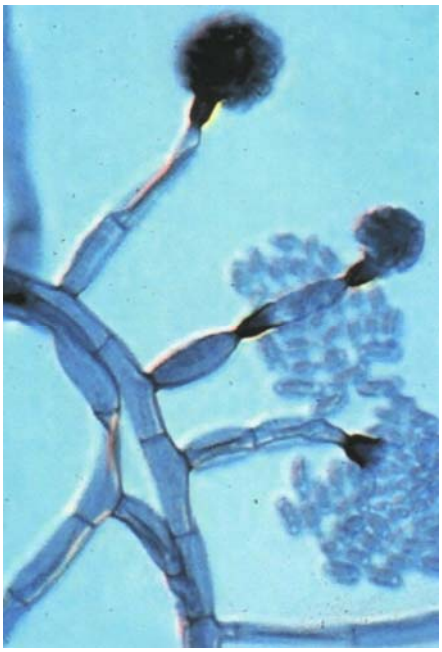


Figure 9. Photomicrograph *of Phialophora verrucosa* fungus (x1000).

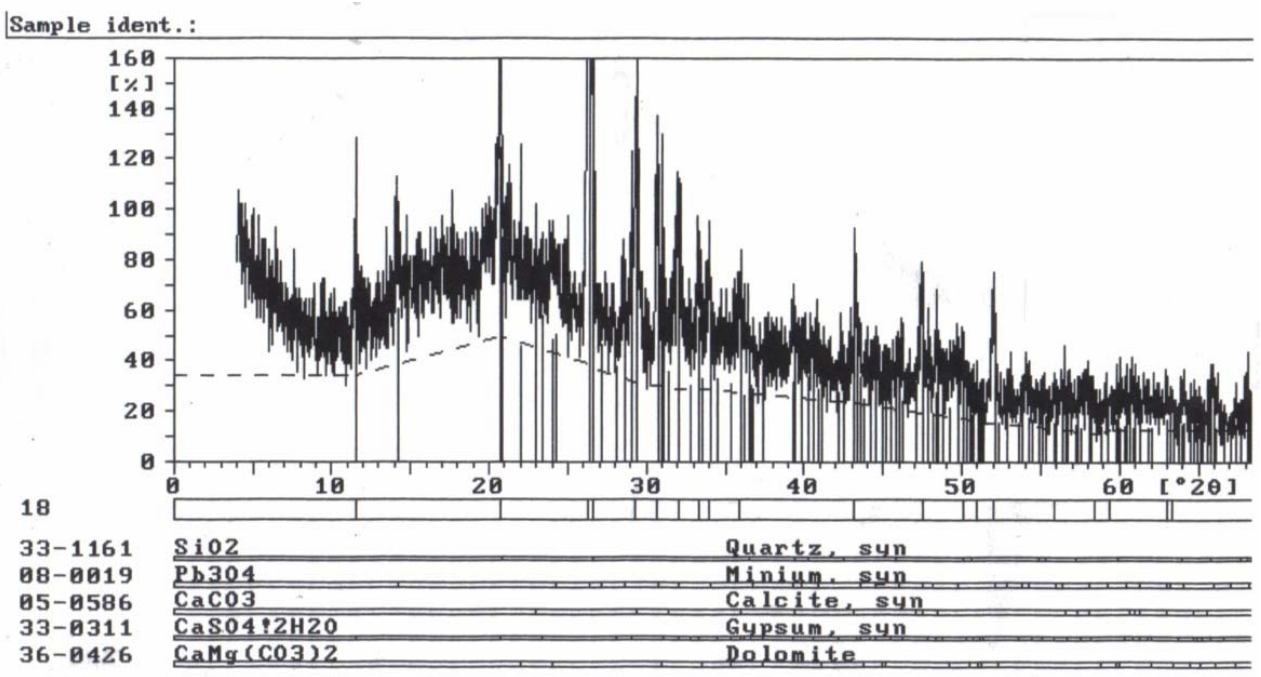


Figure 10. The x-ray powder diffraction analysis of the dirt from the surface of the wood.

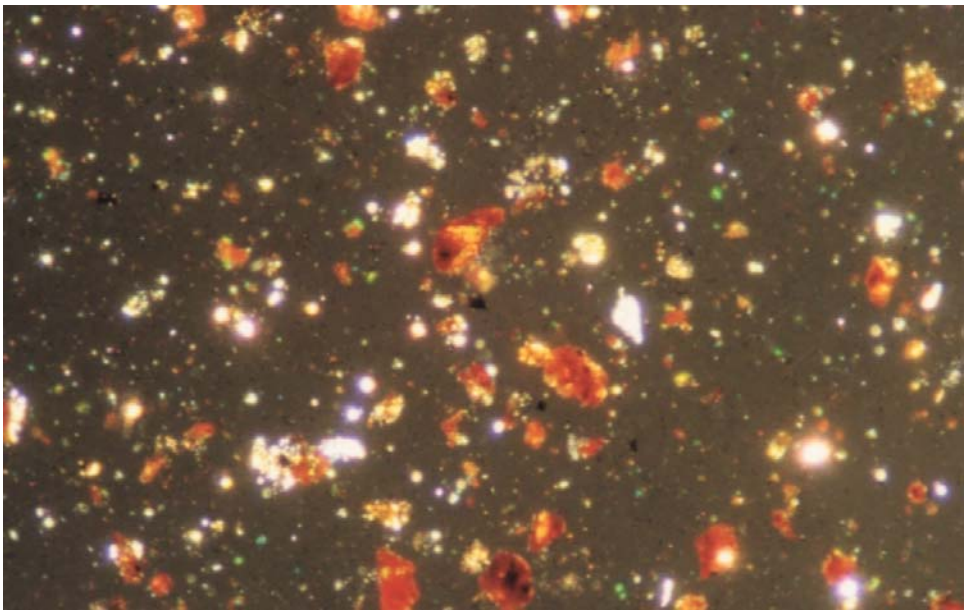


Figure 11: The dirt as it appears under the mineralogical microscope (x125).

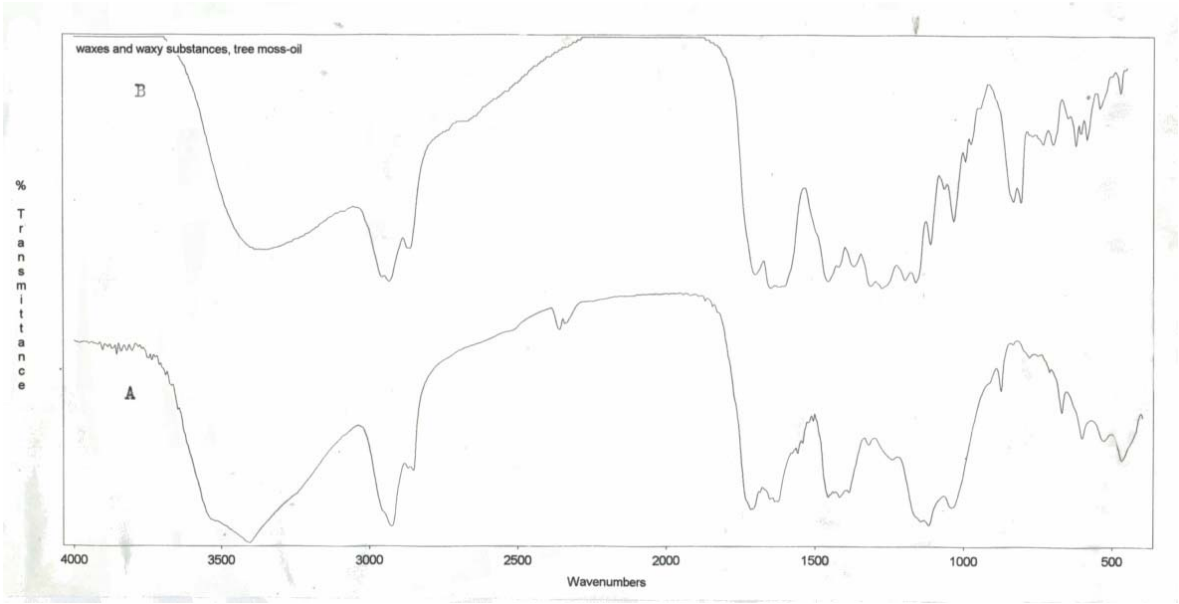


Figure 12. Infrared Spectroscopy analyses for some alternation from the surface of the wood (A), compared with waxes and waxy substances (B).

4. Cleaning

The aim of the cleaning work in general was to remove the dirt and the surface alterations. Specifically, the intent was to removing any dirty or unsuitable non-original coating layer, and to expose any additional non-original layers as well as original paintings and/or inscriptions. The work sometimes proceeded slowly because of the poor condition of the wood, and also to ensure that no original paint was removed.

Cleaning was carried out first by mechanical means, with use of organic solvents as needed, depending on the type of material to be cleaned, the condition of the substrate and the nature of the material to be removed. Methods and materials varied might also vary from the front to the back of the object.

Modern nails were removed using a claw hammer.

Easily removable surface dust was removed with soft brushes and a vacuum cleaner.

Paper, lime plaster, acrylic and oil paint, soot, and damaged coating materials were removed with fine tools such as needles, spatulas, and scalpels, together with electrically powered needlepoints.

The following chemicals were used as needed:

1. 1% acetic acid (CH3 COOH) in water, which was useful in removing both the gum arabic and acrylic paint.

2. Dimethyl formamide (H-CO-N (CH3)2) was used to remove the oil paint.

3. Tetralin (tetrahydronaphthalene C16H12) was used to remove the black carbon soot.

The cleaning work led to the discovery of some previously unknown details. In the case of one church screen (iconostasis), for example, it was necessary to remove the planks affixed to the backs of the screen to clean it. When this was done it was possible to see marks that had been used as guides in the assembly of the decorative pieces (Fig. 19).

Examples of some of the cleaning processes (before, during and after) are shown in Figures 13 - 29.

Figure 13. Central sanctuary screen (iconostasis) at *El-Muallaqa* Church in Cairo, before the cleaning, restoration and conservation work.

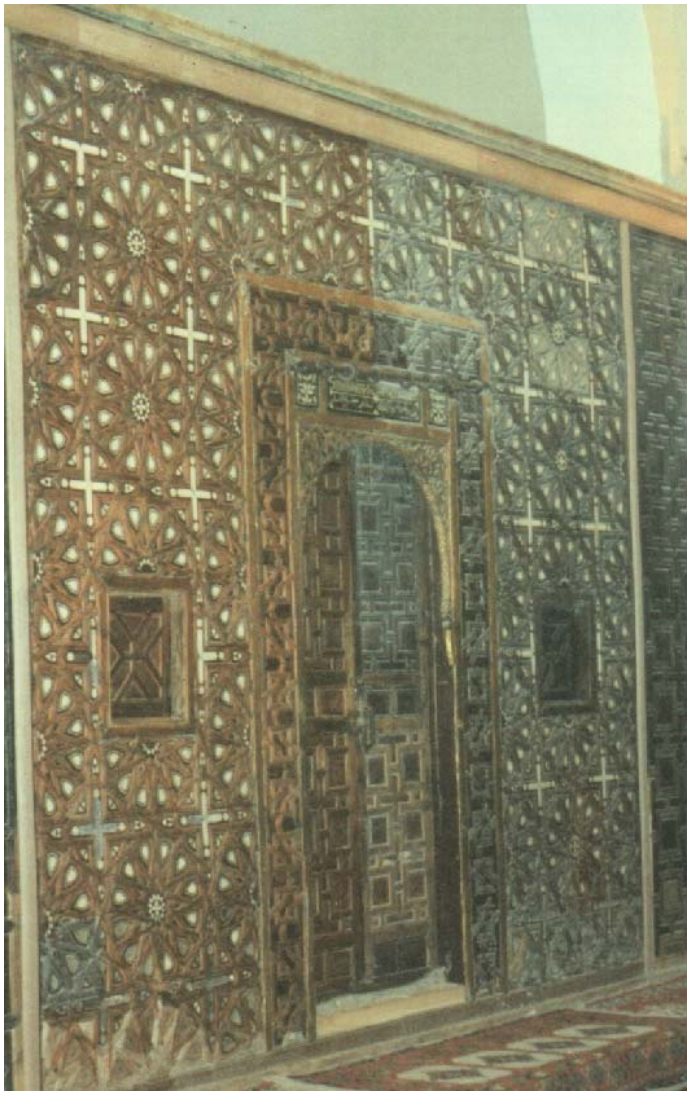


Figure 14. Central sanctuary screen, *El-Muallaqa* Church, during the cleaning, restoration and conservation work (the right half of the screen has been cleaned).

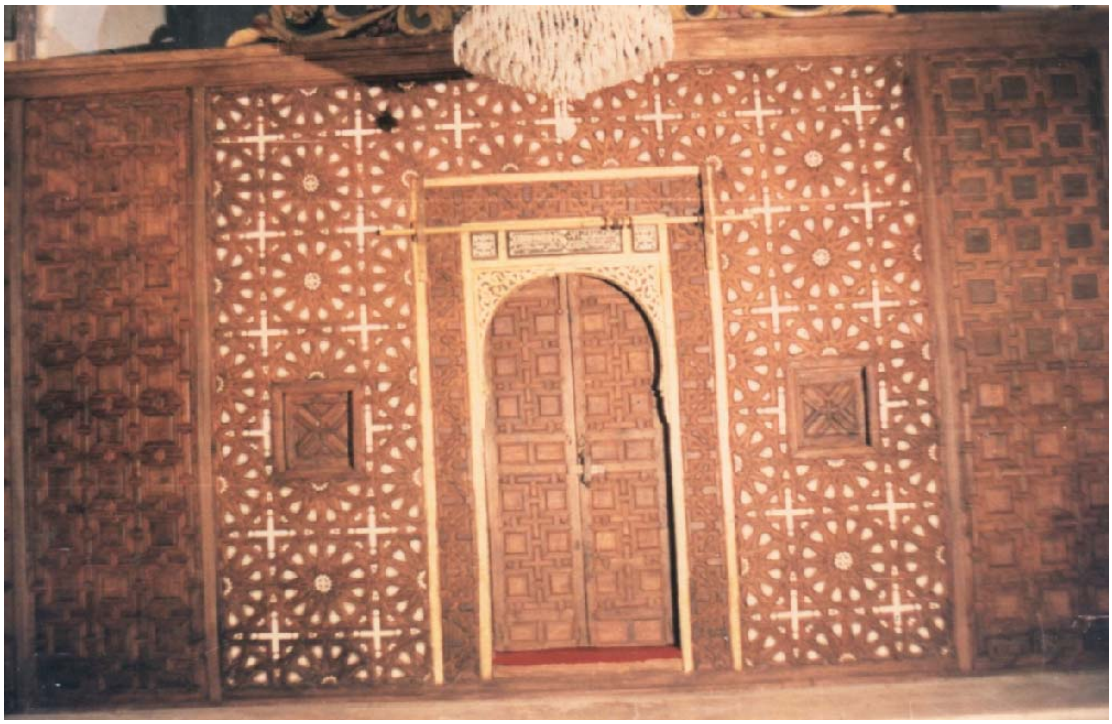


Figure 15. . Central sanctuary screen, *El-Muallaqa* Church, after cleaning, restoration and conservation work.

Figure 16. Detail shows part of the central sanctuary screen, *El-Muallaqa* Church, before cleaning.

Figure 17. Area shown in Fig. 16, during cleaning.

Figure 18. Area shown in Figs. 16 and 17, after cleaning, restoration and conservation work.

Figure 19. Signs to guide the joiner in assembling the decorative pieces were discovered on the back of the central sanctuary screen from *El-Muallaqa* Church.

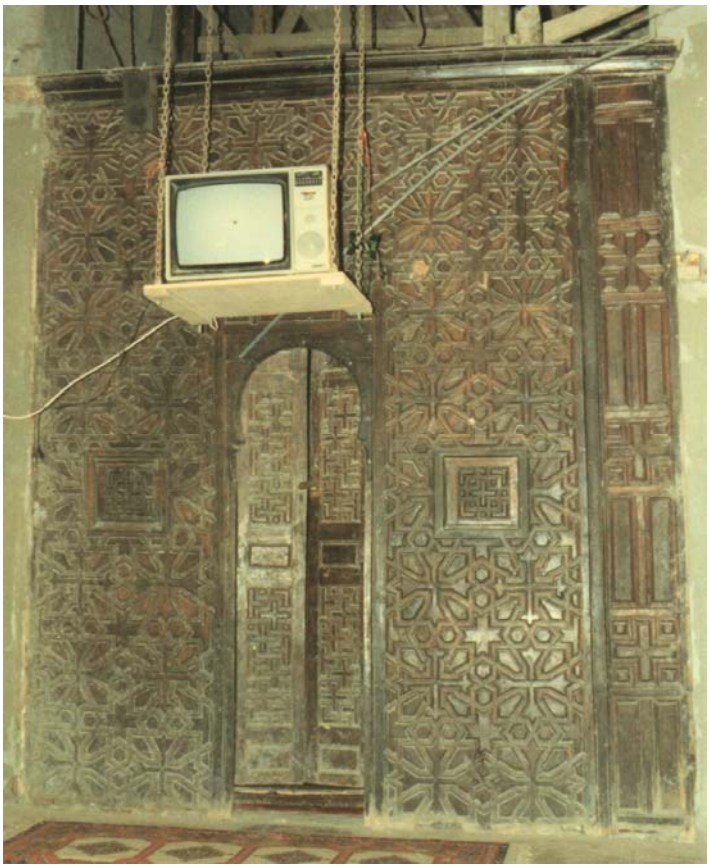


Figure 20: The sanctuary screen (iconostasis) from the St. John the Baptist sanctuary, *El-Muallaqa* Church, before the cleaning, restoration and conservation work.

Figure 21. St. John the Baptist sanctuary screen after the cleaning, restoration and conservation work.

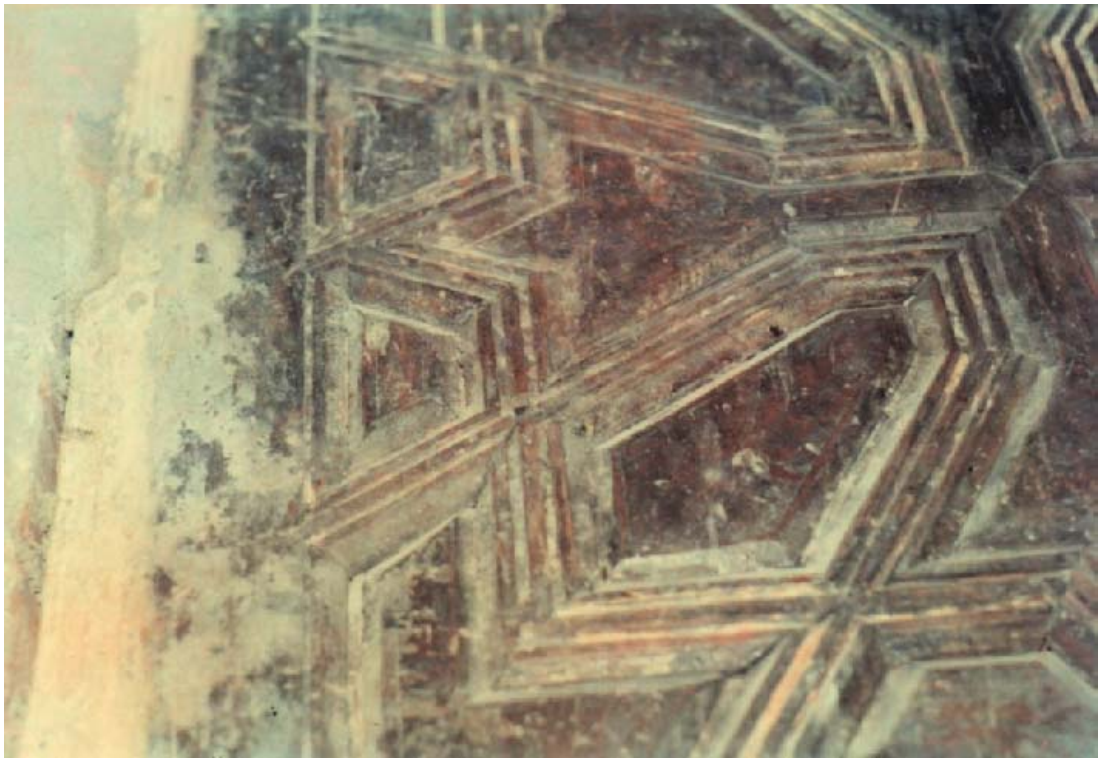


Figure 22: Detail shows part of the St. John the Baptist sanctuary screen before cleaning.

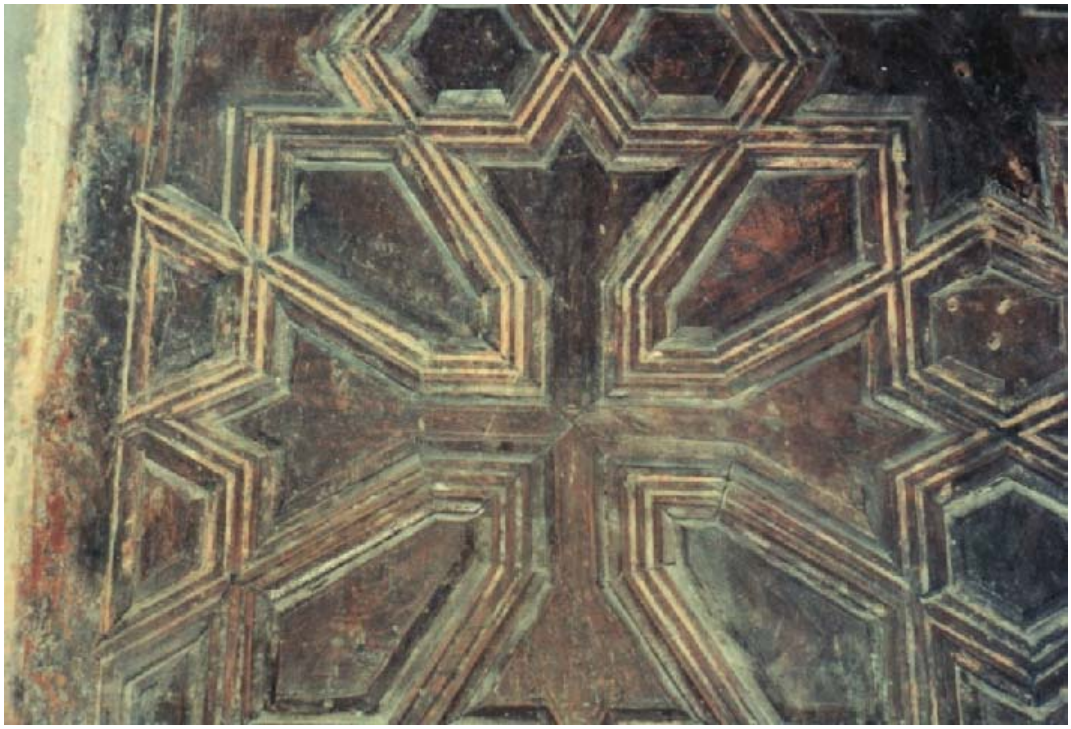


Figure 23. Area of screen shown in Fig. 22, during the first step in the cleaning process.

Figure 24. Area of screen shown in Fig. 23, during the second step in cleaning.

Figure 25. Area of screen shown in Figs. 22-24, after the cleaning, restoration and conservation work.

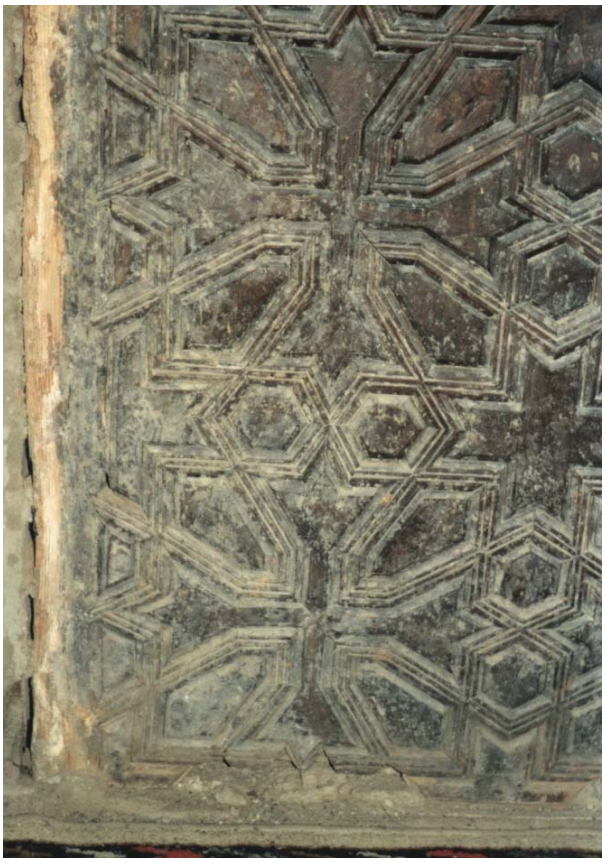


Figure 26 (left). Another area of the sanctuary screen shown in Fig. 21, beforeconservation.

Figure 27 (right). Area of screen shown in Fig. 26, after the cleaning, restoration and conservation.

Figure 28. Detail showing part of *mashrabiyya* No. 2979 in the Museum of Islamic Art in Cairo, before cleaning (cf. Fig. 3).

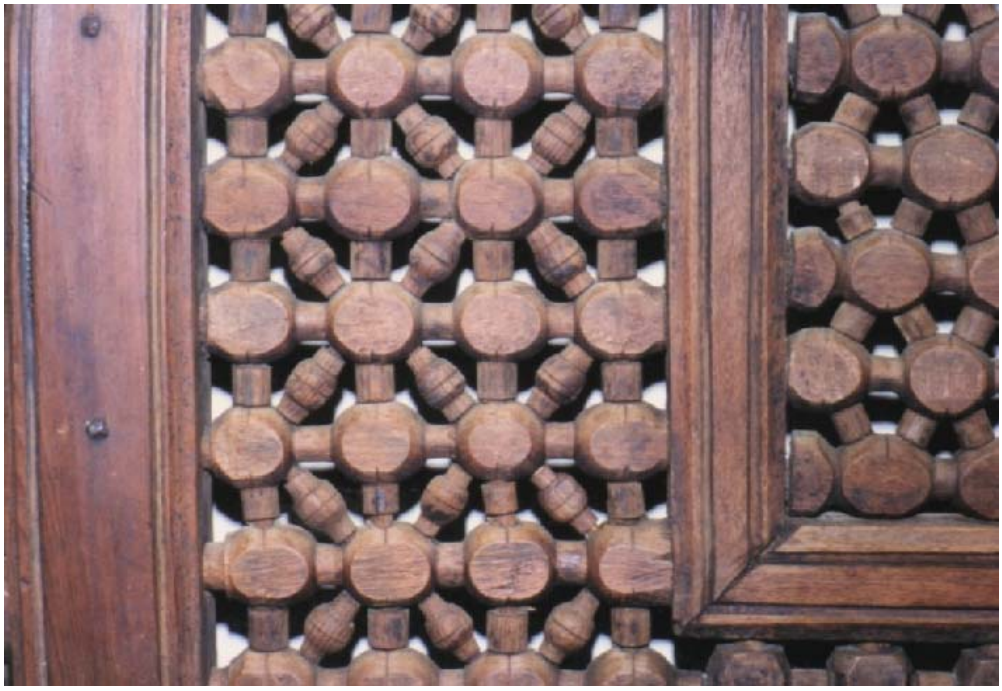


Figure 29. Detail of *mashrabiyya* No. 2979, after cleaning.

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Endnote

1. Editor's comments on transliteration and photos: The transliteration of Arabic into English is inconsistent. *Mashrabiyya* (carved wooden grille used to cover windows or balconies) is a common spelling.

Fig. 1: *El-Muallqa* also appears as *al-Mu'allaqa* and other minor variants; it is also known as the Hanging (or Suspended) Church. The church includes three sanctuaries, the central one dedicated to the Virgin Mary, the north one to St. George, and the south one to St. John the Baptist.

Fig. 2: *El-Amir Bashtak* also appears as *Beshtak, Bashtaq* and several other variants.

Fig. 3: *Mar Mena* also appears as *MarMina* or as St. Menas Church; it incorporates sanctuaries dedicated to *Mar Bahnam* (St. Bahnam or Benham) and St. George.

For information on churches in Cairo, see www.touregypt.net. The editor also wishes to thank Dr. Brian J. Spooner of the Department of Anthropology, University of Pennsylvania, for assistance with Arabic names.

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CONSERVATION TREATMENT CONSIDERATIONS FOR AN EGYPTIAN POLYCHROME WOOD COFFIN

Linda S. Roundhill

Abstract

This paper outlines the investigations and ultimate treatment of an ancient Egyptian polychrome wood coffin owned by the Burke Museum of Natural History and Culture (University of Washington, Seattle). Particularly of interest was discovering that the interior of the coffin appeared to have been previously treated with a carelessly applied dark orange lacquer resembling shellac. This darkened coating had obscured the painted design and it was feared that its further degradation would continue to jeopardize the remaining polychrome layers. Plans were considered for the removal of the coating, followed by the consolidation and stabilization of the coffin. After further investigation, however, it was discovered that the disfiguring resin had been applied by the coffin makers themselves, though the purpose it served remains uncertain. In conclusion, if a reasonable amount of precaution (in the form of study, careful examination and testing) had not been taken, the object's integrity would have been seriously violated. The progress of the investigation is outlined, followed by the methods eventually developed and used for the cleaning and stabilization of this object.

