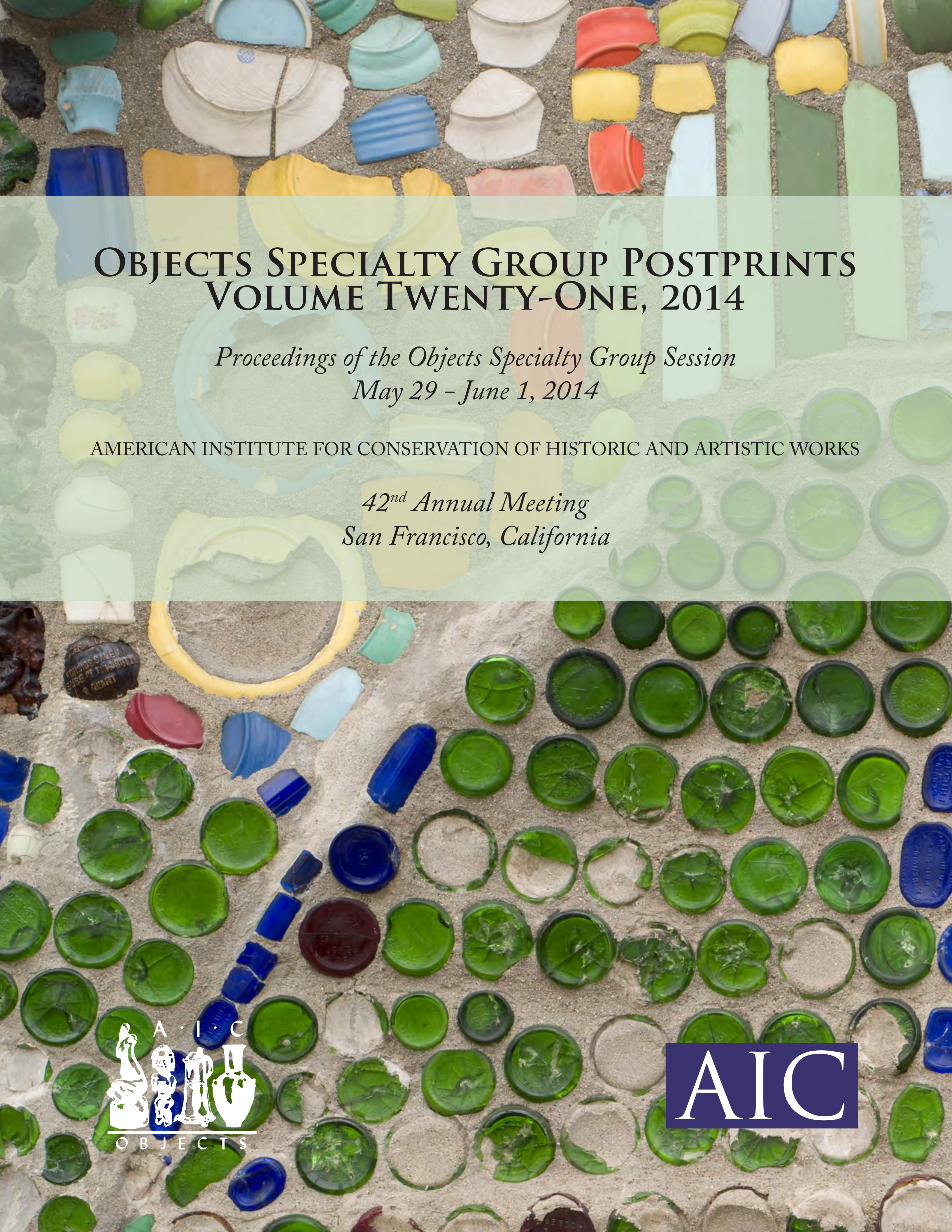

Objects Specialty Group Postprints
Volume Twenty-One, 2014

Proceedings of the Objects Specialty Group Session
May 29 – June 1, 2014

AMERICAN INSTITUTE FOR CONSERVATION OF HISTORIC AND ARTISTIC WORKS

42nd Annual Meeting
San Francisco, California

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Objects Specialty Group Postprints
Volume Twenty-One, 2014

Edited by Suzanne Davis, Program Chair,
with Emily Hamilton and Kari Dodson

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This publication entitled *Objects Specialty Group Postprints, Volume Twenty-One, 2014* is produced by the Objects Specialty Group of the American Institute for Conservation of Historic & Artistic Works.

Cover photograph by Frank Preusser: Detail of embedded decorative ornaments. The Watts Towers, Sabato (Simon) Rodia. City of Los Angeles Department of Cultural Affairs.

The papers presented in the Objects Specialty Group Postprints Volume Twenty-One, 2014, have been edited for clarity and content. Each paper was peer-reviewed by two content area specialists, and the authors revised their papers based on these anonymous reviews. Responsibility for the methods and materials described herein, however, rests solely with the authors, whose articles should not be considered official statements of the OSG or the AIC.

American Institute for Conservation of Historic & Artistic Works
1156 15th Street, NW • Suite 320
Washington, DC 20005

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Contents

Program Chair's Foreword

This conference proceedings volume contains the 18 papers presented in the Objects Specialty Group sessions at the 2014 annual meeting of the American Institute for Conservation. This diverse group of papers represents some of the best and most innovative work in our discipline today. As a practicing conservator, I find conference volumes like this one particularly useful because they report on the daily, real-life work of my colleagues.

The theme of the 2014 meeting was preventive conservation, and many of the papers explicitly address this theme. Other authors discuss preventive conservation as one component of a larger project. Still others focus not on the end goal—the ideal desired solution to the problem—but on understanding the problem itself. What truly unites all the papers is this focus on understanding the underlying challenge. The authors look deeply and thoroughly at the problems they face, consider them carefully, and from this understanding create unique and successful solutions. The challenge of developing understanding is not only an issue in treatment decisions; true understanding is also necessary for conservators to understand and empathize with the public they serve.

The diversity and complexity of this collection of papers reflects the increasingly collaborative nature of our discipline. Twelve of the papers were presented in joint sessions. One session was held jointly with the Research and Technical Studies (RATS) group and the other with the Architecture Specialty Group (ASG). At the 2015 meeting, the Objects Specialty Group (OSG) will hold joint sessions and events with the Electronic Media Group. The multidisciplinary nature of conservation demands shared venues for considering problems and opportunities, and shared vehicles for reporting the results of collaborative efforts. The specialty group silos are beginning to break down as a natural evolution of the discipline, and I hope this trend continues. To continue to work productively, we must work together.

Creation of the joint sessions at the 2014 meeting was a team effort. Ainslie Harrison (RATS) and Jennifer Correia (ASG) were my co-chairs for the joint sessions with their specialty groups, and they participated as managing and content editors for the resulting print papers. It was a pleasure to work with them, and I am grateful to have had the opportunity.

The editing of this volume was also a team effort. 2014 marked the first year that papers in the OSG postprints underwent formal peer review. The session chairs (Jennifer Correia, Ainslie Harrison, and I) identified two reviewers for each paper. The reviewers were conservators, scientists, and scholars who had specialist knowledge appropriate to each paper. This dedicated group of volunteers reviewed content: they identified gaps, suggested additions, and generally made recommendations to improve both the content and the clarity and usefulness of its delivery. Peer review is enormously important in any discipline, but it is especially needed in conservation. There are few peer-reviewed journals in our small field, and conference proceedings like this one often present the most topically relevant current work. Peer review makes these publications immeasurably stronger and more useful. I hope that future OSG postprint editors will take advantage of the expertise in our field and continue to provide peer-reviewed papers.

Last but not least, OSG postprint coordinators Kari Dodson and Emily Hamilton checked citations, references, and image captions, and provided initial editing for style and copy. In many cases, this important work was also significant in terms of time and effort. They also, along with Bonnie Naugle, AIC Communications Director, guided me through the production process.

I speak on behalf of the OSG in thanking all the authors, reviewers, and editorial and publication teams for their hard work on this volume. I hope you will enjoy reading it as much as I enjoyed being managing editor for it. It was truly a pleasure.

Suzanne Davis, Chair of the Objects Specialty Group

COLLABORATIVE STUDY AND PRESERVATION OF COASTAL ALASKAN NATIVE MATERIAL CULTURE WITH MUSEUM STAFF, ALUTIIQ SCHOLARS AND ARTISTS, UNIVERSITY STUDENTS, AND THE VISITING PUBLIC

T. ROSE HOLDCRAFT, SVEN HAAKANSON, ELLEN PROMISE, JUDY JUNGELS, FRAN RITCHIE, PATRICIA CAPONE

ABSTRACT

The Alutiiq Museum and Archaeological Repository in Kodiak, Alaska, and the Peabody Museum of Archaeology and Ethnology, Cambridge MA, partnered together to study and preserve endangered Alaska Native material culture and traditional knowledge. The project stemmed from 2003 consultations and grew through collaborative design and implementation. Staff at both museums along with other consultants worked collaboratively to meet our respective and collective needs and goals. This article shares the working process to achieve the study, preservation, educational exchange, and accessibility of historically significant Alutiiq material culture and knowledge. Results of the project's activities including university and community engagement, and the two museums' current and ongoing partnership are highlighted.

1. INTRODUCTION

The Peabody Museum hosts numerous visits each year from indigenous peoples who come to engage with the collections in various ways. These engagements relate to a core aspect of the Museum's mission: to create links among past and present peoples and local and global cultures whose cultural collections are under the museum's care and stewardship.

During a 2003 consultation, Alutiiq tribal members Sven Haakanson, then director of the Alutiiq Museum, and Ronnie Lind, tribal elder, recognized a watercraft in the Peabody collections as most likely the world's only remaining Alutiiq warrior-whaler kayak. The wood-framed, skin-covered, 15 foot kayak was collected in 1867 and had been in the Peabody's collections since 1869. Because of the early and profoundly disruptive period of Western conquest, historic material from the Alutiiq culture is rare, and less has been published about it than other Alaska Native cultures. The warrior-whaler kayak is likely one of the last of this type to have been traditionally manufactured (fig. 1).

With US expansion and purchase of Alaska, just as this kayak was collected, Alaska Native cultures engaged in a new world order; the lifeway represented by the Alutiiq kayak was immediately in advance of this cusp. The Alutiiq kayak exemplified a turning point in American history. As such the story of this kayak is iconic both of the Peabody Museum's kayak-related collections and of the collection's national significance.

As a result of the 2003 consultation, the Peabody and Alutiiq museums in 2007 began discussing how to support increasing knowledge and preservation of this significant cultural object and related collections of traditional kayaking technology. The Alutiiq Museum focused on material culture and language in their cultural revitalization goals. They had identified kayaks as being among the types of objects that could be instrumental in fostering intergenerational community dialogue around Alutiiq language, arts, and science as building blocks of revitalization. The Peabody Museum was aware that the kayak required physical care, and, in dialogue with the Alutiiq Museum, came to further understand the

Fig. 1. Warrior-whaler kayak, unknown Alutiiq kayakmaker, mid-19th century, wood, Phocini sealskin, humpback whale sinew, hair, wool yarn, plant fiber cordage, 444.5 cm × 71.1 cm × 35.5 cm, © President and Fellows of Harvard College, Peabody Museum of Archaeology and Ethnology, PM# 69-30-10/1619 (digital file# 75530098).

kayak's unique relevance for world heritage, Alaska Native culture, and Alutiiq culture. Kayaks and their accessories embody a chain of traditional technological knowledge, craftsmanship, and spiritual beliefs passed down through generations. When the kayak was made, Alaska natives manufactured traditional items in traditional ways and learned manufacturing skills through apprenticeship. Many of these items in the Peabody, each of which holds significance today¸ are over 140 years old and evoke an era of complex ocean-going travel, trade, and warfare among Alaska Native cultures. Carefully crafted and well-maintained kayaks were a lifeline and supported both everyday economic functions as well as social and spiritual activities. This central means of transportation was tied to all aspects of Alutiiq life. For modern Alutiiq people, the kayak is a symbol of ingenuity. Creating a partnership fueled by diverse (and in some cases threatened) expertise allowed us to most effectively preserve the kayak, to become better stewards for all collections, and to further our goals as educational and research institutions.

2. PROJECT PLANNING

The Peabody and the Alutiiq museums jointly prepared a funding proposal in 2010 to Save America's Treasures, a federal grant program administered by the U. S. Institute of Museum and Library Services (Peabody Museum of Archaeology and Ethnology 2010). The project scope came to involve four kayaks and 125 kayak-related objects from Alaska, all of which are in the Peabody Museum collection. The project prioritized collaborative documentation, research, conservation, and educational exchange through museum and traditional Native approaches. A publicly visible workspace was envisioned to carry out the project activities at the Peabody Museum. In alignment was a Harvard University anthropology course focused on the project, which provided hands-on educational opportunities for undergraduate students and concurrently extended the Alutiiq Museum's goals as described later. A timeline of the entire project is included in the Appendix.

The Alutiiq Museum preserves and shares the cultural traditions of the Alutiiq people through exhibits, educational programs, publications, anthropological research, and the care of traditional objects. The Alutiiq Museum grew from the Kodiak Area Native Association's Culture and Heritage Program, which determined that exploration and celebration of Alutiiq heritage was essential to the health of Alutiiq communities. The Alutiiq Museum, now an award-winning museum nationally and internationally, offers programs designed to promote awareness of Alutiiq history, language, and arts. The layered traditions associated with kayaks and related topics such as subsistence, hunting, and warfare facilitate sharing oral tradition and indigenous language development, which have been successful dimensions of the Museum's educational and heritage building efforts.

The Peabody Museum, as part of Harvard University, has both teaching and research directives serving Harvard students and faculty, outside researchers, and indigenous communities. The museum's mission emphasizes our commitment to an inclusive approach in research, teaching, and public programs development. The Peabody thrives as a gateway for scholars from other institutions, as well as the general public, to engage with the university and its cultural collections. Through this project, Alutiiq consultations would directly contribute to conservation efforts. The project would co-develop and disseminate knowledge for continuing cultural revitalization and for the museums' visiting public.

To ensure the project's participatory and collaborative model, several physical or logistical challenges had to be addressed in the design and planning phase. Regular communication among partners was essential to the project's design. To address the 3,380 mile geographical distance between the kayak collection held at the Peabody and Alutiiq partners living in Alaska, a combined communication structure was developed. At the outset from the planning phase, video-conferencing (via Skype), e-mail, and phone conversations, as well as traditional mail via US Postal Service, served to meet our needs. Incorporated in the grant project design were two on-site week-long visits from three Alutiiq experts who had agreed to participate in this partnership: Sven Haakanson, previously executive director of the Alutiiq Museum, Susan Malutin, a traditional skin sewer, and Alfred Naumoff, a traditionally trained kayak maker (fig. 2). While director at the Alutiiq Museum, Sven had initiated successful youth enrichment

Fig. 2. Alutiiq consultants (left to right, Susan Malutin, Sven Haakanson, Alfred Naumoff) discussing the Alutiiq warrior-whaler kayak © President and Fellows of Harvard College, Peabody Museum of Archaeology and Ethnology, PM# 2010.0.26 (digital file# 66030024).

and community engagement programs and developed the Alutiiq Museum's Traveling Heritage Program. At the Peabody Museum, the project was initiated between the curatorial and conservation departments, each with many years of experience consulting and collaborating on museum and indigenous material culture initiatives.

A proper work space in the Peabody Museum was identified to accommodate the longest kayak and to support activities that aligned with project goals: access, engagement with project consultants, students, researchers, and the visiting public. A first-floor gallery in the Hall of the Native American Indians was modestly renovated with two sets of double-locking doors at opposite ends, fully opened during specified work hours each week (three afternoons) with a simple waist-high stanchion. This design allowed the general public to easily interact with conservation and curatorial staff, students, and consultants in the room and to foster conservation and teaching activities simultaneously.

2.1 PROJECT COMPONENTS

2.1.1 Collaborative Documentation

A project coordinator was responsible for overseeing the overall management of the two-year project. The coordinator, Sandra Dong, has worked extensively with tribal visitors and the museum's departments as part of her ongoing repatriation responsibilities.

Given the size and duration of the project, the number of participants, and the distance between the partner museums, the capture and management of information was designed to support contributions and accessibility. A shared folder on the university's secured research computer server grew to contain a range of documentary information: meeting minutes, Skype conversation notes, transcriptions of consultant interviews, and drafts of project documents that were circulated among team members and between museums for review of content accuracy, sensitivity/specialized knowledge, and voice. These documents included interpretations intended for public or student audiences, such as exhibition information, Harvard course materials, and social media offerings. The folder also contained schedules, financial and time reporting details, public relation activities, scale drawings, and project documentary images and video. Video documentation of project activities included collaborative discussions, student participation, conservation activities (cleaning and stabilization), and interactions among project collaborators.

The museum's collection management database, *The Museum System* (TMS), serves as a crucial tool for documenting objects. Oral commentary, provided by the Alutiiq consultants during their visits to Cambridge or in the course of Skype conversations, was transcribed into the relevant object's record. Conservation staff used a separate but linked conservation module in TMS to record object description notes as new information was gathered, including condition issues discussed with Alutiiq consultants before, during, and after treatment. Object treatment proposals were generated subsequent to discussions with the conservation team and consultants, and detailed photography and material sampling and analysis were also recorded in the object's TMS record.

2.1.2 Material Sampling and Analysis

Through the study of materials and technologies, we have been able to mutually support our different and parallel purposes. The materials of the kayaks and kayak accessories were part of ongoing discussions between the project team members in Cambridge and Kodiak. More specific questions about materials naturally arose during our conversations leading us to seek out additional resources for materials analysis. Some of the foremost questions for the Alutiiq and some likewise directly important to the conservation interventions included: What is the mammalian source of the sinew used for the stitching on the single-man Alutiiq kayak? Are there any traces of pigment, such as the commonly-used red ochre, on the kayak's surface? Was seal oil used to waterproof the skin? What type of wood has been used for the framework? What is the source of gut or inner membrane on parkas worn while kayaking or the skin used on specific kayak models? Decisions were made jointly among the partners about which items to sample and which questions were most important to answer.

Our mutual study of the Alaska objects was supported by university, local and regional museum laboratories, and specialists. For the sinew stitching identification, we collaborated with a Harvard Art Museums' conservation scientist, Daniel P. Kirby, who had been applying a biotechnology technique in protein identification of cultural objects. Peptide mass fingerprinting (PMF) allows for the accurate identification of mammalian materials through the analysis of collagen samples. Although the technique requires destructive sampling, the amount of material taken from objects is less than a square millimeter, which is consistent with micro-destructive sampling sizes routinely used in conservation. Compared with DNA analysis, it offers a better chance of success when looking at aged or degraded samples. Once collected, samples are subjected to an extraction/digestion protocol that cleaves the protein sample, producing a mixture of peptides that is then analyzed by matrix-assisted laser desorption/ionization time-of-flight mass spectrometry (MALDI-TOF MS). This analysis produces a mass spectrum containing characteristic marker peptides (or a "peptide mass fingerprint") that can be compared to reference spectra from known materials for species identification as reported in the work of Kirby et al. (2013) and Promise et al. (2014).

For our application, the first batch of samples was taken from the sinew stitching and the skin covering of the Alutiiq warrior-whaler single-man kayak as well as the sinew and skin of the Yup'ik kayak. Results both confirmed and refined traditional insights. The samples taken from the Alutiiq kayak were identified as sinew from a humpback whale and skin from a type of common seal of the family, Phocidae (fig. 3). The Yup'ik kayak materials were identified as bearded seal skin sewn with caribou sinew.

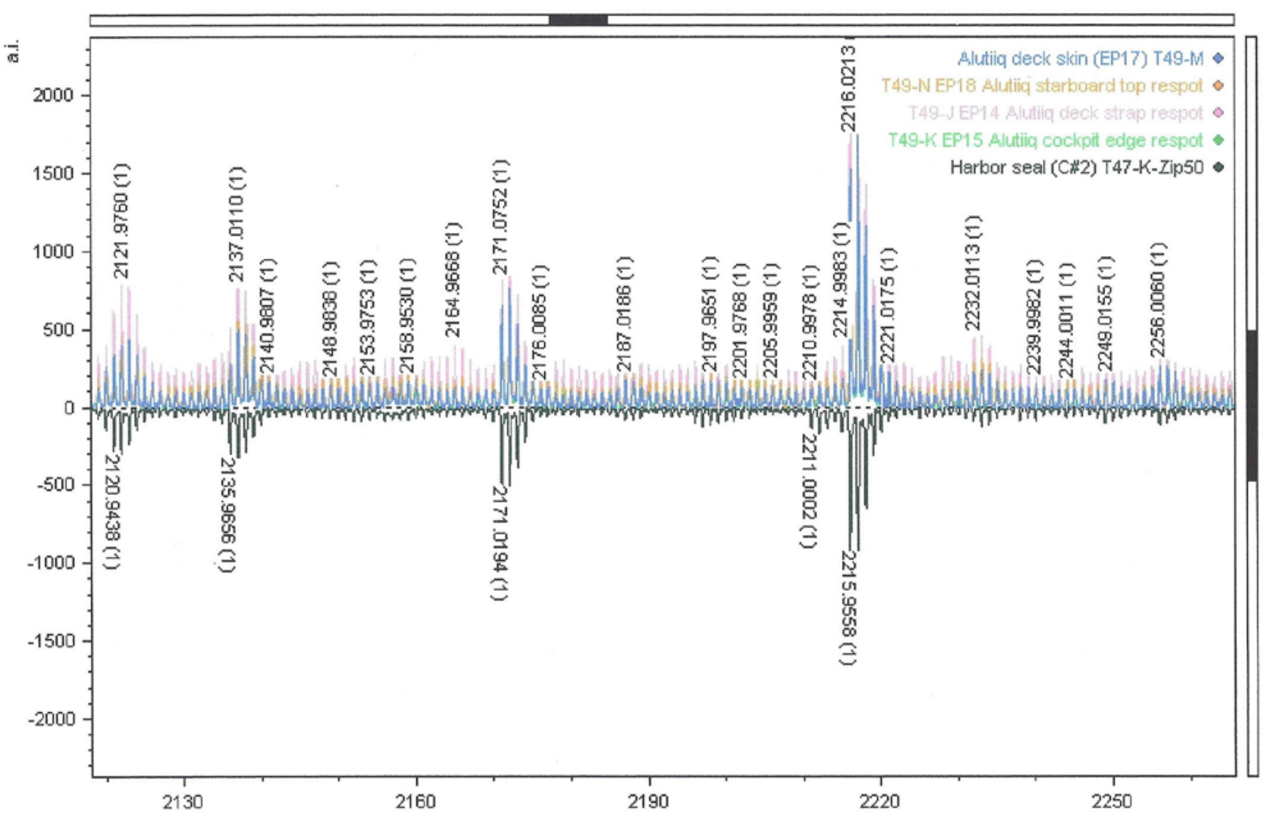

Fig. 3. Comparison of a portion of the peptide mass fingerprints from the Alutiiq kayak covering and deck strap (top, colors) and harbor seal reference (lower in black) a representative member of the Phocini tribe, family Phocidae (Courtesy of Ellen Promise, 2012)

These results were so promising that additional PMF was carried out on samples from the group of objects that the Alutiiq had prioritized during their visits, ranging from gut clothing to harpoons. The PMF technique proved especially invaluable when studying internal tissues such as gut and sinew, which lack the distinguishing features, such as grain pattern or extant hair, often present on external skin. No other existing laboratory method allowed this level of identification.

To address Alutiiq consultants' questions about surface applications or coatings on the skin of the kayaks in relation to better understanding the roles of hunting and warfare as well as the general technology of the kayaks, we consulted the Scientific Research Lab of the Boston-Museum of Fine Arts. Thirty-five samples were collected from the four kayaks and examined by transmitted infrared micro-spectroscopy and gas chromatography/mass spectroscopy (GC/MS). Many samples were found to contain a mixture of oil or oil/wax oil with resulting compounds signaling vegetable oils or oils with some drying character. The type of fat or oil (vegetable and/or seal, whale, or other mammal) may have cultural as well as technological significance. Two samples from the warrior-whaler kayak while showing elevated levels of myristic acid relative to stearic acid, the ratio would be much higher for marine oils (e.g., seal, herring, or whale); thus, it can be stated that the results of the two Alutiiq kayak samples are not consistent with whale oil or seal blubber. The resulting ratios may include a source from sheep, goat, or beef fats and butter fats; however, conclusions are tentative given the limited sampling set. Of the samples taken, no pigment particles were identified on the Alutiiq warrior-whaler kayak.

To identify or corroborate the source(s) of the wood framework of the Alutiiq single-man kayak would require a rather large sample for successful analysis. A Skype conversation among the collaborators confirmed that the information was important enough to proceed. A 1/8 in. × 1/4 in. sample of wood from a broken separated rib on the Alutiiq kayak was sent out to the Forest Products Laboratory in Madison, Wisconsin, which confirmed (to the genus level) that the wood is spruce, as understood from traditional knowledge.

In summary, working closely with research staff at the previously mentioned museum laboratories along with our Alutiiq collaborators made it possible to assess the information provided through oral history and traditions about the animal species harvested for kayak manufacture and other materials in use for related objects. The results from the analyses corroborated traditional knowledge and enhanced existing object information. In several cases, the analytical data provided new information where none existed prior and thus now serves to expand understanding and interpretation of the collections. This knowledge contributes to community understandings about earlier technological traditions and working practices and positively impacts the living art of kayak making and other related art forms. The information likewise serves in the conservation treatment decision-making process.

2.1.3 Collaborative Conservation Treatment Approaches

Engagement with descendant communities was built into the collaborative structure for the project as knowledge, goals, and lines of inquiry were developed. Collaborative conservation between the museums took several forms. Preservation issues were identified in consultation together by the two teams. Decisions about the most appropriate treatment for the objects were developed collaboratively. Questions such as "who decides what treatments are carried out; what is the appropriate extent of conservation; and what methods and materials should be used" were discussed, and decisions were reached on a case-by-case basis. Conservators, for example, early on in the project, prepared prototypes of different types of repair materials and adhesives as options for addressing tears in the skin coverings, and mailed them out to Kodiak Island for the consultants' examination and perspectives. Follow-up discussions on a range of proposed conservation interventions occurred throughout the on-site Alutiiq visits and were further shaped with agreed upon measures for the work process. The level of surface cleaning was informed by analytical results and with Alutiiq consultation. Cleaning for the most part was limited to surface vacuuming with isolated use of solvents.

Outside these Peabody Museum visits, six or seven Skype conversations (scheduled as needed) included close-up visuals of the kayaks and other objects through the use of a tethered portable camera transmitting images to Kodiak from Cambridge. While our Alutiiq colleagues were available via Skype and e-mail, the face-to-face interactions allowed us to study and examine the objects more closely and to work out treatment options in a direct, positive way. Figure 4 illustrates a case study in this collaborative working process as noted by Fran Ritchie, serving at the time as a conservation intern.

"During this project we treated several objects constructed from common and important coastal Alaskan mammalian material—the membrane of internal organs, typically referred to as "gutskin." Despite its diminutive size, a child's waterproof parka was actually a larger project because of its condition and the need for consultation that informed both the cultural context and the extent of treatment in March 2013. The parka was made from strips of tan translucent mammalian intestine, sewn together using sinew. Susan pointed out that the stitch is a lace stitch and that the seams are

Fig. 4. Fran Ritchie consulting with Susan Malutin and Sven Haakanson about a late 19th century child's gutskin parka © President and Fellows of Harvard College, Peabody Museum of Archaeology and Ethnology, PM# 2010.0.26 (digital file# 66030025).

folded in a particular way for waterproofing (the sinew stitching also swells when wet, thus closing off the sewn holes). Women from different regions in Alaska have particular ways of constructing the seams, making provenance identification possible. Sven also showed us that the bottom two strips of the body of the garment have side seams that are staggered (the bottom strip is on the proper left side, the next strip is on the proper right side). The staggering prevents having one full side of seams, which would be a weakness.

Blue and red wool yarns, as well as human hair, were stitched into the seams for the purpose of wicking away water, and for ceremonial garments there was often more elaborate fur and bird trim decorations. Susan noted that she had not seen a child's parka decorated with human hair. She surmised about the purpose of this added decoration in a garment that a child would quickly outgrow. Although waterproof seaming and stitching techniques were used, the decoration and lack of drawstrings suggested to her that, perhaps, this parka was used for a special ceremony, like a baptism. Susan recounted that Russian priests only were able to visit each village sporadically, so a child might not be baptized until older, and thus not an infant big enough to fit this parka. This child's parka, therefore, was most probably made to be both functional and formal.

The child's parka treatment involved conversations with Sven regarding the extent of treatment. Pliable and strong when wet, gutskin becomes stiff when dry. Earlier museum repairs included the sewing together of torn areas. The loose cotton thread repair stitches on the hood and proper right sleeve were removed for treatment because those areas were resulting in new gut tears (fig. 5). The splits were repaired using hog intestine/sausage casings and acrylic adhesive (a 3:1 mix of

Fig. 5. Detail of the child's gutskin parka showing earlier stitching repairs with cotton thread in process of being removed © President and Fellows of Harvard College, Peabody Museum of Archaeology and Ethnology, PM# 08-8-10/73025.1 (digital file# 75720084).

Lascaux 498HV:360HV). A repair on the back of the proper left sleeve and armpit, however, was not removed because that stitching was more secure. Sven agreed that the museum stitching in this region was in good enough condition to remain and that the manipulation required to remove it would likely result in more damage to the fragile surrounding gutskin. Working through this collaborative treatment process served our mutual goals."

During the course of the warrior-whaler kayak's stabilization, the initial impetus for the project, Alutiiq consultants indicated cultural perspectives regarding the broken state of the bow, which rendered the kayak incomplete in appearance and nonfunctional. The form of an Alaska kayak's bow is the main feature that indicates its originating culture. The double-pronged bow of specific shape is characteristically Alutiiq as previously described. It has both stylistic and functional purposes. The consultants explained their sense that replacing the broken bow would be a culturally appropriate treatment to restore its Alutiiq identity and, by appearing more functional or whole, this would restore its potency as a symbol of Alutiiq lifeway. For the kayak's intracultural significance to be most effectively renewed, the bow required replacement. We discussed current approaches in the field of conservation and that replacing the bow would require reconsideration and compromise of current minimal interventive practices. Also, we discussed the benefits of utilizing only reversible conservation treatments. Given the cultural benefits that would be gained by replacing the bow, the opportunity for collaboration it would present, and the great potential for replacement to be completed in a reversible manner, multiple factors outweighed the typical conservation approach, which would have left the broken appearance. Fascinating dialogue followed, which began to envision how a new bow might be traditionally carved, what materials might be used, and how to attach it in a reversible manner. All agreed that completing the bow restoration at the Alutiiq Museum as part of a future collections sharing process, with a native kayak-maker, skin sewer, and with a conservator, would foster expanded educational opportunity and learning for Alutiiq community members and ongoing museum partnership.

3. EDUCATION OPPORTUNITIES

3.1 DISSEMINATION: UNIVERSITY STUDENTS

Both museums' missions emphasize education. The project design included two types of student experiences: an undergraduate seminar and internships for students of varying experience levels and interest.

The Peabody's teaching and research mission and its responsibility to prioritize the interests of the Harvard community were addressed in part through the development of an undergraduate-level course offered through the Anthropology Department, titled *Museum Anthropology: Thinking with Objects*. The undergraduate seminar considered the kayaks and related Alaska collections in the context of exploring the history of anthropology and museum collecting. Students explored the various representations and interpretations of indigenous people in the field of museum exhibition and the modern conservation, care, and treatment of anthropology collections.

The course design aimed for seminar students to take an active participatory role in the class and consultations. Students utilized the knowledge gained through readings and demonstrations to achieve a baseline of knowledge from which they could lead class discussions and engage in the consultations (fig. 6). Selected readings explored through student exchanges highlighted historical context and issues of display, indigenous perspectives on museum representation and conservation, ethics of museum stewardship, and the anthropology of Alaska and the Northwest. Students deployed the knowledge gained through consultations in combination with their reference points in the

Fig. 6. University students engaging with Alfred Naumoff around the 3-person Alutiiq kayak
© President and Fellows of Harvard College, Peabody Museum of Archaeology and Ethnology, PM# 2010.0.26 (digital file# 66030022).

literature and hands-on museum examples to contribute to the modern conservation of the project collections (fig. 7). Each student selected one of the museum objects for the focus of their research, and each researched primary documentation and relevant published literature in order to detail the provenience and provenance of the item. They situated each object within historical and cultural context, detailed the materials and techniques, and assessed the significance of the item. They assessed the physical condition and made preliminary recommendations regarding the conservation care and treatment and were mindful of any cultural considerations to be taken into account in the future care, treatment, and/or display of the object (Clavir 2002; Ogden 2004; Dignard et al. 2008; Richmond and Bracker 2009).

The seminar was offered twice during the project timetable. Project staff and Alutiiq consultants collaborated on the seminar teaching along with contributions from the museum and Harvard archives

Fig. 7. Judy Jungels, Peabody conservator, sharing condition and conservation issues of the kayak models with Harvard University students © President and Fellows of Harvard College, Peabody Museum of Archaeology and Ethnology, PM# 2010.0.26 (digital file# 66030028).

and local area conservation scientists. Conservation staff provided interactive modules on materials, construction technology, object condition assessment, report writing, and a survey of cleaning methods. Conservators discussed conservation methodologies and preventive conservation measures, and students shaped class discussions on conservation readings and case studies.

The project also provided an opportunity for preprogram and graduate students in professional conservation programs to receive culturally enriched specialist training (fig. 8). Conservation interns participated in the development of outreach opportunities with regional and national conservation communities, with the university community, and through teaching opportunities with Harvard students in the anthropology course. Conservation intern Ellen Promise, from the University of Delaware's art conservation program, was engaged in research at UMass-Dartmouth and with scientists at the Harvard Art Museums and the Boston Museum of Fine Arts. Her contributions included presentations at professional gatherings at Harvard, in California, and in Delaware and a filmed interview about the project for a regional magazine's website. Fran Ritchie, conservation intern from the Art Conservation program at the State University College at Buffalo, likewise contributed to the diversity of elements of the project during its second year, and one example is described earlier regarding the collaborative condition assessment and consultative conservation treatment process for the project's selected objects.

Fig. 8. Alutiiq consultants, Alfred Naumoff and Sven Haakanson, discuss with conservation interns, Ellen Promise and Fran Ritchie, details of hair appliqué in a hooded gutskin parka © President and Fellows of Harvard College, Peabody Museum of Archaeology and Ethnology, PM# 2010.0.26 (digital file# 66030023).

3.2 DISSEMINATION: PUBLIC EDUCATION AT THE PEABODY MUSEUM

The visually accessible kayak conservation work space had several features to support the project's goals. The room was designed with a series of inset exhibition cases that featured both objects to be conserved and examples of objects already conserved. In proximity were didactic tools used in communicating specific features of materials and how they were worked into functional objects. A flat-screen monitor mounted on the outside wall of the kayak space featured a montage of landscape and kayaking images from Kodiak Island, Alaska. Another tool used in sharing the context of the project's work was a large-sized moveable mounted map of Alaska.

The conservators working in the space were engaged to reach out to the public to illuminate the collaboration between the Peabody and the Alutiiq communities and to discuss the ways in which conservation bridged the interests of these two groups. Daily visits offered an enriching dialogue about preservation challenges and solutions, traditional/indigenous and contemporary museum preservation approaches, technologies of the constructed objects, and native kayak making. The public could observe and inquire about a range of activities from the cleaning and humidification of a gutskin garment, to a staff discussion about appropriate repair materials for skin and gutskin, to a presentation about new research findings (fig. 9).

Project staff members were equally informed by the knowledgeable and interested visiting public. Among the nearly 3000 museum visitors interested in the kayaks and work activities, recorded in the log

Fig. 9. Ellen Promise, conservation intern, inside the kayak workspace, talking with conservators and visitors about the history and preservation of gutskin bags © President and Fellows of Harvard College, Peabody Museum of Archaeology and Ethnology, PM# 2010.0.26 (digital file# 66030026).

book of visitors to the project space, were local professors with their students, families with children, kayaking enthusiasts, and international travelers. Many guests were familiar with Alaska native culture and had much to share with the project staff. One Alaska Native visitor recalled her grandmother using a gutskin bag, similar to an object being conserved in the work space, for gathering berries. Conversations covered all aspects of materials, construction, age, function, and gender roles in fabrication of the kayaks, as well as approaches to the cleaning and repair of the skin-based objects. Almost everyone enjoyed discovering the unique details of the kayaks' construction. A handheld mirror was used to reflect the interior of the kayak and give visitors a sense of the precise joining of ribs and stringers comprising the wood framework. A professor from a local community college brought students on several separate occasions over the two-year period and specifically chose to come to the museum during the open hours of the kayak space. She incorporated into her lectures, as an educational resource, the dialogue with conservators and other staff on the collaborative project between the two museums.

The Peabody Museum sponsored evening and weekend events for Harvard students and the general public focused in the exhibit gallery. Artist workshops on skin sewing and kayak model making were unique opportunities during the on-site Alutiiq visits to learn further about materials and traditional working processes. Informal engagement with the general public included social media (Facebook, Twitter, student blogs, e-journals) and dedicated kayak conservation project pages on the museum's website. Nontraditional print media platforms ranged from the child-friendly and family-oriented to more scholarly presentation. Students and conservators posted information on treatment and historical/cultural context, newly discovered object construction details, and treatment of project objects. Accompanying these written entries were photographs of the process and of consultation interactions. Visitors were encouraged to visit the Facebook sites for updates on the project.

3.3 DISSEMINATION: COMMUNITY EDUCATION IN ALASKA

For the Alutiiq Museum and its surrounding island village native communities, this project is furthering efforts to revitalize Alutiiq traditional knowledge focused around kayaking technology. As a traditionally trained kayak maker, Alfred had been reaching out to high school programs for several years sharing his knowledge through kayak model-making workshops administered by the Alutiiq Museum (fig. 10). Subsequent to Alfred's second Cambridge visit, he returned to Alaska and constructed a full-sized frame of a kayak incorporating knowledge he gained from first-hand study and collaborative discussions involving both of the Alutiiq kayaks—the single-person mid-19th century warrior-whaler kayak and the three-person kayak—held at the Peabody Museum (fig. 11).

Carvers also have taken inspiration from the paddles. The double-blade paddle, featured here in figure 12, is likely the only of its kind, and it is the subject of several new creations similarly carved by

Fig. 10. Alfred Naumoff teaching model making to high school students in Ouzinkie on Kodiak Island, Alaska (Courtesy of Jill H. H. Lipka, 2009)

Fig. 11. Alfred Naumoff with newly constructed full-sized kayak frame inspired by the Alutiiq kayak at the Peabody Museum (Courtesy of Sven Haakanson, 2013)

Fig. 12. Susan Malutin, Alfred Naumoff, Sven and Eilidh Haakanson featured with a rare double-blade paddle © President and Fellows of Harvard College, Peabody Museum of Archaeology and Ethnology, PM# 2010.0.26 (digital file# 66030027).

today's carvers. Sven and Susan expanded their prior work into the communities offering skin-sewing and other arts enrichment opportunities. As conveyed by Sven, "We can use these items to preserve our culture and to bring this knowledge into a living context that continues to be passed on from generation to generation, rather than tucked away in a book, archived or hidden in a museum collection."

4. SUMMARY: WHAT WAS LEARNED

The project goal was the preservation, exchange, and management of collaboratively created knowledge derived from the study of collections and their materials and the dissemination of that knowledge to a wider audience. The Peabody curatorial research and repatriation department focuses in part on identifying and developing projects that address meet the shared goals of the Museum and descendent communities such as the Alutiiq people.

As staffs of two museums, our combined years of experience and expertise have enabled us to forge a successful collaboration which built on a decade of previous communication and projects. This project's dimensions and the connections that have been possible have been inspiring for everyone. The development and sustainability of ongoing relationships with native communities and museum staff will continue to provide new experiences, ideas, and innovations.

The institutions mutually and individually benefitted through this project. The Peabody learned meaningfully through an improved understanding of object function, technology of manufacture, cultural context, and significance. All of these improve stewardship of the collection in the future. The partnership with the individual Alutiiq colleagues and with the Alutiiq Museum continues to bring benefits. The traditional knowledge revitalized by the Alutiiq consultants has been readily embraced into their communities as noted earlier. Furthermore, Alutiiq community members beyond the project participants already have engaged in creating new kayak-related items that are informed by information from the project.

Strengthening technical investigation of cultural material through broad inclusivity across physical, structural, and cultural differences has achieved greater synthesis creating a framework for focusing resources and perspective for continuing collaborations. The results from the analyses provided information where none existed prior and in many cases corrected misinformation reported in object records, adding to the historical understanding of the kayaks and related objects. The collaborative working process for the kayak project at the Peabody Museum has been captured in part through video documentation and is preserved for future purposes in shaping professional educational programs for traditional and community museums, for developing intercultural exchanges and for use in developing future collaborative conservation-curatorial-exhibition projects and in university seminars. The resulting documentation will further connect Native American community members, the university, the museum's visiting public and web-based participants, and will foster increased research and teaching opportunities and community collaborations.

The next phase of our sharing and partnership focuses on further increasing physical access to this kayak and related objects. The Peabody and Alutiiq museums are in discussion about the possibility of a collections loan. In coming to know more about the warrior-whaler kayak and other kayak-related objects, a methodology and process for their proper care and stabilization has developed that will include their safe transport if a loan were to take place. The bow restoration on the warrior-whaler kayak is being planned to take place at the Alutiiq Museum with a native carver and skin sewer along with a conservation consultant as previously mentioned. Also under discussion is development of the documentary film footage, which had been recorded at the Peabody for use by the Alutiiq Museum, to include a similar exchange of documentary footage of the proposed bow restoration process at the Alutiiq Museum.

This project supports the Peabody's exploration of its role as a twenty-first century museum through ongoing strategic partnerships with our constituent communities. The collections require cultural understanding, continued inclusive study, and the broadest accessibility possible. Within the Alutiiq community, the project will build from the skills gained enriching ongoing youth apprenticeship programs of Alfred in several native villages on Kodiak Island, and the participation of these well-trained Alutiiq youth will enhance their ability to steward the long-term care and preservation of their cultural heritage into the future. The project and ongoing partnership has created a process of collaboration that continues to serve our communities and mutual goals as educational and research institutions.

APPENDIX. PROJECT TIMELINE: HISTORIC ALASKA NATIVE KAYAKS AND RELATED OBJECTS

PROJECT PREPARATION AND MANAGEMENT

8/2011: Project staff review work plan. Consult Alutiiq colleagues via videoconferencing. Prepare kayak work space. Relocate conservation equipment/tools.
10/2011: Move two kayaks to work space with art handlers.
11/2011: Move first group of kayak-related objects to work space.
8/2011–10/2013: Document process with videographer/students throughout project period.

PROJECT IMPLEMENTATION: WARRIOR-WHALER KAYAK AND KAYAK-RELATED OBJECTS

10/2011: Consult Alutiiq colleagues via videoconferencing: assess kayak, discuss work process, condition and treatment options, repair materials, and bow restoration process.
11/2011–5/2012: Document, assess and conserve first group of objects. Sample/analyze material with conservation scientists. Consult Alutiiq colleagues via videoconferencing. Clean and stabilize warrior-whaler kayak. Registrar schedules packing.
1/2012–5/2012: Anthropology class student interaction with museum project staff and Alutiiq colleagues.
3/2012: On-site visit/consult with Alutiiq colleagues at Peabody. Offer public event with Alutiiq artist workshops.
4/2012–9/2012: Document, clean and stabilize second Alaska kayak. Supervise students and interns on kayak project. Continue to consult, document and conserve kayak-related objects.
9/2012: Pack/ship kayak to climate-controlled off-site storage (awaiting loan of the warrior-whaler kayak to Alutiiq Museum). Move three-person Alutiiq kayak to work space with art handlers. Sample/analyze material with conservation scientists.
10/2012–5/2013: Consult Alutiiq colleagues on third kayak and objects (via videoconferencing and on-site visit) as regards materials analysis, cleaning and stabilization of kayak and objects. Sample/analyze material with conservation scientists.
1/2013–5/2013: Anthropology class; student interaction with project staff and Alutiiq colleagues.
3/2013: On-site consult with Alutiiq colleagues at Peabody. Offer public event with Alutiiq artist workshops.
5/2013–10/2013: Pack/ship kayak to climate-controlled off-site storage. Move fourth kayak to work space. Continue to consult, document and conserve kayak-related objects.
10/2013: Move fourth kayak to storage. Project closes on first floor work space and exhibit area.

OTHER ONGOING PROJECT ACTIVITIES

4/2012: Install video loops of project in work space area.
5/2012–10/2013: Prepare interim and final reports to IMLS. Maintain public relations communications. Work with students on social media entries, oral and meeting note transcriptions to collections management database.
10/2013–2014: Dissemination of project results.

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SOURCES OF MATERIALS

Lauscaux 360 HV and Lauscaux 498 HV
Talas
330 Morgan Avenue
Brooklyn, NY 11211
212-219-0770
www.talasonline.com

Natural Hog Sausage Casings
Available from specialty meat markets
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Savenor's Market, 92 Kirkland Street
Cambridge, MA 02138
617-576-6328

T. ROSE HOLDCRAFT has been conservator and administrative head of the Conservation Department at the Peabody Museum of Archaeology and Ethnology developing and overseeing conservation services since 1992. She contributed to the design and implementation of the Peabody's Save America's Treasures grant initiative and for the museum's current NPS-NCPTT funded project. She has been part of international conservation exchanges to Italy, Honduras, and Saudi Arabia. She is a fellow of the American Institute for Conservation with a graduate certificate in Special Studies in Administration and Management, Harvard Extension School, and worked previously at two regional conservation centers. Address: Peabody Museum, 11 Divinity Ave., Cambridge, MA 02138.
Phone 617-495-2487. E-mail: tholdcr@fas.harvard.edu.

SVEN HAAKANSON is associate professor in the Department of Anthropology, University of Washington-Seattle and curator of Native American collections at the Burke Museum of Natural History and Culture. He was previously executive director of the Alutiiq Museum and Archaeological Repository, Kodiak, AK, from 2000 to 2013. He received a PhD in anthropology/archaeology from Harvard University in 2000. Address: Burke Museum, 17th Ave. NE at NE 45th St., Seattle, WA 98195 Phone: 206-543-3210. E-mail: svenh@uw.edu.

ELLEN PROMISE is a 2012 graduate of the Winterthur/University of Delaware Program in Art Conservation with a specialty in objects conservation. Her work at the Peabody Museum as a graduate intern and postgraduate assistant included conservation treatments, public outreach and research, with an emphasis on developing the peptide mass fingerprinting technique as part of the Peabody Museum's Save America's Treasures collaborative Alaska Native kayaks project. She will publish a paper for the International Council of Museums-Conservation Committee in Melbourne in September 2014 on peptide mass fingerprinting. She was the 2013–14 FAIC/Samuel H. Kress Conservation Fellow at the Isabella Gardner Museum and will assume a Mellon conservation fellowship at Historic New England in 2014–15. Address: Historic New England, Collections and Conservation Center, 151 Essex Street, Haverhill, MA 01832. Phone: 207-310-1856. E-mail: ellen.promise@gmail.com.

FRAN RITCHIE earned an MA/CAS in art conservation at State University College at Buffalo in 2013 and an MA in museum anthropology from Columbia University in 2009. Her third year graduate internship at the Peabody Museum of Archaeology and Ethnology at Harvard University introduced her to collaborative conservation work with communities, a practice that she is currently expanding as the Mellon Fellow of objects conservation at the National Museum of the American Indian. Address: NAMI CRC, 4220 Silver Hill Road, Suitland, MD 20746. Phone: 301-238-1421. E-mail: RitchieF@si.edu.

JUDY JUNGELS has been assistant conservator at the Peabody Museum since 2007 and conservator and consultant for the Peabody Museum's Save America's Treasures collaborative Alaska Native kayaks project, and has a recent article in the *Collections* journal on the Peabody's collection of Alaska Native kayak models. She earned an MA/CAS in Art Conservation from the State University College at Buffalo, and an MFA in sculpture from the University at Buffalo. She has worked at the Worcester Art Museum, the Corning Museum of Glass and as a project conservator with research teams in the United States, Turkey, Honduras, and Peru. Address: as for Holdcraft. Phone: 617-496-9745. E-mail: jjungels@fas.harvard.edu.

PATRICIA CAPONE is an associate curator at the Peabody Museum of Archaeology and Ethnology. She manages curatorial and repatriation responsibilities working closely with the peoples and topics of North America. She earned a PhD in anthropology/archaeology from Harvard University. Address: as for Holdcraft. Phone: 617-496-3702. E-mail: pcapone@fas.harvard.edu.

PINE PITCH: NEW TREATMENT PROTOCOLS FOR A BRITTLE AND CRUMBLY CONSERVATION PROBLEM

NANCY ODEGAARD, MARILEN POOL, CHRISTINA BISULCA, BRUNELLA SANTARELLI, MADELEINE NEIMAN, GINA WATKINSON

ABSTRACT

In 2011, the Arizona State Museum was awarded a Save America's Treasures grant to carry out a conservation survey of more than 22,000 basketry objects, including over 4000 ethnological baskets. This survey identified around 100 pitch-coated baskets, and a significant number were found to be in extremely unstable condition. Severe oxidization of the pitch had resulted in cracked, crizzled, brittle, and crumbly surfaces. To prevent further damage, the baskets were triaged; those considered at imminent risk for loss were treated mid-survey using solvent reactivation. This interventive conservation treatment stabilized the remaining pitch surfaces, allowing the baskets to be safely moved to their new storage locations. It also enabled future analysis and the research of the materials and technology used to fabricate these unique baskets.

This project illustrates the value of combining survey, analysis, and treatment activities. It initiated a more in-depth analysis of the pitch used in Southwest Native basketry. Pitch samples from over 70 baskets were analyzed with Fourier transform infrared spectroscopy (FTIR). These results were compared to fresh pine resin heated to simulate traditional pitch processing. Differences in appearance among the pitch surfaces appeared to correspond to different processing regimes. FTIR analysis also confirmed that this conservation treatment did not alter the chemical integrity of the pitch coating.

1. INTRODUCTION

American Indians of the Southwest have long employed pine pitch as a surface coating for basketry. Various trees of the *Pinus* genus exude a thick resin that can be heated and applied hot as a coating to baskets to make them water tight (fig. 1).

An item-by-item conservation survey and storage upgrade project, funded with a national Save America's Treasures grant, included more than 22,000 objects with over 4000 ethnological baskets. Within the ethnology collections, 100 pitch-coated baskets were examined. Seventy of these baskets were determined to be highly unstable due to severe oxidation of the pitch coating. Surfaces were characteristically blanched, cracked, crizzled, brittle, and crumbly. Underpainted designs on many of the baskets had become obscured by oxidized pitch and soiling. Entire surfaces suffering active loss were often accompanied by small Ziploc bags of pitch crumbs inside the baskets, revealing an ongoing need for conservation.

2. OVERVIEW OF THE ASM PITCH BASKET COLLECTION

Pitch baskets were used for transporting water. Baskets may have been repaired over time for reuse but the damages from oxidation make this difficult to determine. Some scholars also indicate there may have been a spiritual function (Simpson 2003). As seen in figure 2, a majority of the pitch baskets in the ASM collections were made by Apache weavers, including the Western, San Carlos, White Mountain, Jicarilla, and Mescalero Apache tribes. Other tribes whose pitch baskets are in the collection include the Navajo, Northern and Southern Paiute, Havasupai, and Hualapai.

Fig. 1. San Carlos Apache woman carrying a pitch-coated water basket from a tumpline around her head (one typically sees use wear and breaks in basket tumplines, in the carrying straps and on the basket pitch coatings, which would have been in contact with the carrier's back) (Courtesy of A. F. Randall, ca. 1883, Western History/Genealogy Department, Denver Public Library)

Of the 100 baskets, 77% are twined, 20% are coiled, and 2% are wicker or twined technology, and the weaving materials are typically stems of Sumac (*Rhus trilobata*) and/or Willow (*Salix sp.*). Tanner (1982) has suggested that before the application of a pitch coating, baskets were often initially waterproofed with a caulking of juniper or other leaves rubbed into the interstices of the weave. While the application of hematite powder imparted a red tint, some baskets were also painted with commercially manufactured red paints. The color of the baskets is subjective, because of the variations in manufacture technology and additives. Ferg (1987) indicates that clan-related designs were brushed on with ground charcoal pigment and other designs were woven in with devils claw seed pod (*Proboscidea*

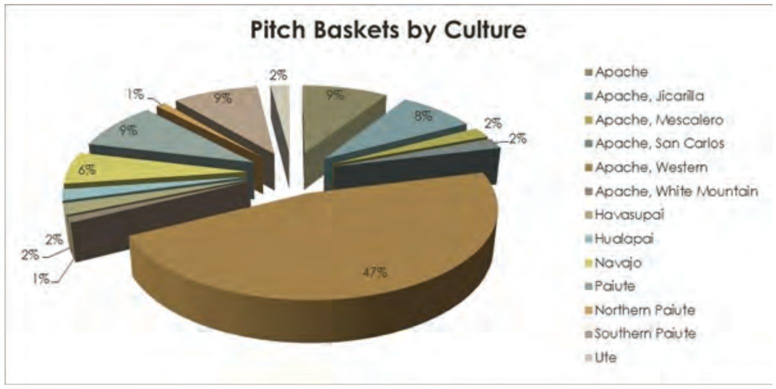

Fig. 2. Pitch baskets by culture at the Arizona State Museum

parviflora). Some Jicarilla baskets had pitch applied only to the interior surfaces with white clay applied to the exterior, and in some instances with polychrome-painted designs over the clay.

Among the possible sources of tree resins in the Southwest, the most common pines found at lower elevations are pinyon (piñon) pines (Richardson 2000) and many descriptions of pitch baskets specifically cite its use (Tanner 1982). Two species of highly resinous pines, *Pinus monophylla* and *Pinus edulis*, are also widespread (Fogg 1966; Richardson 2000; Smith 2000). Ponderosa pine (*Pinus ponderosa*) and Arizona cypress (*Cupressus arizonica*) are also resin producing trees in the area.

3. THE PROBLEM: OXIDATION AND ITS SYMPTOMS

It has long been observed that over time the pitch coatings on baskets oxidize because of environmental exposures including excesses of UV light, temperature, relative humidity, and pollutants in museum storage and exhibition that can cause a dramatic change in appearance. On the basis of empirical observations of the ASM pitch basketry collection, the more transparent and red pitch coatings tend to become discolored, crumbly, and brittle, resulting in flaking and the loss of surfaces (figs. 3–5). The darker, heavier pitch coatings tend to exhibit deeper cracking, discoloration, delamination, and have more localized loss with larger pieces rather than fine crumbles (fig. 6).

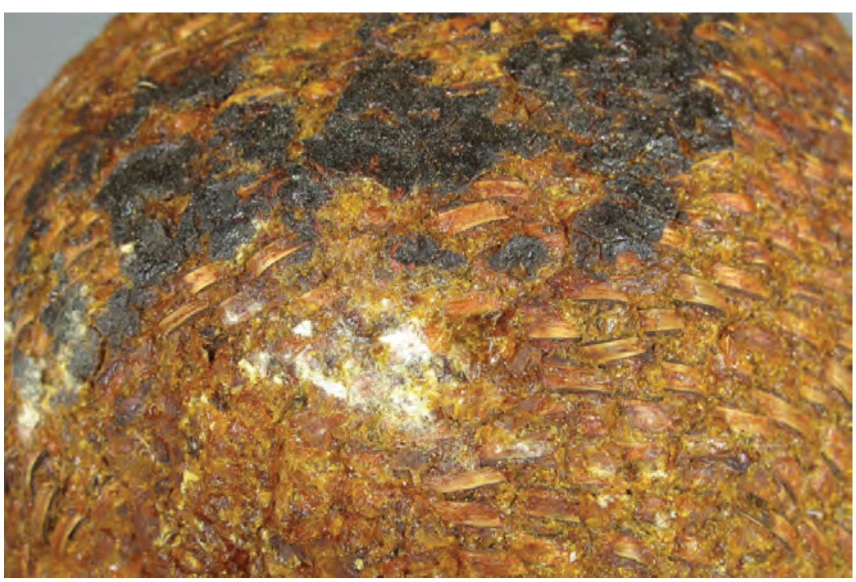

Fig. 3. Lighter-colored pitch exhibiting discolored, crumbling, and brittle surfaces due to oxidation (Courtesy of Marilen Pool)

Fig. 4. Cleaving pitch surfaces resulting in loss (Courtesy of Marilen Pool)

Fig. 5. Cracking and soiling of surfaces (Courtesy of Marilen Pool)

Fig. 6. Darker, opaque pitch exhibiting deep cracking, discoloration, and loss (Courtesy of Marilen Pool)

4. CONSERVATION TREATMENT PROTOCOLS

To prevent actively ongoing surface loss, these baskets were treated mid-survey. The intervention allowed baskets to be moved through the survey process and into their new storage location without additional damage and loss. This also assisted the curatorial activities related to how the baskets were placed in storage on the basis of their cultural designations and upgraded and improved the data entered into catalog records. The conservation treatments prompted further analysis and research on pitch basketry technology.

A literature review of pitch basketry conservation found no published articles; however, treatment reports and the evidence of treatments were noted in several museum collections. These include the use of B-72 acrylic consolidants, glycerin, and a butane torch. For example, a curator described his father's treatment of a pitch basket in the 1970s by saying, "When the torch was used, all the lumps were smoothed out and the appearance was glassy" (Ferg 2014). The results of these various treatments have not been particularly successful in stabilizing the pitch surface.

Conservators of paintings on canvas have previously noted the problem of aging pine resin coatings related to increasing oxidation over time:

The higher oxidized compounds formed in the *Pinaceae* resins during ageing are responsible, in some extent, of the changes in physical and chemical properties of the varnish film and, therefore, they affect directly the changes in solubility undergone by the varnish film. Thus, dissolution of higher oxidized compounds notably enhances the cleaning effect. The study carried out has proved that solvents exhibiting greater capacity for establishing hydrogen bond forces, such as ethanol, are the most effective for dissolving such compounds. Thereby, these solvents are especially effective for cleaning aged varnishes (Osete-Cortina and Doménech-Carbó 2005, 152).

Two considerations that guided the conservation treatment protocol were:

1. We did wish to consolidate the crumbs, integrate cracks, diminish scuffs and blanched areas, and restore some of the original intended gloss, but from a cultural perspective, we were hesitant to add new materials to the baskets. In conversation with Navajo weaver Etta Rock about the pitch basket appearance in 2004, conservator Dr. Nancy Odegaard noted that the look of a newly made pitch basket is always glossy. While it is understood that aged baskets will naturally become dull and deteriorate, Etta felt that weavers prefer to see them as they were made.
2. Selecting a method to reactivate the pitch surface without the use of a consolidant had been considered and tested on other materials by Odegaard and Pool (1999). On the basis of solubility testing and a desire to not introduce new and different material, the use of solvents to reactivate damaged coatings was considered an appropriate approach.

4.1 TREATMENT

To stabilize the damaged pine pitch surface, the baskets were first placed in a glove bag solvent chamber. A glove bag is a flexible, polyethylene chamber with built-in gloves that lets you work in a totally isolated and controlled environment. We placed the bag over a cube-shaped frame made of 1 in. PVC pipe fittings and sealed it with clamps.

An open container of ethanol was placed inside the glove bag for up to 24 hours for vapor conditioning of the surfaces (fig. 7). Sometimes dry surface particulates can be removed before reactivation if the surface is stable enough.

Fig. 7. Solvent chamber for conditioning pitch surfaces (Courtesy of Marilen Pool)

The baskets were moved to the fume hood and a fine mist of ethanol was applied with a handheld pressure sprayer to reactivate the damaged pitch and to stabilize the surface. Reactivated surfaces were initially tacky; therefore, the upper and lower portions of the basket were treated separately. After the first portion was reactivated, it was propped for drying on a plastic beaker to ensure the initially tacky surface did not adhere to anything else. Upon drying, the basket was inverted and the remaining untreated surface was reactivated. Brushes, Teflon film–covered swabs, and Kimwipe tissues saturated with ethanol were employed for cleaning and securing difficult surfaces. Handmade Teflon-covered swabs rolled across the pitch surface were especially useful for imparting a varied surface appearance during solvent reactivation depending on the individual basket (figs. 8, 9).

Fig. 8. Misting the damaged pitch surfaces with ethanol (Courtesy of Marilen Pool)

Fig. 9. During treatment, applying ethanol by brush (Courtesy of Marilen Pool)

An added benefit with this treatment approach is that the reactivated pitch can act to mend simple tears and breaks in the basket weave, eliminating the need for additional mending materials such as Japanese papers and paste. Even very structurally unstable baskets with large areas of loss were significantly strengthened and improved by stabilizing the surfaces. It should be noted that the baskets were allowed to dry for at least 2 days in our low RH controlled conservation lab before subsequent handling, documentation, and storage (figs. 10–12).

Fig. 10. Old storage for baskets at the Arizona State Museum (Courtesy of Nancy Odegaard)

Fig. 11. New storage for baskets at the Arizona State Museum (Courtesy of Marilen Pool)

Fig. 12. New storage for pitch baskets at the Arizona State Museum (Courtesy of Marilen Pool)

5. PINE PITCH ANALYSIS

During the treatment, we noted that not all pitch surfaces reacted the same to the application of solvent. Some pitch tended to solubilize more rapidly, reactivating and readhering to their woven surfaces with less pressure. In other cases, the pitch solubilized less rapidly, requiring more ethanol application between the pitch coating and basketry substrate as well as greater pressure to readhere loose pieces. The chemical analysis of detached and loose pine pitch particles addressed two questions: (1) Did the difference in solubility of pitch surfaces reflect different compositions? (2) Did the reactivation treatment chemically alter the pitch?

5.1 TREE RESIN COMPOSITION

Tree resins are terpenoid-based chemicals that are secreted at a site of physical wounding. They consist of higher-molecular-weight terpenoids with a lower-molecular-weight volatile fraction of mono and sesquiterpenes or phenolic compounds that act as a solvent to carry the larger terpenoids during secretion (Langenheim 2003). In most pine resins, the predominant resin acids are abietic and pimaric type terpenoids (fig. 13), but the components of pine resins will vary depending on species and other environmental factors (Joye and Lawrence 1967; Smith 2000; Silvestre and Gandini 2008). Fresh resin contains ~75% resin acids, with the remaining 25% being mostly volatile terpenoids and phenolics (Zavarin et al. 1971; Panda 2008). This fraction is terpentine and is primarily α -and β -pinene (Panda 2008). Pine species can show a large seasonal variation in components, particularly total phenolics (Nerg et al. 1994).

5.2 EXPERIMENTAL METHODS

Pitch from nearly 70 baskets in the collection were analyzed with FTIR to assess if there was chemical change as result of the treatment and to identify any compositional differences between pitch surfaces. In most cases, loose pitch fragments collected before conservation treatment were used. For comparison after treatment, small samples (< 0.5 mm^2) were removed with a scalpel. FTIR spectroscopy was performed on a Thermo-Nicolet iS10 spectrometer with a Smart-iTR attachment, equipped with a He-Ne laser and CCD detector. Spectra were recorded in reflection mode, from 4000 to 650 cm^{-1}, with 256 scans at 4 cm^{-1} resolution, and using OMNIC ESP 6.1a software.