Background

The Burke Museum of Natural History and Culture (founded in 1885) is located on the campus of the University of Washington. In 1902, a prominent Seattle banker named Manson F. Backus purchased a mummy and coffin from the National Museum of Egyptian Antiquities in Gizah, and sent them to the museum as a gift. The Ptolemaic mummy (300-30 BCE), excavated at Fayum, and the late 21st/early 22nd Dynasty (959 - 889 BCE) coffin, excavated at Thebes, became the centerpiece of the museum for many years (Fig. 1). Through time, however, the focus of the museum began to change. Eventually, Egyptian artifacts no longer fit well with the themes of a museum that was becoming more of a museum for regional natural history, and an interpretive center for the indigenous peoples of the Pacific Rim.

As a result, after being on and off display for about 80 years, the mummy and coffin were relegated to storage. In 1998, when another museum requested both items for loan, the coffin was brought to the attention of the current curatorial staff. The museum requested that the mummy and the coffin be examined to determine if they were in good enough condition for travel. After a cursory examination, both items were found to be in poor condition.

Figure 1. Mummy and coffin on display in 1940's (Photo courtesy of *Seattle Times)*.

Overall Condition

The coffin (Fig. 2) was particularly fragile. The original burial conditions had been far from ideal, as shown by erosion caused by flowing water, and dark organic stains from the slow

Figure 2. Lid of coffin, before treatment.

migration of that water (Fig. 3). The protective yellow lacquer coating on the exterior (common to 'Yellow-type' coffins that were made from the early Nineteenth to the early 22nd Dynasty; Ikram and Dodson 1998), was well preserved in some places, but degraded, blanched and dull in others, and completely eroded in some areas (Fig. 4). Some of the wood used in the construction had shrunk a great deal, causing wholesale loss of the painted layers over the joints. Many years of display caused additional fading of pigments, degradation of media and damage caused by a lack of control over seasonal humidity changes (Fig. 5). It is a credit to the technology of the ancient Egyptians that the polychrome layers survived as well as they had.

Figure 3. Side of coffin, with a large crack, organic staining and incrustations.

Figure 4. Mid-section of coffin before treatment.

Figure 5. Detail of coffin lid, with shrunken joins, before treatment.

Condition of Polychrome

Closer visual examination revealed cracked, cupping and flaking polychrome on upper surfaces and along the proper left side. The head area and decorative collar on the lid was also heavily damaged. The decoration technique in these areas included painting thin washes of color over a white ground, and then using an extremely thin lacquer coating over this, but also leaving unpainted and unvarnished areas of white ground (Fig. 6). Since the lacquer was thinner or absent, water action caused more erosion. There were also layers of dirt and incrustations such as mud, minerals, dust and grimy patches on the ends from handling. The interior had small piles of debris left from the disintegrating mummy that had been displayed inside it for so many years. Past treatments, recorded only by a few fortuitous surviving photographs from 1963, apparently included cleaning the interior with a whisk broom to remove all the fragments of linen, dust, and fragments of fallen polychrome that had accumulated on the inside (Fig. 7).

Figure 6. Detail of flaking polychrome paints in the area of the partially lacquered collar.

Figure 7. Interior of coffin being cleaned, ca.1963 (photographer unknown).

The painting on the interior of the coffin was very different from the exterior. Like other examples from the period, most of the exterior of the lid and trough is covered with small figures in red and dark blue on a dark yellow background (Fig 8). The overall effect is very yellow. The exceptions are the bare foot end and the decorative headdress and collar where the lacquer is very thin and also have some reserve white areas where the ground shows through. The interior, however, has brightly-colored matte paints applied over a thick, bright white ground, and not coated with the same thin yellow lacquer in evidence on the exterior (Fig. 9). The areas of

uncolored white ground are used effectively for robed figures, making them glow against a yellow ochre-colored background.

Figure 8. Coffin exterior, side.

Figure 9. Smears of dark orange resin, eg. on the right-hand figure.

Mysterious Resinous Accretion

Unfortunately, portions of the beautiful vignettes on the interior are marred by smears of a thick, glossy resin the color of dark orange shellac. At first the smears appear to be totally random, but careful study revealed that it was placed deliberately on most of the powdery green areas, even though the application of it was sloppily done and often incomplete (Fig. 10). Sometimes, an entire brightly colored area had been coated and was now dark and streaky, but the same motif repeated on the opposite side of the coffin interior had no such treatment (Fig 11). In the same way, the coating appears randomly on only some of the red and yellow-painted areas. The appearance of it suggested that someone had tried to preserve the flaking, fragile paints with a resin that had since darkened to the orange/brown color with age.

The dark patches resembled an inept conservation treatment to such a degree that a treatment plan was formulated that included their removal, if at all possible. If the coating were left on, the continued shrinking and flaking of it would further endanger the original paint. Success was not assured. If the resin proved to be shellac, it would probably be hard to remove and might leave stains behind. However, there was a chance that the removal of the orange-brown smears would reveal the original detail and luminous colors as they were meant to be, and this seemed worth the extra time involved.

Figure 10. Band of red, white and blue cobras, center left, obscured by dark resin.

Figure 11. Band of cobras on opposite side of coffin interior, no resin coating (image reversed for comparison).

Treatment Considerations

However, a detailed treatment plan had to wait. The funds for a lengthy, involved treatment simply did not exist. Second, there was no suitable location to do the work. The museum has no conservation lab, little extra space and the use of solvents in even small quantities is forbidden by University environmental regulations. The author's own lab was still being constructed, and it would be many months before completion. Third, a lot of research was necessary before it would be understood exactly what had happened to the coffin, and how it should be treated. Fourth, the Ptolemaic mummy was also in need of extensive investigation and research into background and possible treatment plans.

And so, vigorous fundraising efforts began, and several students and volunteers were employed cataloguing bones and doing basic research into Egyptian funerary arts. The Burke Museum also began planning for proper storage of the mummy and coffin, which meant developing a suitable storage and display case with safe environmental controls. At one point it was suggested that it might be better for the Burke Museum to give the coffin and mummy to another museum—one with extensive Egyptian collections. It was decided, however, that these items were too great a part of the tradition and history of the museum to allow de-accessioning.

Background Research Results

Interim research provided little relevant information. Published case studies on this type of coffin were seemingly non-existent, (the article by Johnson, Head and Green was found after this work

was completed) and published catalogues mentioning this type of coffin often had small, indistinct black-and-white snapshots. Inquiries were made along the usual museum and conservation information conduits, but everyone contacted seemed to have limited experience with exactly this type of coffin. The original color of the lacquer should have been more transparent, or close to it, or it probably would not have been applied. Even so, if the lacquer inside proved to be original, what was its purpose? If the Egyptians were the authors of this disfigurement it would seem to cast doubts upon their standards of craftsmanship. These coffins were meant as serious furniture for the dead, designed to help them make the journey to the after-life, painted with prayers and incantations for the deceased. Attention to detail was the expected norm, but this lacquer was often applied sloppily and with almost no regard for the finely painted images.

There were of course, different levels of perfection in coffin manufacture. High social status usually meant the best of everything, but continuing down the social pyramid, things were a little less perfect. Additionally, by this time in the coffin-making business, motifs and scenes were becoming more stylized and mass-produced for the funerary market. While the coffins of the 21st Dynasty enjoyed a sort of renaissance of pictorial elaboration, designs tended to be generic, and only personalized in limited ways. Coffins and coffin parts were sometimes re-used to save on wood. Concurrently, somewhat less attention to detail was paid to the mummification process, with the result of more mummies decaying with time. This may account for the excessive damage and staining of the interior bottom of the coffin.

It is therefore possible that after the master coffin-painter was finished with his work on the inside, a less experienced trainee or common laborer completed the coffin in an assembly line fashion. This work may have included applying a resin as a fixative for certain colors, or to enhance or highlight certain features on the inside. There is also the possibility that this coating was meant as an aromatic unguent with religious or spiritual significance and aesthetics were not a consideration. There are several examples of coffins from this Dynastic Period where a black, bitumen-like substance was liberally applied over beautiful painted decorations, intentionally placed but without regard to the aesthetic result. These are assumed by Ikram and Dodson to imitate the style of high-status black coffins of the Eighteenth Dynasty and meant to "endow the coffins with the power of the black-fleshed King of the Dead, Osiris" (Ikram and Dodson 1998, 233). If so, then sometimes the aesthetic decorations and even the inscriptions were clearly subordinate in importance to the spiritual significance of the added layer. Obviously, one should never consider removing such a layer for the sake of our modern aesthetic preferences.

Detailed Investigation Results

The search began for clues to determine whether the old resin should be removed or preserved. Eventually, a detailed examination was arranged and the evidence for and against began to accumulate. For instance, the resin was still quite soluble in alcohol, less soluble in acetone, but insoluble in water, toluene and mineral spirits. It also fluoresced under ultraviolet light in the same way as shellac, which seemed to enhance the case for a modern shellac treatment.

On the other hand, the lacquer on the exterior (which undoubtedly was original) had all the same properties mentioned above, even though it was a thin, transparent yellow. Examples of the lacquer having been applied to exposed wood, which one would expect if it had been a salvage treatment to stop flaking, were conspicuously missing. It would seem plausible, then, that both coatings were original. Judging from the dark tide-lines surrounding the area where the mummy was laid, perhaps the excessive darkening of the resin on the interior may have been due to having been enclosed with the organic vapors associated with decaying organic material. The decay was probably caused by the water seepage mentioned above, or from a failed mummification process. The latter is not common in this period, but this coffin shows some evidence of having been reused or changed at the last minute. It is also possible that a different formulation of lacquer was used.

A closer look at the interior bottom revealed a lot of the orange resin under the layers of dirt. Besides general debris there was also a thin layer of a fine alluvial mud on top, presumably from burial, which should authenticate the resin beneath it. However, the same sort of muddy accumulation was found within the drilled holes in the coffin bottom (Fig. 12). No other examples of similar holes were found in any publications, and various sources indicated that they were highly unlikely to be original. This seemed to indicate that at least some of the mud was post-excavation and could not, therefore, authenticate the resin it covered. Alas, the original assumption (that the resin was a modern treatment attempt) could not be disposed of entirely, and conflicting evidence continued to delay the treatment decision.

Figure 12. Holes drilled into bottom of the coffin along with muddy accumulation

Finally a reference to Alfred Lucas's 1927 studies of ancient Egyptian technology was found, referring apparently to the smears of resin on similar coffins of the period:

> "There can be no doubt that this varnish…was originally colorless, or practically so, since there are a number of instances where a white painted surface, [which] is partly varnished and partly unvarnished,…and the edges of the varnished portions are so very irregular and unsightly that this cannot have been the original appearance…" (Lucas 1934, 357).

It would seem that this sloppy ancient technique was not only possible but normal for coffins of this type. This was eventually corroborated by Helena and Richard Jaeschke (conservators with extensive experience in the treatment of Egyptian artifacts; Jaeschke H & R 2000). Shortly after this, the gas chromatography analysis ordered by the Burke Museum finally came back. The results were negative for shellac and positive for a variety of organic compounds such as camphor and verbenone (mono-terpene ketones found in various plants, including species found in Egypt; Nicholson and Shaw 2000).

Work finally began on the coffin in August 2000. Many different samples of pigments, coatings, putties and accretions were saved for future analysis before any treatments were performed.

Treatment of Coffin Lid and Trough Exterior

The coffin was first cleaned of surface debris from non-damaged areas, using cotton swabs dampened with just enough distilled water to encourage dust and powdery residues to stick to the cotton when rolled gently across the surface. Damaged areas had to be cleaned under magnification with small natural-hair brushes. Some areas could not be cleaned before consolidation as there were loose flakes of paint just resting on the surface. These had to be consolidated in place under magnification. A tiny dental instrument was used to tease the fragments into place during drying, as the application of the consolidant solution sometimes caused the fragments to move.

Many tests were performed to determine the best solvent/consolidant combination because there were several important criteria:

- the fragile paint flakes had to be re-affixed to the surface of the ground layer
- the loose and crumbling ground had to be strengthened and re-affixed to wood substrate
- the consolidant must not alter the intended appearance of the polychrome decorations
- the treatment had to at least offer the hope of reversibility, so only resins that had proven longevity and that remained soluble in non-damaging solvents were considered.

The lacquer coating was generally water resistant, but wherever it was degraded or missing the red and yellow paints used on the exterior of this coffin were quickly affected by water, with some loss of pigment. As a result, consolidants that are only reversible in water had to be eliminated from consideration. Alcohol and acetone were not appropriate solvents because of the solubility of the original yellow lacquer, and the blues and green paints began to crumble and dissolve in acetone, suggestive of a resin binder. Other solvents were tested, but only toluene, and xylene had no negative effect on any of the original coffin materials. It was eventually decided that the fragile paint layers should be consolidated on the exterior with Acryloid B-72

(70/30 ethyl methacrylate/methyl acrylate copolymer) in xylene. Various concentrations were tried, but only those ranging from 15% to 20% weight/volume had any stabilizing effect on the paint flakes.

The exterior was coated with 20% B-72 w/v in xylene, applied by brush. If, after drying, more consolidant was necessary, an additional coat was applied. The resin solution was absorbed quickly and deeply, seeming to penetrate all the way down to the wood substrate. The only visible color changes occurred in the degraded areas. Where the lacquer was well-preserved, the consolidation appeared to cause no visible change, except a slight increase in gloss, which was corrected by swabbing afterward with toluene. Where the lacquer had become white and opaque and the colors had become faded and tonally bleached, the consolidation restored the colors and resin transparency to that approaching the undamaged areas (Fig. 13). Exposed wood did darken as a result of the consolidation, but since the wood would not have been seen originally and was only exposed as a result of damage, this color change was not considered problematic.

Figure 13. Side of coffin lid, after treatment.

Large fragments of paint and gesso separating from the wood substrate were stabilized using 40% B-72 in toluene to which was added about the same volume glass micro-spheres. Dry powder earth pigments were added to match the color of the wood. Enough solvent was added to aid mixing and flow. This fill mixture was then injected between the flake and the wood through 24g Teflon needle attached to a 5 ml syringe.

Treatment of the Trough Rim

The flat rim of the trough upon which the lid sits has a very thin wash of lacquer on top of an extremely thin layer of yellow-painted gesso. The lacquer had become fragmentary and brittle in

places, and tiny cupped fragments of lacquer and the underlying paint were easily dislodged by incidental contact. Simple consolidation helped but did not prove to lend enough mechanical stability to allow treatment of the interior of the trough to proceed. It was found that a combination treatment worked well, and this was extended for use on some of the interior surfaces as well. First, the entire rim was consolidated by saturation with 5% Acryloid B-72 in toluene. This acted as a waterproofing layer as well as a toughening treatment for the powdery gesso and paint. After drying, all the tiny lifting flakes were further fastened down by running a solution of Primal WS-24 acrylic colloidal dispersion (diluted 1:2 with distilled water) under each from the tip of a small brush. When touched to the edge of a flake it ran under it but the water was not absorbed because of the B-72 pre-treatment. Then, as the bead of resin slowly dried, it formed a bridge between the flake and the wood. Primal WS-24 dries clear and can be reversed in toluene in the same way as B-72.

Treatment of Trough Interior

The interior required a different approach. Not only was the painting technique entirely different but the sheer amount of accumulated soil and debris made treatment much more difficult. Consolidation with concentrations of B-72 greater than 2.5% tended to darken the colors unacceptably. The trough bottom had a very thick lacquer layer in places. It also contained a great deal of debris which included fallen paint flakes, soil, dust and deteriorated linen fragments (left from when the mummy had been displayed inside the coffin). This debris was removed after two preliminary steps. First, a search was made for fragments of wood or painted gesso that could either be reattached or saved for analysis. Second, very soft camel-hair brushes were used to both clean off paint remains and to corral the debris onto areas of bare wood, avoiding areas where there were loose paint flakes. On well-preserved areas, stiffer natural bristle brushes could be used to clean off soil and debris. A vacuum was then used to suck out the debris through a rubber latex tube.

The remaining muddy soil (source unknown) was removed where possible using damp swabs as described above. Next, all the painted areas were consolidated with 2.5% Acryloid B-72 in toluene using a 1/4” natural bristle brush.

The complex paint layers on the interior that were lifting or needed more consolidation were treated individually, depending upon whether there was also ancient lacquer present or not. If original resin was present, more concentrated solutions of B-72 (approaching 20%) were used if necessary. Injections of the B-72 putty described above were employed where large fragments were detaching, and the technique developed for the fragile rim paint was used when required.

Beneath the soil on the interior bottom were several areas of very thick, hard mineral incrustations over the painted designs. In some places, the paint was protected by well-preserved original resin and the incrustation had formed on top. A small sample of the incrustation was removed with a scalpel and mixed with a solution of hydrochloric acid to test for carbonates, but there was no reaction at all. A larger sample was removed for future analysis, and then a glass bristle brush (0.5 cm wide) was used to reduce the heavy incrustation down until it became translucent enough to discern the painted details beneath, but not far enough to abrade the

original lacquer. A 20% solution of B-72 in xylene was then applied to help restore the transparency of the lacquer. This minimized the effect of the incrustation and helped to reveal some previously obscured details (Fig. 14).

Figure 14. Coffin trough interior, after treatment.

Structural Stabilization

It was expected that a certain amount of wood joint stabilization would be necessary, but multiple forms of manual testing proved that the main joints of the coffin were all surprisingly tight. Some surface splitting and detached fragments were mended or stabilized with B-72 used as an adhesive, or with the B-72 putty described above. All mends to wooden parts were performed after first sealing the surfaces with 10% B-72 in acetone.

Comments

No loss compensation was attempted at this time.

An excellent display/storage case for the mummy and coffin was designed and constructed by Snow and Company of Seattle, WA, with guidance from the museum staff and utilizing conservation principles. The coffin environment is now controlled by a CICU Air-safe System (developed by NoUVIR Research) to minimize damage due to humidity changes and control air quality. Lighting is provided by fiber optics to minimize light damage while still providing enough light to allow the interior to be studied.

The occupant of the coffin (whereabouts unknown) was later identified as "(something illegible) Khonsu" by the inscription on the exterior, proper right side, at the waist. The time period was further narrowed to the Reign of Osorkin the First, 924-889 BCE, and the type declared to be Yellow-type YV (Dodson 2002).

The stabilization treatment was successful and subsequent regular examinations have discovered no new damage, even during and after a loan period to another museum.

Conclusion

It is hoped this candid account of an error averted may help other conservators facing a similar crisis of decision. The temptation to clean off all disfiguring accretions for the sake of aesthetics must be resisted until decisions concerning irreversible procedures can be made with confidence.

Acknowledgements

The author would like to thank Laura Phillips and the staff of the Burke Museum Archaeology Department for their hard work, continuing dedication to the proper conservation of their collections and their patience during the long treatment process. Thanks also go to the late Frany Backus, granddaughter-in-law of Manson Backus, and her friends who raised money for this project in her name.

Suppliers

Acryloid B-72, dry pigments, glass microspheres:
Conservator's Emporium, Reno, NV (www.consemp.com)

CICU Air-safe System:
NoUVIR Research, Seaford, Delaware (www.nouvir.com)

Glass-bristle brush:
Original source discontinued, similar items found at Earnest Miner, Ouaquaga, NY, (www.hailcesare.com)

Primal WS24, Conservation Resources, Inc., (www.conservationresources.com).

Teflon needle and syringes:
Small Parts, Inc., Miami Lakes, FL (www.smallparts.com)

References

Berman, L.M. and K.J. Bohac, eds. 1999. *Catalogue of Egyptian Art*. Cleveland: The Cleveland Museum of Art.

British Museum Department of Antiquities. 1968. *Catalogue of Egyptian Antiquities in the British Museum*. London: British Museum.

Brown, C., F. Macalister, and M. Wright, eds. 1995. *Conservation in Ancient Egyptian Collections*. London: Archetype Publications.

Conservation Information Network Search.

Corzo, M.A. and M. Afshar, eds. 1993. *Art and Eternity*. The J.Paul Getty Trust. Santa Monica: The J.Paul Getty Trust.

Dodson, A. 2002. Unpublished examination notes and private communications. Egyptologist, Department of Archeology, University of Bristol, U.K.

D'Alessandro, L. 2000. Personal communication. Oriental Institute Museum, Chicago.

J. Paul Getty and Getty Conservation Institute. 1992. *In the Tomb of Nefertari*: *Conservation of Wall Paintings*. Malibu: J. Paul Getty Museum.

Ikram, S. 2001. Personal communication. Associate Professor of Egyptology, American University in Cairo.

Ikram, S. and A. Dodson. 1998. *The Mummy in Ancient Egypt*. London: Thames and Hudson.

Jaeschke, H. and R. 2000. Personal communication. Private conservators, Lynton, U.K.

Johnson, C., K. Head, and L. Green. 1995. The conservation of a polychrome Egyptian coffin. *Studies in Conservation* 40:73-81.

Leonhard, A. 2000. Personal communication. Former objects conservator at University of Missouri Museum of Art and Archaeology, Columbia.

Lucas, A. 1934. *Ancient Egyptian Materials and Industries, 2nd Ed*. London: Edward Arnold Publishers, Ltd.

Lucas, A. and J.R. Harris. 1962. *Ancient Egyptian Materials and Industries, 4th Ed*. London: Edward Arnold Publishers, Ltd.

Nicholson, P.T. and I. Shaw, eds. 2000. *Ancient Materials and Technology*. New York: Cambridge University Press.

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DEINSTALLATION AND CLEANING OF THE 1950s GALLERIES OF ETHNOGRAPHICAL AND ARCHAEOLOGICAL MATERIAL FROM THE AMERICAS AT THE FIELD MUSEUM, CHICAGO

Joanna Minderop, Cheryl Podsiki and Ruth Norton

Abstract

The Field Museum in Chicago is updating a major portion of the Americas Halls that was on permanent display from 1950 until 2003. The deinstallation phase included the complete de-installation of 53 cases and the relocation of 54 intact cases (i.e. with artifacts inside) within the museum galleries. Of the 2,128 artifacts removed from the old cases, 1,461 artifacts needed to have their old mounts removed before being reintegrated into storage. Understanding the mounting methods used in the old exhibit was imperative to the safe removal of the artifacts from their mounts. Mount types included adhered wire mesh, wooden shelves and dowels as well as wire, mannequins and nails. Mount removal methods included a vapor chamber, poultices, and mechanical removal. The written and photographic documentation of the alterations caused by the mounts will be critical to future interpretation of artifacts. Samples of the various mount materials and techniques used in the 1950s exhibition have been added to the Conservation Department's reference collection of past mounting and storage materials used at The Field Museum. The experiences gained from the extensive gallery revision will be used to develop museum guidelines for future deinstallations of permanent exhibitions. Conservation staff required for the complete deinstallation process was two person years.

1. Introduction

Founded in 1893, The Field Museum presently houses over 25 million artifacts and specimens, with collections in the Anthropology Department numbering more than 1.5 million. The collections originated with the 50,000 artifacts and specimens that were assembled for the World's Columbian Exposition of 1892/93 in Chicago (Fig. 1). In 1923 the collection was moved to the present museum facility. Most of the current Americas Halls were designed in the early 1950s as a permanent exhibition, with content, design, mounts and installation being reflective of that time period.

The Arctic and Northwest Coast galleries were redesigned in the 1980s to acceptable museum standards. In 2003 most of the remaining Americas cases containing ethnographic artifacts were resituated within adjacent galleries, while the cases displaying primarily archaeological artifacts were deinstalled in preparation for the new Ancient Americas exhibition. The process of revising and updating the old Americas Halls is referred to as the Americas Project.

Figure 1. General view in the anthropological building showing exhibits at World's Columbian Exposition, 1893. Photographer: R. Testa from an unknown book. Photo courtesy of The Field Museum, A110185.

2. The Americas Project

The first phase of the Americas Project included the complete deinstallation of 53 cases and the relocation of 54 intact cases within the museum galleries. Of the 2,128 artifacts removed from the old cases, 1,461 artifacts were taken to the conservation laboratory where the mounts were removed. Only 200 of the deinstalled artifacts will go back on display in the new exhibit. The remainder of the artifacts will be reintegrated into designated storage areas.

The second phase is dedicated to the development and installation of the new exhibit. Conservation provided individual assessments of the 2250 chosen artifacts, as well as assessment of exhibit and case design, artifact layout, and environmental, housekeeping, pest control and maintenance needs. Treatment of the artifacts and assisting with their installation will conclude this phase.

Throughout the entire process of renovating the Americas galleries, communication concerning intellectual and practical development of the exhibition continues to be key to maintaining an effective and efficient relationship with the entire Americas Project team. Team members include the project manager, curator, researcher, native community

liaison, developers, designers, collections managers and assistants, conservators, mount makers, exhibition and production staff, and educators.

3. Deinstallation

The deinstallation process of the old Americas Halls involved the coordination of a team of people composed of a conservator, a collections manager, and staff from the exhibitions and productions departments. Each step was planned in detail and discussed within the team in advance of artifact removal or intact case transport. The physical removal of the permanently mounted artifacts from cases included the pulling of nails from the case walls, sawing through wooden dowels attached to the mounts and the case walls, and cutting away the canvas wall lining onto which small artifacts had been directly adhered (Fig. 2).

Figure 2. De-installation. Removing nails from artifacts that have been hammered to the case wall; personal protective equipment included overalls, booties, gloves and respirators. 2003.

3.1. Documentation

One of the most important procedures conducted by the conservator was the written and photographic (using digital imaging) documentation of the entire process. The documentation will be a useful tool in the future for communicating the reasons why certain damage, or features such as holes, distortion patterns, fading, or surface losses are

present on artifacts (Figs. 3, 4). Documentation of any alterations to the artifacts due to extended exhibition was essential for maintaining archival records, understanding artifact damage, and assisting in cultural interpretation. To aid in this, examples of each mount type were added to the Conservation Department's reference collection of materials and techniques from past displays and housing.

Figure 3 (left). Mannequin wearing blouse (catalogue #155674) as photographed shortly after installation in 1949. Photographer unknown. © The Field Museum, A92758.

Figure 4 (right). Mannequin wearing blouse (catalogue #155674) after de-installation in 2003 showing location of fading. 2003.

Archival photographs of the display cases from the 1950s provided important information when recording some of the visible damage that occurred to artifacts as a result of the original mounting techniques. Artifact catalog numbers and mount locations were recorded on photocopies of the original case photographs. These photocopies were then used as a tool to indicate exactly where damage to the artifact occurred. For example, lines were drawn on the images to represent the placement of nails hammered through certain artifacts (Fig. 5). A copy of the annotated case photograph was placed into each individual object conservation file for future reference.

3.2 Arsenic Treated Cases and Artifacts

Arsenic was known to have been commonly used at The Field Museum as a pesticide from the 1890s through the 1940s. Based on compiled information about the usage of arsenic in the museum (Klaus, *et al.* 2004), the Americas deinstallation team expected

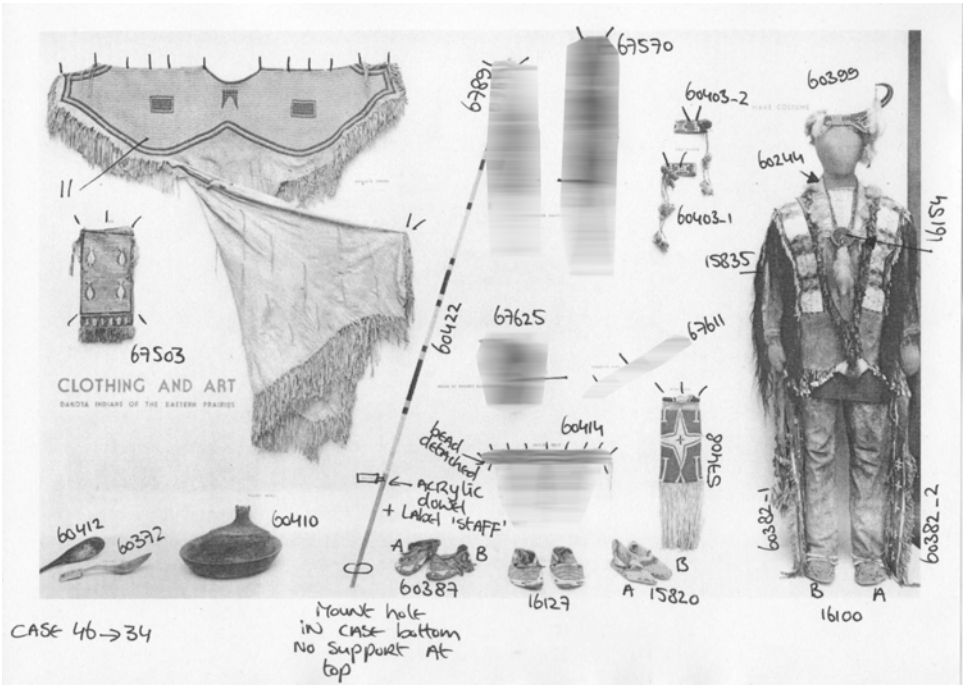

Figure 5. Case layout as photographed just after installation in 1950 with de-installation notes made in 2003. Some artifacts have been blurred out of respect to cultural sensitivity. Photographer unknown. Photo courtesy of The Field Museum, A92979.

arsenic to be present on the artifacts in the 1950s cases. Cautionary measures dictated that standard personal protective equipment (cotton jump suits, disposable Tyvek booties, nitrile gloves and respirators with particulate P100 filters) would be worn throughout the actual deinstallation process (Fig. 2). The disposal method for the empty cases would depend on whether or not arsenic was indeed present. This meant that arsenic testing had to be conducted on each of the cases prior to their dismantling and disposal. The Merckoquant Arsenic Test (see Suppliers) was employed to detect the presence of arsenic. Out of 150 samples taken (3 per case), the one sample that was positive showed only a trace of arsenic. It was later found that this sample was taken from an area located below an arsenic positive artifact. Following the museum's health and safety guidelines, this particular case was vacuumed and wiped clean with a damp cloth so that it could be disposed of in the same manner as the other non-contaminated cases. If arsenic positive samples above the trace level had been found, the case would have been disposed of as hazardous material.

Following this intensive deinstallation phase the conservators were able to test individual artifacts for arsenic. Following standard Conservation Department procedures, all organic and 10% of inorganic artifacts were tested; this amounted to a total of 499 artifacts (319

organic and 180 inorganic). Five of the organic and none of the inorganic artifacts tested positive for arsenic.

Following the Museum's anthropology conservation procedures, the arsenic positive artifacts were bagged and clearly labeled prior to being re-integrated in storage (Fig. 6). The testing did not include the ethnographic artifacts that remained in the intact cases.

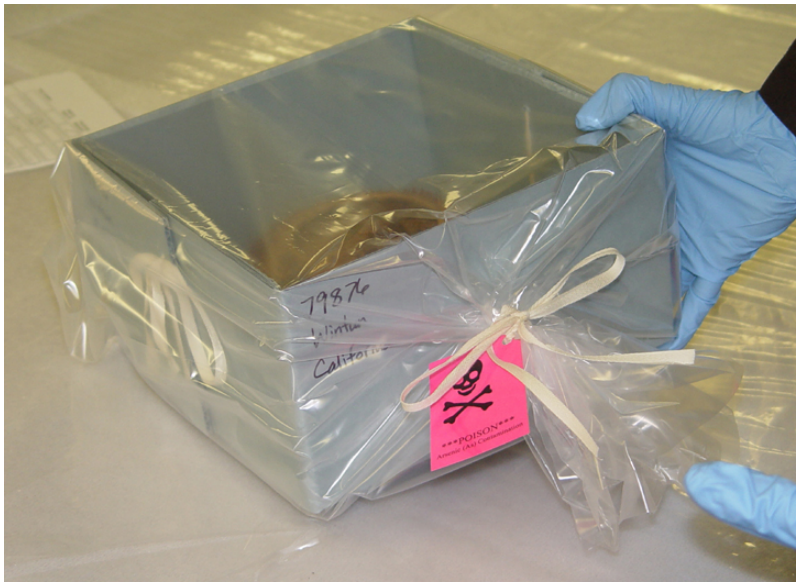

Figure 6. Bagged and tagged arsenic positive artifact. 2004.

3.3 Artifacts with Cultural Restrictions

The deinstallation of some cases needed special attention. These cases contained artifacts that specific indigenous representatives requested be handled by men only. Cultural restrictions dictated the gender composition of the deinstallation team, ensuring that removal of particular artifacts was carried out by male team members. Because there were no male conservators available at the time of deinstallation, simple mount removal tasks such as pulling nails out of artifacts were completed by male collections managers under the guidance of a female conservator. Artifacts needing more complicated treatments were set aside for male conservators and interns to address in the future.

3.4 Relocation of Intact Cases

The 54 cases containing artifacts from the post-contact period were not deinstalled but were moved to a new location within the museum galleries with mounted artifacts still intact. Prior to preparing the cases for relocation, digital images were taken of the cases to record artifact placement. Those artifacts that were merely sitting on the case floor

were removed. Permanently fixed artifacts were secured to the case wall or to their mounts with washed Tyvek 1422, cotton tape, and low-tack blue painters' masking tape to reduce vibration and movement of artifacts while moving the case. Examples of these methods can be seen in Figs. 7 and 8. Once the artifacts were secured, the cases were placed on custom made dollies and moved to their new gallery space (Figs. 9, 10). The securing materials were removed and the unfixed artifacts were reinstalled. Ironically, the ability to move these cases intact without causing damage to artifacts was, in part, due to the permanence of the mounting and installation techniques used in the 1950s.

Figure 7. Securing dress on mannequin with Tyvek inside display case. 2003.

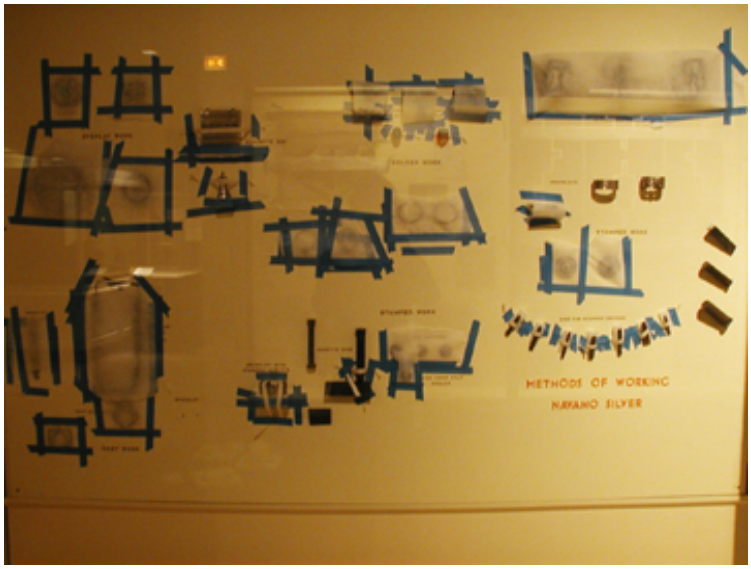

Figure 8. Small metal artifacts secured by covering with Tyvek and painters' masking tape inside display. 2003.

Figure 9. Custom made dollies are placed underneath cases. 2003.

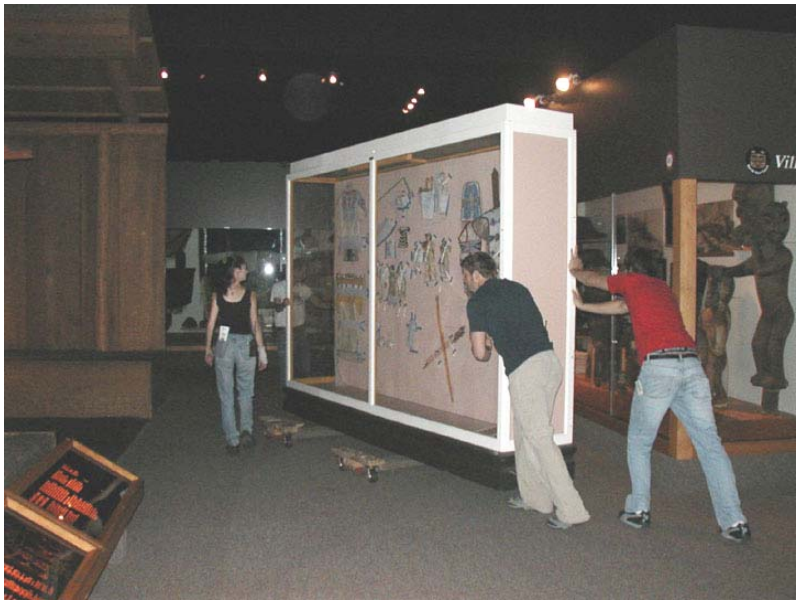

Figure 10. Intact cases are moved through the museum galleries. 2003.

4. Mount Removal

The process of removing 50-year-old mounts was a major component of the deinstallation phase. Due to budgetary constraints, conservation treatment of the deinstalled artifacts was limited to the removal of the mounts. Stabilization treatment was carried out only for those few artifacts in critical need. Documentation focused on the specifics of the mount and any accompanying damage. Photographic documentation was done for those artifacts that required further treatment, those mounts that significantly

compromised the artifact, or those mounts that were of particular interest for future reference and comparison.

The manner in which these artifacts were mounted at The Field Museum 50 years ago followed methods considered acceptable at the time and used in many museums nationwide. The main installation objective that seemed to prevail in the late 1940s and the early 1950s was the need to attach the artifacts firmly to the display case walls and shelves. For the most part this objective was achieved in that damage caused to artifacts was not the result of being mounted insecurely, but rather from the techniques used to secure them so well.

4.1 Types of Mounts and Techniques

The mount and installation techniques used on the artifacts varied depending on the specific artifact, the desired orientation and the mount makers' preferences. Fortunately, only half a dozen mount techniques and materials were used consistently throughout the 1950s exhibit, allowing the conservators to develop standardized treatment techniques for their removal (Fig. 11).

Figure 11. Various mounts (wire mesh mounts, wooden shelves, dowels, nails and wire) from the 1950s installation. 2004.

The most common mount was made of wire mesh (Fig. 12). This mount was composed of a copper alloy mesh screen which had a protruding (iron) nail or heavy wire soldered onto its outer side. The flat side of these wire mesh mounts was adhered directly to the surface of the artifact with one, or in some cases two, different clear adhesives. The protruding nail or wire was secured to the case wall. The artifacts treated with this type of mount included large and small ceramic and stone figures, and objects of shell, bone, and antler.

Individual wooden shelves were a common mounting technique for ceramic vessels (Fig. 13). The base of the vessel was adhered directly to the shelf with a clear adhesive. In some cases, yellowish-brown glue was found underneath the clear adhesive along with a different color case paint, indicating that the artifact had most likely been mounted in a previous exhibit. The wooden shelf was secured to the case wall by a wooden dowel inserted into one of the side edges of the shelf. Once installed, many of the vessels were then additionally secured by adhering their sides and/or rims directly to the canvas lined wall.

Figure 12 (left). Wire mesh mount. Ceramic figure (catalogue # 188131) reverse.

Figure 13 (right). Wooden shelf mount. Ceramic vessel (catalogue # 240548) side.

Mounts that were commonly used on large or heavy stone and some metal artifacts were dowels of various sizes made from wood, steel, or acrylic (Fig. 14). Holes were drilled into the artifact to accommodate the dowel. One end of the dowel was inserted directly

into the hole and the other end was used for attachment to the case wall. The wooden dowels were often reinforced with a clear adhesive.

Figure 14. Wooden dowel mount. Stone figure (catalogue # 189288).

Ferrous wire used for stringing beads, bells, or ornaments was often attached to a ferrous wire hook, which was then secured to the case wall. Corrosion products and/or stains on the artifacts frequently resulted from either of these wire sources. Wire was also used to provide the actual mounting material for artifacts such as smoking pipes, where it was inserted through the mouthpiece and bowl and then secured to the case wall. This technique caused abrasive damage on the interior of these artifacts.

Nails and pins were commonly used directly on ethnographic textiles and skins in order to tack them to the walls. As a result, the artifacts became distorted and holes were created; in a few instances metal corrosion stains occurred. Nails or pins were sometimes found placed through sinew or thread, resulting in tears and breakage; in some cases this caused the loss or loosening of attached beads.

The mounts used in the former exhibit to display costumes were humanoid forms. Comprised of a painted *papier-maché* upper body shape resting on an upright pole, the pole was secured to the case bottom with a flange. In one instance the metal pole was inserted through the seam of a moccasin causing the opened seam area to become vulnerable to further tearing and loss of ornamentation (Figs. 15, 16). Some of the artifacts were secured to the form with nails and others were tied down tightly with metal thread. Staining and compression occasionally occurred.

Of all the mounts encountered, the three most problematic types were those involving adhesives: wire mesh mounts, wooden shelves and wooden dowels. These artifacts were removed from their cases with mounts intact and taken to the conservation laboratory.

Figure 15 (left). Mannequin wearing moccasins (catalogue #16100 A & B) as photographed shortly after installation in 1950. Photographer unknown. Photo courtesy of The Field Museum, A92979.

Figure 16 (right). Moccasin (catalogue # 16100 A) as photographed in 2003 during de-installation. Moccasin seam had been opened in the 1950s to insert mannequin rod. 2003.

4.2 Adhesive characteristics

Prior to removing any of the adhesive-held mounts, chemical spot tests were conducted to indicate the types of adhesives that were most likely present. Based on visual observation and the types of adhesives available in the early 1950s, cellulose nitrate, poly(vinyl)acetate (PVAC) or a derivative, and an animal glue (such as hide glue) seemed probable. The tests followed those outlined in *Material Characterization Tests for Objects of Art and Archaeology* (Odegaard, *et al.* 2000). The clear adhesive samples tested positive for the poly (vinyl) alcohol (PVAL) test or its PVAC derivatives, and the yellowish-brown glue tested positive for protein (Fig. 17).

Solubility tests (Fig. 18) revealed that the clear adhesive on the wire mesh mount responded well to ethanol and acetone. Different reactions to ethanol and acetone indicated that two different PVACs were used. The one underneath the mesh mount was more readily soluble in acetone. The one around the edges of the wire mesh mount swelled and became more elastic in ethanol than in acetone. Warm deionized water was effective for dissolving the brown-yellowish glue sometimes found on vessels that had been previously mounted.

	Polyvinyl alcohol and its derivatives, PVA[1]	**Cellulose Nitrate[2]**	**Protein[3]**
1 - Clear adhesive from edge of mesh mount A; same as solubility test sample 1.	Positive: Red	Negative: Clear to yellow	Negative: No color change
2 - Clear adhesive underneath mesh mount A; same as solubility test sample 2.	Positive: Dark Red	Negative: Clear to yellow	Negative: No color change
3 - White residue from edge of mesh mount A, after acetone vapor exposure; same as solubility test sample 3.	Positive: Dark Red	Negative: turned Brown almost immediately	Negative: No color change
4 - Clear adhesive from edge of mesh mount B.	Positive: Dark Red	Negative: turned Brown almost immediately	Negative: No color change
5 - Clear adhesive from center of mesh mount B.	Positive: Dark Red	Negative: Clear to yellow	Negative: No color change
6 - Clear adhesive from wooden shelf C.	Positive: Red	Negative: Clear to yellow	Negative: No color change
7 - Yellow adhesive from wooden shelf D.	Negative: No color change	Negative: No color change	Positive: turned Purple almost immediately
8 - Clear adhesive from wooden dowel.	Positive: Dark Red	Negative: Clear to yellow	Negative: No color change
Positive Control	Polyvinyl acetate resin:[4] Red.	Lab reference sample: Blue	Fish Glue (high tack): Purple
Negative Control	Acrylic: Yellow with a red outline on edges.	Not tested.	Not tested.
Negative Control	Epoxy: Yellow with a red outline on edges.	Not tested.	Not tested.
Negative Control	Fish Glue (high tack): absorbed color – Yellow-brown	Polyvinyl acetate resin:[4] No color change	Polyvinyl acetate resin:[4] No color change

Figure 17. Spot Tests on Adhesive Samples from De-installed Artifacts

[1] Test for poly (vinyl alcohol) using iodine/potassium iodide. 166-7.
[2] Test for nitrate (cellulose nitrate) using diphenylamine. 164-5.
[3] Test for protein using copper (II) sulfate (Biuret test). 144-5.
Odegaard, N., S. Carroll, W. Zimmt. 2000. *Material characterization tests for objects of art and archaeology.* London: Archtype Publications Ltd.
[4] Union Carbide, Bakelite PVA AYAA.

Sample	Aqueous: Deionized Water	Alcohol: Ethanol	Ketone: Acetone	Aliphatic: Stoddard	Aromatic: Xylene
1 Adhesive from edge of mesh mount A; same as spot test sample 1.	After 5 min.: white, soft and gooey	After 1 min.: swollen, soft	After 2 min.: white, swollen, and soft	After 5 min.: no change	After 5 min.: no change
2 Adhesive underneath mesh mount A; same as spot test sample 2.	After 5 min.: elastic, stays clear	After 2 min.: partially dissolved	After 1 min.: completely dissolved	After 5 min.: no change	After 2 min.: partially dissolved
3 White residue from edge of mesh mount A, after exposure to acetone vapor; same as spot test sample 3.	After 2 min.: sticky and elastic After 5 min.: no further change	After 1 min.: swollen and soft, elastic	After 1 min.: soft	After 5 min.: slightly elastic	After 5 min.: no change

Figure 18. Solubility Tests on Adhesive Samples from Mesh Mount A

4.3 Wire Mesh Mounts

Two basic methods were used to remove the wire mesh mount: an acetone vapor chamber and acetone or ethanol poultices. The method used took into consideration such matters as the size of the artifact, its surface and body condition such as flaking or crumbling, previous breaks and mends, and pigments, as well as the original use of two separate adhesives (Fig. 19).

Figure 19 (left). Wire mesh mount. Ceramic figure (catalogue # 240853) reverse. Before treatment. 2004.

Figure 20. Wire mesh mount. Ceramic figure (catalogue # 240853) reverse. During treatment. White residue is visible from second type of clear adhesive. 2004.

Exposure to acetone vapors in a glass desiccator jar softened and dissolved the adhesive underneath the mount for easy removal. The opaque adhesive on the outer edges remained and was only soft and elastic for about 40 seconds after immediate exposure to the air, after which it turned white in color (Fig. 20). Taking advantage of this window of time, the substance was lifted off as much as possible with a plastic scraper. The white residue left behind was then removed by using an ethanol poultice (Fig. 21). Ethanol swelled the residue sufficiently to allow mechanical removal with a wooden stick and tweezers. Based on the results of the solubility tests for the white residue, poultices using a 50/50 solution of acetone and ethanol on cotton batting were initially attempted on several of the artifacts attached to wire mesh mounts. While this method worked, it took a longer period of time for the adhesives to soften or swell than did the use of the acetone vapor chamber and ethanol poultice combination.

Figure 21 left). Wire mesh mount. Ceramic figure (catalogue # 240853) reverse. During treatment. Ethanol poultice. 2004.

Figure 22. Wire mesh mount. Ceramic figure (catalogue # 240853) reverse. After treatment. 2004.

Most of the artifacts mounted to a wire mesh mount showed no visible signs of damage due to the use of the mount (Fig. 22). However, on a few artifacts, minute amounts of adhesive remained in the deep crevices of porous stone and ceramic. Adhesive stains and slight surface and pigment loss also occurred on a few artifacts. In one instance, a conservation and curatorial decision was made not to remove the mesh mount from a low-fired ceramic figurine that exhibited a crumbling body and several mends in order to prevent further loss.

4.4 Individual Wooden Shelves

With the individual wooden shelf, the artifact was directly adhered to the shelf and sometimes adhered to the painted canvas wall lining as well (Fig. 23). In most cases three large spots of the acetone-soluble, clear adhesive were found between the wooden shelf and the base of the artifact; on occasion the entire bottom of a vessel was adhered to the shelf. In some instances, animal glue was found directly between the clear adhesive and the artifact indicating previous mounting.

When possible, a vapor chamber was used to soften the adhesive to allow separation of the artifact from the shelf. However, some artifacts were larger than the glass desiccator available and others had previous restorations that would be affected by the acetone vapor. In these situations, localized poulticing was necessary.

Figure 23. Wooden shelf mount. Ceramic vessel (catalogue #240959). Before treatment. Adhered to wooden shelf and to case wall painted canvas. 2004.

Figure 24. Wooden shelf mount. Ceramic vessel (catalogue #240959). During treatment. Acetone and absorbent cotton poultice. 2004.

As shown in Fig. 24, a cotton batting and acetone poultice was applied at the join area between the vessel and the shelf, and then sealed with plastic wrap. The poultice was kept moist with the solvent, and allowed to stay in place until the adhesive was completely softened and the vessel could be easily lifted away from the mount. Most of the artifacts that were mounted onto wooden shelves were not altered in any manner. In a few instances, artifacts with porous stone or ceramic bodies or with already fractured surfaces suffered minor surface loss (Fig. 25).

Figure 25. Wooden shelf mount. Ceramic vessel (catalogue #240959). After treatment.

4.5 Wooden Dowels

While metal and acrylic dowels were occasionally used, the most common and most problematic to remove were the wooden dowels. Often used on stone artifacts, the wooden dowels presented a particular challenge in that they were almost always adhered inside of the hole with a clear adhesive (Fig. 26).

Figure 26. Wooden dowel mount. Stone *mano* (catalogue #206121). Before treatment. 2003.

Figure 27. Wooden dowel mount. Stone *mano* (catalogue #206121). During treatment. Core of wood removed by drilling; hole filled with acetone to remove remaining adhesive. 2003.

In a few situations, placing small artifacts in an acetone vapor chamber resulted in the dowel being sufficiently loosened to be pulled out with pliers, but this method rarely succeeded. The more regularly used method of removing the wooden dowel involved several steps. First, pliers were used to twist and break off the exposed portion of the dowel as flush to the artifact's surface as possible. Next, an awl was used to make a small hole in the center of the wood for use as a starting guide for a portable drill. Using successively larger bits, the wood was drilled out until only a millimeter of wood remained around the wall of the hole. Proceeding at a slow speed, care was taken not to actually drill to the very bottom of the hole. The depth of drilling was determined by observing the continual decrease in the amount of wood debris that was being produced. The hole was filled with acetone to dissolve the adhesive. The last of the wood debris was loosened and picked out with the aid of a wooden stick, a scalpel, and tweezers (Fig. 27). The use of the dowel mounting technique left permanent holes in these artifacts.

5. The Americas Project Continues

As the deinstallation mount removal process concludes and design development of the new exhibit takes form, conservation continues to be an integral part of the Americas Project. Assessing the designer's exhibit plan drawings, individual case layouts, and new mounts is an ongoing process involving the project team. Conservation treatment of the 2250 artifacts chosen for the new exhibit commenced in January 2005. Installation of the new exhibit is expected to be completed by the spring of 2007.

6. Conclusion

The deinstallation and relocation processes of the old Americas Halls were successful; only two artifacts were slightly damaged and almost all of the mounts were removed. Fortunately, the particular adhesives selected for use 50 years ago remained soluble in acetone, ethanol or water. Examples of each mount type were added to the Conservation Department's reference collection of materials and techniques from past displays and housing. These samples aid in distinguishing between pre-collection and post-collection materials found on artifacts. Documentation of any alterations to the artifacts due to extended exhibition was essential to maintaining archival records, understanding artifact damage, and assisting in cultural interpretation. Time and budget constraints dictated that both written and photographic documentation had to focus only on mount-related conditions, damages, and treatments. The use of archival photographs enabled documentation to be done efficiently so that information essential to interpretation of the artifacts was not lost. Established guidelines for exhibitions and production already existed at The Field Museum's Anthropology Department, however, there were no guidelines for de-installation. The processes developed in the Americas Project will help establish the resources required for future de-installations of permanent exhibits.

Acknowledgments

The authors wish to thank everyone involved with the Americas Project including professional colleagues at the museum, indigenous community representatives and the funding agencies that provided the financial opportunity to update and revise the old Americas Halls at The Field Museum. Unless noted, photographs were taken by the authors.

Suppliers

Acetone (ACS grade), Xylene (ACS grade), Ethanol (denatured ethyl alcohol):
Daigger Chemicals. A. Daigger & Co., 620 Lakeview Parkway, Vernon Hills, IL 60061-8135.

Rhoplex AC-33, water-based acrylic emulsion:
Conservation Support Systems, 924 W. Pedregosa Street, Santa Barbara, CA. 93101.

Epoxy: Ciba Araldite Precision:
Bostik Ltd., Ulverscroft Road, Leicester, England LE4 6BW.

Fish Glue (high tack):
Lee Valley Tools, Ltd., 1080 Morrison Drive, Ottawa, ON K2H 8K7.

Merckoquant Arsenic Test Kit:
Chemical kit NA1760/EM Quant Arsenic (As) Test. EM Science, Gibbstown, NJ 08027.
Merck KgaA, Darmstadt, Germany.

Polyvinyl acetate resin, AYAA:
Union Carbide. Conservation Material, Ltd., 340 Freeport Boulevard, Sparks, NV 89431.

Stoddard Solvent, Class II:
Fisher Chemical/Fisher Scientific, 1600 W. Glenlake Avenue, Itasca, IL 60143.

References

Conservation, Anthropology Department. 2003. *Exhibition guidelines*. Chicago: The Field Museum.

Odegaard, N., S. Carroll, W. Zimmt. 2000. *Material characterization tests for objects of art and archaeology*. London: Archtype Publications Ltd.

Klaus, M., J. Plitnikas, R. Norton, T. Almazan, S. Coleman. 2004. *Preliminary results from a survey for residual arsenic on the North American ethnographic collections at The Field Museum*. Poster presentation. Western Association of Art Conservation (WAAC), 2004 Annual Meeting, Santa Fe, New Mexico. Chicago: The Field Museum.

The Field Museum Photo Archives. Chicago: The Field Museum.

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EFFECTS OF CLEANING AND REGARD FOR CLEANING GOALS: ELEVEN YEARS LATER

Niccolo Caldararo

Abstract

This paper revisits the 1993 article in *North American Archaeologist* 14:289-303, "Some effects of the use of ultrasonic devices in conservation and the question of standards for cleaning objects", and includes a summary of recent research and advances by the author and in the field, including the effects of cleaning on ancient DNA. The paper discusses how both attitudes and needs in the conservation field have changed since 1993 and will reexamine earlier work, especially with regard to ultrasound. The paper includes an assessment of how conservation has responded to the challenge of both technology and changing fashion, focusing on the idea of information lost versus idealized appearance. A number of philosophical and ethical questions are posed.

1. Introduction

The author has a long standing interest in the effects of cleaning on artifacts and the evaluation of conservation treatments historically employed. Beginning in the early eighties, the author has questioned accepted treatments. For instance, the author began correspondence with H. Brinch Madsen about the long-term effects of BTA treatment on bronzes (Madsen 1983) and with Joan Gardner at the Carnegie Museum about some techniques she had used on the Spiro artifacts (Gardner 1980) in order to learn of the current condition of the artifacts and whether Gardner had adapted the treatments previously used by Forest Clements (1936) or Douglas (1931); see also Bennie Keel, 1963, on Leechman).[1]

Gardner replied that she had read the Clements article several years beforehand, but was not sure if her treatments had in fact been the same as Clements (Clements 1936). She thought he described a “too stringent” approach and felt it was unwise to cite his paper as it would “call attention to it.” “Too many people, “ she pointed out, “blindly follow instructions without considering the condition of the specimens involved and without considering all the cautionary notes associated with a treatment method.” Certainly this is true, but it is also true that we can only make progress through an evaluation of the deficiencies of prior methods and materials.

As a result of this correspondence, the author decided to undertake a study of the durability of specific treatments and the decision-making process that led to treatment selection. Other conservators also have evaluated current conservation methodology. For instance, in 1975 Judith Weston and Meryl Johnson reported on the conservation of Benin Bronzes at the Detroit Institute of Arts. The focus of their paper was the use of protective coatings, including waxes and resins which were applied by collectors, restorers and conservators to enhance the aesthetic qualities of the objects. These coatings also covered previously treated areas, as well as untreated ones, which later became active sites of bronze disease and caused substantial damage and loss. The authors pointed out the need for attention to forms of compensation that mask potential areas of

future damage. Also essential to an assessment of treatment goals was an understanding of what was viewed as the original surface.

Research has shown that even a 'gentle' cleaning treatment such as wiping a saliva dampened swab across a paint surface can have a perceptible effect. Figures 1 and 2 show a comparison of cleaning with saliva on a painted surface by Alan Phenix and Aviva Burnstock (1990). Certainly the surface is cleaned of dirt and other debris but there are also visible diagonal lines on the cleaned surface from the swabbing process; apparently the result of the physical action of the swab against the paint and/or the process of leaching water-soluble components in the varnish film**.** Figures 3 and 4 illustrate another example of the use of a cotton wool swab on varnish producing unmistakable lines in the varnish (Phenix and Burnstock 1990). There has been considerable debate concerning the process of leaching and solvents. Ken Sutherland has provided more information on the effects of cleaning on painting materials with his measurements of both cleaning and the leaching of soluble components during varnishing (Sutherland 2004). The question is not whether change occurs, but how much change is acceptable.

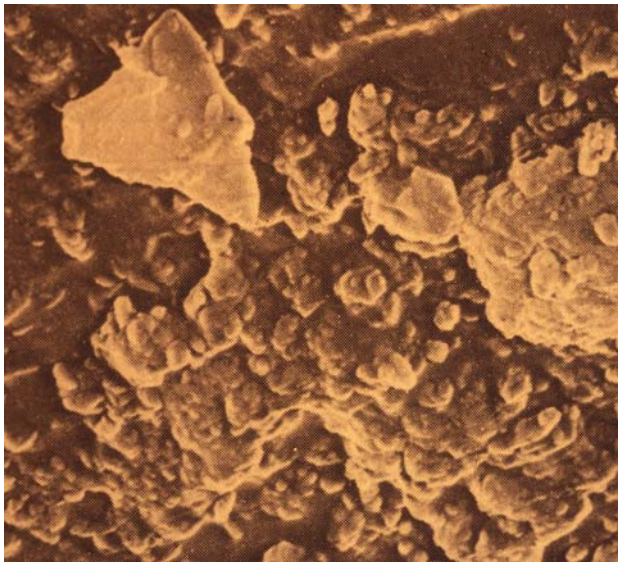

Figure 1. Painted surface, before cleaning with saliva.

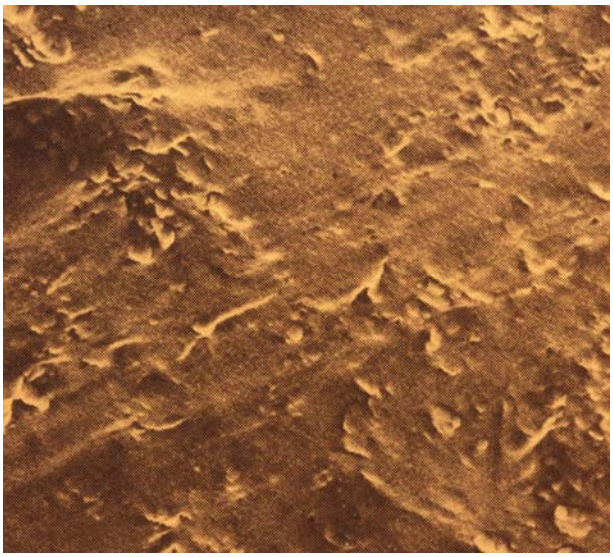

Figure 2. Painted surface, after cleaning with saliva.