Heating experiments were also carried out on raw pine resin to study changes in the chemistry of pine resins during processing. Samples of fresh resin were collected by removing excess exuded resin from the surface bark of pinyon pines from the Navajo Reservation in northern Arizona, approximately 30 miles west of Canyon de Chelly (probably *P. edulis* or *P. monophylla* based on geographic distribution). The samples were heated using a VWR 1320 oven to the temperatures described in section 5.3.2 later. The resin samples were then held at each temperature for 30 minutes and monitored with a thermocouple (Cole Parmer type J thermocouple). At this time, changes in flow properties and color were recorded. It should be noted that the collected resin contained contaminants, primarily bark, and other woody materials from the scraping of

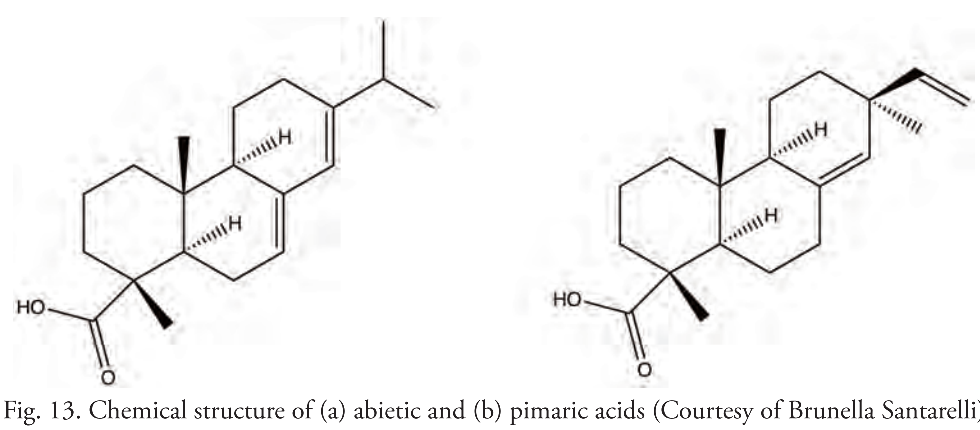

Fig. 13. Chemical structure of (a) abietic and (b) pimaric acids (Courtesy of Brunella Santarelli)

the resin from the trees. To identify the impact of these wood contaminants in these heating experiments, pitch samples were divided into two subgroups. In the first group, the resin was heated with the woody material present in it. In the second group, the resin was heated until fluid and the woody material was removed by pouring off the resin. FTIR spectra of the resin were collected after each heating step.

5.3 RESULTS

5.3.1 Analysis of Pitch from Baskets

Representative FTIR spectra of pitch samples removed from pitch baskets are shown in figure 14, and bands and band assignments are shown in table 1. Band assignments were made based on published studies of tree resins and processed pitch products (Robinson et al. 1987; Senftle and Larter 1988; Font et al. 2007). The spectra are consistent with diterpenoid resins and match reference spectra for pine resin

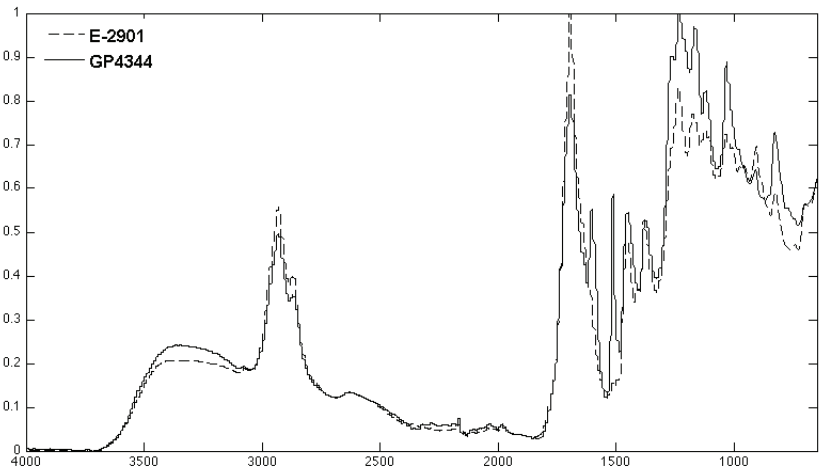

Fig. 14. FTIR spectra (absorbance units vs. wavenumber, normalized) of samples of pitch from baskets ASM E-2901 and ASM GP4344

Table 1. Band Frequency and Assignment of Typical FTIR Spectra of Pitch from Baskets (Courtesy of Christina Bisulca and Brunella Santarelli)

Band Frequency (cm)	Band Assignment
3070	(C=C)
2930–31	$\nu(CH_2)$
2869	$\nu(CH_2)$
1694	$\nu(C{=}OO)$
1604–10	$\nu(C{=}C)$
1514–16	$\nu(C{=}C)$
1452–54	$\delta(CH_2)$, $\delta(CH_3)$
1375–83	$\delta(CH_3)$
1260–75	$\nu(C{-}O{-}H)$, carboxylic acid
1240–45	$\nu(C{-}O{-}H)$
1123–26	$\nu(C{-}O{-}C)$, ester
1107–20	$\nu(C{-}O{-}C)$
1032–35	$\nu(C{-}O)$
908–10	$\delta(C{=}CH_2)$

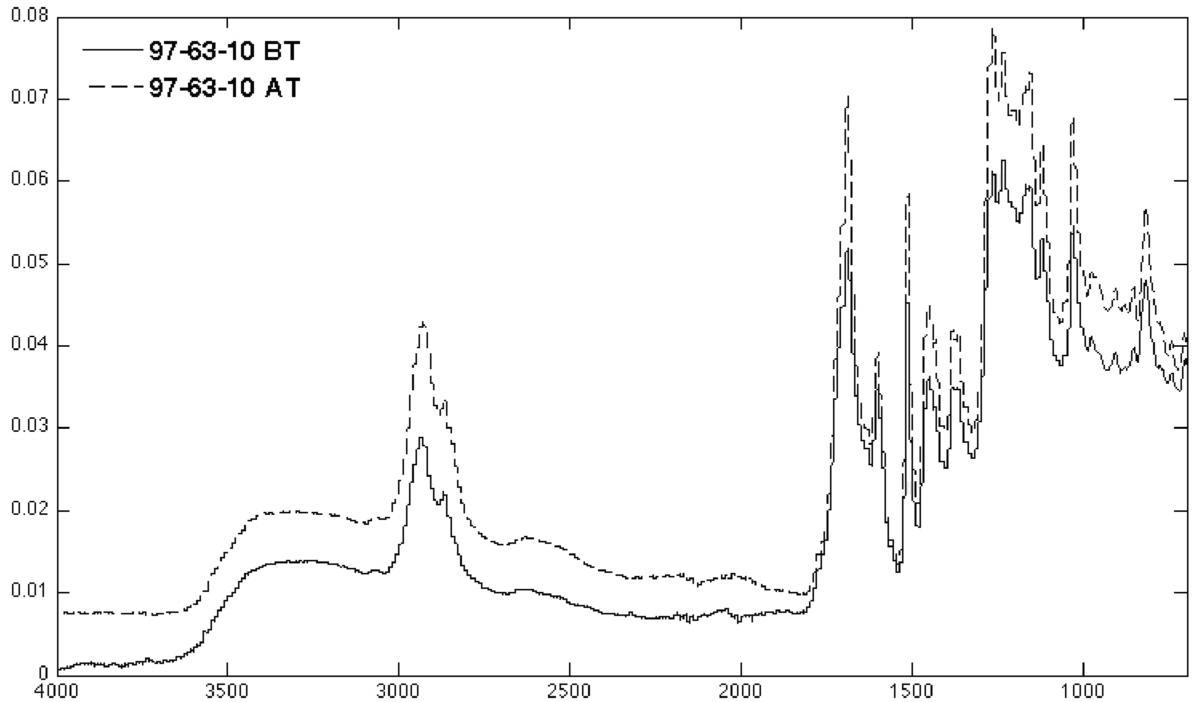

Fig. 15. FTIR spectra (absorbance units vs. wavenumber, normalized) of pitch sample before and after conservation treatment

(Derrick et al. 1999). It is, however, not possible to distinguish between various pine species with FTIR. The presence of abietic acid was also confirmed with the microchemical Raspail test that uses sugar and sulfuric acid to determine the presence of rosin (Odegaard et al. 2005).

Figure 15 shows the FTIR spectra from pitch before and after treatment with ethanol. No changes are observed after the conservation treatment, suggesting that this treatment does not interfere with the chemical composition of the pitch. Future analysis with other techniques such as gas chromatography-mass spectrometry (GC-MS) should provide more detailed information on the effects of solvent treatment.

FTIR spectra before treatment with ethanol revealed some notable differences in the pitch chemistry among the baskets sampled. Approximately 15% showed significant aromatic ν(C=C) bands at ~1605 and 1515 cm^{-1}, which are not observed in fresh pine resin. In other studies of pine pitch, these bands are attributed to aromatic groups formed during the processing into pitch (Robinson et al. 1987; Font et al. 2007). Figure 14 shows the FTIR spectra of pitch with and without an aromatic component. In general, the pitch coating of baskets with a significant aromatic component seen in the FTIR spectra is dark in color and opaque, similar to the pitch shown in figure 6. Those with a low aromatic component are typically translucent, and range in color from golden yellow, to red, to dark brown (figs. 3–5).

5.3.2 Heating Experiments

Heating experiments were also carried out using fresh pine resin collected locally. These experiments revealed that temperature directly impacted the color and working properties of the resin. The color changes observed during the heating of the resin are described in table 2. The fresh resin was a soft, opaque resin, white to yellow/brown in color (fig. 16). The resin became clear and translucent with low heating (80–90°C), and then hardened upon cooling (fig. 17). The resin did not become fluid enough to flow readily until it was heated to temperatures above 100°C. The resin remained a yellow color until a temperature over 180°C was reached, at which point the resin began to darken significantly (fig. 18). This color change appeared to be a function of high temperatures: resins heated at a constant 175°C show very little color change even with heating times up to 6 hours.

When the resin was heated without the woody component, no aromatic $\nu(C=C)$ bands were noted in the FTIR spectra even at temperatures up to 210°C. This finding is consistent with other reports that suggest that dehydrogenation leading to double-bond formation and formation of aromatic groups in resin acids is achieved at temperatures well over 200°C (Beck et al. 1998; Silvestre and Gandini 2008).

Table 2. Heating Experiments (Courtesy of Christina Bisulca and Brunella Santarelli)

Heating Temperature (°C)	Observations
90	Softened, no flow, sample hardens upon cooling due to loss of volatile component
100	Some flow, cools very rapidly, no significant chemical change based on FTIR
120	Golden yellow, flows easily but still viscous, no chemical change in FTIR
140	Starts to yellow slightly, flows readily
160	Flows readily, but is much more brittle when cooled, some chemical changes noted in FTIR
180	Golden brown/golden yellow, very fluid
200	Deep brown, very fluid

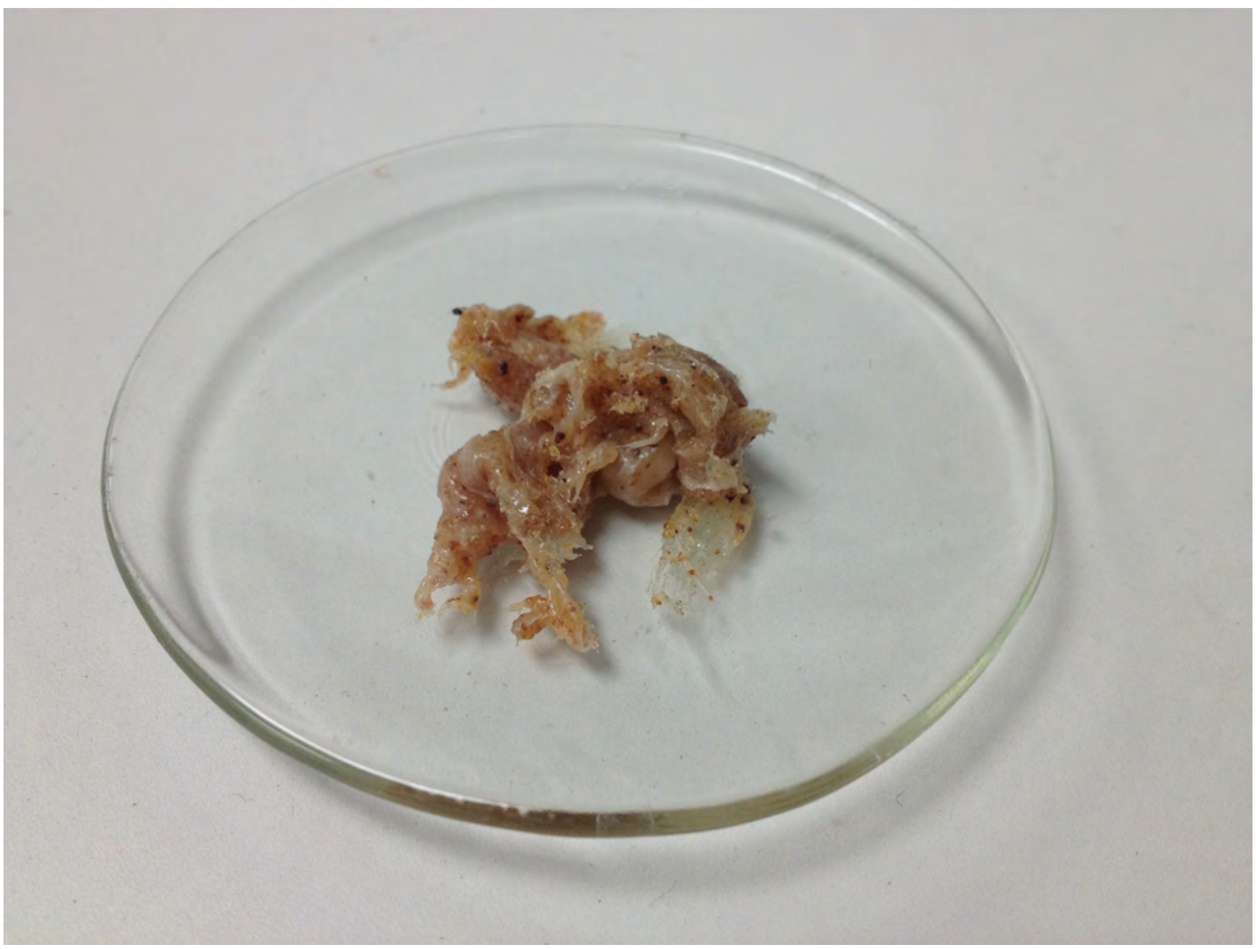

Fig. 16. Fresh resin as collected (Courtesy of Christina Bisulca)

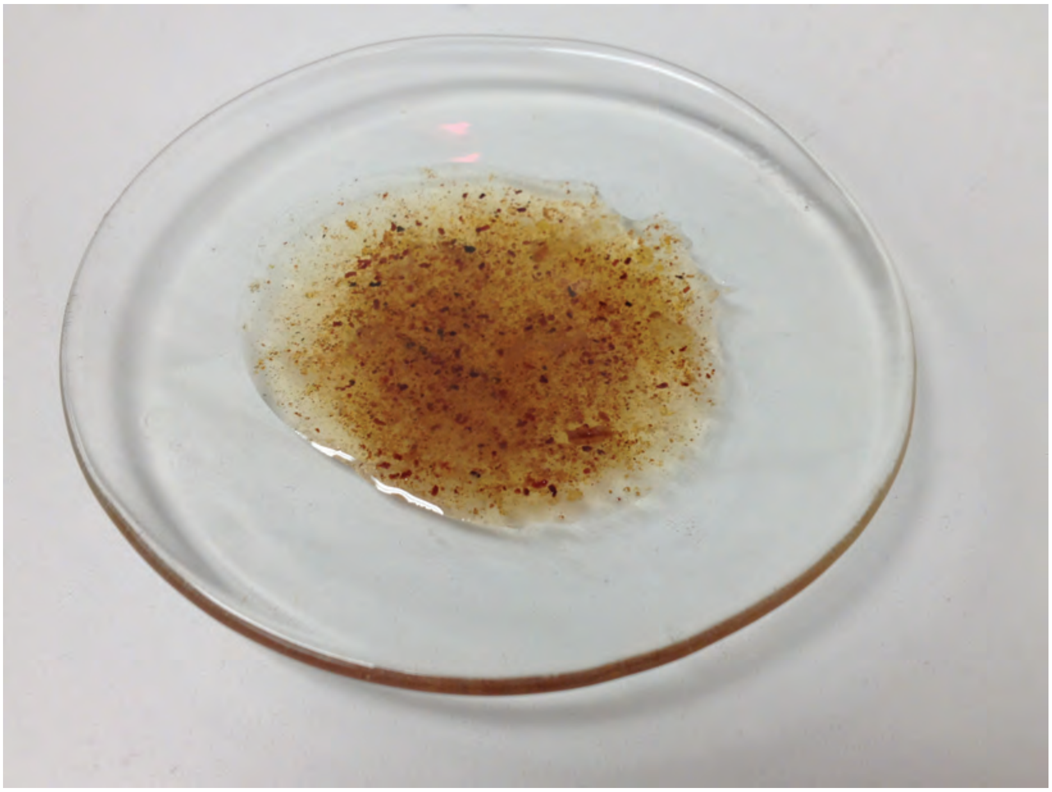

Fig. 17. Resin after heating to 90°C. Small particulates within the resin are pieces of bark or wood that were imbedded in the resin during exudation from the tree (Courtesy of Christina Bisulca)

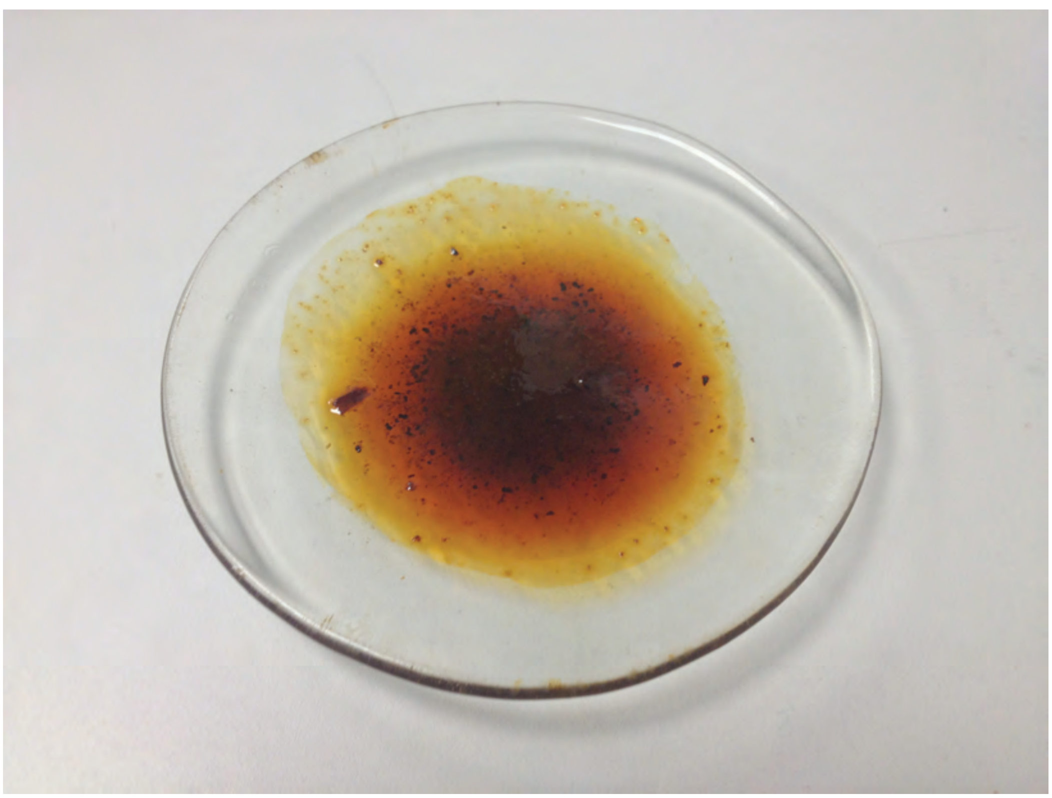

Fig. 18. Resin after heating to 200°C (Courtesy of Christina Bisulca)

FTIR analysis of the samples, however, showed increased oxidation upon heating, with the formation of a shoulder in the main carbonyl band at ~1725cm^{-1}, increased absorption of ν(C–O–C) bands in the 1200–1100cm^{-1} range, ν(–OH) in the ~3500–2500cm^{-1} range, and ν(C–O–H) at ~1240cm^{-1}.

When the resin was heated with the woody component present (as collected), significant changes were seen in the FTIR spectra. Most noteworthy were the formation of aromatic bands at 1515 and 1604cm^{-1} and the formation of a shoulder on the carbonyl band at ~1725cm^{-1}. Because these bands were not seen in the resin samples heated without a woody component, it is assumed that these changes are due to a reaction of the woody materials with the resin acids.

5.4 DISCUSSION

In the examination of the FTIR spectra of pitch basket samples, pitch coatings with a high aromatic component are typically dark brown to black opaque. Translucent yellow, red, to deep ruddy brown pitch basket coatings have a low aromatic component. On the basis of the heating experiments, it can be surmised that during manufacture, the darker pitch coating with a high aromatic component was heated at high temperatures with woody materials present in the resin. Conversely, pine pitch baskets with lower aromatic components were most likely heated with the wood material removed. In appearance, these coatings are translucent, and the color range from yellow to deep ruddy brown in these baskets is indicative of heating temperatures.

The formation of aromatic groups in processed pine resin is associated with *wood tar,* a product typically produced by heating highly resinous wood (Senftle and Larter 1988; Beck et al. 1998; Font et al. 2007). In our experiments, the reaction occurred even with minor contaminants from bark present in the resin as collected. The lack of an aromatic component in some pitch may suggest some form of processing of the resin before or during heating to preferentially remove the woody component, or else specialized collection techniques. Heat used in the technology of pitch baskets is described by several anthropologists (Tanner 1983; Simpson 2003), but a detailed description of the process is not given. In commercial production of pitch ("naval stores"), woody contaminants are removed by filtration (Panda 2008).

To confirm that the presence of wood during heating is the primary difference between these two pitch types, samples of each type were taken from pitch baskets for analysis. Figure 19 shows microscope images of pitch samples dissolved in ethanol. The sample taken from the dark opaque pitch with a high aromatic component shows that this pitch does indeed have a greater amount of woody contaminants (Fig. 19a, 19b).

Although the precise reactions produced by heating were not determined in this study, there were some unexpected results. The formation of aromatic bands in the resin itself normally associated with higher temperatures (over 300°C) was found to occur as low as 170°C when the resin was heated with woody materials present. The precise nature of the aromatic component noted in the FTIR spectra is currently under further investigation.

A concern noted during treatment was how the presence or absence of an aromatic component in pitch and the increased oxidation will affect its solubility. For example, when the darker, opaque pitch was observed to be less soluble and required more ethanol and increased pressure to readhere loose pieces, our experiments suggest that this is due to the difference in chemical composition of the pitch, which, in turn is related to the physical properties of the coatings.

6. CONCLUSIONS

Conservation surveys have evolved greatly over the years at the Arizona State Museum. They have moved from sequential steps of condition survey, proposal, analysis, experimentation, treatment to a more integrated approach. This project illustrates the value of combining survey, analysis, and treatment activities. The survey identified pitch baskets in an unstable condition prompting

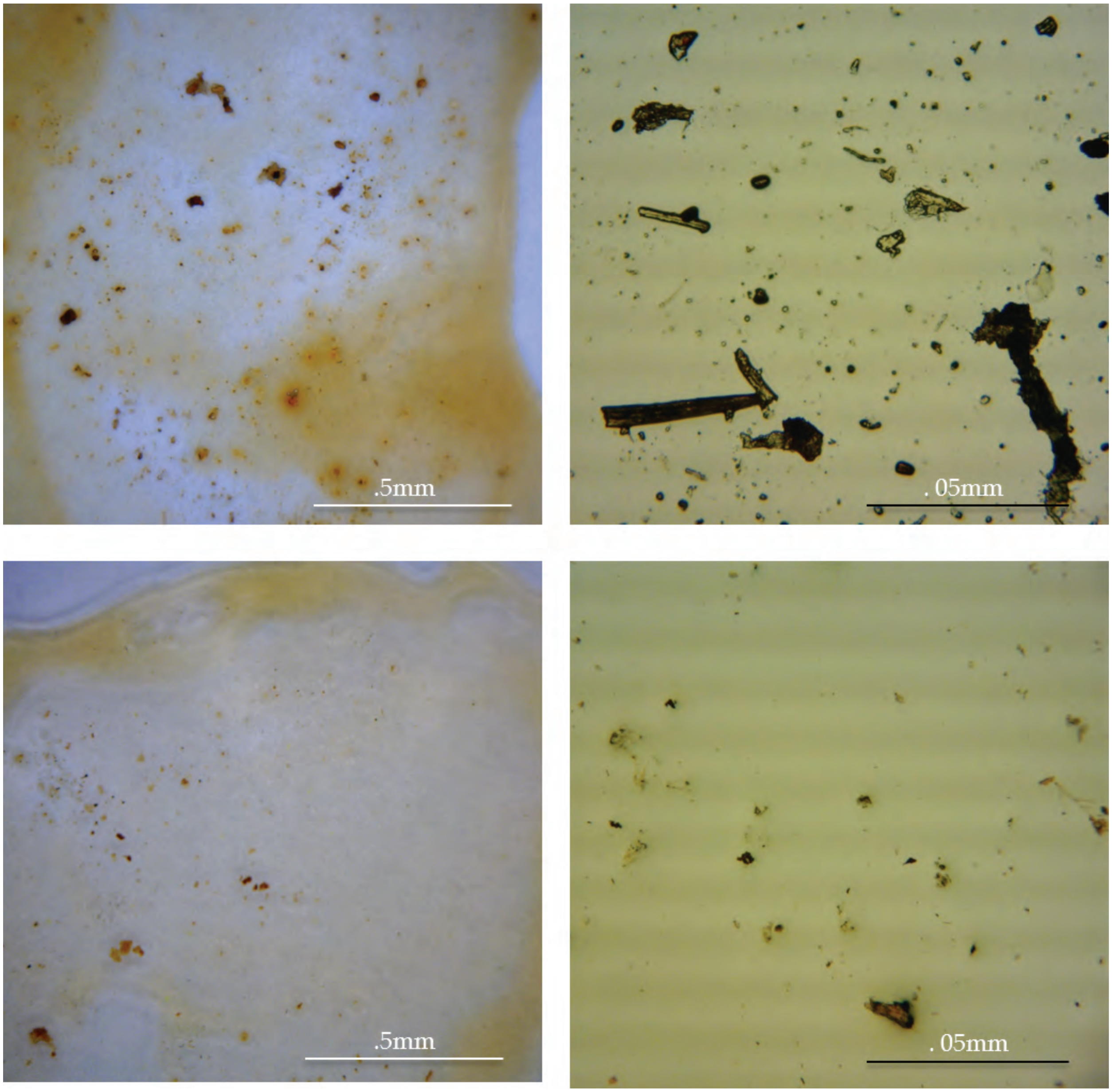

Fig. 19a. Sample of pitch dissolved in ethanol taken from a deep brown, opaque pitch coating with a high aromatic component in FTIR (ASM GP4344). 19b. High magnification image of (a) showing woody contaminants present in the pitch. 19c. Sample of pitch dissolved in ethanol taken from a light, translucent pitch coating with a low aromatic component in FTIR (ASM 1983-65-1). 19d. High magnification image of C showing minimal contaminants from woody materials. (Courtesy of Madeleine Neiman)

conservation treatment; the treatment required a protocol that would address ethical cultural and conservation concerns as well as questions related to chemical composition; the composition questions brought about analytical studies; the analytical studies supported the ethanol reactivation treatment protocol and provided information that clarified aspects of the lighter and darker appearance of pine pitch basketry technology. When allowed to be carried out in tandem, these activities serve to inform each other resulting in better care and understanding of collections. This project and its outcomes illustrate the benefit of conducting condition surveys–they highlight important preservation needs in a holistic way.

ACKNOWLEDGMENTS

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NANCY ODEGAARD, PhD, FAIC, FIIC, is the conservator and head of the preservation division at the Arizona State Museum. She is also a professor in the School of Anthropology, Department of Materials Science & Engineering, and Drachman Institute at the University of Arizona. She received her MA at George Washington University and advanced certificate in conservation at the Smithsonian, and earned a PhD in resource, environment and heritage science at the University of Canberra, Australia. She is a fellow of the AIC and IIC. Address: Preservation Division, Arizona State Museum, University of Arizona, PO Box 210026, Tucson, AZ 85721-0026. Tel: 520-621-6314. Fax: 520-621-2976. E-mail: odegaard@email.arizona.edu

MARILEN POOL, PAAIC, is a project conservator for the Save Americas Treasure's Basketry Project at the Arizona State Museum, University of Arizona. She received an MA in museum studies from Oregon State University and a diploma in Conservation from Sir Sandford Fleming College. Address: Preservation Division, Arizona State Museum, University of Arizona, PO Box 210026, Tucson, AZ 85721-0026. Tel: 520-621-6314. Fax: 520-621-2976. E-mail: mpool@email.arizona.edu

CHRISTINA BISULCA is a chemist in the Preservation Research and Testing Division of the Library of Congress. She received a MS in art conservation from the Winterthur-University of Delaware program and a PhD in the conservation science track in the Department of Materials Science & Engineering at the University of Arizona. Address: Preservation Research and Testing Division, Library of Congress, 101 Independence Ave SE, Washington DC, 20540-4560. Tel: 202-707-1638. E-mail: cbis@loc.gov

BRUNELLA SANTARELLI is a PhD candidate in the conservation science track in the Department of Materials Science & Engineering at the University of Arizona. She received a BS in chemistry and archaeology from Boston University and an MS in materials science from the University of Arizona. Address: Preservation Division, Arizona State Museum, University of Arizona, PO Box 210026, Tucson, AZ 85721-0026. Tel: 520-621-6314. Fax: 520-621-2976. E-mail: bsan@email.arizona.edu

MADELEINE NEIMAN is a third year graduate intern in the Conservation Laboratory, Arizona State Museum, University of Arizona. She received a BA in anthropology from Bryn Mawr College and a MA in conservation from Getty-UCLA. Address: Preservation Division, Arizona State Museum, University of Arizona, PO Box 210026, Tucson, AZ 85721-0026. Tel: 520-621-6314. Fax: 520-621-2976. E-mail: mkneiman@email.arizona.edu

GINA WATKINSON is the laboratory coordinator for the Preservation Division at the Arizona State Museum, University of Arizona. She received a BA from the University of Delaware Art Conservation Department and an MA in American Indian Studies with a graduate certificate in heritage conservation at the University of Arizona. Address: Preservation Division, Arizona State Museum, University of Arizona, P.O. Box 210026, Tucson, AZ 85721-0026. Tel: 520-621-6314. Fax: 520-621-2976. E-mail: gwatkins@emai l.arizona.edu

CONSERVATION AT 33 1/3 RPM: THE TREATMENT OF AN ATTIC TREFOIL OINOCHOE

ANTHONY SIGEL

ABSTRACT

Ancient vessels that have a third of their original fabric missing present complex ethical and technical challenges to conservators; such was the case with a fifth century bce oinochoe in the collection of the Harvard Art Museums. The decorative painting features a woman playing a *barbitos*, a type of lyre associated with leisure and revelry. This vessel's modern history begins sometime before 1903, when Henry Hucks Gibbs, Lord Aldenham of England, acquired it and lent it that year to an exhibition at London's Burlington Fine Arts Club. The vase scholar John Beazley described it in 1939 as having "a mouth and neck hardly original, which had disappeared when I saw it, in bits, some years ago; was sold at Sotheby's the year before last; and has since been cleaned and restored." It is likely that he was describing the condition in which the vessel entered the Harvard Art Museum's collection.

Before the treatment described in this article, the vase was unstable with loose joins and had substantial, broadly overpainted losses in the body. Close examination revealed that the neck, shoulders, and handle were all poorly shaped plaster fabrications from an earlier restoration. Removal of the overpaint also revealed considerable damage inflicted by previous restorers to the original slip painted decoration, who filed down the surfaces and edges of many sherds during their reconstruction in an effort to make them fit together.

In different kinds of institutions and collections, an object with such substantial losses could legitimately be treated in several different ways, ranging from simple removal of the flawed earlier restorations to full restoration. Curatorial research and documentation of a similar vase by the same potter in the collection of the British museum helped establish convincing evidence of the vessel's original form. Armed with scale drawings and photographs, the oinochoe was reconstructed to a high state of completion and finish. A combination of conventional and novel techniques were used to re-create the complex neck, trefoil spout, and handle, based upon a close study of their original material and techniques of formation. These techniques will be discussed here and also demonstrated in linked video clips. They include methods for the assembly and alignment of poorly fitting sherds; shaping and forming of replacement elements using a 1970s record turntable—complete with pitfalls to be avoided; the mold-making and casting of elements with complex inner and outer shapes in simplified, one piece molds; and inpainting strategies and techniques. The rationale and methods of loss compensation for damage caused by earlier restorers will also be discussed.

1. HISTORICAL BACKGROUND AND CONTEXT

Ancient vessels that have a third of their original fabric missing present complex ethical and technical challenges to conservators. Such was the case with a fifth century bce oinochoe acquired by the Harvard Art Museums in 1960 (1960.354, fig. 1).

Its shape is unusual, with elements of both a wine pitcher and an oil flask. The decorative painting features a woman playing a *barbitos,* a type of lyre associated with leisure and revelry. There has been some question as to whether this woman is the famous poet Sappho of Lesbos (Yatromanolakis 2007). Its modern history begins sometime before 1903, when Henry Hucks Gibbs, Lord Aldenham of England, acquired it and lent it that year to an exhibition at London's Burlington Fine Arts Club. The exhibition catalog referred to it as having been "put together out of several fragments" (Burlington Fine Arts Club 1903). The vase scholar John Beazley described it in 1939 as having "a mouth and neck hardly original, which had disappeared when I saw it, in bits, some years ago; was sold at Sotheby's the year

Fig. 1a–b. Before treatment. Greek, Oinochoe, fifth century bce, terracotta, 26.5 × 10.5 cm (Courtesy of Tony Sigel, © President and Fellows of Harvard College, 1960.354)

before last; and has since been cleaned and restored" (Beazley 1939). It is likely that he was describing the condition in which the vessel entered the Harvard museum's collection. David Moore Robinson, most known for the discovery and excavation of the ancient city of Olynthus, bequeathed it to the Harvard Art Museums in 1960.

2. CONDITION

Scheduled for installation in the renovated Harvard Art Museum's Ancient Art galleries in 2014, the oinochoe was brought to the laboratory. It had indeed been broken into many pieces and restored in the past. Visible cracks now appeared along the old join and fill lines. Clearly loose and unstable, the vessel "rattled" when tapped. The previous reconstruction was poorly executed, with sherds joined out of plane, and the fills rough, poorly shaped, and colored (fig. 2).

The missing and restored neck, trefoil spout, and handle, also broken, were clearly incorrect in shape, size, and profile. In addition, the placement of the neck on the vase shoulder appeared angled rearward, giving the vessel an unstable-appearing "leaning back" posture (fig. 3).

Fig. 2. Loose, out of plane joins and abrasions (Courtesy of Tony Sigel, © President and Fellows of Harvard College)

Fig. 3. Plaster neck, trefoil spout, and handle before treatment (Courtesy of Tony Sigel, © President and Fellows of Harvard College)

3. TREATMENT OPTIONS

In different kinds of institutions and collections, an object with such substantial losses could legitimately be treated in several different ways, and several different possible approaches to treatment were considered, involving the degree of restorative intervention. In this case, the vessel's unstable joins and unattractive, poor quality restorations necessitated treatment. One strategy might simply have been to remove the unattractive and inaccurate restorations and display the vessel without them. This approach has been advocated (Koob 1998) and has the advantages of absolute fidelity to the original and no chance of misinterpretation by scholars. It is also the least time-consuming—often a consideration when time and resources are limited. Another less severe but equally rigorous approach would be to fully restore the losses, but in a purposefully visible fashion. This practice, commonly seen on archaeological sites or in strictly archaeological collections, involves re-creating the missing elements in colors or textures that allow them to stand out as restorations. For example, one might leave fills white, or color them to an approximation of the adjacent original surfaces, and perhaps also modify them in tone; a shade lighter is common. Other strategies for disclosing restored areas of ancient vessels have included recessing the fills slightly, or incising their edges. It must be said that these approaches can be distracting and are less commonly seen on finely potted figural ceramics.

The Harvard Art Museums' collections represent fine and decorative arts as well as strictly archaeological materials, and a level of interpretive, aesthetic treatment is expected in our galleries. Our approach to finely potted and painted archaeological ceramics has been to bring them to a higher state of restorative "aesthetic reintegration" than a strictly archaeological museum might choose to undertake. This allows our audience a more straightforward and understandable reading of the scenes depicted on these works. However, I also feel that Attic vase painting is one of the highest expressions of ancient Greek decorative arts and that we must balance the presentation of these spectacular and highly refined works of art against a strict archaeological approach whose primary concern lies only with their artifactual, evidentiary value. Scholars seeking to clarify the level of restoration may examine curatorial and conservation files with careful "during treatment" photography, and we hope that this type of photographic treatment documentation will soon be available online.

Another factor influencing our decision was that Beazley had identified a "twin" vessel to ours, an oinochoe in the British Museum (1836,0224.11 London E-15, see Green 1978). Scale drawings and photographs were made and generously provided by the British Museum, and after discussing the options, our curator of ancient art, Dr. Susanne Ebbinghaus, and I agreed that we should restore the losses in accord with the evidence provided by the British Museum twin (fig. 4).

The techniques I used to re-create the complex neck, trefoil spout, and handle were based upon a close study of their original material and techniques of formation.

4. TREATMENT

4.1 DISASSEMBLY

The use of PVA emulsion glue dated the present restoration to the early to mid-20th century. The vessel was immersed in acetone and then water to swell and soften the PVA restoration adhesives, which allowed for the vessel's controlled disassembly. Overpaints, fill materials, and adhesive remnants were removed with steam, water, and acetone. Following the disassembly, a soak in deionized water and conductivity testing for soluble salts revealed levels below 100 micro-mohs, well within the acceptable range of ceramics in a climate controlled environment.

Fig. 4a–b. Greek, Trefoil-mouth oinochoe, terracotta, Height: 26.67 cm (Courtesy of and © Trustees of The British Museum, 1836,0224.11 London E515); drawing by Kate Morton (© Trustees of The British Museum)

4.2 THE HORROR

As the disassembly and cleaning progressed it became clear that during an earlier restoration, the surfaces and edges of many sherds had been aggressively filed down with a rasp like tool, no doubt to fit them into an increasingly poorly aligned reconstruction (figs. 5a, 5b).

The result was not only the loss of ribbons of ceramic and slip-glaze surface along affected edges and broad swaths of glaze surface, but widespread, fine scratches to the glaze elsewhere from rasping down projecting fills and glaze surfaces. Later in the treatment, when I was reconstructing the vessel, these edge and surface losses made it very difficult to achieve proper alignment of the sherds. Even on joins that had not been so damaged, most break edges were rough and chipped, a testament to the numerous campaigns of restoration the oinochoe had endured. In the more delicate red-ground design areas of the female lyre player, the miltos, or fine ocher slip, had become abraded, with loss of surface sheen and areas of the fine light brown drapery folds. Also lost through earlier carelessness were many of the fine, raised black slip lines that made up her image (fig. 6).

Fig. 5a. Filed down edges; 5b. Filed down surfaces (Courtesy of Tony Sigel, © President and Fellows of Harvard College)

Fig. 6. During treatment: detail of abraded and lost black slip surfaces and lines. Note glossy, protective temporary B-72 coating. (Courtesy of Tony Sigel, © President and Fellows of Harvard College)

4.3 HOW NOT TO LOSE PIECES

Immediately after disassembly, following my typical practice, I laid out all the disassembled sherds, photographed them, and printed the images out at slightly over 1:1 scale. I taped the photographs to a corrugated cardboard support, which became a place for me to index and store the sherds during the lengthy treatment process (fig. 7). This method helps to keep track of the sherds during the adhesive and overpaint removal, cleaning, poulticing stages. It ensures that you will notice immediately if any sherds are misplaced!

I primed and consolidated the break edges with a 10%–15% coating of B72 and coated other areas to provide protection during the filling of losses (see fig. 6). I reconstructed the vessel with an adhesive formula of 45% B-72 in acetone/ethanol following the Koob recipe (Koob 2009). I filled spaces between sherds where the ceramic was lost with Paraloid B-72 bulked with micro-balloons. For theory, techniques, and detailed descriptions of cleaning, joining, and filling losses, see Sigel and Koob (1997) and Sigel (2003).

4.4 ALIGNMENT

While the fingertip remains a very sensitive means of ensuring the proper alignment of two sherds, for this treatment I also used a piece of aluminum venetian blind material (figs. 8, 9).

Following reassembly, I used a Leister hot air tool to adjust the final alignment of the sherds. Very often when assembling vessels with sherds missing joining surfaces (and also over losses where one or more sherds are missing altogether), one can only approximate the proper positioning, and it is only after the adhesive is cured that a final adjustment of position can be made. Though it may seem counterintuitive, subtle adjustments can easily be made to the hardened B-72 adhesive joins by the local application of heat. Using a Leister hot air tool or other means, when the Tg of the adhesive is reached, signaled by a slight

Fig. 7. During reconstruction, sherds placed on a photograph of the sherds laid out (Courtesy of Tony Sigel, © President and Fellows of Harvard College)

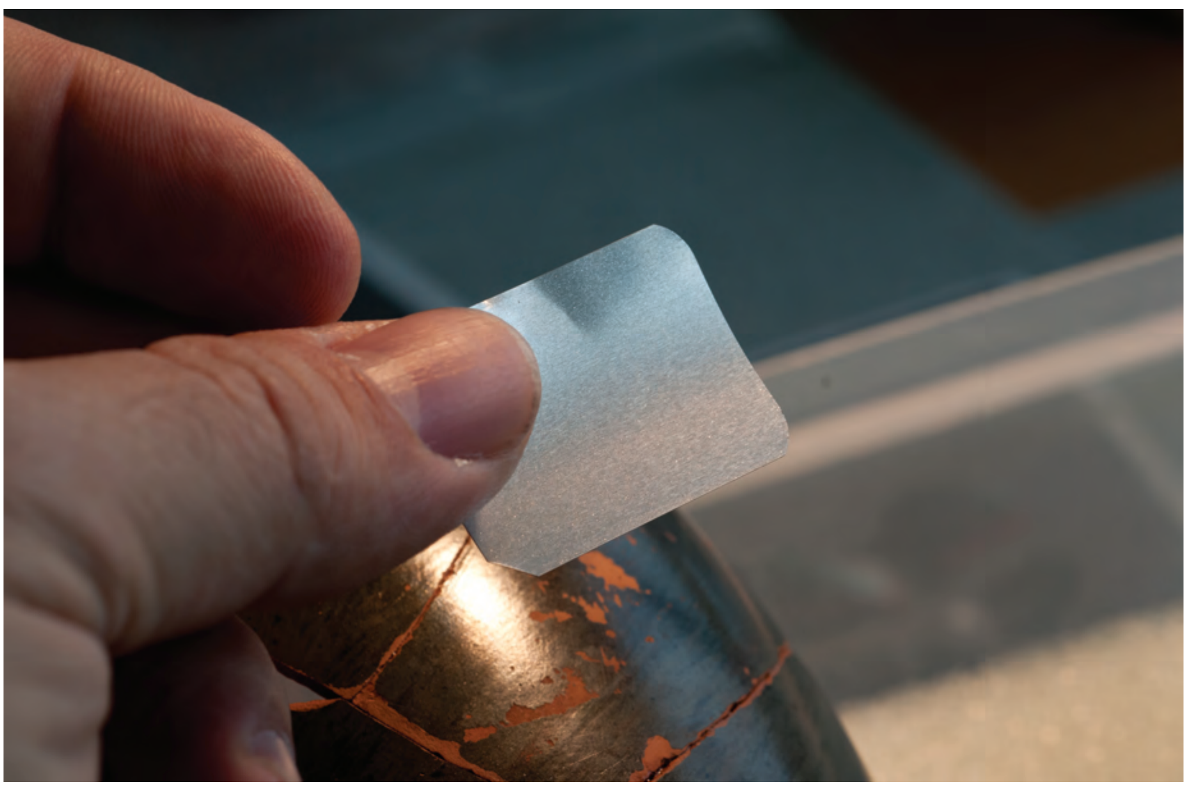

Fig. 8. Cut piece of flexible aluminum window-blind material (Courtesy of Tony Sigel, © President and Fellows of Harvard College)

Fig. 9. Conformed to the curvature of the vessel against a strong light, it shows the left side of the join was low (Courtesy of Tony Sigel, © President and Fellows of Harvard College)

bubbling in the join, the alignment of the sherds can be corrected. A helper can then rapidly cool the join to retain the new position by spraying frozen propellant gas onto the surfaces from an inverted can of Dust-Off.

4.5 FILLING LOSSES

Before filling the losses, I coated absorbent break edges and adjacent surfaces with 15% Paraloid B-72 to prevent them from absorbing moisture or being stained by the Newplast Plasticine, a nonhardening commercial modeling clay used as a backing material during filling. I backed loss areas with Newplast sheet and filled the losses with plaster of paris. When the plaster was hard but not dry, I shaped the slightly overfilled surface to the proper contours with scalpels, files, and waterproof sandpaper, always being extremely protective of the adjacent original surfaces. Water was used as a lubricant through successive grades of sandpapers. During this process, the protective B-72 coatings on these surfaces are invaluable. After the fills dried completely, I sealed them with 15% B-72 (Sigel and Koob1997; Sigel 2003).

5. RE-CREATING THE SPOUT, NECK, AND HANDLE

When re-creating losses or elements in a variety of types of objects, I have found it useful to follow the materials and techniques of the artist as closely as possible. In this case, for example, I chose to throw the neck and spout on a potter's wheel, guided by the measured drawings and photographs of the twin in the British Museum. Nonhardening clay, often referred to as "Plasticine," was an ideal modeling material, as it is essentially clay mixed with paraffin rather than water. I would then cast the modeled elements into a stable material—plaster of paris—and attach them to the vessel body. Rather than a potter's wheel, I employed a record turntable.

I scaled up the drawings provided by the British Museum by enlarging them on a photocopier (see figs. 20a, 20b). This allowed the use of calipers to directly measure and compare critical diameters at several points on the spout. I also cut a Plexiglas sheet template to measure and correct the profile of the neck and rim of the spout before pinching it into the final three-lobed, or “trefoil” shape. This profile was interpolated from the four-view drawings by measuring the diameter of the spout at its widest point.

5.1 TURNING THE SPOUT

I cut a square Plexiglas sheet and center drilled it to receive the turntable spindle, attaching it temporarily to the platter with balls of Plasticine. I began initially by forming a hollow tube of Plasticine as the basis for the spout, thinking that after warming it with a hair dryer to render it more pliable, I would be able to shape it with my fingers much as the original potter did on his wheel (fig. 10).

Unfortunately, things did not quite work out as I had hoped, and the Plasticine was too rigid and unyielding to “throw,” resulting in a wrinkled, heaped mess.

Reconsidering, I decided that rather than working like a potter, with a wheel, I might shape the spout the same way a woodworker would shape a wood bowl on a lathe – subtractively. In this method, I would start out with a larger mass of clay and use sculpture and modeling tools to remove clay until I achieved the desired shape (fig. 11).

This turned out to be a very successful approach (see fig. 12, video of lathing the spout). Using principally wire-loop tools for controlled clay removal, making frequent references to the British Museum

Fig. 10. Initial, unsuccessful attempt with hollow tube (Courtesy of Tony Sigel, © President and Fellows of Harvard College)

Fig. 11. Successful subtractive method—"lathing" element out of a solid clay mass (Courtesy of Tony Sigel, © President and Fellows of Harvard College)

Fig. 12. Video showing the process of lathing the spout (Courtesy of Tony Sigel, © President and Fellows of Harvard College) https://www.youtube.com/watch?v=OzOHgzXVSF4

drawings with calipers for measurements, and using the Plexiglas template as a guide, I was able accurately to form the exterior contours of the neck and spout. I made use of a Manfrotto Magic Arm, a photo equipment support that clamps onto the table top and has a flexible 2-1/2 ft. long arm that locks with one knob. With one end clamped to the tabletop, I attached a large metal loop clay modeling tool to the other end. I secured its position with the locking knob, and then used the Magic Arm both as a steady rest for other smaller tools (not unlike a wood turning lathe) and also as a tool holder for the modeling tool (fig. 13).

Fig. 13. Using the Magic Arm as a steady rest and tool holder (Courtesy of Tony Sigel, © President and Fellows of Harvard College)

When the exterior shaping was complete, it was time to hollow the interior to its final thin wall thickness. The rigidity of the tool clamped in the magic arm allowed me to take light skimming cuts. This minimized the risk of digging the tool tip in too far and thus tearing or distorting the model. The arm itself, used as a steady rest, allowed me to make minute controlled movements, which were also essential in creating the fine detail of the decorative raised line in the mid-section of the neck (see fig. 16).

When the final form had been achieved, I completed the surface finishing with smooth wooden modeling tools and a piece of silk wrapped around my fingertip and held against the spinning form, leaving fine wheel-thrown textures and smoothing marks.

5.2 FORMING THE TREFOIL SHAPE

After much study of the British Museum photographs, drawings, and numerous other trefoil spouted vessels in our collection, I realized that toolmarks within the tight folds of the spout indicated that the original potters used a tool to push the opposing outside edges inward to form the rather sharp interior corners of the three-lobed spout.

After warming the Plasticine under a halogen light for several minutes, I took a deep breath and plunged into shaping the spout, beginning to push inward on the rim approximately one-third of the diameter away from the tip of the spout on either side, using my fingers and wooden tools shaped for the purpose (fig. 14).

Careful not to damage or distort the delicate rim, I coaxed the Plasticine into shape, to a point where I was satisfied with the results. I also lifted and molded the back edge of the rim, which was to receive the handle, into its final shape with my fingers.

Fig. 14. Halfway through the "pinch" (Courtesy of Tony Sigel, © President and Fellows of Harvard College)

Fig. 15. Cutting the Plasticine model free with the wire tool (Courtesy of Tony Sigel, © President and Fellows of Harvard College)

I added the small "rotelles," or circular knobs, to either side of the handle attachment area following the drawings and photographs. When all was complete and smooth, I cut the neck and spout free from the turntable using a tightly stretched cutting wire of a design by Benner Larson in his superb mold-making and casting course (fig. 15). Many things I learned in his course informed this treatment.

5.3 SCRIBING THE JOIN

After freeing the neck and spout from the turntable, I placed it on top of the projecting break edges atop the shoulders of the vessel, propped level with small balls of Plasticine. I used a small pair of dividers to scribe the projecting neck remnants into its base, so that the Plasticine could be trimmed to allow an accurate seating (fig. 16).

After trimming the excess Plasticine with a scalpel, I joined the neck to the body of the vessel with gentle pressure, then dressed and smoothed the join between the Plasticine and ceramic with small modeling tools and a piece of silk wrapped around my finger (fig. 17).

5.4 FORMING THE HANDLE

The D-shaped profile of the handle of this vessel would in ancient times have been extruded through a die or shaped by pulling and stretching the wet clay through the potter's fingers (Schreiber 1999). This was not possible for my re-creation because (as before with the spout) the Plasticine was simply too hard. I needed to devise another method of creating the subtle contours of the handle.

Fig. 16. Scribing the joining break edge with dividers. Note the delicate, raised line. (Courtesy of Tony Sigel, © President and Fellows of Harvard College)

Fig. 17. Smoothing the joining surface with modeling tools (Courtesy of Tony Sigel, © President and Fellows of Harvard College)

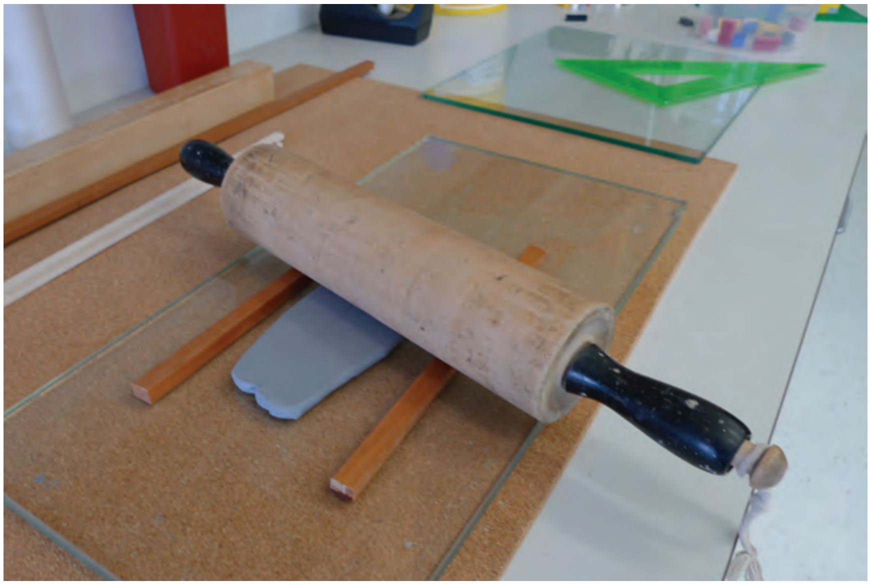

Fig. 18. Rolling Plasticine sheet between battens (Courtesy of Tony Sigel, © President and Fellows of Harvard College)

I rolled Plasticine out on a glass plate using a pair of equal-sized battens to maintain the desired overall final thickness, lightly misting the Plasticine with water to prevent its sticking to the glass (fig. 18).

This technique can be used to prepare Plasticine sheet to any given thickness for such uses as creating mold walls, or backing sheets for filling losses on a vessel. I cut a strip from the Plasticine sheet of the width needed, and beveled its long edges with a scalpel to the approximate D-section of the handle as provided on the British Museum drawing. After some experimentation, I found that by sandwiching the handle blank between two sheets of glass I could form even, smooth radii by tilting the glass sheets under pressure, back and forth along the length of the handle blank repositioning the blank at different angles (see fig. 19, video of rolling the handle).

Having formed a nicely shaped strip of Plasticine with the correct dimension and profile, I formed the distinctive curves of the handle directly on the drawing (figs. 20a, 20b).

Fig. 19. Video of rolling the handle (Courtesy of Tony Sigel, © President and Fellows of Harvard College)
https://www.youtube.com/watch?v=H20qBipk7so

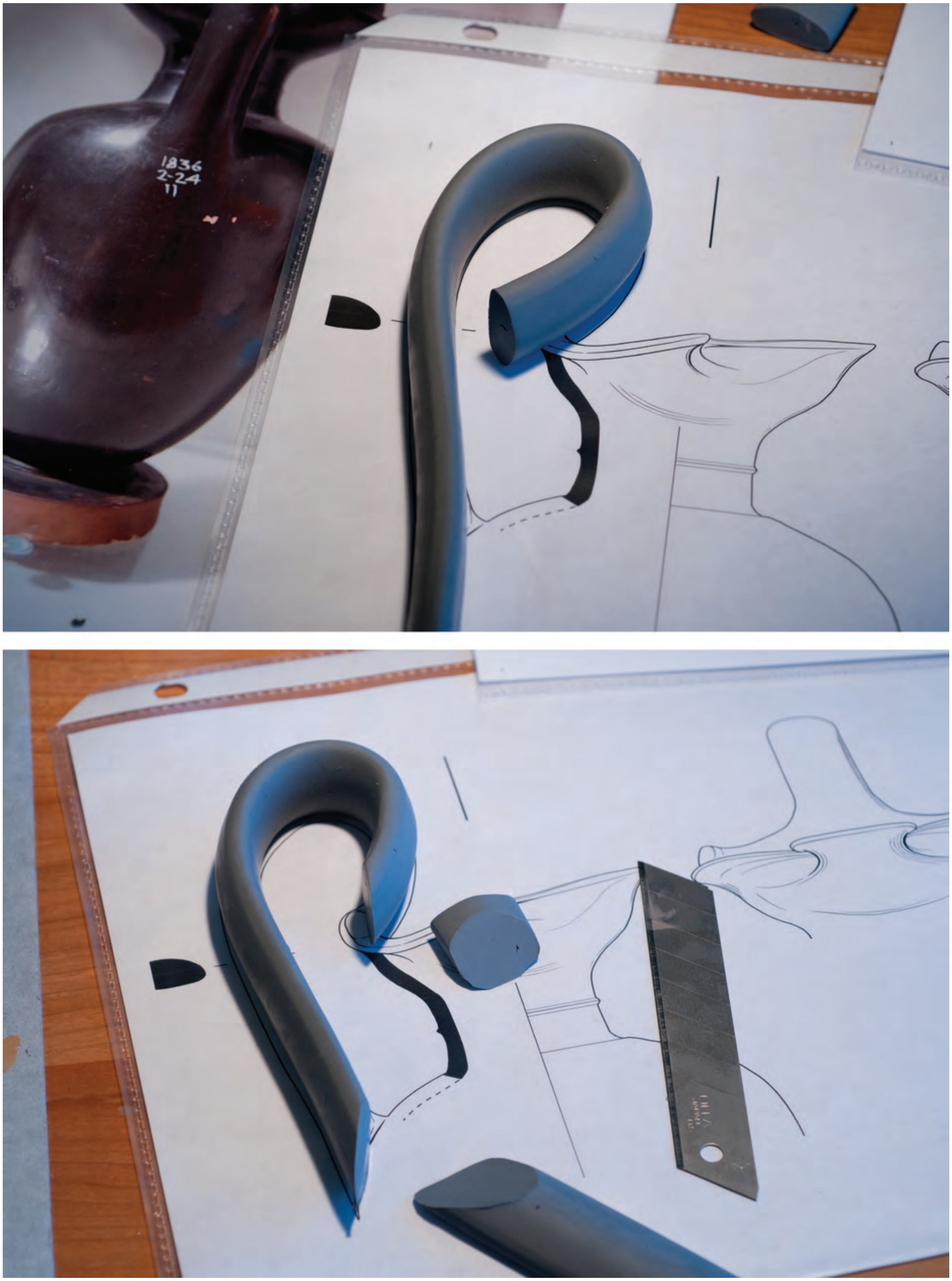

Fig. 20a. Forming the handle curvature; 20b. trimming each end with a razor sharp blade to the joining angle to attach the handle to the spout and oinochoe body (Courtesy of Tony Sigel, © President and Fellows of Harvard College)

Fig. 21. Faired attachment of handle (Courtesy of Tony Sigel, © President and Fellows of Harvard College)

I joined the handle to the oinochoe with additional clay to form smoothing fillets to its receiving surface at each end (fig. 21).

I made subtle adjustments to the angle and position until it conformed precisely to the photographs and drawing (see figs. 22a–d).

6. MOLD-MAKING

I judged that it would not be possible to cast the neck, spout, and handle all in one piece; the mold would have been too complex and unlikely to yield a successful cast. I decided to remove the handle from

Fig. 22a–d. Comparative images after modeling (22a and 22c Courtesy of the British Museum; 22b and 22d Courtesy of Tony Sigel, © President and Fellows of Harvard College)

the neck and body first, by making a self-aligning V-cut to the handle just above its attachment to the back rim of the spout (see fig. 23, video of preparing the handle). A temporary clay strut served to stabilize the Plasticine handle during removal, which was removed before casting.

After removing the handle, which involved some stress on the pliable material, I gently replaced it on the vase momentarily to correct any distortions that might have crept in during the removal process. I created a simple Plasticine wall mold, forming a thin sheet to the correct shape and attached it to a glazed ceramic tile base. I attached several balls of clay to one side of the handle to act as spacers to keep it off the floor of the mold, so that it could be surrounded by the mold-making material.

To remove the considerably more delicate neck and spout (see fig. 24, video of removing the spout), I used a can of "Dust-Off," inverted so that the frozen propellant would spray out, to freeze the Plasticine hard so that it could be eased away from the vessel without causing distortion, particularly along the joining areas where the Plasticine was irregular and feather-thin. Again after removal, I gently replaced the spout and corrected any small distortions that had occurred.

Once more, I chose to make the most expedient type of mold possible, and after much discussion with colleagues and sketching designs on paper, came up with a plan to form a four-part, one-piece mold, made in a single pour. A multipart piece mold/mother mold system would certainly have worked, but was rejected as being needlessly complicated and too time-consuming for a "one-off" production.

Fig. 23. Video of preparing the handle (Courtesy of Tony Sigel, © President and Fellows of Harvard College)
https://www.youtube.com/watch?v=jyTcw-GM9HU

Fig. 24. Video of removing the spout (Courtesy of Tony Sigel, © President and Fellows of Harvard College)
https://www.youtube.com/watch?v=MMvmyuWi0UY

I first made a small X-shaped support out of Plasticine sheet to hold the spout level and off the tile floor of the mold, as I had done with clay balls for the handle. I then rolled out thin Plasticine sheet and formed the outer mold walls, sealing them to the base with modeling tools to prevent leakage. I mixed Smooth-on Mold Max 30, a room temperature vulcanizing (RTV) tin-cure silicone rubber (shore 30A hardness) and poured it in to fill the molds. This more rigid molding rubber is better suited to this type of mold.

After the rubber set, I cut the mold block almost completely in half with a large carving knife, stopping 1 cm before reaching the bottom. The same large knife served to cut the mold block free from the ceramic tile. I peeled off the Plasticine walls of the mold and pulled the two halves open to disclose the two halves of the Plasticine spout contained within, the un-cut RTV remaining at the bottom serving as a hinge.

The Plasticine spout halves, however, were still trapped in the mold, so I made further cuts with a scalpel. These cuts were made from the top of the mold down to intersect with the Plasticine. This allowed me to open the mold completely, remove the halves of the spout, and then prepare the mold for casting. Normally, somewhat irregular cuts rather than straight are preferable, as they aid in accurate registration of the mold sections when closing.

I drew a paper template to describe the approximate position of the spout within the mold, and the location of the additional cuts needed to free it (see fig. 25, video of de-molding the spout). I transferred this outline to the top of the mold and used a scalpel with a slender no. 11 blade to carefully cut down into the mold along the line. To my relief, the cuts intersected the spout rim, and after completion it proved quite simple to spread the now four sections of the flexible mold open and extract the Plasticine model. Now a four-part mold, each segment was still held in proper registration—the inner

Fig. 25. Video of de-molding the spout (Courtesy of Tony Sigel, © President and Fellows of Harvard College)
https://www.youtube.com/watch?v=-HgmqKF5204

and outer halves of each side of the piece—by the uncut mold material at the bottom. I cut open and emptied the much simpler handle mold in the same way.

7. CASTING

I cut entrance "sprues" channels into the walls of both spout and handle molds to inject the plaster and exit "vents" to exhaust air as they filled. A sheet of silicone release Mylar inserted between the mold halves served to separate the casting into two pieces. I cleaned, closed, and secured the mold with rubber bands and a small clamp. I mixed plaster and injected it with a curved tip "ear" syringe (fig. 26).

After the plaster had cured, the mold was opened (fig. 27).

Removing the delicate convoluted shapes was difficult, and I needed to further cut the interior "lobes" into halves, while still retaining the bottom attachment (fig. 28).

In all, several sets of neck/spout halves were cast, and I chose only the two best—those with the fewest air bubbles and other defects—for use. An RTV mold of this type can be reused numerous times before the material begins to degrade.

I trimmed the two plaster halves and cut small keys into each joining surface to provide a mechanical attachment for the joining plaster (fig. 29).