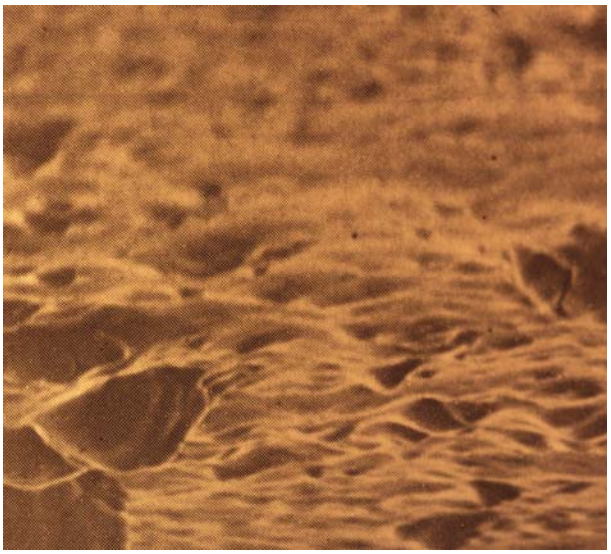

Figure 3. Varnish, before cleaning with swab.

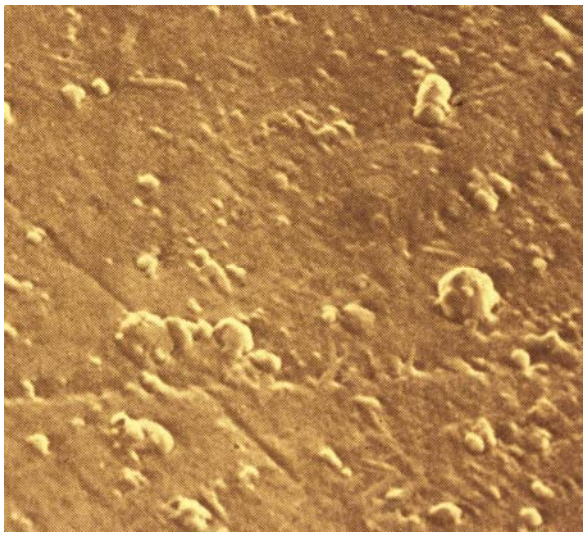

Figure 4. Varnish, after cleaning with swab.

The earlier comparison using SEM images (Phenix and Burnstock 1990) shows a discernible change from the cleaning process. On the other hand, photography of a horn artifact before cleaning (Figure 5, overall and Figure 6, detail at 40x) compared with subsequent treatment photography after cleaning using ultrasound with a detergent (Figure 7) does not produce such a dramatic effect when compared by the eye. Of course, some change must have taken place but

Figure 5. Horn artifact before cleaning.

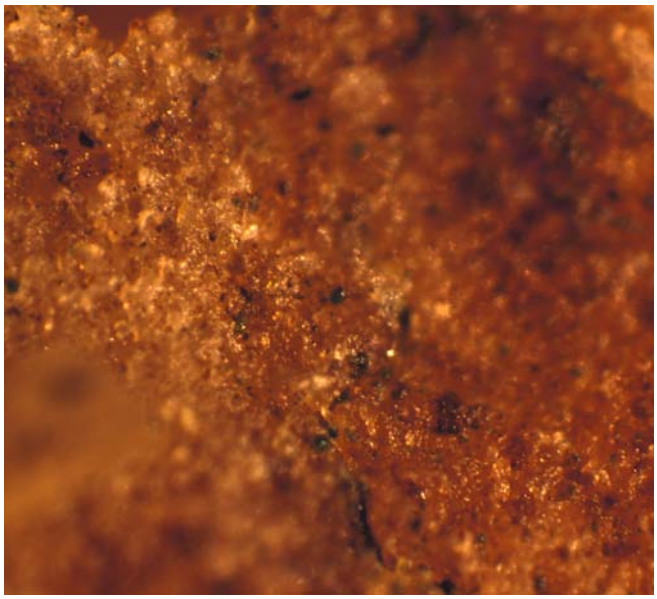

Figure 6. Horn artifact before cleaning, detail.

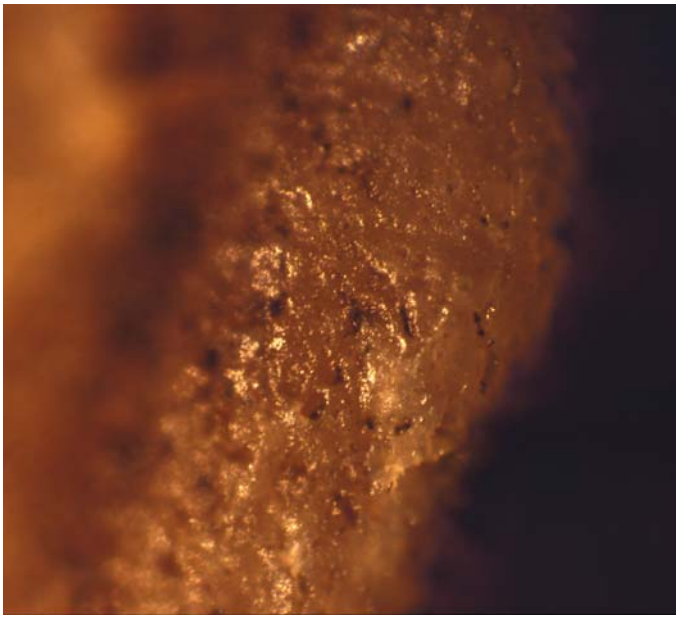

Figure 7. Horn artifact, after cleaning, detail.

within the viewing context none is apparent. In another example, when before treatment photographs of a political pin shown full size in Figure 8 and in detail at 40x in Figure 9 are compared with subsequent treatment photograph (Figure 10) after cleaning with ultrasound and a detergent, a visible change is perceived. Something has happened.

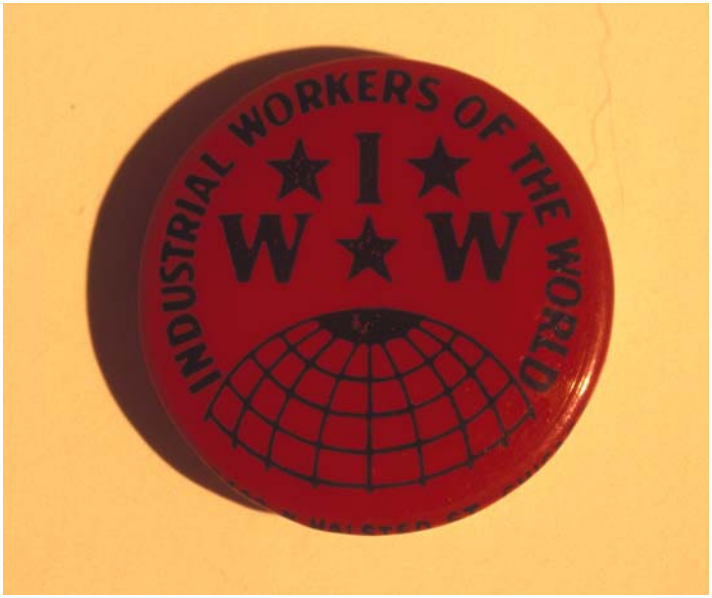

Figure 8. Political pin, before treatment.

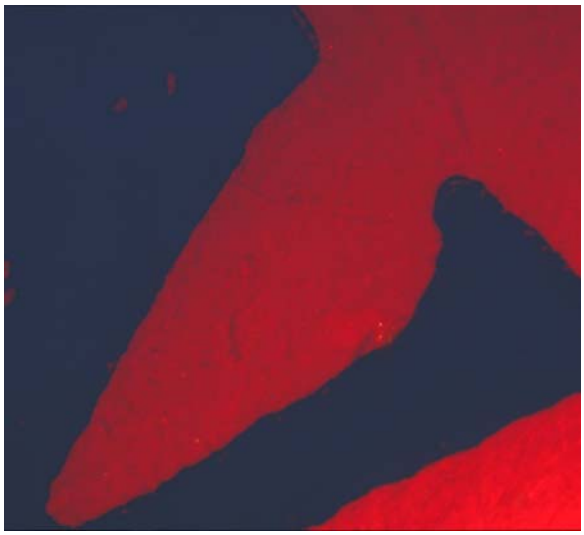

Figure 9. Political pin, detail before treatment.

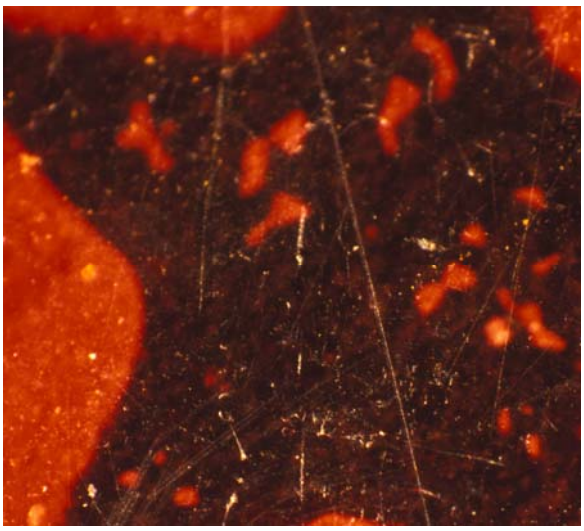

Figure 10. Political pin, detail after treatment.

2. Treatment, Retreatment or No Treatment

How do conservators determine whether a treatment is acceptable? (See Calderaro 1993). Are controlled long term studies required, similar to those required by the FDA for drugs, or is it acceptable to simply use the treatment for a while and see what happens?

Treatment, retreatment and no treatment in combination with preventive conservation have become common themes in conservation discussions in the past 20 years. For example, in search of data to understand the durability of treatments, Julie Dawson (1988), restudied bronzes treated at the Fitzwilliam Museum. She notes that one of the most difficult problems conservators face in attempting assessments of past treatments is the lack of documentation as well as the expense of re-examination. A study of the long-term durability of the treatment of painting on glass and ceramics (Calderaro 1997) found that these problems were magnified by the difficulty of gaining the cooperation of the owners of objects, especially museums. This study used a list of conservators who had responded to a previous request for information from conservators who treated reverse glass paintings (Aiken 1990). Aiken felt that the response was disappointing and her comments on the results of efforts to elicit information were prophetic. With few exceptions conservators did not share information about the durability of their treatments. This was not entirely unexpected, given the time required to contact an owner, compare their documentation with the present condition and then write an assessment. Thomas G. Stone also reported that a 1994 survey of objects in Canadian collections was hampered by both the lack of documentation and by the variable nature of the documentary information (Stone 1996).
It was obvious that cleaning, and the goals of cleaning, were of concern to many people. Sheldon Keck's illuminating and thoughtful article (Keck, S. 1984) described many of the issues that have

been restated with less clarity over the past 20 years, and Eric Hulmer's book (Hulmer 1955) is a stimulating and careful analysis with excellent illustrations of how the conservator and the curator/collector relate to the problem of cleaning and the changed surface. Contrary to Beck's view expressed at the 2004 AIC conference (Beck 2004), there has been a considerable history of criticism in conservation, one need look no farther than Caroline Keck's criticism (1973) of Kelly's book, *Art Restoration* (Kelly 1972). It is true that the debates and concerns of conservators have not become well known to the public, and perhaps this is a good thing. Acrimonious debate is detrimental to a constructive and positive public image, and detracts from the confidence conservators wish to earn in the public eye. On the other hand, science advances by study and re-study, debate and disagreement. Science is self-corrective and the process of this progress is public criticism. The history and nature of criticism in conservation would make an excellent topic for a dissertation.

In the 1980s the author was working with archaeologists whose main reason for cleaning was to make objects available for analysis. Using Thomas Loy's research (1983) on the identification of blood proteins on lithics, it was possible to convince the archaeologists that cleaning could destroy significant information. Current procedures for artifact cleaning were potentially destroying information about diet as well as the possible use of the lithics as weapons.

Test cleaning strategies suggested by CAS suggested the possibility of cleaning only portions of objects, but this approach was unacceptable to the archaeologists. At the 1982 IIC conference in Washington, during a discussion of cleaning archaeological artifacts, Caldararo engaged in a discussion with Garry Thomson on this dilemma. The conclusion was that mass collections of shards, lithics and other material could be sampled by randomly selecting objects to be treated for analysis, and that rare objects should be able to be partially cleaned. As rational and logical as this seems now, it was not an easily workable solution at the time. The concern was that since the archaeological record is already a sample produced by the processes of degradation and accident, cleaning only a random sample of artifacts might not produce an accurate picture of the material that was recovered. Still, this was only an assumption, and given that resources for collection maintenance and conservation have always been tiny, in retrospect these feelings seem today rather absurd.

In 1981 and 1982 the author sent out a survey to conservators and archaeologists to determine current practice, attitudes towards cleaning, who was doing the work and how they had been trained. The questionnaire asked what methods were used to treat artifacts, what books, articles and other information sources were used as reference material and what training they had taken to produce the skills necessary to carry out conservation treatments in their laboratories. Over 200 requests were sent out; there were fewer than 50 responses. Some were written and some were only phone conversations based on a randomly selected group who had not responded by mail. The results of this study were published as part of a more comprehensive study of the preservation approach and methods used in anthropology and archaeology (Calderaro 1987). One of the most interesting results of the survey was the great variety of methods and techniques that were picked up by archaeologists through conferences and publications generally, without reference to the conservation literature. In fact, many of the most important artifacts, especially fossils, were being treated in field or university labs by archaeologists who had learned their

skills from other archaeologists.

The dominant attitude was that the information that was being sought by the scientist was available only to his or her eye based on their knowledge of the unique nature of the specimen or the techniques of manufacture of the object. The idea that a technician trained in conservation could do better or preserve the object with greater skill was often dismissed as naïve. An example often referred to was the notorious case of a cast described by Marsh (1876) of the endocranial cavity of Coryphodon, a large ungulate that lived about 55 million years ago. In the specimen in question, the entire auditory bullae were removed when the skull was readied for the cast by a preparator. Marsh then mistook the excavated region of the auditory bullae for a cerebellum. The error was not realized until noticed by Ediger and Tilney more than 50 years later (Jerison, 1973).

Cleaning can reveal information otherwise not visible as well as remove original materials and information. It stands to reason that that experience and knowledge will lead to the recovery of more information. The renowned archaeologist Sir Leonard Woolley was also famous for his restoration skills. Yelena Rakic (1998) describes his efforts to salvage the sculpture, "Ram Caught in a Thicket" from the Royal Cemetery of Ur. No conservation records exist, but Woolley's notes, and later retreatment efforts, have uncovered the process he used. Virginia Greene's recent article (2003) describing the use of excavation reports and conservation examination methods to discover the original form of an object goes far towards defining that element of professionalism which identifies the essential role conservation can play as a necessary part of archaeological science. Such examples also address the difficulties in defining the original state as Caple (1999) has so aptly described it**.**

Some times the anthropologist's expertise is not employed, as in the case of the Thunder Pipe of the Blackfoot; long one of the most renowned objects on display at the American Museum of Natural History. Stanley Freed (1981) described how he discovered the pipe was a pastiche produced by a museum worker who created a bowl for the pipe. This bowl did not exist when the pipe was collected and was not mentioned by Clark Wissler, the collector. It is assumed that Wissler must have permitted the addition of the bowl as the pipe was on display for so long during his lifetime.

Any conservation treatment can cause a visible change in an artifact, as illustrated by the design of a hanging method for painted skins of Kiowa origin (Figure 11). The Native Americans involved in the show ("Plains Indian Painting", DeYoung Museum, San Francisco, Downtown Center, 1980) wanted the skins exhibited in the manner of Western art, and the skins were framed. The attachment of Japanese tissue hinges to the reverse with wheat starch paste was considered the least damaging intervention (Figure 12). The process of removing the hinges resulted in the removal of some of a yellow coating from the back of two skins (Figure 13).

Figure 11. Kiowa painted skin.

Figure 12. Attachment of hinges to the reverse of the painted skin.

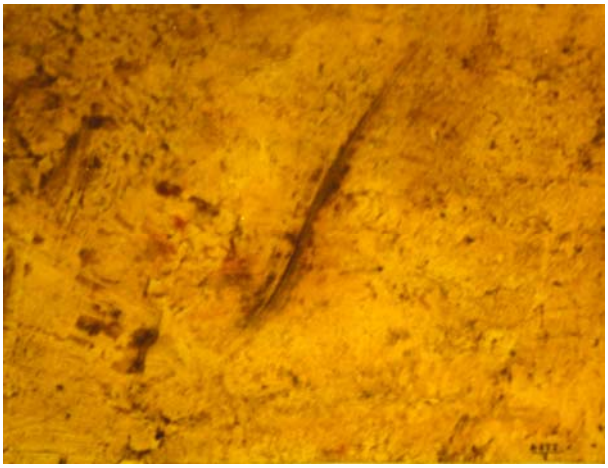

Figure 13. Reverse of skin, after removal of hinge.

The coating was identified as an arsenic compound applied with a brush, and the removal of a minute quantity was not considered significant as no change was visible. No transfer was noted on the removed hinges, but there was a texture change on the object, even though the paste was

entirely removed. The coating was later analyzed to confirm that it did not contain pigment of Native American origin (Calderaro 1991). Nevertheless, the conservation process had changed the object.

This brings up another topic, mistakes. All conservators make mistakes, but they are seldom described in print (Calderaro 1993). This failure contributed to the problem noted by Reedy & Ready (1988) in their survey of conservation science research, that there were no studies prior to 1988 which tried to validate previously published conservation research techniques. Certainly we have seen a considerable change from this situation in the last 16 years, especially the volume edited by Vincent Daniels in 1988 and volume 42, no. 2 of the *Journal of the American Institute for Conservation* in 2003, both of which focused on treatment reviews and evaluations. Still, without a discussion of mistakes, both in the choice of materials (even allowing for what was available at the time) and in judgment or execution, we cannot understand the process of our work - and cannot train students adequately. Barbara Applebaum is currently writing a book on decision making in conservation which should make a valuable contribution.

3. The Nature of Cleaning

In a paper given at the 1987 AIC meeting, Richard D. Smith maintained that reversibility did not exist (Smith 1987). Surfaces are cleaned and materials removed, consolidants are added, and it would be impossible to remove every molecule should one attempt to reverse the treatment.

Barbara Appelbaum took this idea further in her attempt to address the limits of treatment within the framework of an object's context and original appearance, acknowledging that treatment can change or remove information. However, her argument that "cleaning does not necessarily destroy information" and that the goal of conservation should be "retreatability" is problematic (Appelbaum 1987:67). She did acknowledge that cleaning was irreversible and that exact materials could never be replaced; and that conservators should adjust their thinking about changes introduced by cleaning. In her mind, the important goal of treatment was to achieve a state where the "...capability of reversing the visual effect [is] important" (Appelbaum 1987:67). Also she makes the point that an informed conservation plan could determine the nature of the information affected by cleaning and that based on this knowledge a determination could be made to limit loss or to preserve certain aspects of this information. While all types of cleaning destroy some information, perhaps conservators must accept the idea that there are both acceptable levels of loss and of degrees of reversibility. This idea was also encompassed in a talk by Arno Schniewind which focused on the problem of communication between conservators and owners/curators (Schniewind 1987). Changes do occur, as both Schniewind and Smith note, and the conservator has an essential role to play in the process of discussing both practical results of treatment (including the possibility of critical losses) and the client's goals.

The author's response to this discussion (Calderaro 1988, 1990) addressed the issue of "no effect" and "no change". By reference to a number of studies it attempted to demonstrate that most treatments, and specifically in this case, no paper conservation treatment could be said to result in either "no change" or have "no effect" on the object. Treatments from erasure to

deacidification all induced change and have effects on both the paper support and the media. Significantly, conservators were edging toward despair because new analytical techniques could detect and measure change and its effects where nothing had previously been perceptible. It was found that deacidification changed some colorants chemically and both water and solvent treatments resulted in paper fiber repositioning (Cook & Mansell 1981). As Schnienwind reflects, this knowledge certainly makes the job of the conservator harder, but it also heightens the challenge. Learning to communicate that any treatment will effect change to curator and client alike should enhance regard for conservation and not be a source of disillusion.

For example, in the 1990s the author began to work with Steve Gabow (Anthropology Dept., San Francisco State University) and Dr. Joe Romeo (Molecular Biology Dept., San Francisco State University) on a project to develop a teaching module for molecular biology designed to address aDNA analysis and phylogenetic studies in human evolution. The research also covered the possible effect of conservation treatments on ancient DNA. A number of studies were conducted (Calderaro and Gabow 2000). The research focused on the nature of DNA degradation and how conservation activities might impinge on this process. This followed research on the effects of conservation treatments on dating methods (Caldararo, 1994; Kahle & Caldararo, 1986). Cleaning methods have been shown to further degrade samples, making them difficult to analyze (Lassen 1996, see Fig. 14)) or skewing data (Caldararo and Gabow 2000, see Fig. 15; Pusch and Bachmann 2004, see Fig. 16).

TABLE 1 Summary of the results of Lassen *et al.* (1996), showing relatively poor amplification of amelogenin sequences from bones treated with preservatives

Burial site	*Number of PCRs*	*Number of successful PCRs*	*Number giving 106-bp product*	*Percent success rate*
Ofnet[a]	8	2	0	25
Wremen	21	8	5	38
Lubeck	4	3	2	75
Aegerten	106	72	2	68

a. Bones treated with preservative.

Figure 14. Chart from Lassen 1996, showing evidence of degradation of bone treated with preservative.

Substitution	*Modern H. sapiens sapiens*		*Neandertal*		*Ancient H. sapiens sapiens*	
	Number	*%*	*Number*	*%*	*Number*	*%*
T→A	4	1	0	0	4	3
C→G	2	0.5	1	1	0	0
G→C	2	0.5	0	0	0	0
G→T	0	0	2	3	4	3
C→T + T→C	261	68	41	57	59	49
Totals	383		72		119	

Data refer to nucleotide positions 16020–16409.

Figure 15. Chart from Caldararo and Gabow 2000, with evidence of skewed data.

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Table 3
Frequency of Mutations Listed in Table 2 Among Cloned PCR Products of a 148-bp Stretch of Mitochondrial HVRI (16147–16294) of Spiked Contemporary Human DNA

mtDNA Position	Observed Mutation	Number of Clones Affected	Percentage of Clones Affected	mtDNA Position	Observed Mutation	Number of Clones Affected	Percentage of Clones Affected
16172[a]	T→C	3	0.6%	16223[a]	C→T	317	57.9%
16182[a,b]	A→C	2	0.4%	16224	C→T	15	2.7%
16183[a,c]	A→C	340	62.1%	16230[a,c]	A→G	225	41.1%
16188	C→T	131	23.9%	16234[a,c]	C→T	225	41.1%
16189[a,c]	T→C	373	68.2%	16236	C→T	3	0.5%
16191	C→gap	5	0.9%	16244[c]	G→A	233	42.6%
16192[a]	C→gap	13	2.4%	16244	G→C	3	0.5%
16192[a]	C→T	6	1.1%	16245	C→T	103	19.8%
16193	C→gap	59	10.8%	16247	A→G	114	21.9%
16193.1	gap→C	142	25.9%	16253	A→G	94	18.1%
16196	G→C	4	0.7%	16255	G→A	85	16.3%
16211	C→T	17	3.1%	16256[c]	C→A	4	0.8%
16213	G→A	302	55.2%	16258[d]	A→G	254	48.8%
16216	A→T	302	55.2%	16260	C→T	3	0.6%
16216	A→G	4	0.7%	16261	C→T	3	0.6%
16217	T→C	302	55.2%	16261	C→gap	8	1.5%
16221	C→T	3	0.5%	16262[c]	C→T	12	2.3%
16222	C→T	30	5.5%	16263.1[c]	gap→A	12	2.3%
16222.1[c]	gap→C	281	51.4%	16269	A→G	4	0.8%

[a] Mutation hotspots according to Gilbert *et al.* (2003b).
[b] Mutation also found in Neandertal sequences AF254446, AF282971, AY149291.
[c] Mutation also found in Neandertal sequences AF011222, AF254446, AF282971, AY149291.
[d] Mutation also found in Neandertal sequences AF011222, AF282971.

Figure 16. Chart from Pusch and Bachman 2004, with evidence of skewed data.

To advance, the field must produce critical reviews of treatment and methodology. Such reviews must be based not only on the changes in condition that may be found to be detrimental to appearance or to have destroyed information (see Gardner 1980). Conservators must also evaluate the effect of treatment materials on the durability of the work, as well as the question of how much variability of outcome is due to variations between conservators. How reliable are treatment methodologies in producing desired outcomes? (See Calderaro 1987). As Giorgio Torraca has pointed out, we need more time and research directed to the needs of conservators:

> Conservation today is a production line....It no longer proceeds at the leisurely pace of the still-recent past, when conservation was such a quiet and pleasant profession. Problems must be solved within deadlines that do not allow sufficient time for experimentation and analysis. (Torraca 1999:9)

The Getty is undertaking such research, especially in the area of the effects of different conservator's styles of working and skill level in carrying out the same tasks (Anon. 1999). Torraca also asks if conservation science is really a science or if we are "gambling" with explanations of complex problems in a science which has not yet established a thorough characterization of its goals (Torraca 1999). These questions have been asked for 300 years with little progress in the development of goals and the understanding of outcomes (Koller 2000) and the discussion needs to be continued in an open forum, not just behind closed doors

4.0 Ultrasound and Conservation

4.1 Introduction

Research into the use of conservation and restoration techniques in anthropology revealed that a large number of people have been using ultrasound - a powerful tool that is still not well understood. With the waning interest in manual methods of cleaning and approaches like air abrasion techniques due to the increasing dissatisfaction over procedure and aggressive results, one could expect the introduction of new cleaning methods (Caldararo, 1987). There are two approaches to the use of ultrasound. Batching-- immersing objects in an ultrasonic bath and misting of a surface using a nebulizer, humidifier or steamer. Robert Organ introduced ultrasound to the field of conservation in 1959 and had always warned people of the potential consequences of the energy directed against fragile surfaces. Few people, however, seemed to understand or take heed of his concerns (Organ, 1992). However, when ultrasound was first used for cleaning the consensus was that little damage could be done, and the results were quite striking.

As research on ultrasound continued, however, it became clear how much energy was involved, even for short exposure. The phenomenon of energy delivery in ultrasound is caused by the application of oscillatory electrical energy on two metal plates, creating an electric field in which a crystal vibrates generating waves in a medium. If concentrated, this energy can result in such effects as the abrasion of small glass fragments off the walls of test tubes filled with distilled water (Abdulla 1988). Bursting bubbles in the ultrasound process collapse and an imploding shock wave results along with high temperature and light emission. Katz and Man (1978) have noted that ultrasound results in significant diagenic change in shell. Research has demonstrated that temperatures of up to 7,000 degK can be created by ultrasonic devices, and that collapsing bubbles produced in ultrasonic tanks can create holes in metal (Crum and Suslick 1995; Flint and Suslick 1991). Ultrasound can produce a specific chemical reaction known as aqueous sonochemistry (Suslick and Doktycz 1990), and can also induce unique chemical changes in non-aqueous solutions (Abdulla 1988). Ultrasound drives interparticle collisions, especially of metal particles at high enough velocities to induce melting on collision (Doktycz and Suslick 1990).

Ultrasound is deflected by low concentrations of fluid (Lin, Chou and Chang 2004) and this deflection may be the agency by which ultrasound effects the uniform distribution of moisture in a humidifier and of consolidant in a nebulizer. It has been found that ultrasonic nebulizers produce a drop size that differs significantly from other kinds of spray formation, like air sprayers (Shoh 1979) and airless sprayers (Fair 1984). Two influences seem to be involved with droplet formation, one is described by cavitation phenomena and the other, simplified wave theory**.** But explanations of the process are still subject to controversy. Nevertheless, it is apparent from experimental results that ejection velocity from the transducer depends on cavitation as droplet velocity increases with voltage and droplet size varies as well along an air/liquid interface of a wave front (Barreras, Amaveda & Lozano 2002) .

Bubbles identified as resulting from cavitation are seen in photographs of the process (Barreras, Amaveda & Lozano 2002: 407-409, Figs. 3-9). The atmosphere contains water molecules and a steamer produces a directed flow of moisture toward a target object. The application of ultrasound then has no boundary to prevent its passage. This is true of the degradation of propellers during cavitation produced by pressure and thrust (Anon. 2003), other bubble production and degradation effects as in film damage (Debregeas, de Gennes & Brochard-Wyart 1998) or of the use of ultrasonic scalers which act under the same principle (Drisko, et al. 2000). It has been demonstrated that microcracks appear under ultrasonic radiation as well as other damage to the tooth, dental work and gum tissue (Drisko et al. 2000).

4.2 Conservation Applications of Ultrasound

There has been a lot of conservation research into ultrasound both to investigate its potential for use in humidification, consolidation and cleaning, and to improve upon the working properties of the technique.

Still, evidence for the effects of misting via ultrasound is contradictory. On the one hand, Stephan Michalski (1998) argues that there will be no effect since there is no continuous film to carry the ultrasonic energy. Michalski quotes from a review by K.S. Suslick in the Encyclopedia of Chemical Technology (Suslik 1998) to support his interpretation. His references, however, do not cover the entire subject of energy-induced changes of ultrasound as reviewed here, but only some aspects of sonochemistry. This is a misinterpretation of how ultrasound works, but also a problem of emphasis. For example, Michalski states that ultrasound cannot be transmitted in air, and that air forms a barrier, an air/liquid one. However, neither of these assertions is true: ultrasound does travel in air (Petculescu & Sabatier 2004) and there is always some moisture in "air".

In response to Michalski's argument, it is worth asking what effect ultrasonic nebulizers and steamers have if there is no ultrasonic radiation. Is there any reason to use the more expensive device rather than one without ultrasound? Does the ultrasonic device add a quality that might be described as the "spooky action at a distance" discussed by Bell's Theorem (Herbert 1985). Is it magic? Michalski (Michalski, Dignard, Handel and Arnold 1994) discusses a number of applications for consolidants delivered by ultrasound, but the action of ultrasound is never explained. Michalski (1998) recommends that even if ultrasonic energy is involved, the mister transducer be a considerable distance (one meter) from any surface that is being treated. However, in the same article the authors state that a distance of only "a few millimeters from the surface" is required for the effects desired for the handpiece (Michalski, Dignard, Handel & Arnold 1994: 500). There is, therefore, a continuous ejection stream from transducer to handpiece and object, and the separation of this stream occurs at the mouth of the handpiece. The area in which Barreras, et al. (2002) observed bubbles is within 5 mm from ejection sprays. Since their experiments were limited to areas close to transducers it is not known at present if bubbles exist all along the stream. The design of the LDPE bottle with the consolidant (Michalski, Dignard, van Handel & Arnold, 1998:500) shows the bottle above the ultrasonic oscillator, so that the ultrasound must move through the plastic bottle to cause effects [2]. If a

liquid contact is necessary, as Michalski maintains, how does the ultrasonic energy reach the consolidant and produce the mist effects? The use of ultrasonic nebulizers has found acceptance in medical contexts due to some delivery problems noted with pneumatic nebulizers (Hess 2000). However, their expense and more frequent breakdown (Hess 2000) and the possibility of drug inactivation (Gale 1985) make them less attractive. As heat is generated over conversion of ultrasonic energy to mechanical energy the transducer produces heat. Water couplant chambers are provided for most nebulizers (Hess 2000) to disperse this heat and one imagines that Michalski's water bath in which the bottle of consolidant sits (Michalski et al. 1998) has a similar function.

Some discrepancy exists between the comparison of effects in the use of ultrasonic humidifiers and nebulizers as reported by Arnold (1996). This may be due to the differences in apparatus and not in the droplet delivery potential of the two systems. Weidner (1993) has recommended a modified delivery method that provides the positive effects of ultrasound but avoids the possible exposure to elevated levels of ultrasonic energy. Nevertheless, the use of ultrasound in humidification and consolidation of powdery pigment produces very effective and desirable result. There is no doubt that the research and development of methods and materials by Michalski and his colleagues has greatly benefited the field, advancing the use of ultrasound greatly since the technique was first introduced by Organ; see for instance their research testing consolidants (Michalski & Dignard, 1997; Dignard, et al., 1997). However, the effects of use still need characterization. It is clear that the newer means of application allows for a substantial increase in control in the delivery of moisture and consolidant (Michalski, Dignard, Handel and Arnold 2002). Michalski and his colleagues have provided the bench worker with a substantial amount of direction in the use of ultrasound. Their apparatus is well designed and their cautions regarding overspray and health effects timely. The handpiece not only produces a variable spray that can be tailored to use, but attached to a vacuum it sucks back the mist that is not discharged directly to the object surface.

The experiments of Marilyn Kemp Weidener leading to the development of the suction and ultrasonic misting table (Weidner 1993) have been of great importance to the field of paper conservation. This achievement has advanced the treatment of fragile works on paper and paper-like supports. An additional benefit of her work is the complete reporting of her working method, which at times included problems in treatment design or the decision not to treat. Weidener also reports on a number of treatments using ultrasound that have been reexamined after several years and found to exhibit no reversal of staining, changes in coloration or physical conditions.

The ways in which sonochemistry and the physical aspects of the radiation affect paper, fabrics and cellulose in general are yet to be discovered and characterized. Timothy Barrett conducted a number of experiments in 1989 to describe and measured the ways in which papers were affected by exposure to ultrasound. A number of measurable changes in behavior were found. For example, when sized after irradiation, in chainline direction grain, higher in-plane and out-of-plane values, and again, associated with gelatin concentration. Zero span values were changed, though not greatly in all cases.

Bonnie Rose Curtin (1988), in experiments with ultrasound as a deacidification method, found

variations regarding gelatin-sized papers in the pH achieved in washed and unwashed papers exposed to ultrasonic alkaline humidification. Also, the distribution of pH and alkaline reserve tended to vary slightly across a sheet of paper buffered with their ultrasonic method.

Barton & Wiek's experiments (1986) with feathers fibers showed that exposure to ultrasound in water had little effect on fiber condition or cleaning, but the use of solvents or additives produced drastic breakage in feathers, but less damage than that observed using a soft artist's brush and detergent. Cooke's experiments (1989) with textiles using a variety of additives and solvents, especially Industrialized Methylated Spirits (IMS) and Carbon Tetrachloride, demonstrated superior cleaning with little damage to the fabric (3.5% change in weight Use of water and detergents produced the release of soiling, but also size of the fibers and 22% of the original fiber mass became detached.

It is worth noting that this research has focused on studying the application of technique, rather than long-term effects of the treatment. For instance, in testing the changes different consolidants impart to powdery pigment, Michalski and his colleagues have essentially reproduced Debra Daly's 1978 experiments (Michalski & Dignard, 1997; Dignard, et al., 1997). Their findings that gelatin produces a durable adhesive bond, and is the best consolidant producing the least change, support her results. However, Michalski and his colleagues did not investigate Daly's (1978) conclusion that gelatin does not age well, and darkens considerably, which are problems in considering gelatin as a consolidant for many objects.

Understanding the inherent properties of original materials in an object brings up another aspect of long-term effects. Michalski et al. (1998) mention that individual pigments have different bonding requirements. They note that particles of green earth, red ochre and raw umber formed cohesive layers even though no binder was present and suggest that no consolidation may be necessary. They cite Grisson's analysis of one kind of green earth pigment . Mayer (1970) notes a number of variations of green earth pigment including a burnt green earth, a native clay colored by small amounts of iron and manganese, though there are a legion of varieties of burnt green earth. Michalski et al. report that other pigments such as calcium carbonate, chrome yellow, ivory black and ultramarine (the specific ultramarine is not given) "were found to be much more powdery". While "powdery" is a difficult term to quantify in scientific terms, a variety of physical and chemical characteristics can be used to group these pigments and their tendencies to adhere with and without binders. Ian Cook and Heather Mansell (1981) have characterized many of these pigments, and described their behavior in a number of solvents as well as consolidants. However, as Grubenmann (1993) has noted, there are a number of reasons why uniform responses to exposure to solvents cannot be expected. Nevertheless, while the immediate benefits and improvements to consolidation of fragile objects are obvious and well documented (Michalski and Dignard 1997, Michalski et al. 1998), the long-term effects are uncertain. It is not clear if color changes occur or if there is a long term benefit in adhesion.

Maheux and McWilliams (1995) note that in the use of the mister to consolidate flaking gouache paint, the size of some flakes reduced the effectiveness of the delivered consolidant and traditional methods were required to adequately adhere these flakes. It would be helpful to know the limitations of the misting process, and how large a flake can be successfully treated. Arnold

(1996, 2004) believes that the size of flake determines the success of consolidation with the mister approach. The use of a nebulizer to deliver more consolidant and reduce the wet/dry cycle, as well as the speed of application, simplicity and cost is appealing. This is especially true given the problem of over-spray error (due to both sprayer manufacture and operator error) that seems difficult to avoid

One aspect of the research of Michalski and Dignard is the use of the ultrasonic mister as a means of removing adhesives from fragile surfaces. Dignard et al.(1997) describe this method in detail on a work of art on paper with a suction table. But Michalski and Dignard (1997) note potential uses on other objects where tidelines and stains have developed. Dignard et al. (1997) have also suggested its use for reforming small areas of bloomed varnish and to allow for consolidation and correction of deformed surfaces. The ability to apply consolidant, humidity or solvents in localized and minute areas and structures gives the ultrasonic methodologies of Michalski and Dignard great utility over earlier methods such as tenting objects in enclosed areas.

5. Experiments with Ultrasound

Ultrasound cleans by the delivery of mechanical waves produced by the piezoelectric effect through a gas or a liquid to the surface of an object. Therefore, it was determined that both immersion and humidification were both valid techniques to investigate. It had become popular to humidify paper using an ultrasonic humidifier and to use such a device to deliver small amounts of pigment or consolidant. As Grattan has pointed out (Grattan 1989) thermally applied energy in one form (vibrational, translational or rotational) is redistributed to the others. This leads to a number of questions: What effects would ultrasound have on objects? Could these effects be quantified? Is it possible to observe such effects before damage was done? How much of the damage, if any, could be seen by an observer?

If objects are exposed to ultrasound through a medium like air or moisture, would the effects be visible? This would be more indicative of the power of the energy delivered instead of objects sitting directly in a solution exposed to ultrasound, as more power means more chemical action. Concentrated delivery of water in the form of steam involves the action of at least three kinds of energy: ultrasound, heat from the steam and the mechanical entrance of the water molecules into the substrate, this is a force and there is also the factor of a pressure created by the bubbles created by the ultrasound (McNamara, Didenko and Suslick 2003Published research suggesting that ultrasound can be destructive to all types of surfaces. This realization led the author to organize and carry out a number of experiments with ultrasound.

Experiments were conducted to determine some specific effects that might occur when ultrasound was used for humidification and mist delivery of consolidant. Both immersion and steaming were included (Caldararo, 1992). The results can be seen in Figures 17- 21. Samples of paper were prepared by typing text onto Strathmore 20% cotton fiber typewriter paper using a Brother Ax-22 electronic typewriter. Sample “A” (Figure 17) was the control with no treatment. Sample “B” (Figure 18) was soaked in de-ionized water for 10 minutes. Sample “C” (Figure 19)

was exposed to steam from an Osrow Model SB hand fabric steamer for 3 to 5 minutes, enough time to saturate the paper with moisture. The steamer mouth was kept at least 3 to 5 inches from the sample to minimize heating. Sample "D" (Figure 20) was exposed to moisture delivered by an ultrasonic humidifier (Biotech BT-200) for 5 minutes. Sample "E" (Figure 21) was exposed to an ultrasonic bath in de-ionized water for 5 minutes using a Sonicor Model SC-105T, 50/60Hz cycles, at 1.5 amps.

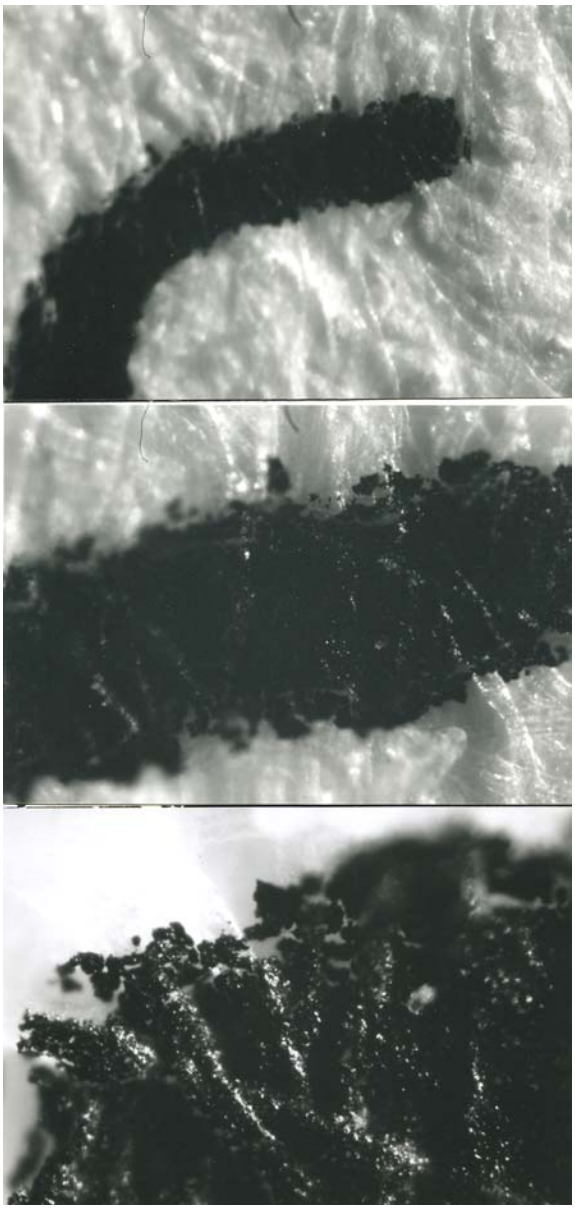

Figure 17. Paper sample 'A': control, no treatment. Top to bottom: 40x, 100x, 200x.

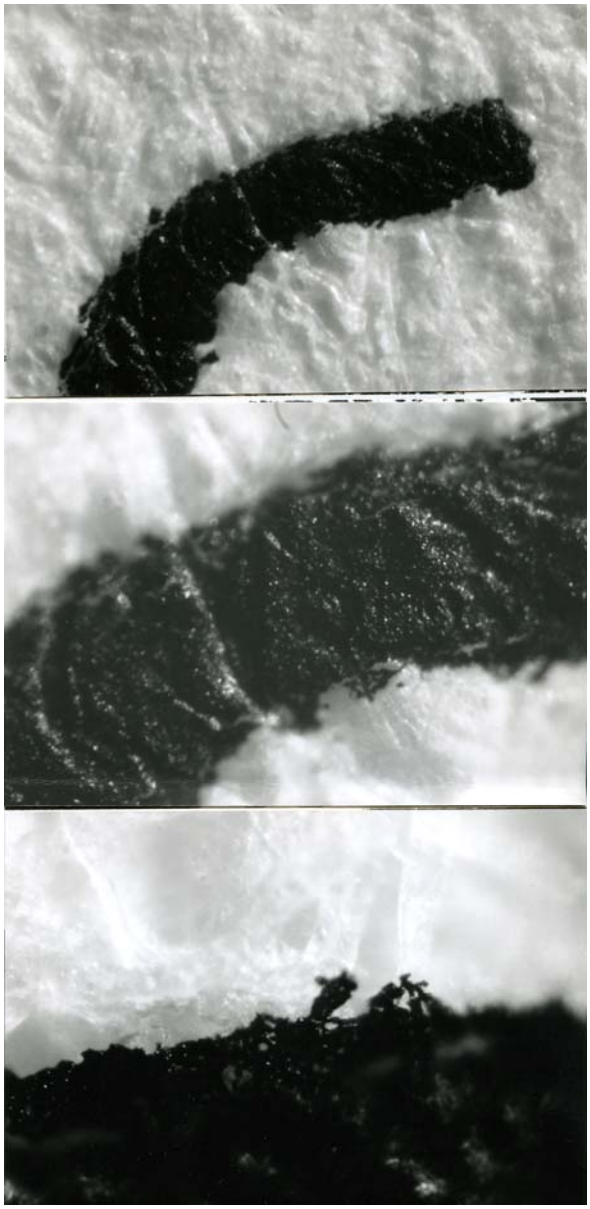

Figure 18. Paper sample 'B': soaked in deionized water, 10 min. Top to bottom: 40x, 100x, 200x.

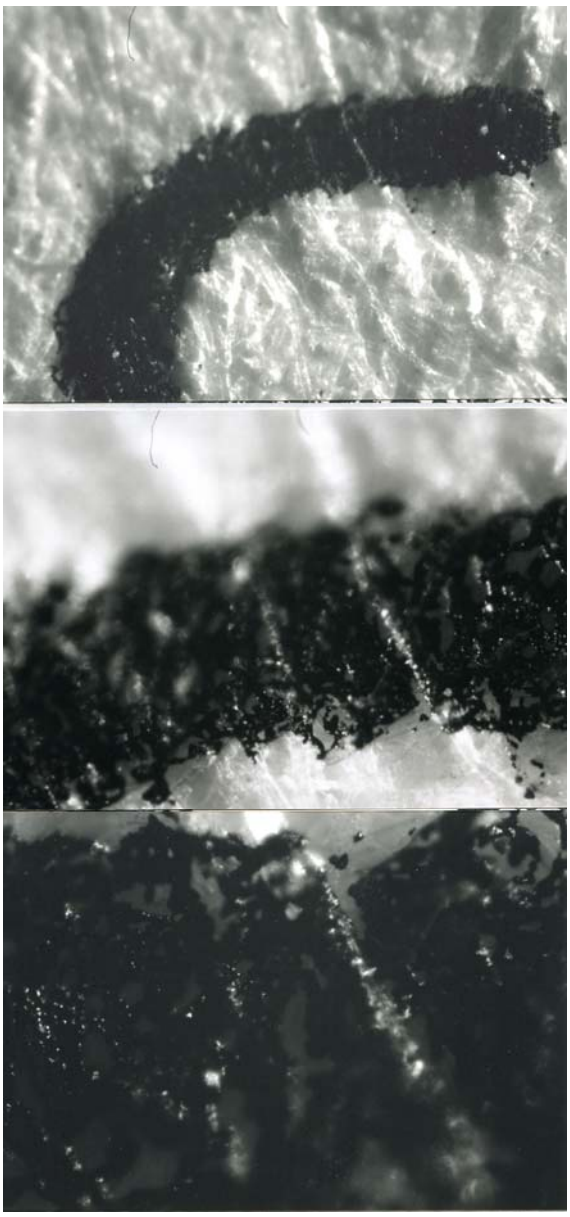

Figure 19. Paper sample ‘C’: exposed to steam. Top to bottom: 40x, 100x, 200x.

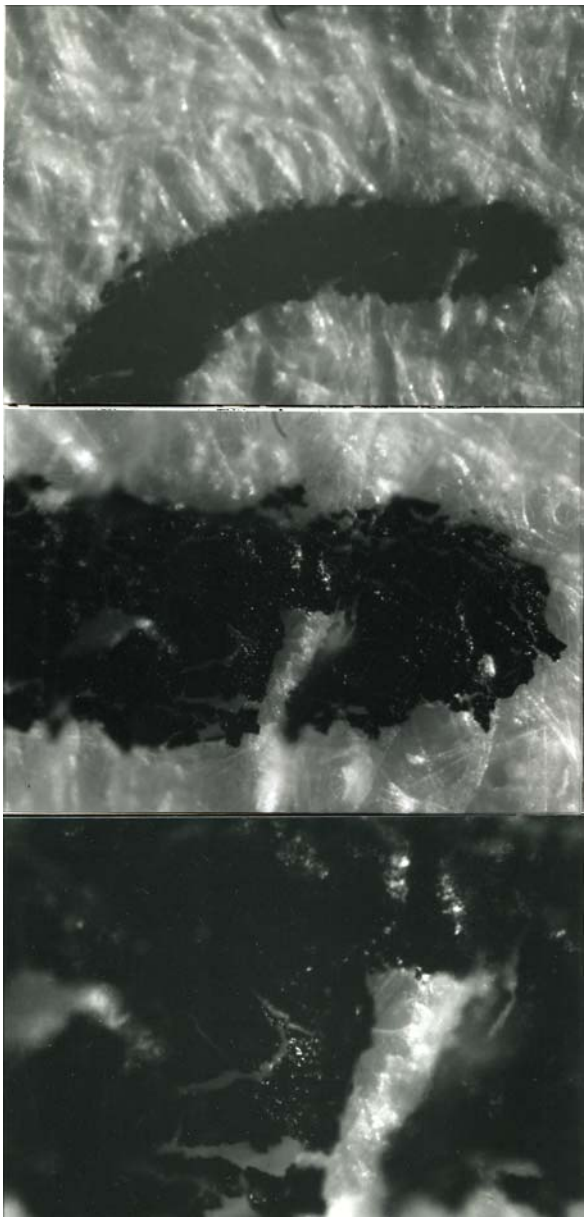

Figure 20. Paper sample ‘D’: Humidified by ultrasound. Top to bottom, 40x, 100x, 200x.

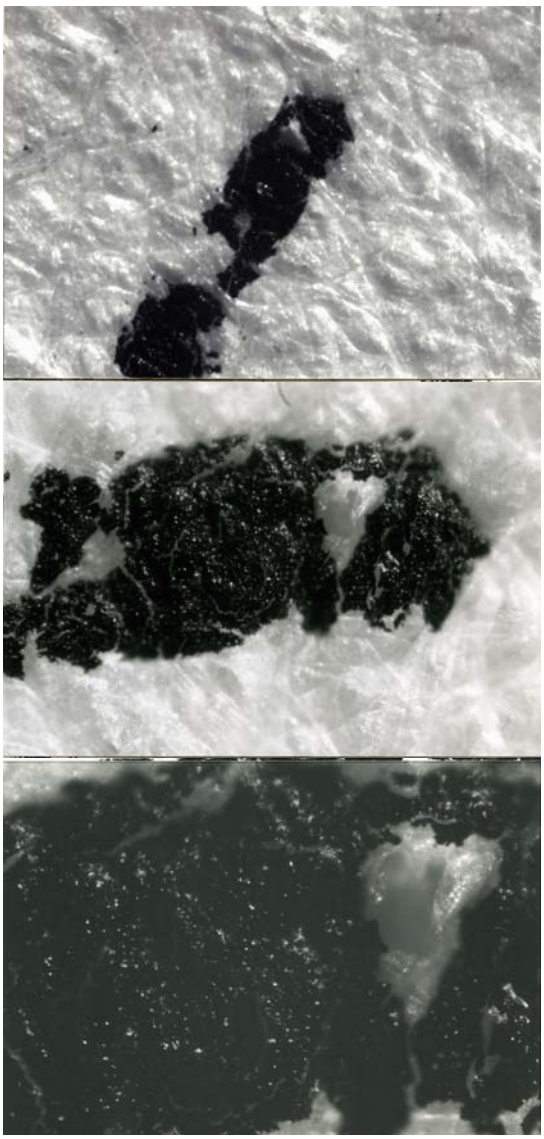

Figure 21. Paper sample ‘E’: placed in ultrasonic bath. Top to bottom: 40x, 100x, 200x.

Comparison of the results with the control showed that the letter matrix fragmented and fissured in the ultrasonic bath and less so under the direction of moisture delivered by the ultrasonic humidifier. Fiber movement is evident in all the samples compared with the control. The sample exposed to the steam humidifier demonstrated the kind of degradation seen when the type matrix is exposed to heat or solvent. Soaking samples in hot water did not have the same effect.

The fact that these procedures induce changes is not a surprise. To use the method with understanding it is necessary to know the magnitude of the changes, and whether they are appropriate and acceptable.

Many individuals use sonicators to clean fragile shells (Katz and Mann 1978). It is known that diagenic changes are induced by such exposure. The question is then whether they can be

cleaned by any other means with less damage or change. If there is no other more satisfactory treatment, then should these objects be treated at all?

Can these results be applied to other objects and other contexts? Certainly when an object is immersed in a fluid it is subject to a greater degree of energy produced by the ultrasound, especially with regard to sonochemistry and other induced chemical changes and interactions.

6. Cleaning Goals: Surprises and Conflicts

Conservators in museums and in private practice must deal with the expectations of the owner or guardian of an object. Sometimes the goal of cleaning can change during treatment based on unexpected discoveries. In one case in the author's experience, the owner of a Maya sculpture requested analysis of a coating to determine if it should be removed. The object in question was similar in some regards to the one illustrated by Shimbunsha (1974: page, figure or plate number) but differed in surface texture and finish (Figure 22). As can be seen in Figure 23 the sculpture has a broken base that has been repaired. There is no published information or unpublished notes on this restoration or when it occurred. The figure was covered with what appeared to be original dirt from burial. Tests demonstrated that it was soil embedded in a resin-like adhesive, and a small area was cleaned to show the client. This cleaned area can be seen in the “lap” or bench area and was partly cleaned with saliva and turpentine (Figure 23; see Calderaro 2000 for complete results of examination and testing). The owner opted for a general reduction of the coating but not its complete removal (Figure 24). The coating hid a greenish toned stone which also had what appeared to be a crack that was filled with a paste. Throughout this process the owner continued to consult with dealers, museum curators and archaeologists in an attempt to find what should be the “restored” image.

Questions concerning the object revolved about several aspects of both the one treated by the author and the one illustrated in Shimbunsha (1974). What was the significance of the crack in both objects? Was the crack in the object treated by the author purposely introduced to mimic the image published in the catalogue, and if so, why was the crack subsequently concealed? While the discoveries from the examination proved disturbing to the owner, they can provide scholars with new information about objects and art history. The influence of catalogues and other publications on fakers has been discussed by the author in an article which compared the recently-treated object with that illustrated by Shimbunsha, as well as 52 other published images, some with archaeological provenance and many without (Caldararo, 2000).

Figure 22. Figurine illustrated by Shimbunsha, for comparison.

Figure 23. Figurine conserved by author.

Figure 24. Figurine treated by author, after cleaning.

7. Conclusion

One of the most obvious conclusions is that the development of new instrumentation over the past 30 years has allowed conservators to perceive the nature of interventions with greater clarity. The difference in what can be seen in terms of the effects of treatment is on a scale of magnitude comparable to the visual perception of the naked eye and SEM. But this really does not do justice to the changed situation. During the 1980 AIC meetings in San Francisco Caroline Keck came into the Conservation Laboratory at the California Palace of the Legion of Honor. She sat down and one of the first things she said was, "What's that thing here for?", as she gestured towards a new Nikon microscope on the lab table. "Trying to impress clients with science? That's the only reason most people have them!" The same comment appears in an important article on the future of conservation, published in 1980 (Keck, C. 1980). In many ways she was right, and yet the routine use of the microscope in conservation practice has increased dramatically in the past 30 years. Certainly there were microscopes available to many conservators 30 years ago and SEM was also being applied to conservation treatments, especially to evaluate treatments in paper conservation (Cook and Mansell 1987). But conservators have become much more sensitive to the micro level and more knowledgeable in how and why changes take place.

When Talley described the pressuring role of the Art Historian in conservation at the AIC Conference in Portland this year (Talley 2004), it struck a cord for many bench conservators. He pointed out that it is not so much that conservators have driven treatments, but that curators and owners have, and that our role has become nearly impossible by owing to two contradictory improvements: one in our perceptions of the effects of treatments and the other in new techniques to control and to limit those effects. We are more able to make changes and to make them imperceptible and yet know more precisely how significant they are than ever before. Like Sisyphus the nature of our work is impossible, we aspire to perfection and yet we are trained to see every imperfection.

Acknowledgements

I would like to thank all the students who have worked in my laboratory while the projects mentioned in this paper were undertaken. I would also like to thank all the conservators and scientists who I have tormented with questions over the years. The kindness and goodfellowship which characterizes our field is a constant source of inspiration.

Endnotes

1. Keel's (1963) pamphlet is valuable for a number of reasons, one of which is that it tells us what was recommended for use on objects for those museum and park service employees, local museum staff and university preparators in the 1960s and 1970s. For example, Keel (1963:17) recommends spraying Krylon on glass which has lost it luster. For other sources used by such workers during this period see Caldararo (1981).

2. Maheux and McWilliams (1995) note that the bottom of bottles in his position often become blistered and bubbled with prolonged use. They also mention that the use of solvents with the mister assembly can deliver solubilized components of the hoses and other parts of the apparatus. This should be quantified and verified by testing.

References

Abdulla, R.F. 1983. Ultrasound in organic synthesis. *Aldrichimica Acta* 21:31-42.

Aiken, C. 1990. Personal Communication.

Anonymous. 1999. Gels cleaning research. *GCI Newsletter* 14:20.

Appelbaum, B. 1987. Criteria for treatment: reversibility. *Journal of the American Institute for Conservation* 26:63-74.

Arnold, D. 1996. Recent developments in the mist consolidation of powdery painted surfaces. Paper presented at the Wooden Artifacts Group Session, Annual Meeting of the American Institute for Conservation. Norfolk, Virginia, June 15, 1996.

Arnold, D. 2004. Personal Communication.

Barreras, F., Amaveda, H. & A.Lozano. 2002. Transient high-frequency ultrasonic water atomization. *Experiments in Fluids* 33:405-413.

Beck, James. 2004. The glory of the original and other myths. Paper presented at the General Session, Annual Meeting of the American Institute for Conservation. Portland, Oregon, June 10, 2004.

Barrett, T.D. 1989. Early European papers/ contemporary conservation papers: a report on research undertaken from fall 1984 to fall 1987. *The Paper Conservator* 13+:49-53.

Barton, G. and S.Wiek. 1986. Ultrasonic cleaning of ethnographic featherwork in aqueous solution. *Studies in Conservation* 31:125-132.

Caldararo, N. 1981. Techniques and skills in anthropological conservation: an outline. *California Anthropologist* 11:1-21.

Caldararo, N. 1987. An outline history of conservation in archaeology and anthropology as presented through its publications. *Journal of the American Institute for Conservation* 26:85-104.

Caldararo, N. 1988. Letter to the Editor. *AIC Newsletter*13:10-11.

Caldararo, N. 1990. Paper treatments. *Paper Conservation News* 55.

Caldararo, H. 1991. Mounting two Plains Indian hide paintings. *Curator* 34:187-198.

Caldararo, N. 1992. Tests on the effects of the use of ultrasound in the humidification of paper. *The Book and Paper Annual* 11:1-20.

Caldararo, N. 1993. Some effects of the use of ultrasonic devices in conservation and the question of standards of cleaning objects. *North American Archaeologist* 14:289-303.

Caldararo, N. 1994. Storage conditions and physical treatments relating to the dating of the Dead Sea Scrolls. *Radiocarbon* 37:21-32.

Caldararo, N. 1997. Conservation treatments of paintings on ceramic and glass: two case studies. *Studies in Conservation* 42:157-164.

Caldararo, N. 2000. Fake or transitional form?, analysis of a purported Pre-Columbian Olmec artifact and comparison with similar published objects from Mesoamerica. *Mexicon* 22:58-63.

Caldararo, N. & S.Gabow. 2000. Mitochondrial DNA analysis and the place of Neanderthals in Homo. *Ancient Biomolecules* 3:135-158.

Clements, Forest. 1936. Notes on archaeological methods: excavation of fragile objects. *American Antiquity* 1:193-207.

Cook, Ian & Heather Mansell. 1981. The effects of conservation treatments on watercolors. *ICCM Bulletin* 3:73-103.

Cooke, W.D. 1989. A pilot study in the use of ultrasonic cleaning in textile conservation. *The Conservator* 13:41-48

Crum, L.A. & K. S. Suslick. 1995. Bubbles hotter than the sun. *New Scientist* April:36-40.

Curtin, Bonnie Rose. 1988. Effect on paper pH and alkaline reserve from magnesium bicarbonate introduced via ultrasonic humidification. *The Book and Paper Annual* 7:1-6.