After soaking in water to avoid premature setting from pulling moisture out of the fresh plaster, they were assembled using additional plaster as an adhesive. While simply gluing would have been

Fig. 26. Closed and filled molds (Courtesy of Tony Sigel, © President and Fellows of Harvard College)

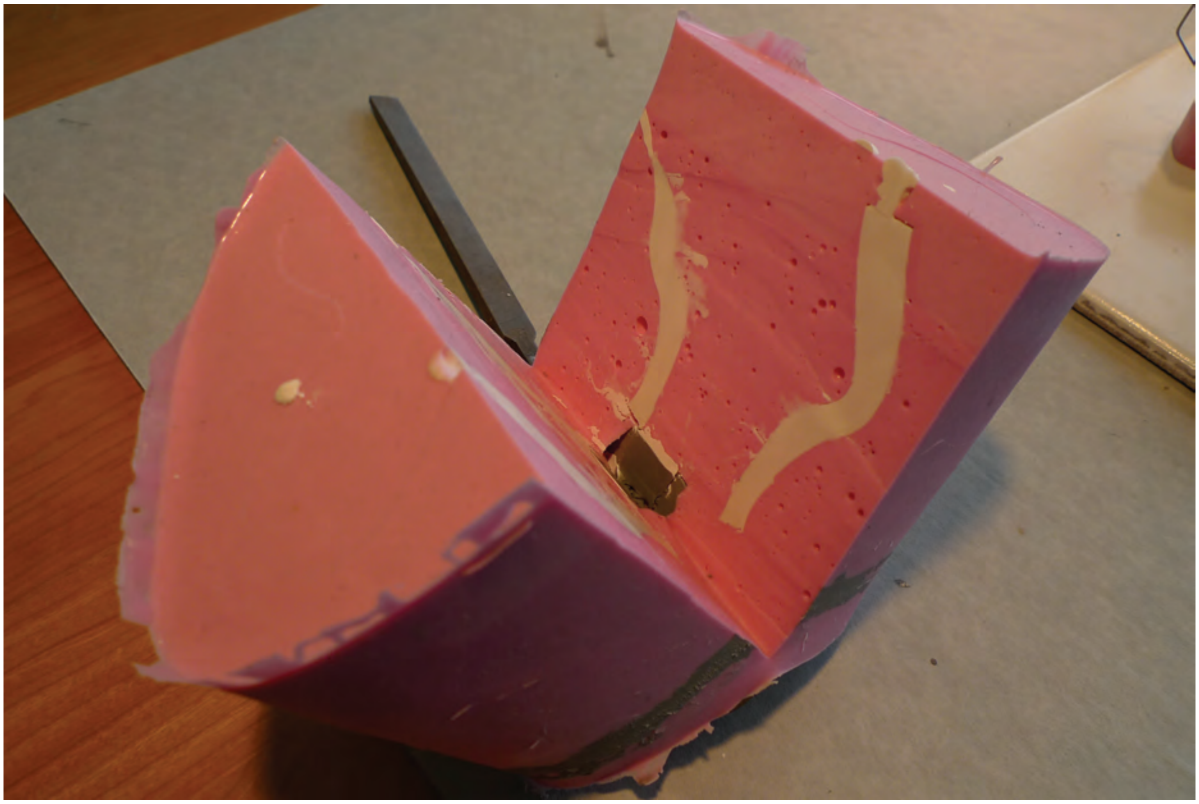

Fig. 27. Opened mold showing filled plaster halves, and filled sprues and vents. (Courtesy of Tony Sigel, © President and Fellows of Harvard College)

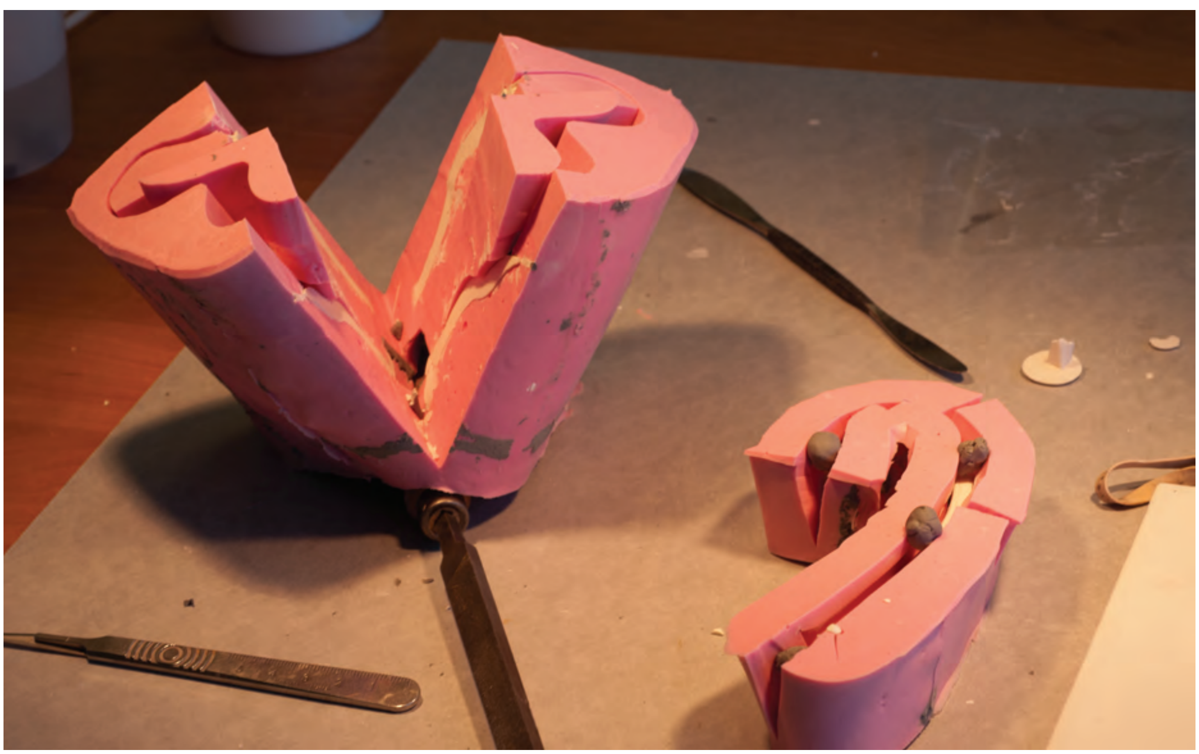

Fig. 28. Molds propped open, showing additional cuts in rubber (Courtesy of Tony Sigel, © President and Fellows of Harvard College)

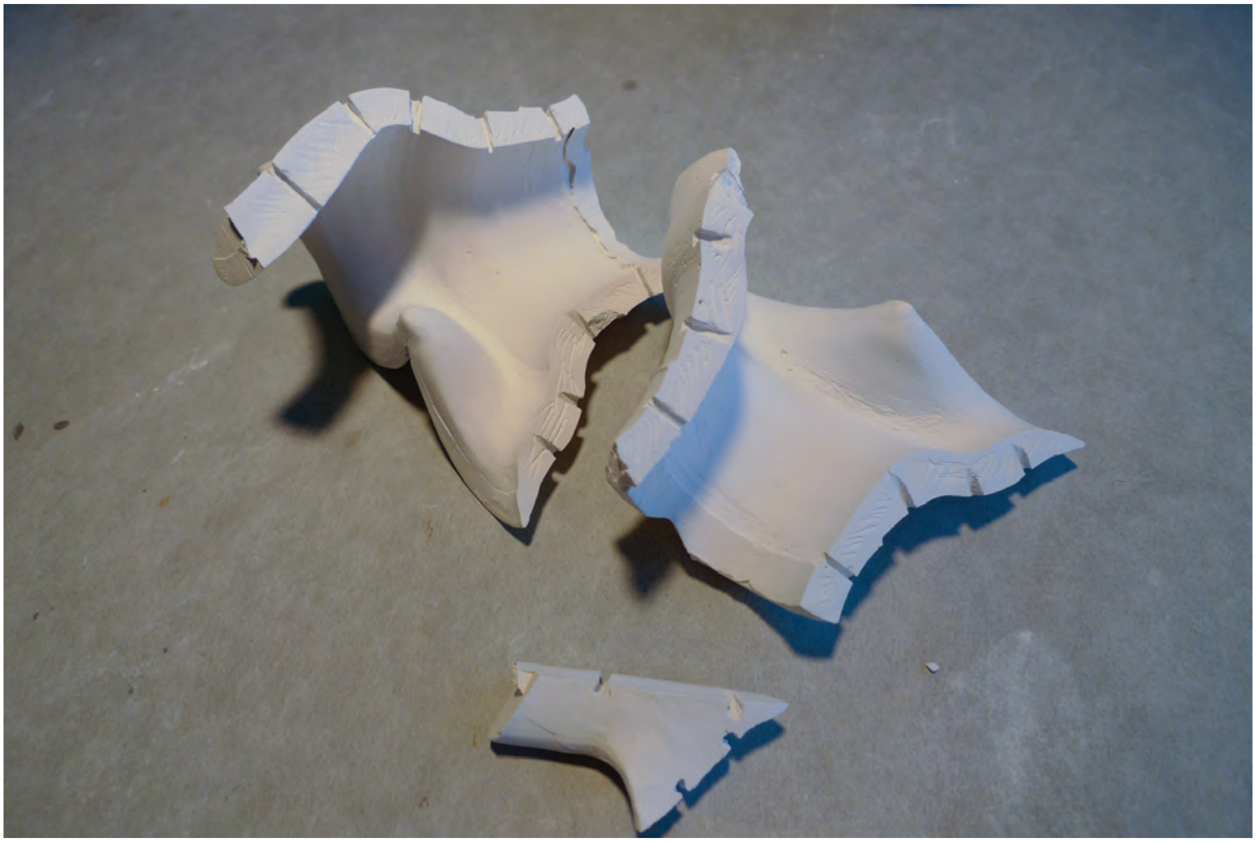

Fig. 29. Keys cut in plaster (Courtesy of Tony Sigel, © President and Fellows of Harvard College)

simpler, I have found it best to use plaster rather than adhesive for this purpose. When dressing and sanding the joins, it is difficult to achieve a smooth surface when the harder glue-line is encountered. After drying, final shaping, and sanding, I consolidated the neck/spout and handle in 15% B-72 in acetone. When dry, they were finally assembled to the vessel with B-72 adhesive.

Finally intact and in one piece, all of the remaining fine losses, mold and join lines, and air bubbles throughout the vessel were filled with Modostuc acrylic spackle tinted with dry pigments and applied with fine tools and flexible plastic spatulas. Several techniques were used in this process. I applied the Modostuc with spatulas cut from polyethylene container lids and plastic sheet (see fig. 30, video of filling and scraping the oinochoe). As the water-based Modostuc shrinks, several thin applications are often needed. When dry, I scraped the break-line fills level and smooth with slightly harder ABS (acrylonitrile butadiene styrene) plastic and other "credit"-type cards (fig. 31). The plastic being harder than the fill material but softer than the ceramic surface allows for absolute safety. I periodically dressed the edges of the card at a 90° angle on fine sandpaper to make a sharp, square edge.

I also used a modified sanding block to adjust and level the break-lines and broader fill areas. This is a technique I use frequently with water-resoluble fill materials such as Modostuc and Flugger acrylic. To be both accurate and protective of the original surfaces, I use a block of a piece of flexible but stiff eraser material such as a Staedtler Mars white vinyl/plastic eraser. A piece of dampened silk wrapped around the block, rather than an abrasive sandpaper, serves to abrade and level the fill. I cut the eraser to thickness with a razor knife and make a further two cuts on the top. A small sheet

Fig. 30. Video of filling and scraping the oinochoe (Courtesy of Tony Sigel, © President and Fellows of Harvard College)
https://www.youtube.com/watch?v=o5wZuFNlOBg

Fig. 31. Leveling fills with a plastic scraper (Courtesy of Tony Sigel, © President and Fellows of Harvard College)

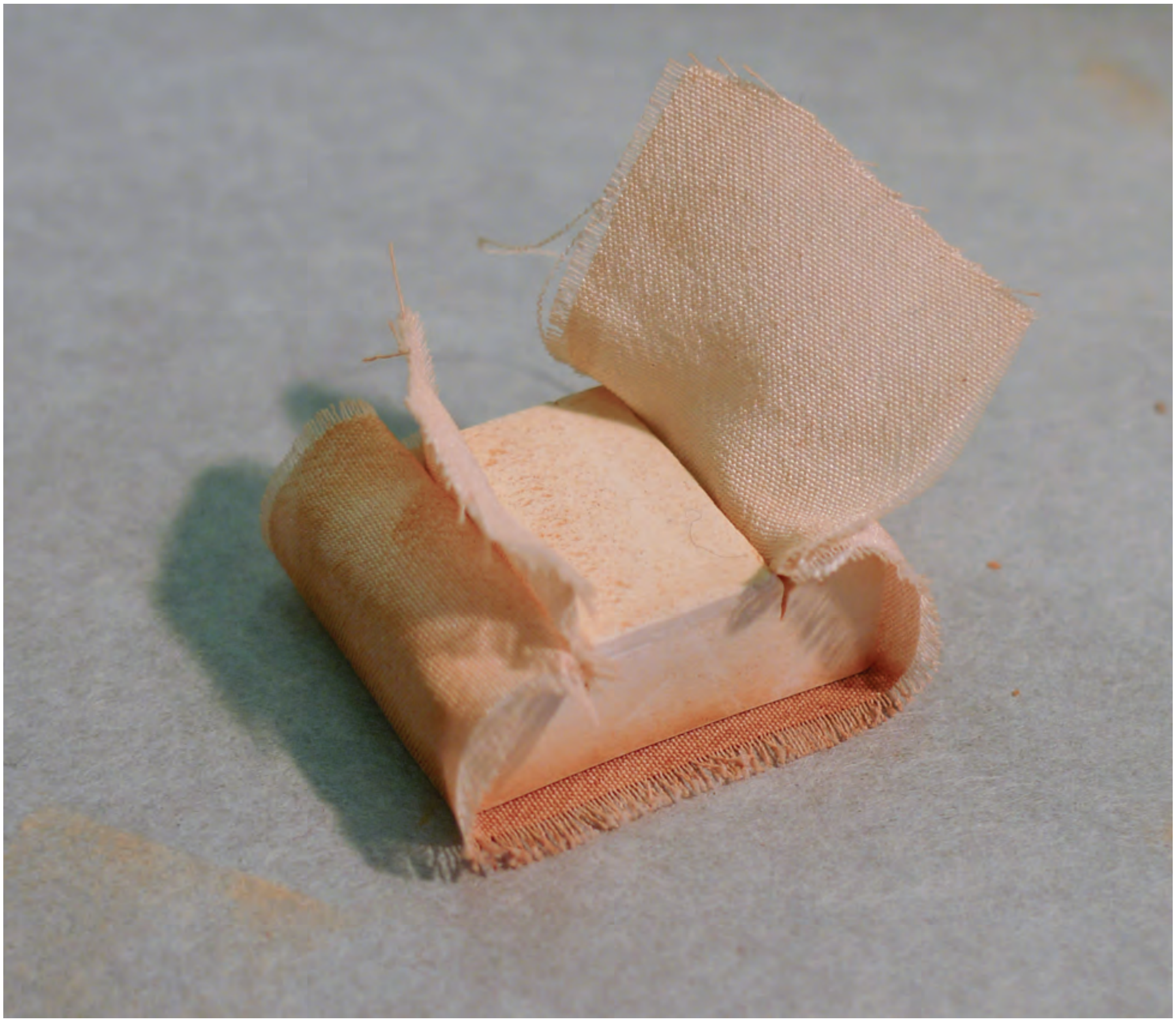

Fig. 32. The silk-wrapped smoothing block cut from eraser material. (Courtesy of Tony Sigel, © President and Fellows of Harvard College)

of fine silk is wrapped around the block and secured by tucking it into the slot on each side with a spatula (fig. 32).

Alternatively, the silk can be fastened by wrapping it around the block and anchoring it with a small bulldog clip.

I dampened the block on a wet sponge and lightly played it over the fills, smoothing and leveling, as you can see in the images illustrating treatment of this oinochoe (figs. 33a–c).

As the silk became clogged with material, I cleaned it by blotting on a wet sponge (fig. 34).

Care should be taken not to overwet the silk, or the fill will soften and dissolve too readily. Toward the end of the leveling process, I used the silk in an increasingly drier state, to remove less material and impart a final smoothing, polishing effect.

Very small, fine scratches in the surface of the vessel were also effectively filled in this way (fig. 35). When complete, the fills were sealed with 7.5% B-72. Any remaining haze of fill material on adjacent original surfaces was then easily removed with swabs and water, without risk of damaging the now consolidated fill. The eraser itself also works well to clean any remaining haze. Micromesh-coated

Fig. 33a–c. Sequence of three images showing smoothing process (Courtesy of Tony Sigel, © President and Fellows of Harvard College)

Fig. 34. Cleaning silk on a sponge (Courtesy of Tony Sigel, © President and Fellows of Harvard College)

Fig. 35. Leveling broad fill areas and filling fine imperfections (Courtesy of Tony Sigel, © President and Fellows of Harvard College)

abrasive sheets were also used for final smoothing, often laminated in strips to small wood sticks of the coffee-stirring variety (Sigel 2003).

8. INPAINTING

8.1 COHERENCE AND BEAUTY VS. PRESERVATION OF VISUAL EVIDENCE

After completion of filling (see fig. 36), the vessel was requested for inclusion in a temporary exhibition at short notice.

With insufficient time to properly complete the inpainting as envisioned, the losses were temporarily inpainted using black and ocher gouache with the airbrush (fig. 37). The colors were uniform

Fig. 36. The oinochoe after reassembly and filling, ready for paint (Courtesy of Tony Sigel, © President and Fellows of Harvard College)

Fig. 37. During treatment. The temporary, removable gouache inpainting follows a strict archaeological approach. (Courtesy of Tony Sigel, © President and Fellows of Harvard College)

and approximate, and the gouache provided only a matte surface. None of the figural design areas were completed, and only necessary contours were added to separate color areas—necessity dictated a strict archaeological approach to the interim inpainting.

This temporary treatment was instructive, as it provided a basis for comparison and only confirmed our desire to complete the treatment using a more restorative approach.

Following the exhibition, the vase was returned to the laboratory and I removed the temporary, water-soluble gouache inpainting with water, cotton pads, and swabs. The break-lines and fills on the vessel body were inpainted by brush using Golden Fluid Matte acrylic paints and gloss, satin, and matte Golden Polymer UVLS varnishes as needed to adjust surface sheen. I made an effort to match the adjacent original surfaces as closely as possible in color, while leaving the surface slightly differentiated in sheen. I feel that this still allows a discerning viewer to visualize the restored areas without being overly distracted by more purposefully visible restorations that can draw attention to themselves.

8.2 MASKING TECHNIQUES

Fill areas on the vessel's lower, original surfaces were masked with Iwata Stretch Mask, a flexible "frisket" material, and Parafilm M, a stretchy, wax-based film material used to seal containers in the laboratory. Unlike the Parafilm masking techniques described in an earlier publication (Sigel 2003), I used a new method, creating "soft" mask at the neck and handle joins to avoid leaving a hard paint edge, typical of conventional frisket and tape masking techniques. First, I cut ribbons of Parafilm approximately one-quarter to one-half inch wide and stretched to lengthen and render them more thin and flexible.

In this method, the Parafilm strip is rolled between the fingers to make a string, then another strip is rolled over it to create a smooth outer surface (figs. 38a–c). I applied the Parafilm string to the base of the neck and handle and stretched Parafilm sheet to protect the shoulders and lower areas of the vase, overlapping the Parafilm strings (figs. 39a–c).

Another advantage of the system is now apparent; trimming the excess Parafilm sheet mask can be done with a scalpel directly over the solid strings without fear of scoring or scratching the underlying inpainting or original surface.

8.3 INPAINTING TOOLS AND METHODS

I painted the neck, spout, and handle restorations with the airbrush, spraying several thin layers of a black color sympathetic to, but not imitative of, the original highly "brushy" and variegated black slip surfaces found elsewhere (fig. 40).

Their more uniform color and texture subtly but clearly announce their status as nonoriginal replacements. As I removed the Parafilm, the other advantages to this masking technique became apparent—no adhesive residues, no lifting of underlying fill and inpainting, and no hard, raised paint edges of the kind found when using masking tapes or conventional frisket film. Only a gentle "soft-edge" graduation of paint from original to fill (fig. 41).

The size of the transition is governed by the diameter of the Parafilm string and the spray angle and can be easily governed by altering both. Afterward, to reduce the "sprayed" look to the surfaces, I lightly sanded, burnished, and smoothed the paint with fine sandpaper (Micromesh-coated abrasives) and quick linear brushstrokes of neat acetone to recover some of the surface gloss. Care is needed with this last technique, as flooding the paint with acetone can be disastrous! A coat of microcrystalline wax can also be used to adjust the gloss/matte characteristics.

Fig. 38a–c. Preparing Parafilm strings (sequence of three images) (Courtesy of Tony Sigel, © President and Fellows of Harvard College)

Fig. 39a–c. Applying the Parafilm string and sheet mask (Courtesy of Tony Sigel, © President and Fellows of Harvard College)

Fig. 40. Applying thin layers of paint with the airbrush (Courtesy of Tony Sigel, © President and Fellows of Harvard College)

Fig. 41. The completed neck and spout (Courtesy of Tony Sigel, © President and Fellows of Harvard College)

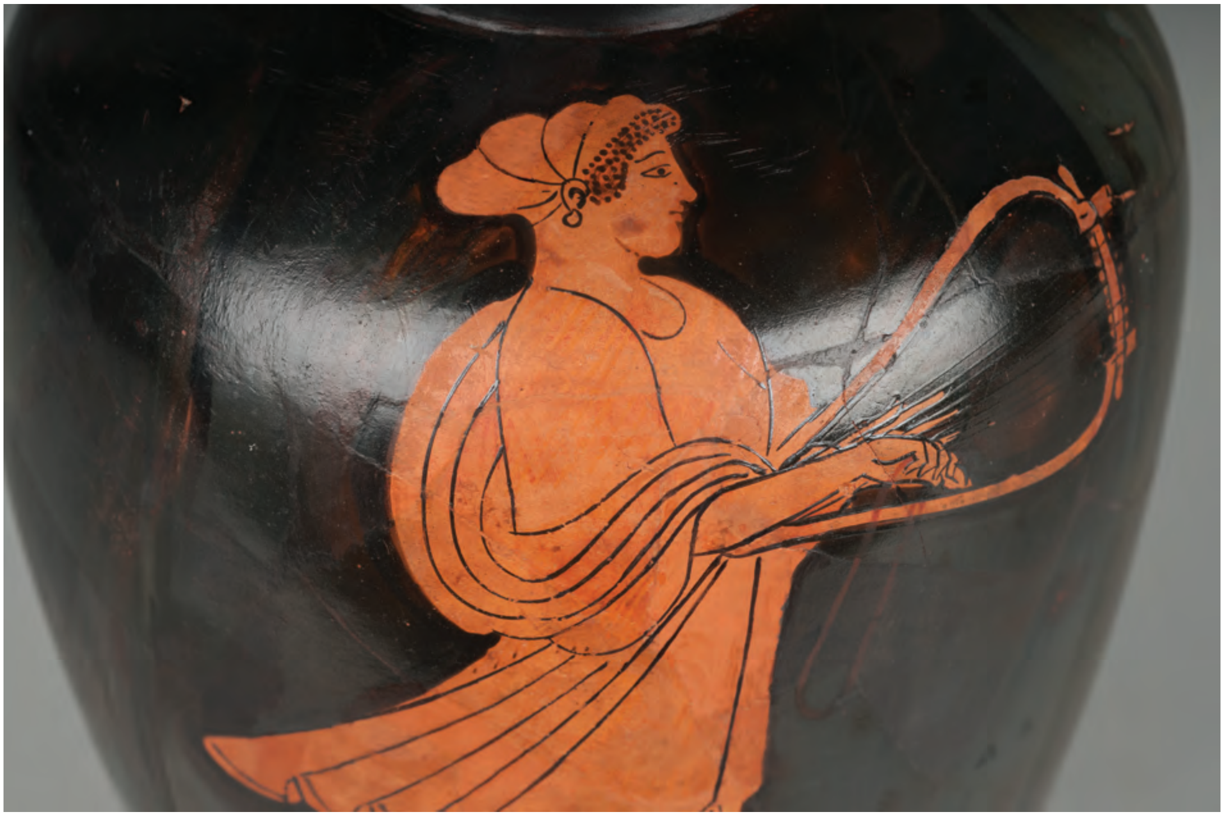

Fig. 42. The completed figural inpainting—note differences in sheen of gloss areas (Courtesy of Tony Sigel, © President and Fellows of Harvard College)

I inpainted the losses in the figural blackline areas with a fine sable brush and black gouache. This allowed for corrections to be made in the water soluble paint, and when satisfied, I sealed the lines with 3% B-72 in acetone. Although this proved effective, I did not feel I had enough control over the drawing process, and since this treatment I have successfully experimented with other methods for re-creating fine blackline decoration, including the methods used by the original vase painters (Artal-Isbrand and Klausmeyer 2013), and by testing both proprietary nonrefillable drafting pens and Rapidograph style refillable pens. The last method proved quite successful—but that is a subject for another article. While inpainting the losses to the design areas closely matching in color, I again allowed slight tonal and gloss differences to remain visible (fig. 42).

Finally, I inpainted many of the smaller damages—especially the very visible fine scratches and abrasions in black slip areas from the tools of careless restorers, which greatly increased the visual coherency and beauty of the vase. It is my opinion that damages inflicted by modern restorers should be rendered as invisible as possible (figs. 43a–b).

ACKNOWLEDGMENTS

Thanks are offered to my friends and colleagues in our discipline of objects conservation and at the Straus Center for Conservation—particularly our interns and fellows, who have shared and taught me so much over the years.

Oh, and especially Steve Koob.

Fig. 43a–b. The oinochoe after treatment (Courtesy of Tony Sigel, © President and Fellows of Harvard College)

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SOURCES OF MATERIALS

Deroter steam cleaner
Preservation Equipment Ltd
Vinces Road, Diss
NorfolkIP22 4HQEngland
https://www.preservationequipment.com
+44 (0)1379 647400

Dust-Off (or similar), Manfrotto 244 variable friction magic arm with camera bracket and 649 quick action release clamp
B&H Photo
420 9th Ave. at 34th St.
New York, NY 10001
(800) 606-6969
http://www.bhphotovideo.com/

Flugger acrylic spackle (fine surface filler), glass microballoons, Newplast (formerly Harbutts) Plasticine, Paraloid B-72 (acrylic resin)
Conservation Resources International, LLC
5532 Port Royal Road
Springfield, VA 22151
(800) 634-6932
http://www.conservationresources.com/

Modostuc
Peregrine Brushes and Tools
1211 South 60 West
Wellsville, UT 84339
(267) 888-6657
http://brushesandtools.com

Flexible frisket film
Iwata Medea
1336 N. Mason
Portland, OR 97217
(503) 253-7308 x2000
http://www.iwata-medea.com/artool-category/masking-film/

Golden fluid acrylics, matte and gloss, and gloss, satin, and matte Golden polymer UVLS varnishes
Golden Artist Colors, Inc.
188 Bell Road
New Berlin, NY 13411-9527
(800) 959-6543
http://www.goldenpaints.com/

Leister hot air tool, Modostuc (fine surface filler), Staedtler Mars white plastic/vinyl eraser
Talas
33 Morgan Ave.
Brooklyn, NY 11211
(212) 219-0770
http://www.talasonline.com/

Micromesh micro-surface finishing products
Micro-Mark
340 Snyder Avenue
Berkeley Heights, NJ 07922
(800) 225-1066
http://www.micromark.com

Parafilm M
Sigma-Aldrich
3050 Spruce St.
St. Louis, MO 63103
(800) 325-3010
http://www.sigmaaldrich.com

Smooth-On mold-max 30RTV rubber
Smooth-On, Inc.
2000 Saint John Street
Easton, PA 18042
(800) 762-0744
http://www.smooth-on.com/

ANTHONY SIGEL is conservator of objects and sculpture at the Straus Center for Conservation and Technical Studies, Harvard Art Museums. He was trained through a 10-year unofficial museum apprenticeship at the Art Institute of Chicago, followed by an Advanced-Level Internship at the Straus Center. He gained his initial experience treating ancient ceramics under the tutelage of Stephen Koob during four summers at the Archaeological Exploration of Sardis, Turkey. His training in clay sculpture while a student at the Art Institute of Chicago led him into the technical study of Gian Lorenzo Bernini's works in terracotta. In 2004–2005, he spent a year as a Fellow of the American Academy in Rome studying these works in situ. His publication range includes the study of Baroque terracotta sculpture and the treatment of Islamic and other ancient ceramics. Most recently he co-curated and co-authored the catalog for the 2012–2013 exhibition "Bernini; Sculpting in Clay" at the Metropolitan and Kimbell museums. Address: Straus Center for Conservation and Technical Studies, Harvard Art Museums, 32 Quincy Street, Cambridge, MA 02138. E-mail: tony_sigel@harvard.edu

RESTORATION BY OTHER MEANS: CT SCANNING AND 3D COMPUTER MODELING FOR THE RE-RESTORATION OF A PREVIOUSLY RESTORED SKULL FROM THE MAGDALENIAN ERA

J. P. BROWN, ROBERT D. MARTIN

ABSTRACT

The Cap Blanc skeleton was discovered in France in 1911 by a workman who struck the skull at least once with a pickaxe while lowering the floor of the recently excavated rock shelter at Cap Blanc. The skeleton proved to be a Magdalenian era human and was subsequently acquired by the Field Museum in 1927. It was initially displayed with the fragmentary skull, but, in the early 1930s, the skull was reconstructed under the direction of Dr. Gerhardt von Bonin of the University of Illinois.

In 2012, we were able to use a mobile CT scanner to image the bones of the skeleton, including the skull. Upon examination of the scans, it became apparent that some features of the reconstruction of the cranium (sloped brow, small orbital cavities, and projecting nasal bones with large nasal opening) were anatomically incorrect, perhaps due to a self-consciously primitive restoration of the skull. We briefly considered reversing the 1930s reconstruction and using the original skull fragments to produce a more anatomically realistic reconstruction, but the importance of the specimen and the robust nature of the adhesive and gap-fill used in the 1930s reconstruction made the risk of damage while reversing the restoration unacceptably high. We, therefore, attempted to restore the skull to a more anatomically feasible state by converting the CT scan to a 3D software model showing each fragment in its current alignment, and then repositioning the fragments in software to produce a new reconstruction which could be viewed in software. We then 3D-printed the new reconstruction for further study.

In this paper we discuss the methods and software used for extracting and repositioning the fragments and the problem of arriving at a definitive reconstruction by this method. We include some commentary on 3D printing as a long-term preservation problem with consideration on the longevity of 3D-printed artwork. Finally, we review the result of our re-restoration of the skull.

1. INTRODUCTION

From 2006, thanks to the generosity of local hospitals and private companies, x-ray computed tomography (CT) scanning has become part of the methodology of technical examination and documentation of objects and natural history specimens at the Field Museum. Since then we have scanned and analyzed over one hundred objects both large and small. This is not to say that CT scanning has replaced conventional examination by projection x-radiography, but rather that the high dimensional accuracy of CT scans, and the ability to reconstruct the interior of objects in three dimensions, provides essential information for complex objects. This three-dimensional accuracy largely eliminates the geometric distortion and superimposition effects which can be a problem when using conventional projection x-radiographs to examine the interior of objects.

This article briefly outlines the acquisition of x-ray CT data using medical gantry CT scanners, how this data can be processed to show useful information about the interior of complex museum collection items, and how 3D polygon models can be extracted from the CT data for further work. It shows how CT-derived 3D models of the fragments of a previously restored prehistoric human skeleton were used to produce a new, and more anatomically feasible, reconstruction of the skull.

2. CT SCANNING

2.1 ACQUIRING CT DATASETS

There are two stages in generating CT scan data: the first is scanning and the second is mathematical reconstruction. In practice, particularly where helical scanning is used on modern medical CT scanners, these activities may proceed approximately in parallel.

In the scanning phase, a large number of projection x-ray images are taken around a single axis of rotation to give 360° imaging of an object. In a third-generation medical gantry CT scanner (the most commonly encountered type), scanning is achieved with an x-ray source and x-ray detector mounted on opposite sides of a steel ring housed in the gantry. The object to be scanned is placed prone on a bed with appropriate supports and the bed is raised or lowered so that the axial center of the object is aligned with the axis of rotation of the ring. To acquire projections, the ring spins while the bed moves into the bore of the gantry, carrying the object through the ring, and a fan beam of x-rays is projected from an x-ray source, through the object, to the detector. This method of helical (*spiral*) scanning is our preferred data-acquisition method if 3D rendering or multiplanar reformatting is required.

The projection images acquired from scanning are used as inputs for a mathematical reconstruction of the scanned volume. Multiple different reconstructions can be performed from one set of projections by applying alternative mathematical filters to the same projection data. In medical CT scanning, the mathematical convolution filter (*kernel*) used in reconstruction determines the trade-off between image sharpness and noise: higher spatial resolution and therefore image sharpness implies greater noise; *softer* kernels imply less noise but have lower spatial resolution (Weiss et al. 2011). Medical reconstruction software for a particular make of scanner will come preloaded with a range of proprietary reconstruction kernels, which can be selected to provide the best balance between noise and image sharpness for a particular scanning situation.

The reconstructed data are represented as a 3D grid of x-ray attenuation values. Each non-null value in the matrix is the mean x-ray attenuation calculated for a small, rectangular portion (*voxel*) of the total volume scanned. In medical CT scanning, the matrix is stored as a stack of evenly spaced bitmap images in DICOM (Digital Imaging and Communications in Medicine) format.[1]

2.2 IMAGING CT DATA SETS

2.2.1 Two-Dimensional Imaging

Medical CT data stacks are conventionally viewed axially, slice-by-slice, as a series of 2D grayscale images which are scrolled through in sequence. As an example, consider the Peruvian mummy in a wooden tray (shown prior to rehousing) in figure 1. The mummy was scanned in the tray on a 64-slice GE Medical Systems Lightspeed VCT scanner. Scan settings were 120 kV and 100 mA with 1.2 mm focal spot, 0.625 mm collimation, and a spiral pitch factor of 0.5. The series was reconstructed as 512 × 512 pixel axial slices with 0.7 mm pixel spacing and a thickness of 0.625 mm. These numbers imply that each pixel in the image represents the means x-ray attenuation value of a 0.7 × 0.7 × 0.625 mm portion of the scanned volume. A standard convolution kernel and medium filter were used in the reconstruction.

A single axial slice from the scan, about mid-way through the stack is shown in figure 2a. As in a conventional x-radiograph, whiter areas indicate higher x-ray attenuation values. we can see the layers of textile used in the wrappings, the grain and profile of the wood slats used to create the tray, sections through the mummy's bones (ribs, etc.), the inverted 'U' shape of a section through a gourd vessel

Fig. 1. Peruvian mummy bundle, Chancay culture, ca. 1200 CE, human remains, textile, cordage, ceramic, gourd, cotton boll, seeds, 61 × 42 × 44 cm. (Courtesy of the Field Museum, Department of Anthropology, catalog no. 183925)

inverted above the mummy's chest, and sections through two highly attenuating pottery figurines at right and left.

The reconstruction matrix can be resliced orthogonal to the axial plane to show other views through the series of slices. Figure 2b shows a sagittal slice from the middle of the stack: The role of the inverted gourd vessel in supporting the wrappings above the torso is somewhat clearer in this image. Figure 2c shows a coronal slice through the middle of the stack: The position of the skeleton and the profile of the pottery figurines is made somewhat clearer. The relationship between the axial, sagittal, and coronal planes is shown in figure 2d. Ten years ago such multiplanar reconstruction (MPR) from axial slice data was quite exotic, but nowadays these views can be generated interactively in real time from medical slice data on most desktop computers with freely available software such as ImageJ.

2.2.2 Three-Dimensional Imaging

Three dimensional renderings of CT data can be achieved by mapping the attenuation values in the reconstruction matrix to color and opacity (RGBA) values using a lookup table or transfer function. The structures can be rendered in three dimensions directly from the slice data either by isosurface methods (a particular attenuation value is selected to represent the solid surface, and this value is then rendered as an opaque surface) or by ray-tracing with transparency. These methods work reasonably well on objects where the attenuation values are low at the outside of the object and get higher towards the center, but are less satisfactory where the features near the outside of the object are more attenuating than

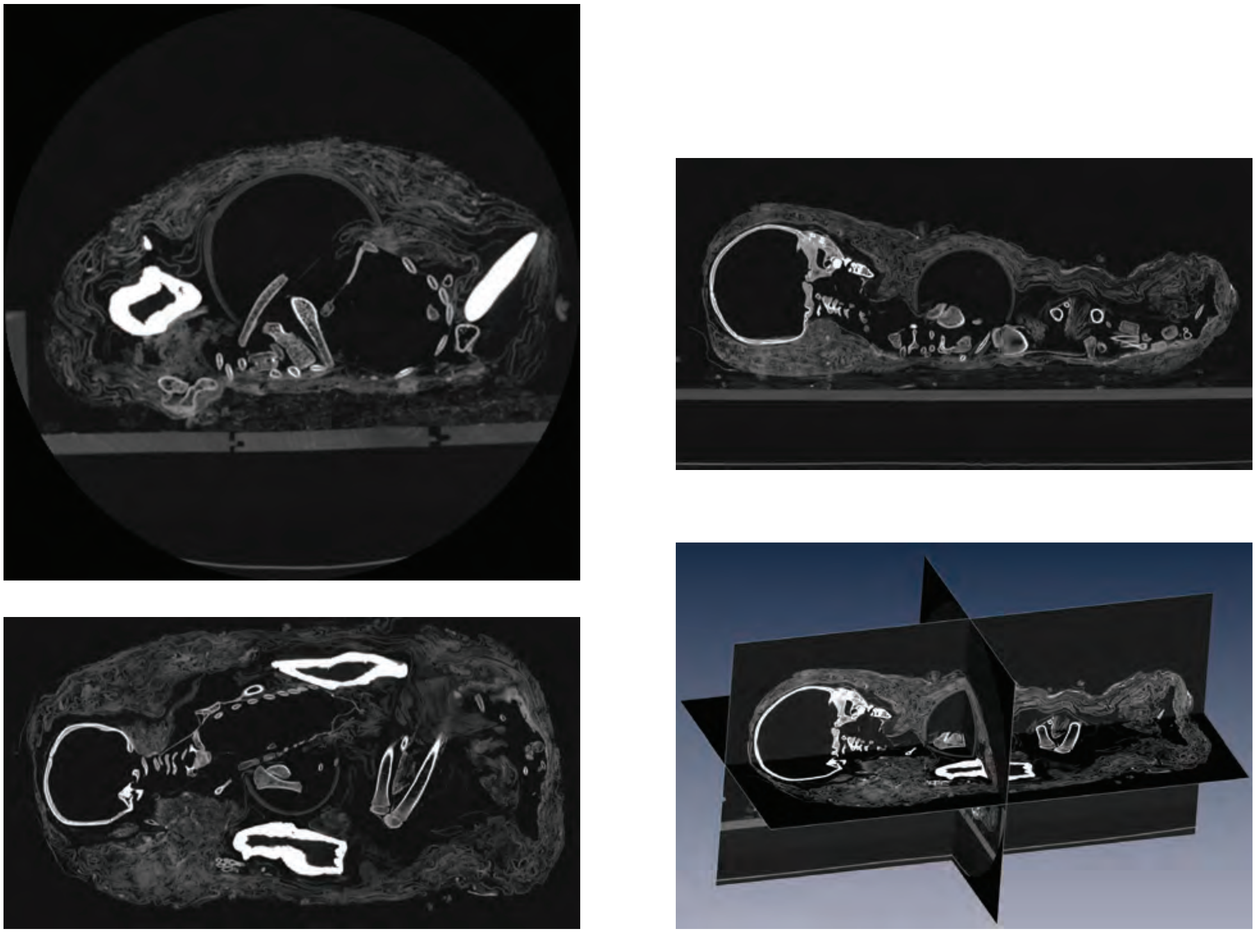

Fig. 2. Two-dimensional views of the reconstructed data set from CT scanning the mummy shown in figure 1: a. axial view at mid-point of the reconstruction matrix, rendered in ImageJ; b. sagittal view at mid-point of reconstruction matrix, rendered in ImageJ; c. coronal view at mid-point of reconstruction matrix, rendered in ImageJ; d. relationship between axial, sagittal and coronal views, rendered in Amira.

the inside, where the surface of a feature inside the object varies significantly in attenuation value, or where different components of the same object have similar attenuation value. For example, figure 3a shows a volumetric rendering of the mummy from figure 2 with a simple linear transfer function to remove the overlying low-attenuation textiles. Although the high-attenuation elements such as bones, teeth, and ceramics show up well, mapping the cloth to a transparent value has also made the (equally low-attenuation) gourd transparent. If the opacity of the low-attenuation values is increased, the cloth reappears and obscures the gourd. Also, while the teeth and the cortical bone of the diaphyses show up well, the spongier bone of the epiphyses and the phalanges are translucent and hard to see clearly.

If applying a single transfer function to the whole reconstruction matrix will not give adequate volumetric rendering, as in the case of the wrappings and the gourd, then segmentation of the data matrix into parts (sometimes called *labeling*) must be performed. Three-dimensional regions of interest (ROIs) are defined on the data and a different transfer function is applied to each ROI. Some ROIs may be made transparent or translucent, others may be made solid, and false color may be applied. ROIs can be defined semi automatically by region growing on the basis of attenuation value: A small sample of voxels that is representative of the region of interest is nominated and then the region is allowed to grow from there so long as the adjacent pixels are within some threshold range close to the attenuation value of

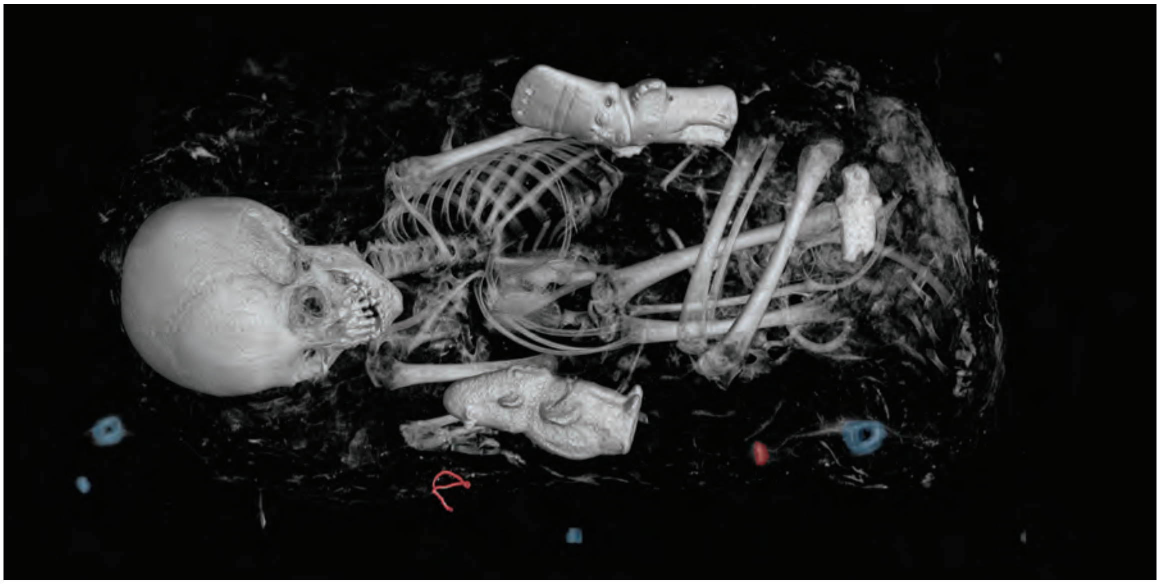

Fig. 3. Three-dimensional views of the reconstructed data set shown in figure 2, rendered in VG Studio Max: a. volumetric rendering with a simple linear transfer function to make overlying wrappings transparent; b. segmentation of the data set allows different transfer functions to be applied to different regions of the data.

the initial sample. Alternatively, when the feature of interest approximates a 3D geometric primitive, the primitive may be outlined on the object to roughly define the region. Some software packages offer Boolean operators that allow the operator to intersect, add, or subtract one or more regions from another, which can make it somewhat easier to refine the region of interest. Where clear attenuation differences between adjacent features of interest are absent, segmentation must usually be performed by manually drawing the profile or outline of the feature on each slice in which it appears. Some segmentation packages offer an interpolation mode which allows outlining the profile on only some of the slices and then allow the software to guess the remainder.

Figure 3b shows the segmented data for the mummy from figure 1; ROIs were defined for the rope, wrappings, wood tray, skeletal elements, ceramics, and the gourd. The wood tray ROI has been made transparent, and the color and translucency of the other regions has been varied independently.

Free software packages for 3D segmentation and rendering include Osirix, Drishti, Voreen, and ImageVis3D. In general these packages work reasonably well on small data sets ($<$ 0.25 GB, about 500 512 $\times$ 1512 CT slices) but less well on large data sets ($>$ 1 GB). Commercial packages for handling large data sets include Amira, VG Studio Max, and Mimics. Given adequate hardware, these packages perform well on large data sets, but are expensive, costing from $4,000 to more than $15,000 even after academic discount.

2.3 EXTRACTING POLYGON MESHES

Once a region of interest has been defined, it becomes possible to generate a polygon mesh that approximates its surface in three dimensions.[2] The mesh can then be saved in a suitable digital file format and refined and rendered independently of the CT volume.

To get good polygon meshes from CT data, we need voxels that are as near as possible isotropic; that is, the pixel spacing on the slice images should be as close as possible to the spacing between slices. It is also desirable to have as much detail as possible, so increasing the number of pixels per slice and decreasing the thickness of the slices naturally improve the quality of the resulting mesh. Increasing the resolution of the slices and decreasing slice thickness not only increases the amount of data to be handled (which implies more expensive hardware and software for processing), but also increases the noise on the slice images.

Small-feature contrast improves linearly with decreased slice thickness, whereas noise increases as the square root of slice thickness ratio (Nagel 2004, 24). Essentially, taking thinner slices improves the visibility of small details despite increased noise.

Fig. 4. Polygon meshes of the three ceramic figurines in the mummy bundle shown in figure 3. Meshes were extracted with VG Studio Max, saved to disk, and then rendered in Blender.

On medical systems, the increase in noise down to around 0.5 mm slice thickness can usually be dealt with by choosing an off-the-shelf scanning protocol. As slice thickness is reduced to 0.2 mm (the current limit for medical gantry scanners), setting aside a significant amount of time to optimize the scanning technique and fine-tune the reconstruction parameters for the particular object under examination becomes important if results are to be usable.

Space does not permit a full discussion of optimization of medical CT scanning protocol, but Prokop (2003) provides an accessible summary from a medical perspective. The most important differences between scanning human beings and scanning objects of cultural heritage are the medical necessity to reduce x-ray exposure as far as reasonably achievable (essential for living specimens), and the concern to take scans as quickly as possible to prevent patient movement during the scan. Both of these problems can usually be ignored when CT scanning cultural objects: The ring rotation speed, bed speed, and spiral pitch can all be reduced, and the current to the x-ray source can be increased. All these settings increase the time of the scan and the x-ray exposure, but reduce noise. In practice, the reduction in noise that can be achieved is limited by the ability of the x-ray tube to sustain high output during the extended scanning period.

2.4 PHYSICAL REALIZATION OF POLYGON MESHES

Given a suitable polygon mesh, it is possible to produce a physical copy of the mesh using manufacture that is additive (3D printing) or subtractive (computer numeric control [CNC] cutting); however, a caveat must be inserted here. Although all the segmentation software mentioned earlier can produce good polygon meshes for rendering, a mesh often needs significant modifications to be actually manufacturable. Such modifications include ensuring a manifold surface, removing noise meshes, and repairing self-intersections.

The requirement for a manifold surface can be difficult to achieve by hand. Noise meshes are sometimes discrete *bubbles* located inside the main mesh, other times they are nonplanar mesh faces (those which do not share all their edges with adjacent faces, but stick out on their own). The bubble meshes are not usually anchored to the main surface, but can complicate printing and are usually best removed. Nonplanar faces and self-intersections usually result in an unprintable mesh. Resolving these imperfections requires additional software directed towards 3D printing or CNC cutting. At present, we have found only one free software package that is reasonably satisfactory for preparing polygon meshes for additive manufacture: MeshMixer. Commercial packages directed toward producing manufacturable objects from polygon meshes (Geomagic, Magics, and 3-matic) are relatively expensive and have a fairly steep learning curve. Often, it is easier to pay a local 3D printing service to refine the mesh to manufacturability, or there may be a local MakerSpace that can assist.

2.4.1 Additive Manufacture

In additive manufacture, the solid is built up from thin layers of material, each layer deposited on the previous one (Gibson et al. 2010). Techniques for additive manufacture include extrusion of thin layers of molten polymer, which is allowed to harden (fused deposition modeling [FDM]), selective laser sintering (SLS) of powdered metals or polymers and stereolithography (SLA) with UV-cured resins.

Figure 5 shows an example of an additively manufactured copy of one of the ceramic figurines, printed from a polygon mesh derived from the CT data shown in figure 3. What is particularly exciting about this is the possibility of nondestructively imaging features inside an object and then producing a physical copy for study. There is a wide variety of materials—metals and polymers—that can be used, and, with appropriate software, it is possible to find a technique that will print most shapes. Current disadvantages of additive manufacture are that production is quite slow (one vertical inch per hour is

Fig. 5. 3D print of the polygon mesh of the center figurine from figure 4. The mesh was extracted using VG Studio Max, refined in 3-matic and printed in white polylactic acid on an FDM machine.

considered fast), the build volumes are limited (18 × 12 × 8 in. is considered a large build volume), and machines are optimized for a particular, narrow range of output materials.

Printing in metals is prohibitively expensive for large volumes. Printing in polymers is more affordable, but unfortunately many of the polymer materials perform poorly in Oddy tests. The tests we have performed on FDM and SLA materials, although by no means exhaustive, have given results equivalent to the unusable and temporary criteria described by Schiro (2011).

This finding has important implications for the collection of 3D-printed art and the use of 3D-printed materials in museum exhibits. The general attitude of 3D-printer suppliers seems to be that, given the polygon mesh, we can always print another one. This is true up to a point, but there is considerable variation in the surface finish of 3D-printed objects, particularly when manufactured on hobbyist FDM and SLA machines. If an artwork is manufactured on a particular kind of machine with a particular brand of output material, there is no guarantee that the surface finish of the resulting piece will be replicable 20 or 30 years from now. This problem is somewhat parallel to that encountered in computer-based installation art. As technology changes, realizing the original artistic intent from a digital original can become difficult or impossible.

The most satisfactory additive production method we have found so far is laser sintering using nylon powder. We find no reaction on the Oddy test, and parts made with this technique are robust, relatively inexpensive, and take paint well.

2.4.2 Subtractive Manufacture

Subtractive manufacture is faster and has larger build areas than additive manufacture; machines to process 4 × 8 ft. stock are readily available. In the simplest set-up—a three-axis CNC machine—a computer-controlled milling head moves over a sheet of material, progressively cutting away excess stock to leave the required shape behind. A wide range of conservation-safe materials can be machined to shape by this method, but the build height is limited and undercuts are a problem. If the object to be manufactured has significant thickness, it is usual to divide the model into multiple sections of an appropriate depth, machine these individually, and then assemble the parts.

This workflow of CT scanning, segmentation, 3D modeling, and 3D printing brings us to the reconstruction of the previously restored skull of the Cap Blanc skeleton at the Field Museum.

3. HISTORY OF THE CAP BLANC SKELETON

3.1 DISCOVERY AND EARLY TREATMENT

The early human skeleton familiarly known as the Cap Blanc skeleton, more recently as Magdalenian Girl, and more recently still as Magdalenian Woman, was discovered in France in 1911. The discovery occurred while a protective structure was being built around the mouth of the Abri du Cap Blanc, a recently excavated rock shelter with a large (15 × 3 m) and important prehistoric carved frieze of running horses and bison on its back wall (Bourdier et al. 2010). Part of the planned work involved lowering the floor level inside the shelter to permit a better view of the carvings. During the digging, one of the workmen discovered the skeleton after striking it with a pickaxe, breaking the skull. Two specialists, Capitan and Peyrony, were dispatched from Paris to assess the skeleton and found that the blow had broken the cranium, but that the rest of the skeleton was reasonably complete (Capitan 1911). The skeleton was block-lifted and, after some delay, transported to Paris for treatment at the *Laboratoire de Paléontologie* of the *Muséum National d'Histoire Naturelle* (MNHN). A receipt for Fr. 180 for the restoration of the skeleton, written to M. Grimaud, the owner of the rock shelter, by Capitan shows that the treatment was either in progress or complete in the summer of 1914 (Capitan 1914).

After treatment was complete, the skeleton was returned to the owner of the Cap Blanc site with a letter from the preparator at the MNHN, J. Papoint (1915). Papoint noted that the damaged skull could not be fully reconstructed and was being returned in two blocks, one of which comprised the upper and lower jaws and the cervical vertebrae. Papoint did not detail the contents of the other block, but it seems reasonable to presume that it contained whatever had been recovered of the cranial vault. He also noted that the two blocks were "very fragile and should be unpacked with care."

3.2 ACQUISITION BY THE FIELD MUSEUM

At some point between 1915 and 1924, the skeleton was shipped to the American Museum of Natural History in New York (AMNH) so that it could be evaluated for purchase.

The AMNH ultimately declined to purchase the skeleton and, in 1927, the skeleton was acquired by the Field Museum. Concerned about shipping such a fragile specimen, the AMNH, with the assent of the Field Museum, consolidated the skeleton with Ambroid, a recently developed cellulose nitrate cement.

The first detailed photograph we have of the skeleton shows it on display in 1927 (fig. 6). The skeleton appears much as described by Papoint, except that the skull is now in six pieces. Of the two blocks mentioned in 1915, the block comprising the jaws and cervical vertebrae appears to be intact, but the block that presumably contained the cranial vault has separated into at least five pieces. A letter immediately before the acquisition of the skeleton describes the skeleton as "intact, except for the fact that the skull is in several pieces"(Nicoll 1926), so it is possible that damage occurred before shipment to the Field Museum.

Fig. 6. The Cap Blanc skeleton on display in the Field Museum in 1927: a. overall view; b. detail of the fragments of the skull. The skeleton dates to 13,000 to 11,000 BCE (Courtesy of The Field Museum, CSA55472. Department of Anthropology, catalog no. 42943)

3.3 PRE-WORLD WAR II RECONSTRUCTION OF THE SKULL FRAGMENTS

In 1932, the skeleton was taken off display so that the skull could be restored by Mr. T. Ito under the direction of Dr. Gerhardt von Bonin, a medical anthropologist at the University of Illinois at Chicago (Field 1938). von Bonin subsequently published an analysis of the skeleton (1935) in which he briefly described seven pieces of the skull before reassembly, the seventh resulting from cleaning and separating the block containing the upper and lower jaws. Later in the publication, he described the reconstruction of the skull and mentioned that the joint between the rim of the left orbit and the frontal bone was "somewhat worn down so that the position of this piece could not be ascertained with perfect accuracy" (1935, 20). The skull fragments were readhered and the areas of loss (particularly the nasal region and the proper right half of the cranial vault) were gap-filled with plaster, most of which was then painted black,

Fig. 7. von Bonin's 1932 reconstruction of the skull fragments shown in figure 6. Human remains with painted dental plaster fill, 21 × 15 × 14 cm. (Courtesy of The Field Museum, CSA77605. Department of Anthropology, catalog no. 42943)

while the upper half of the interior of the cranial vault was coated with multiple applications of plaster. The final result of the reconstruction is shown in figure 7.

3.4 RECENT WORK

In 2004, the skeleton was taken off display for transfer to new exhibit, and we were able to perform projection x-radiography on the bones. As evident from figure 8, von Bonin's reconstruction

Fig. 8. Digital x-radiograph of the cranium of the Cap Blanc Skeleton, Dec 10, 2004.

Fig. 9. Magdalenian skeleton on display in the Evolving Planet exhibit, 2006. Courtesy of William Pestle.

included an undocumented metal pin to hold the rim of the left orbit in place. The skeleton was placed back on display in the new Evolving Planet exhibit in 2006 (fig. 9).

4. PRODUCING A NEW RECONSTRUCTION OF THE SKULL

4.1 CT SCAN

In 2012, the skeleton was taken off display before its appearance in an exhibit devoted to the Lascaux cave paintings, and we were able to x-ray CT scan all the bones. The condition of the skull at this time is shown in figure 10. There is some loss of paint from the plaster fill, and unpainted fills are apparent at the joint between the left orbital margin and the frontal bone and at the front of the upper jaw.

Two scans were conducted on a 64-slice GE Medical Systems Lightspeed VCT scanner mounted in a mobile trailer and positioned in the museum's parking lot. The first scan was taken at 140 kV, 94 mA, and the second at 120 kV, 100 mA, both with 0.7 mm focal spot, 0.625 mm collimation, and a spiral pitch factor of 0.5. The data were reconstructed as 512 × 512 slices with 0.48 mm pixel spacing and

Fig. 10. Condition of the cranium of the Cap Blanc skeleton in 2012. Courtesy of J.P. Brown.

0.625 mm slice thickness, the higher kV scan using a bone kernel and the lower-kilovolt scan using a convolution kernel, both with a medium filter.

On examination of the scans, it seemed to us that the restoration provided a self-consciously *primitive* reconstruction of the skull's appearance. In particular, the low, backward-sloping brow and the narrow orbital cavities did not seem anatomically modern even though the C14 dates for the skeleton would indicate that an anatomically modern reconstruction would be appropriate. The essential feature that gave von Bonin's reconstruction this primitive appearance was the positioning of the maxilla relative to the frontal bone, and the main evidence for the position chosen by von Bonin was the link, albeit floating, formed between the two pieces by the fragmentary proper left zygomatic bone.

We briefly discussed reversing the 1930s reconstruction and using the original fragments to produce a new and more anatomically realistic reconstruction; however, the importance of the specimen and the extensive nature of the restoration (including the embedded metal pin) made the risks of reversing the restoration quite high. We decided instead to try to create a virtual 3D model of each of the fragments in their current alignment and then reposition the fragments in software to produce a new, virtual, restoration.

4.2 SEGMENTATION

The x-ray attenuation of the plaster fill (calcium sulfate) was sufficiently similar to the attenuation of cortical bone (calcium hydroxyapatite) that automatic segmentation produced unsatisfactory results. The large area of plaster reconstruction at the right of the skull could be easily selected using 3D lasso tools and Boolean operations, but the segmentation of plaster from bone where the two materials joined had to be conducted by eye, almost slice-by-slice in some regions. Where plaster met the trabecular bone of the skull, this was not too difficult. The plaster is relatively homogenous and has a very different texture from the spongy interior bone. Where the plaster met the outer cortical bone of the skull, distinguishing between plaster and fill could be quite difficult. We used VG Studio Max to divide most of the plaster from the bone, taking about three days to achieve a satisfactory result (fig. 11).

Fig. 11. Segmentation of the bone and fill on the skull of the Cap Blanc skeleton; the regions of fill are colored amber. Rendered in VG Studio Max.

4.3 MAKING POLYGON MESHES OF THE FRAGMENTS

Having divided the bone from the plaster, we then needed to segment out the individual fragments of bone and make polygon meshes of them. This task proved extremely difficult in VG Studio Max and, in the end, we transferred the problem to the Mimics software package and produced polygon meshes in the 3-matic package that accompanies Mimics (fig. 12). Even so, it took over two weeks to get close to a good representation of the fragments, primarily because we found that the skull was far more fragmentary than we had suspected. In all, we identified 36 fragments (not counting loose teeth). On the basis of the previous reading of the history of the skeleton, we had expected to be looking for seven or eight fragments. The additional fragmentation of, for instance, the left parietal bone of the cranium is fairly obvious in figure 10, but this was not apparent before removing the skeleton from display because, as figure 9 shows, the skeleton was displayed in a crouched position with the skull lying with its left side down.

4.4 DIGITAL RESTORATION

The question then became how to arrive at a more satisfactory arrangement of the fragments. Reconstruction of skulls from CT scanned fragments is not new (Zollikofer et al. 1995), but has generally been carried out on objects with six or fewer fragments. More recently, automatic alignment of meshes from fragmentary objects has been achieved (Brown et al. 2008), albeit in wall-paintings, but this method relies on the constraint of a near flat plane (the painting's surface) and good knowledge of the profile of the edges.

One possible option was to 3D print the fragments and then reassemble them manually. There were two principal difficulties with this approach: first, the difficulty of correctly aligning the floating fragments such as the right mastoid-glenoid and the left orbital margin; second, the uncertainty in the profile of the edges of the fragments meant that the principal guide to correct manual alignment—whether fragments are felt to *lock* into position properly or not—would be compromised. We chose to reassemble the fragments in software. The principal advantages were that we did not have to deal with gravity (no need for intricate supports to hold the floating pieces and the narrow bridge in the left parietal while gap fill was setting) and that we could use mirroring to exploit left–right symmetry to check alignment of the fragments on either side of the skull.

After discussing the problem with craniofacial reconstructive surgeon Dr. Pravin Patel and biomedical engineer Dr. Linping Zhao, we determined that the best approach to the reconstruction was to proceed iteratively. Because we had little *a priori* information on the original shape of the skull, each successive step of the virtual reconstruction would need to be determined on the basis of the previous state of the assembly. To reposition the fragments, we used the free software package, Blender, because it

Fig. 12. Polygon models from the segmentation of the bone fragments of the skull of the Cap Blanc Skeleton: a. composite of screen grabs from 3-matic showing the position of the fragment models in von Bonin's reconstruction; b. individual fragments arranged and rendered in Blender.

allows for mirroring, nested parent–child relationships, and can be configured for intuitive interactive repositioning. The parent–child relationship feature was particularly useful in this project. Given the relatively tight joints of von Bonin's reconstruction, we could define groups for each of the 1927 fragments. When the root parent was moved or rotated, all the child fragments would retain their alignment to the parent. Once the position of the group was satisfactory, the positions of the children could be refined individually to give final alignment.

We needed a strong starting point, and we chose to begin with the mandible (lower jaw). As shown in figure 11, the arch of the mandible is broken, just at the proper right of the mid-point. If we could determine the correct alignment of the fragments of the mandible, then we would have a baseline from which to build up the rest of the skull as shown in figure 13. First, we defined a mid-sagittal

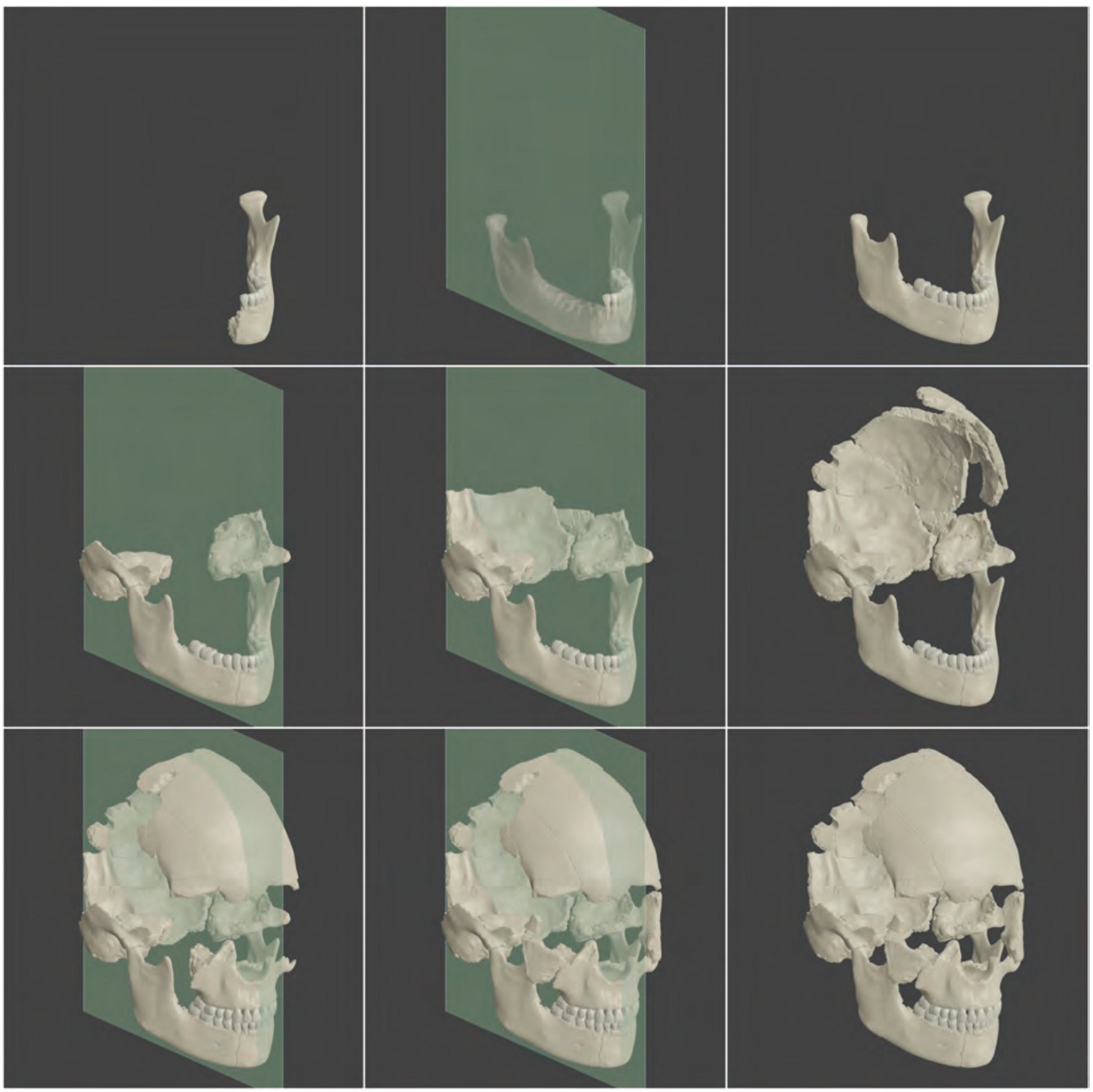

Fig. 13 Process of assembling polygon meshes into a new model of the skull. Top row: aligning the broken fragments of the mandible. Middle row: adding fragments of the temporal, occipital and parietal bones. Bottom row: adding the frontal, mandible, and left orbital arch.