Daly, Debra. 1978. An Investigation into the Use of Several Substances as Fixatives for Work of Art in Pastel. Master's Thesis, Queens University, Ontario.

Daniels, V. 1988. *Early Advances in Conservation*. British Museum Occasional Papers, no. 65. London:The British Museum.

Dawson, J. 1988. Ulick Evans and the treatment of bronze disease in the Fitzwilliam Museum 1948-1980. In *Early Advances in Conservation,* ed. Vincent Daniels. London: British Museum. 71-80.

Debregeas, G., de Gennes, P.-G. and F. Brochard-Wyart. 1988. The life and death of "bare" viscous bubbles. *Science* 279:1704-7.

Dignard, C., et al. 1997. Ultrasonic misting, Part 2: Treatment applications. *Journal of the American Institute for Conservation* 36:127-142.

Doktycz, S.J. & K.S. Suslick. 1990. Interparticle collisions driven by ultrasound. *Science* 247:1067-9.

Drisko, C.L., Cochran, D.L., Blieden, T., et al. 2000. Position paper: sonic and ultrasonic scalers in periodontics. Research, Science and Therapy Committee of the American Academy of Periodontology. *Journal of Periodontology* 71:1792-1801.

Fair, J. 1984. Liquid-gas systems. In *Perry's Chemical Engineer's Handbook*, 6th ed. New York: McGraw-Hill.

Flint, E.B. & K.S. Suslick. 1991. The temperature of cavitation. *Science* 253:1397-9

Freed, Stanley A. 1981. Research pitfalls as a result of the restoration of museum specimens. *Annals of the New York Academy of Sciences* 376:229-246.

Gardner, Joan S. 1980. *The Conservation of Fragile Specimens from the Spiro Mound, Le Flore County, Oklahoma*. Contributions from the Stovall Museum, University of Oklahoma, No. 5.

Grattan, D. W. 1989. Personal Communication.

Greene, Virginia. 2003 Conservation of a lyre from Ur: A treatment review. *Journal of the American Institute for Conservation* 42:261-278.

Grubenmann, A. 1993. The solvent dependence of the solubility of organic solids, and solubility parameter theory: investigation by means of an organic pigment. *Dyes and Pigments* 21:273-292.

Herbert, Nick. 1985. *Quantum Reality: Beyond the New Physics*.

Hulmer, E.C. 1955. The Role of Conservation in Connoisseurship. Ph.D. Dissertation, University of Pittsburgh, Pennsylvania.

Jerison, H.J. 1973. *Evolution of the Brain and Intelligence*. New York:Academic Press.

Kahle, T.B. & N. Caldararo. 1986. State of preservation of the Dead Sea Scrolls. *Nature* 321:121-2.

Katz, B. and E.H. Mann. 1978. The effects of implications of ultrasonic cleaning on the amino

acid geochemistry and foraminifera. In *Biogeochemistry of Amino Acids*. Conference Papers. 215-222.

Keck, C. 1973. Kelly's art restoration. *Studies in Conservation* 18:188-9.

Keck, C. 1980. Conservation's cloudy future. *Museum News*, May/June:35-39.

Keck, S. 1984. Some cleaning controversies: past and present. *Journal of the American Institute for Conservation* 23:47-62.

Keel, Bennie Carlton. 1963. The Conservation and Preservation of Archaeological and Ethnological Specimens. *Southern Indian Studies* 15.

Koller, Manfred. 2000. Surface cleaning and conservation. *GCI Newsletter* 15:5-9.

Leechman, Douglas. 1931. Technical methods in the preservation of anthropological specimens. *National Museum of Canada Annual Report for 1929*, Toronto. 127-158.

Lin, F.C., Chow, C.W. and S.C. Chang. 2004. Differentiating pyopneumothorax and peripheral lung abscess: chest ultrasonography. *American Journal of Medical Science* 327:330-5.

Loy, Thomas. 1983. Prehistoric blood residues: detection of tool surfaces and identification of species of origin. *Science* 220:1269-1271.

Madsen, H. Brinch. 1983. Personal Communication.

Maheux, Anne F. & W. McWilliams. 1995. The use of the ultrasonic mister for the consolidation of a flaking gouache painting on paper. *The Book and Paper Annual* 14:19-26.

Marsh, O.C. 1876. On some characters of the genus Coryphodon (Owen). *American Journal of Scientific Arts* 11:425-8.

Mayer, Ralph. 1970. *The Artist's Handbook*. 3rd ed. New York:Viking Press.

McNamara III, W.B., Didenko, Y., and K.S. Suslick. 2003 Pressure during acoustic cavitation,. *Journal of Physical Chemistry* 107:7303-7306.

Michalski, S. 1988. Posting to Cons DistList, Conservation OnLine, 11:95. http://palimpsest.stanford.edu/

Michalski, S. and C. Dignard. 1997. Ultrasonic misting, Part 1:Experiments on appearance change and improvement in bonding. *Journal of the American Institute for Conservation* 36:109-126.

Michalski, S., Dignard, C., van Handel, L. and D. Arnold. 1998. The ultrasonic mister. In

Painted Wood: History and Conservation, eds. V. Dorge & F.C. Howlett. Los Angeles:Getty Conservation Institute, Los Angeles. 498-513.

Organ. R. 1992. Personal Communication.

Petculescu, A.G. and J.M. Sabatier. 2004. Air-coupled ultrasonic sensing of grass-covered vibrating surfaces; qualitative comparisons with laser Doppler vibrometry. *Journal of the Acoustical Society of America* 115:1557-1564.

Phenix, Alan & A. Burnstock. 1990. The deposition of dirt: a review of the literature, with scanning electron microscope studies of dirt on selected paintings. In *Dirt and Pictures Separated*, ed. S. Hackney, J. Townsend and N. Eastaugh. London:United Kingdom Institute for Conservation.11-18.

Pusch, C.M. and L. Bachmann. 2004. Spiking of contemporary human template DNA with ancient DNA extracts induces mutations under PCR and generates nonauthentic mitochondrial sequences. *Molecular Biology and Evolution* 21:957-964.

Radic, Yelena. 1998. Rescue and restoration: A history of the Philadelphia "Ram Caught in a Thicket. *Expedition* 40:51-59.

Reedy, T.J. and C.L. Reedy. 1988. *Statistical Analysis in Art Conservation Research*. Research in Conservation Series, No. 1. Los Angeles:The Getty Conservation Institute.

Schniewind, Arno. 1987. What goes up must come down…but is it reversible. *AIC Preprints* . American Institute for Conservation, 15th Annual Meeting, Vancouver. Washington DC:AIC. +107-117.

Shimbunsha, Y. 1974. *Tesoros Mayas de Guatemala*. Guatemala City.

Smith, Richard D. 1987. Reversibility: A questionable philosophy. *AIC Preprints* . American Institute for Conservation,15th Annual Meeting, Vancouver. Washington DC:AIC. 132-137.

Shoh, A. 1979. Ultrasonics (high power). In *Encyclopedia of Chemical Technology*, 3rd ed., ed. K. Othmer. New York:Wiley & Sons.

Stone, Thomas G. 1996. Artifacts revisited: The evaluation of old treatments. *ICOM Preprints* 11:649. Committee for Conservation, Working Group B7.

Suslik, K.S. 1998. Ultrasound. In *Encyclopedia of Chemical Technology*, 4th ed.

Suslick, K.S. and Doktycz, S. 1990. Sounding out new chemistry. *New Scientist*, 3 Feb., 50-53.

Sutherland, Ken. 2004. Personal Communication. Discussion following presentation of paper: Measurements of solvent cleaning effects on paintings. General Session, American Institute for

Conservation 32nd Annual Meeting, Portland, Oregon, June 11, 2004.

Talley, M. Kirby, Jr. 2004. Personal Communication. Discussion at American Institute for Conservation 32nd Annual Meeting, Portland, Oregon, June 9-14, 2004.

Torraca, G. 1999. The Scientist in Conservation. *Getty Conservation Institute Newsletter* 14:8-10.

Weidner, Marilyn Kemp. 1993. Treatment of water-sensitive and friable media using suction and ultrasonic mist. *The Book and Paper Annual* 12:75-84.

Weston, Judith, and Meryl Johnson. 1975. Benin Bronze Preservation. *African Arts* 8:50-84.

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THE SURFACE REVEALED: CLEANING OF TWO PAINTED PLASTER SCULPTURES

Richard C. Wolbers and Margaret A. Little

Abstract

In approaching surface cleaning of an art object, treatment typically starts with analysis of the object to understand the materials used to create it, and the nature of the soiling on the surface. This information aids in designing the cleaning system used in the treatment. In situations where the nature of the soiling and/or the geography of the object's surface are complex, it can also be important to find a way to monitor and measure the efficacy and level of cleaning of the surface.

An approach to designing a cleaning system and measuring the level of cleaning will be discussed in the context of the cleaning of two painted plaster busts in the collection of the Winterthur Library Archives. The busts, one of Pierre Samuel du Pont de Nemours, the other of his first wife Nicole Charlotte Marie Louise Le Dée de Rencourt, are copies of plaster busts attributed to Louis Simon Boizot which date to 1775-6. These objects were chosen for inclusion in a Winterthur Museum exhibition, and required treatment prior to exhibit, specifically cleaning, minor paint consolidation and loss compensation. The painted surfaces of the busts were heavily soiled, and removing these soils efficiently and evenly presented an interesting challenge, given the range of surface materials (including a possible original painted surface), overpaint and exposed plaster surfaces.

Introduction

In May 2004, the exhibition "The Winterthur Library Revealed: Five Centuries of Design and Inspiration" opened at Winterthur Museum. At the entrance to the exhibit, two painted plaster busts from the Winterthur Library Archives were installed. The life-size busts depict Pierre Samuel du Pont de Nemours (du Pont de Nemours), patriarch of the du Pont family in the United States, and his first wife Nicole Charlotte Marie Louise le Dée de Rencourt (Madame du Pont). These plaster busts, made in the 19th century, are copies of busts made in France in 1775-6, possibly by Louis Simon Boizot (Hughes, 2003). The maker of the Winterthur Archives plaster busts is unknown, as are the circumstances and precise date of manufacture. However, it is know that a number of copies of the original plaster busts were made for du Pont family members (Anonymous, 1992).

When the busts were first examined prior to treatment, they were found to be in overall poor condition (Fig. 1). The most serious condition issue was the heavy accumulation of dirt on the surface. Some of the dirt was loosely held to the surface and could be mechanically removed with a soft brush and vacuum. However, a significant amount of the dirt was ingrained in the painted plaster surface and could not be mechanically removed. Overall, the paint was well adhered to the plaster substrate, though there were areas where paint was lost, abraded or poorly

adhered to the substrate.

Figure 1: Busts of Madame du Pont (OB 373b) on left and du Pont de Nemours (OB 373a) on right, before treatment. Winterthur Library Archives.

The plaster itself appeared to be in stable physical condition. X-radiographs (taken with Staveley Instruments CPX 160 X-Ray System at 100kV, 2.5 mA for 2 minutes) revealed that the busts were hollow cast, probably in a two piece mold, and that there was no internal metal armature. The x-radiographs also revealed that there were no cracks which would undermine the physical stability of the busts. There were losses of plaster, both large and small, and this afforded an opportunity to examine the plaster on break surfaces. In both objects the plaster appeared "hard" and did not crumble if touched. Qualitatively, though, the plaster of Madame du Pont's bust seemed somewhat "softer" than that of du Pont de Nemours.

Both busts had been repaired at least once in the past. Repairs were evident to the unaided eye because the color of the inpainting and/or fill material no longer blended with the original surface. When the objects were viewed in both long and short wave ultra violet light (Fig. 2) the fills and inpainting were more clearly visible, as was a discontinuous yellow fluorescence present on the paint surfaces, indicating the presence of a varnish coating. On unpainted plaster surfaces, the yellow fluorescence was completely absent.

Figure 2: OB 373a (on right) and OB 373b (on left) in long wave ultra-violet light, before treatment. Winterthur Library Archives.

After initial examination of the busts, their condition was discussed with Heather Clewell, Winterthur Library Archivist and curator for the objects, and goals for the treatment were established. Because the busts would be prominently displayed in the exhibit, it was felt that the conservation treatment should return them to visual and physical state as close to "original" as possible. That meant that dirt/grime needed to be cleaned from the painted surfaces in a way that maintained visual harmony both within a single bust and between the two busts; where necessary paint would be consolidated to the substrate; losses of plaster would be compensated; and finally areas of restoration would be inpainted to visually integrate with the cleaned painted surfaces.

Cleaning the painted plaster surfaces would clearly be the most challenging aspect of the treatment. First, there was the large and complex three-dimensional surface to consider. The cleaning system – the material used and its method of application – would have to be one which could be used both on flat surfaces and also hard to reach three-dimensional folds and crevices found on the objects.

Second was the need to maintain visual harmony both within a single object and between the two busts. This was challenging because of the uneven distribution of soiling on the surfaces of the

two objects, and further complicated by the fact that the treatment would need to be accomplished quickly to meet an installation deadline. Realistically the treatment would be carried out by more than one conservator and reaching the aesthetic goal established by the curator would be made more difficult by the number of hands involved in the treatment.

Third, the ultraviolet light examination and analysis of paint cross sections indicated the presence of a varnish coating on the painted surface. Cross sectional analysis of paint samples taken from the busts suggested the presence of significant amounts of Pb and Ca in both paint and substrate; these metals could conceivably contribute to the tenacious binding of soiling materials on the paint surface.

With these issues in mind, criteria were established for the cleaning system to be used in the treatment of the plaster busts:

- The system/method needed to be effective in removing dirt without damaging the varnish coating, paint or plaster substrate.

- It was critical that whatever cleaning system/method was chosen would allow the conservator to control the level of cleaning so that visual harmony could be maintained.

- An objective means of monitoring the level of cleaning would be crucial given the emphasis on the aesthetic appearance of the busts after treatment. Without a means of evaluating the level of cleaning, it could be difficult to maintain visual harmony given the unevenness of soiling.

Literature Review

Literature relating to the conservation of plaster objects, both painted and unpainted, was reviewed to gain an understanding of methods used to clean plaster objects in the past (Andre 1977; Beale et al. 1977; Canadian Conservation Institution n.d.; MacKay 1997; Maudueche 1992; Mel'inkova and Lebel 1978; Richie 1933; Stable et al. 2002). In terms of cleaning plaster and painted plaster surfaces, there did not appear to be a single method of treatment recommended. The choice of cleaning system was dictated by whether or not a painted or other decorative layer was applied to the substrate, the nature and condition of the paint and/or the plaster substrate, and the nature of the soiling to be removed. However, most articles indicated that while water could be effective in cleaning a plaster surface, it should be used sparingly as it could damage the plaster.

Analysis and Materials Characterization

To determine the appropriate cleaning method for the busts, instrumental analysis of samples of plaster substrate and painted decoration were performed in the Scientific Research and Analytical Laboratory at Winterthur Museum (Mass and Carlson, 2004). Analysis of paint cross sections from both objects were also carried out in the Paintings Conservation Laboratory at

Winterthur Museum.

Samples taken from the two busts were divided into two portions. One portion was mounted in Bioplast resin (Ward's Scientific). The embedded samples were initially sectioned on a belt-type sander, and prepared using progressively finer bonded abrasive clothes (Micro-Mesh Inc.) to a grit of 12,000, lubricated with mineral spirits. The samples were cover-slipped prior to examination, again using mineral spirits. The other portion was used for analysis of the paint binding media and elemental composition of the substrate by infrared spectroscopy.

Images of the cross sectioned samples were recorded on Kodacolor 200 print film using a Nikon Labophot microscope equipped for epi-illumination in UV and normal light. The magnification for each sample was 125x. For the UV light shots, the illumination conditions were a 360-430 nm excitation, 430 nm suppression filter, from an HBO 100 W mercury source. For the normal light image, a tungsten-halogen lamp (15W, Osram) was used without any additional color correction, but with cross polarization.

Cross sections of paint samples were photographed in normal light and UV light. They were then photographed in UV light after the following stains were applied: 4% Triphenyl Tetrazolium chloride (TTC) in methanol; 0.2% Rhodamine B (RHOB) in ethanol; and 0.2% Alexa Fluor 488 in a 0.05M borate buffer at a pH of 9.0.

The stained samples were then re-polished slightly (8000 grit adhesive) to a uniform cross sectional view using a fresh Micro-Mesh abrasive cloth, then sputter-coated with carbon and examined at various magnifications using a scanning electron microscope or SEM Topcon ABT 60 electron microscope with an Evex x-ray microanalysis system. A 20kV beam voltage was used in conjunction with a 22 mm working distance. Backscatter images were obtained for these samples, as well as Energy Dispersive Spectra (EDS) for additional elemental and distribution information.

Synopsis of Analytical Data

The results of qualitative energy dispersive x-ray microanalysis (carried out using ArtTAX μ-XRF spectrometer, molybdenum tube, 50 kV, 600μamp, 100 sec), Fourier transform infrared (FTIR) microspectroscopy (carried out using Thermo-Nicolet Magna 560 FTIR spectrometer, Nic-Plan microscope, 120 scans, 4 cm^{-1} resolution, range 4000-650 cm^{-1}) and scanning electron microscopy and energy dispersive x-ray microanalysis (SEM-EDS) indicate that both objects were made primarily of gypsum ($CaSO_4 . 2H_2O$) with small amounts of plaster of Paris ($CaSO_4 . ½ H_2O$), indicating an incomplete conversion of plaster to gypsum upon mixing with water (Mass and Carlson, 2004).

SEM-EDS was used to examine the paint on the surfaces of both objects. Lead was identified as the primary pigment in the paint. This analysis also identified silicon in the soil on the surface of the sample (Fig. 3).

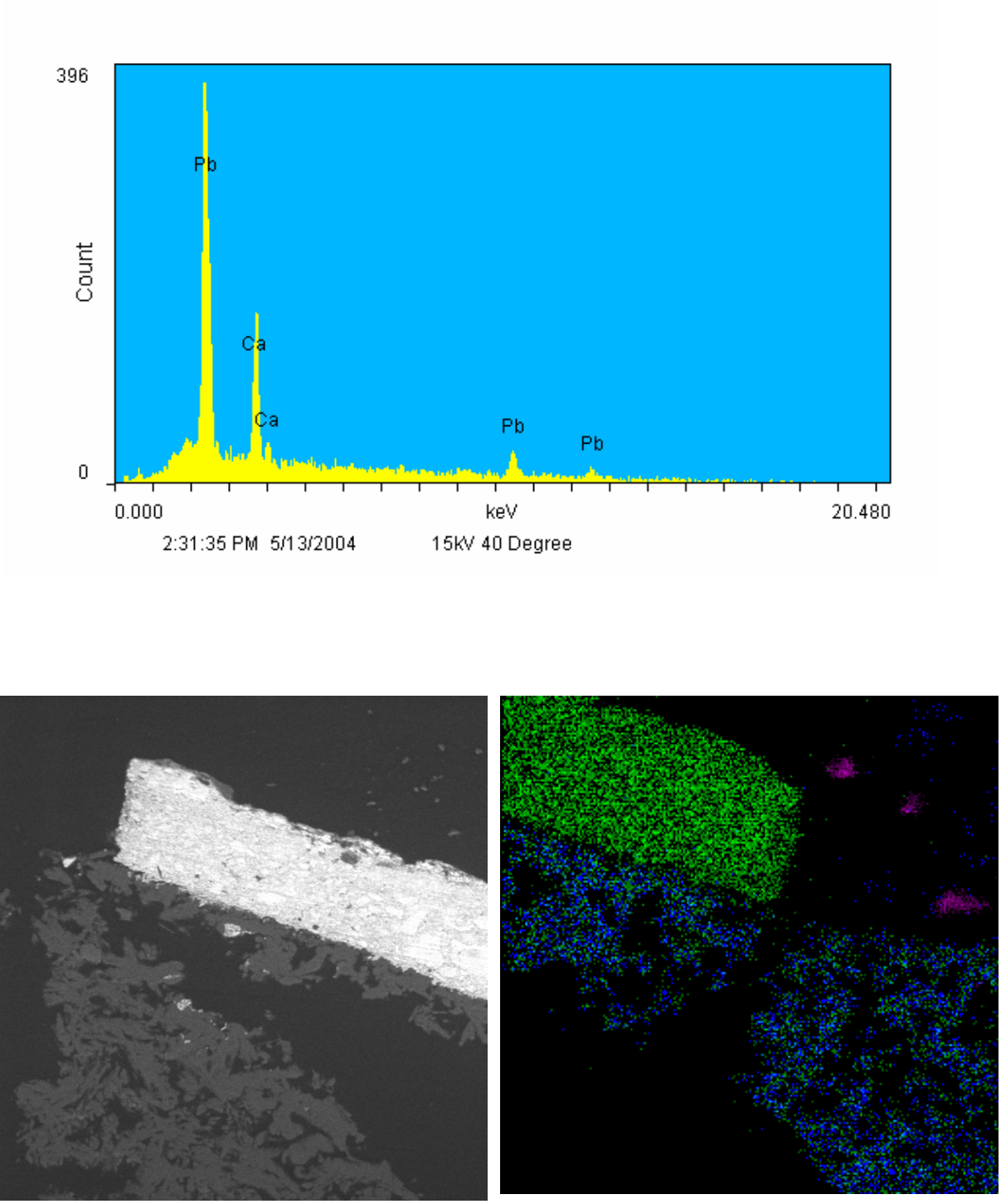
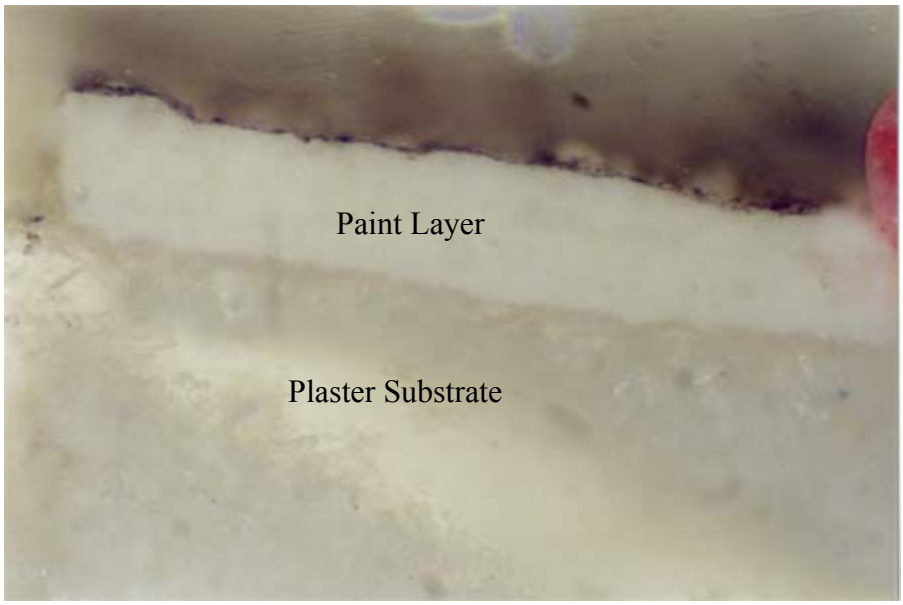
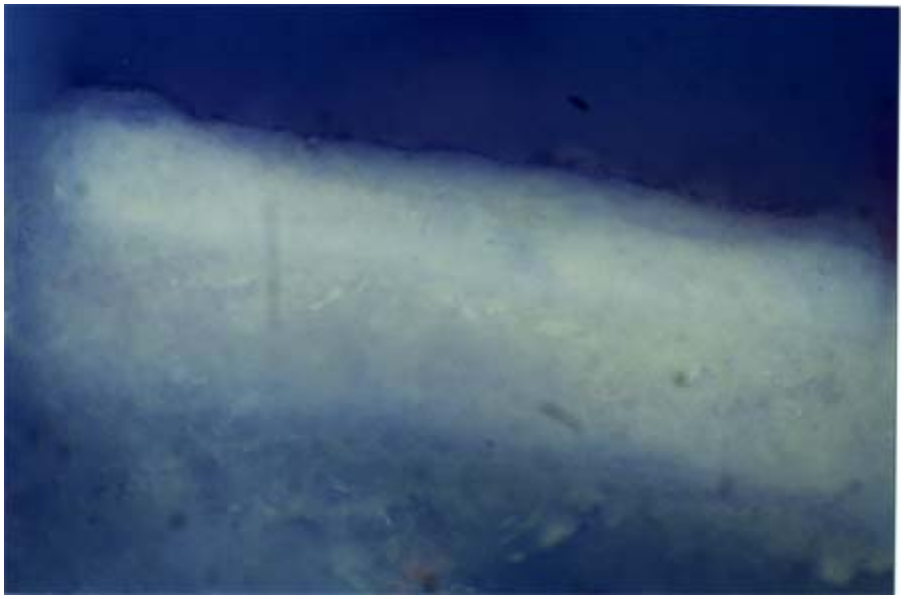


Figure 3. Du Pont de Nemours (OB 373a) sample: x-ray spectrum (top), electron backscatter image (bottom left) and elemental map (bottom right; Ca , blue; Pb, green; Si, red)

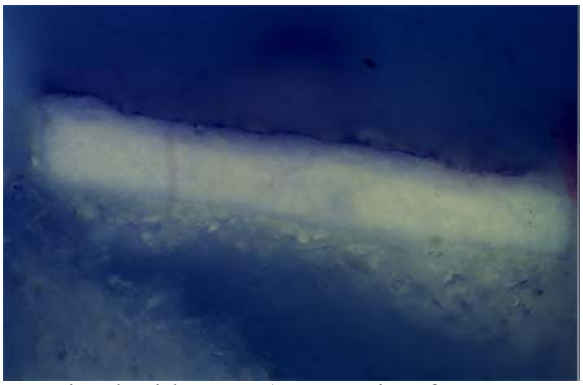
Figure 4 shows the paint cross section taken from the bust of du Pont de Nemours (OB 373a), and Figure 5 shows the paint cross section from the bust of Madame du Pont (OB 373b).



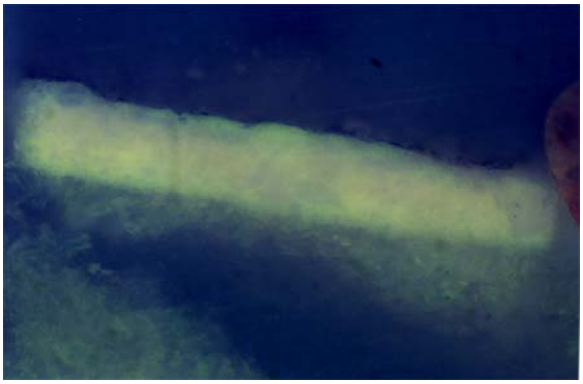
a. Visible Light



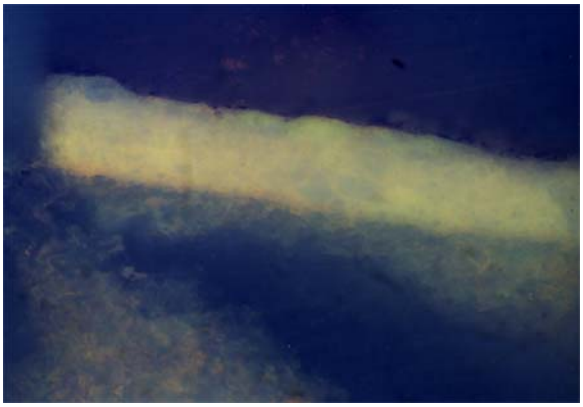
b. Ultraviolet Light



c. stained with TTC (no reaction for carbohydrates)

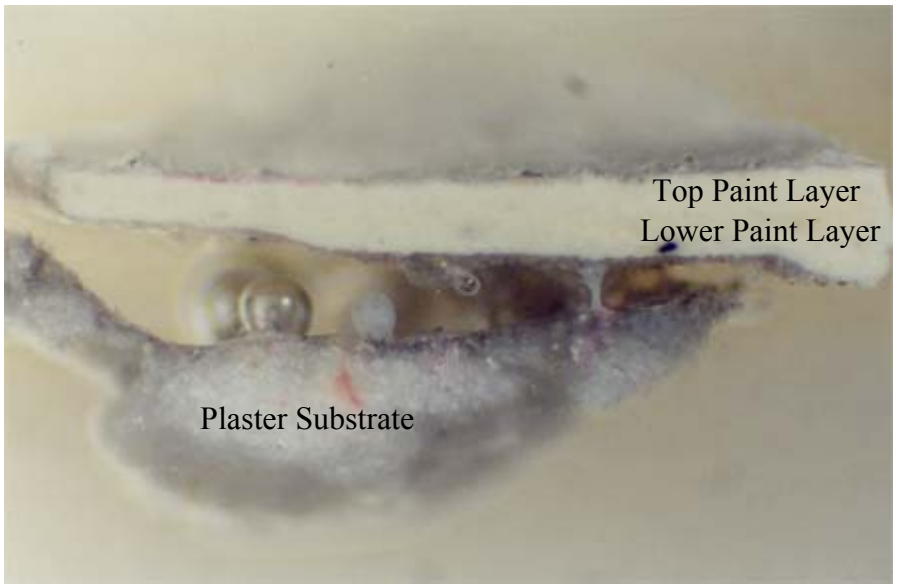


d. stained with Alexa Fluor 488 (note positive reaction for protein as indicated by green fluorescence in paint layer)

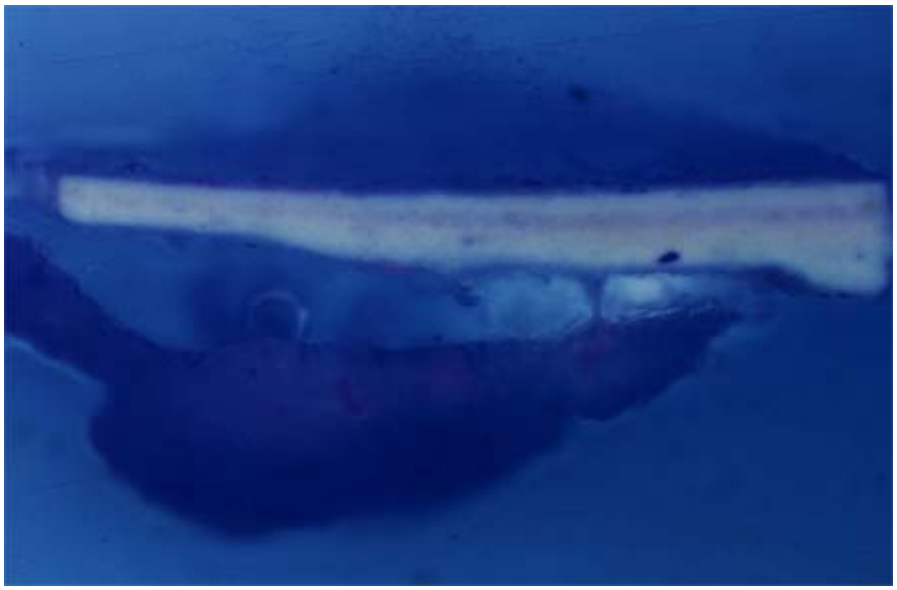


e. stained with RHOB (note positive reaction for oil as indicated by red-orange fluorescence in paint layer)

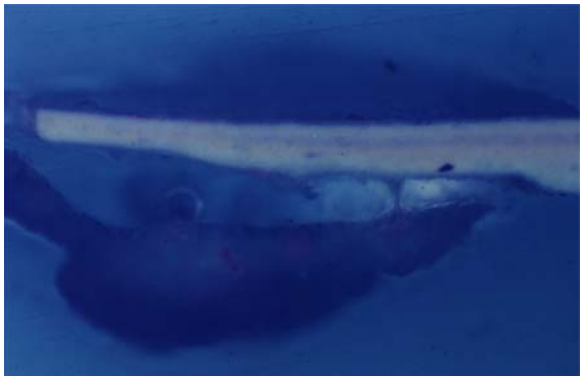
Figure 4 a-e. du Pont de Nemours (OB 373a), cross-sectional view, 125x magnification



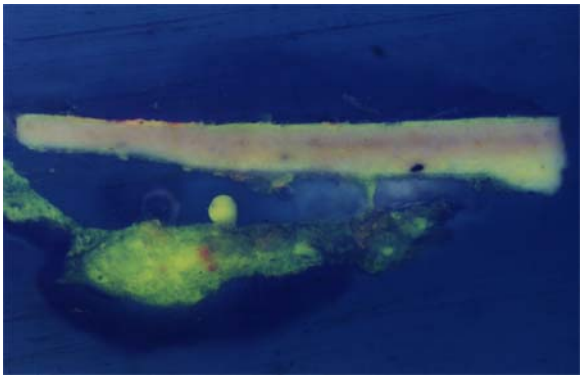
a. Visible Light



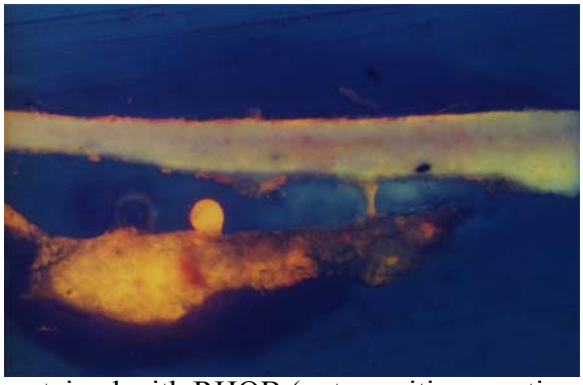
b. Ultraviolet Light



c. stained with TTC (no reaction for carbohydrates)



d. stained with Alexa Fluor 488 (note positive reaction for protein as indicated by green fluorescence in paint layer)



e. stained with RHOB (note positive reaction for oil as indicated by red-orange fluorescence in paint layer)

Figure 5 a-e. Madame du Pont (OB 373b), cross-sectional view , 125x magnification

Portions of the samples held in reserve from each portrait bust were analyzed by infrared spectroscopy for additional characterization of paint binding media. A Thermo-Nicolet IR100 bench top spectrometer was used to characterize the samples. All spectra were the result of identical instrumental run parameters (gain: 4; no. of scans 32; 4000cm^{-1} to 400cm^{-1} spectral range, and converted to absorbance spectra). Baseline corrections, smoothing, and library searches were performed using Thermo-Nicolet Encompass proprietary software. The samples were usually divided by scalpel; pressed with a piston, and run "neat" on a Thermo-Nicolet Thunderdome ATR cell. Spectral results for the gypsum substrate and paint from the bust of du Pont de Nemours are shown in Figure 6.

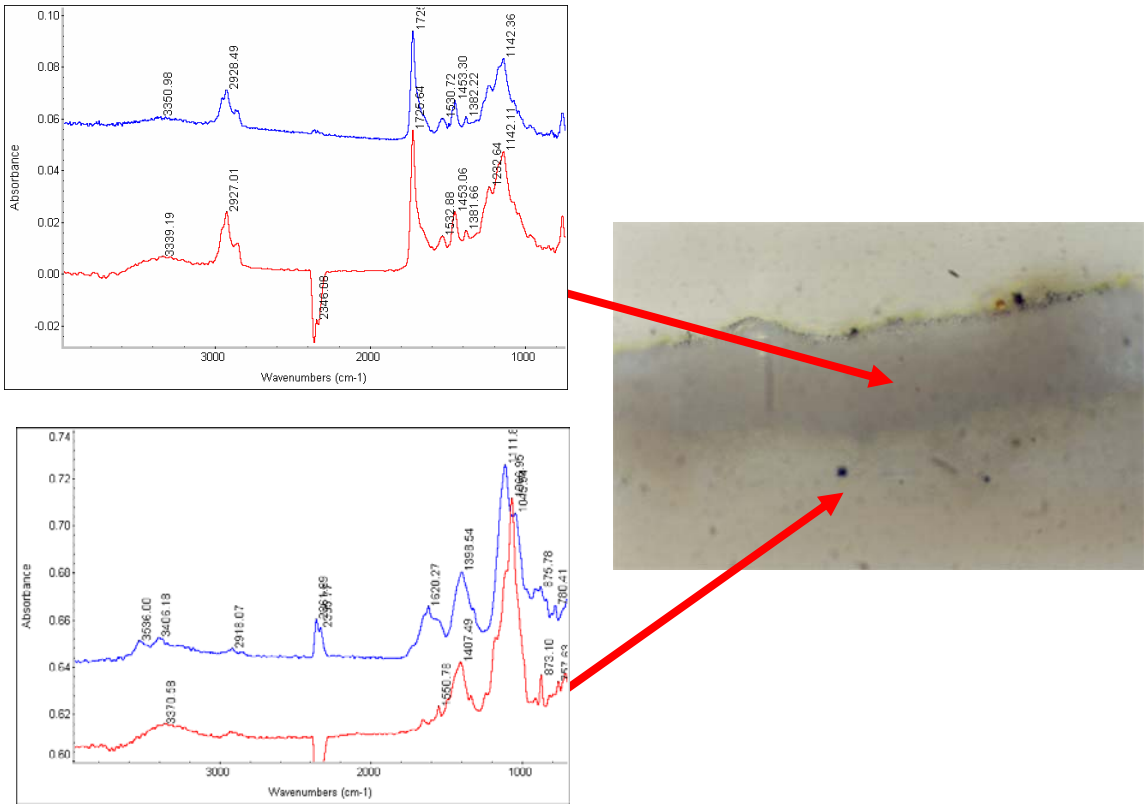


Figure 6. Top Left: FTIR Spectra of du Pont de Nemours Paint (blue) and a reference spectrum for a casein/oil paint standard (red). Bottom Left: FTIR Spectrum to the plaster substrate material of the bust (blue) and a reference spectrum for a gypsum standard (red). The cross-sectional detail (right) shows the approximate arrangement to the two materials tested.

From cross sectional views and media staining, it would appear that the plaster surface of both busts was sized with a proteinaceous material prior to painting. On both busts, the paint binder appears to be an emulsion (e.g. a blend of protein and oil binding materials); this observation seems to be confirmed by the infrared spectra obtained from the paint films as well. The paints in both cases appear to be lead containing materials (e.g. lead white as the bulk colorant). The soiling layer predominantly appears to contain both lead-based compounds and calcium-based compounds.

One additional note: during cross sectional sampling, there were some samples that at higher magnifications appeared to carry a droplet or spray like application on the surface of the paint layer, in effect fixing the accumulated oil to the paint surface in those areas where it had been applied. Figure 7 is a cross sectional image in normal light of one such sample from the bust of du Pont de Nemours.

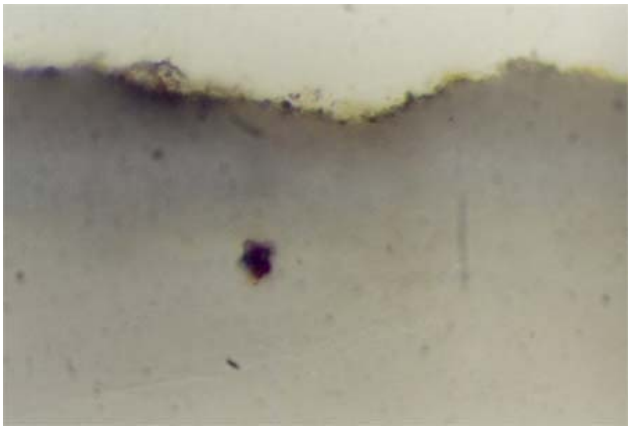


Figure 7. Cross sectional image, normal light 250x from du Pont de Nemours bust (OB 373 a).

Materials and Methods

Though the literature indicated that water should be used sparingly in the cleaning of plaster, initial cleaning tests indicated that aqueous cleaning systems were more effective than solvents in removing dirt and grime from the painted and plaster surfaces. In evaluating cleaning systems for general soil removal on the two busts, five solution properties for aqueous cleaning systems were specifically tested for their efficacy or contribution to the overall cleaning effect: pH, solution conductivity, the nature and strength of a chelator or chelators needed for the dissociation of relatively low solubility soil salts, the form and strength of surfactant needed, and the solution viscosity.

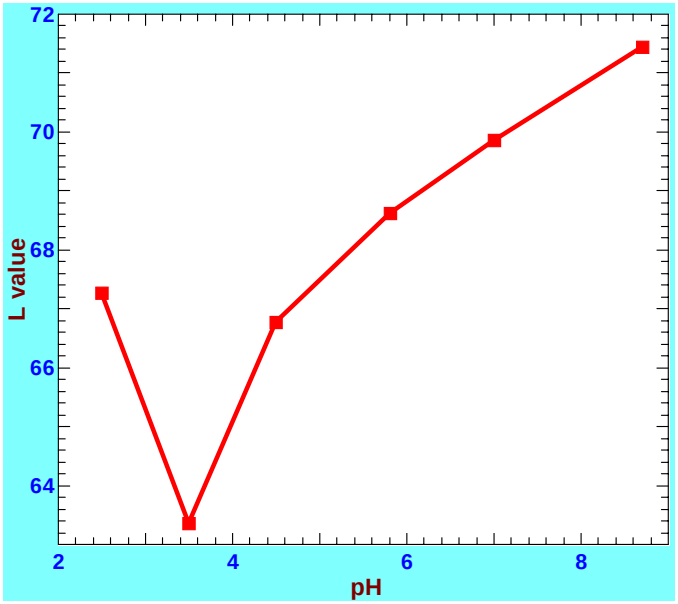
pH

A series of test solutions were created to evaluate the pH sensitivity of the paint/plaster surfaces on both busts. Standard buffer solutions were prepared at a 0.05M concentration for the following buffers, adjusted as close to the individual pK_a's for each material.

Buffer	pK_a
phosphate	(1) 2.15
citrate	(1) 3.13
citrate	(2) 4.76
succinate	5.6
BIS-TRIS	6.44
triethanolamine	7.76
borate	9.23

The test buffer solutions were applied with a cotton swab. Generally these test cleanings were done on the base and on the reverse of each bust.

The cleaning effect of the buffered test solutions was monitored used the Minolta CR100 chromameter to compare the brightness of test cleaning areas to the average brightness measurement obtained for the relatively unsoiled paint/plaster surfaces in a protected area of the busts. For the du Pont de Nemours bust the average of brightest areas measured L* 78.68 a* +0.37 b* +13.14 (where L=light,dark, a=red,green, and b=blue,yellow); for Madame Du Pont the average of brightest areas measured L* 68.84 a* +1.16 b* +13.45. The treated area was rinsed with a swab dampened with de-ionized water and allowed to dry 60 minutes prior to measurement. For the du Pont de Nemours bust the relative brightness or L value recovered on cleaning is recorded here in Graph 1 as a function of pH.



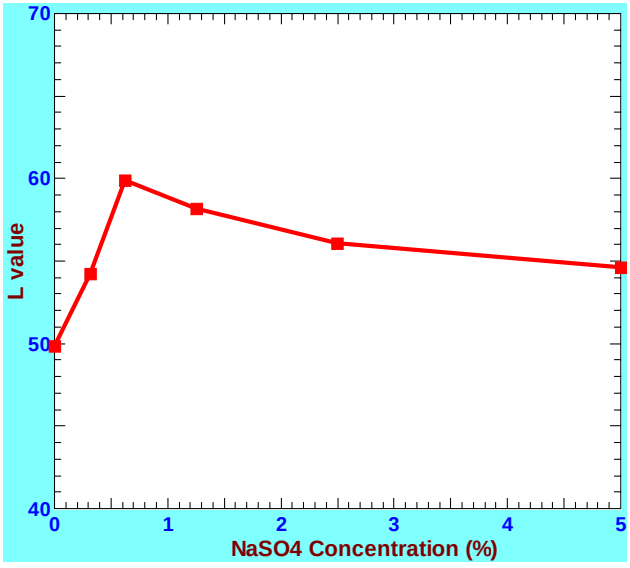
Graph 1. The relationship between L value and pH of cleaning solution.

No single test solution completely recovered the relative brightness of the average unsoiled surface, L 78.68 in the case of the du Pont de Nemours bust. The test cleaning results did suggest that soil removal was at a minimum at, or close to, pH of 3.5 (presumably close to the iso-electric point of the proteinaceous binder in the paint), and that raising the pH as high as 8 (with triethanolamine) was a more effective strategy than lowering the pH below the apparent iso-electric point where the recovered brightness was about 92% of the unsoiled average surface.

Conductivity

As an additional solution parameter, the overall conductivity of any potentially useful aqueous solution that contained ionizable materials was considered in our evaluation of aqueous methods for cleaning. A set of standard solutions were prepared with varying amounts of $NaSO_4$, to evaluate the general effect of increasing ionic strength on the paint/plaster surfaces of the busts. Again, the effect of the sulfate test solutions was monitored used the Minolta CR100 chromameter to compare the test cleaning results to the average brightness measurement obtained for the relatively unsoiled paint/plaster surface in a protected area of the bust (Madame Dupont: average of brightest areas measured L* 68.84 a* +1.16 b* +13.45; du Pont de Nemours: average of brightest areas L* 78.68 a* +0.37 b* +13.14). The test buffer solutions were applied with a cotton swab; the area treated rinsed with a swab dampened with de-ionized water, and the area thus treated was allowed to dry 60 minutes prior to measurement. Generally these test cleanings were done on the base and on the reverse of each bust.

On the du Pont de Nemours bust (see Graph 2), as the sulfate concentration was increased from zero to 1%, the conductivity rose from 0 to about 10^4 microSeimens (µS), with a concomitant rise in apparent cleaning effect. At this conductivity (10^4 µS), the recovered brightness was only about 76% of the average unsoiled surface. In addition, the brightness of the test-cleaned surfaces actually leveled off slightly at higher concentrations of sulphate. The data suggested that higher conductivities added no additional cleaning effect beyond about 10^4 µS.



Graph 2. The relationship between L value and $NaSO_4$ concentration

Chelators

The initial cross sectional and analytical data suggested that both high levels of lead (from the paint) and calcium (from the plaster support) were likely metallic cations to be present on the paint/plaster surfaces, and therefore most likely to be present as part of insoluble complexes or salts accumulated there. Several chelating materials were tested for their efficacy in cleaning the soiled paint surfaces:

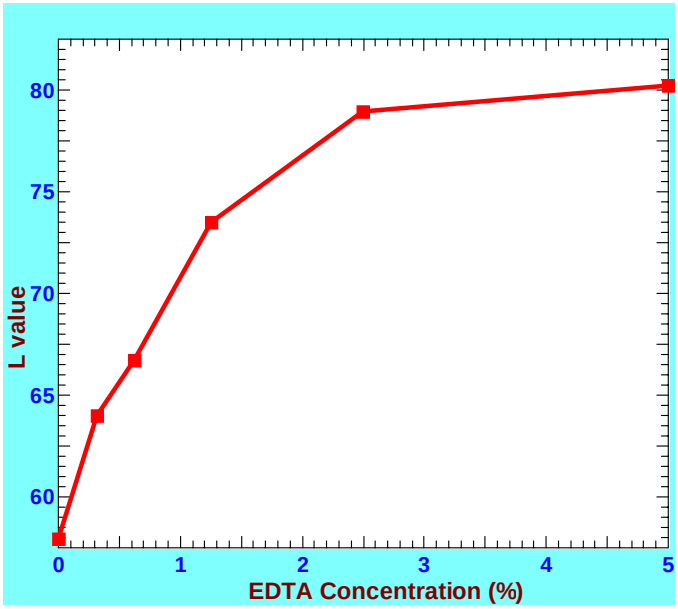
- citrate
- ethylenediamineteraacetic acid (EDTA)
- ethyleneglycoltetraacetic acid (EGTA)
- N-(hydroxyethyl)-ethylenediaminetriacetic acid HEDTA (reduced EDTA)
- nitrilotriacetic acid (NTA)

These chelators generally exhibit increasing formation constants in this order (formation constants from Dean 1985):

Chelator	Formation Constant Ca^{+2}	Formation Constant Pb^{+2}
Citrate	4.66	8.32
NTA	6.41	11.39
HEDTA	8.14	15.5
EDTA	10.96	18.04
EGTA	11.0	14.71

While the specific lead and calcium salts present on the soiled paint/plaster surfaces were not characterized, both exhibited concentrations of each metal ion accumulated on their surface. In the case of the du Pont de Nemours bust, the SEM-EDS data suggested a relatively higher proportion of lead to calcium at the paint surface. All of the chelators were made into test solutions at a constant molar concentration (.05M) and at the same pH (8.0 adjusted with triethanolamine) for comparison purposes. Only the EGTA and EDTA containing solutions appeared to have any cleaning effect on the accumulated soils (presumably because of the higher affinity for Pb^{+2}). The concentration vs. cleaning effect curve for EDTA on the du Pont de Nemours bust surface is shown in Graph 3.

The tests indicated 1) only chelating materials with the highest affinity for (i.e. formation constant with) lead and calcium in the series tested would suffice for the efficient cleaning of the paint/plaster surface, and 2) that concentrations as high as 2-2.5% of EDTA could be tolerated on the surface to be cleaned without going beyond the level of cleaning (identified as L* 78.68) deemed appropriate. Both EDTA and EGTA at a pH of 8 are fully ionized, and contribute significantly to the overall conductivity of the solutions they are in (a 1% solution of EDTA raised to pH 8 with triethanolamine yielded a solution conductivity of about 10^4 μS). At concentrations of about 2 – 2.5%, maximum cleaning effect is reached with both chelators.



Graph 3. The relationship between L value and EDTA oncentration.

Surfactant

Tests were conducted using various surfactant solutions in water at about five times their critical micelle concentrations (cmc). These represent surfactant solutions of widely different strengths (i.e., solubilization effects) as defined by their hydrophile-lipophile balance (HLB) numbers.

Surfactant	CMC	HLB
Triton XL-80N	0.1 mM	12.5
lauryl sulfate	8 mM	40
Pluronic L-40 (BASF)	0.2 mM	60

The presence or absence of any of these surfactants either alone, or in concert with the buffers, chelates, and salt material ($NaSO_4$) tested seemed to be particularly effective or useful in cleaning the soiled paint/plaster surfaces of the busts.

Viscosity

Tests with standard methylcellulose preparations in water (15, 400, 4000 centipoise (cps), from Fisher Scientific) suggested that the handling properties of our optimal cleaning solution (i.e. ease of application, stirring, wiping away, and rinsing of cleaned surfaces) felt best at about 4000 cps. Increasing the viscosity of aqueous preparations was a distinct advantage when working on

vertical surfaces. Raising the viscosity seemed also to slow the diffusion of aqueous materials into the paint surfaces to which they were applied.

Results

The aqueous set of conditions or materials that seemed most likely to clean (but not over-clean) and provide the best handling properties on the painted surfaces combined a slightly alkaline pH, a strong chelator for both Pb and Ca and a slightly viscous quality. The preparation used over much of the surface area on the busts was an aqueous preparation of EDTA (2.5%), buffered to a pH of 8 with triethanolamine, and thickened with about 2-3% of methyl cellulose (>4000cps). The overall conductivity of the cleaning solution was about 2.5 x 10^4 μS, largely because of the ionized EDTA in this preparation, at this pH. It should be noted that no surfactant was needed specifically for cleaning, nor was one initially included in this preparation.

However, as treatment progressed, a modified cleaning system was necessary. The clear coating material posed a serious problem for working evenly over the surface of the busts with the simple aqueous cleaning system. It was necessary to even out the cleaning by using an emulsified version of the aqueous system with the aliphatic hydrocarbon solvent Shell Solv D-38. The emulsion consisted of a 45:33:22 v:v:v mixture of the EDTA solution at pH 8:Triton XL-80N:Shell Solv D-38.

Conclusion

Analysis of the materials and soiling on the busts of du Pont de Nemours and Madame Du Pont gave an understanding of the nature of the soiling and how it was held to the painted surface. From this, a two step process was established for removing the soil. First, removing soiling held to the surface with the clear coating material with the EDTA/Triton XL-80N/Shell Solv D-38 solution; second, applying with the 2.5% EDTA solution, buffered to pH of 8 with triethanolamine thickened with 2-3% methyl cellulose. The results of cleaning were dramatic and clearly met the expectations of the curator (Fig. 8).

It can also be said that the cleaning system met the conservation goals established at the start of the project:

- A cleaning system which could effectively remove dirt/grime held to a physically and chemically complex surface had to be devised. Understanding the ways in which the dirt was held to the painted surfaces helped in designing the two part cleaning system used in this treatment and cleaning was accomplished with out damage to the paint or exposed plaster surfaces.

- Given the complexity of the surfaces and soiling, the cleaning system needed to be flexible so that it could be varied as necessary. In the course of treatment, it was found that some areas need only the EDTA solution, or only the EDTA/Triton/Shel Solv solution, or repeated applications of one or both solutions. These variations could be

accommodated without harm to the paint or plaster surfaces.

- A method of monitoring the level of cleaning was needed so that the visual harmony within and between the surfaces of the two busts could be maintained. In the course of analysis, it was found that brightness measurements taken with the Minolta CR 100 Chromameter could be used to monitor the progress of cleaning. Having a means of measuring the extent of cleaning allowed for more than one conservator to work on the project without compromising the aesthetic of the objects.

The cleaning was the most time consuming portion of the treatment of the busts, but once that step of the treatment was completed, losses to the plaster were compensated using plaster of Paris or Flügger (a commercially prepared acrylic spackling compound, available from Conservation Resources). Fills were separated from the original plaster surfaces with Japanese tissue adhered to the plaster substrate using methyl cellulose. Finally, inpainting was executed using Winsor & Newton Gouache Paints or Charbonnel Restoration Paint.

Figure 8. Madame du Pont (OB 373a) on left, and du Pont de Nemours (OB 373b) on right after cleaning.

Acknowledgements

The authors would like to thank Jennifer Mass and Janice Carlson of the Scientific Research and Analysis Laboratory at Winterthur Museum for analysis of samples. We are also indebted to Peggy Olley, fellow in the Winterthur/University of Delaware Program in Art Conservation, who worked side by side with us on this project and deserves equal credit for the successful treatment.

References

Andre, J-M. 1977. *The Restorer's Handbook of Sculpture*. New York: Van Nostrand Reinhold Company.

Anonomyous. 1992. Memorandum of known portraits of du Pont de Nemours. Unpublished typescript. Hagley Museum and Library.

Beale, A., C. Craine and C. Forsythe. 1977. The conservation of plaster casts. *AIC Preprints*. American Institute for Conservation 5th Annual Meeting, Boston. Washington, D. C.:AIC. 18-24.

Canadian Conservation Institute. n.d. Care of objects made of plaster of Paris. *CCI Notes*. 12/2. Ottawa: Canadian Conservation Institute.

Dean, J. A. 1985. *Lange's handbook of Chemistry*. 13th edition. NewYork: McGraw-Hill Book Company.

Hughes, D. 2003. Personal communication. Curator of Collections and Exhibits, Hagley Museum and Library.

MacKay, A. 1997. Treatment of a painted plaster sculpture: The Bard by Emanuel Hahn. *Journal of the Canadian Association for Conservation* 22:31-38.

Maudueche, J. 1992. The ecorché. *Conservation News* 47 (March):21-22.

Mass, J. and J. Carlson. 2004. Scientific Research and Analysis Laboratory Analytical Report No. 4562. Winterthur Museum.

Mel'nikova, E. A. and M. N. Lebel. 1978. Application of polymer films for removing surface contaminations from sculptures made of different materials. ICOM Committee for Conservation 5th Triennial Meeting, Zagreb, Yugoslavia. 78/10/8/1–78/10/8/6.

Richie, J. 1933. Cleaning and preserving sculpture casts by a cellulose method. *The Museums Journal* 32 (March): 465-468.

Stable, C., B. Cobo del Arch and H. Spencer. 2002. Investigation, conservation and mounting of a fiberous plaster frieze by Charles Rennie Mackintosh. ICOM Committee for Conservation, 13th Triennial Meeting, Rio de Janeiro, Brazil. 533-539.

Wolbers, R. 20000. *Cleaning painted surfaces*. London: Archetype Publications.

http://www.sigmaaldrich.com/brands/fluka_riedel_home/bioscience/biochemica-ultra/biological-buffers.html

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"BRICK BY BRICK": PIECING TOGETHER AN 8TH CENTURY B.C. FAÇADE FROM IRAQ

Alison Whyte, Vanessa Muros and Sarah Barack

Abstract

This poster addresses the history, analysis and conservation treatment of a collection of polychrome glazed bricks excavated in the first half of the 20th century, at Khorsabad, Iraq. The bricks originally formed part of a tableau that flanked the entrance of the 8th century BC Sin Temple. After excavation in 1933, they were packed in wooden crates and then shipped to the Oriental Institute Museum, University of Chicago. The bricks remained in storage until 1990, when the first of several crates was opened. Initial consolidation tests were performed at that time. Extensive conservation of the pieces began in 2001 with an analytical study to determine the compositions of the colored glazes. Treatment then focused on the stabilization of the bricks in preparation for their exhibition in the newly reinstalled Mesopotamian galleries.

1. History of the site

Khorsabad, located in Iraq some 12 miles northeast of the city of Mosul, was founded by Sargon II, who ascended to the Assyrian throne in 722 BC. The founding of a new capital city was a rare occurrence in ancient Assyria, and the vast amount of resources and material it required is indicative of the strength of the empire at that time. Sargon never lived to see his capital flourish, however, as he died in battle in 705 BC. Modern interest in the site began in 1843, when the then French consul to Mosul, Paul Emile Botta, unearthed some of the stone reliefs. Botta left Iraq in 1844, and further work at Khorsabad was suspended until 1852-4, when it resumed briefly under the direction of the next French consul, Thomas Victor Place. The Oriental Institute began to excavate at the site in 1929, with Henri Frankfort at the helm of the project. This directorship was later passed on to Gordon Loud and excavation proceeded for several seasons (1929-30, 1931-2, 1933-4). (Albenda 1986).

Figure 1. Map of Ancient Near Eastern archaeological sites. http://oi.uchicago.edu

Figure 2. Excavating the threshold of the doorway to the Sin Temple. Glazed brick façade partially visible at the foreground. (Loud 1936, 91).

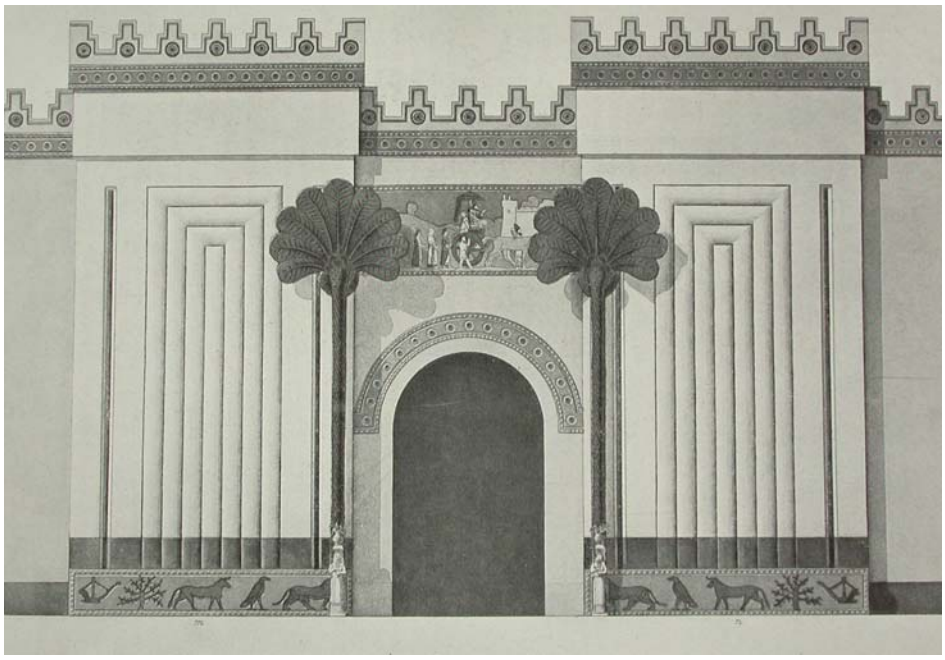


Figure 3. Reconstruction drawing of the Sin Temple façade (Place 1870, 24).