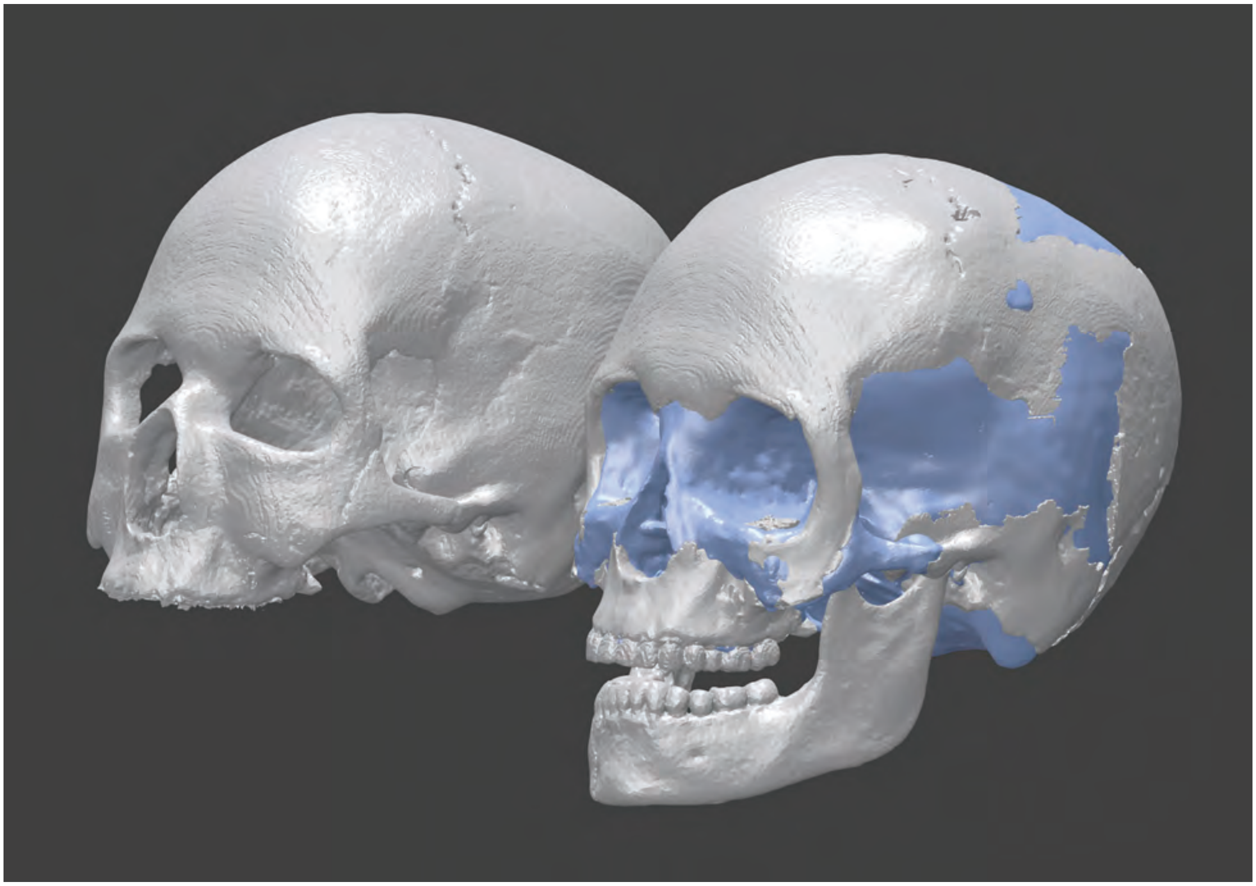

Fig. 14. Comparison of our virtual reconstruction (front) with von Bonin's reconstruction (rear).

mirror plane and then aligned the proper left fragment of the jaw so that, together with its mirror image, we had the appearance of a complete jaw. We then introduced the right-hand fragments and aligned them as best as we could with the mirror image to form the complete jaw. Once the mandible was complete, we were able to align the left and right temporal bones with the condyles of the mandible. We used the mirror plane to check the alignment of the temporal bones with each other until asymmetry was minimized, and this gave us a basis for building the cranium. We could then place the occipital, again using the mirror plane to check alignment. Then we built up the proper left parietal and added the fragments of the frontal, again checking alignment with the mirror plane. Next we added the maxilla, checking the alignment with the teeth of the mandible and with a mirror plane. Finally, we added in the fragment of the left zygomatic arch, again using a mirror plane to check alignment.

The losses on the proper left side of the cranial vault were gap-filled using virtual clay sculpting in Blender and ZBrush, and then the left hemisphere was mirrored across to fill the loss on the proper right side. Figure 14 shows our virtual model in comparison to von Bonin's reconstruction. The resulting model was refined in 3-matic to create a printable solid and then printed off-site using a Stratasys PolyJet printer (fig. 15).

5. CONCLUSIONS

The result of this virtual reconstruction is a physical model that is an anatomically defensible reconstruction of the skull, achieved without risking damage to the original specimen. All steps taken were nondestructive and reversible. The virtual reconstruction is well documented and, in principle, other

Fig. 15. The new reconstruction 3D printed in UV-cured acrylic resin. Courtesy of John Weinstein, courtesy of The Field Museum, A114938d_021B.

interested researchers could proceed through the same sequence of segmentation and virtual reconstruction and compare their result to ours. This ability to repeat or reconsider a virtual restoration is in sharp contrast to hands-on restoration, where detailed documentation and ready reversibility are hard to achieve. On the one hand, the extensive use of the sagittal mirror plane may have made our reconstruction overly symmetrical; on the other, it is not clear how this procedure could be improved, given the loss of original material on the proper right side of the cranium.

One question remains: Why did we identify significantly more fragments than are explicitly mentioned in von Bonin's account of the restoration of the skull? Some of these fragments are clearly present. The matching cracks at the exterior and interior surfaces of the cranial vault can be checked by visual inspection. In the case of some other fragments, the crack is visible at the outside of the skull, but plaster from the von Bonin reconstruction overlying the interior of the cranium prevents visual confirmation of the continuity of the crack at the inside surface. The question of whether some of the fragments that we identified are truly separable pieces of the cranium or whether we have over identified fragments on the basis of stress cracks on the outer surface of the cranium, cracks which do not fully penetrate to the interior surface of the skull vault, could not be resolved at the resolution of the CT scans taken in 2012. We are tackling this question as a new research project and have obtained two sets of higher-resolution scans: 0.2 mm thickness medical CT scans courtesy of the University of Chicago Hospitals and 0.1 mm isotropic micro-CT scans courtesy of local nondestructive testing company Alloyweld Inspection Co. We are in the process of segmenting these scans to see if we can resolve the question of how much resolution is required in practice to reliably differentiate fragment breaks from nonpenetrating stress cracks.

It should be noted in passing that the process of segmenting the CT scans, generating the mesh models of the fragments, repositioning and mirroring the meshes, gap-filling the resulting model, making it manufacturable, and then producing the printout of the reconstruction was considerably more time-consuming than we had anticipated: at least equivalent to a major object treatment. A nontrivial amount of this time was spent climbing a number of steep learning curves with unfamiliar software, so future work on similar resolution data should proceed significantly faster.

ACKNOWLEDGMENTS

We gratefully acknowledge fruitful discussions of craniofacial reconstruction methods with Pravin Patel, MD, and Linping Zhao, PhD, both of the University of Illinois, Chicago. Thanks are due to Will Pestle for initial background discussions and to John Weinstein for photographic contributions. We are also very grateful to Robert Dakessian, Randy Walker, and Melissa Roy of Genesis Mobile Imaging, Inc. for their help in bringing a mobile CT system to the Field Museum in 2012 so that the Cap Blanc skeleton could be scanned. The 3D print of the skull was performed by the Paradigm Development Group Inc. Funding to support the project was generously provided by Joyce Chelberg.

NOTES

1. DICOM is a digital image format in which each file carries both an image and associated metadata about the object being scanned and the machinery and equipment settings used to generate the image. The format was developed in the 1980s to produce an open standard to replace the multitude of mutually incompatible proprietary medical imaging formats that were proliferating and to ensure backward compatibility. Uncompressed DICOM files (the type currently generated by most medical CT scanners) can be opened in free software such as ImageJ and also by the segmentation packages listed in the text. The DICOM standard is defined online by NEMA at http://dicom.nema.org/. See Pianykh (2008) for an accessible introduction.

2. Of the free segmentation packages mentioned earlier, only Osirix and Drishti have the capability to produce meshes. The commercial packages Amira, VG Studio Max, and Mimics all provide functionality for extracting polygon meshes from CT data stacks.

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SOURCES OF SOFTWARE

3-matic
Materialise
http:/biomedical.materialise.com/3-matic

Amira
FEI Visualization Sciences Group
www.vsg3d.com/amira/overview

Blender
Blender Foundation
www.blender.org

Drishti
Ajay Limaye
https://code.google.com/p/drishti-2

Geomagic
3D Systems
www.geomagic.com/en

ImageJ
National Institutes of Health
http:/imagej.nih.gov/ij

ImageVis3D
University of Utah
www.sci.utah.edu/software/imagevis3d.html

Magics
Materialise
http:/software.materialise.com/magics

MeshLab
Visual Computing Lab—ISTI—CNR
http:/meshlab.sourceforge.net

MeshMixer
Autodesk
http:/meshmixer.com

Mimics
Materialise
http:/biomedical.materialise.com/mimics

Osirix
Antoine Rosset
www.osirix-viewer.com

Voreen
University of Münster
www.voreen.org

VG Studio Max
Volume Graphics, Gmbh
www.volumegraphics.com

ZBrush
Pixologic
http:/pixologic.com

J. P. BROWN is the Regenstein conservator at The Field Museum, Chicago, IL. He has a BSc in archaeological conservation from University College Cardiff and an MS in computer science from the University of Chicago. His research encompasses environmental monitoring and control, object conservation methods, and 3D imaging and analysis of objects. He taught practical and preventive conservation at the University of Wales, Cardiff, for five years until 1993 when he moved to the United States to work on the environmental monitoring and control of historic buildings. He joined the staff of The Field Museum in 2002 and was appointed Regenstein conservator in 2009. Address: The Field Museum, 1400 S Lake Shore Drive, Chicago, IL 50505. E-mail: jpbrown@fieldmuseum.org

ROBERT D. MARTIN received his BA in zoology from Worcester College, Oxford, England, in 1964 and his DPhil in zoology (animal behavior) from the same institution in 1967. He held an ascending series of academic posts in University College London and Birkbeck College, London, before being appointed professor and director of the *Anthropologisches Institut und Museum, Universität Zürich-Irchel*, Switzerland, in 1986. In 2001, he moved to the United States to take up the position of vice president and then provost of the Field Museum, Chicago, followed by his tenure as a Watson Armor III Curator of Biological Anthropology. His primary research interests include reconstructing primate evolution, inferring divergence times in the primate tree, allometric scaling analyses with particular reference to the scaling of brain and reproduction in primates. His new book *How we do it: the evolution and future of human reproduction* was released by Basic Books on June 11, 2013. In connection with the book, he recently started a regular monthly blog with *Psychology Today*, which can be accessed at http://www.psychologytoday.com/blog/how-we-do-it. Address: as for Brown; E-mail: rmartin@fieldmuseum.org

CONSERVING STRINGED SCULPTURE: THE TREATMENT OF HENRY MOORE'S *MOTHER AND CHILD,* 1939

NICOLE LEDOUX

ABSTRACT

Objects with tensioned string elements are found in many types of collections, ranging from fine arts sculpture to scientific and historic models. Deterioration and damage to these vulnerable elements in the form of fraying, breakage, and loss of tension can render these pieces undisplayable. This article presents the treatment of Henry Moore's stringed sculpture *Mother and Child* in the collection of the Harvard Art Museums.

Upon entering the collection, the string elements of *Mother and Child* were in very poor condition, with 11 of the 12 strings broken and one missing. This article discusses aspects of the sculpture's fabrication and outlines the various considerations involved in deciding whether to replace or repair the damaged strings. It also describes in detail the development and execution of a treatment technique for repairing the original strings using wheat starch paste and Japanese tissue paper.

1. INTRODUCTION

Stringed sculpture, and objects with tensioned strings in general, frequently pose significant conservation challenges. This is due to the inherent vulnerability of the string elements, which deteriorate and are easily damaged as they age. Despite their impermanence, the preservation of their physical integrity and appearance is of critical importance to the work as a whole. This poses a predicament for conservators and curators of these collections: Do we opt to replace strings in poor condition, or do we make it our goal to preserve the originals until no longer feasible? For this particular piece, we chose the latter approach, and in this article, I describe the decision-making process and technical challenges involved in doing so.

Henry Moore's (1898–1986) stringed sculpture *Mother and Child* dates to the early half of his career in 1939. The sculpture is cast in solid lead and rests on a stone base. A continuous length of linen thread, now broken in numerous places, was originally laced tightly back and forth across the sculpture 12 times. Figure 1 shows the condition of the sculpture when it entered the collection over a decade ago.

The sculpture came to the museum from a private collection, and unfortunately we do not have any information about when, or how, the strings came to be broken. The piece has been in storage virtually ever since, awaiting treatment in its fragile and unexhibitable state; however, its planned inclusion in the inaugural exhibit of the new Harvard Art Museum's facility, which opened in November 2014, provided the opportunity to finally give this object the full time and attention it deserves.

2. STRINGED SCULPTURES BY HENRY MOORE

Henry Moore was a British artist who had a very long and prolific career that spanned much of the 20th century. Mother and child figures, like the one in Harvard's collection, were a frequent subject of his works, in addition to reclining figures and other abstract human forms. He worked in a variety of media throughout his career, but is perhaps most well-known for his large-scale bronze sculptures, which can be found in public settings all across Europe and North America. Moore's experimentation

Fig. 1. Before treatment. Henry Moore, *Mother and Child*, 1939, lead and string on stone base, 13.5 × 18.8 × 5.1 cm (Courtesy of Harvard Art Museums, 2003.40.19)

with stringed forms coincided with his use of lead as a casting medium between 1938 and 1940. Moore made a series of 16 sculptures in lead, seven of which were strung (Tate Gallery 1988). Moore and his assistant cast these pieces themselves from wax originals using an improvised kiln at his bungalow in Kent; however, not all of his stringed sculptures were made in lead. Some were carved in wood and many were cast in bronze. Moore was not the only artist of his time to use tensioned string elements in his sculpture. In the 1930s and 1940s, both Barbara Hepworth and Naum Gabo were also producing string sculptures.

The stringed sculptures by Moore are very reminiscent in form to mathematical string models. Moore credits these objects, on display at the Science Museum in London, as an important source of inspiration (Toland et al. 2012). Mathematical string models date back to the late 18th century when they were used by mathematicians in the emerging field of descriptive geometry, allowing the viewer to visualize the intersections of surfaces in three dimensions. Moore states that "it wasn't the scientific study of these models but the ability to look through the strings as with a bird cage and see one form within another which excited me" (Hedgecoe and Moore 1968, 105). Moore's string sculptures were strung, and likely many of them restrung, using strings in a variety of colors, materials, and thicknesses.

3. *MOTHER AND CHILD*, 1939

3.1 BACKGROUND

By using a casting process for fabrication, Moore was able to produce multiple editions of his works. Editions of *Mother and Child* were cast in both lead and bronze. Although it is possible that the Harvard Art Museum's edition in lead is unique, there are some interesting differences between this sculpture and the lead edition published in Moore's first catalogue raisonné. In the catalog image, the sculpture rests on a different base that is oval and appears to be made of wood; furthermore, the catalog description lists the materials as "lead and wire," which may also suggest that it is a different edition, or could be evidence of an earlier stringing that used a different material (Moore 1944, 130). The bronze version of the sculpture was produced in an edition of seven (Dyer 1992, 79).

3.2 MATERIALS AND FABRICATION FEATURES

The sculpture was cast in solid lead, and there are several surface features that relate to its fabrication. The lighter spots shown in figure 2 are solder plugs.

These plugs fill the back ends of the holes and notches where the string was threaded over and into the adjacent hole. Without these plugs, the knotted ends and loops of string would have been visible on the outer surface. The solder also serves to lock the strings in place so that they cannot shift. While these plugs are soft like the surrounding lead, their lighter appearance suggests that they are a different alloy composition that did not develop the same dark patina as the rest of the sculpture. It seems unlikely that this contrast was intended, as evidenced by some other solder fills in the surface that appear to be covering small casting defects.

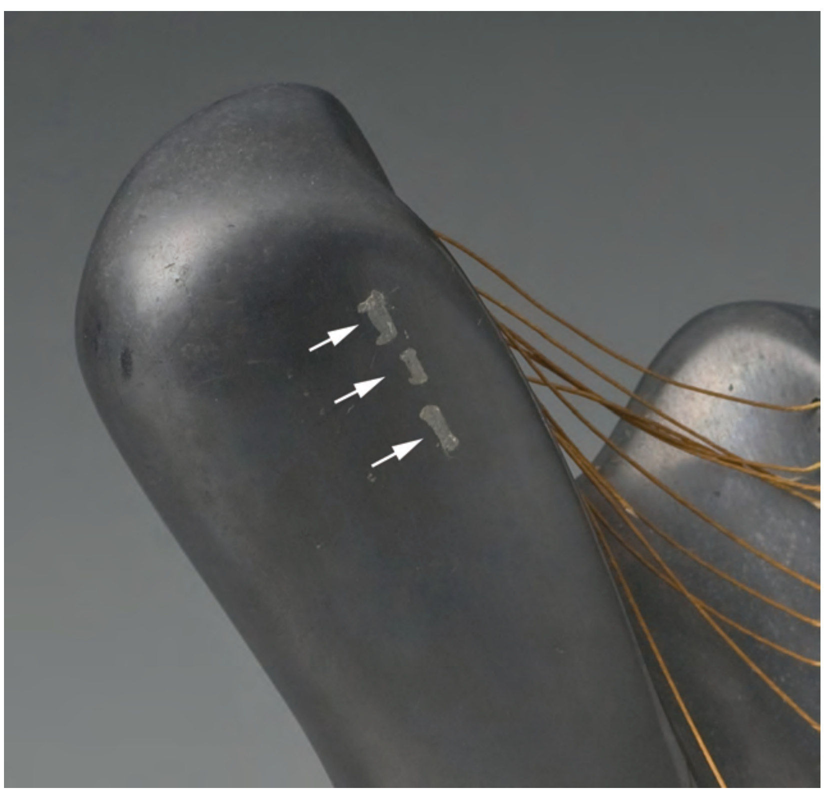

Fig. 2. View of solder plugs, visible as light grey spots on the surface (Courtesy of Nicole Ledoux)

The sculpture is anchored to a light-colored stone base by a threaded rod, which is secured by a nut at the bottom. The string is a three-ply linen thread with an unidentified waxy coating. The overall dimensions of the sculpture are 13.5 (w) × 18.8 (h) × 5.1 (d) cm.

3.3 CONDITION

In addition to the obvious breaks, the strings exhibit other signs damage and aging. It seems likely that the strings were once lighter in color and have darkened significantly with age. The areas of string that once passed through the perforated ridge at the center of the sculpture preserve this lighter yellow appearance, while the areas exposed to light over the years appear more amber to brown in color. Overall, the strings have stiffened over time and retain the shape of their original configuration. The ends of the strings are frayed, and at some points the plies have loosened and have begun to unravel. The lead itself also has signs of age and wear. The surface is dulled by grime, fingerprints, and a faint white bloom in some areas, in addition to scattered abrasions and a few isolated deep gouges.

Given all these complexities of both construction and condition, I felt the best way to understand and document the piece was to create my own diagram, which I could then use to map the locations of the breaks and losses, and visualize how the strings should come together. I began with a tracing of the sculpture and numbered the holes according to how the string ends match up, using the catalogue raisonné image as an additional source of information. By connecting these numbered holes, I produced an image of the original string configuration. I then used this diagram to map out where the breaks and losses are specifically (fig. 3).

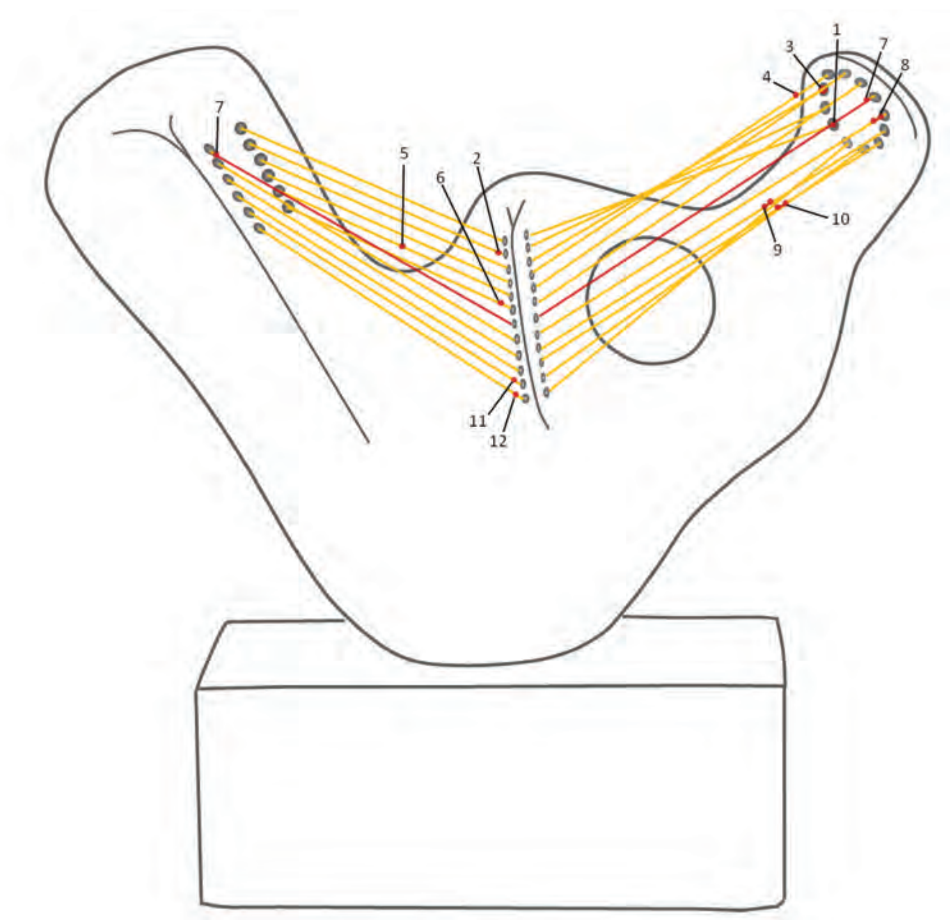

Fig. 3. Condition diagram showing the locations of breaks and losses in the string (Courtesy of Nicole Ledoux)

There are eight strings broken where the ends still meet up, three strings broken with small losses at the break ends, and one string that is missing almost entirely. This diagram also shows patterns in the locations of the breaks, which are located mainly on the proper left side and along the perforated ridge at the center.

4. DEVELOPING A TREATMENT APPROACH

4.1 REPAIR OR RESTRING?

The information gathered through background research and examination provided a basis for deciding on an appropriate treatment approach in consultation with Mary Schneider Enriquez, Houghton Associate Curator for Modern and Contemporary Art. If we decided to restring the piece, it would require the destructive and irreversible step of removing and replacing the solder plugs, in addition to the string itself; however, repair would require that the mends be made seamlessly to preserve the artist's intent and not be visually distracting. In addition, repairs would need to be strong enough to withstand handling and movement associated with packing, transit, and installation. Weighing these factors, we both agreed that, despite the obvious challenges, repair should be attempted before resorting to restringing. Ms. Schneider Enriquez, in particular, appreciated the aged appearance of the strings, since it corresponds well to the overall patina and wear on the lead surfaces. We decided to first attempt repair and reevaluate if necessary.

4.2 ADHESIVE AND SUPPORT MATERIALS

An acceptable repair method for the strings needed to meet high standards for both stability and aesthetics. In proceeding to develop a suitable technique, I first reached out to the greater conservation community via the AIC Objects Specialty Group listserv for advice. I received many helpful suggestions from those who had worked with stringed sculptures and other objects, such as mathematical string models and ship models. The conservation literature on woven materials, such as textiles and basketry, also provided a great source of techniques for the repair of fiber-based objects. Synthesizing all of this information, I decided to test my materials and methods using mock-ups. To make these, I stretched lengths of modern linen thread tightly across a board using push-pins and sliced them at the center to replicate the kind of tensioned repairs I would making on the sculpture itself.

Although there were multitudes of potential conservation materials, I decided to test three different adhesives, which I selected on the basis of my experiences, background research, and recommendations from colleagues. These were Paraloid B-72, for its tack and fast-drying properties, Lascaux 498 HV, a water-based acrylic dispersion that is frequently used in the conservation of textiles and other organic objects, and wheat starch paste, for the same reason (Hillyer et al. 2011). Very early on in my testing, it became clear that a support material would also be necessary to strengthen the joins, so I tested two: Stabiltex threads and twists of fine Japanese tissue paper fibers, which I created by rolling small torn-off sections of tissue between two fingers (fig. 4).

I have to say all of these materials were capable of making adequate joins, but there were differences in their appearance and compatibility with the substrate. Both of the acrylic-based adhesives had a very synthetic appearance and did not impart the join with the flexibility I had hoped for. The wheat starch paste, on the other hand, bonded well, and was much more invisible. As for the support, the Japanese tissue twists, though thicker than the Stabiltex, gripped the thread much better and was much less likely to come undone when the string was pulled or flexed. It is also very compatible with the wheat

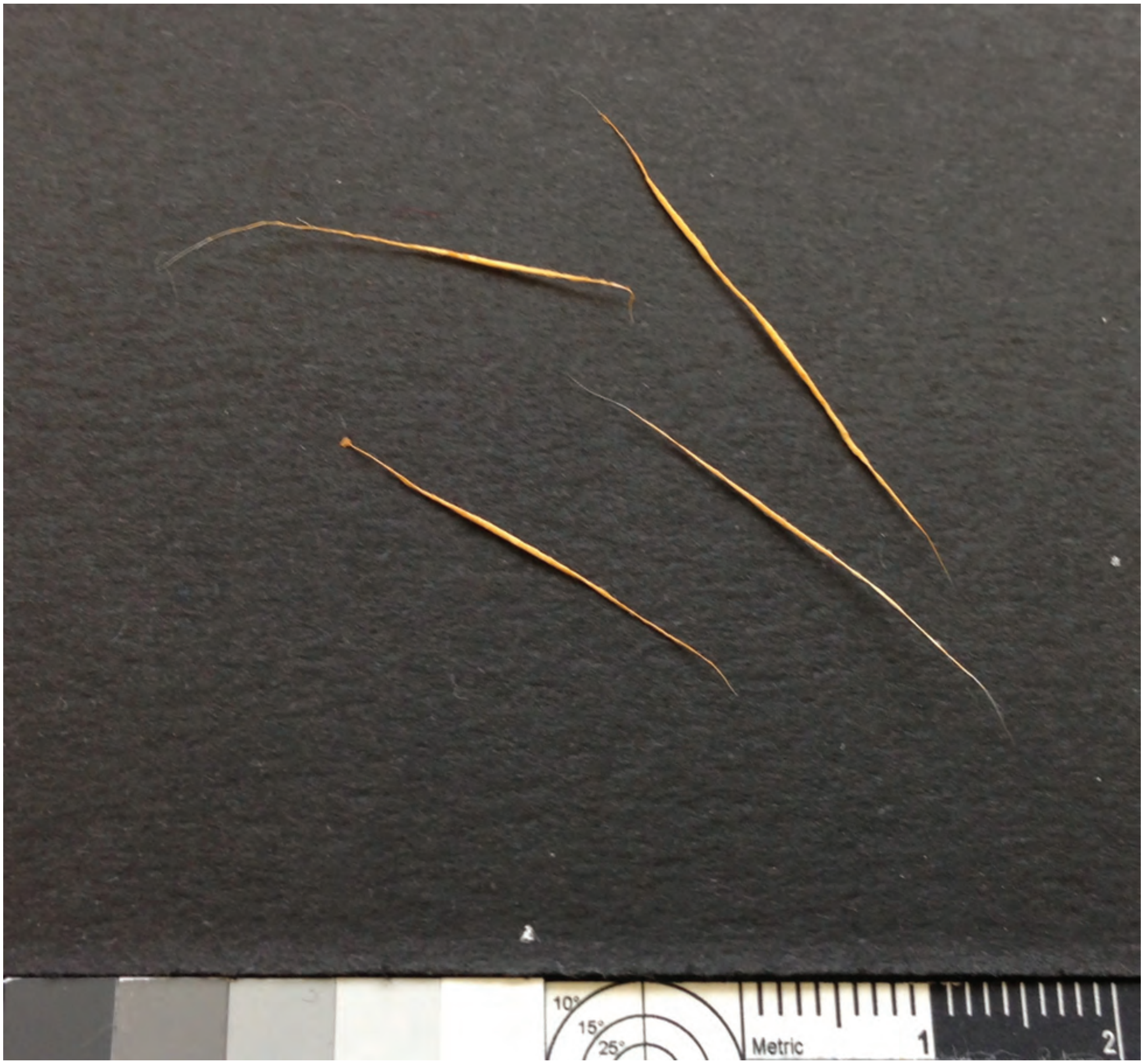

Fig. 4. Japanese tissue twists toned with fluid acrylic paints (Courtesy of Nicole Ledoux)

starch paste, and each twist can be custom-toned to match the coloration of the string at a specific location.

4.3 CLAMPING SYSTEM

Finding an adequate clamping system (fig. 5) was important to the success of this treatment and involved a great deal of trial and error.

Making the thread joins required precision alignment, and due to the tension on the strings, the ends needed to be held firmly in this alignment until the adhesive was completely dry. Rob Napier, a local ship model restorer, suggested that I try electrical wire test clamps (fig. 6), which have small spring-loaded hooks for capturing wire (Napier 2012).

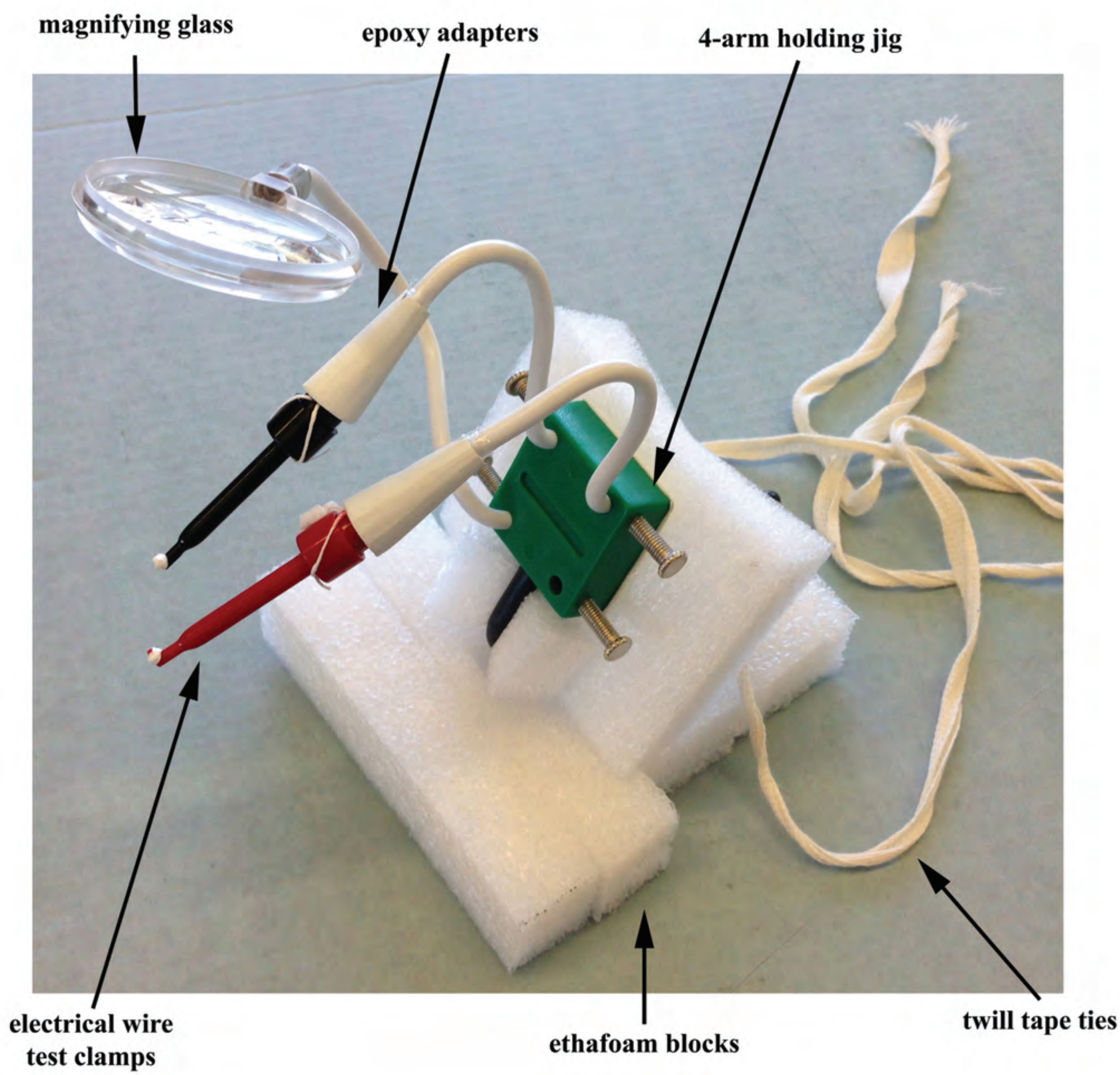

Fig. 5. Diagram of clamp components (Courtesy of Nicole Ledoux)

At first, I found the hooks placed excessive pressure on my test strings and created deformations, but by compressing the spring mechanism with thread ties, I was able to make the space inside the hook just right for my string thickness. I then made custom adapters out of epoxy to connect the clamp ends to the arms of the holding jig, which I clamped to foam blocks to orient the jig vertically. The advantage of using foam was that I could use it to secure bamboo skewers, which can support the wire arms of the jig when necessary during clamping. I then tied the entire contraption around the sculpture base, so that there was no potential for movement. I used a lazy Susan to rotate the entire setup as needed during treatment (fig. 7).

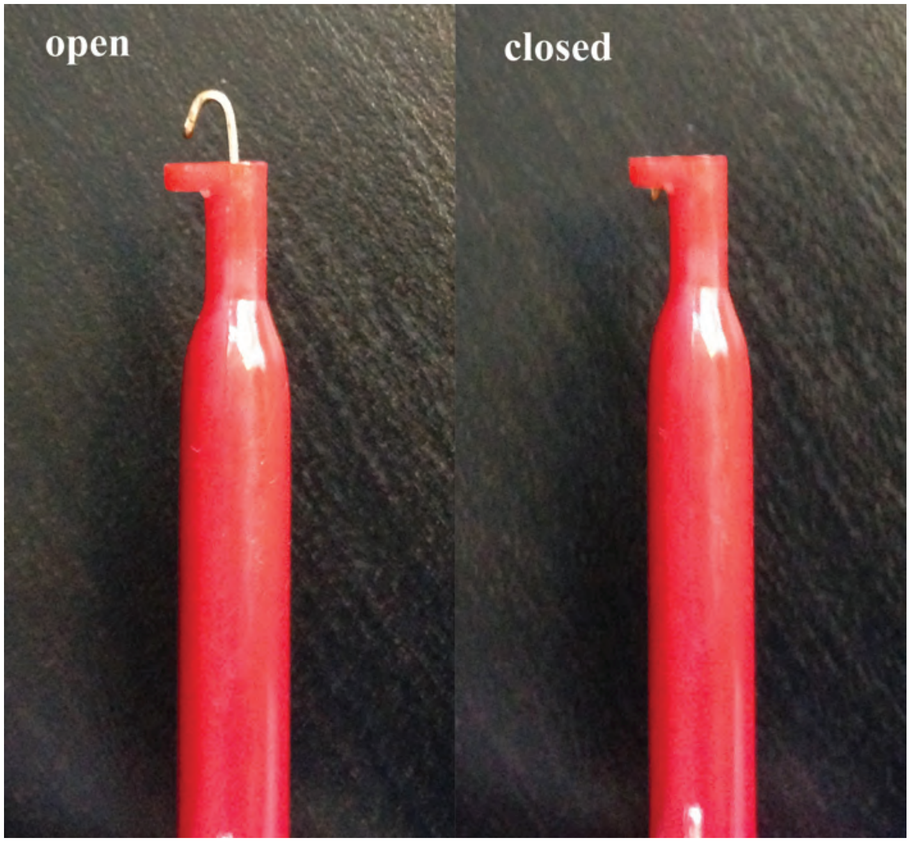

Fig. 6. Electrical wire test clamp shown in open and closed configurations (Courtesy of Nicole Ledoux)

Fig. 7. Clamping setup during treatment (Courtesy of Nicole Ledoux)

5. TREATMENT TECHNIQUES

5.1 PRELIMINARY TREATMENT STEPS

With a working technique in place, I was ready to proceed with the treatment. But before beginning the string repairs, there were a few other treatment steps that I completed. First, the entire sculpture, including the base, was cleaned lightly overall with saliva and ethanol to remove surface grime and the white bloom. The surface of the lead was then coated with Renaissance wax (a proprietary mixture of microcrystalline and polyethylene wax) to protect the surface and produce a more even appearance. The solder plugs were toned with graphite powder mixed with acrylic medium to integrate them with the surrounding lead. Finally, the areas of the strings that were frayed and unraveled were consolidated with methyl cellulose in deionized water to impart some strength before mending.

5.2 STRING REPAIR

I proceeded with the string repairs sequentially according to the numbering scheme on my diagram. Each string repair followed one of three basic techniques, each based on the location of the break (fig. 8): near or adjacent to the end sockets, near or adjacent to the center holes, or along a visible span of stretched string.

These were approaches that generally worked well, though each individual string repair required some tweaking of these techniques.

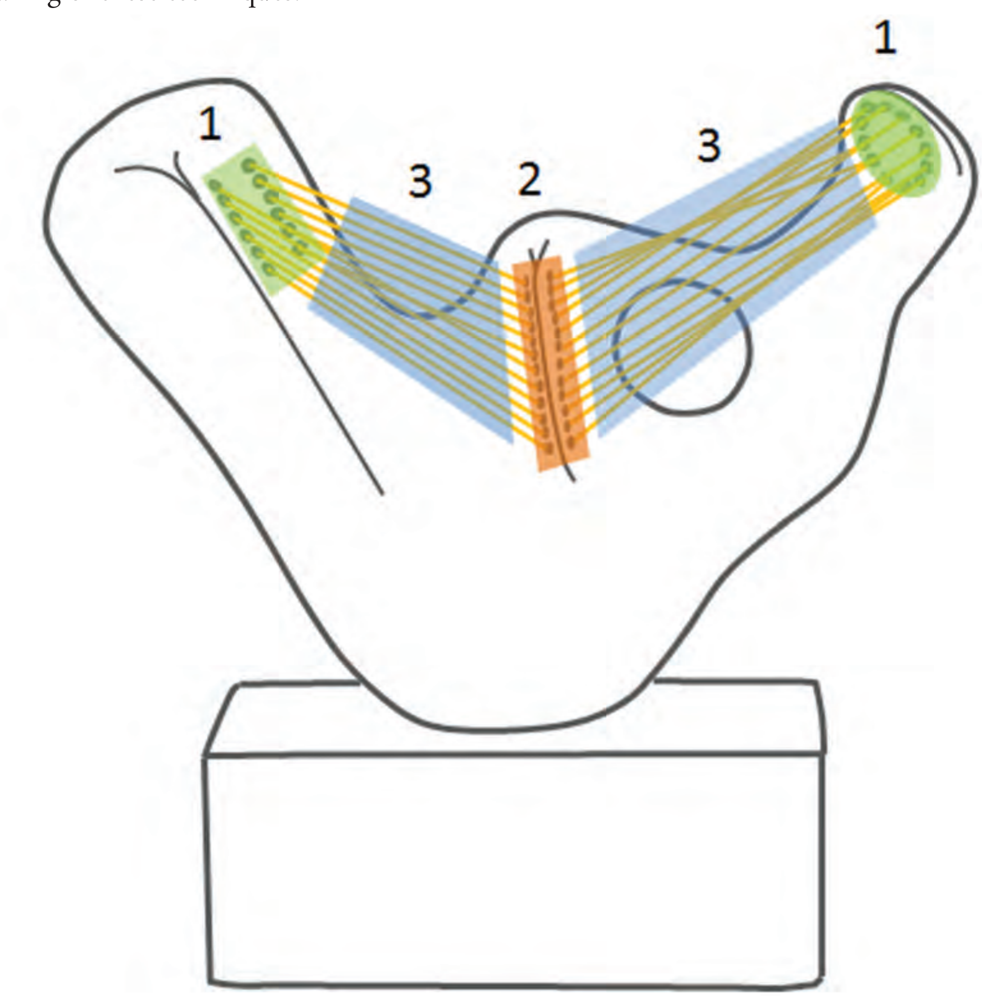

Fig. 8. Repair techniques used according to location of break (Courtesy of Nicole Ledoux)

5.2.1 Repairs Inside or Adjacent to the End Cavities

My first method involved securing one end of the string into an end socket. End sockets tended to have either a small stub of a string protruding or, as shown in figure 9, nothing inside.

Where no string protruded from the socket, I first reinforced the end of the string by adhering a small piece of Japanese tissue around the end of the string to form a sheath, which further supported the end and gave it some added thickness and surface area for bonding to the cavity (fig. 10).

If the end of the string was especially fragile, I also supported the area with a twist of Japanese tissue, which I wet with wheat starch paste and then wound around the compromised section of string, following the direction of the plies. Once dry, I adhered the reinforced string end directly into the lead socket with a small dot of Paraloid B-72, using a clamp to hold it in place as it dried (fig. 11).

I sometimes inserted Volara and Teflon tape inside the clamp to cushion the string and adjust the pressure, particularly in areas where the string is especially thin or fragile.

In cases where a small stub of string protruded from the end cavity, I modified the technique so that the long portion of the string would be secured to the protruding stub in addition to the inside of the cavity. This way, if one of the bonds fails, the other would provide a back-up. To begin, I adhered part

Fig. 9. Empty socket with no string protruding (Courtesy of Nicole Ledoux)

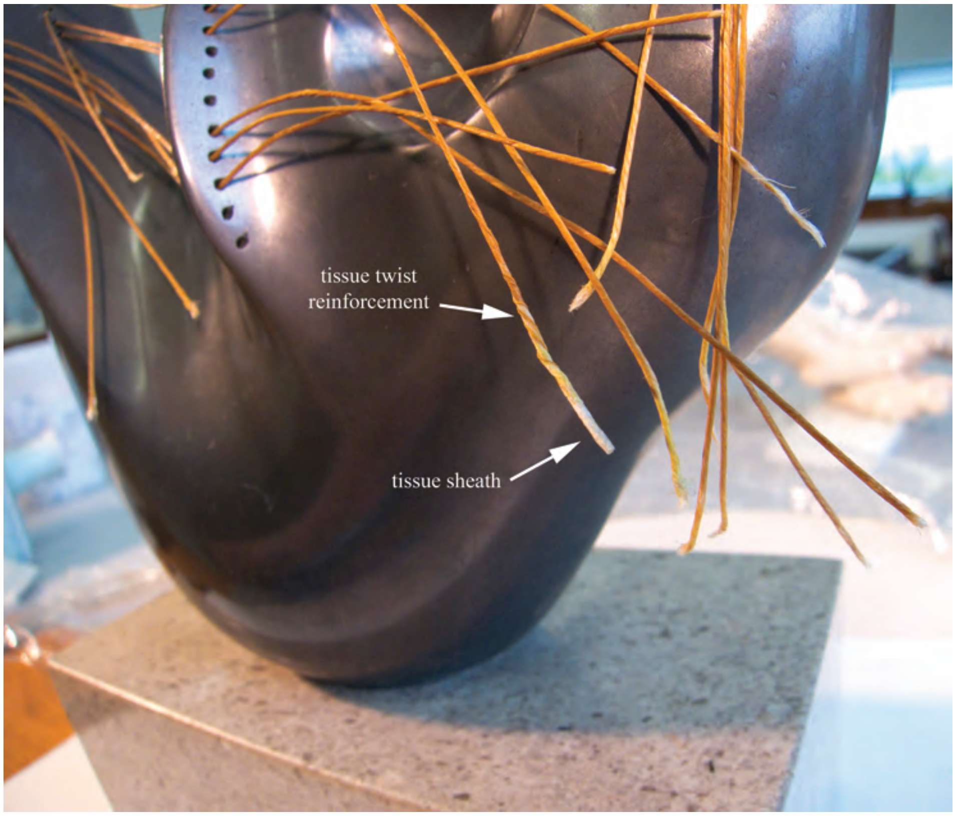

Fig. 10. String end reinforced by Japanese tissue and wheat starch paste supports (Courtesy of Nicole Ledoux)

Fig. 11. String adhered into empty socket with Paraloid B-72 and held in place by clamp (Courtesy of Nicole Ledoux)

Fig. 12. Tissue twist tails attached to end of string (1) and protruding stub of string in socket (2, 3) Courtesy of Nicole Ledoux)

of two tissue twists to the protruding stub of string, leaving the ends of the tissue twist extending to form tails (fig. 12).

I then adhered a third tissue twist to the long portion of string in a similar manner, with one part of the twist wrapped around the string in the direction of the plies and the remaining part left extending. After the wheat starch paste dried, I adhered the tissue twist tail extending from the long portion of string to the side of the lead cavity with a drop of Paraloid B-72, using a clamp to hold it in place as it dried. When dry, I secured the two tails attached to the protruding stub of string to the long portion of string with wheat starch paste.

5.2.2 Repairs Inside or Adjacent to the Center Holes

My second method of repair involved strings that had broken at points either inside or adjacent to the perforated ridge at the center. See figure 13 for a video showing the process of joining a string at a breakpoint located inside a hole at the center of the sculpture. These, and the following repairs, are string-to-string bonds and use wheat starch paste as the sole adhesive. I started these mends by first attaching tails of Japanese tissue twists to each end of the string: two on one end, one on the other (fig. 14).

As described earlier, half of each twist is wrapped around the string in the direction of the plies, and the other half, at least a centimeter long, is left extending. Once the starch paste was dry, I threaded

Fig. 13. Video showing the process of joining string at breakpoint located in hole at center of sculpture (Courtesy of Nicole Ledoux) https://youtu.be/RYkyrBWvM5M

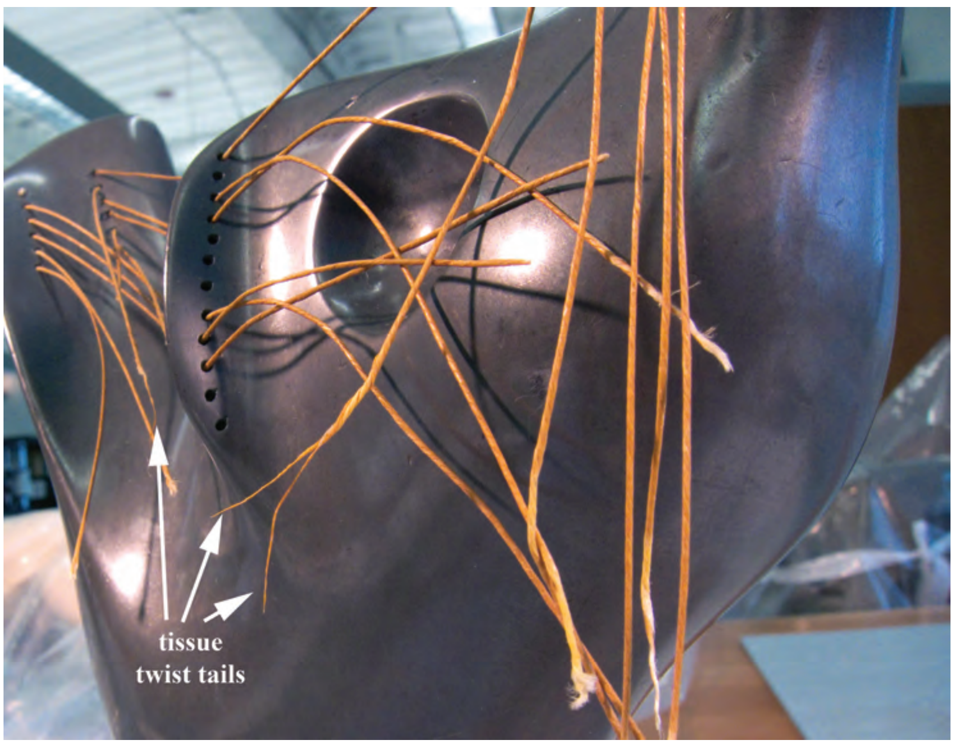

Fig. 14. Tissue twist tails attached to string ends in preparation for joining at middle of sculpture (Courtesy of Nicole Ledoux)

each of the three tissue twist tails through the hole, and used the clamps to pull on the tails, bringing the ends of the string together (fig. 15).

While the clamps held the alignment of the strings, I secured the third tissue twist to the opposite string by winding it around the string in the direction of the plies (fig. 16).

Once it was dry, I secured a tissue twist from the opposite string in same manner (fig. 17), and when that was dry, I secured the final tissue twist.

By this method, each string mend is supported by three tissue twists, each wrapped securely around both ends of the string.

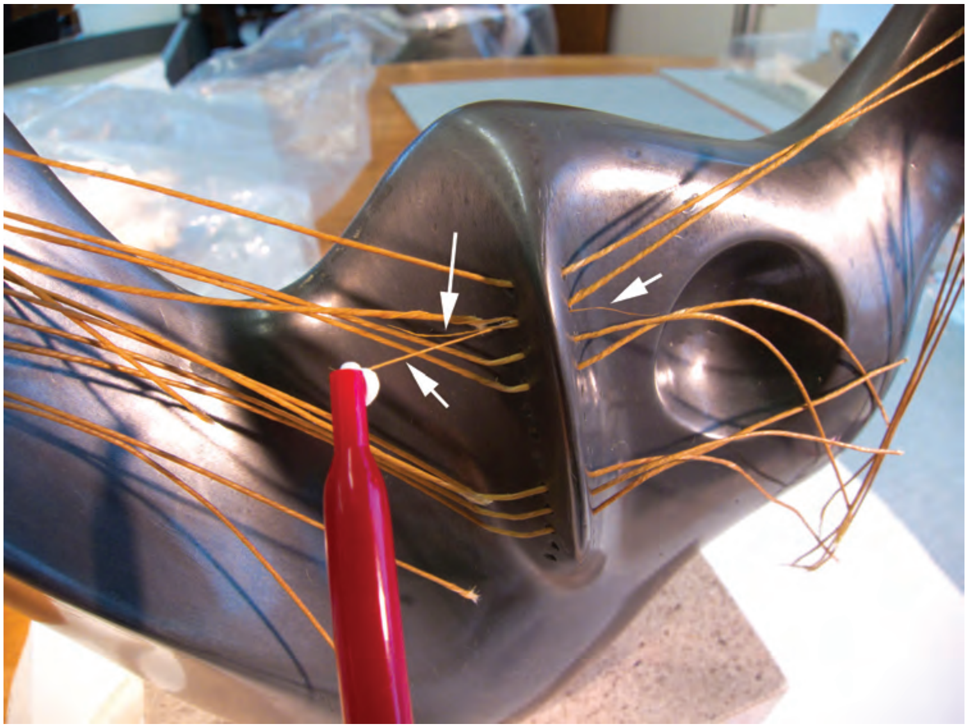

Fig. 15. Three tissue twist tails (shown by arrows) threaded through center hole, with one held under tension by clamp (Courtesy of Nicole Ledoux)

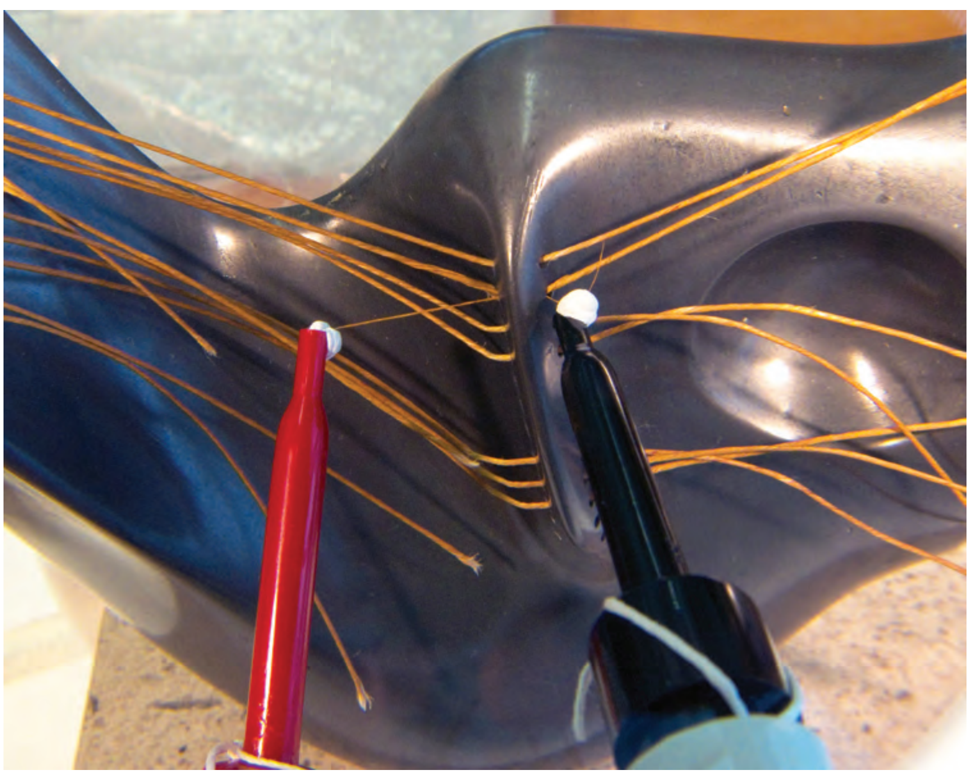

Fig. 16. Strings held together under tension by clamping a tissue twist from each side of string. Third tissue twist is secured to opposite string with wheat starch paste. (Courtesy of Nicole Ledoux)

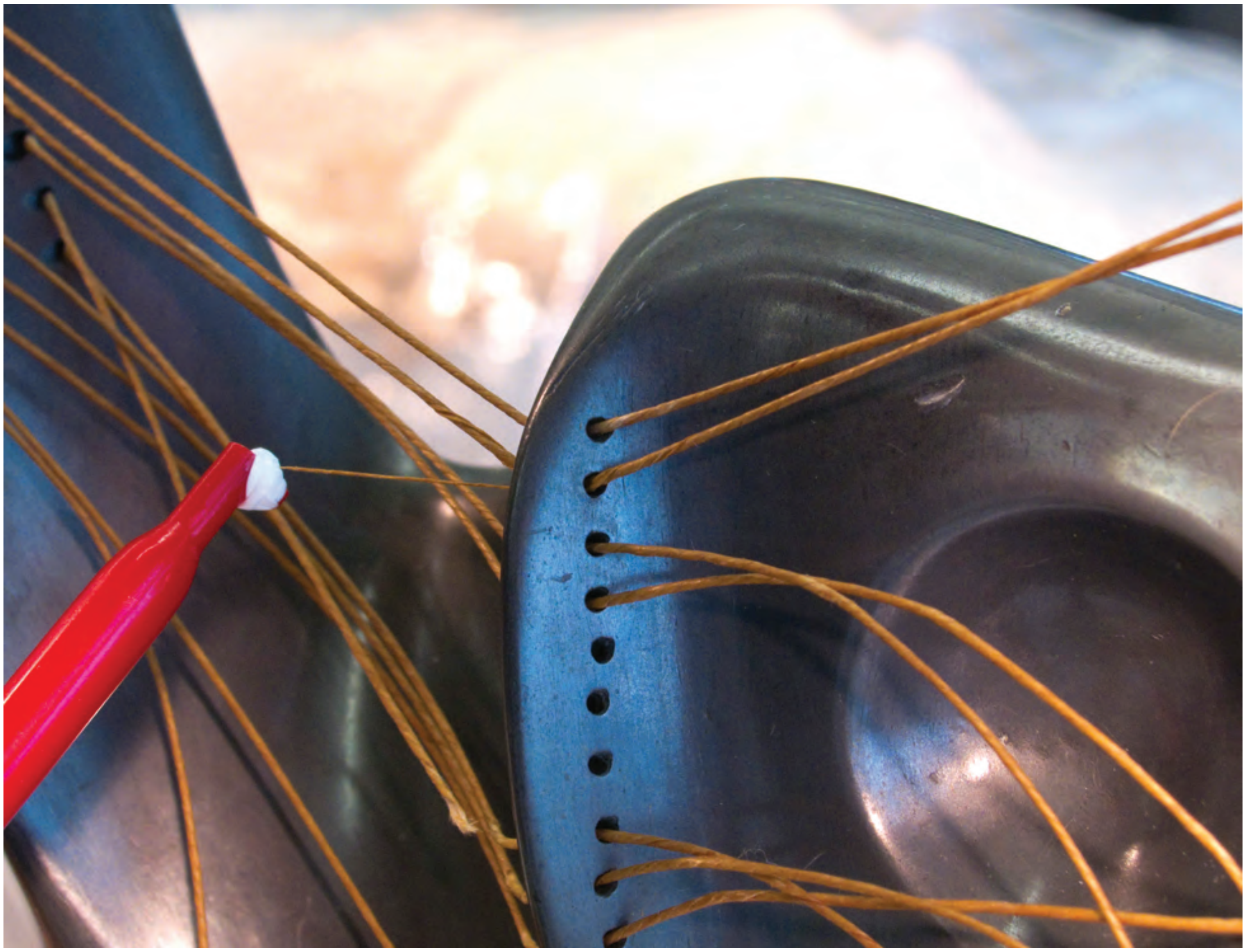

Fig. 17. On the right side, the clamp (shown in fig. 15) has been released and the tissue twist it held is now adhered to the string (Courtesy of Nicole Ledoux)

5.2.3 Repairs along a Visible Span of String

My third method, used where the break occurred in the middle of a span of string, is very similar to the second technique described earlier. The only difference is that aligning the ends is more difficult, because there is no hole nearby to act as a guide. I still used three tissue twists for these mends, but instead of being able to just pull on their tails during clamping, I often had to clamp and pull on both the tissue twist tails and the string itself to get the alignment just right (fig. 18).

In a few of these cases, the ends of strings did not meet up due to small losses. This did not prevent me from making the joins using this technique, but it did leave a noticeably thinner area where only the tissue twists bridge the gap (fig. 19).

In these cases, I placed an additional small tissue twist across the gap to provide the added width.

5.2.4 Replacing the Missing String

An additional aspect of this treatment that I would like to discuss is the replacement of one long section of missing string. In this case, there were short broken string ends protruding from the cavity on either side of the loss, with no remaining string in between. First, I created a replacement string by stretching the linen thread I used in my trials, and then toning it with fluid acrylic paints. Fortunately, the width of this string was nearly identical to that of the original. Another great aspect of this thread is that it is Z-twist, meaning that it twists in the opposite direction of the original threads, which are S-twist.

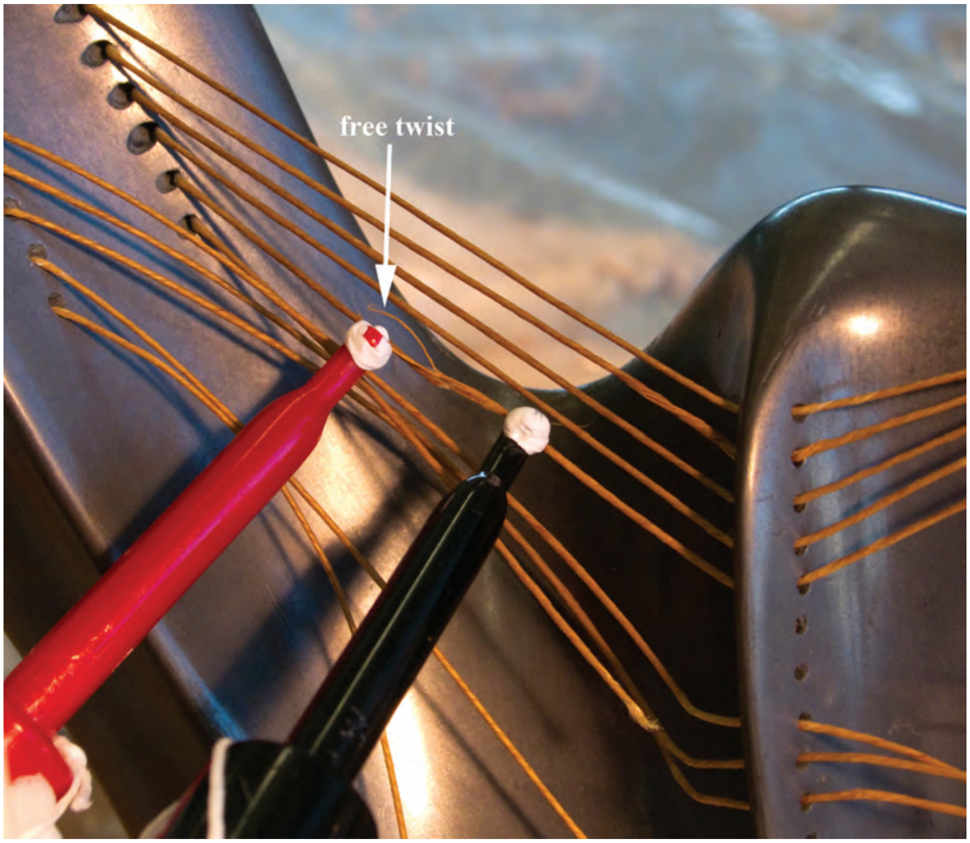

Fig. 18. Clamps holding ends of string together under tension. One tissue twist is left free for joining. (Courtesy of Nicole Ledoux)

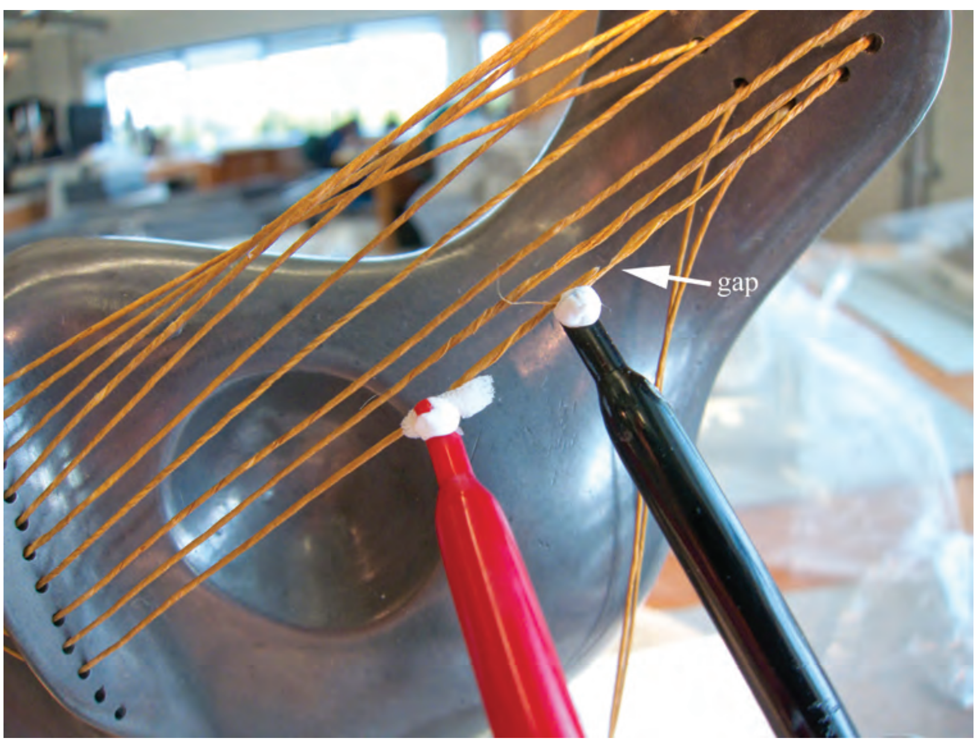

Fig. 19. Gap between string ends spanned by tissue twist supports during joining (Courtesy of Nicole Ledoux)

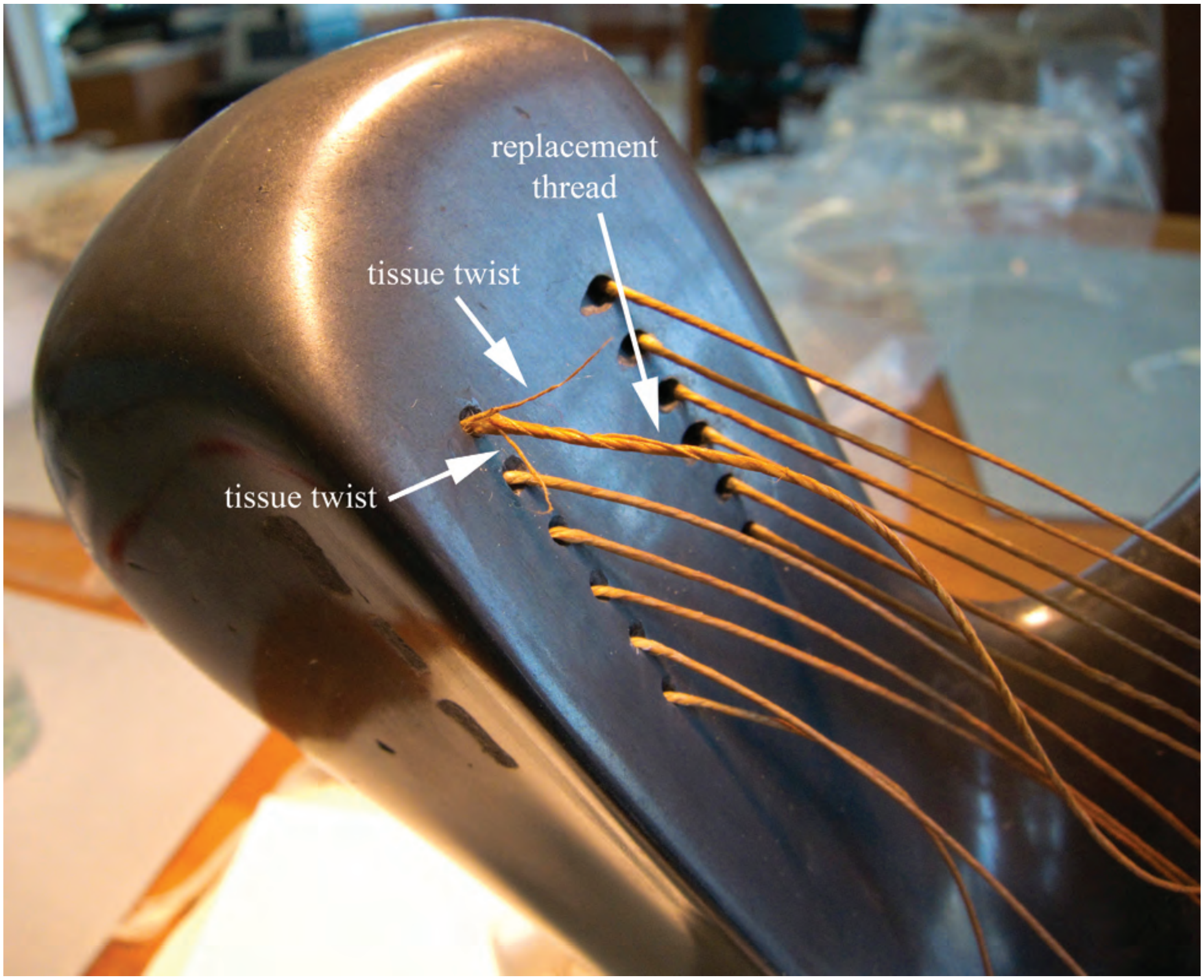

Fig. 20. Attachment of replacement string (Courtesy of Nicole Ledoux)

This provides a very easy way of distinguishing replacement from original and is only noticeable on close inspection. The replacement string was secured to the corresponding sockets at each end of the sculpture using the method described in section 5.2.1 for repairs with small stubs of string protruding (fig. 20).