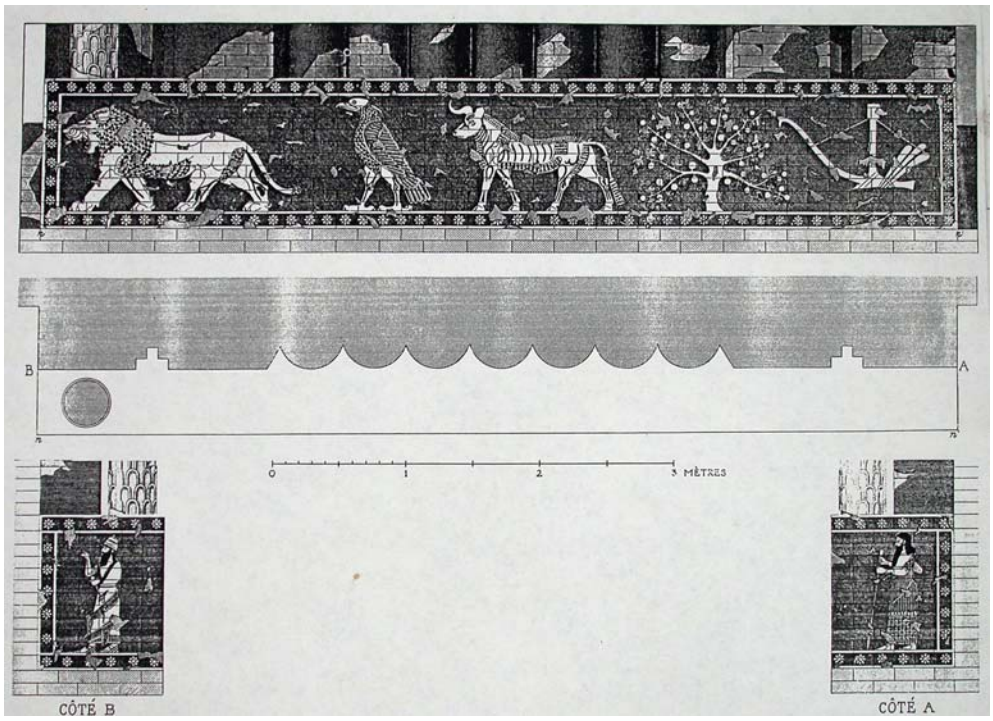


Figure 4. Reconstruction drawing of brick tableau. (Place 1870, 26).

Figure 5. Gordon Loud, ca. 1930. (Oriental Institute Archives). Loud's journal describes the excavation conditions, including notes on the removal of the bricks, stating: "… what a climate, popping out of the cold rainy weather into this glorious spring variety, almost over night. Today it was actually uncomfortable working with even a suit on, and we both ended up in short sleeves! …As we get away from the corner the bricks seem to be less broken, though I had to cast off several that were too hopelessly in fragments. I now realize as we get them in boxes that the job of removing them from the containers will be the more ticklish of the two…" (Loud, 1933).

Figure 6. Brick façade in situ; the numbers were written on the photograph at some point after the bricks had been shipped. (Oriental Institute Archives).

2. Analysis of the Glaze Using Scanning Electron Microscopy with Energy Dispersive Spectrometry (SEM-EDS)

Samples of blue, black, yellow and white glaze were removed and then prepared in one of two ways for SEM-EDS analysis. The smaller samples of glaze were mounted on aluminum stubs using carbon paper. Larger cross section samples, which contained both glaze and brick fabric, were mounted in Buehler Epo-Thin Low Viscosity Epoxy Resin (No. 208140032 – resin, No. 08142016 – hardener). The excess epoxy resin was cut away from the mounted sections using the Buehler Isomet 1000 Precision Saw (No. 11-2180). Buehler Isocut Cutting Fluid (No. 112293016) was used as a lubricant during the cutting process. The sections were then polished using a rotating wheel (Buehler Metaserv 2000 Grinder/Polisher – No. 95-2809) and progressively finer grits of 8" Buehler Carbimet Discs – PSA backed (silicon carbide paper - No. 305128).

The results of the SEM-EDS analysis suggest that the bricks are decorated with alkaline glazes consisting of a silica glaze former and several glaze modifiers including sodium, potassium, aluminum and/or calcium compounds. Elements detected which could have acted as colorants for the blue, black, yellow and white glazes are listed below.

Glaze Color	*Colorant Elements Detected*
Blue	Copper (Cu), Manganese (Mn)
Black	Manganese (Mn), Iron (Fe)
Yellow	Lead (Pb), Antimony (Sb) - opacifier
White	Calcium (Ca), Antimony (Sb) - opacifier

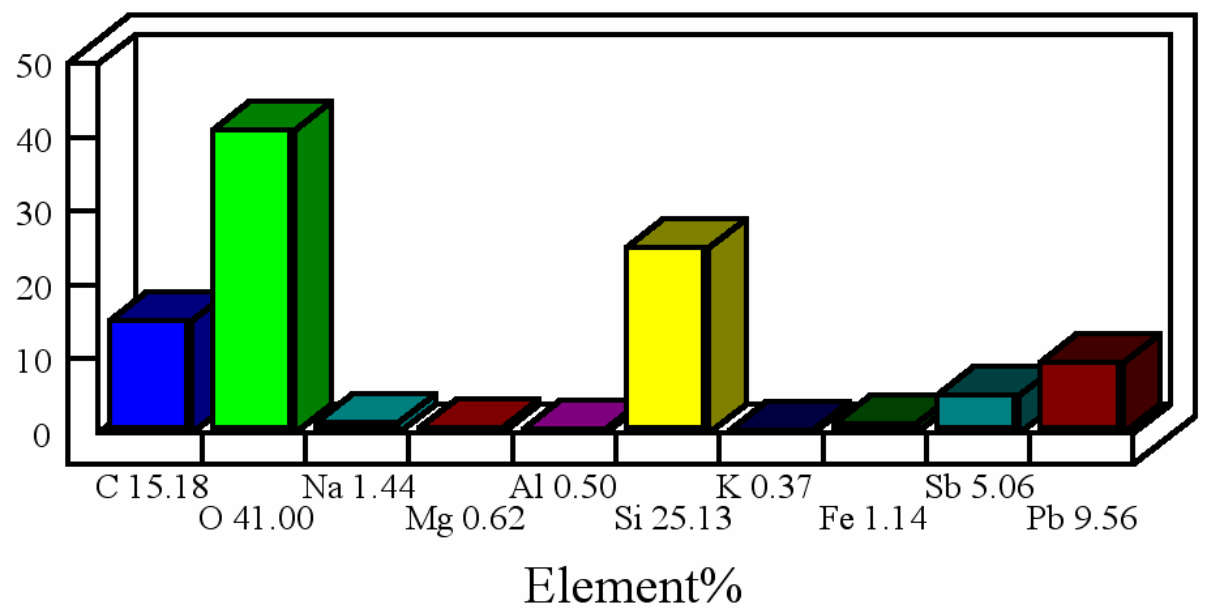


Figure 7. EDS spot analysis of sample of yellow glaze. Sample taken from glazed clay brick, Sin Temple, Khorsabad, Iraq, 722-705 BC, Oriental Institute Museum, OIM A11810.269.

Other Observations

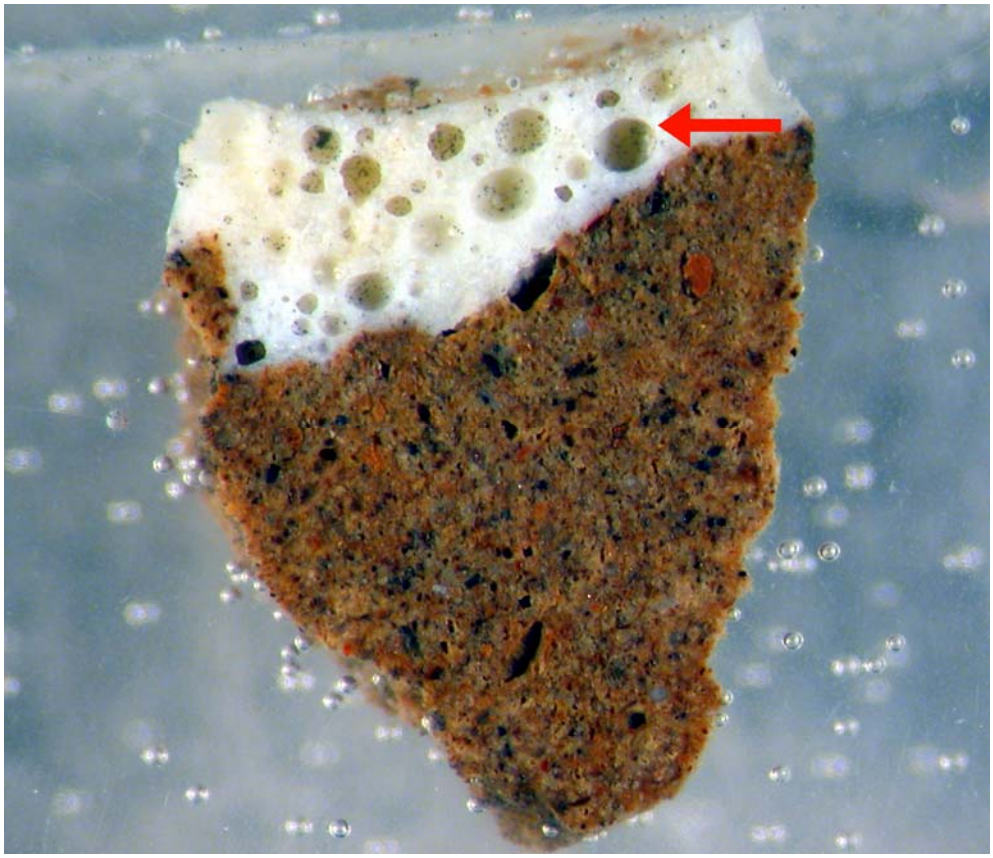


Figure 8. Cross section of white glaze showing air bubbles (see arrow). The presence of these bubbles may indicate overly rapid firing of the glaze, insufficient mixing or a lack of fluidity in the glaze prior to firing. Magnification: 20x. Sample taken from glazed clay brick, Sin Temple, Khorsabad, Iraq, 722-705 BC, Oriental Institute Museum, OIM A11810.108.

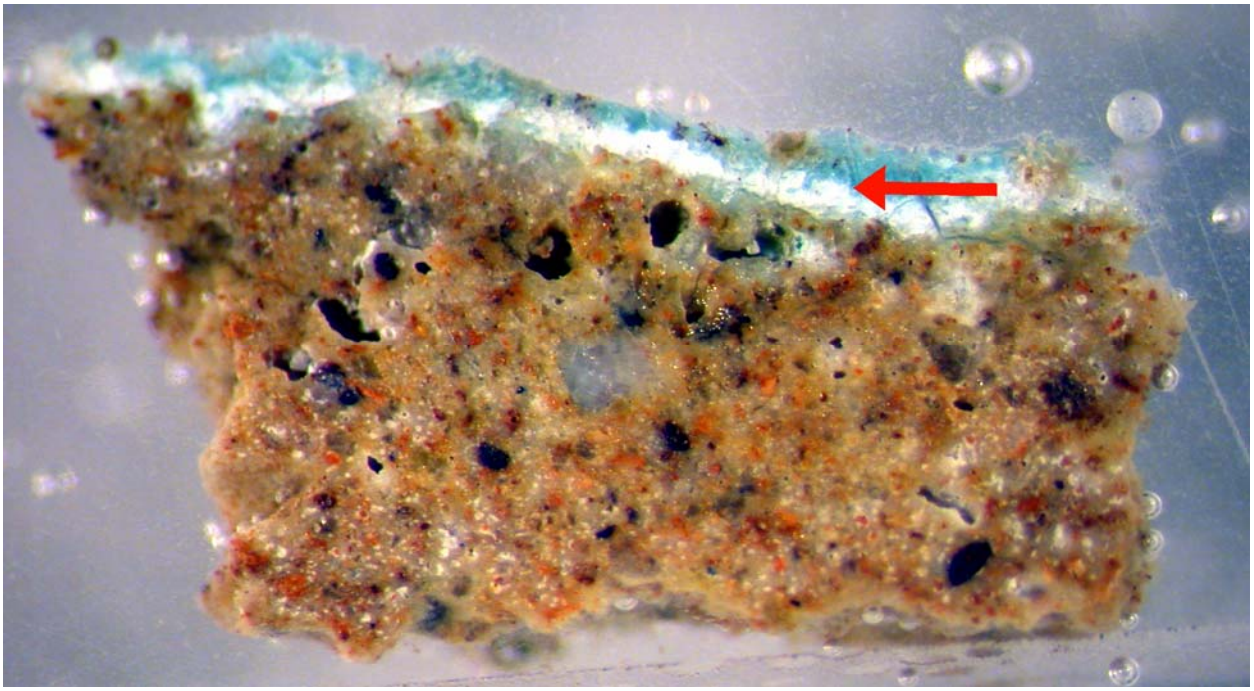


Figure 9. Cross section of blue glaze showing layering of white glaze underneath (see arrow). The reason for this layering is unclear; however, one theory suggests that white glaze was applied first in order to manipulate the tone of the final blue glaze. Magnification: 45x. Sample taken from glazed clay brick, Sin Temple, Khorsabad, Iraq, 722-705 BC, Oriental Institute Museum, OIM A11810.147.

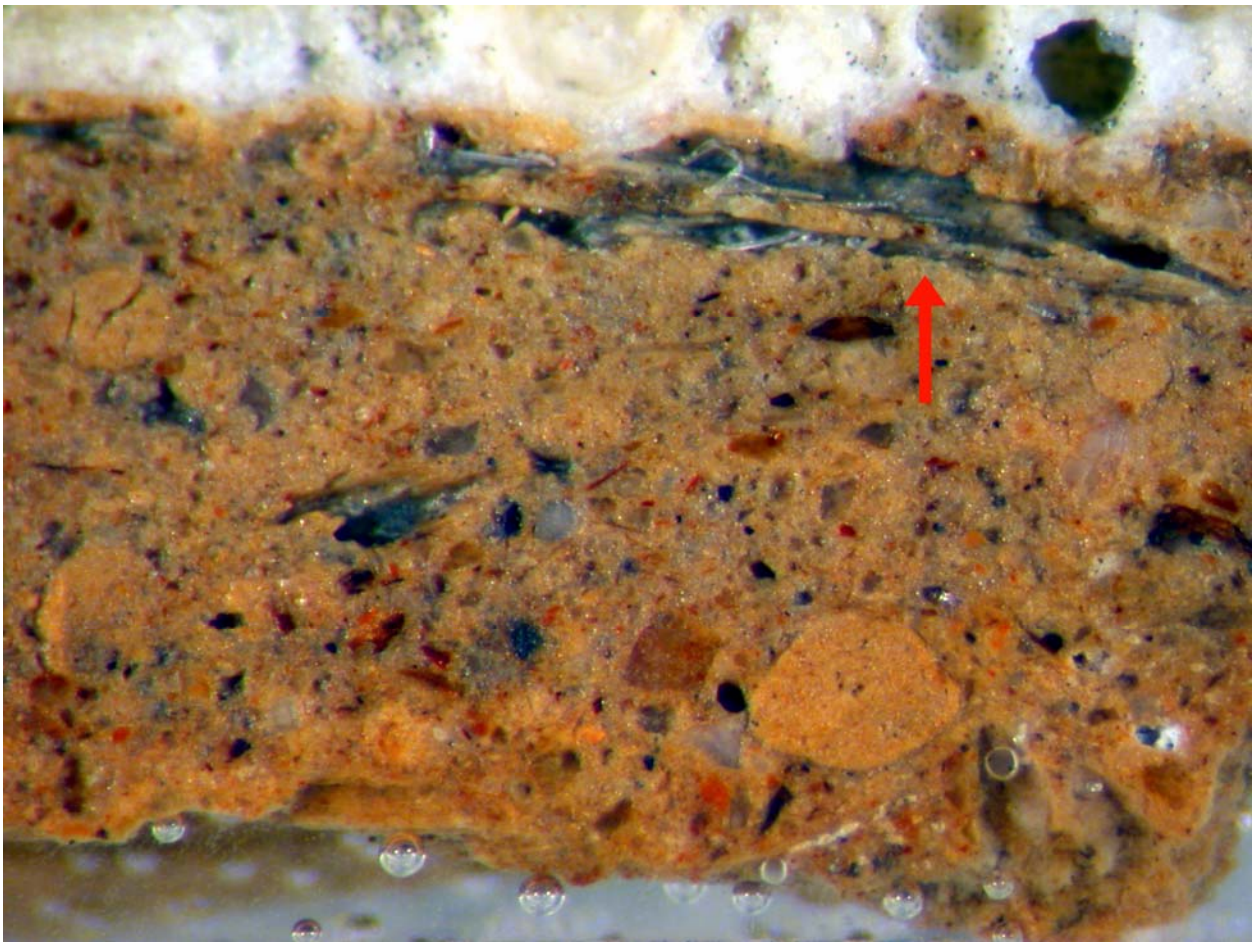


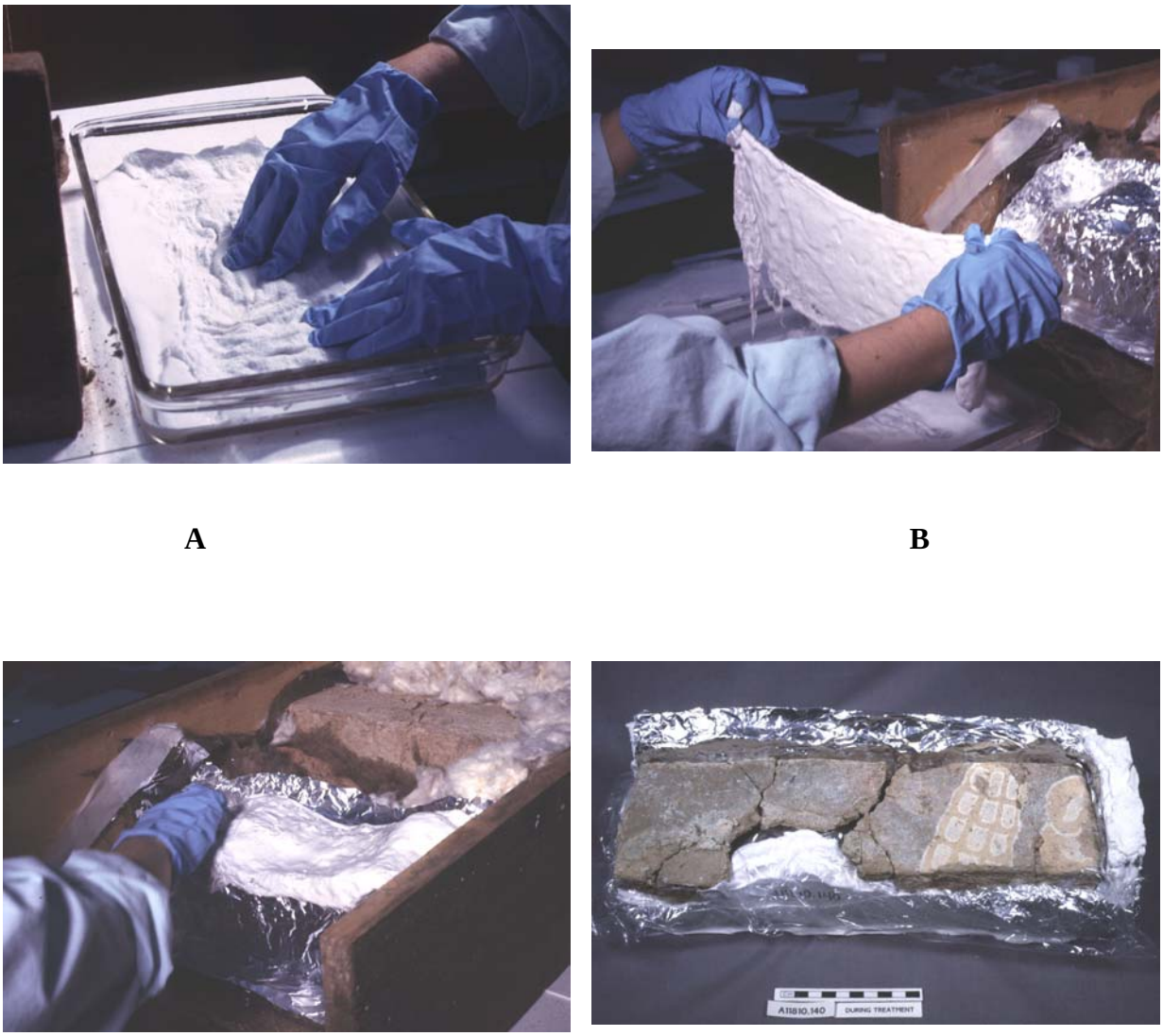
Figure 10. Detail of brick fabric showing possible evidence of plant fibers (see arrow). Vegetal material would have been added to the clay to improve its working properties and to prevent cracking. During firing, most of the fibers would burn leaving casts of their original form preserved in the brick. Magnification: 30x. Sample taken from glazed clay brick, Sin Temple, Khorsabad, Iraq, 722-705 BC, Oriental Institute Museum, OIM A11810.146.

3. Conservation Treatment

Figure 11. A crate before opening.

Figure 12. In 1990, one crate was opened and the bricks were removed for examination. The bricks were in a very fragile and fragmentary condition. Consolidation tests were conducted on these bricks to determine which consolidant was most effective. The bricks had also been treated in the field with a cellulose-nitrate based adhesive ("Ambroid"; Loud 1933), and the tests would help determine the compatibility of the modern resin with the aged cellulose-nitrate consolidant. Glazed clay brick, Sin Temple, Khorsabad, Iraq, 722-705 BC, Oriental Institute Museum, OIM A11810.158.

Figure 13a (left) & b (right). In 2002, a crate containing the bricks belonging to the bull's head was opened. The fragile condition of the bricks was immediately apparent upon opening the crates. Preliminary cleaning and stabilization of the glazed surfaces was executed at this time. Based on the results of the 1990 consolidation tests, Acryloid B72 was chosen for both the adhesive and consolidant. Loose brick and glaze fragments on the exposed surface were tacked in place using HMG Acryloid B-72 adhesive. Friable areas of the glazed surface were consolidated with a 1.5-3% solution of B-72 in 1:1 acetone:ethanol. The glazed surface was vacuumed to remove soil and brick dust. Gauze was placed over the nozzle of the vacuum to collect any material removed. This material was placed in glass vials for future analytical work. Glazed clay bricks, Sin Temple, Khorsabad, Iraq, 722-705 BC, Oriental Institute Museum, OIM A11810.149-152 and A11810.154-157 (left) and OIM A11810.265-266 (right).



A **B**

C **D**

Figure 14. A method similar to block lifting was devised to remove the bricks from the crates. Gauze was dipped into dental plaster (a), and draped over two exposed brick sides, which had been protected with polyethylene film and, in some cases, aluminum foil (b and c). The bricks were rotated onto a reinforced side, and a second long side was similarly treated (d). Finally, secure in their plaster support, the bricks were lifted from the crate.

Figure 15. Excess dirt was removed from each brick by both brush-vacuuming and lightly swabbing with 1:1 ethanol:deionized water where necessary. The bricks were then consolidated several times with a 3-5% solution of Acryloid B-72; after each consolidation, the pieces were placed in polyethylene bags to retard solvent evaporation. Glazed bricks, Sin Temple, Khorsabad, Iraq, 722-705 BC, Oriental Institute Museum, OIM A11810.147.

Figure 16. Finally, the stabilized fragments were joined with HMG Paraloid B-72. Glazed clay brick, Sin Temple, Khorsabad, Iraq, 722-705 BC, Oriental Institute Museum, OIM A11810.158.

A **B**

C

Figure 17. Many bricks were missing large sections of their original backs. As the display called for stacking them on top of one another, false backs were constructed for additional support and to better approximate the ancient appearance. Thick planks of Ethafoam® were carved to fit the break edge contours of individual bricks; the depth of the backs was cut to match the few intact bricks (A). The Ethafoam® was coated with a layer of regular dental plaster (B). Before fully curing, the plaster-coated foam was pressed against the back of the brick, protected with polyethylene film, to ensure that the topography of both halves still matched. Lascaux® Modeling Paste B, an acrylic, course-textured paste, was applied to the plaster in order to imitate the texture of the original surface. The foam backs were tacked onto the bricks using 50% Acryloid B-72 in acetone, bulked with 3M™ Scotchlite™ Glass Bubbles. Finally, the backs were toned with Liquitex© Acrylic paints to better integrate with the bricks (C).

Figure 18. The façade, after treatment, mounted in the exhibition case. Glazed bricks, Sin Temple, Khorsabad, Iraq, 722-705 BC, Oriental Institute Museum, OIM A11810.147-150, 156-158, 163.

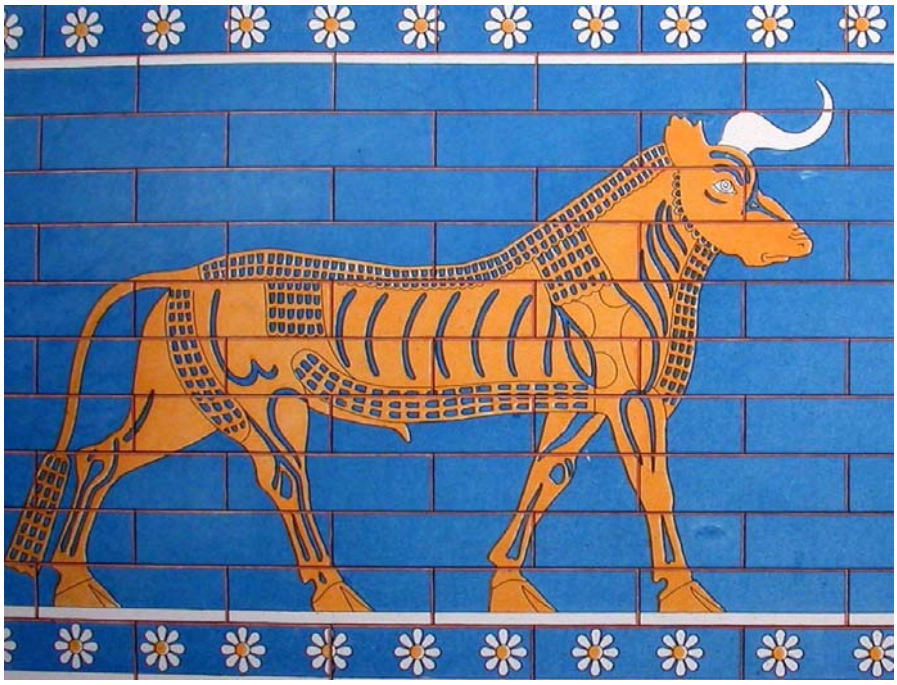


Figure 19. Reconstruction drawing of the bull figure (from Place 1870). The drawing helps clarify what the head of the bull, seen in Fig. 18, looks like.

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The authors wish to thank Laura D'Alessandro, Karen Wilson, Ray Tindel, Gil Stein, Ian Steele, Markus Dohner, Erik Lindahl, Joey Corbett, Joe Scott and Vicki Parry

Suppliers

Acryloid B72 (ethyl methacrylate copolymer):
Talas, 20 West 20th Street, 5th Floor, New York, NY 10011, (212) 219-0770.
(http://talasonline.com)

Epo-Thin Low Viscosity Epoxy Resin (No. 208140032 – resin, No. 08142016 – hardener), Isomet 1000 Precision Saw, Isocut Cutting Fluid (No. 112293016), Metaserv 2000 Grinder/Polisher, Carbimet Discs (No. 305128):
Buehler 41 Waukegan Rd., Lake Bluff, IL 60044, (847) 295-6500/1-800-283-4537.

Ethafoam® (polyethylene close cell foam):
Republic Packaging, 9160 South Green Street, Chicago, IL 60620, (773) 233-6530,
(www.corrugated.com)

HMG Acryloid B72 (ethyl methacrylate copolymer in acetone):
Conservation Resources International, 5532 Port Royal, Springfield, VA 22151, (800) 634-6932,
(www.conservationresources.com)

Lascaux© Modeling Paste B (coarse):
Dick Blick Art Materials, P.O. Box 1267, Galesburg IL, 61402-1267, (800) 828-4548,
(www.dickblick.com)

Liquitex© Acrylic Paints:
Pearl Fine Art Supplies, 255 W. Chicago Ave., Chicago, IL 60610, (312) 915-0200,
(www.pearlpaint.com)

3M™ Scotchlite™ Glass Bubble, Product K15:
3M Specialty Materials, 3M Center Building 223-6S-04, St. Paul, MN 55144-1000,
(800) 367-8905

Regular Dental Plaster:
Lance Gypsum Products, 4225 Ogden Ave., Chicago, IL 60623, (773) 522-1900,
(www.lancegypsum.com)

References

Albenda, P. 1986. *The Palace of Sargon, King of Assyria*. Paris, France: Editions Recherche sur les Civilisations.

Loud, Gordon. February 18, 1933. Excavation journal, Khorsabad. Unpublished notes. Chicago: Oriental Institute Archives.

Loud, Gordon. 1936. *Khorsabad, Part I: Excavations in the palace and at the city gate*. Oriental Institute Publications 38. Chicago: University of Chicago Press.

Oriental Institute Archives. Courtesy of the Oriental Institute, University of Chicago.

Place, Victor. 1870. *Nineve et l'Assyrie, Volume III*. Paris, France: Imprimerie Impériale.

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