6. CONCLUSIONS

After over 50 hours of documentation and treatment, the strings of *Mother and Child* are now returned to their original, intact configuration (figs. 21, 22).

The chosen approach and execution has satisfied the goals identified at the outset of the treatment: to stabilize and repair the original strings in a way that is strong, seamless, and consistent with the artist's aesthetic intent. On close inspection, the mends can be identified as areas that appear slightly thicker than the surrounding string due to the added volume of the tissue twists (fig. 23).

This feature is, however, overall consistent with the inherent variations of the original thread, and a viewer is unlikely to notice from normal viewing distance. Since completion of the treatment, the sculpture has withstood packing, transportation, and installation in the new museum facility without failure of the joins.

It is my hope that these repairs will carry this object through the next phase of its exhibitable life. It is difficult to predict how long these mends will last, as the strings will undoubtedly continue

Fig. 21. *Mother and Child*, front after treatment (Courtesy of Nicole Ledoux)

Fig. 22. *Mother and Child*, back after treatment (Courtesy of Nicole Ledoux)

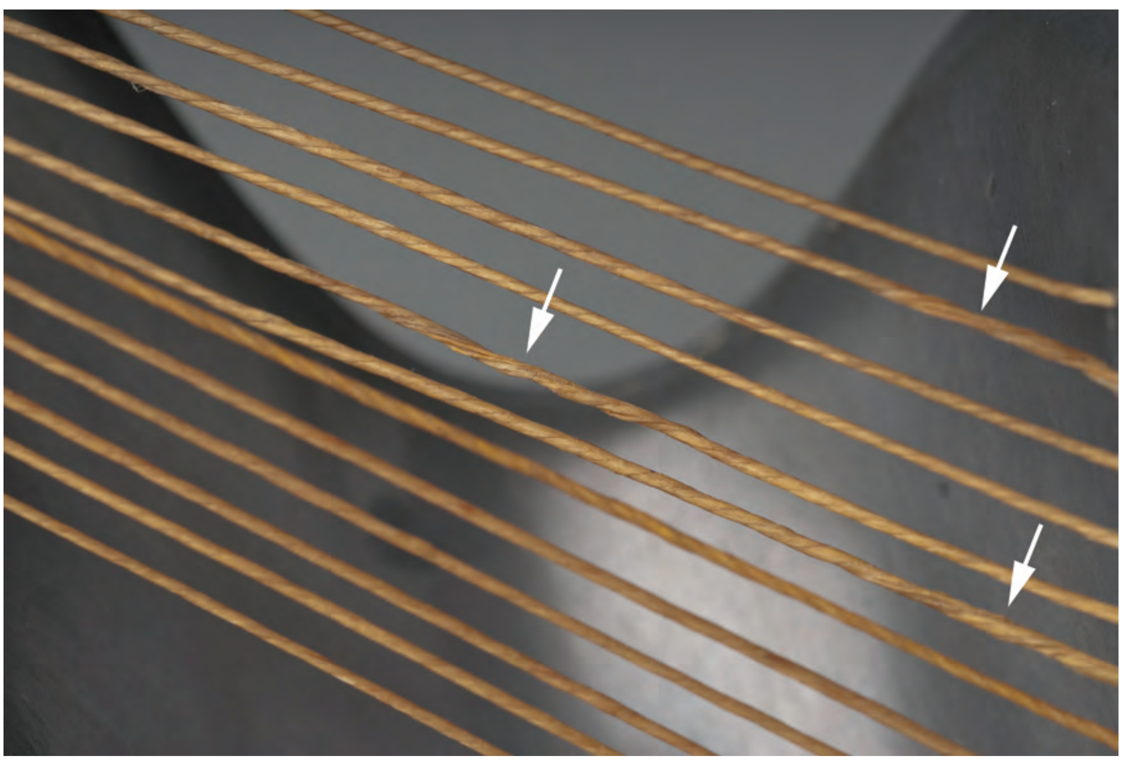

Fig. 23. Close-up view of string repairs after treatment (Courtesy of Nicole Ledoux)

to weaken with age; however, with the museum carefully monitoring and controlling the object's light exposure, we can expect the weakening of the threads to proceed at a slower rate than in the past. Restringing may very well become the only solution at some point in the future, but for now these repairs are an approach that has proven successful.

ACKNOWLEDGMENTS

I would like to thank the Samuel H. Kress Foundation for supporting this fellowship, as well as my colleagues at the Harvard Art Museums who provided valuable input on this treatment. I also am grateful to the many colleagues in the wider conservation community who took time to share their experiences and thoughts on conserving stringed objects of all kinds.

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Toland, J., B. Phipps, and J. Wess. 2012. *Intersections: Henry Moore and stringed surfaces*. London: The Royal Society.

SOURCES OF MATERIALS

4-arm Holding Jig
Micro-Mark
340 Snyder Ave.
Berkeley Heights, NJ 07922
888-263-7076
wwwmicromark.com

Electrical Wire Test Clamps
RadioShack Co.
300 RadioShack Circle
Fort Worth, TX 76102
800-843-7422
www.radioshack.com

Japanese Tissue Paper (Light Weight Kozo, White)
New York Central Art Supply
62 Third Ave.
New York, NY 10003
212-473-7705
www.nycentralart.com

Lascaux 498HV; Methyl Cellulose; Paraloid B-72; Renaissance Wax; Stabiltex (product discontinued)
Talas
330 Morgan Ave
Brooklyn, NY 11211
212-219-0770
www.talasonline.com

Wheat Starch Paste (Zin Shofu)
Museum Services Co.
385 Bridgepoint Dr.
South Saint Paul, MN 55075
651-450-8954
www.museumservicescorporation.com

NICOLE LEDOUX is the Samuel H. Kress Objects Conservation Fellow at the Straus Center for Conservation and Technical Studies at the Harvard Art Museums. She received her M.A. in conservation of archaeological and ethnographic materials from the UCLA/Getty program in 2012 and her A.B. in anthropology from Harvard University in 2007. Nicole has worked at archaeological sites in Italy, Jordan, and Germany and completed conservation internships at the American Museum of Natural History, the Museum of Fine Arts, Boston, and the Hearst Museum of Anthropology at UC-Berkeley. Address: 103 Spruce St., Watertown, MA 02472. E-mail: nledoux@gmail.com

TESTING AND IMPLEMENTATION OF MICROCLIMATE STORAGE CONTAINERS

DANA K. SENGE

ABSTRACT

This article presents microclimate storage research recently conducted by conservators in the National Park Service (NPS) Intermountain Region Museum Services Program. Museum collections in the Intermountain Region encompass artwork, historic objects, prehistoric and historic archaeological objects, and natural history specimens. These collections contain metals that are subject to environmentally induced deterioration and plastics whose inherent deterioration can be slowed with environmental control. Microclimates have been used in various forms to protect these materials while in storage.

We have been reassessing microclimates currently used in the NPS Intermountain Region and researching improved methods. This has included reviewing microclimate storage methods used in museum collections throughout the United States, Canada, and Europe. Our research has examined: access to materials to create microclimates, ease of creation, ability to maintain a climate, ease of access to objects inside, and maintenance. This article summarizes our research and testing to date.

1. INTRODUCTION

The conservation and curation staff in the National Park Service (NPS) Intermountain Region Museum Services Program (IMR-MSP) at the Western Archeological and Conservation Center (WACC) in Tucson, Arizona, has identified significant numbers of actively corroding metals in storage at WACC and in several collections in parks in the region. Over several decades, the staff has worked with various preservation solutions for the collections in storage at WACC including item-level treatment, maintaining dry microclimates in cabinets, and using heat-sealed, vapor barrier bags to create small dry microclimates. These storage solutions have all provided some level of stability for the actively corroding metals; however, the solutions have not been fully successful for our program, either limiting accessibility or requiring monthly maintenance that staff did not have time to address. The effort to maintain the microclimates in cabinets was abandoned in the late 1990s, and many of the collections were sealed in Marvelseal vapor barrier bags.

In 2010, we began testing variations of microclimate storage solutions that could not only be useful in the repository at WACC but also with park museum collections throughout the region. Our goal was to create microclimate containers that could be easily constructed from affordable, easily accessible supplies and would maintain a stable environment with minimal maintenance. For actively deteriorating metals, the most desirable environment consists of relative humidity held below 15%; gradual fluctuations in this environment are acceptable. In addition, we hoped to improve object accessibility. Within a few months, we found a solution that was worth placing in a real-time test scenario. The results of the first year of real-time testing were so positive that the microclimate solution was implemented in the first park collection in 2012.

The results of the initial microclimate research inspired possible solutions for storage microclimates for plastic objects. Different environments are necessary for different plastics; some require pollutants to be removed from the storage environment, whereas others require a carefully sealed storage environment, and still others require low oxygen. Storage for different plastics is discussed further in section 5. During 2013, we began examining the condition and the needs of the plastics in storage at WACC. Current literature on preventive conservation of plastic objects was reviewed, and objects in the collection were individually surveyed to document condition and develop preservation recommendations. In addition, the survey included identification of plastic materials through visual cues and spot testing and weighing the objects to gather baseline data to monitor deterioration.

Existing literature for plastic storage has helpful guidance on environments that would slow the deterioration of various plastic materials, especially *Conservation of Plastics* by Yvonne Shashoua (2008). However, we did not find many practical solutions for creating those storage environments. As a result, we have begun testing a variety of options to create the recommended environments while maintaining some level of accessibility.

The following sections describe the testing and solutions developed for microclimate storage of metal objects and the testing underway for microclimate storage solutions for plastics.

2. METALS MICROCLIMATE BACKGROUND

The microclimate storage of archeological metals is not a new topic in objects conservation. Variations of storage solutions have been tested for years and are regularly refined on the basis of collection need and the availability of new products. A common storage box used in the United Kingdom is a polyethylene box with a *sandwich seal* closure containing a desiccant (Watkinson and Lewis 2005) often referred to as a Stewart box, the name of the box manufacturer. Newer solutions utilize a vapor barrier film, such as Marvelseal or Escal, to contain the objects and desiccant (Brown 2010). And most recently, testing of oxygen absorbers in the sealed environment was presented at the ICOM-CC Metals 2013 conference (Boccia Paterakis and Mariano 2013).

3. EXISTING METALS STORAGE

Museum collections at WACC are stored in a repository that has temperature held around 68°F and relative humidity (RH) held between 35 and 40%. Although the building experiences a few environmental spikes related to equipment failure or power outage every year, overall the repository maintains a very stable environment.

Large metal archeological objects are stored on open shelving and small archeological metal objects are currently stored in multiple ways:

1. in trays in cabinets,
2. in polyethylene zipper lock bags in cabinets,
3. double bagged in polyethylene bags, the object in the inner bag and packets of Desi-Pak desiccant and a humidity indicator card between the inner bag and the outer bag, or
4. groups of objects stored individually in polyethylene zipper lock bags sealed together in a vapor barrier bag with desiccant and a humidity indicator card.

Each of these storage solutions has drawbacks: either the storage environment is not dry enough to slow active corrosion, or the objects are very difficult to see and access.

4. TESTING NEW METAL MICROCLIMATE SOLUTIONS

4.1 INITIAL TESTS

The best sealed environment is created with a vapor barrier bag of Escal or Marvelseal (fig. 1). These materials, however, are often intimidating for people without conservation experience to use and maintain. In addition, our preferred material, Escal, is expensive. Our goal with these tests was to identify a second solution that could be easily implemented without a conservation team onsite, either at the repository at WACC or in a park.

Tests began by examining a wide range of lidded plastic containers selected on the basis of availability and ease of use. These included various brands of lidded polystyrene containers, polyethylene snap lid storage containers, and silicon gasket seal plastic food storage containers. These containers were placed inside a humidity chamber, and data loggers were used to monitor humidity inside the containers as well as inside the chamber. This allowed us to record the rate at which the humidity entered the containers (fig. 2).

There was a marked difference between containers with and without the silicon gasket in the lid. Although the RH rapidly increased in each container, the containers without gaskets had an increase of 65 percentage points over the course of 36 hours (fig. 3) and the containers with gaskets showed an increase of 7.5 percentage points over the same amount of time (fig. 4). Storage containers without a gasket seal were quickly ruled out.

In addition, the vapor-proof container design currently recommended for storing photographic materials in cold storage (Voellinger et al. 2009b) was tested. Although this box design maintains a steady environment, the fabrication includes placing a box inside three bag layers, taping each bag closed after it

Fig. 1. Example of an object in tray enclosed in Escal vapor barrier bag (Courtesy of Dana K. Senge)

Fig. 2. Humidity chamber with testing (Courtesy of Dana K. Senge)

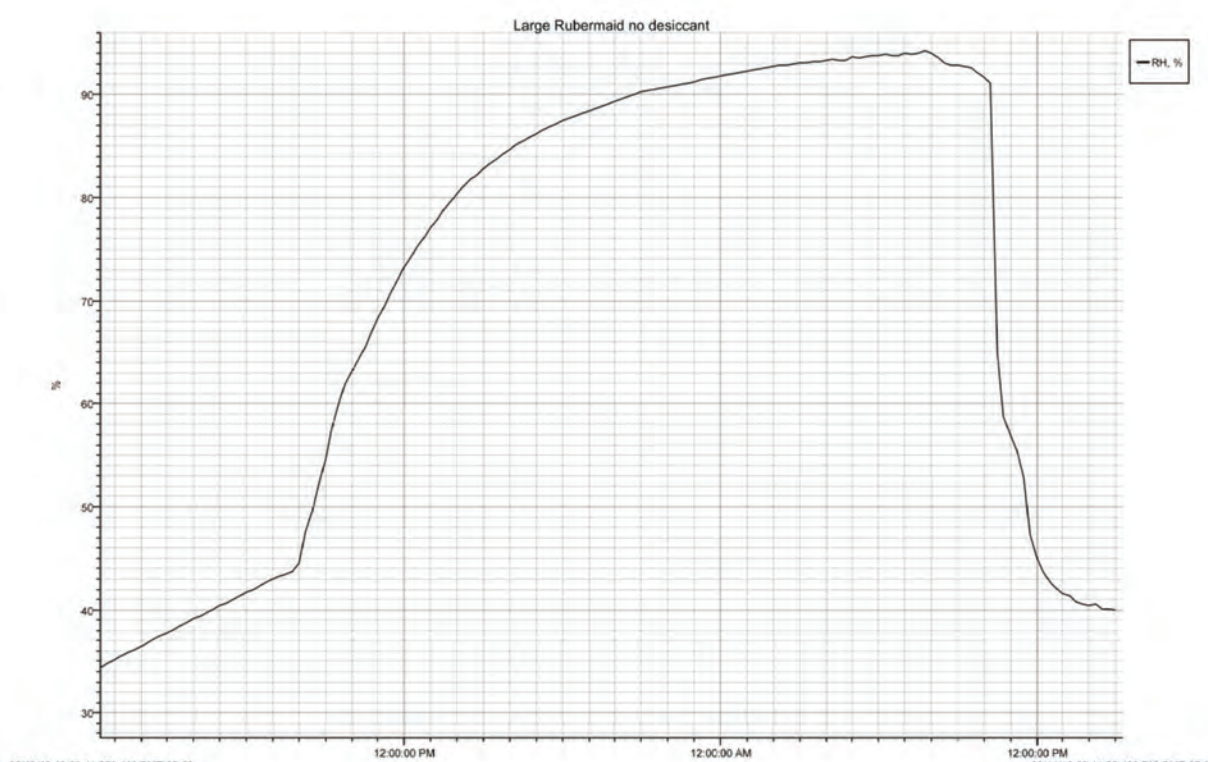

Fig. 3. Relative humidity of box without silicon gasket at closure. RH increases 65 percentage points over the course of one day.

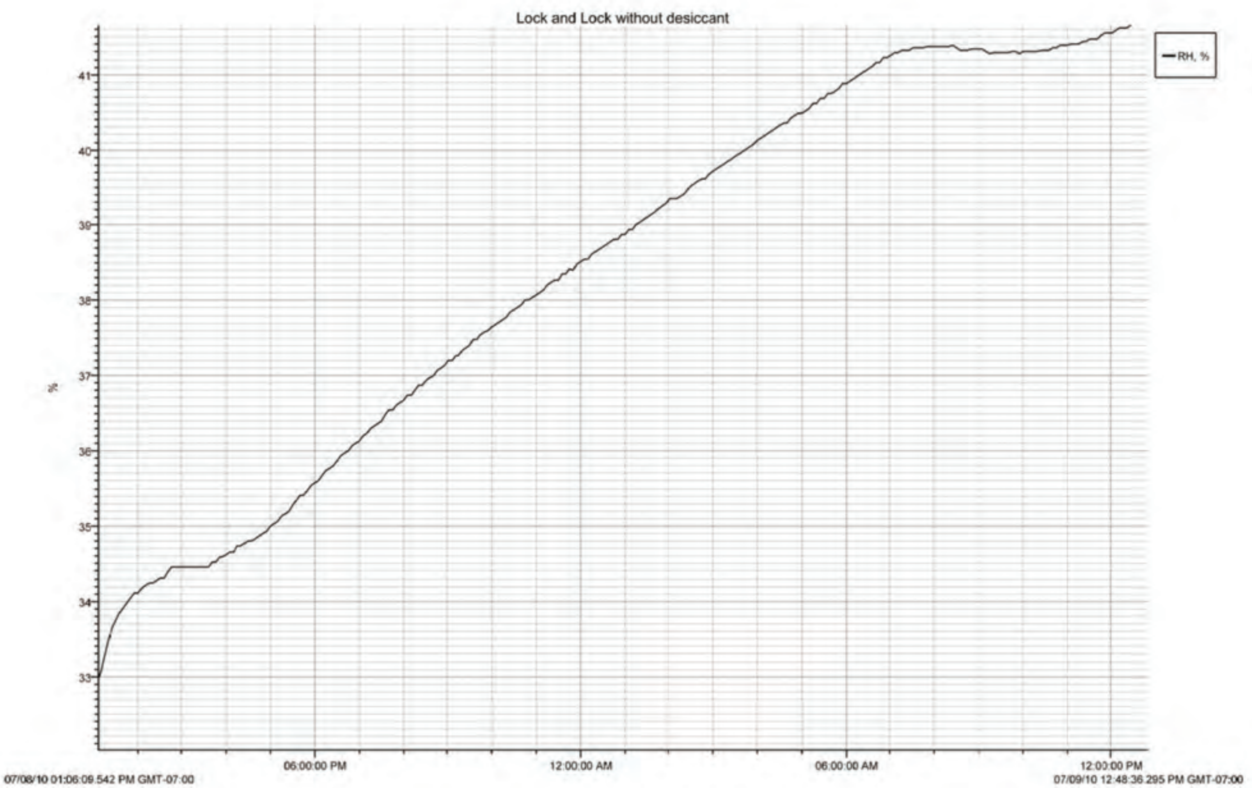

Fig. 4. Relative humidity of box with silicon gasket at closure. RH increases 7 percentage points over the course of one day.

has wrapped around the box. In the initial testing, we realized that enclosing the box required a lot of handling, which would place the objects potentially stored inside at significant risk from mechanical damage. As a result, we performed no further testing on this storage method.

The initial testing narrowed the box candidates to containers with silicon gasket in the lids, commonly used for food storage. We designed the next round of testing to observe the performance of the desiccant, which is needed to regulate the internal environment in the containers. Specifically, we wanted to know if the desiccant would be quickly exhausted. Packets of Desi-Pak desiccant and a data logger were placed in each test box, and the boxes placed back in the humidity chamber for up to a month. Each of the boxes tested held the RH steady for the testing period.

As the end of the initial tests, samples of the materials of these containers, the silicon and polyethylene, were Oddy tested. Metal coupons were also placed in a sample box and observed over the course of the year to determine if the plastic components were off-gassing any undesirable pollutants. None was detected through this period.

4.2 REAL TIME TESTING

To understand the limitations of these containers, sample boxes containing desiccant and data loggers were tested in three different storage environments for 1 year. One box was placed in our storage facility in Tucson, Arizona, a climate controlled space with RH around 35%, plus or minus 5%. The second was placed in an NPS storage facility in Montana that has minimal RH control, the RH in this environment gradually increases from 25% in the winter months to a high of 45% in the summer and gradually decreases again in the fall. The third was placed in an NPS storage facility in Texas, where the humidity is around 50%, plus or minus 5%, with spikes of higher humidity in during the summer months. For this test, the quantity of desiccant placed in the boxes was double the standard amount recommended (Weintraub 2002) to regulate the environment.

Fig. 5. Test box on shelf in storage for two years (Courtesy of Dana K. Senge)

The data gathered during the first year showed the greatest increase in RH was in the test box stored in the most humid environment in Brownsville, Texas. The RH in this box only increased its RH by 2 percentage points (fig. 6). This minor increase was encouraging and the boxes were placed back into the test storage environments for a second year without changing or reconditioning the desiccant.

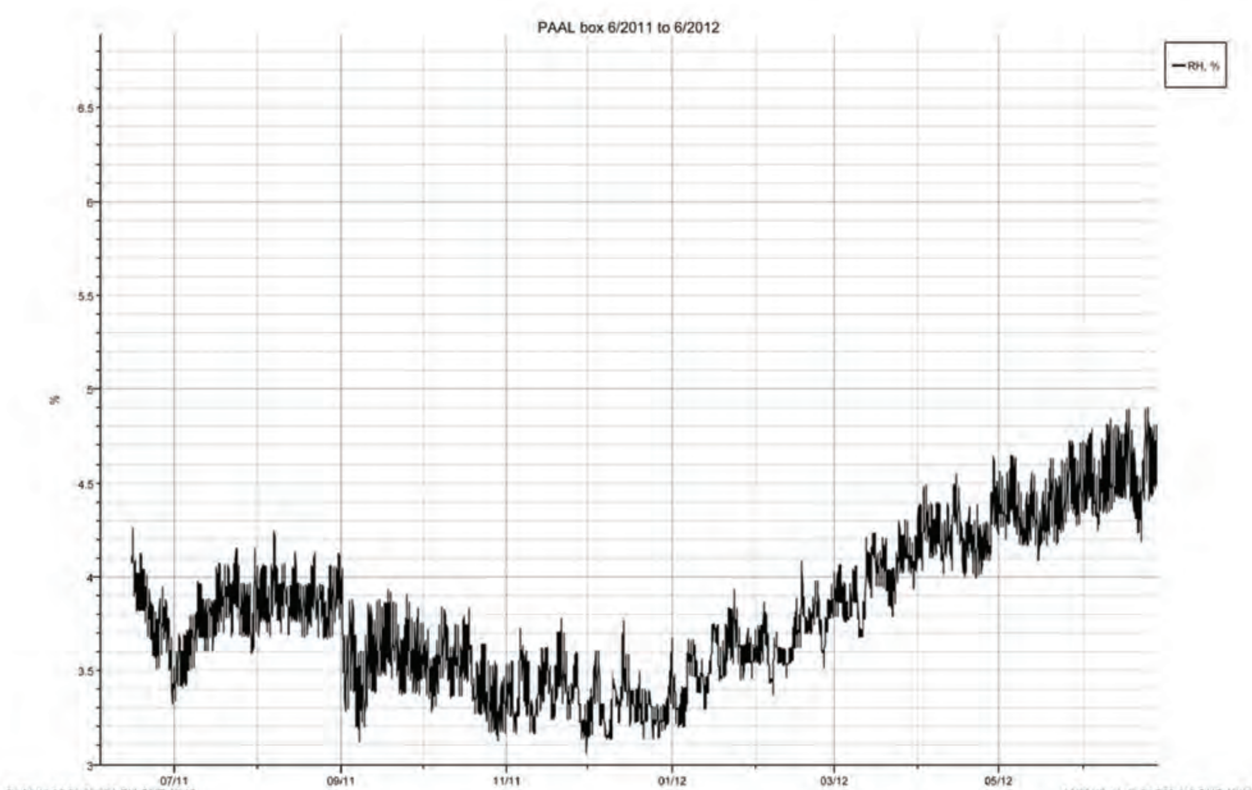

Fig. 6. RH data showing an increase of 2 percentage points over the course of the first year.

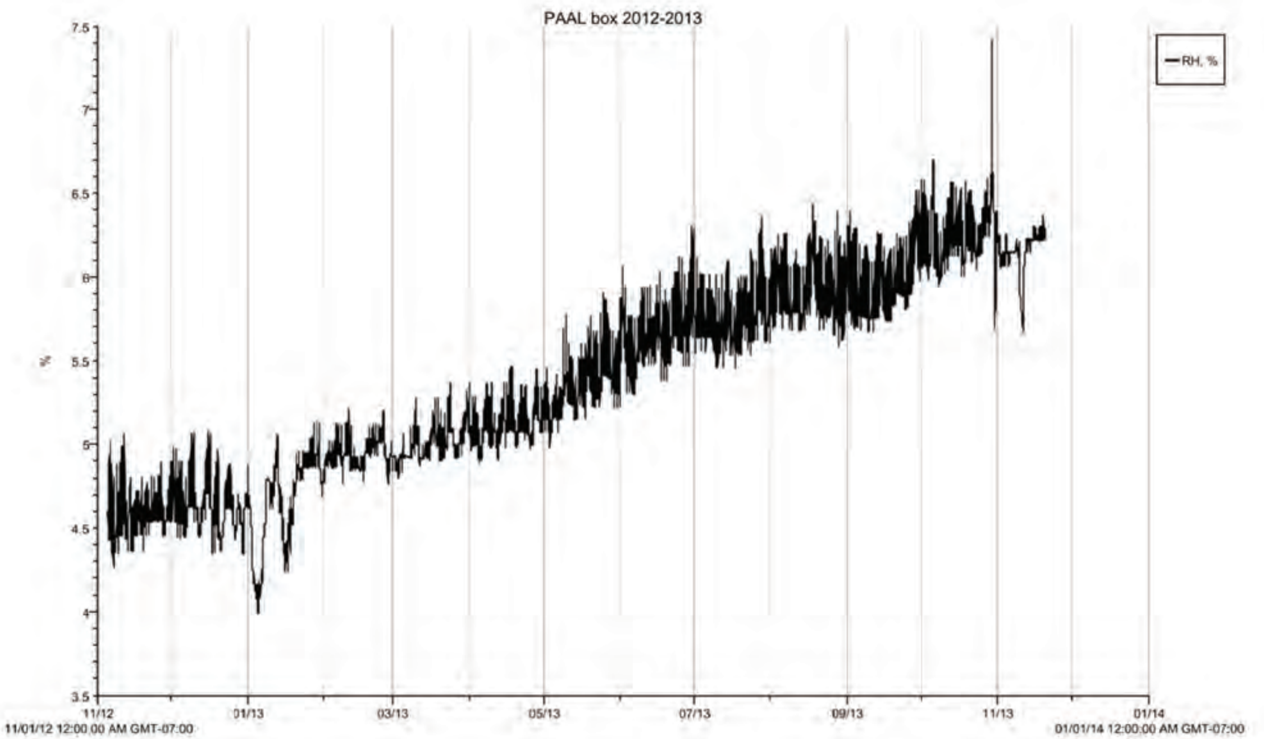

Fig. 7. RH data showing an increase of an additional 2 percentage points over the course of the second year.

The RH increase in the second year was very similar, rising another 2.7 percentage points (fig. 7). This rate of increase was acceptable to us, and on the basis of this testing, we estimate that to keep the RH under 15% in these containers, the desiccant will need to be changed every 5 years or so.

4.3 IMPLEMENTATION

After the positive results of the first year of real-time testing, an opportunity arose to implement the storage method for small metal objects in a single park's museum collection. This first collection had more than 7,600 of metal objects that were placed in over 200 microclimate storage containers.

Unfortunately, after a single year of storage, the RH in many of these boxes had risen from below 5% to over 15%. This was a surprising rate of increase in RH given the initial test results of an empty box gaining only 2 percentage points over the same time period. This increase in RH may be attributed to human error during box preparation, such as over exposing the desiccant to humidity during fabrication. A wide range of people were involved in the project, and it is plausible that human error played a role in the quick rate of RH increase.

The desiccant packets for this museum collection were changed in the summer of 2013 by a single staff member who paid attention to box closure and exposure of the desiccant packets. The boxes are currently being monitored quarterly to determine if the increase in RH observed in the first year was an anomaly, or if this experience is showing that new issues need to be addressed. Nine months after the desiccant was replaced, the boxes still maintain RH below 5%.

4.4 METALS MICROCLIMATES SUMMARY

The best container we found for creating metals microclimates is a polyethylene snap lid container. It is an accessible, reusable storage container that maintains a stable environment. Unconditioned desiccant, desiccant at or around 0% RH, is used to hold the environment below 15%

for as long as possible. As noted earlier, box preparation requires careful attention detail to ensure boxes are completely sealed when closed.

Product manufacturing and availability, of course, changes over time; thus, as new microclimate boxes are purchased, the materials are Oddy tested to ensure the containers do not off-gas products that may cause damage to museum collections.

5. PLASTIC MICROCLIMATES BACKGROUND

Current recommendations for storage of plastic objects vary by material type. Most plastics, especially cellulose nitrate and cellulose acetate, require an environment that removes pollutants, including the degradation products of the plastics themselves, from the surrounding environment. This is thought to slow the rate of deterioration by removing acids derived from the deterioration process and minimizing autocatalysis. The recommended storage environments focus on either ventilated storage or the use of pollutant scavengers in the storage environment (Shashoua 2008).

One exception to this guideline is the storage of rubber objects. Current research indicates that "the rates of crazing, crumbling and discoloration of natural rubber" (Shashoua 2008, 198) can be slowed in low-oxygen environments.

The other main exception to the general storage guidelines for plastics is storage for plasticized poly(vinyl chloride), PVC. Current research indicates that plasticized PVC objects deteriorate most severely by plasticizer migration, which is hastened by contact with materials which are adsorbent to these plasticizers. These materials include the most common materials used in museum collection storage: paper-based and polyethylene-based materials. Mylar (polyethylene terephthalate sheeting) and glass containers are currently the only recommended storage materials for these objects (Shashoua 2008).

Cold storage is commonly recommended for the preservation of plastic film materials (Shashoua 2008, Voellinger et al. 2009a), but has not been regularly implemented for 3D objects (Shashoua 2008). Cold storage is recommended as a possible solution for slowing deterioration, but there is a risk of condensation occurring during the cooling process of thick walled materials that may cause additional damage to the plastic (Shashoua 2008). Because variations in thickness are more likely found in 3D objects, this is a risk that should be considered.

6. EXISTING STORAGE

Plastic objects in storage at WACC are currently stored stacked in boxes, in single layers in cabinet drawers, and in trays on open shelving. The objects are commonly enclosed in polyethylene bags in each of these locations. For the most part, storage location is determined by ease of access for researchers rather than by material type and need; however, a small group of objects received storage upgrades on the basis of recommendations from a plastics survey in 1998. The objects identified as cellulose nitrate and cellulose acetate in this survey were placed in deep trays with Tyvek lids and are stored in an area where air flow is present (fig. 8).

7. PLASTIC MICROCLIMATE TESTS

Through the 2013 condition survey, we realized that existing storage is not fully successful in creating the recommended preservation environments for plastic objects. The majority of plastics in the collection were found to require storage that removes any off-gassing to slow deterioration. Existing storage in

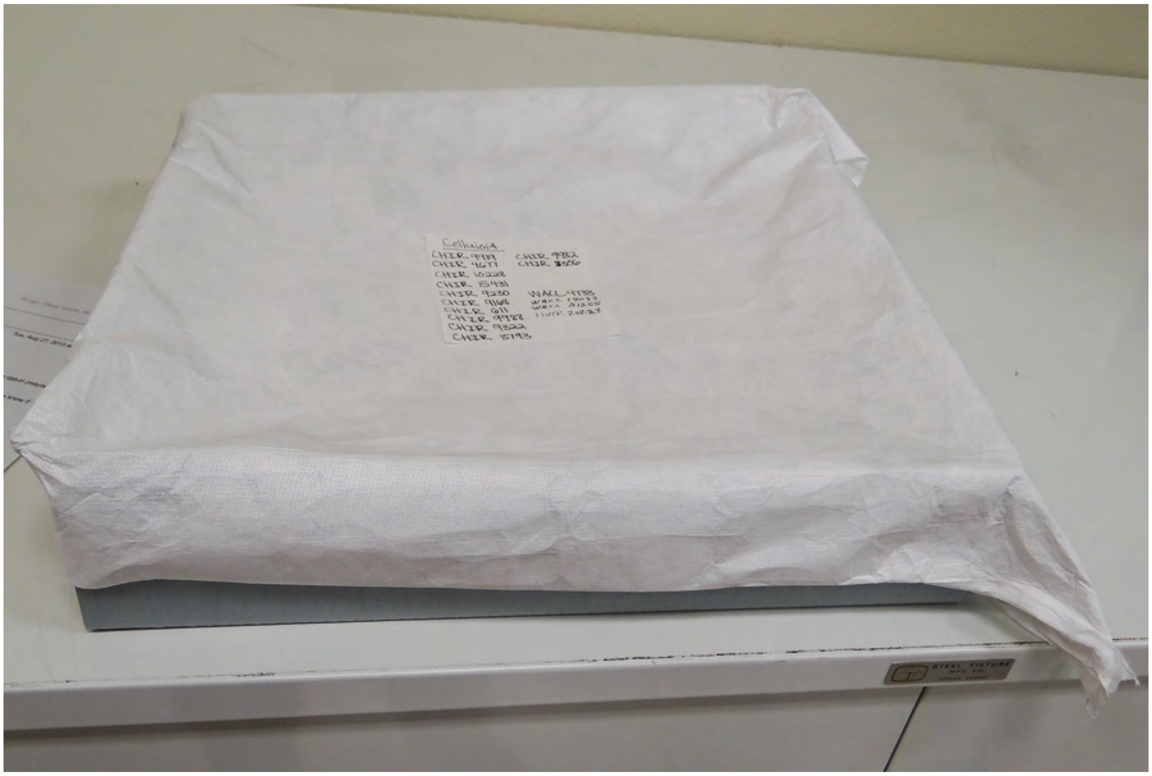

Fig. 8. Existing ventilated storage for cellulose nitrate and cellulose acetate objects (Courtesy of Dana K. Senge)

cabinets, in boxes, even in the trays with breathable lids, does not remove the deterioration products as needed. Currently there is no low-oxygen storage for rubber materials, and PVC objects are not fully enclosed in nonadsorbent materials as recommended in conservation literature.

The solutions we develop at WACC are likely to be implemented in other NPS museum collection storage repositories and, as with the microclimates for metal storage, need to be easy to construct, monitor, and maintain. The following sections describe our initial attempts to find practical solutions to create these recommended environments through ventilated storage, adsorbent storage, and low-oxygen storage solutions. Section 7.4 summarizes the storage solution technique we have begun to implement for plasticized PVC.

7.1 VENTILATED STORAGE TESTS

Ventilated storage is difficult to achieve in a dense storage space. In the existing storage repository at WACC, there are two main storage options: inside an enclosed cabinet or on shelves in compact shelving units. Cabinet storage obviously has no ventilation; however, several modifications were considered including using screen or grating on the front and back, which may permit more air flow. Unfortunately, in the WACC repository, cabinets are stored along the walls of the facility, a location with limited air flow regardless of how the cabinets may be modified.

The upper shelving of the end units of the compact storage system have decent air movement and was selected as a testing location for ventilated storage containers.

Another issue we needed to take under consideration for ventilated storage is potential dust accumulation on the objects. This is an especially important issue for plastic objects as dust can become affixed to the surface of degrading plastics, and removing it may cause additional damage.

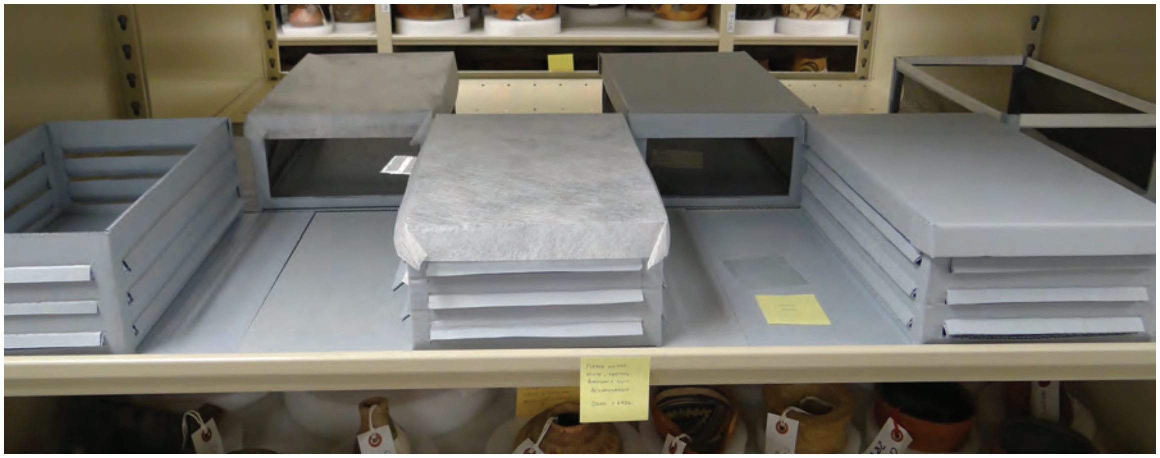

Fig. 9. Initial ventilated storage box tests and shelf layout (Courtesy of Dana K. Senge)

7.1.1 Initial Testing of Ventilated Storage Options.

The initial tests were developed to understand dust accumulation of various box and lid combinations. Two box styles and three lid options were placed in the ventilated storage location. Double-stick tape mounted to glass microscope slides were placed in the boxes and in unprotected locations on the shelf to monitor dust accumulation. The boxes were staggered on the shelf to maximize airflow (fig. 9).

Two box variations were tested: boxes with openings in the walls that were covered with polyethylene window screen and boxes with slats cut into the walls. Three lid variations were tested: no lid, a Hollytex fabric lid, and a solid acid-free corrugated board lid.

The boxes were left in this storage location for four weeks and then the tape and the microscope slides visually examined for dust accumulation. As expected, the slides placed in unprotected locations on the shelf had the most dust accumulation. The slides in containers without lids had the next most dust accumulation. The slides in each of the lidded containers had very little to no dust accumulation. This initial test indicated to us that dust accumulation was minimal regardless of lid or wall style.

Because of the ease of creating the screened wall versus the cut slat wall, the screened wall boxes were selected for further testing of ventilated storage.

7.1.2 Testing Acid Vapor Buildup in Ventilated Storage

Actively deteriorating cellulose acetate objects and A-D test strips were selected to test acid vapor buildup in both ventilated storage and the adsorbent storage tests described in section 7.2.

The cellulose acetate objects selected are shower curtain rings from Chiricahua National Monument. These were determined to be actively deteriorating because the smell of acetic acid would build up in their storage container over the course of just a few hours, a common indicator of the deterioration of cellulose acetate. This object group is ideal because it has multiple components that are similar in size, age, and deterioration. An A-D Strip (acid-detecting strip), manufactured by the Image Permanence Institute, was placed in the shower curtain ring storage box for 24 hours at room temperature and 30% RH. The A-D strip shifted from deep blue to a marine blue or deep blue green. This is between 0 and 1 on the A-D strip scale, indicating deterioration is just beginning.

A-D strips from the Image Permanence Institute were selected to help monitor the buildup of acids in the test environments. The A-D strips are a diagnostic tool to determine how much acid is released by film in an enclosed space over a specific amount of time at a determined temperature and RH. While our use of these strips as an indicator of acid trapped in an environment is not the official intended

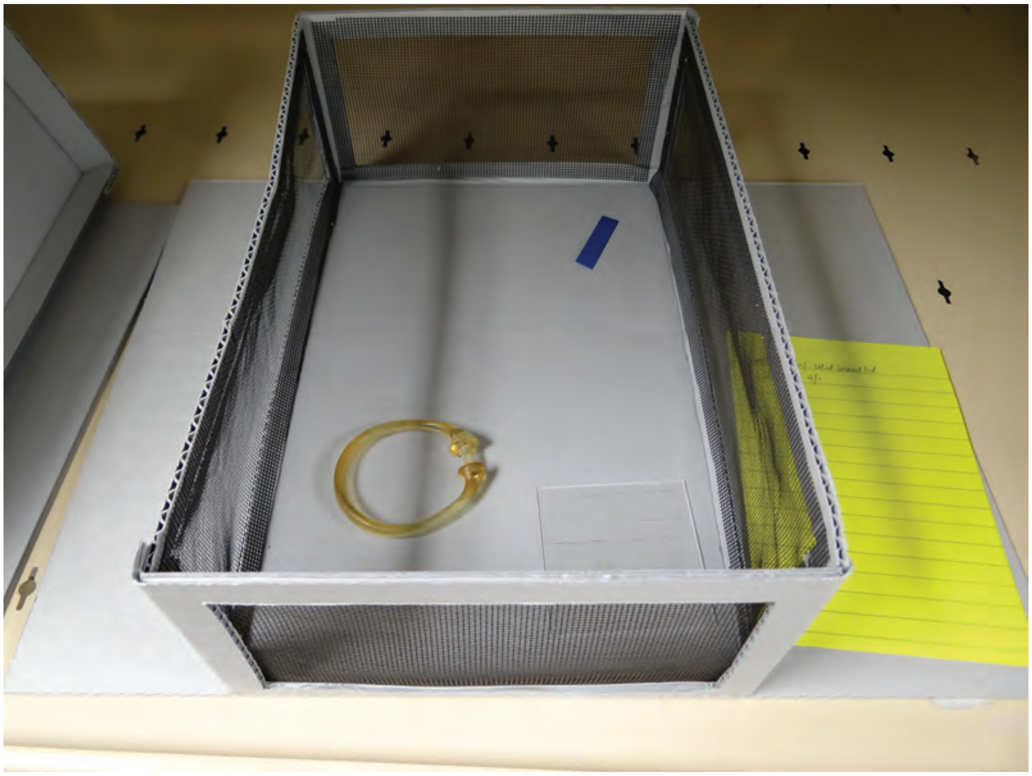

Fig. 10. Contents inside ventilated test storage (Courtesy of Dana K. Senge)

use, we believe that they are a good indicator of the effectiveness of the test environments. Product literature indicates that longer exposures may not give an accurate account of object condition. Because our use in this scenario is not to monitor object condition but, instead, the possible increase of acidic gases in a given environment, we believe these strips are good general indicators.

Two screened wall boxes, one with a Hollytex fabric lid and one with an acid-free corrugated board lid, were set up in the ventilated storage test location in the collections repository. Each contained an individual curtain ring, an A-D strip, and the double-stick tape on the microscope slide to continue monitoring dust accumulation (figs. 10, 11).

Fig. 11. Two test boxes on shelf (Courtesy of Dana K. Senge)

After eight weeks of testing, the A-D strips in the test containers remained their original dark blue color, indicating that there was no buildup of acidic vapor in the containers. Given that the existing storage container for the shower curtain rings shows a buildup of acidic vapor in only a few hours, the results of the initial tests are very promising for improved ventilated storage. A small amount of dust has accumulated on the glass slide in the box with the Hollytex fabric lid, reducing the desirability of this environment for long-term storage.

Our next round of testing will be to increase the quantity of actively deteriorating objects in the test environment. In addition, we are considering how the pollutants released from the plastics may affect the objects stored in surrounding areas.

7.2 ADSORBENT STORAGE TESTS

Although ventilated storage may be a good option in some locations, the use of adsorbents, such as activated carbon or zeolites, in a sealed environment is another way to remove gaseous pollutants from the storage environment and may permit denser storage of museum objects than the ventilated storage solution.

The polyethylene storage containers with silicon gasket seals identified in the testing for microclimate storage of metals were used to test the effectiveness of a microclimate containing an adsorbent or pollutant scavenger. Six test boxes were created to test the effectiveness of four adsorbents against a control (fig. 12).

The adsorbents tested were: Getter Pak activated carbon packets, Zorflex activated carbon cloth, Kodak molecular sieve packets, ArtCare museum mat board with microchamber technology.

The test boxes that were calculated hold 168 in.^{3} of volume. Determining the quantity of adsorbent to use in a specific volume of air is difficult; comparing products to each other is even more

Fig. 12. Adsorbent microclimate test boxes (Courtesy of Dana K. Senge)

difficult. Because the type of pollutants and quantity of pollutants present in a given volume of air vary, many of the companies that manufacture adsorbents do not test their products in a way that would tell how much to use for a given volume for a period of time. We used available product information and direct phone calls with the companies to help guide us in determining quantity of adsorbents to the microclimate boxes.

The Getter Pak activated carbon packets are listed on the supplier website (see Sources of Materials) as odor-adsorbing packets. The 2 g packets are listed as protecting 45 $in.^3$ of space. Four 2 g packets (8 g) of the Getter Pak were placed in the microclimate test box for the initial tests.

The Zorflex product information states that 1 g of the activated carbon cloth has the internal surface area of over half the size of a football pitch (Chemviron Carbon 2014). There is no comparable data to the Getter Pak product. For the initial tests, we elected to use the same weight of each activated carbon product to see what variation would occur between the two; therefore, 8 g Zorflex activated carbon cloth was used in the test microclimate box. Because the weight of Zorflex includes the weight of the cloth, it is possible that 8 g of Zorflex activated carbon cloth has less activated carbon than 8 g of Getter Pak activated carbon packets.

The Kodak molecular sieve packets were specifically developed to protect cellulose acetate film in a film canister. Because of this narrow range of use, the product has recommended quantities for a specific volume: Kodak recommends the use of three 12.5 g molecular sieves in a film canister that holds 1000 ft. of film (Kodak 2014). The film canisters of this size tend to be approximately 11 in. in diameter and 2 in. deep, creating 190 $in.^3$ of volume. Three molecular sieve packets were placed in the initial test container.

The ArtCare board manufactured by Nelson Bainbridge has no product information that provides how much of the adsorbent is present in the board or how much board to use in a given space. Phone conversations with representatives of the company did not provide insight into determining how much board to use in a given volume of space. Two test boxes were made to monitor the variation that may occur between two different quantities of this product, a single piece of 4.75 × 7 in. 4-ply ArtCare board was placed in one box, and two 4.75 in. × 7 in. pieces of the 4-ply ArtCare board were placed in the second box.

The adsorbents were placed in the microclimate boxes with a cellulose acetate shower curtain ring and an A-D strip. The control box contained only a shower curtain ring and an A-D strip. Digital data loggers were placed in four of the test boxes: the control, the Getter Pak activate carbon packets, the Kodak molecular sieve box, and the box containing two sections of ArtCare board to monitor any desiccating effects the adsorbents might have on the enclosed environments.

Within a month, the A-D strips in each test container detected the presence of acidic vapors. The A-D strip in the control box (with no adsorbent) began to shift color from dark to marine blue within 24 hours. The A-D strip in the box containing Kodak molecular sieves began to shift color within the first 5 days; the strip in the box with one piece of ArtCare board began to shift within the 8 days; the strip in box containing the Getter Pak activated carbon packets also began to shift within 8 days; the strip in the box with two pieces of ArtCare board began to shift at 11 days; and the A-D strip in the box containing the activated carbon cloth was the last to begin color shifting, after 18 days.

After the first 3 weeks of testing, the A-D strip in the control box had shifted color to bright green, two on the A-D strip scale, and the object was removed from the control test box due to concern that the increase in concentrated pollutants would trigger an increased rate of deterioration in this object by exposing it to a concentrated volume of pollutants.

The environmental data showed that each adsorbent lowered the RH of the climate to a certain extent. The ArtCare board and the Getter Pak immediately lowered the RH in the climate from 38 to 20% RH; however, over the course of the month the RH crept up toward 26% RH in each container. The Kodak molecular sieves lowered the RH to approximate 0% RH. The first month of data shows some spikes in the middle of the month, up to 12%, which may be associated with opening the container temporarily.

The second round of tests for the adsorbent products began on May 1, 2014. In this round of testing, quantities of adsorbent materials were doubled to determine if quantity of adsorbent would slow the rate of color shift in the A-D strip. During this second month of testing, the test strips shifted color at rates similar to that in the first month, with the exception of the activated carbon cloth, which did not shift color in the 30-day period.

Testing continues, the next test will be to place a larger quantity of the deteriorating cellulose acetate objects in the test environments, and our goal is to determine if one or two adsorbent products can be tested over the course of a 12-month period to being understanding the longevity of the pollutant scavengers and the viability of monitoring over the long term with the A-D strips. We continue to look into other pollutant monitoring solutions. At the same time, we are considering a maintenance program that replaces the adsorbent on a cyclic basis, likely starting at an annual cycle.

7.3 LOW OXYGEN STORAGE TEST

Low oxygen environments can be created with an oxygen scavenger, such as Ageless or Oxy-Guard enclosed in a vapor barrier film such as Escal or Marvelseal that is closed by heat-sealing.

Although good storage containers can be created with trays enclosed in a vapor barrier film, we want to fully investigate the possibility of using containers that are easier to open and close. The main goal of testing other options is to understand if a rigid container can withstand the pressure of the reduction of 20% of the air volume in a container with the oxygen removed, and the general rate that oxygen enters a storage container with a silicon gasket lid.

The first test was set up using the polyethylene box with a silicon gasket in the lid as the container rather than the vapor barrier bag. The container held a ZerO2 Alert indicator and ten times the quantity of Ageless needed to remove oxygen from the volume of the box. Oxygen was removed from the container within 1 day and a low-oxygen environment was held for 21 days. The second test has begun with a similar style container with a glass body to understand if the variation in material type will have a major influence on the rate of oxygen flow into the container.

Monitoring multiple storage environments with the ZerO2 Alert indicator is not a practical solution; an individual monitor is over $500 at this time, and takes up a significant amount of space in the storage environment. The Ageless Eye Oxygen Indicator has been used as a monitoring tool in the past, but it is becoming more difficult to find because of its short shelf life and inconsistent behavior when placed in a long-term monitoring situation. A possible replacement is the Tell-Tab Oxygen Indicator by SorbentSystems, which will be tested in 2014 and 2015. Another solution under consideration for monitoring the presence of oxygen is an optical oxygen sensor. This equipment utilizes a sensor inside the storage container and uses a fiber optic probe to read the sensor (Matthiesen 2007). Although more expensive than the ZerO2 Alert indicator, this equipment has the flexibility to check multiple environments.

Unfortunately the overarching goal of creating microclimates that are easy to prepare, maintain, and access is limited in this circumstance. At this time, low-oxygen microclimates can only be created at WACC and maintained by the conservation staff.

7.4 STORAGE OF PLASTICIZED PVC OBJECTS

Published recommendations for PVC include enclosing in glass or Mylar, and excluding other plastics or paper-based materials that might absorb the degradation products (Shashoua 2008). Storage improvements have begun on the basis of these recommendations; Mylar was selected as the more desirable storage material given its flexibility and durability. Objects have been enclosed in 1-mil Mylar

Fig. 13. Plasticized PVC object enclosed in sealed Mylar and set on a handling tray. National Park Service, Chiricahua National Monument, CHIR 6875 (Courtesy of Maggie Hill-Kipling)

packages that are closed with a single-impulse heat sealer. The sealed object is then placed on a support tray (fig. 13).

7.5 PLASTIC MICROCLIMATE SUMMARY

Our testing is not complete, but we have learned a great deal about possible solutions to store the plastic collections at WACC. As our testing continues, we have narrowed our focus to one or two solutions to provide ventilated or adsorbent storage environments and are observing how the containers perform with greater quantities of objects contained inside. Our concern about the pollutants released from plastics stored in ventilated storage causing damage to nearby objects may be easily resolved by placing the plastics near materials inert to the acids that they release; for example, storing plastics near ceramics and glass. We continue to look for options to monitor low-oxygen storage. These include inexpensive solutions such as the Tell-Tab Oxygen Indicator detection tablets as well as more expensive solutions such as an optical oxygen sensor. And, as discussed in section 7.4, published recommendations for PVC storage have proved simple to develop and implement.

8. SUMMARY

Developing microclimates for metals and plastics is an ongoing cycle of learning and testing, implementing, and testing again. We have made progress in understanding what containers create well-sealed environments, and we are beginning to understand ways to use these environments and various scavengers to create storage for various materials in our specific repository. In a few situations, we are developing solutions that are fairly basic to use; however, some, such as low oxygen environments, require more experience to create and maintain.

With metals, we have the flexibility to suggest to a park that all of their small metals be stored in the low RH environments, and we expect little to no harm to come to those objects. With plastics, more upfront investigation has to occur before we can advise specific climate type. In some situations, we may have to create the climates and then advise the park staff how to maintain them, or suggest that those items be stored in Tucson where we can provide cyclic maintenance for the objects.

Recognizably all of these microclimates will fail with time, can fail with human error, and require cyclic attention. We continue to research better options for monitoring the environments for storing plastics. We are, however, able to create effective environments by replacing adsorbents at regular intervals.

ACKNOWLEDGMENTS

I would like to thank Brynn Bender, who determined the need for the microclimates for metals; Maggie Hill Kipling, who performed the initial plastics survey and brainstormed microclimate options for plastics to begin the testing; and the IMR-MSP staff for their support.

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Voellinger, T., S. Wagner, and C. McCabe. 2009b. *Cold storage for photograph collections—vapor-proof packaging.* Conserve O Gram. Washington, D. C.: National Park Service. 14/12.

SOURCES OF MATERIALS

Ageless Oxygen Absorber; Escal; ZerO2 Alert indicator
Keepsafe Microclimate Systems
9 Oneida Avenue
Toronto, ON Canada M5J 2E2
800-683-4696
www.keepsafe.ca

ArtCare Microchamber Board; Marvelseal; Mylar (1-mil); Zorflex Activated Carbon Cloth
Talas
330 Morgan Ave
Brooklyn, NY 11211
212-219-0770
www.talasonline.com

Desi-Pak (Manufactured by Süd Chemie)
The Rust Store
8376 Murphy DrMiddleton, WI 53562
877-256-9301
www.theruststore.com

Double Impulse Heat Sealer, AIE610FDA Dual 24 Sealerlothg. McCabe AIC. 9:169–194.
American International Electric
1325 S. Johnson Dr.
City of Industry, CA 91745
626-333-0880
www.aieco.com

Hefty Clip Fresh gasket seal containers (discounted rate for bulk orders)
Heritage Mint
PO Box 13750
Scottsdale, AZ 85267-3750
480-624-2422
www.HeftyFoodContainers.com

Humidity indicator cards (#S-8027); Getter Pak activated carbon packets (#S-20194); Oxy-guard (S-19586); Single Impulse Heat Sealer
Uline
12575 Uline Drive
Pleasant Prairie, WI 53158
800-295-5510
www.uline.com

Kodak Molecular Sieves
Spectra Film and Video
5626 Vineland Ave
North Hollywood, CA 91601
818-762-4545
www.spectrafilmandvideo.com

Tell-Tab Oxygen Indicator
SorbentSystems
13700 S. Broadway
Los Angeles, CA 90061
310-715-6600
www.sorbentsystems.com

DANA K. SENGE is the assistant conservator for the National Park Service's Intermountain Region Museum Services Program based in Tucson, Arizona. She holds a bachelor of fine arts in studio art from Western Washington University, a master's degree in art conservation from Buffalo State College, and she trained with several institutions around the country, including the J. Paul Getty Museum in Los Angeles, CA, The Field Museum of Natural History in Chicago, IL, and The Nelson Atkins Museum of Art in Kansas City, MO. Address: Western Archeological and Conservation Center, 255 N Commerce Park Loop, Tucson, AZ 85745. E-mail: dana_senge@nps.gov

INTRODUCTION TO THE JOINT OBJECTS AND RESEARCH AND TECHNICAL STUDIES SESSION PAPERS

AINSLIE HARRISON

The next six papers in this volume come from a conference session held jointly by the Objects Specialty Group and the Research and Technical Studies Specialty Group. Our goal for the session was to go beyond presentation of technical studies to focus on the role of research in the development of conservation and preservation strategies.

Research informs our understanding of materials as well as their interactions and degradation—concepts that are always central to the conservation treatment and care of collections. These six papers demonstrate how information obtained through research and analysis can be applied to the decision-making process. They explore research on a diverse range of collections objects, from materials made of glass beads and brightly colored feathers, to a Nazi bat-wing aircraft. They also present research into the degradation of Disney animation cells, the mitigation of pesticides on Navajo textiles, and the effects of vibration on the Egyptian collection at the Met. These innovative studies all share a heightened awareness of their end goal—the conservation and care of their collection objects.

ULTRAVIOLET-INDUCED VISIBLE FLUORESCENCE AND CHEMICAL ANALYSIS AS TOOLS FOR EXAMINING FEATHERWORK

ELLEN PEARLSTEIN, MELISSA HUGHS, JOY MAZUREK, KEVIN McGRAW, CHRISTEL PESME, RENÉE RIEDLER, MOLLY GLEESON

ABSTRACT

Feathers are found in cultural heritage collections of tribal arts from the Americas, Africa, and the Pacific as well as in contemporary art, European and American fashion, and in taxidermy and ornithology specimens. Although museum conservators routinely evaluate feathers by looking at insect damage and mechanical wear, as well as fading as evidence of light exposure, examination of feathers for visible fluorescence under an ultraviolet (UV) source is atypical. Recent research by both the authors and bird biologists indicate that nondestructive UV fluorescence examination can provide valuable information about the identification and pigmentation of feathers found in museum collections, but must be used with caution as both light exposure and adventitious materials may compromise fluorescence. The authors also evaluate different methods of chemical analysis for detecting light-induced chemical changes in feathers.

Recent research conducted jointly by UCLA and the Getty Conservation Institute illustrated the importance of identifying feather pigmentation systems in the design of a preventive conservation strategy. The difference in the quantity of light needed to fade undyed feathers can be 10-fold depending on the colorant systems present in the feather and the emission spectrum of the light. Feathers with color derived from the scattering of light through small scale feather structures are known to be more light-stable than feathers with coloration based on biological pigments. A number of feather pigments, including psittacofulvins found only in red and yellow pigments in birds in the Psittaciforme family, as well as porphyrins found in rusty brown owl plumage, may be identified by their specific ultraviolet-induced visible fluorescence (UVIVF).

Feathers whose pigments are not directly fluorescent may still undergo appearance changes under an UV source as a consequence of light aging. Fluorescence is an early marker of chemical change, and can be used to detect such change before it can be measured colorimetrically. Beyond knowing that UV fluorescence is a stable attribute of some feather pigments, and a light-sensitive attribute in others, the current authors were motivated to determine whether color shifts visible in UV-induced fluorescence could provide a nondestructive marker of photochemical change to the keratin feather structure. This article describes a variety of analytical techniques applied to light-aged feather samples to present the most sensitive methods for detecting chemical changes that parallel fluorescence changes. Museum featherwork, some with records of estimated display, were examined using UVIVF both to document psittacofulvin pigmented feathers expected to display fluorescence, and to compare non-psittacofulvin-pigmented feathers with accelerated-aged feather samples.

1. INTRODUCTION

Feathers are found in cultural heritage collections of tribal arts from the Americas, Africa, and the Pacific as well as in contemporary art, European and American 18th to 21st century fashion, and in taxidermy and ornithology specimens. Undyed feathers are selected culturally and aesthetically for their color-producing mechanisms as well as mnemonic meanings (Tidemann and Gosler 2010; Gleeson et al. 2012; Riedler et al. 2012), and color is a significant factor in species discrimination in scientific-type collections (Pyke and Ehrlich 2010). Contemporary artists are electing to use undyed feathers for the spectacular addition of color and meaning to composite works (see, for example, Coyne 2014).

In considering the conservation of featherwork, recent research conducted jointly by the UCLA/Getty Program in Archaeological and Ethnographic Conservation and the Getty Conservation Institute illustrates the importance of identifying feather pigmentation systems in the design of a preventive lighting strategy (Riedler et al. 2014). Undyed feathers can fade at dramatically different rates depending on the natural colorant systems present in the feather and the emission spectrum of the light source. This difference in susceptibility to fading can be as great as a tenfold difference in light dose. Feathers with color derived from the scattering of light through the nanoscale protein structures are known to be more light-stable than feathers with coloration based on biological pigments. Conservators, therefore, need to be able to estimate the most fugitive colorant source in feathers found in collections, allowing for cumulative display lighting recommendations to be developed for different colorant systems. As all feathers are supported by a keratin structure, photochemical damage to that protein support presents risks even if visible coloration is unaffected.

The authors compared the efficacy of different analytical methods for assessing color loss and photochemical change to feather keratin and carotenoids. These comparisons were conducted following a process of accelerated light aging of white turkey feathers with structural color (i.e., color rendered by the scattering of incident light), and brilliant red biopigmented Scarlet ibis feathers that gain their color from carotenoid sources from ingested plants and insects. Analytical techniques utilized appear in table 1.

Table 1. Techniques Used to Evaluate Photochemical Damage

Technique	Specifications
UV-induced Visible Fluorescence	1. Mini Crimescope Alternate Light Source and 365 nm filter, SPEX Forensics, Edison NJ and Nikon D90 camera with a 2e filter 2. HQRP 365 nm UV 12 LED Flashlight, LEDs: 12, Wavelength: 365–370 nm, Canon G12 camera with a 2e filter
Fluorescence Spectroscopy	FLS920 spectrometer from Edinburgh Instruments. To minimize scattering caused by feather structure, the monochromatic slits are set at 4 nm.
Reflectance Spectroscopy	Control Development Model PDA 512 USB/380-900/1/100μm; Ocean Optics Halogen Light Source HL 2000; 0/45 angle set up with AVANTIS AFH–5 multiangled head.
Fourier Transform Infrared Spectroscopy	Perkin Elmer Spectrum 100 FTIR spectrometer equipped with a universal attenuated total reflectance (ATR) sampling accessory. Feathers were placed face down on the ATR crystal of the FTIR and force was applied using the pressure arm until acceptable signal to noise was achieved; four scans were averaged for each spectrum
X-Ray Photoelectron Spectroscopy	AXIS Ultra DLD spectrometer from Kratos Analytical. Feathers were affixed face up to the sample holder using copper tape. The spectra were measured using a monochromatic $Ar+$ ion source; charge neutralization was employed due to the insulating nature of feather samples. Binding energy was calibrated using the C 1s peaks (BE = 285 eV). Broad band spectra as well as high resolution spectra for the C 1s, N 1s, O 1s, and S 2p regions were collected. It was necessary to average 3 scans for the S 2p region to obtain an adequate signal to noise ratio.
Gas Chromatography/ Mass Spectroscopy	A ZB-1 (30 m × 0.25 mm × 0.25 μm) capillary column was used for the separation. Helium carrier gas was set to a linear velocity of 50 $cm \cdot sec^{-1}$. Split injection was used 20:1 and was set to 270°C. The MS transfer line was set to 280°C. The GC oven temperature program was 105°C; 40°C $\cdot$ min^{-1} to 280°C; isothermal for 1 min. Total run time is 5.38 min. SIM conditions were used (m/z 268). For GC/MS the derivitization solution is prepared by mixing 0.5 mL dry pyridine with 1 mL N,O-Bis(trimethylsilyl)trifluoroacetamide (BSTFA) and 60 μL of this solution is added to each vial. Vials are capped and heated for 15 minutes at 75°C, they are then immediately injected into the GC/MS.

A surprising outcome is that UVIVF, a common nondestructive conservation tool rarely used for the examination of featherwork, can aid in the discrimination between certain feather color mechanisms as well as provide evidence of photochemical degradation. We found that shifts detectable under UV-induced fluorescence may provide an indication of past lighting exposure, contributing important information for calculating museum lighting for current and future display.

2. GOALS FOR FEATHER ANALYSIS

Original goals for the UCLA/GCI study were to determine whether both structural and biopigmented feathers were equally sensitive to accelerated light aging, and whether optimum methods for detecting and quantifying photochemical damage to feather pigments and keratin could be developed. Results from the first study have been reported elsewhere (Pearlstein and Keene 2010; Riedler et al. 2014), and results of the second study emphasizing analysis of photochemical damage to pigments and protein are presented here.

The application of protein amino acid analysis as a marker of light-induced degradation has been limited in the field of cultural heritage and requires the removal of a small sample, adding a methodological disincentive. Schilling et al. (1996) and Schilling and Khanjian (1996) applied gas chromatographic methods to amino acid analysis to distinguish between different proteinaceous binding media in paintings. We also looked to the work of Vanden Berghe (2012) and Vanden Berghe and Wouters (2005) who measured ratios of cystine to the oxidation products cysteine and cysteic acid in wool tapestries, finding increased oxidation products to be a reliable marker of photodegradation. These authors used acid hydrolysis and prederivitization, followed by high-performance liquid chromatography (HPLC) to detect amino acid ratios, and found this technique to be a more sensitive marker of oxidation than either color change or strength measurements. The use of amino acid ratios has also been applied to evaluate preservation states in the fibroin of silk textiles, with dry thermal aging and UV radiation altering the alanine to glycine amino acid ratios (Zhang et al. 2011).

We are not aware of previous studies characterizing the amino acid ratios in feather keratin as an indicator of photodegradation. Photo-oxidation of the chemical structure of feather keratin produces breakage of the disulfide bonds in the cystine amino acid, a reaction estimated by other authors to be detectable through either spectroscopic or chromatographic methods. Photo-oxidation of feather keratin has also not been systematically studied, while photolysis of wool keratin has received considerable attention and will be further discussed.

3. ULTRAVIOLET FLUORESCENCE

UVIVF occurs when shorter energy photons of UV wavelength are absorbed by materials that act as fluorophores by reemitting energy at longer visible wavelengths. When observed under visible light in which UV is excluded, fluorophores can also be chromophores and appear colored, or they may appear colorless, such as is the case with keratin. It is known that UV-induced fluorescence can be useful to natural organisms as an energy-quenching mechanism that converts potentially damaging UV radiation to a range of longer wavelengths that are less harmful or even useful for biological functions (Maxwell and Johnson 2000).

3.1 UV FLUORESCENCE OF FEATHER PIGMENTS

A number of feather pigments have been identified as having significant UV-induced fluorescence (Völker 1936, 1937). Völker (1965) summarized UV fluorescence as found within feathers of bird genera as follows: Type 1 *Cacatua*–gold-yellowish fluorescence (specifically the yellow crown feathers of a group of cockatoos and cockatiels) (figs. 1a, 1b); Type 2 *Melopsittacus*–sulfur-yellowish

Fig. 1. (a) Wing and crest feathers of a cockatiel under diffused light (Courtesy of Ellen Pearlstein); (b) Wing and crest feathers of a cockatiel showing UVIVF of psittacofulvin pigments (Courtesy of Ellen Pearlstein)

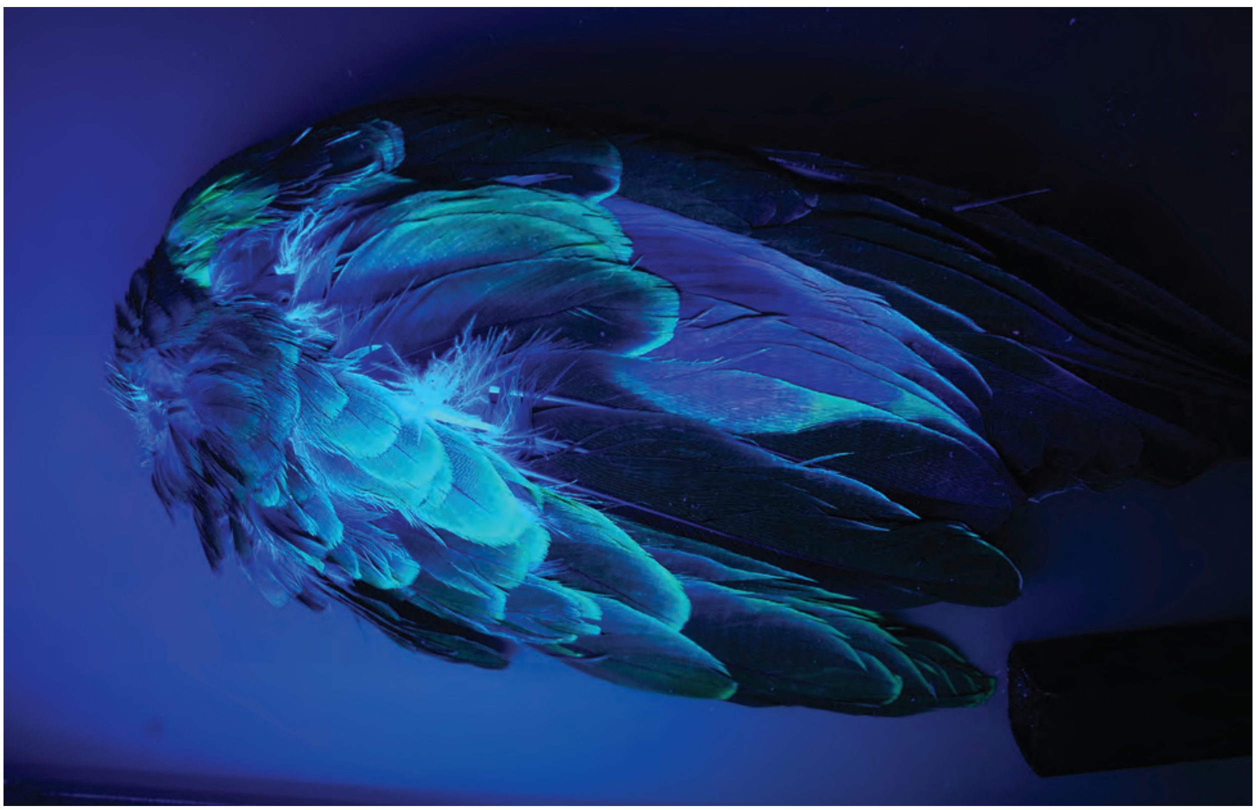

Fig. 2. (a) Parrot wing (most likely blue-fronted amazon or *Amazona aestivia*) under diffused light (Courtesy of Renée Riedler); (b) Parrot wing (most likely blue-fronted amazon or *Amazona aestivia*) showing UVIVF of psittacofulvin pigments in yellow, green and red areas (Courtesy of Renée Riedler)

fluorescence (specifically the yellow head feathers of a specific budgerigars or parakeets); and Type 3: *Palaeornis*–greenish fluorescence (green wing coverts of specific parrots including blue-fronted amazon or *Amazona aestivia*, and parakeets) (figs. 2a, 2b).

As a group, feather pigments with consistent fluorescence include many psittacofulvins found in yellow pigments, predominantly in birds in Australian species in the psittaciform order (including three genera mentioned earlier) but also more recently found elsewhere, as well as porphyrins found in rusty brown owl plumage, which are described later. Psittaciforms include culturally significant birds such as parrots, macaws, cockatoos and lorikeets, whose plumage comprises not only yellow feathers but also green feathers colored by mixtures of structural colors and yellow psittacofulvins.

Following the identification by Völker of a fluorescence generated by yellow psittacofulvin pigmented feathers, numerous other authors have reported similar and expanded observations (Boles 1991; Arnold et al. 2002; Hausmann et al. 2003; Pohland 2006). In evaluating study skins in Australian museums, Hausmann et al. (2003) detected red, orange, yellow, and green fluorescence in 68% of surveyed psittaciforms species examined with a UV source with a peak at 365 nm (62). Pohland (2006) in his dissertation detected fluorescence in plumage on study skins from 181 species within 14 families. Barreira et al. (2012) recently brought quantitative methods to biological fluorescence by measuring green fluorescence from green plumage of the blue-winged parrotlet (*Forpus Xanthopterygius*) with spectrofluorometry, and these authors are the first to report a violet fluorescence restricted to blue feathers, which are estimated as being structurally colored but with a small biopigment concentration.

Utilizing UVIVF, collections stewards might augment visual observation to better estimate both feather sources as well as pigment types. Pohland (2006) concludes that parrots are the taxonomic category most likely to include fluorescent plumage, i.e. more than a third of all parrots exhibit fluorescent plumage, and fluorescence has been found in plumage from every biogeographical region in the world. In an online discussion group devoted to parrot genetics and coloration, breeders remarked about how fluorescence in parrot plumage increases as birds mature, a subject for further study (List n/d). Various authors (Pearn et al. 2001; Parker 2002; Pearn et al. 2003; Pohland 2006) have hypothesized about the biological signaling advantages of fluorescent plumage, postulating also that it is characteristic of birds living in regions with exposure to a great deal of UVA energy, which is absorbed and then dissipated through the mechanism of fluorescence. A connection between past UVA exposure and visible UV fluorescence was determined experimentally in the current study, where UV-induced fluorescence has been confirmed as an indicator of past lighting exposure.

The identification of showy parrot feathers on cultural objects is simpler than the identification of many other feather types, especially through reference to websites that aid in identification (Assen 2011–12). Birds in the *Cacatua* genus may appear almost pure white or very pale yellow until viewed with UVIVF. It is more difficult to identify plumage sources when only partial or less visually familiar feathers are used or extant. The following example illustrates the cultural value of identifying psittaciform feathers used on a sculpture. Parrot and macaw feathers are not native to the area where the sculpture originates, and can therefore provide information about the selection of exotic species and suggestions about means of procurement.

Feathers estimated to be from blue-and-yellow macaw (*Ara ararauna*), African grey parrot (*Psittacus erithacus*) and yellow-naped parrot (*Amazona auropalliata*) were found on a contemporary Hopi wood carving from the American southwest (Ledoux 2010) (figs. 3, 4).

The presence of a violet fluorescence from red regions and a yellow fluorescence from a central yellow and black feather provide further indication that psittacofulvin pigments are present, supporting the feather attributions. Parrots and macaws are not traditionally native to the American southwest, and their feathers found there have historically been thought of as exotic imports from Mexico (Eckert and Clark 2009). In the case of this contemporary sculpture carved in 2001 by Gregory Lomayesva, many of the feathers used are from endangered or protected species (Federal Register 2009). As these feathers are unavailable for sale, those used on this sculpture may be from domestic birds owned by the artist, or may have been given to the artist through the Feather Distribution Project, a wildlife protection effort that has provided feathers to Native American artists and religious practitioners living in Arizona and New Mexico (Reyman 2007). Confirming the feather types is significant not only to preventive conservation practice, but also for the cultural information it provides.

Fig. 3. Mask, Gregory Lomayesva , 2001, wood, paint, feathers, 45 cm (l); 27 cm (h); 16 cm (d) (Courtesy of Zena Pearlstone, photo by Nicole Ledoux)

Fig. 4. UVIVF image of feathers on sculpture by Gregory Lomayesva shown in figure 3 (Courtesy of Nicole Ledoux)

Another culturally significant feather pigment for which fluorescence is an identification aid is porphyrin. Porphyrin is a reddish-brown pigment displaying a pinkish purple fluorescence, and is found in 13 different orders of birds (McGraw 2006). Porphyrin-containing feathers from owls are of notable cultural importance. Various owl feathers are significant in Native American regalia, including materials drawn from California, the Plains, the Southeast, and extending into Central America (Howard 1957; Gillespie and Joyce 1998; Gleeson et al. 2012). Porphyrin is light sensitive. In an empirical study where owl feather fluorescence was evaluated as a marker of owl feather age, fluorescence of newly molted feathers displayed a strong fluorescence in contrast with a complete lack of fluorescence on year old and permanent plumage on the same individual (Weidensaul et al. 2011). Porphyrin pigmentation is found on feathers that also contain more light-stable melanin pigments. The porphyrin is restricted to the light-protected base of dorsal sides, and to the ventral sides of feathers, concentrated on the proximal third of newly created feathers, on the underwing coverts, and on down feathers, all areas protected from light on the body of the bird (Weidensaul et al. 2011) (Riedler et al. 2014, 54).

As in the case of psittacofulvins, the presence of fluorescence associated with porphyrins can aid collection stewards in identifying plumage of a number of different owls. The well-documented light sensitivity of this pigment and its correspondingly fugitive UV-induced fluorescence, contributes to the evaluation of previous light exposure of these feathers throughout their entire useful life. If fluorescence is found on owl feathers used on regalia, it would suggest that newly molted feathers were used and were protected from light during all stages in the manufacture, use, and storage of the featherwork, as well as following museum collection. We have not detected porphyrin fluorescence on owl feathers found in museum collections.

3.2 ULTRAVIOLET FLUORESCENCE OF KERATIN

UVIVF was recognized as a significant tool for the examination of both wool textiles and feather materials soon after UV lamps became commercially available in 1925 (De la Rie 1982, 2). In a 1927 publication of the *Journal of the Textile Institute Transactions*, British industrial researcher H. R. Hirst described an UV-induced blue-white fluorescence detectable in wool as "characteristic of some of the amino compounds produced by the decomposition of keratine (*sic*). Cystine shows no distinct fluorescence; leucine, asparagine, tyrosine, alanine, and glycocol fluoresce similar to wool" (Hirst 1927, T372). Hirst goes on to acknowledge the likely benefits of exploring UV fluorescence as a way to characterize keratin decomposition products. Although multispectral imaging has been adapted for the detection of fluorescent dyes and pigments on textiles, until recently the application of UV fluorescence to wool fabrics has been limited to the detection of optical brighteners, biological alteration products, and stains (Andrew and Eastop 1994).

Fluorescence characteristics of degraded keratin have been thoroughly explored through the examination of wool and impacts of industrial processes (Collins et al. 1988; Smith 1995; Davidson 1996; Sionkowska and Płanecka 2011). Various authors have noted that the cystine disulfide bond essential to the keratin structure quenches UV-induced fluorescence and that treatments that disrupt disulfide bonds may cause energy to be emitted as fluorescence (Collins et al. 1988, 349–51). Collins et al. (1988) noted the development of a blue fluorescence under a 365 nm source following the application of oxidizing agents to wool keratin. Davidson (1996) and Dyer et al. (2006) looked specifically at photo-oxidation and its effects on tryptophan, and on the oxidative coupling of cystine. An important difference between the amino acid makeup of wool, which is α-keratin (helical in structure), and feather, which is β-keratin (pleated sheet structure), is tryptophan, which is a major constituent of wool and is minor or unreported in feathers (Schroeder et al. 1955, 3904; Arai et al. 1983; Murphy et al. 1990, 918). Davidson identifies tryptophan degradation products as the source of blue fluorescence in wool keratin following irradiation at 360 nm (1996, 7). Sionkowska et al. (2011) found that keratin chromophores with fluorescence between 360 and 500 nm developed following 60 min of peak irradiation of wool at 254 nm, and ascribed these to tryptophan deterioration. Researchers examining chemically induced fluorescence and phosphorescence (or chemiluminescence) of four proteins including white feather keratin-detected luminescence of both collagen and keratin samples following irradiation between 320 and 400 nm, concluding that chemiluminescence occurs even in the absence of tryptophan (Millington et al. 2008). While not linked by earlier authors to a fluorescence change, wool keratin has been noted to experience measurable bleaching and fading upon exposure to visible blue light (Lennox and Rowlands 1969, 359).

Keratin hydrosylates from feather protein include the breakdown of cystine to cysteic acid (Sionkowska et al. 2011). Free radicals of sulfur are known to be reactive and destructive to keratin. The effect of irradiation on cystine "involves the initial formation of its monoxide, followed by dioxide formation and then cleavage by water to generate cysteic acid" (Davidson 1996, 5). Cysteic acid, cysteine S-sulfonate, and cysteine thiol groups have been identified as photodegradation products of cystine in all keratins using FTIR and Raman spectroscopy, used to detect photolysis of the disulfide bonds (Millington and Church 1997). The connection between formation of these products and UVIVF has not been suggested for featherwork, and thus provides the basis for the current work.

4. MEASURING PHOTOCHEMICAL DAMAGE IN FEATHERS

Beyond knowing that UV fluorescence is a stable attribute of some feather pigments, and a light-sensitive attribute in others, we were motivated to determine whether color shifts visible in UV-induced fluorescence could provide a nondestructive marker of photochemical change to the keratin feather structure. We detected changes in UVIVF and appearance changes in accelerated light-aged feathers, lending credence to the early remarks of Hirst who suggested that a blue-white fluorescence is indicative of a degradation product within wool keratin. To understand the chemical processes corresponding to observed changes in UV fluorescence in feathers and to quantify fluorescence outcomes, a pilot study was conducted where spectroscopic and chromatographic techniques outlined in table 1 were utilized on aged and unaged samples of study feathers.

4.1 MATERIALS AND METHODS

4.1.1 Feather Samples

Two feather samples were selected for the application of color measurement and analysis before and after accelerated light aging. Feathers utilized in this study are pure white wing feathers lacking biopigment, from the domestic Broad Breasted White Turkey (*Meleagris gallopavo*), and scarlet ibis (*Eudocimus ruber*) wing and tail feathers with brilliant red carotenoid pigmentation (Fox 1962). The distributor of the commercially purchased turkey feathers confirmed that they are washed with a detergent called Wool Wash, which contains triethanolamine, sodium lauryl sulfate, various surfactants, mild alkalis and glycerin, and are then sterilized with hydrogen peroxide. These feathers were selected because they are pure keratin that reflects all visible wavelengths equally.

The scarlet ibis feathers were collected from four different zoos, each committed to maintaining plumage color to breed standards through a carotene rich diet. These feathers were selected because previous research provided information about the light sensitivity of the carotenoid biopigments present (Pearlstein and Keene 2010; Riedler et al. 2014). Scarlet ibis feathers were observed to display

Table 2. Accelerated Aging Conditions

Aging Conditions	Description
Accelerated "Museum" Light	Chamber with GE Precise MR 16 bulbs ACG141CI with individual UV filters; filtered bulbs emit primarily in the 400–700 nm range 20,700 average lux 6.0 μw/lm average UV
Daylight Conditions (typical of many small museums and historic houses)	South facing window with 26% transmission between 300 and 380 nm, and 74% between 400–700 nm 5000 average lux 1300 μw/lm average UV
UVA Irradiance	QUV Chamber with F-40T12TR50 Westinghouse 5000K lamps with peak UV emission at 340 nm 71,750 mW/m^2 radiant energy 68,250 μw/lm average UV
Control Total darkness	Closed cabinet

considerable variation in color between feathers and within single feathers. As determined through pigment extraction carried out by McGraw, pigment content varied from 47 to 938 μg of pigment per gram of feather on unexposed feathers. The largest intra feather variation was a difference of $417 \mu g \cdot g^{-1}$ between the feather tip and the lower portion, with the tip having the most pigment and appearing most saturated.

4.1.2 Accelerated Light Aging

Feathers were exposed to four lighting environments to represent accelerated examples of conditions present in the illumination of plumage on the bird, on items during cultural use, and within the parameters of museum display (table 2).

In each instance the feathers were enclosed in semiopaque card stock enclosures that uniformly reduced light exposure on the bottom halves of each feather. Control feathers were stored in a dark closet at otherwise ambient conditions. The feathers were exposed in all four environments for time periods of 3, 10, 29, and 100 days. Total exposure hours as well as emission spectra vary under different aging conditions as both natural and artificial sources were used.

5. ASSESSMENT METHODS AND RESULTS

5.1 ULTRAVIOLET-INDUCED VISIBLE FLUORESCENCE

Pure white feathers selected to display the impact of light on unpigmented feather keratin demonstrate fluorescence changes following accelerated aging. Exposure-induced change in keratin fluorescence appears wavelength dependent, and specifically responsive to the presence or absence of UV in the spectral power of the light source. Unexposed feather shafts produce a characteristic white

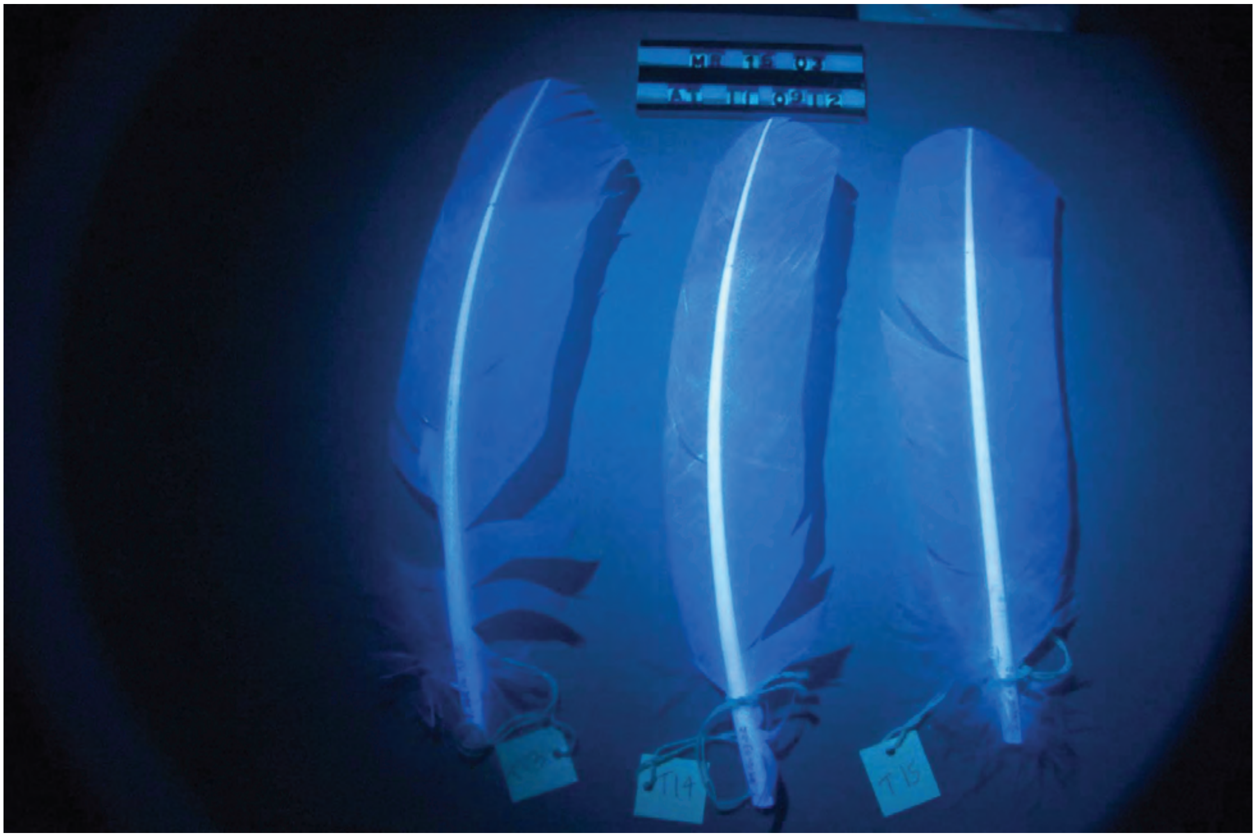

Fig. 5. UVIVF image of turkey feathers after 3 days of accelerated museum lighting (Courtesy of Ellen Pearlstein)

appearance under UV, while the unexposed barbs and barbules (side branches and hooks creating the vane) are a lower density of keratin and exhibit a pale blue fluorescence. White feathers exposed to UV-filtered light do not exhibit color shifts even after 100 days of accelerated aging when observed under visible light; however, shifts in color are detectable with UVIVF. UV-induced fluorescence was revealed to be a sensitive technique for assessing light-induced degradation in turkey feathers, as changes in appearance were clearly detectable after only three days of aging independent of the type of aging; however, the consequential changes in UVIVF were different depending on the aging conditions to which the feathers were exposed.

After three days of UV-filtered museum lighting, exposed regions of white feathers observed under UV display a darkening and a shift toward blue-violet, while the unexposed region remains unchanged (fig. 5).

Window-aged feathers also display an increased darkening and a shift toward blue-violet after 3 days, and feathers aged under extreme UVA conditions exhibit a shift toward yellow despite the absence of measurable colorimetric changes using reflectance spectroscopy. White feathers aged for both 10 and 29 days under accelerated museum lighting conditions continue to further darken and shift toward blue-violet in exposed regions, whereas extreme UVA conditions result in further yellowing in exposed regions, along with the development of fluorophores producing yellow UV fluorescence. The penetration of UVA radiation through the paper mask used to protect the lower "unexposed" regions resulted in shifts of the lower regions toward blue-violet in 29 and 100 days UV-aged feathers (figs. 6, 7).

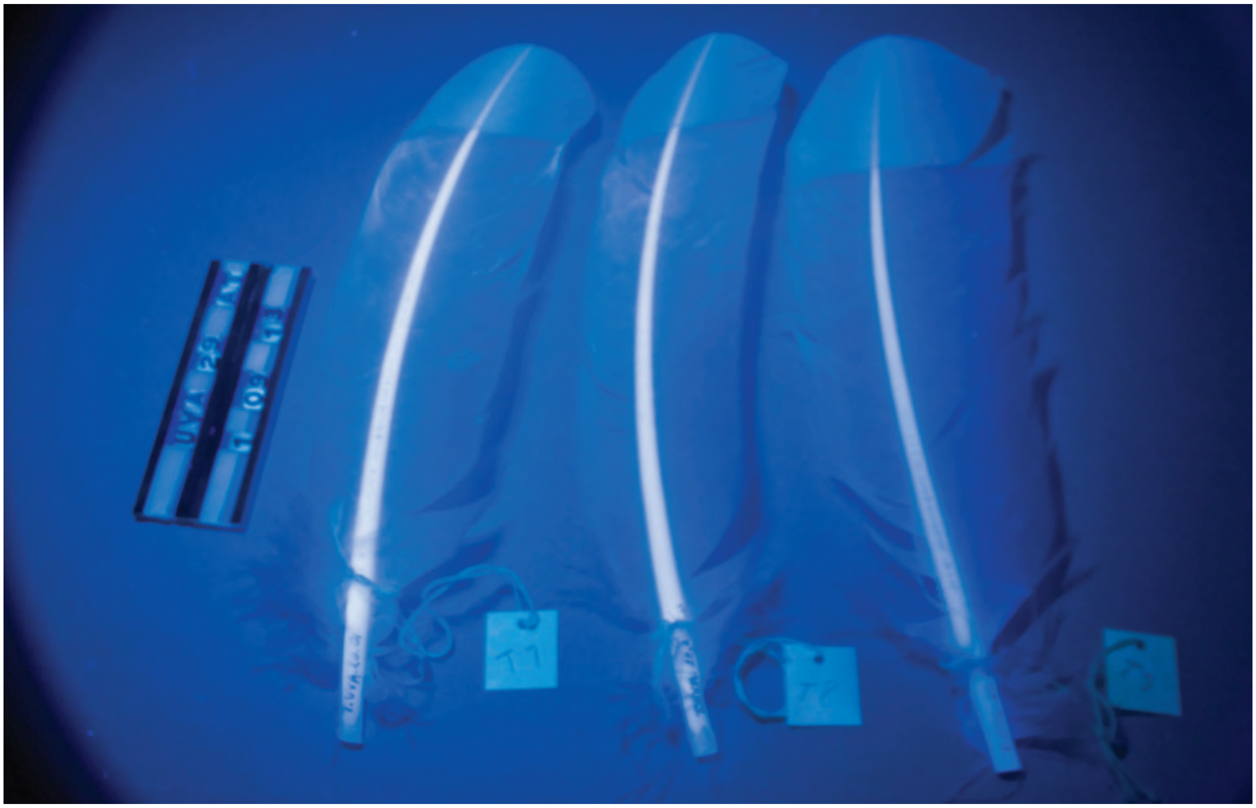

Fig. 6. UVIVF images of turkey feathers after 29 days of accelerated UVA aging (Courtesy of Ellen Pearlstein)

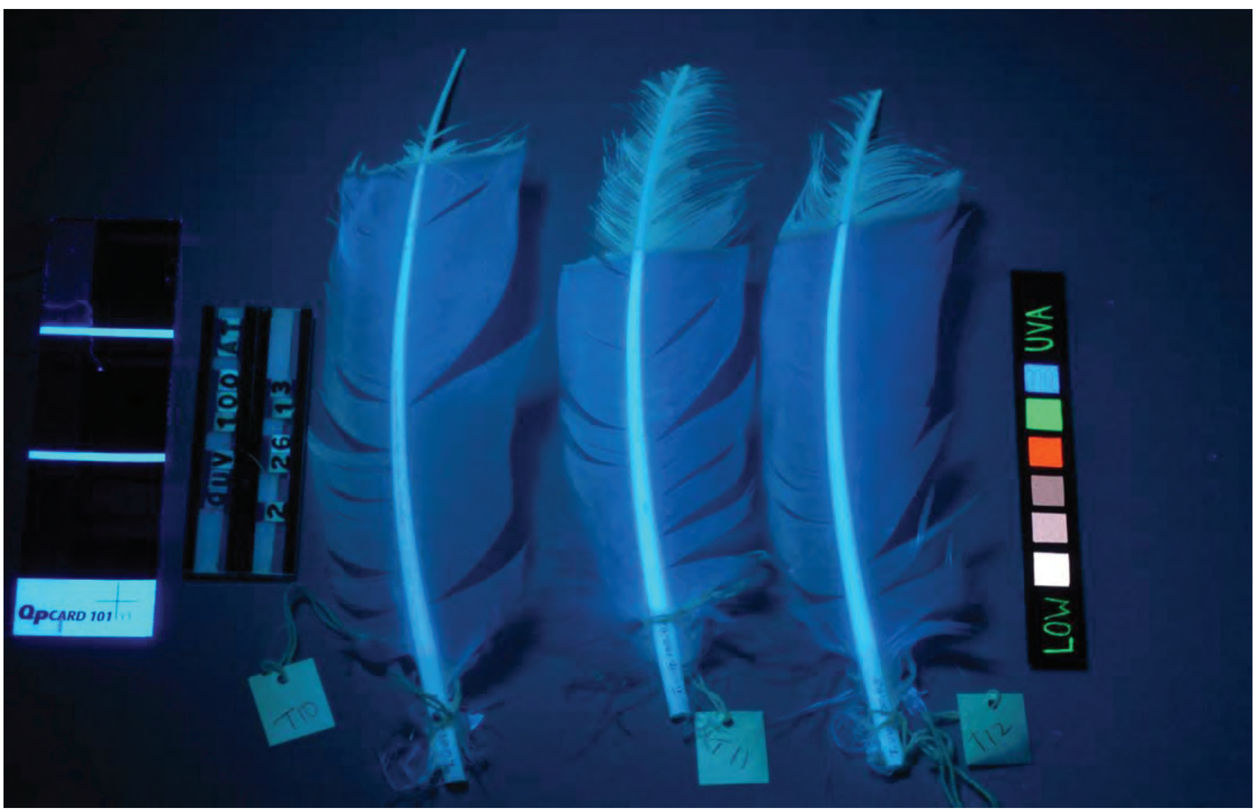

Fig. 7. UVIVF images of turkey feathers after 100 days of accelerated UVA aging (Courtesy of Ellen Pearlstein)

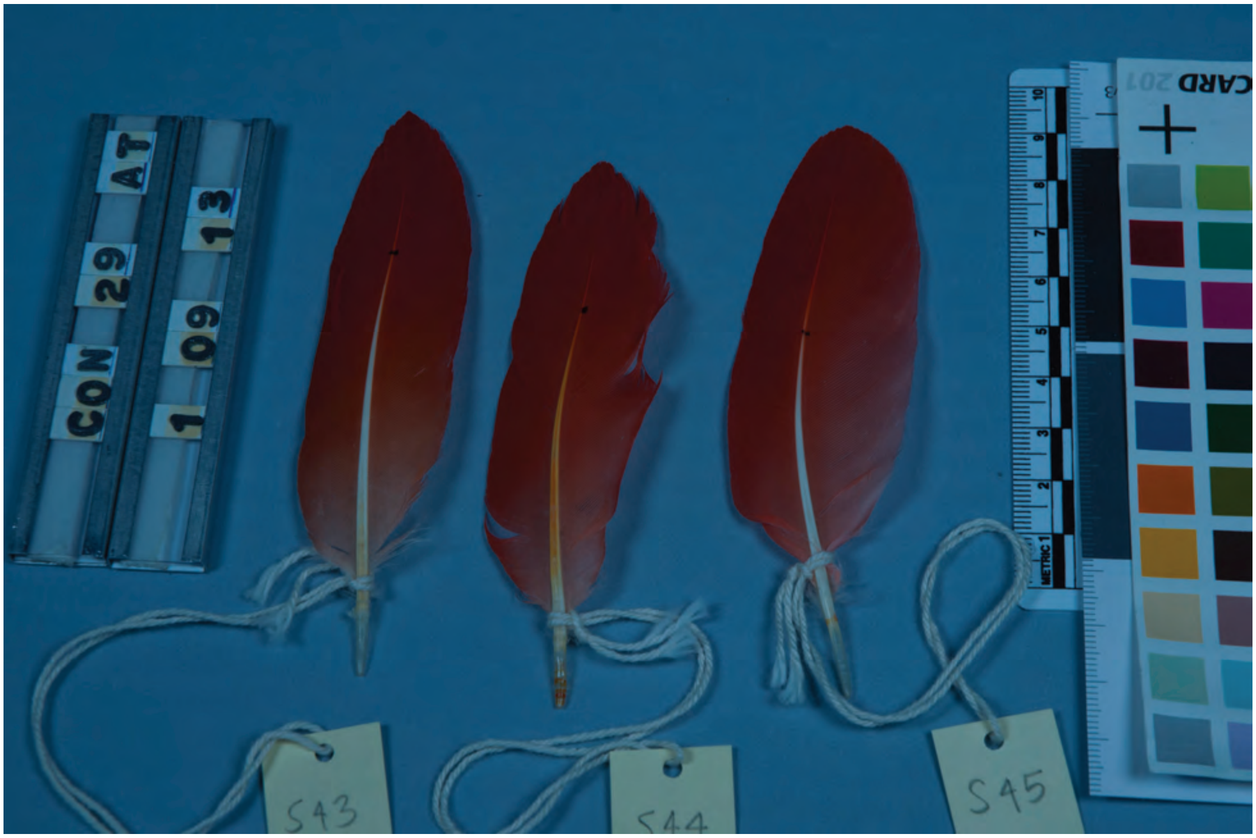

Fig. 8. Scarlet ibis control feathers showing the uneven distribution of pigment (Courtesy of Ellen Pearlstein)

This blue-violet shift is more extreme but otherwise similar to that evidenced by feathers exposed to window light. After 100 days of aging, exposed regions of UVA-aged feathers have suffered severe visible yellowing and embrittlement and losses to barbs, and the corresponding areas have an intense yellow-white fluorescence.

Scarlet ibis feathers pigmented with carotenoid also exhibit fluorescence change, but are more difficult to assess due to a greater variety of coloration both within and between feather samples. The authors now recognize the limitations of exposing the top half of the feathers for comparison with the lower halves, as color in unexposed samples is often more intense on the upper half of the feather (fig. 8).

When observed under UV light, unaged scarlet ibis feathers also present great variety of appearance: some of the feathers fluoresce emitting in the red part of the visible spectrum, while others do not. Despite this variation, scarlet ibis feathers display an increased darkening and shift toward blue violet under UV with increased exposure to museum lighting beginning with 3 days, or a total of 1.5 Mlux hours. Visible color loss and a corresponding yellow fluorescence occur after 10 days of UVA aging (fig. 9), while other lighting conditions including museum lighting and window lighting result in increased darkening and blue violet appearance in exposed regions.

After 29 days, increased blue violet appearance is evident in UV-filtered (museum lighting) feathers and more strongly in feathers exposed to partially UV-filtered window light; UVA exposed feathers display severe color loss and yellowing in visible light (fig. 10).

As in the case of turkey feathers, scarlet ibis feathers following 100-day aging display darkening and blue violet appearance in regions exposed to UV-free or partially UV-filtered light, and after

Fig. 9. Scarlet ibis feathers after 10 days of accelerated UVA aging (Courtesy of Ellen Pearlstein)

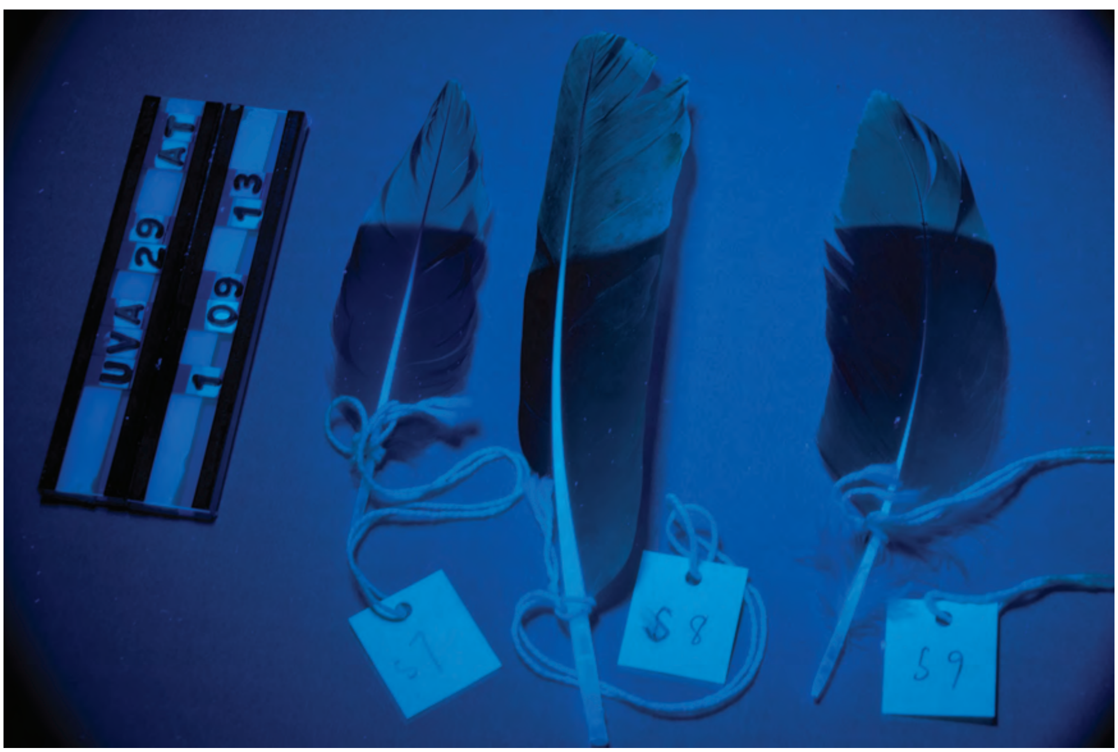

Fig. 10. Scarlet ibis feathers after 29 days of accelerated UVA aging (Courtesy of Ellen Pearlstein)

Fig. 11. Scarlet ibis feathers after 100 days of accelerated museum lighting aging (Courtesy of Ellen Pearlstein)

UVA aging display visible color loss, feather embrittlement, severe yellowing, and yellow fluorescence (figs. 11–13).

The interpretation of color changes detectable by UVIVF have been limited to measurable changes in pigment concentration in the case of scarlet ibis feathers, and to ratios of intact disulfide bonds, i.e., cystine, to oxidized sulfur in the form of cysteic acid or a precursor, measurable in feather keratin by techniques applied below. Previous work has indicated that UV exposure is responsible for destruction of carotenoid pigmentation in feathers (Pearlstein and Keene 2010), and current work indicates further that a reduction in pigment concentration results in a detectable shift in UVIVF. As wool studies indicate the development of new fluorophores and quenching of others in keratin following exposure to specific wavelengths of UV, the same may be occurring in the feather keratin. Precise mechanisms contributing to feather appearance changes induced by UV-filtered lighting are part of ongoing research.

5.2 FLUORESCENCE SPECTROSCOPY

Fluorescence spectra of the feather samples were collected in an attempt to corroborate the changes in UVIVF. The fluorescence changes that are quite noticeable in photographs produce only subtle spectral changes, except in the case of the UV-aged feathers. With an excitation wavelength of 365 nm–comparable to the UVIVF–the emission spectra of turkey feathers UV-aged for 3, 10, and 29 days display a change

Fig. 12. Scarlet ibis feathers after 100 days of accelerated window aging (Courtesy of Ellen Pearlstein)

Fig. 13. Scarlet ibis feathers after 100 days of accelerated UVA aging (Courtesy of Ellen Pearlstein)

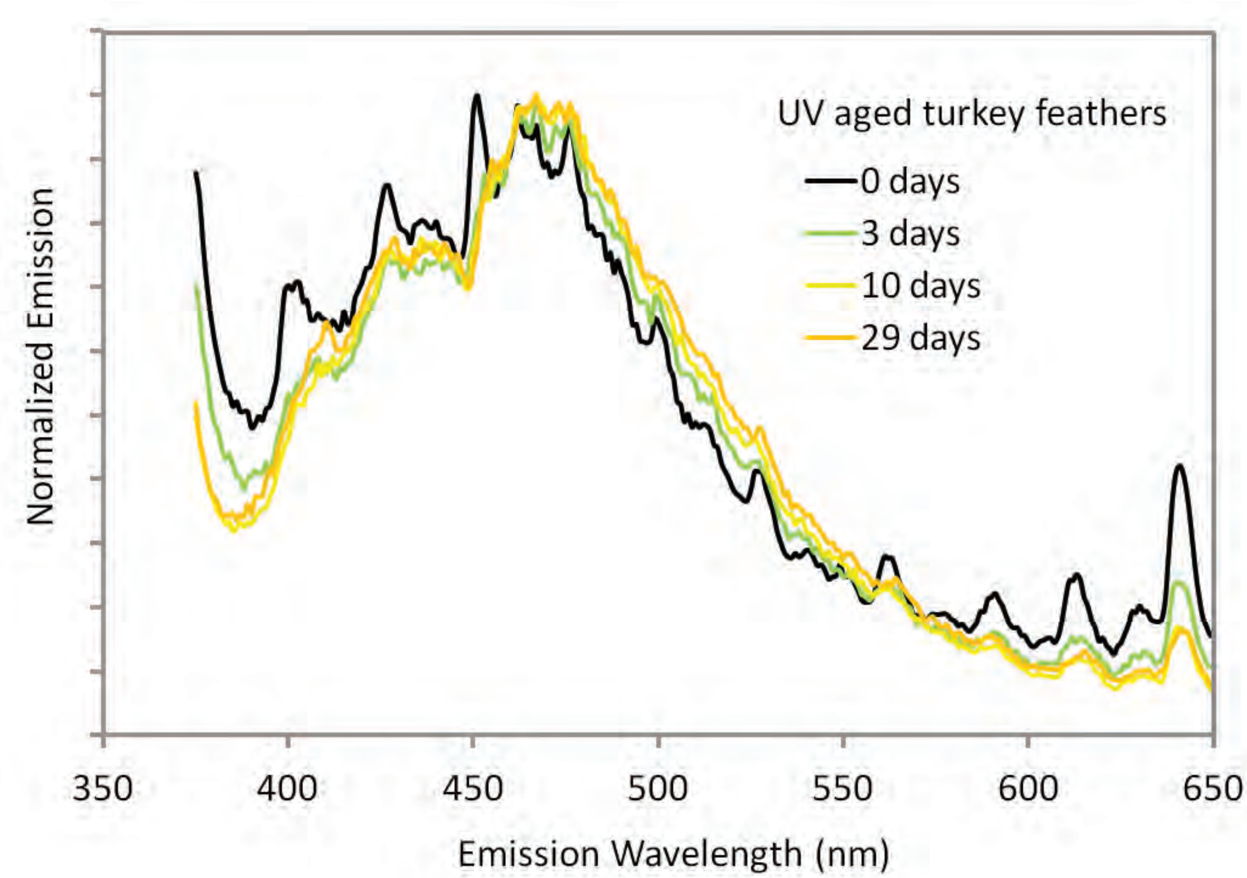

Fig. 14. Fluorescence emission spectrum of a turkey feather that has been UVA-aged for 0–29 days with an excitation wavelength at 365 nm (Courtesy of Melissa Hughs)

with increased aging. Figure 14 shows the emission spectrum of a turkey feather that has been UVA-aged for 0–29 days; the excitation wavelength is 365 nm.

There are numerous sharp peaks present that correspond to structural scattering rather than absorption emissions. There is a slight spectral red-shift, and an average of the change in emissions is centered at 505 nm. This corresponds to an increase in greenish emission, which is observable in the UV-induced fluorescence photographs. It was not possible to gather spectral data for the feather that had been aged 100 days due to extensive feather deterioration. These spectral changes provide data in support of the reduced blue and increased yellowish appearance of UVA-aged turkey feathers.

5.3 REFLECTANCE SPECTROSCOPY

All turkey and scarlet ibis feathers utilized in the study were measured with reflectance spectroscopy both before and after accelerated light aging. Measurements were taken with illumination and detection at two different angles relative to the barbs, and these measurements were recorded separately as P (parallel) and D (diagonal) to the barbs. This method accounts for the anisotropic light reflection of feather structures, and is described elsewhere (Riedler et al. 2014). Mylar templates were created for each feather to assure measurement repetition in the same four locations pre- and post- aging, and two to four measurements per location and per angle were captured and averaged. Differences in color between exposed and unexposed sites were calculated according to International Center of Illumination standards, abbreviated as CIE ‘76 Delta E.

Despite efforts to achieve reproducible color measurement, features such as the camber of individual turkey flight feathers (Scott and McFarland 2010, 51) and minor structural damage in reference scarlet ibis feathers that prevented identical repositioning under the template created measurement challenges. These changes also found in control feathers due to the physical repositioning of the feather and template—caused us to be conservative in our assessments of color change. In the case of scarlet ibis feathers, measurable color change was evident in feathers UVA-aged for 10, 29, and 100 days but was only the case for turkey feathers after 100 days of UVA aging. "Unexposed" regions of these turkey feathers also displayed measurable changes as the enclosures were not light tight.

5.4 PIGMENT CONCENTRATION ANALYSIS

Scarlet ibis feather pigment concentration was measured for all control and accelerated light-aged feathers to determine whether a decline in concentration could be correlated with spectral power distribution of the light source, or length of aging. Pigment was extracted thermochemically and analyzed by UV-Vis spectrometry using a method developed by McGraw (McGraw and Nogare 2005) and total carotenoid pigment content was quantified. Separation of the individual pigments was beyond the scope of this study. Maximum spectral value absorptions ranged from 460 to 475 nm, which is consistent with the presence of ketocarotenoids (specifically canthaxanthin). The formula described by McGraw et al. (2003) was used to determine total carotenoid concentration, using the extinction coefficient of 2200 for canthaxanthin. The inconsistency in pigment distribution within unaged feathers makes the interpretation of data difficult. It is not possible to simply record the loss of pigment in aged feathers, since feathers at each point may possess drastically different amounts of pigment. Instead, the pigment content of the tip was subtracted from the pigment content of the covered portion of the feather for each time point to give a "pigment change parameter" (fig. 15).

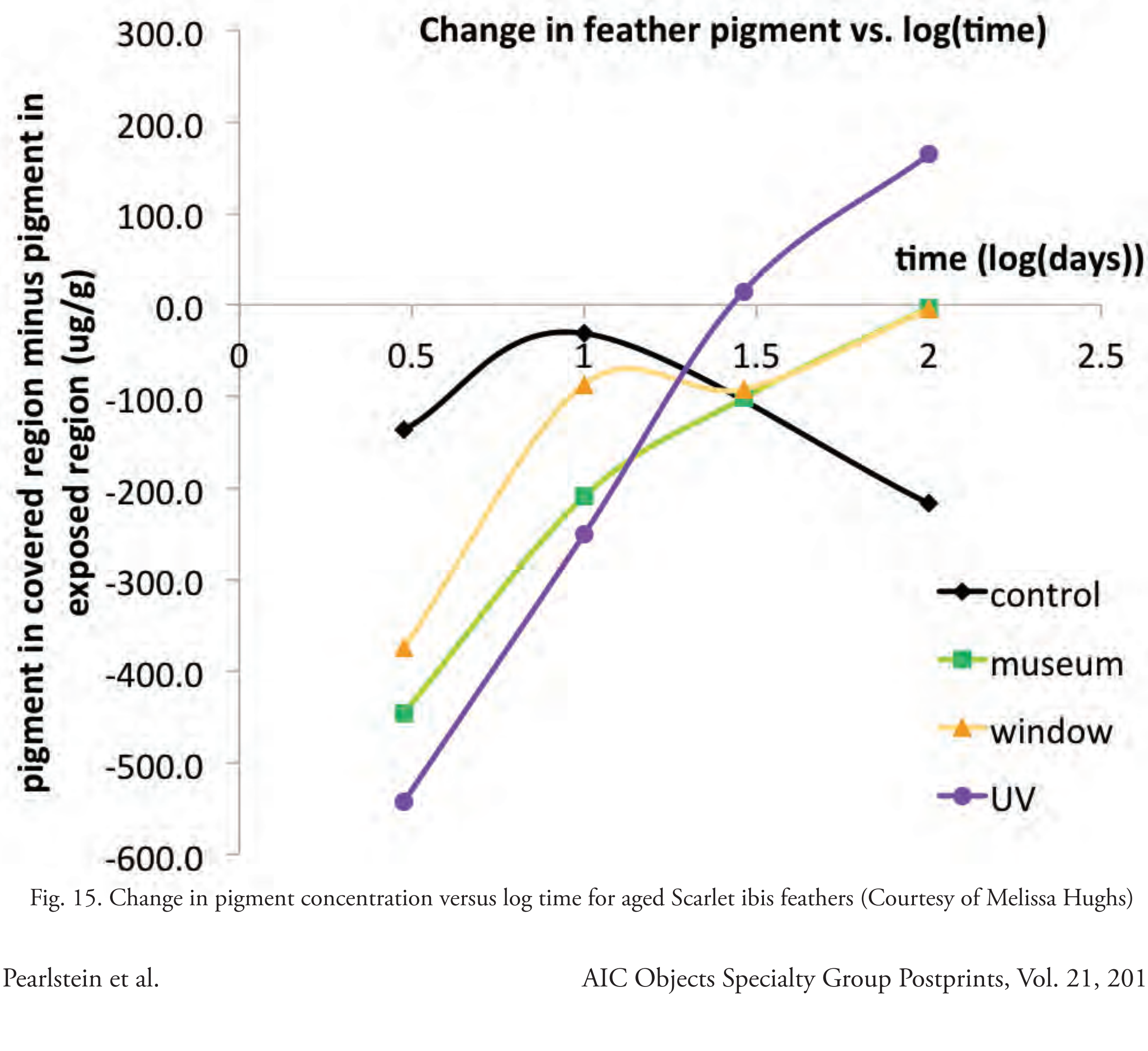

Fig. 15. Change in pigment concentration versus log time for aged Scarlet ibis feathers (Courtesy of Melissa Hughs)

For control feathers the pigment change parameter is always negative because the tips have more pigment. The window, museum, and UVA-aged feathers exhibit a clear trend of increasing pigment change parameters, indicating that while the feather tips may still contain more pigment than the bases, this difference decreases over time. Only in UVA-aged feathers do the feather tips become less pigmented than the bases. These results are somewhat more sensitive to small changes in pigment content than is visual evaluation, as changes in window and museum-aged feathers could not be observed visually, likely due to the uneven distribution of feather color.

5.5 FOURIER TRANSFORM INFRARED SPECTROSCOPY

FTIR spectroscopy nondestructively analyzes the vibration of the functional groups present in feather samples. Unaged feather spectra collected in this study were quite similar to previously reported ATR-IR spectra of feathers (Xhang et al. 2012). The spectra of the unaged scarlet ibis and turkey feathers were highly consistent with one another with the exception of a peak at 1040 cm^{-1}, the peak attributed to asymmetric S=O stretching of cysteic acid, which is present in the turkey feathers but absent in the ibis feathers. This apparent species variation is certainly the result of the turkey feather vendor's disinfecting peroxide wash. In the case of aged feathers, FTIR proved to be insensitive to changes in feather samples aged in window or museum light; however, spectral changes in UVA-aged feathers are pronounced. Most of the spectral changes occur below 1700 cm^{-1} and are consistent with an increasing concentration of keratin oxidation products. Figure 16 shows the difference between spectra of UVA-aged Scarlet ibis and turkey feathers and their unaged controls; a feather sample that has been chemically oxidized by soaking for 5 days in 30% hydrogen peroxide is also included for reference.

The chemically oxidized feather spectra as well as the 10, 29, and 100 day UVA-aged feathers have two clearly defined peaks at 1175 and 1040 cm^{-1}, which can be attributed to the symmetric and asymmetric S=O stretching of cysteic acid. An additional, more difficult to assign band in the feathers is seen at 1090 cm^{-1}. This peak may be attributable to cystine S-monoxide, which typically absorbs at 1070–1080 cm^{-1}. A peak at 1090 cm^{-1} would be consistent with alanine sulfinic acid that absorbs at 1093 cm^{-1} (Setiawan et al. 1985).

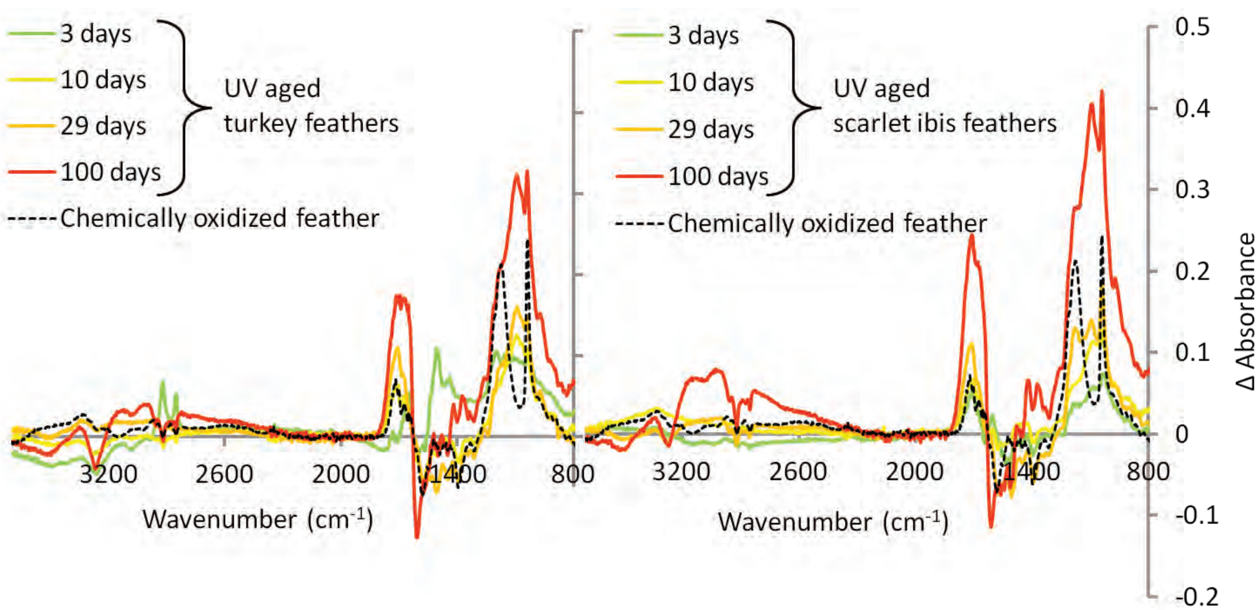

Fig. 16. FTIR absorbance differences between spectra of UVA-aged turkey feathers (left) and Scarlet ibis feathers (right) and their unaged controls (Courtesy of Melissa Hughs)

The changes seen in the spectra of chemically oxidized feather samples are highly consistent with changes in chemically oxidized wool and human hair samples (Shah and Gandhi 1968; Alter and Bit-Alkhas 1969; Strassburger 1985). The cysteic acid and cystine S-monoxide species are both present in UV-oxidized wool. An increase in the absorbance at 1720 cm^{-1} is observed, appearing as a subtle increase in the shoulder of the prominent carbonyl stretch in the IR spectrum, however in the difference spectrum shown in figure 16, this change is quite prominent. To the best of our knowledge, such a change has not been reported in the IR spectra of oxidized wool or hair; however, a close examination of the published spectra of oxidized wool does reveal an increase in the shoulder of the carbonyl peak (Church and Millington 1996). Because of the density of possible functional groups in this region, this peak is difficult to precisely assign. It is consistent with carboxylic acid or ketone bonds, which could be produced by the oxidation of amino acid side chains or the hydrolysis of the peptide backbone. Alternately, the increase may be due to changes in the keratin secondary structure, as studies of the denaturation and recrystallization of feather keratin have shown a similar increase in this shoulder (Xhang et al. 2012, 23).

5.6 X-RAY PHOTOELECTRON SPECTROSCOPY

XPS monitors electron energy levels and can give information about a sample's elemental content and bonding. It was applied in this study to determine whether the spectral results would allow for detection of changes in the disulfide bonds. UV-aged feathers show significant changes in their S 2p peaks, indicating increasing presence of oxidized sulfur. In turkey and ibis feathers, the S 2p peak area increases over time. This may be due to cystine residues and their oxidation products becoming increasingly exposed as feather structure breaks down. The broadband XPS spectrum of feathers is quite similar to the spectrum of wool; photoelectron peaks are observed for O 1s, N 1s, C 1s, S 2s, and S 2p at 533, 400, 285, 230, and 165 eV, respectively. In wool, the S 2p region of the XPS spectrum has been extensively studied (Carr et al. 1985; Carr et al. 1986; Carr et al. 1987). In untreated wool, the S 2p peak occurs at 164 eV, corresponding to cystine; wool that has been oxidized by plasma, corona discharge, or chlorine water has an S 2p peak at 168 eV, which has been identified as cysteic acid (Carr et al. 1986). Wool that has been treated with performic acid or hydrogen peroxide has peaks at 165.5 and 167 eV, which correspond to cystine monoxide and alanine sulfinic acid respectively. For unaged feathers, the scarlet ibis and turkey spectra already show significant differences in their S 2p peak: Ibis feathers have a fairly clean cystine peak centered at 163 eV, whereas turkey feathers have two additional peaks at 165.5 and 168 eV, which can be identified as cystine monoxide and alanine sulfinic acid on the basis of the wool studies. As noted earlier, this difference is almost certainly due to the vendor's pre-treatment of the turkey feathers with hydrogen peroxide.

As with the FTIR analysis, XPS is sensitive only to spectral changes demonstrated by the samples that were aged under UVA. The S 2p region in turkey and in scarlet ibis feathers is significantly altered after only 3 days of UVA exposure: In turkey feathers, the cystine monoxide peak at 165.5 is lost, whereas in the ibis feathers, a new peak at 168 eV begins to grow while the reduced sulfur peak at 163 eV decreases in size. After 10 days of UVA aging, the cysteic acid peak becomes more prominent for both types of feather. By 29 days, the reduced sulfur peak is gone in the turkey feathers, while it takes the full hundred days before this peak is eliminated from the scarlet ibis feather spectrum, possibly suggesting a protective role for the carotenoid pigment. Intriguingly, the total area of the S 2p peak increases as the feathers become more oxidized.

5.7 GAS CHROMATOGRAPHY/MASS SPECTROMETRY

Because the changes that were readily apparent as UVIVF in the window and museum light-aged feathers could not be chemically corroborated by XPS or FTIR, and only UVA-aged changes were corroborated, amino acid analyses was performed using GC/MS. On the basis of the work of previous authors who detected light induced amino acid change (see Vanden Berghe 2012) as well as the XPS and

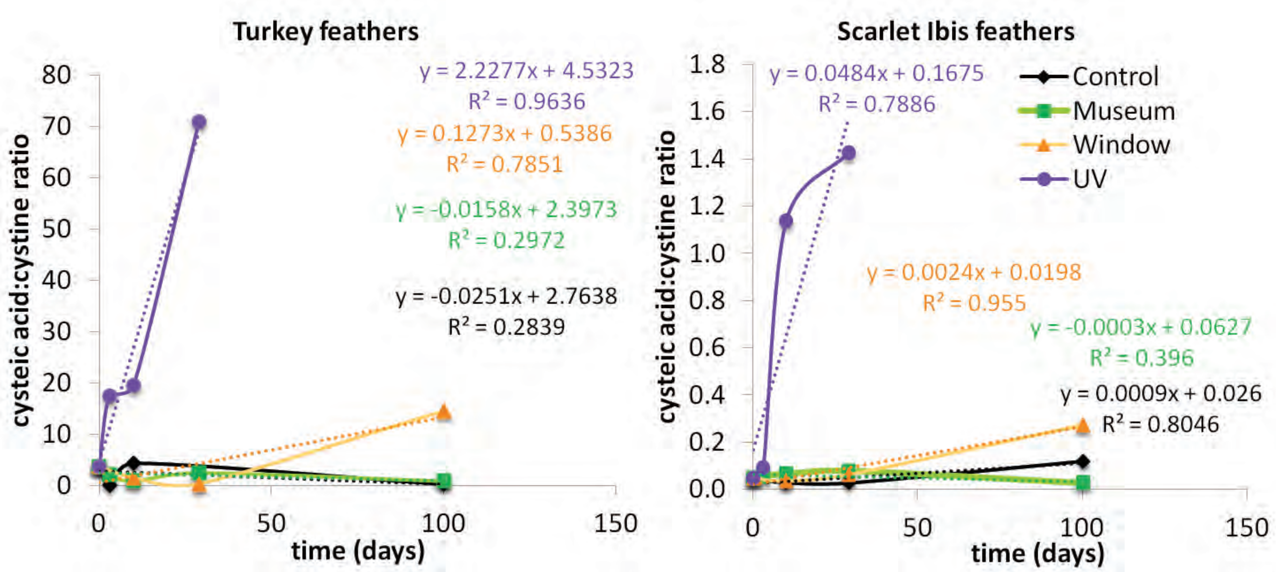

Fig. 17. Ratios of cystine to cysteic acid measured using GC/MS versus log time for aged turkey feathers (left) and Scarlet ibis feathers (right) and their unaged controls (Courtesy of Melissa Hughs)

FTIR results, we focused our analysis on cystine and its photo-oxidation product cysteic acid. Qualitative measurement of amino acid profiles was performed on all pre- and post- accelerated light-aged feathers except those exposed to UVA for 100 days and consequently too damaged, to determine whether fluorescence could be correlated with measurable changes in amino acids.

The amino acids were hydrolyzed by heating in hydrochloric acid under nitrogen and subsequently functionalized with trimethylsilyl groups before injecting into the GC/MS, as reported by (Shahrokhi and Gehrke 1968). Figure 17 shows the change in the cysteic acid to cystine ratio over time. Corroborating the results shown by XPS and FTIR, the cysteic acid content of UVA-aged feathers increases dramatically with time.

It is also intriguing that the cysteic acid to cystine ratio of turkey feathers is almost two orders of magnitude higher than that for scarlet ibis feathers over most of the samples; again, this is probably the legacy of the peroxide wash given to the turkey feathers by the vendor. A trend of an increasing cysteic acid to cystine ratio over time was observed for both UVA and window-aged feathers. After 100 days of window aging, the cysteic acid to cystine ratio is 5 times higher than the average among unaged scarlet ibis feathers and 7 times higher than the average among unaged turkey feathers. For UVA-aged feathers, the results were more dramatic and after only 29 days the cysteic acid to cystine ratio was 26 times higher than unaged ibis feathers and 36 times higher than unaged turkey feathers. Feathers aged under UVA for 100 days suffered disintegration and could not be analyzed.

6. DISCUSSION

6.1 DISCUSSION OF ANALYTICAL RESULTS

A variety of analytical methods were applied to understand the chemical changes caused by different lighting doses on feather keratin with and without carotenoid pigmentation. Color measurement using reflectance spectroscopy presents challenges for measuring the same location and maintaining the feather structure for measurement before and after aging. Analytical methods including FTIR and XPS were found to be capable of detecting dose related molecular changes following exposure of feathers to UVA radiation. In the case of pigment extraction, once results were adjusted to account for variable pigment distribution within each feather, changes in pigment concentrations were reliable indicators of increased lighting damage for carotenoid pigmented scarlet ibis feathers. GC/MS found increased ratios of the photo-oxidation product cysteic acid to unhydrolysed cystine, which correlated to increasing exposure to unfiltered UV. The reasons why FTIR, XPS, and GC/MS were not sensitive to changes in feathers aged under museum lighting is being further explored; those techniques may not be sensitive enough to detect light-induced changes from sources without UV.

UVIVF assessment proved to be the most sensitive method for detecting changes associated with light dose, even when no changes were detectable under diffused visible light. Fluorescence changes are evident after a short exposure of three days of UV-filtered museum lighting, as fluorescent behavior changes toward darker blue-violet in white feathers may be correlated with light dose. Inclusion of UVA in the light source produces an accelerated yellowing, detectable as a fluorescence shift in feather keratin compared to blue fluorescence changes of feathers exposed to UV-filtered museum lighting. In the case of carotenoid pigmented feathers, a shift toward less fluorescence and toward blue-violet is detectable, which increases with time under the same light dose. Irradiation with a UVA source produces color loss that is perceptible in scarlet ibis feathers after 10 days under visible light, and fluorescence changes toward bluer or darker, supporting the reduction in biopigments found in the pigment change evaluation. Window aging after 29 days shows further fluorescence changes, and irradiation with a UVA source continues to show both color loss under visible light as well as a shift toward yellow fluorescence.

7. EXAMINING MUSEUM FEATHERWORK

Examining museum featherwork for evidence of fading presents challenges because of the varying sensitivity of biopigments and structural colorants, the complex nature of feather color production, and the typical lack of historical data about lifecycle, cultural, and exhibition use (Pearlstein et al. 2012). Estimating original feather color is difficult because of the pronounced variability within and between feathers of the same species. Dorsal and ventral sides of feathers often differ in coloration, and feather structures permit the passage of light through the vane, which taken together may eliminate options for comparing front and back sides for estimating the impact of lighting on feather coloration (Riedler et al. 2014). Recognition of the value of documenting type and duration of museum lighting as part of a preventive strategy did not develop until the 1970s and 1980s, and such records generally represent only a fraction of the overall exposure, omitting dosages accumulated during cultural use and private display.

Museum featherwork, some with records of estimated display, were examined using UVIVF both to document psittacofulvin-pigmented feathers expected to display fluorescence, and to compare non-psittacofulvin-pigmented feathers with accelerated-aged feather samples. Results of accelerated aging revealed UVIVF to be particularly sensitive to the development of a blue fluorescence on pure white structural feathers, and a purple shift or darkened fluorescence on carotenoid pigmented feathers. Both feather types experienced visible color loss and yellowing upon exposure to UV irradiation, and in these instances color loss was more pronounced under UVIVF. Museum examples were, therefore, examined for the presence of reported fluorescence changes, including a blue fluorescence on more exposed regions, or for color loss and corresponding yellow fluorescence under UVIVF.

An example of psittacofulvin fluorescence was found in a full wing from an orange-winged amazon (*Amazona amazonica*) in a private collection. Yellow fluorescence corresponds to ventral regions of the feathers where the concentration of yellow pigment is greatest. From the Natural History Museum in Vienna, a rainbow lorikeet (*Trichoglossus haematodus*) (fig. 18a) INV # 49847 displays yellow fluorescence corresponding to the bright yellow regions of the chest and tail. For comparison, the same bird is shown under visible light in figure 18b.

As both the orange-winged amazon and the rainbow lorikeet examples are drawn from study collections, and are not mounted for taxidermy, dark storage during museum lifespans is estimated.

Fig. 18. (a) UVIVF image of a rainbow lorikeet (*Trichoglossus haematodus*), Natural History Museum in Vienna (INV # 49847) (Courtesy of Renée Riedler); 18 (b) Visible light image of a rainbow lorikeet (*Trichoglossus haematodus*), Natural History Museum in Vienna (INV # 49847) (Courtesy of Renée Riedler)

7.1 EXAMINATION OF FEATHERWORK WITH DOCUMENTED AND UNDOCUMENTED DISPLAY HISTORIES

Feathers with display histories were examined in museum collections including the Los Angeles County Museum of Natural History (LANHM), the British Museum (BM), and the Hibulb Museum and Cultural Center in Tulalip, WA (HCC). An American Indian Hupa/Hoopa Dance cap from California accessioned into the collections of LANHM in 1932, A.2749.32-95 with great horned owl (Bubo virginianus) feathers and red-shafted flicker wing feathers, has been documented as being on display in internally lit cases with unfiltered fluorescent lights in the Native American Hall between 1992 and 2006 (Kajeian 2013) (figs.19, 20).

Fig. 19. Detail of a feathered Hupa/Hoopa Dance cap from California LANHM (A.2749.32-95), ea. 1900s, hide, feathers, cordage, 27 (h) × 60 (l) × 39 cm (w) (Courtesy of Ellen Pearlstein)

Fig. 20. Detail of a feathered Hupa/Hoopa Dance cap from California LANHM (A.2749.32-95) (Courtesy of Ellen Pearlstein)

Not surprisingly, porphyrin fluorescence is not observed on the owl feathers, and the carotenoid pigmented flicker feathers appear more purple than red (fig. 21).

Also at LANHM, a Pomo feathered basket from California was accessioned in 1914 (FA 2458.83-247) and displayed in ca. 1945, again in 1973, and in the Native American Hall from

Fig. 21. UVIVF image of detail of great horned owl (Bubo virginianus) feathers of Hupa/Hoopa Dance cap from California LANHM (A.2749.32-95) in figures 19 and 20, (Courtesy of Ellen Pearlstein)

Fig. 22. Detail of the brow band and red- and yellow-shafted flicker feathers (*Colaptes auratus cafer* and *Colaptes auratus*) on a Nez Perce headdress, BM (Am.9064) (Courtesy of Ellen Pearlstein)

1992–2006 in internally lit cases with unfiltered fluorescent bulbs (Kajeian 2013). The basket is covered with what are estimated to be red pileated woodpecker scalp feathers, alternating with pale yellow feathers, with dark borders of mallard duck feathers and California quail topknot feathers. Pileated woodpecker feathers are pigmented with carotenoid pigments (McGraw 2006). The red feathers on the three sides of this basket are not visually different under diffused light however under UVIVF one side displays a markedly yellow appearance and the same feathers on other two sides display a reddish purple fluorescence. A similar phenomenon is apparent with red feathers on Pomo basket FA 2458.83-180, which is also documented as having the same 14-year display. A headdress acquired in 1874 by the BM (Am.9064) estimated to be Nez Perce from the Idaho and Montana Plateau has magpie and eagle feathers and what appears to be red- and yellow-shafted flicker feathers on the brow band (fig. 22). Color loss is suspected for these red and yellow feathers based on the contrast with other samples, but color loss appears more pronounced under UVIVF where a pale yellow appearance is visible (fig. 23).

Results of accelerated aging of scarlet ibis feathers suggest that the yellow appearance of feathers may be indicative of greater UV exposure than the same feathers unexposed to UV, which retain a reddish-purple fluorescence.

Featherwork in museums was examined by adjusting overlapping feathers to detect variation in UVIVF, where increased blue fluorescence corresponds to areas of increased exposure. Two examples

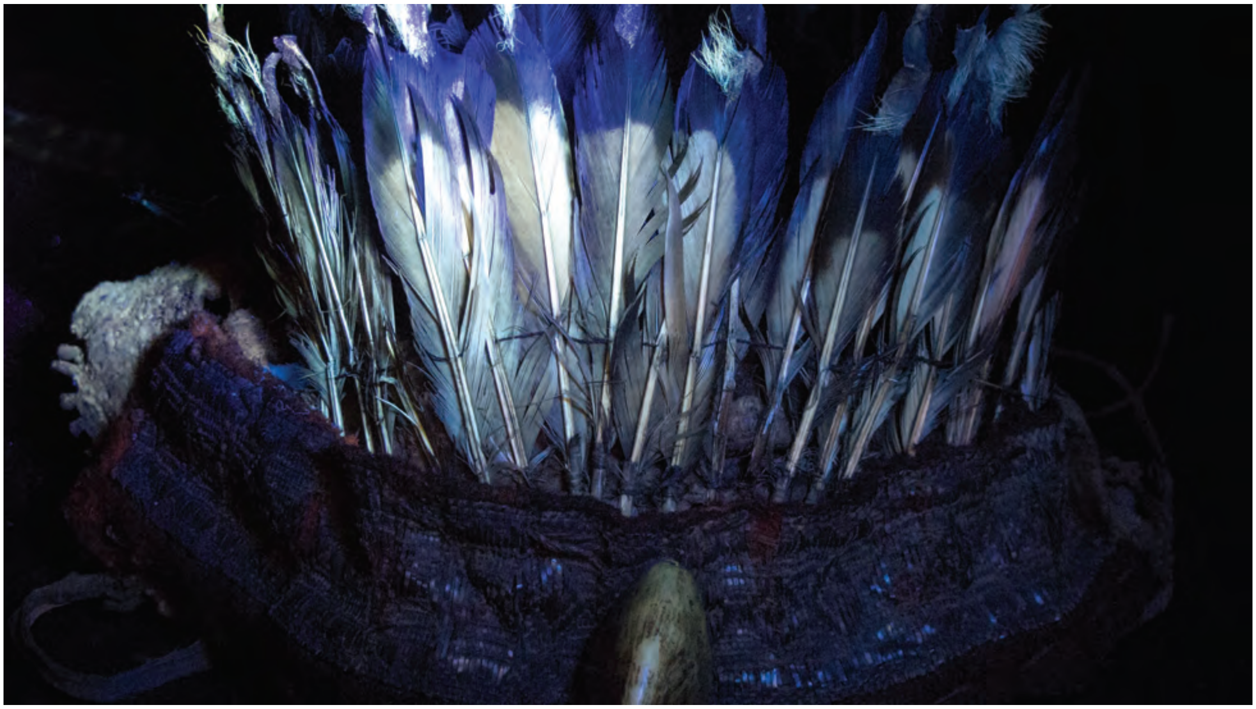

Fig. 23. UVIVF image of detail of headdress shown in figure 22, BM (Am.9064) (Courtesy of Ellen Pearlstein)

include white feathers with melanin coloration. An Ojibwe eagle feather fan (1970.09.4) (fig. 24) acquired by the British Museum in 1970 was displayed between1999 and 2011 under 50 lux, excluding daylight (Davy 2013). A detail image was taken with overlapping eagle feathers moved aside to reveal differences between light protected, fluorescing feathers and blue fluorescing exposed edges (fig. 25). Similar evidence is visible in a war bonnet in the Hibulb Cultural Center made from turkey feathers (identified by the fine parallel striations on the shaft) (Trail 2003),where light exposed edges fluoresce blue while concealed feathers maintain a white fluorescence.

Fig. 24. Ojibwe eagle feather fan, BM (1970.09.4) 38.3 (l) × 13 cm (w) (Courtesy of Ellen Pearlstein)

Fig. 25. UVIVF image of eagle feather fan in figure 24, with feathers moved to show contrast in appearance (Courtesy of Ellen Pearlstein)

The Ojibwe feathered headdress in figure 26 (AM 1982.Q. 801) was donated in 1893 to the British Museum, with documented display from 1982 to 1986 at “safe levels” without daylight (Davy 2013). Examined for its characteristic complexity, including multiple types of tail feathers that are possibly duck, heron, and falcon on the basis of color, size, and origin, UVIVF illustrates the correlation between purple fluorescing feathers tips and regions likeliest to have received illumination (fig. 27). UVIVF also aids in distinguishing between feathers.

Fig. 26. Ojibwe feathered headdress (AM 1982.Q. 801) (Courtesy of Ellen Pearlstein)

Fig. 27. UVIVF image of Ojibwe feathered headdress in figure 26 (AM 1982.Q. 801) (Courtesy of Ellen Pearlstein)

7.2 NEED TO STANDARDIZE FLUORESCENCE PARAMETERS

The application of UVIVF as an analytical method within conservation that uses a standard and repeatable workflow has only recently been developed (Dyer et al. 2013; McGlinchey Sexton et al. 2014). Fluorescence examination of feathers must be used with caution, as adventitious matter may contribute to fluorescence. Pohland and Mullen (2006) report on a study of the fluorescence of 20,000 museum bird study skins, where they found that museum-applied "preservation agents" contributed to fluorescence in 2% of the examples. The current authors acknowledge the variation produced by fluorescence detection applied to collection items of different size and under different lighting conditions, as well as the variations possible through the use of different cameras, filters, and lamps with different peak wavelengths, spectral densities and angles of emission. Examination of single feathers such as those subject to accelerated aging allows for a more uniform setup than does the examination of complex three-dimensional objects of varying size in a less controlled environment. The current authors suggest that the UVIVF assessment method is most successful when variation can be detected within a single feather, or within groups of related feathers within the same item, and also recommend comparison with feathers aged under controlled conditions such as presented in this article.

8. CONCLUSIONS

The present study demonstrates how examination of featherwork by UV-induced fluorescence may convey information about feather type and past lighting exposure. Observations by bird biologists of UVIVF in yellow, green, and some blue feathers with psittacofulvin pigments, sometimes in combination with structural color, in feathers of culturally significant birds such as parrots, macaws, cockatoos, and lorikeets are introduced to a conservation audience as a diagnostic aid. Fugitive fluorescence of porphyrins found in owl feathers and circumstances necessary to detect this fluorescence are described. UV fluorescence as a marker of photochemical change in feathers is research in progress, but is introduced as a tool for a preventive conservation strategy.

The results of the application of UVIVF assessment as an analytical tool supported by results of destructive chemical analysis of featherwork are reported. Results of analysis indicate that even limited exposure to UV irradiation in the feather's cultural lifecycle and in museums results in chemical alteration of feather keratin, with long term accelerated exposures producing dramatic damage in the form of yellowing and embrittlement to both turkey and scarlet ibis feathers. Because feathers are molted periodically on the bird, culturally preserved featherwork requires a different strategy for preservation than is found in nature. In the case of turkey and Scarlet ibis feathers exposed to UVA, changes detected in UVIVF may be correlated with chemical photolysis measured using FTIR and GC/MS, and with changes in total pigment concentration in scarlet ibis feathers. Museum lighting with UV filtration also cause changes detectable in UVIVF, suggesting either different photochemical changes, or changes too small to be detected by analytical methods used. Current work includes carrying out additional amino acid and peptide analysis to determine whether fluorophors produced through visible light reactions in wool keratin, i.e., increased cysteic acid and tryptophan, also occur in feathers. Because preventive conservation strategies are often based on a total cumulative radiant exposure that is difficult to reconstruct, the authors are proposing the examination of featherwork with UVIVF as an assessment tool. Increased use of this examination strategy will aid in further refinements in fluorescence interpretation.

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SOURCES OF MATERIALS

Turkey Feathers
SmileyMe
Arapahoe, NC 28510
www.smileyme.com

ELLENPEARLSTEIN is an associate professor at the University of California, Los Angeles, in Information Studies and is a founding faculty member in the UCLA/Getty Program in Archaeological and Ethnographic Conservation. Her research interests include American Indian tribal museums and how museum staff defines cultural preservation; effects of environmental agents on ethnographic and natural history materials; introducing context into cultural materials' conservation education; and curriculum development. She is co-director of the UCLA and Getty Conservation Institute feather research project and a Fellow of the AIC. Address: Information Studies and UCLA/Getty Master's Program in Archaeological and Ethnographic Conservation, A410 Fowler, Los Angeles, CA 90095. E-mail: epearl@ucla.edu

MELISSAHUGHS is a doctoral student in the Department of Chemistry at UCLA; she works on the design and synthesis of crystalline molecular gyroscopes and studies the photodecarbonylation of dicumyl ketone derivatives. She earned a BS in chemistry in 2006 from Cal Poly Pomona where she worked on the synthesis of amino acid derived liquid crystal twisting agents. Address: 650 N 300 W #240, Salt Lake City, UT 84103. E-mail: mlhughs@gmail.com

JOY MAZUREK has worked at the Getty Conservation Institute, Los Angeles, as an assistant scientist in the Organic Materials Research Laboratory since 1998. She specializes in the identification of binding media and modern materials by gas chromatography/mass spectrometry. She received her BS in biology from University of California, Davis, and her MS in biology from California State University, Northridge. Address: The Getty Conservation Institute, 1200 Getty Center Drive, Suite 700, Los Angeles, Ca 91106. E-mail: jmazurek@getty.edu

KEVIN McGRAW is professor of Evolutionary and Systems Biology and director of Undergraduate Research in the School of Life Sciences at Arizona State University. His research program centers on the control, function, and evolution of exaggerated traits in animals, especially the bold colors of birds. More recently, his work has extended into studying human impacts on wildlife health. Address: School of Life Sciences, Arizona State University,Tempe, AZ 85287-4501. E-mail: kevin.mcgraw@asu.edu

CHRISTELPESME received a BA in biochemistry from the University of Paris 6-Pierre et Marie Curie, an MA in art history and an MA in paper conservation, both from the University of Paris 1-Pantheon Sorbonne (France). She worked part time with Jim Druzik as an assistant scientist at the Getty Conservation Institute, Los Angeles, and part time as a paper conservator, and is presently working in Europe as a paper conservator, Microfading Testing provider, and teacher on museum lighting. Address: Mittlere Strasse 105, Basel 4056- Switzerland. E-mail: Christel.pesme@gmail.com

RENÉERIEDLER received an MA in philology and art history from the University of Vienna and an MA from the Academy of Fine Arts in Conservation and Restoration. As postgraduate intern and consultant she was researching full time for the collaborative UCLA-GCI feather research project. She is currently a conservator at the Weltmuseum Wien. Address: 1010 Wien, Neue Burg, Vienna, Austria. E-mail: renee.riedler@weltmuseumwien.at

MOLLY GLEESON received a BA in art conservation from the University of Delaware and an MA from the UCLA/Getty Master's Program in the Conservation of Archaeological and Ethnographic Materials. She served as a research associate on the UCLA-GCI feather research project and is presently the Rockwell Project conservator at the Penn Museum, Philadelphia. Address: Penn Museum, 3260 South Street, Philadelphia, PA 19104. E-mail: mollygleeson@gmail.com

COPING WITH ARSENIC-BASED PESTICIDES ON TEXTILE COLLECTIONS

JAE R. ANDERSON, NANCY ODEGAARD, MARTINA DAWLEY, DELANA JOY FARLEY, WERNER ZIMMT

ABSTRACT

This article discusses the development of a protocol for testing and removing arsenic pesticide residues from textiles. This research was conducted by a team at the Arizona State Museum Conservation Laboratory and with funding from a National Center for Preservation Training and Technology (NCPTT) grant that partially supported the purchase of equipment, supplies, and a stipend for a graduate student assistant. A procedure for the survey of toxic metal pesticides on textiles and a methodology for a treatment to remove arsenic-based pesticides from textiles were created.

The project included the following activities.

- Scholars of Navajo (Dinè) textiles and Navajo weavers were consulted as the project was developed.
- The entire collection of Navajo textiles was surveyed with a portable x-ray fluorescence instrument (pXRF). A protocol for the testing procedure was developed to make this task both (1) efficient in sometimes difficult storage access conditions and (2) useful for the development of an arsenic removal method.
- A protocol for arsenic removal was based on testing of a series of arsenic-treated samples (doses based on typical amounts found during the survey on ASM collections). The samples were pXRF tested before and after variations in washing technique including time, temperature, pH, and agitation. Wash water from the samples was also tested for arsenic.
- Three museum textiles were successfully cleaned of arsenic pesticide residues.

1. INTRODUCTION

Traditional conservation care of historic textiles is a tiered system of conservation treatments. No treatment is preferred, considering any degree of handling induces irreversible effects; however, circumstances may require some form of treatment, which should be minimal. Removing arsenic through wet cleaning is highly invasive; nevertheless, the benefit may be necessary to reduce potential health risks for cultural, occupational, or scholarly handling of these contaminated materials.

The removal of arsenic-based pesticides on textile collections is a complex conservation issue. A grant from the National Center for Preservation Training and Technology (MT 2210-11-NC-07) was awarded to the Arizona State Museum (ASM) at the University of Arizona to develop guidelines for the use of portable x-ray florescence spectroscopy (pXRF) instruments for both the survey of pesticide residues on historic textiles and their removal through an aqueous conservation treatment using technically sound methodologies.

The removal process leads to post-wash arsenic solutions, which need to be legally and safely disposed of as nonhazardous arsenic waste, <5 mg/L or <5 parts per million (ppm) (U.S. Environmental Protection Agency 2009). Research into water treatment of arsenic for safe drinking water standards offers various filtration methods, which may be beneficial.

2. BACKGROUND

After a longer history in environmental conservation, the pXRF has become a common and powerful tool in museum conservation. The study described here combined the growing standardization and versatility of pXRF technology with ASM's knowledge and extensive experience in pesticide residue studies. Portable XRF technology has evolved significantly over the past 10 years. Notable manufacture changes include the move from sealed radioactive sources which, depending on the half-life of the source, have varying life-use expectancies, to the use of x-ray tube sources; the ability to detect and differentiate a broader range of elements including light elements; and improved analytical software that allows for batch processing of data. X-ray tube source pXRFs are being used for pesticide surveys; however, new guidelines have not been published, and reporting is inconsistent. NCPTT funding permitted ASM to obtain an up-to-date x-ray tube source pXRF analyzer and to use it to develop survey guidelines on the basis of a documented collection. It has also allowed us to develop guidelines for treatment evaluation on the basis of removal methods developed.

Navajo textiles provided an excellent material type for this case study as they have a uniform format, density, and consistent use of wool yarns. They are secular and distributed throughout the United States in private and institutional collections. They were often treated with pesticides to prevent or arrest insect damage. ASM has over 600 Navajo textiles. These items are well documented and curatorial expertise at ASM is foremost in the world. This project considered the links in pesticide residue type and distribution with other historic details of the collection. This study provided broader information for the ASM collection, and we anticipate there is a potential to predict the presence of pesticide residues in other institutional collections.

3. EXPERIMENTAL METHODOLOGY FOR TEXTILE COLLECTIONS SURVEY

A systematic and efficient approach to conduct a complete survey of the entire collection of Navajo textiles was developed using the handheld x-ray florescence (XRF) spectrometer. The pXRF analyzer was efficient and easy to use in the storage rooms, where textiles of varying sizes are housed in cabinets and shelving units as seen in figure 1.

Fig. 1. Storage of ASM Navajo Textiles (Courtesy of Martina Dawley)

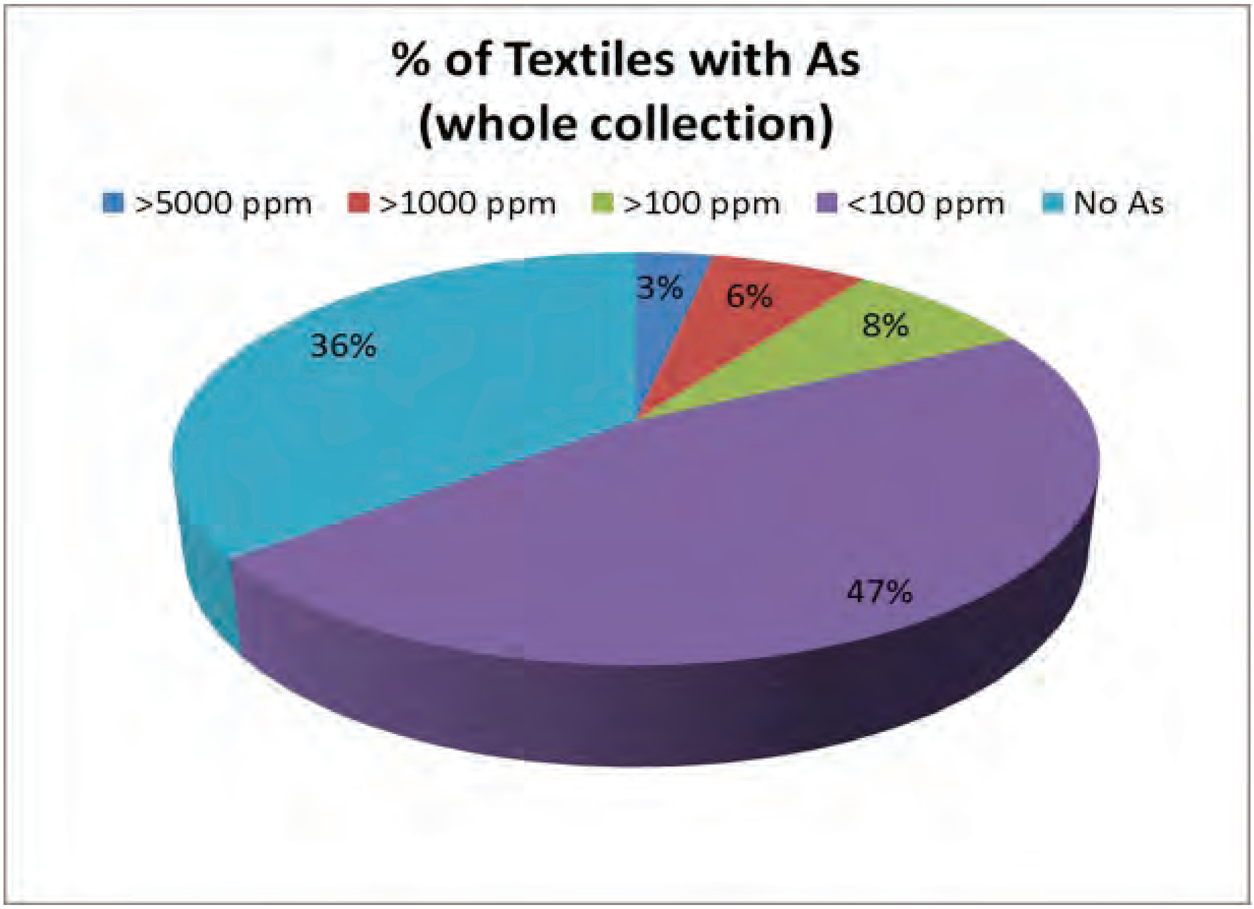

Fig. 2. Percentages of arsenic levels (Courtesy of Martina Dawley)

The Navajo textiles were tested for the presence of toxic metal pesticide residues (As, Zn, Hg, and Pb). Arsenic levels were organized into the following categories: No As, <100 ppm, 100–1000 ppm, 100–5000 ppm, and >5000 ppm as seen in figure 2.

The highest reading was 29,105 ppm. Ultimately, textiles with high levels of arsenic correlated with a particular time period, creating a time line for arsenic-based pesticides used in collections from early museums and private collectors.

3.1 SURVEY PREPARATION

Preparations for the survey included an ASM Navajo Textile Analysis Workshop, which was open to the general public with priority registration given to grant personnel, Friends of ASM Collections, ASM's membership group, and Tucson's Textile Study Group. In addition, University of Arizona's required radiation and chemical lab safety training courses ensured proper safety practices such as personal protective equipment as shown in figure 3.

Additional research was conducted in areas of arsenic in museums, arsenic in the natural environment (ground and water), safety precautions on how to handle toxic materials, care and handling of Navajo textiles, and Navajo textile makers, collectors, and trading posts. The research constructed a time line of arsenic use in collections from early museums and private collectors up to the mid-1900s as seen in figure 4. This time line helped determine which textiles were most likely to be contaminated.

Fig. 3. Personal protective equipment worn while conducting pXRF testing on textiles (Courtesy of Gina Watkinson)

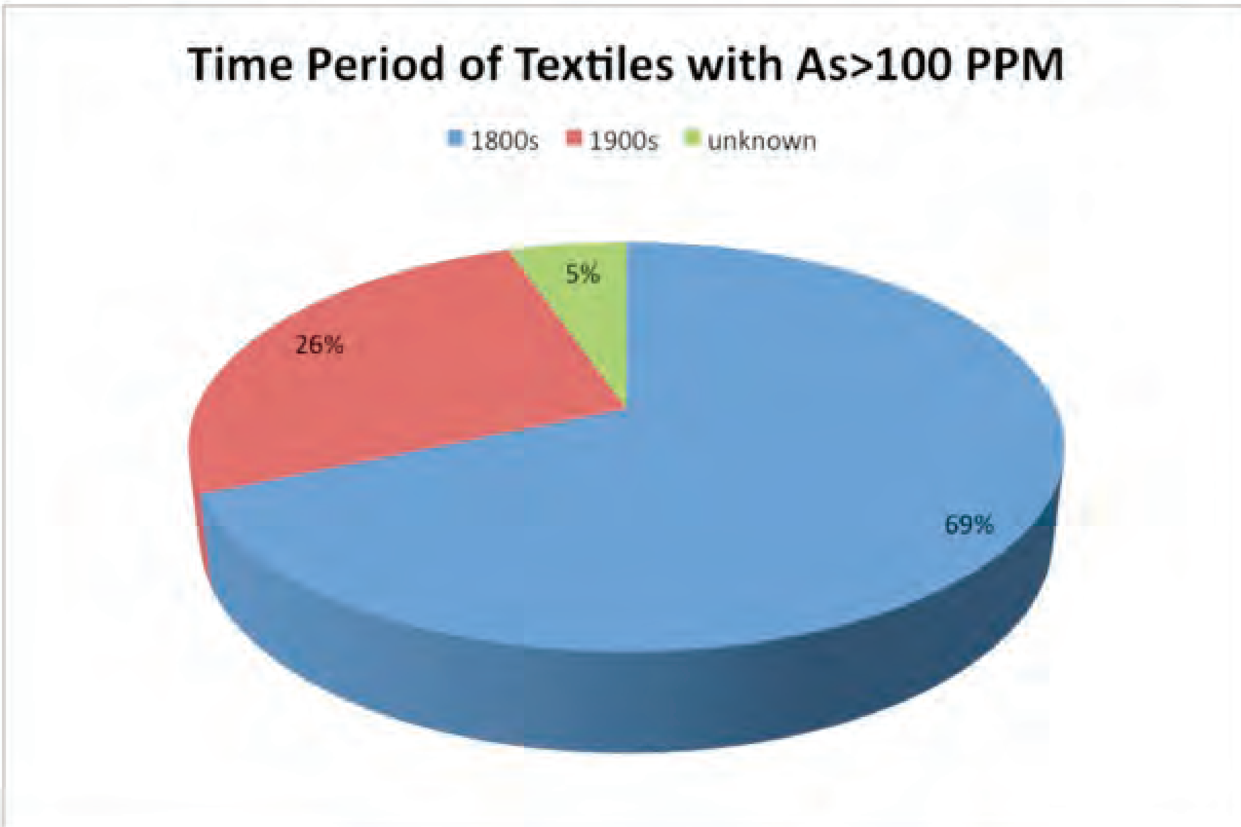

Fig. 4. Arsenic use in ASM collections based on date (Courtesy of Martina Dawley)

3.1.1 Goal Set for Survey

A list of goals to conduct the survey was as follows:

1) test all Navajo rugs for pesticides (As, Zn, Hg, and Pb);
2) create Excel spreadsheet to compile data;
3) organize by highest readings of arsenic;
4) consider size of rug for pesticide removal to fit lab sink;
5) find the highest occurrence of arsenic by collector and organize by region, location of highest occurrence, organize by time period of highest occurrence;
6) organize into schematic of very high to very low arsenic levels.

3.2 PROTOCOL DEVELOPMENT FOR THE SURVEY

The methodology for this project included use of an instrument log sheet, and after each day of testing, data were downloaded onto a computer and stored. The testing procedure evolved somewhat over time. Each textile was laid out flat as shown in figure 5, and a printed photo was used to record the exact area tested.

The catalog label was used to determine the orientation of the test areas on the textile. Label side was recorded as *recto label* and the reverse as *verso label*. The area tested started with the label side up. The first reading was done directly above or below the label (depending on how the label is oriented). This procedure was used for the first 50 textiles resulting in 5 to 10 readings taken on the recto and verso for each textile. Preliminary data from this group showed that if a textile has less than 100 ppm of arsenic from the first reading, then the textile will most likely have subsequent readings below 100 ppm.

Fig. 5. Textile laid flat for pXRF testing (Courtesy of Martina Dawley)

Likewise, if the first pXRF reading contained more than 100 ppm of arsenic then the textile will most likely have subsequent readings above 100 ppm.

After the first 50 textiles were tested, the protocol was modified. Each rolled textile was first read directly above or below its catalog label. If the pXRF reading was above 100 ppm then the textile was unrolled and tested in two to three more random areas recto and verso the label. If large textiles were over 100 ppm, they were partially unrolled and read once more verso the label.

4. EXPERIMENTAL METHODOLOGY FOR WET CLEANING

Developing a wet treatment procedure to remove arsenic, a toxic substance, from a textile requires a systematic approach in a controlled environment to ensure the safety of individuals and objects. The approach first observed the properties of test materials with deionized water to determine the best technique to efficiently fabricate arsenic test samples. The process then proceeded to pXRF instrument calibration of cotton and wool arsenic test samples. Arsenic test samples correlated with common arsenic levels from the Navajo textile survey. Traditional textile conservation wet cleaning variables were considered in the testing of conditional effects relating to time, temperature, agitation, and pH. Each conditional effect used the same concentration of arsenic, which related to arsenic levels on potential Navajo textile candidates. Supplementary analysis examined the post-wash water for arsenic.

4.1 TEST SAMPLE PREPARATION

Initial test samples consisted of unbleached cotton interlock knit and wool jersey knit (55 mm diameter) with a dry mass of approximately 0.4 g. The selected fabrics were acquired from a previous textile study and appropriately reflected fibers associated with Navajo textiles. The wetting properties of the fabrics and application techniques were evaluated with de-ionized water to devise a method to produce homogenous arsenic test samples. Preparation of samples included a progression of application techniques that started with a dropper, transitioned to more traditional pesticide treatment methods such as spraying, and ended with a dipping process.

The hydrophobic effects of each fabric prevented ideal homogenous arsenic test samples. A drop of Triton X-100, a nonionic surfactant, was added to approximately 400 mL of deionized water with a glass micropipette, which improved wetting properties of both fabrics. Wetting of the wool test sample resulted in a curling effect when saturated with deionized water, causing nonhomogenous dry arsenic samples. The wool test sample was substituted with a thicker undyed handwoven Chimayo wool fabric, which also directly correlated with historic Navajo textiles. Homogeneous absorption was visually confirmed by adding dark food coloring such as green or blue to the solution as shown in figure 6.

4.2 ARSENIC TEST SOLUTIONS

Arsenic is a chemical element, atomic number 33, derived from natural and anthropic sources, which presents worldwide environmental and health concerns. The element exists naturally as organic or inorganic compounds, with the inorganic form considered more abundant and toxic. Arsenite (As[III])

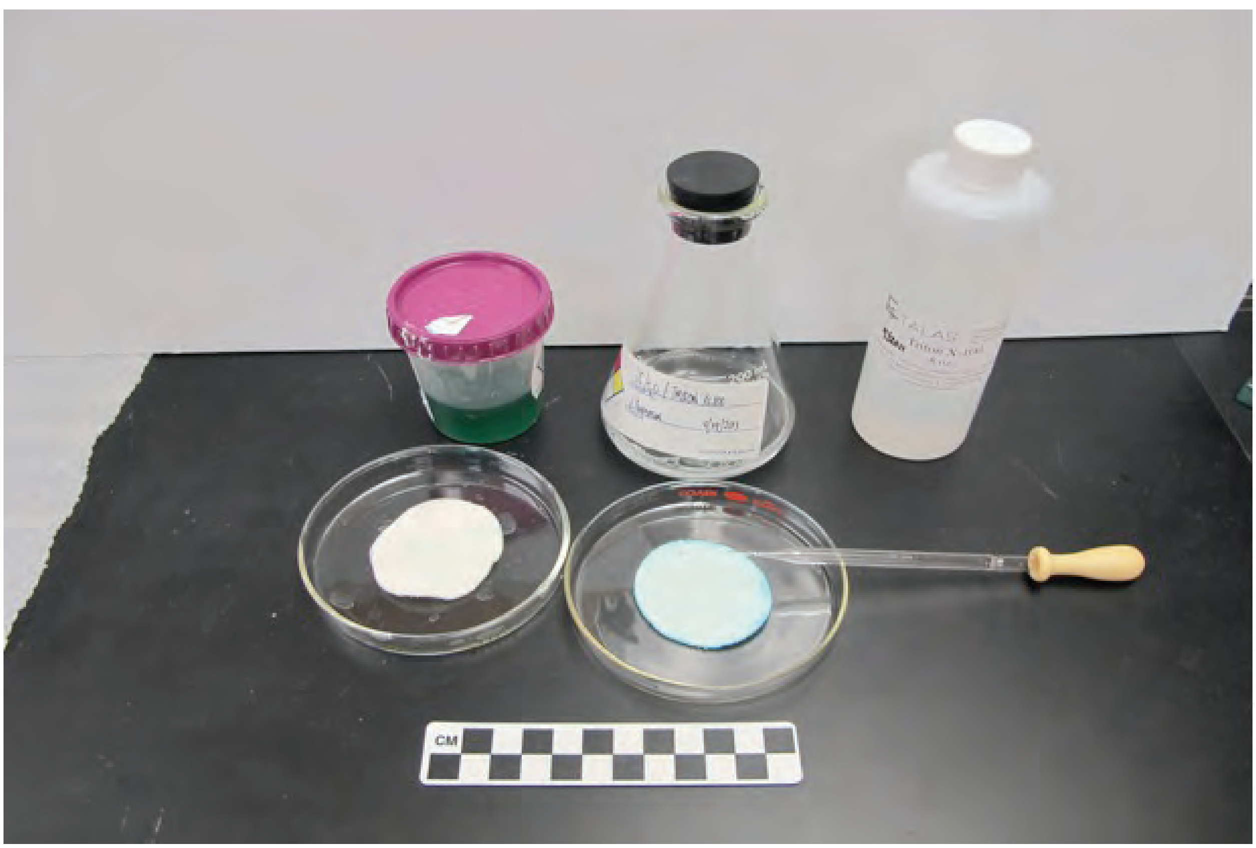

Fig. 6. Homogeneous absorption into cotton sample: deionized water, Triton X-100, and McCormack food coloring (Courtesy of Jae R. Anderson)

and arsenate (As[V]) are two species of inorganic arsenic compounds, with As[III] specified to be 25–60 times more toxic than As[V] (Vasudevan et al. 2012). Arsenous acid (As_2O_3) and sodium arsenite ($NaAsO_2$) were primarily used as traditional preservation pesticide treatments on artifacts by museums and collectors (Odegaard et al. 2005).

Arsenic test solutions were created using sodium meta-arsenite ($NaAsO_2$), deionized water, and Triton X-100. Approximately 400 mL of deionized water was pretreated using a glass micropipette to add a drop of Triton X-100. A measured amount of sodium arsenite was dissolved into the deionized water and surfactant solution to generate a 100 mL arsenic solution with a concentration of 10,000 ppm. Five 50 mL arsenic solutions were prepared by diluting 10,000 ppm to produce concentrations of 5000 ppm, 2500 ppm, 1000 ppm, 500 ppm, and 100 ppm.

4.3 HANDHELD PXRF CALIBRATION

A pXRF arsenite calibration curve was constructed for both cotton and Chimayo wool textile as seen in figures 7 and 8. A total of 15 wool samples were contaminated with known arsenic concentrations. A concentration set consisted of three wool samples immersed in one of five prepared arsenic solutions: 5,000 ppm, 2,500 ppm, 1,000 ppm, 500 ppm, or 100 ppm. Each contaminated wool sample was pXRF tested wet and dry, in five different areas to ensure uniformity and quality of concentration. Each pXRF reading was conducted in the manufacturer's "soil" mode for a period of 90 seconds with beam settings at 40 kV for 60 seconds and 15 kV for 30 seconds. This generated a total of 150 measured pXRF wool readings partitioned into five controlled concentration sets. The process was repeated with 15 samples of cotton.

The detection of arsenic on dry Chimayo wool nearly doubled from wet samples. A quick study doubling the thickness of a thinner dry cotton sample by folding it in half and pXRF testing nearly

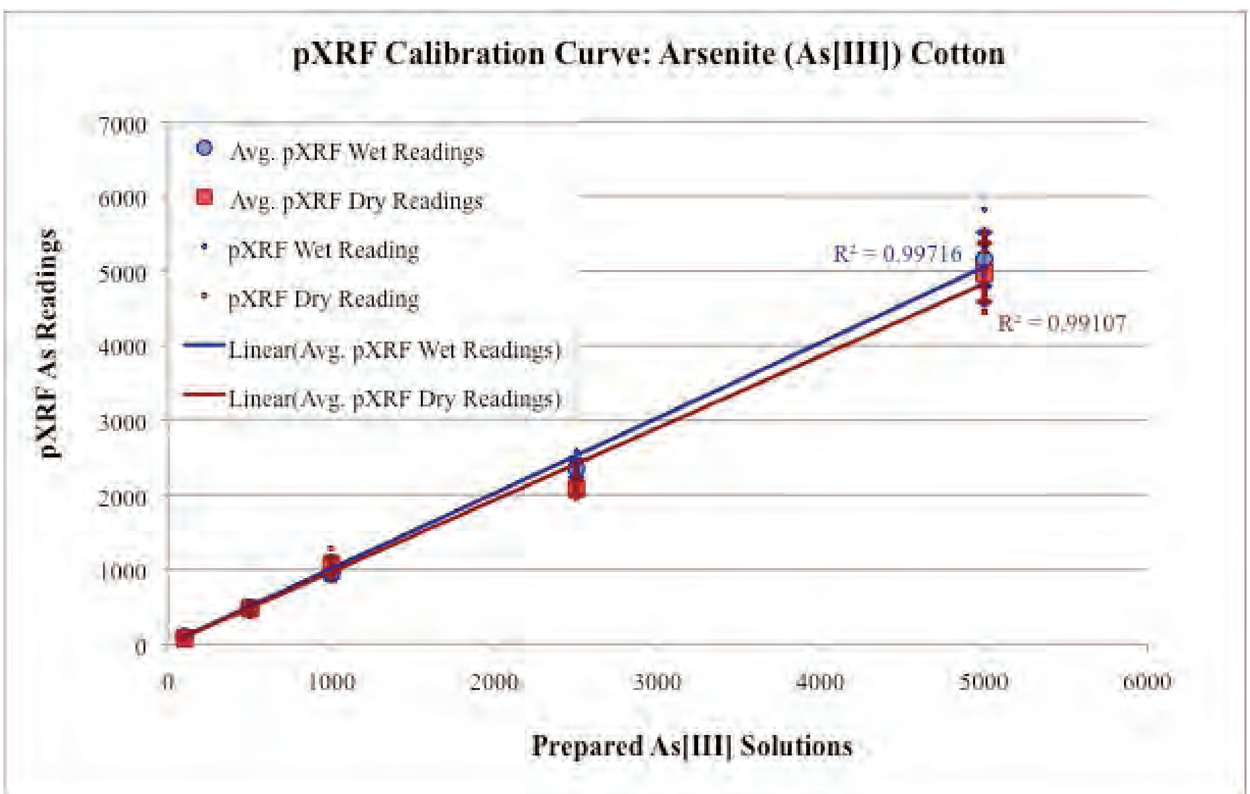

Fig. 7. pXRF cotton calibration curve (Courtesy of Jae R. Anderson)

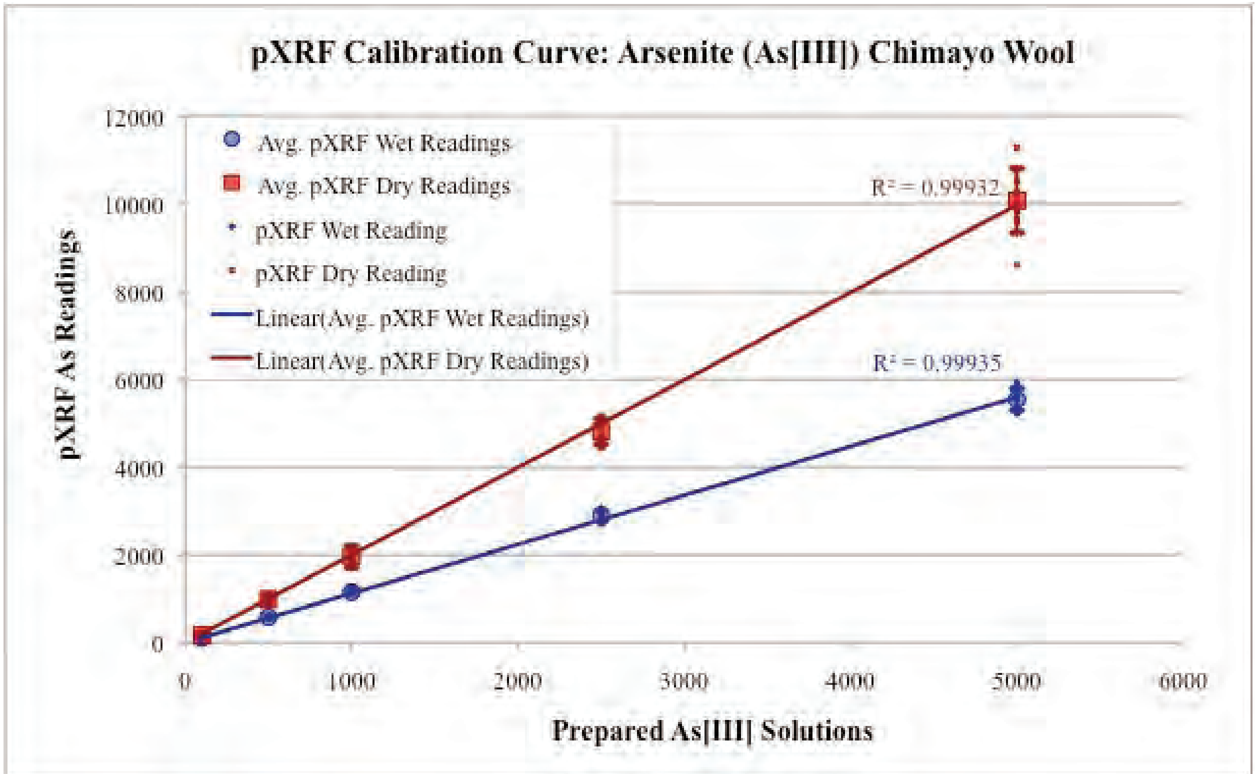

Fig. 8. pXRF Chimayo wool calibration curve (Courtesy of Jae R. Anderson)

doubled the detection of arsenic. The calibration curves display corresponding detection levels of arsenic on wet samples regardless of thickness or fiber; thus, the thickness of a dry fabric sample is significant in the detection of arsenic, which is likely due to efflorescence, but is a topic for further investigation. The conditional effects for removing arsenic from cotton are also a topic for further research.

4.4 CONDITIONAL EFFECTS

Conditional effects were based on variables in traditional textile conservation wet cleaning practice. Time, temperature, agitation, and pH were investigated in the removal process of arsenic from Chimayo wool textiles. Each investigation utilized a 2-L Tupperware Square Pick-A-Deli Container with a measured volume of deionized water (200 mL or 400 mL), and 1000 ppm arsenic samples. Two lift-up strainers of different dimensions assisted in retaining a fixed sample position during deionized water submersion and extraction as seen in figure 9. Samples were extracted from deionized water and immediately wet tested with the pXRF instrument on a nonabsorbent glass surface, then retested on the same glass surface after being air-dried.

4.4.1 Time

The investigation of time was considered the most straightforward test since temperature (23°C), agitation (none), and pH level (~7.0) were all held constant. Published research established a minimum and maximum range of time for a textile to be in an aqueous solution (Rice 1972; Cross 2007). A total of 15 wool samples were divided into five sets of three samples. Each sample set was immersed in 200 mL of deionized water at a respective time interval of 1, 5, 10, 15, or 20 minutes. Samples were pXRF tested wet and dry, and results plotted as seen in figure 10.

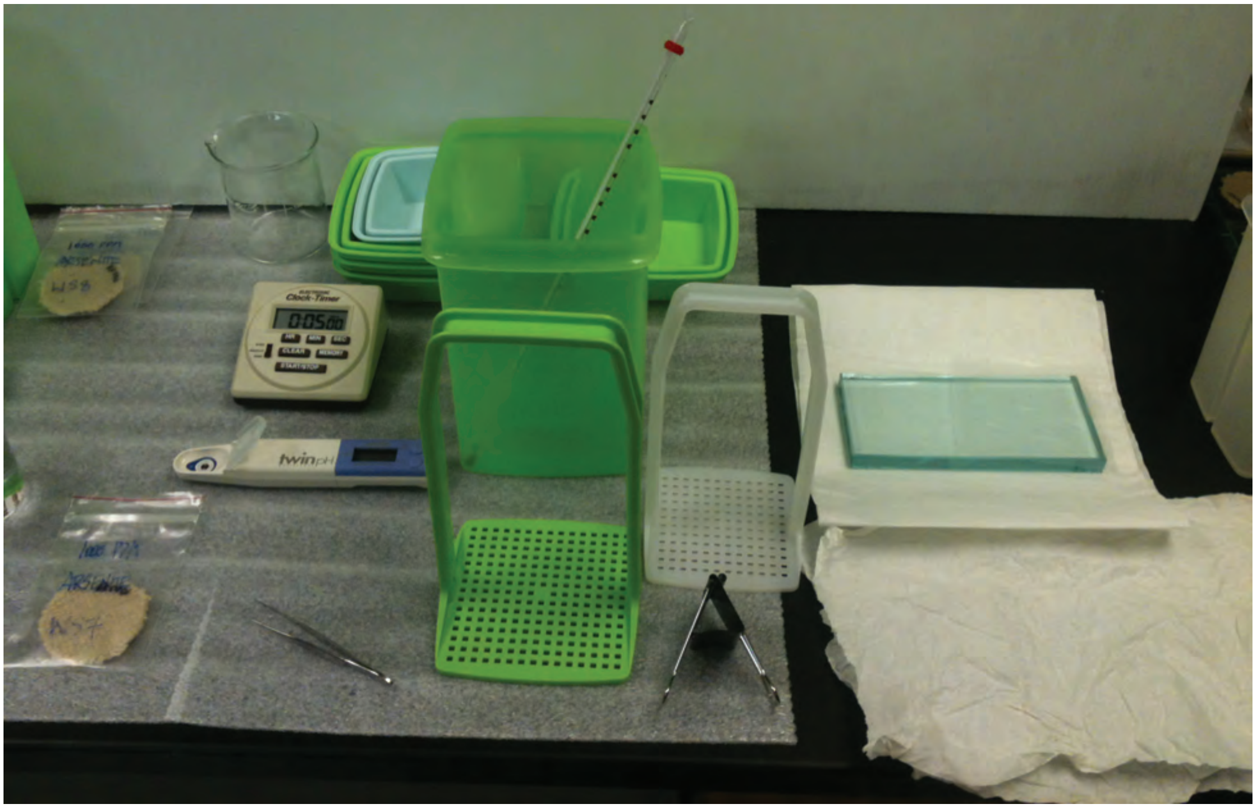

Fig. 9. Conditional effects testing setup (Courtesy of Jae R. Anderson)

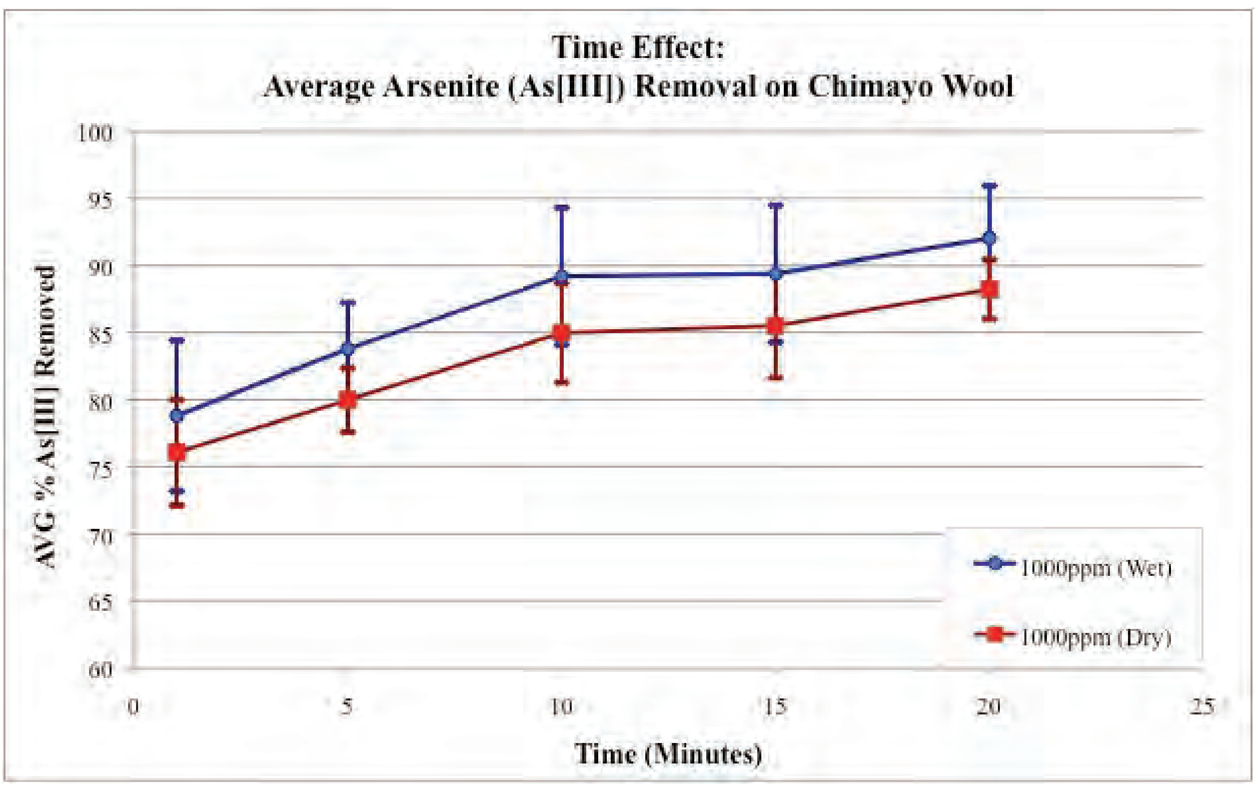

Fig. 10. Effects of time (Courtesy of Jae R. Anderson)

4.4.2 Temperature

The effects of temperature were evaluated with time (15 minutes), agitation (none), and pH (~7.0) held constant. Published research established an upper temperature limit to minimize potential structural damage of the wool (Rice 1972).

A bench top combined stirrer and hot plate were employed to slowly increase the temperature of the water to 30°C and 40°C. The Tupperware container was filled with 200 mL of deionized water and placed into a larger pool of water to maintain the desired temperature for duration of the test as seen in figure 11.

Fig. 11. Temperature test setup (Courtesy of Jae R. Anderson)

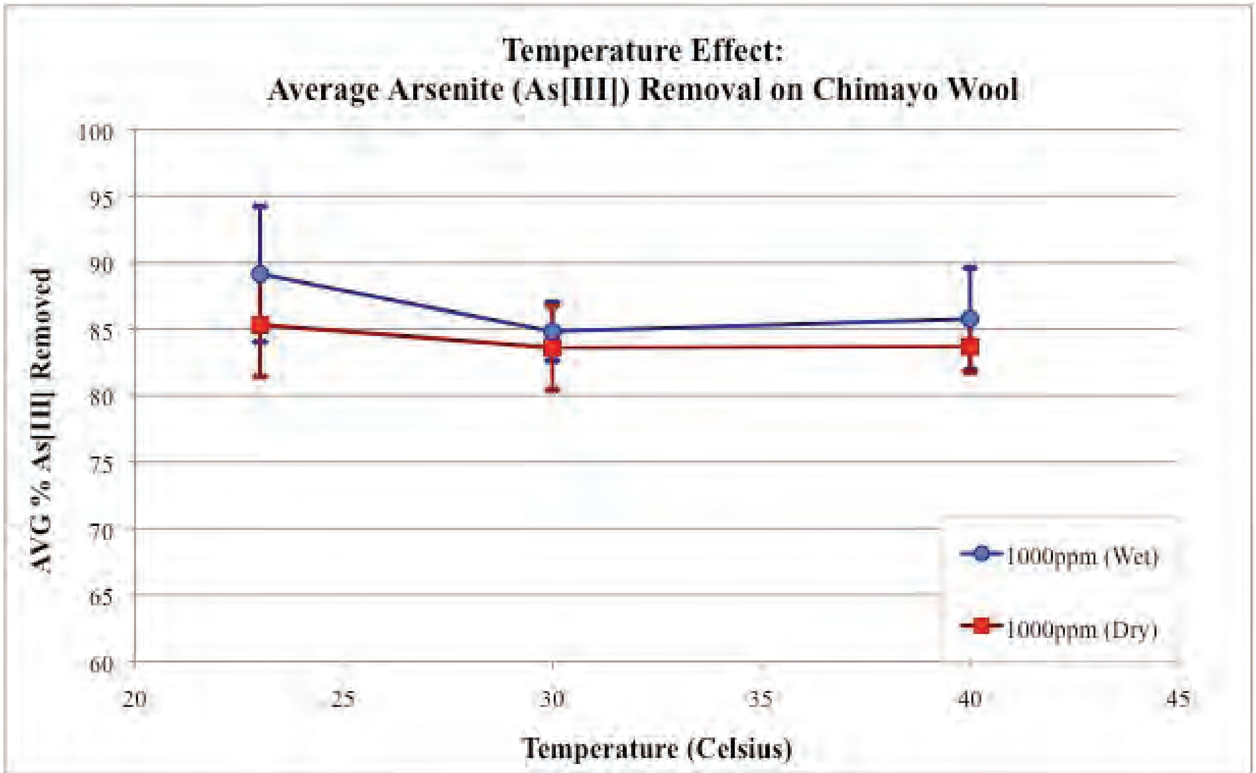

Fig.12. Effects of temperature (Courtesy of Jae R. Anderson)

Samples were placed in the water bath when the temperature of the larger pool of water and the measured water within the Tupperware container reached equilibrium. Data were analyzed and plotted as seen in figure 12.

4.4.3 Agitation

Initial tests with minimal constant agitation were carried out to determine whether investigation of higher agitation speeds would be necessary. If arsenic removal increased over time with minimal agitation, then an elevated level of agitation would be tested and evaluated. Temperature (23°C) and pH (~7.0) were both held constant.

A bench top combined stirrer and hot plate generated constant agitation. A stirring bar, 4 cm in length, was centered at the bottom of the plastic Tupperware container, with four rubber stoppers placed in corners to generate space between the stirring bar and sample testing apparatus as seen in figure 13. A volume of 400 mL of deionized water was used to account for the added height of the testing apparatus.

Low agitation was created with the Corning instrument's stirring dial set to 2.5 notches, which resulted in minimal movement of the water surface. A total of 12 samples were divided into four sets of three samples. Each set was tested at respective time intervals of 1, 5, 10, or 15 minutes. The pXRF data were analyzed and plotted as seen in figure 14.

High agitation was created with the Corning instrument's stirring dial set to 4 notches, which resulted in a more aggressive movement of the water surface. A total of 12 samples were divided into four

Fig. 13. Agitation testing setup (Courtesy of Jae R. Anderson)

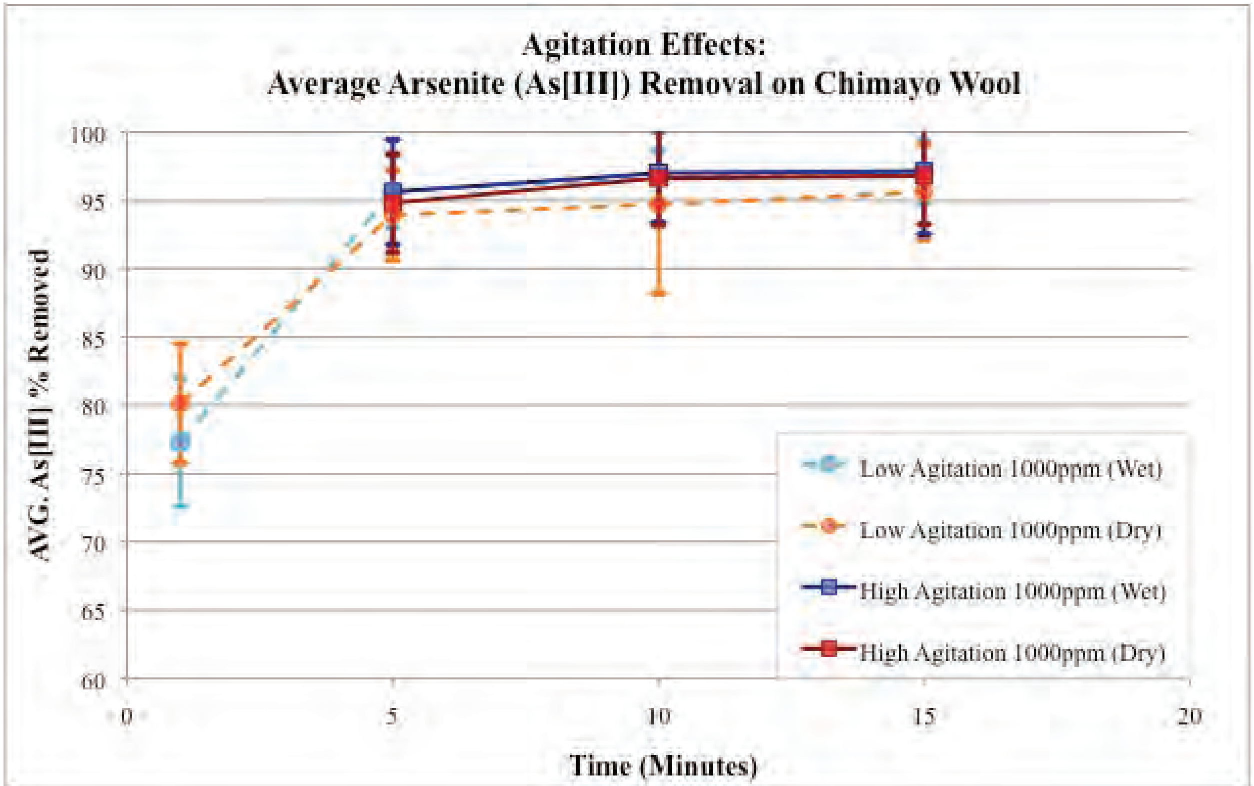

Fig.14. Effects of agitation (Courtesy of Jae R. Anderson)

sets of three samples. Each set was tested at a respective time interval of 5, 10, or 15 minutes. The pXRF data were again analyzed and plotted, also seen in figure 14.

4.4.4 pH

The pH effect was a single case study with time (15 minutes), temperature (23°C), and agitation (none) held constant. One wool sample was tested in an acidic solution with a pH level ~5.3. A second sample was tested in a basic solution with a pH level ~8.6. The effects of pH on arsenite removal from wool initially indicated no significant changes as shown in figure 15.

4.5 ARSENIC POST-WASH STUDY

Approximately 10 mL of post-wash water for each conditional effect test was preserved to conduct a supplementary analysis with an arsenic paper test. The study confirms desorption of arsenic

pH Study: Average Arsenite (As[III]) Removed on Chimayo Wool		
pH	**Wet (%)**	**Dry (%)**
~5.3	85	88
~8.6	87	86

Fig. 15. pH preliminary results (Courtesy of Jae R. Anderson)

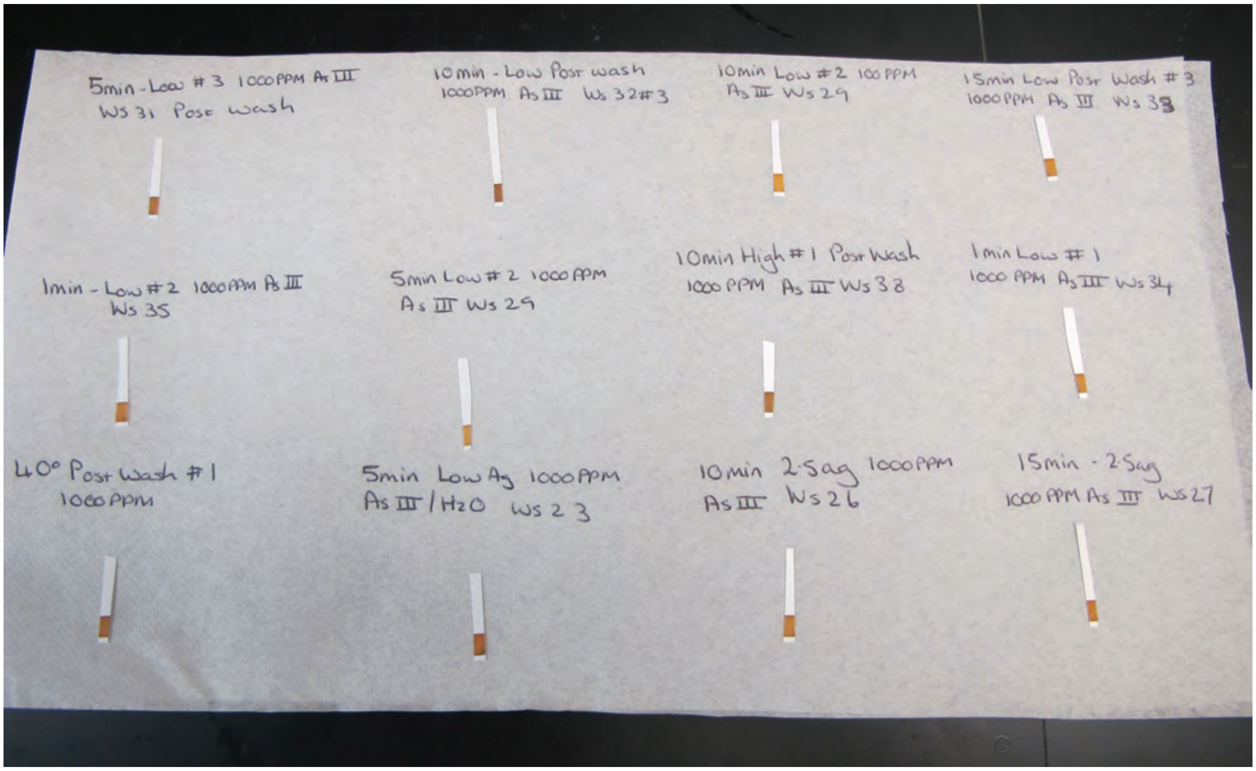

Fig. 16. Arsenic post-wash paper test (Courtesy of Jae R. Anderson)

from the wool textile into deionized water; however, the results from the arsenic paper test were not sensitive enough to provide reliable quantitative data to the arsenic concentration in the post-wash solution as seen in figure 16.

Dr. James Farrell, Department of Chemical and Environmental Engineering, University of Arizona, subsequently recommended inductively coupled plasma optical emission spectrometry (ICP-OES) as a secondary analytical technique for arsenic detection in post-wash solutions. The instrument is a powerful tool used to detect metals in a variety of matrices such as arsenic in an aqueous solution. The instrument has the potential to provide quantitative data of post-wash arsenic solutions.

5. ARSENIC REMOVAL ANALYSIS ON ASM NAVAJO TEXTILES

Three late 19th and early 20th century ASM Navajo textiles were selected on the basis of overall size (small) and arsenic presence results from the textile survey conducted as part of this study. Prewash investigation for each textile consisted of documentation of physical properties (dimensions and mass), a colorfastness test to determine potential reactions of dyes with deionized water, and thorough pXRF testing of both sides of the textile. Experimental research established preliminary guidelines that suggested submersion of the wool textile in deionized water at room temperature (23°C) for at least 10 minutes with constant mechanical agitation. The washing conditions predicted approximately 95% of arsenic could be removed from the textile.

5.1 WASHING TREATMENTS

The first washing treatment was performed on an Early Rug Period (ca. 1910–1915) Double Saddle Blanket, Rug (ASM catalogue #3917) approximately 0.55 × 1.15m. A tapestry weave used

Fig. 17. Wash treatment #1 of ASM catalog no. 3917 (Courtesy of Gina Watkinson)

handspun sheep's wool (wefts) and string cotton (warps) to produce a design of two serrated diamonds. A red synthetic dye outlined diamonds with the colors of gray, blue, black-brown, and white. Gray serrations on a white background flanked the diamond designs. The textile contained an arsenic concentration approximately 44 ppm, which is considered low for the scope of this study.

A shallow tub (1.40 × 0.56 × 0.11m) was used to submerge the textile in a minimal volume of deionized water (~13 L). The textile was placed between vinyl fiberglass screens to provide support in handling. A plastic grid screen was placed at the bottom of the tub as a spacer. A constant gentle hand agitation was applied as seen in figure 17. The textile was removed from the aqueous bath, wet-tested with pXRF, and blotted with terry cloth towels. After air-drying at room temperature, the textile was retested on documented prewash test locations.

A Transitional Period (ca. 1880–1890) sheep's wool blanket (ASM catalog no. 8423) measuring 0.66 × 0.59 m was selected for the second washing treatment. A plain weave used synthetic dyes to create a banded design of yellow and orange on a red-orange background. The second textile contained a higher arsenic concentration of approximately 1000 ppm.

Fig. 18. Wash treatment #2 of ASM catalog no. 8423 (Courtesy of Gina Watkinson)

The first washing treatment did not produce anticipated results on the basis of the investigations into conditional effects. Before the second treatment, a larger volume of deionized water was calculated on the basis of experimental measurements: mass of the dry wool fabric divided by the measured volume of water; however, time and the size of the Nalgene container (0.91 × 0.61 × 0.61 m) limited the volume of water to approximately 70 L.

Vinyl fiberglass screens were again used to support immersion of the textile into the Nalgene container as seen in figure 18. A plastic grid was used in conjunction with the vinyl fiberglass screens to create agitation by vertical movements of the textile. The textile was removed from the aqueous bath with noted minimal bleeding of the red-orange dye. The textile was quickly pXRF wet-tested, and blotted with terry cloth towels to arrest further bleeding of the dye. The textile was air-dried at room temperature, and pXRF dry-tested on prewash test locations.

The third washing treatment involved a Transitional/Early Rug Period (ca. 1880–1910) Rug (ASM catalog no. 2322) measuring 0.82 × 1.29m. A tapestry weave used cotton (warps) and sheep's wool (wefts) to create a concentric and outlined serrated diamond shape design. The multicolored design

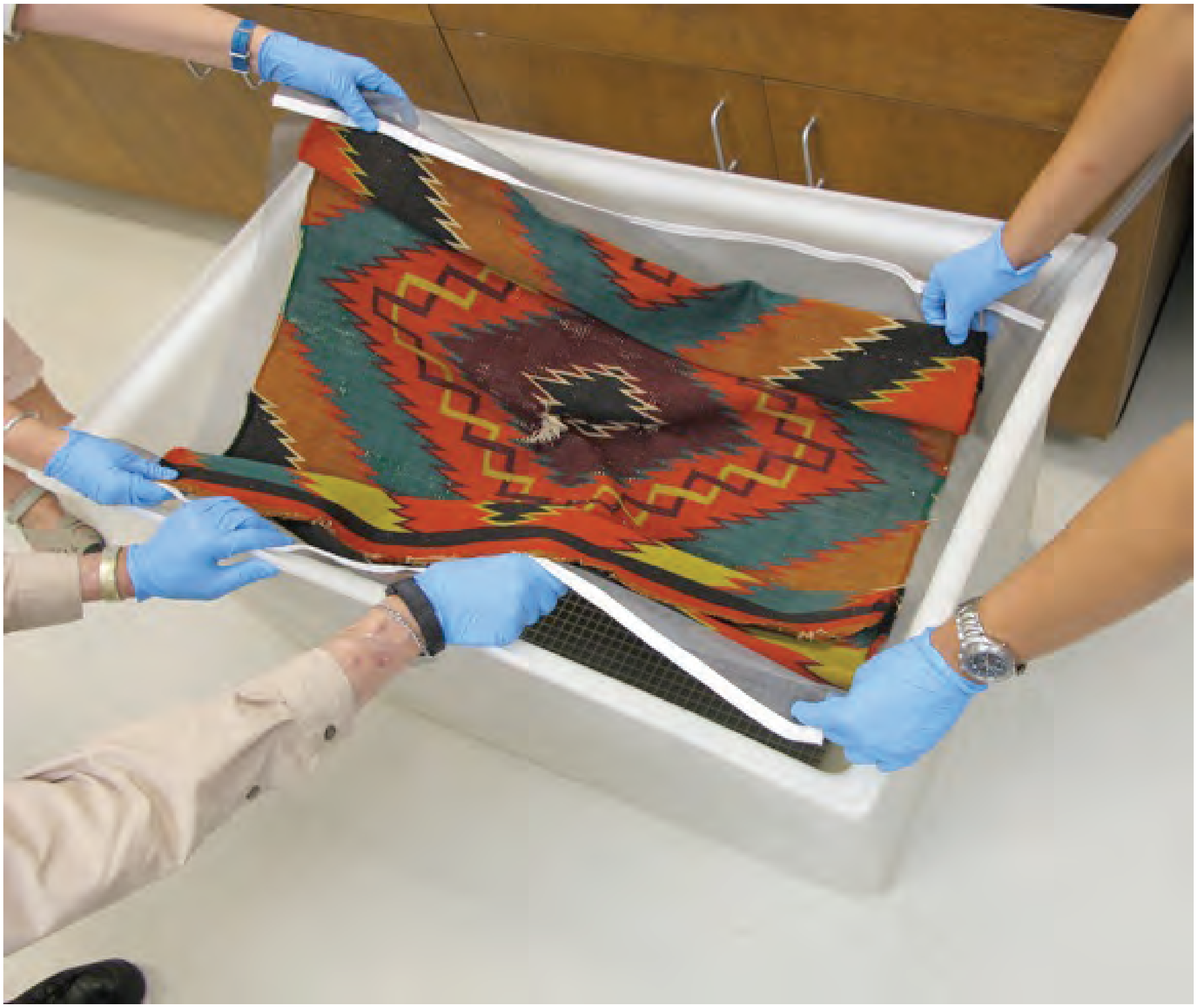

Fig. 19. Wash treatment #3 of ASM catalog no. 2322 (Courtesy of Gina Watkinson)

used natural white with black, brown, green-blue, yellow, and red synthetic dyes. Prewash testing detected a concentration of arsenic approximately 44 ppm.

The devices, volume of deionized water (~70 L), and washing from the second washing treatment were kept identical. The textile ends were loosely rolled because of container size restraints. The washing process developed in the second washing treatment was implemented for the final washing treatment as shown in figure 19.

5.2 RESULTS

The wet treatment of wool-based experimental textiles and three historic Navajo textiles from the ASM collection provided positive preliminary results. The experimental test sample aqueous washing treatment correlated with one Navajo textile washing treatment.

5.2.1 Experimental Aqueous Washing Methodology

Calibration of handheld pXRF analyzer strongly correlates observed wet and dry pXRF readings with known arsenic test samples. Testing of wet fabric samples appears to be independent of fabric

Wash Treatment	ASM Catalogue No.	Total pXRF Readings	PRE-Wash Overall AVG. (ppm)	POST-Wash Overall AVG. (ppm)	Arsenic (As[III]) Removed (%)
1	3917	18	44	43	**2**
2	8423	10	967	41	**96**
3	2322	13	44	38	**14**

Fig. 20. ASM wash treatment results (Courtesy of Jae R. Anderson)

thickness considering observed pXRF readings are consistent with known arsenic concentrations. This conveys a liquid quantification, opposed to dry samples, which is viewed as a solid quantification. The difference between dry cotton and wool pXRF readings is associated with fabric thickness. This was confirmed by observing the detection of arsenic nearly doubling when the cotton thickness was doubled.

Each conditional effect resulted in removing a certain percentage of arsenic from wool samples with an initial concentration of ~1000 ppm. Time indicates the greatest percentage of arsenic is removed within the first 10 minutes. Increasing temperature does not increase the percentage of arsenic removal for a washing period of 15 minutes. Agitation significantly increases the removal of arsenic within the first 5 minutes and increasing agitation moderately improves arsenic removal. Increasing or decreasing pH does not increase the effectiveness of arsenic removal.

5.2.2 ASM Navajo Textile Aqueous Washing Treatments

The following results for arsenic-based pesticide residues on historic Navajo textiles are considered preliminary as shown in figure 20. The first and third wash treatments removed minimal amounts of arsenic. The second water treatment removed approximately 96% of arsenic, which directly correlated with experimental results.

5.3 DISCUSSION

Approximately two years of research coincided with the Navajo textile pXRF survey to engineer a cost-effective and conservation conscious aqueous washing treatment for wool-based textiles. The Navajo textile pXRF survey identified a range of arsenic concentrations associated with the ASM collection, and identified three Navajo textiles for wet treatment. Survey data provided significant institutional knowledge of the collection leading to introduction of labeling, handling, or storage protocols to reduce potential health risks.

Each washing treatment was a unique experience and reinforced a necessary collaborative effort to safely manage and assess various elements of a hazardous arsenic removal process. Experimental research of conditional effects utilized an effective liquid (200 mL) to solid (1.6 g) ratio that removed a high concentration of arsenic (~1000 ppm), which was used to calculate a larger volume of water needed for a larger textile, as conducted in the second Navajo washing treatment. Sufficient space, time, and assistance are key elements when undertaking a potential wet treatment to remove arsenic from larger textiles.

Preliminary testing of low arsenic concentrations (<100ppm) on prepared samples was not achieved due to time constraints. However, the third washing treatment of ASM #2322 indicates a low concentration of arsenic (~44ppm) is not affected by an increase of water volume. This warrants further investigation as a low concentration of arsenic may be irreversibly bonded to the wool fibers. Therefore, treating textiles with very low levels of arsenic may be futile and should probably be avoided.

Attempting to remove a high arsenic concentration (~1000ppm) from a textile produces an arsenic post-wash solution substantiated by the arsenic paper test. Initial arsenic concentrations, volume of water, and textile mass were determined to be significant components for approximate arsenic concentration in post-wash solutions:

$$[\text{As detected on dry textile (ppm)} \times \text{Mass of textile (g)}] \div 10^6 = \text{As on textile (g)}$$

$$[\text{As on textile (g)} \div \text{Volume of deionized water (L)}] = \text{As in post-wash solution (g/L)}$$

Arsenic water treatment is a prevalent worldwide concern to ensure safe drinking water. Treatments encompass a variety of effective methods to remove arsenic levels below 10 parts per billion (ppb), the maximum contaminant level set by the U.S. Environmental Protection Agency; however, non-hazardous arsenic waste levels are determined to be <5 mg/L or 5 ppm (U.S. Environmental Protection Agency 2009). Ideally, drinking water standards need to be attained if post-wash arsenic solutions are to be disposed of in public drainage systems.

Recent exploration into the post-wash issue has garnered interest from The University of Arizona Department of Chemical and Environmental Engineering. As mentioned earlier, Dr. Farrell and his team have expertise in arsenic sorption systems and have communicated the capability to quantitatively measure post-wash arsenic concentrations using an ICP-OES. Collaborating on devising a closed-loop sorption system would be beneficial on several levels. Theoretically, constant filtering of arsenic from the water would limit the volume of water needed to conduct a wet treatment on any textile size. Further, safe levels of arsenic in post-wash water could be achieved and properly disposed of. The process of treating the water while conducting a wet treatment is a positive initiative to the arsenic textile removal issue, and needs to continue.

Overall, the attempt to remove arsenic from a historic textile was a preliminary success, with further work needed to refine and enhance the wet treatment removal process. Conducting a wet treatment to remove arsenic on a historic textile is complex and needs to be fully evaluated in terms of space, time, and resources.

6. CONCLUSIONS

The ASM Conservation Laboratory demonstrated successful preliminary results for a method to remove arsenic-based pesticides from a wool-based textile via an aqueous cleaning treatment. A complete pXRF survey of ASM's Navajo textile collection provided knowledge of potential arsenic-based residues, identified trends relating to time period and collector, and created a foundation for further experimental research. Preliminary experiments showed that when arsenic is at high concentrations, approximately 95% of arsenic was removed from wool within the first 10 minutes by submersion in deionized water at room temperature with constant agitation. Experimental washing guidelines were implemented on three ASM Navajo textiles with low (< 100 ppm) and high (~1000 ppm) arsenic concentrations. Textiles with arsenic levels <100 ppm had minimal arsenic removal through washing. Approximately 96% of arsenic was removed from the high-concentration textile. Our results suggest that the concentration of arsenic, the mass of textile, and the volume of deionized water used are key factors to the aqueous treatment process and that it is unlikely that all arsenic can be removed.

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SOURCES OF MATERIALS

McCormick & Co., Inc.
18 Loveton Circle
Sparks, MD 21152
800-632-5847
www.mccormick.com

Ortega's Weaving
53 Plaza Del Cerro
Chimayo, NM 87522
877-351-4215
http:/ortegasweaving.com/

EM Science Division of EM Industries Inc.
480 Democrat Rd.
Gibbstown, NJ 08027
856-423-6300

Sigma-Aldrich
3050 Spruce St.
St. Louis, MO 63103
800-325-5052
www.sigmaaldrich.com/united-states.html

Conservation Materials Ltd.
1395 Greg St., Suite 110
Sparks, NV 89431
702-331-0582

Testfabrics, Inc.
415 Delaware Ave.
West Pittston, PA 18643
570-603-0432
www.testfabrics.com/

JAE R. ANDERSON, MS, is a PhD student in the Department of Materials Science and Engineering at the University of Arizona. He is a cultural heritage preservation consultant focusing on non-destructive research of cultural materials at such organizations as the Smithsonian Institution's National Museum of the American Indian and Library of Congress. More specifically, his work examines the issues involved

with inorganic pesticides used on cultural materials as preservation treatments. He received his BS in applied mathematics, MS in materials science and engineering, and a Heritage Conservation Graduate Certificate at the University of Arizona. Address: PO Box 3301 Ft. Defiance, AZ 86504. Tel: 520-991-5170. E-mail anderson.jae@gmail.com

NANCY ODEGAARD, PhD, FAIC, FIIC, is the conservator and head of the preservation division at the Arizona State Museum. She is also a professor in the School of Anthropology, Department of Materials Science & Engineering, and Drachman Institute at the University of Arizona. She received her MA at George Washington University and advanced certificate in conservation at the Smithsonian, and earned a PhD in resource, environment, and heritage science at the University of Canberra, Australia. She is a fellow of the AIC and IIC. Address: Preservation Division, Arizona State Museum, University of Arizona. PO Box 210026, Tucson, AZ 85721-0026. Tel: 520-621-6314. E-mail: odegaard@email.arizona.edu

MARTINA DAWLEY, PhD, is the assistant curator for American Indian Relations at the Arizona State Museum and University of Arizona faculty member. She is Hualapai on her father's side and Diné on her mother's. She earned her PhD and MA in American Indian studies in 2013 and 2009 at the University of Arizona and her BA in anthropology with a minor in geology in 2006 at the University of Arizona. Her position at ASM includes management of ASM's Southwest Native Nations Advisory Board, oversight of the museum's American Indian internship program, assists with program development at ASM, facilitation of tribal consultations related to programs throughout the museum, and providing training and technical assistance to tribal museums, libraries, archives, and cultural centers. Address: American Indian Relations, Arizona State Museum, University of Arizona. PO Box 210026, Tucson, AZ 85721-0026. Tel: 520-621-6276. E-mail: Mdawley@email.arizona.edu

DELANA JOY FARLEY, MA, is the curator of collections at the Tohono O'odham Nation Cultural Center & Museum, Himdag Ki: Hekĭhu, Hemu, Im B I-Ha'ap. She received her BA in museum studies from the Institute of American Indian Arts. She earned her MA at the Graduate School of Arts and Science at New York University. She is also a member of the Navajo Nation. Address: Tohono O'odham Nation Cultural Center & Museum, PO Box 837, Sells, AZ 85634. Tel: 520-383-0200. E-mail: Delana.Farley@tonation-nsn.gov

WERNER ZIMMT (1921–2014), PhD, served as museum fellow-conservation scientist with the preservation division at the Arizona State Museum for thirty years after his retirement from a distinguished career with the Dupont Corporation. A beloved colleague and mentor, he inspired and assisted many conservators, scientists, and students with his deep chemistry knowledge, love of archaeology, and good humor. His many research interests included chemical spot testing methods and the collaborative assessment of the presence of pesticides on cultural materials and their removal methods. He held a PhD in chemistry from the University of Chicago and a MA in archaeology from the University of Pennsylvania.

RED, BLUE, AND WOUND ALL OVER: EVALUATING CONDITION CHANGE AND CLEANING OF GLASS DISEASE ON BEADS

ROBIN O'HERN, KELLY McHUGH

ABSTRACT

This article presents the results of two surveys focused on the condition and treatment of deteriorated glass beads in the collection of the National Museum of the American Indian (NMAI). Glass deterioration occurs when hygroscopic alkali components of the glass migrate to the surface and form salts. The leaching of alkali components leaves a silica enriched surface layer, which is vulnerable to further deterioration. Environmental parameters, glass composition and manufacturing processes, contact with other materials, and previous use of the object can all affect the deterioration process. Because of the large number of beaded objects at the NMAI, glass disease is a collection-wide condition issue.

Two targeted collections surveys were, therefore, carried out to monitor condition change and treatment results for at-risk beads. To assess changes in condition over time, a selection of objects originally surveyed in 1999 were re-surveyed in 2013. Ninety percent of the beads had no visible change to the deteriorated glass over 14 years. A second survey was conducted to evaluate whether treatment options used for blue and red beads—cleaning with deionized or distilled water, ethanol, 1:1 deionized or distilled water: ethanol, or mechanical cleaning—had different long-term results. Approximately 50% of the beads cleaned with water or 1:1 water: ethanol and 47% of beads cleaned with ethanol redeveloped glass deterioration; however, if the results for beads cleaned with 1:1 water: ethanol and ethanol alone are compared over the same time period, the rate of return for beads cleaned with ethanol drops to 42%. The identification of beads most likely to have or develop glass deterioration and the long-term success of treatment will help prioritize conservation resources.

1. INTRODUCTION

Glass disease is an important issue for museums with Native American Collections, and at the National Museum of the American Indian (NMAI), it is one of the most pervasive preservation problems. Of the non-archaeological object records in the NMAI's collection database, approximately 10% (11,000) contain glass beads. Not all of the objects at the NMAI have conservation records; however, for those that do, 25% of objects with glass beads have records of unstable glass. Because objects with conservation records tend to be those in the best condition that were chosen for exhibition, it is likely that the actual percentage of objects with glass deterioration is much higher. Developing greater understanding regarding how the unstable glass is deteriorating will help with long-term preservation (fig. 1).

Additionally, evaluating the effectiveness of different cleaning techniques over several years may help develop better protocols for treating glass beads. This article describes an ongoing project to assess glass disease on ethnographic beadwork in the collection of the National Museum of the American Indian.

The NMAI has its roots in New York's Heye Foundation's Museum of the American Indian (MAI), established in 1961 by financier George Gustave Heye. The Smithsonian Institution took over the extensive MAI holdings in 1989, establishing the National Museum of the American Indian. As part of the Smithsonian Institution, a new museum was built on the National Mall and the collection moved from a storage facility in New York to the Cultural Resources Center in Suitland, Maryland. In preparation for the move, which took place from 1999 to 2004, the ethnographic portion of the collection underwent a detailed, item-specific conservation survey. All cases of glass disease visible to the naked eye were noted in the survey. The items surveyed in 1999 became the foundation for this project's initial stage.

Fig. 1. Image of blue seed beads with unstable glass on a Potawatomi Bag (Courtesy of Robin O'Hern, National Museum of the American Indian, Smithsonian Institution, 19/0580)

1.1 HISTORY OF GLASS TRADE BEADS IN NORTH AMERICA

The history of non-Native-made glass beads in North America requires a brief introduction about countries of origin, colorants, manufacturing techniques, shapes, and significant historical events. Glass beads imported to North America came from Venice, Bohemia (now the Czech Republic), Holland, England, France, China, and other countries. The earliest glass beads likely came from Venice, with increased production by Holland in the 17th century and by the Czech Republic in the 19th century. Beads also entered North America from China in the 19th century (Karklins 1974, 2012; Francis 1986, 1988, 2008, 68–70; Ross 1990, 2000; Burgess and Dussubieux 2007).

Glass beads are made using several different techniques, including but not limited to drawn, wound, mold-pressed, and hollow blown (Sprague 1985). Beads made by each of these techniques can be identified by manufacturing marks such as the direction of air bubbles and the presence of seam lines. By the late 15th century, the Venetians developed a technique for making large numbers of drawn beads, the technique used for pony and seed beads (Francis 2008, 68). Pony beads are larger than an eighth of an inch and seed beads range from 1/16th of an inch to 3/16ths of an inch (Lyford 1997). Later in the 18th century, seed beads were exported to North America (Francis 2008, 71) and they began to be used in the Great Plains region in the 1840s (Francis 2008, 71).

1.2 USE OF BEADS ON NATIVE AMERICAN OBJECTS

Beads made from locally sourced or traded natural materials, such as bone, shell, or teeth have been used by people of North America for thousands of years (Dubin 2009, 261). Pueblo people in the Southwest continue to manufacture and use beads made of turquoise, coral, and shell. The conveyance of social position and status, and communication with other tribes and the spiritual world, was and continues to be through a visual language. Further, hundreds of different languages spoken throughout North America combined with an extensive trade network necessitated a visual form of expression for communication.

The introduction of glass beads exponentially increased the opportunity for broader and more sophisticated visual articulation. In the Plains, glass beads quickly replaced traditional forms of adornment like quillwork, which were laborious and time consuming. A design explosion can be seen among tribes like the Apsaalooke (Crow) and Lakota with the availability of seed beads, needles, and trade cloth (Dubin 2009, 261). The Iroquois, Tuscarora, and Seneca sold Victorian-inspired items, heavily decorated with glass beads, to tourists visiting New York and Canada. Woodlands beadwork was inspired by French floral designs, created by women who were taught embroidery in the mission schools (Dubin 2009). Round, blue, Russian beads, not originally from Russia, but traded from Hong Kong or Bohemia, made an impact on Arctic and Pacific Northwest Coast cultures.

An affinity for glass beads, a medium that appealed to a well-established aesthetic need, inspired the beautification of objects and garments used in daily life or ceremony. The preservation of glass beads is inextricably linked to the preservation of Native American cultural material, and therefore, the importance of understanding the mechanisms of deterioration and treatment must be examined and well understood.

2. INTRODUCTION TO GLASS AND ITS DETERIORATION

Glass is made from approximately 70% silica (SiO_2), 20% alkali component (soda, Na_2O; potash, K_2CO_3; or lead oxide PbO), 10% calcium carbonate ($CaCO_3$) as a stabilizer, and other minor components (Koob 2006). Refined or processed sand, or another silicate material, provides the silica component and is called a *network former*. The soda or potash alkali flux releases carbon dioxide to leave sodium oxide or potassium oxide in the glass. The final ingredient, calcium carbonate, also releases carbon dioxide to leave calcium oxide (CaO) in the glass, which acts as a network stabilizer. It may have initially been unintentionally added as an impurity in the sand, but it can also be added intentionally (Francis 2002; Lovell 2006, 21, 23; Kunicki-Goldfinger 2008). Additional components can include other fluxes, oxidizing agents, fining agents, reducing agents, and colorizing or decolorizing agents. Previous studies on deteriorating glass focused on the percentages of calcium oxide and alkali components in the glass.

2.1 WHAT IS GLASS DETERIORATION?

Scholars and researchers use many different terms to describe unstable glass, including glass disease, glass illness, glass deterioration, sick glass, weeping glass, sweating glass, and crizzling glass. Visually, unstable glass will develop a fine network of cracks (crizzling), a white crystalline growth on the surface, aqueous or oily surface droplets (weeping), and pitting. Unstable beads may also break. Most of the glass beads with unstable compositions were made in Europe during the 17th to mid-18th century when glass makers tried to achieve particular visual characteristics such as color or transparency, or tried to produce beads with less expensive materials (Lougheed 1988; Kunicki-Goldfinger 2008).

Breakdown of the glass begins with the interaction of water—as liquid or vapor—with the glass surface. Hygroscopic components in the glass as well as surface dust and soiling attract moisture to the bead. If the surface pH is <9, then the moisture leaches the alkali and alkaline ions out of the network. This creates a leached layer at the surface of the glass that is depleted in alkali ions and enriched in silica. The ions interact with carbon dioxide or atmospheric pollutants in the air and form salts on the glass surface. Oily and fatty salts were found on the surface of some beads in contact with leather. When the pH becomes >9, the silica structure can break down (Kunicki-Goldfinger 2008, 50).

Most scientific research on composition and deterioration of glass beads focuses on blue beads, with significantly fewer articles about red glass beads (Sempowski et al. 2001; Burgess and Dussubieux 2007) or black beads (Lord 2001). These three colors will be discussed in detail throughout the article. In general, dark blue beads are most likely to be colored by cobalt. Light blue and turquoise beads tend to be colored by copper, in the form of cuprous oxide or as finely dispersed elemental copper (Weyl 1959; Hancock et al. 1994; Sempowski et al. 2001). There are three techniques for coloring glass red: copper to make opaque redwood beads (Sempowski et al. 2001, 503), a colloidal suspension of gold to make ruby red glass available after 1859 (Francis 2008, 64), and selenium and cadmium available after 1890 (Weyl 1959; Francis 2008, 73). Red glass also frequently includes lead oxide as an alkali flux (Weyl 1959, 385; Burgess and Dussubieux 2007, 62, 70). Research on black beads has identified their colorants as manganese—occasionally grayed with tin—and chromium with cobalt, copper, or ferric silicates (Karklin 2002; Ross 2005). These studies were done on glass from various regions and other trends may exist in glass from different locations.

The deterioration of glass beads occurs as a result of the chemical composition of the glass, the use-history of the object on which they are attached, and the environmental history of the object (Kunicki-Goldfinger 2008) (fig. 2).

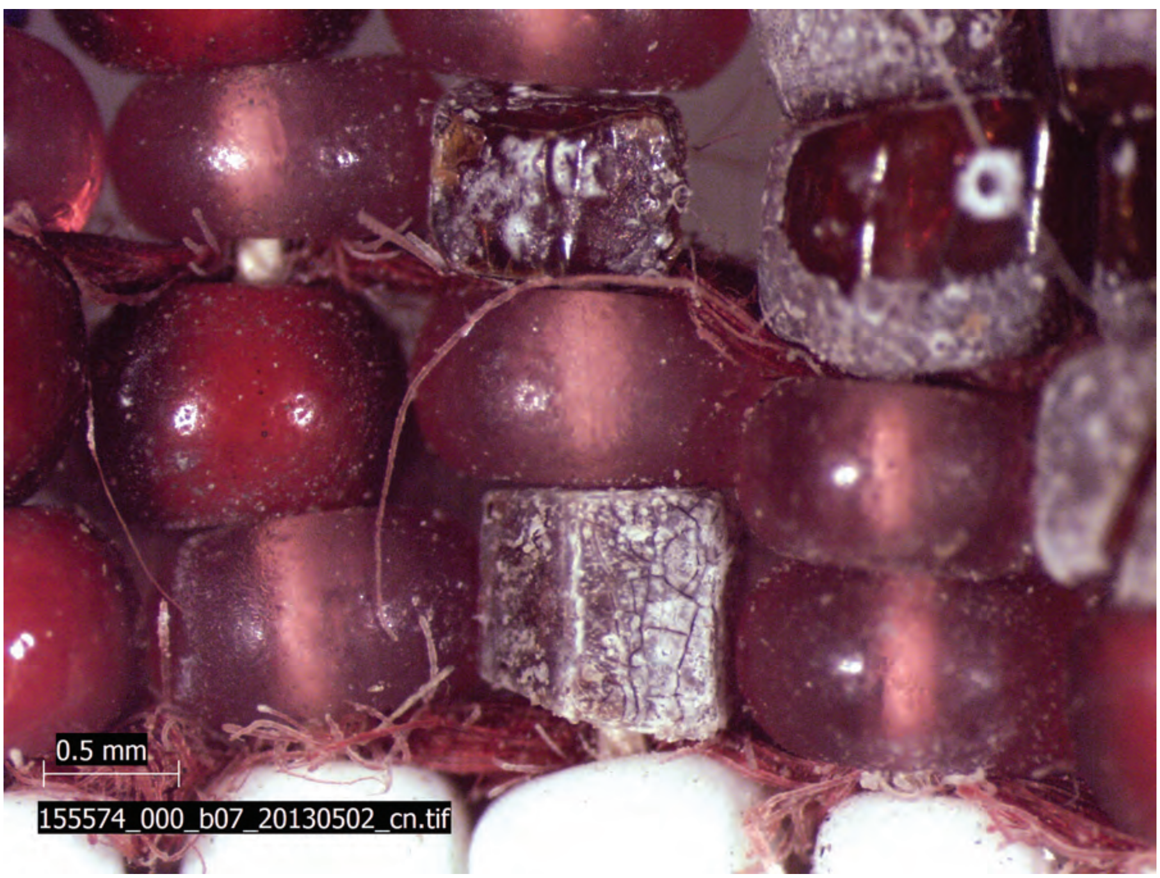

Fig. 2. Image of hexagonal red seed beads with glass disease. The other red beads are not deteriorating, which suggests that the glass composition of the hexagonal beads is unstable, Mushuaunnuat (Barren Ground Naskapi) bracelet (Courtesy of Robin O'Hern, National Museum of the American Indian, Smithsonian Institution, 15/5574)

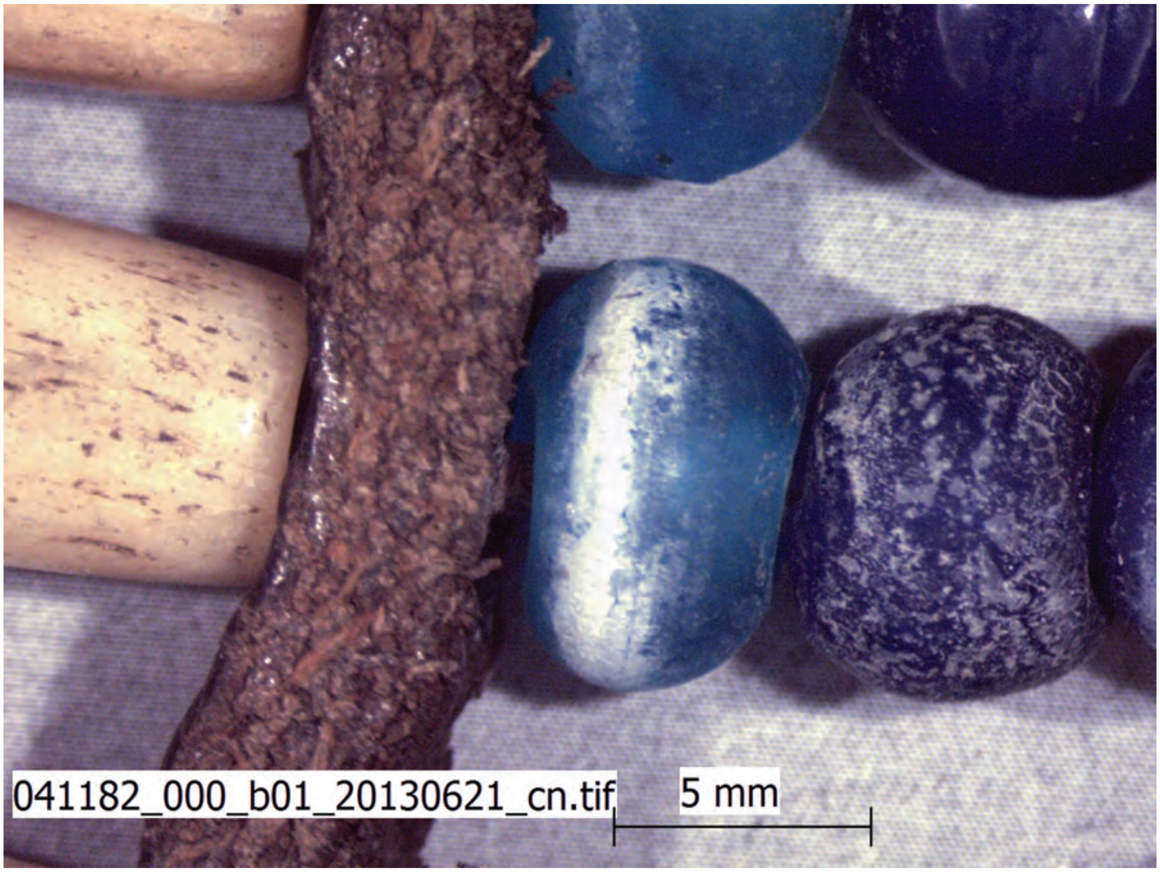

Fig. 3. Detail image of beads developing glass disease where they are in contact with leather on a Plains Breastplate (Courtesy of Robin O'Hern, National Museum of the American Indian, Smithsonian Institution, 04/1182)

It can also be influenced by the substrate and facilitated by the threading material (Fenn 1987; Carroll and McHugh 2001) (fig. 3). The interaction between glass beads and hide seems to facilitate their deterioration and the development of an oilier, waxy white crust or conversion into soap (Fenn 1987; Carroll and McHugh 2001). Glass objects with low concentrations of calcium oxide or high concentrations of flux (soda or potash) are susceptible to deterioration. An unstable glass composition will inherently cause the glass to deteriorate; however, any glass object can deteriorate given the wrong environmental conditions (Lovell 2006, 16). Unfortunately, the process cannot be stopped once it begins; it can only be slowed down by removal of the surface salts and by maintaining stable, low relative humidity conditions (Koob 2006; Kunicki-Goldfinger 2008).

2.2 UNSTABLE GLASS IN MUSEUM COLLECTIONS

Published literature was searched for other surveys of deteriorating glass beads (Carroll and McHugh 2001; Lord 2001; Lovell 2006; Fusco and Speakman 2010) and glass collections that assessed percentages of unstable glass (Cobo del Arco 1999; Oakley 1990, 1999).

The four published examples of collection-wide glass surveys include information about the percent of the collection susceptible to deterioration. These percentages range from 13.5 to 38% of collections:

- 20 and 13.5% of glass objects were unstable in two storage areas at the National Museums of Scotland (Cobo del Arco 1999)
- 17% of 344 beaded sculptures and costumes had unstable glass beads at the National Museum of African Art (Fusco and Speakman 2010)

- 16% (400 glass objects out of 6500) at the Victoria and Albert Museum were unstable (Oakley 1990)
- 38% (49 of 130) costumes required conservation, due to unstable glass and potentially other reasons, in the National Museums and Galleries' Merside Decorative Arts Department's collection (Lord 2001)

Three collections surveys discuss their results in terms of color and reach different conclusions. The survey of the National Museum of African Art glass beads found two different types of deterioration on specific colors of beads (Fusco and Speakman 2010). In contrast, the collection survey done in the United Kingdom in 2001 found "no obvious correlation between color and shape of bead and deterioration" (Lord 2001, 131). Finally, in Adam Lovell's discussions with bead researchers, he learned that "certain colors of beads—namely blues, reds, and black—tend to be more susceptible to glass disease" (Lovell 2006, 37).

2.3 CONSERVATION OF GLASS BEADS

Maintaining specific stable environmental parameters is the best method for the long-term preservation of unstable glass. The recommended parameters vary among the scholars who have published recommendations. Some of the ranges found in the conservation literature for unstable vessel glass include the following:

- 38% RH + 3% (Ryan et al. 1995; Oakley 1999, 2001)
- 40% RH + 1–2% (Koob 2006)
- < 35% RH (Sirois 1999)
- 35–40% RH (Lougheed 1988)

However, these relative humidity parameters may be too dry for the safe storage of adjacent leather or threading materials (Rose 1992).

At the NMAI, there is no separate storage area for objects with degrading glass beads—all the objects are stored in the same storage environment—because of a cultural mandate to store materials from the same culture, peoples, and nations together. The composite nature of the objects and collections at the NMAI requires environmental parameters that are best for the collection as a whole. The relative humidity of the storage environment ranges from 45% ± 8 RH, which is slightly higher and wider than the recommended percentages for unstable glass listed earlier but closer to the recommended parameters for stable glass. The actual RH range for the museum's storage environment is typical of conditions for other ethnographic collections.

Clearing surface salts from the glass bead can help to prevent additional deterioration by reducing the pH and removing hygroscopic components. When cleaning Native American beadwork, it is important to consider whether the surface grime is soiling or if it is a traditionally applied material like red ochre or kaolin (a type of white clay). According to conservation philosophy at the NMAI and other museums, these traditionally applied materials would not be removed from the object (Doyal 2001). The literature recommends several different options for cleaning glass beads: mechanical cleaning, swabbing with water, with ethanol, or with 1:1 water: ethanol. Conservators begin the cleaning process with mechanical techniques like vacuuming while brushing or using cosmetic sponges (non-latex polyurethane foam), which are least likely to cause damage (Doyal 2001; Frisina 2004).

Depending on the object, conservators can also use water or solvents to clean beads. These techniques are only used after testing the surrounding materials for adverse effects. Deionized or distilled water and ethanol have distinct advantages and disadvantages depending on the bead, substrate, and other factors (table 1). In all cases, a cotton swab is moistened with the solution and then rolled gently over the beads (Frisina 2004). Although the literature on glass beads strongly recommends using ethanol over water, a 2006 survey of conservators found that most choose water as their cleaning method (Lovell 2006, 62).

Table 1. Advantages and disadvantages of each treatment material

Material	Advantages	Disadvantages
Deionized or Distilled Water	Preferred for cleaning vessel glass. Effectively removes surface salts (Newton and Davison 1989; Ryan et al. 1996; Oakley 2001; Koob 2006; Smith 2006).	Can cause staining or tide lines on the substrate material. Can corrode nearby metal beads. May create a microenvironment around the thread facilitating glass deterioration. Can break weakened beads through the expansion of the moistened thread (Lougheed and Shaw 1982; Lougheed 1988; Stone 2010).
Ethanol	Does not cause corrosion of metal beads. Does not create a microenvironment around the threading material. Does not play a role in facilitating the beads' deterioration. May also help to solubilize fatty components of the surface accretion (Lougheed 1988; Doyal 2001; Lord 2001).	Can displace the moisture in the glass. Can reveal the full extent of crack development. May solubilize components of the backing material or substrate (Ryan et al. 1996; Koob 2006; Smith 2006).
1:1 Deionized or Distilled Water: Ethanol	Effectively removes surface salts. Dries more quickly than water on its own. May help to solubilize fatty components of the surface accretion (Stone 2010; Grabow 2011).	May cause staining. May corrode nearby metal beads. Can still create a humid microenvironment (Stone 2010).

3. EVALUATING CONDITION CHANGE FOR UNSTABLE BEADS

The previous survey of the NMAI's collection in 1999 provided the sample set used to examine the rate of deterioration for glass beads (Carroll and McHugh 2001). During the survey, conservators identified 187 objects with severe glass disease and undertook focused analysis on 20 objects. The objects studied in detail included bags, bracelets, breastplates, clothing, necklaces, fishing equipment, gloves, pipe stem fragments, and a rattle. Seventeen different cultures are represented by the objects, mostly from the Great Lakes Region, the Plains, and Alberta, Canada. These objects provide an ideal study group because they were rehoused shortly after surveying and have not received treatment since.

Resurveying the objects to evaluate whether the glass beads have deteriorated further is of particular interest because the objects moved from a variable storage climate in New York to a more stable—though not ideal for unstable glass—climate in Washington D.C. Because it is unlikely that glass beads on ethnographic objects will be stored in the ideal environmental conditions for unstable glass because of the presence of other materials, it is important to assess how the beads deteriorate in the standard museum environmental conditions.

3.1. SURVEY METHODOLOGY

The authors began with a survey of 20 objects on which McHugh and Carroll had focused additional analysis. None of these objects had been treated since their initial survey and they had each been rehoused shorlty after 1999. This means that if any condition change or loss has happened since 1999, the deterioration was not reduced through treatment. Each color or type of bead on an object—called a "bead type" for this article—has an individual survey entry. The survey of 20 objects resulted in 176 bead type entries.

O'Hern developed a Google survey form for internal use to survey the objects. The form includes questions designed to record bead color (using Munsell Color standards), manufacturing technique, size, shape, condition, pH, and standardized terminology for glass disease. The questions about manufacturing technique, size, and shape were designed to follow the Kidd and Kidd (1970) system as modified by Karklins (2012), but the information was not recorded in the codes developed by them.[1] Objects were always examined under UV-filtered fluorescent lighting conditions. We developed a visual glossary (fig. 4) to standardize the terms we used to describe glass deterioration products on the objects.

Measurement of the pH on the glass bead surface is essential for determining whether the bead has alkaline surface salts present, or culturally applied kaolin, or a matte surface (Lougheed 1988; Sirois

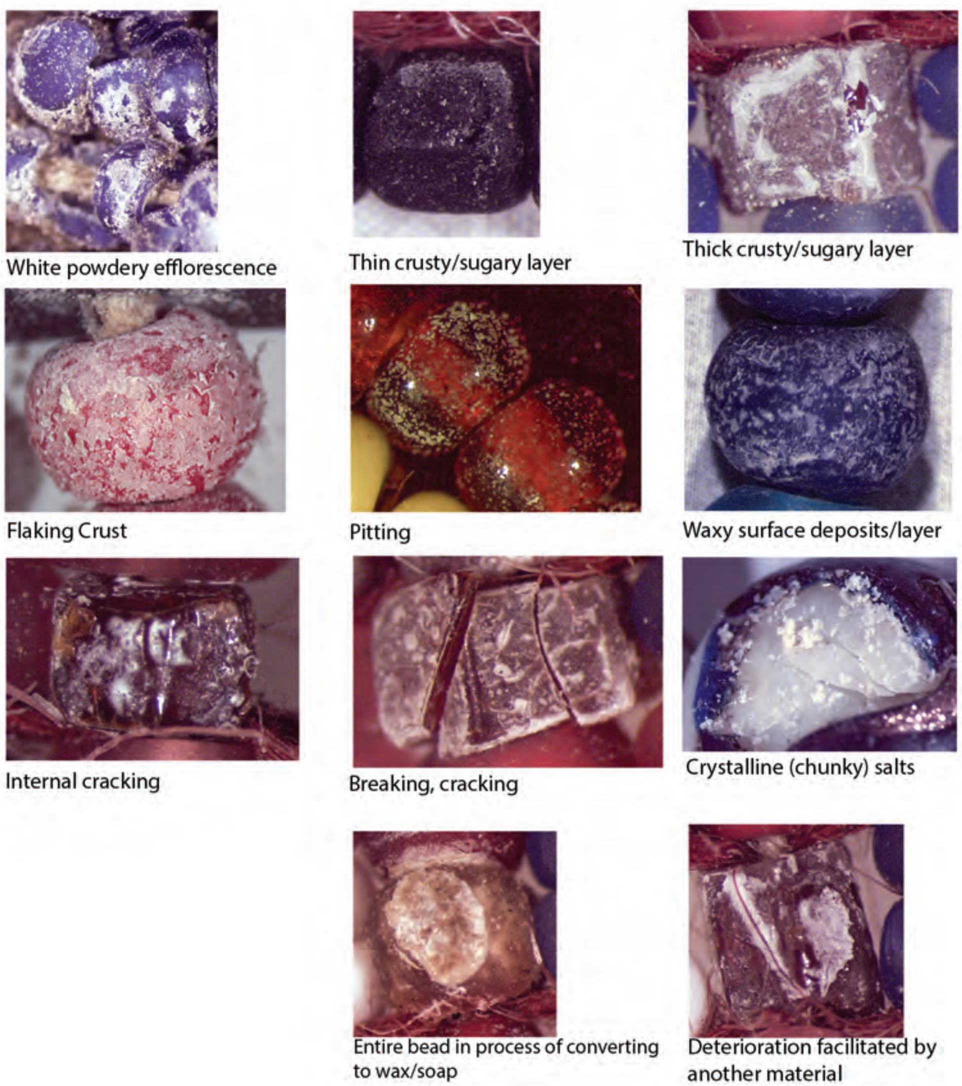

Fig. 4. A visual glossary of observed glass deterioration products (Courtesy of Robin O'Hern)

1999; Lord 2001, 129; Smith 2006; Lovell 2006, 37). Matte surfaces with neutral pH may be from manufacture, a sign of previous glass disease damage that disrupted the surface but has not reoccurred, or a result of wear (fig. 5a; 5b). Finally, in some instances, it is difficult to see the glass disease present on the beads, in which case an alkaline pH alerted us to its occurrence; therefore, measuring the pH of all the bead colors or types proved an essential practice.

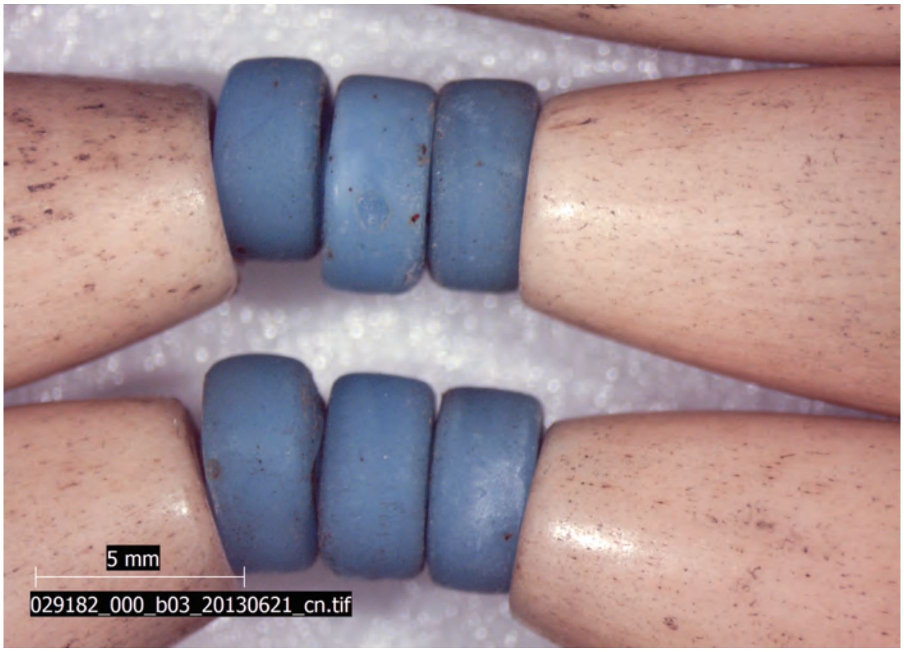

Fig. 5a. Northern Athapaskan Necklace with unstable glass beads that initially appear stable but have an alkaline pH. 5b. The matte surface on these beads in a detail from an Anishinaabe (Chippewa/Ojibwa) Man's leggings looks like glass deterioration; however, pH testing results were neutral. This indicates that the matte surface may be a sign of previous glass disease damage that disrupted the surface but has not reoccurred, or a result of wear. (Courtesy of Robin O'Hern, National Museum of the American Indian, Smithsonian Institution; NMAI 02/9182, NMAI 18/8382)

Fig. 6. Hollow blown black faceted beads on a Mi'kmaq (Micmac) Necklace that have continued to break apart since rehousing (Courtesy of Robin O'Hern, National Museum of the American Indian, Smithsonian Institution, 17/6455)

We used the following technique for measuring pH (fig. 6):

1. Cut tiny rectangle of ColorpHast paper (pH 6.5–10.0).
2. Moisten paper with deionized water.
3. Tap on towel to draw off excess moisture.
4. Place and hold on bead for 3 seconds.
5. Evaluate color change of pH paper.

The color change—or lack thereof—of the pH paper indicated if the surface pH was close to neutral and the glass was stable. Alternatively, a pH of 8 usually corresponds with barely visible surface salts, and a pH of ≥9 usually occurs when the salts are clearly visible on the bead surface.

3.2 RESULTS AND DISCUSSION

The results of the survey were studied to assess trends in the beads most susceptible to deterioration and whether their condition has changed in the past 15 years.

3.2.1 Percentage of Beads with Further Deterioration

Sixteen percent (28 out of 176) of all the bead types have more glass deterioration present now than they did during the 1999 survey. This number comprises the 23 types of beads that did not have a record of glass deterioration in 1999 but do have alkaline salts on their surfaces now and the five bead types that did have a record of glass deterioration in 1999 and have visibly deteriorated further (fig. 6). The visibly identifiable further deterioration typically takes the form of split beads, or beads with fragments that have or are about to separate.

The evaluation of change in the quantity of white deposits on a bead's surface is somewhat subjective in the case of glass disease. It depends on the relative humidity at the time of surveying because of the deliquescence point of the salts involved and involves comparing an image or description of the beads with the object to determine if there is an increase in the appearance of white salts.

3.2.2 Assessing Trends in Unstable Glass by Color

We evaluated the results of the survey to assess whether particular colors were more susceptible to deterioration than others. To determine this, we calculated the percentage of each bead color that had unstable glass and then compared the colors in figure 7.

Three colors have approximately 60% of their bead types display glass deterioration: black, red, and blue. Three colors have approximately 50% of their bead types—yellow, brown, and purple—exhibiting deterioration; however, there were many fewer beads of these colors. Green, clear, and orange beads were approximately 40% likely to have glass deterioration. White and pink beads had no examples of unstable glass.

For comparison, we conducted a similar investigation (figure 8) on the objects with conservation records in the museum's database that included the words "glass disease" or "bead disease." The beads on these objects were summed by color and then the percentage of each color identified as having unstable glass was calculated.

This technique for assessing trends in glass deterioration yields slightly different results: The blue beads are much more likely to have a record of glass disease (68%), followed by the red (48%) and then black (30%) beads. The other beads are less than 20% likely to exhibit glass degradation. The information in this graph does depend on the conservators accurately reporting which beads have glass deterioration as well as on them naming each of the colors of beads on the object in their treatment report.

These results correspond with Lovell's findings from discussions with bead researchers that blues, reds, and black tend to be most susceptible to glass disease (Lovell 2006, 37). There are several

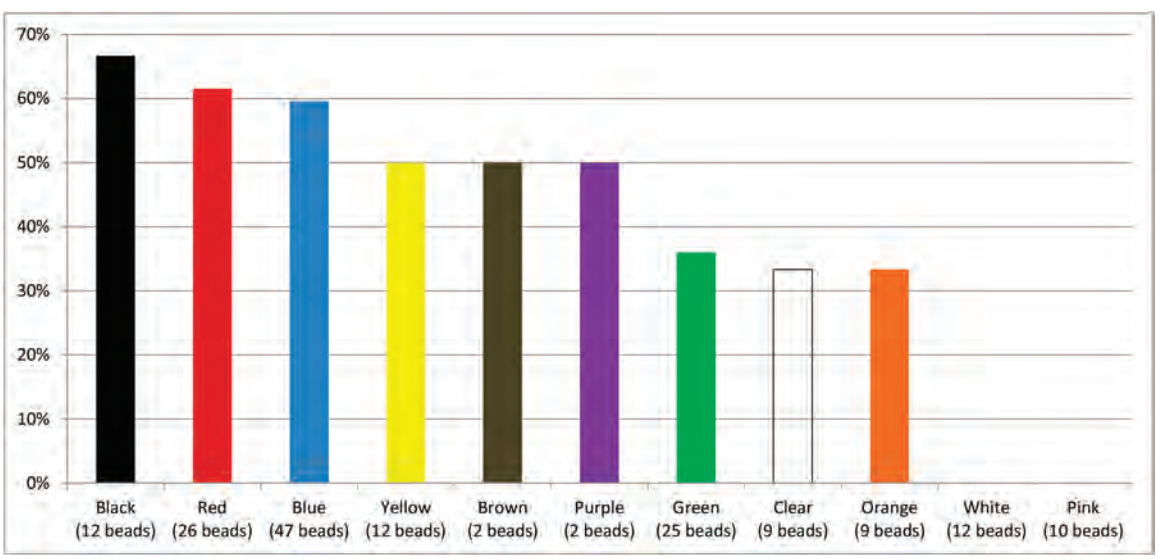

Fig. 7. Percentage of beads that have glass disease by color. The number below each column is the total number of beads of that color included in the survey. (Courtesy of Robin O'Hern)

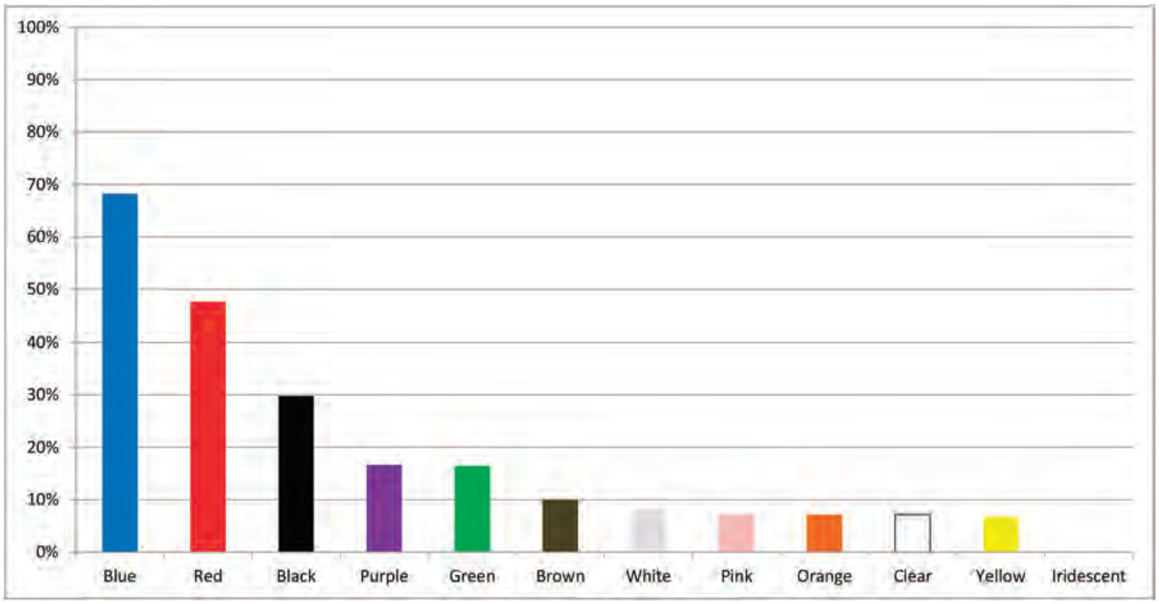

Fig. 8. Percentage of deteriorating beads by color on objects with records of unstable glass (Courtesy of Robin O'Hern)

explanations for the susceptibility of these colors to deterioration. Copper oxide creates different colors in glass, ranging from blue to green. Low lime and high alkali components help to achieve a blue—rather than green—color with copper. Unfortunately, this also destabilizes the glass and renders it susceptible to deterioration (Weyl 1959, 164; Hancock et al. 1994). The red beads we surveyed tend to be more translucent than opaque; therefore, their susceptibility to deterioration can be explained by the reduction in calcium oxide that causes the glass to be translucent or transparent. An explanation for the high deterioration rates for black beads is harder to establish but is likely also related to reduced calcium content (Karklin 2002). Further analysis on the unstable and stable glass beads is recommended to better understand the factors leading to their deterioration.

3.2.3 Assessing Trends in Unstable Glass by Manufacturing Technique

As part of our survey, we recorded information about the beads' manufacturing technique. Upon interpreting the results, we found a potential correlation between manufacturing technique and the stability of the glass composition. While most of the beads we encountered are drawn beads (108 bead types), only 20% of those bead types were deteriorating. In contrast, of the 50 wound beads types on the objects, 95% of them were deteriorating. We encountered two other techniques, hollow-blown beads and mold-made beads. Of the three hollow-blown bead types, all exhibit deterioration. Sixty percent of the five mold-made bead types are made of unstable glass. We focused our interpretation on the wound and drawn beads because we encountered the most of them; however, further work could be done to explore whether hollow-blown beads are also particularly susceptible to deterioration.

There are two possible explanations for the difference in wound and drawn bead deterioration: one based on composition and one based on bead usage. Drawn beads tend to be soda-lime-silica glass, whereas wound beads are made of potash glasses with slightly lower calcium oxide percentages. The lower calcium oxide concentration could contribute to the tendency for wound glass to be unstable. Additionally, the larger size of potassium ions in comparison with sodium ions could result in larger voids in the silica network, which could in turn cause more cracks or splits in the beads (Karklins 1983; Hancock 2013, 460–461). Alternatively, our data may be influenced by the small number of objects chosen for this subgroup. Additionally, drawn beads such as seed and pony beads tend to be used in significantly higher numbers on objects than wound beads, thereby increasing the probability that some of the beads will be unstable.

There are numerous challenges with conducting research on the deterioration of glass beads. The challenges can be roughly broken up into those related to glass disease and those related to the collection itself. Unstable glass is difficult to study because of the number of factors that can contribute to its deterioration—most of which are unknowable for a museum object. One important factor includes the composition of the glass, which will vary from batch to batch even within the same factory and which is difficult to determine on a large scale using noninvasive techniques. Additionally, the current and previous environmental conditions and the use of the object can contribute to the deterioration of glass beads. Once again, most of the information about their preaccession life remains inaccessible for museum objects. Compiling the complete environmental history of an object after it enters the NMAI's collection—or the earlier collection of the Museum of the American Indian—can be difficult. Beads are used in innumerable ways and associated with a variety of media to adorn items across the Americas—this also presents a significant research challenge.

4. EVALUATING TREATMENT TECHNIQUES FOR UNSTABLE BEADS

Does it matter if glass beads with salts on the surface are cleaned with water, ethanol, or 1:1 water: ethanol? Do beads treated with the different techniques redevelop glass disease differently? No published research was found that evaluated the long-term effects of different cleaning options for glass beads. The authors developed this second survey to assess whether there is a correlation between the treatment material and the redevelopment of visible deterioration products on the beads' surfaces. If there is no correlation between treatment material and redevelopment of salts on the surface, then conservators can choose the cleaning material on the basis of other factors, such as the sensitivity of surrounding materials.

This survey has several challenges associated with it. First of all is the difficulty of selecting a representative sample. Ideally, the objects would all be from the same culture, of the same type (i.e., moccasins), and treated using the different techniques in the same year. Unfortunately, this ideal sample group does not exist. The selected objects are based on those with treatment records, which naturally biases selection towards those areas of the collection that were chosen for exhibitions. Objects included in exhibitions tend to be in better condition than those that are not selected. Finally, individual conservators may clean beads with slightly different techniques, for example, using different amounts of moisture and cleaning the entire bead or just the exposed areas.

To research the long-term effect of treatment, objects that have a history of glass disease on blue and red beads and documented conservation treatments from each technique were surveyed to assess their current condition. The authors chose to use color to identify a subset of the collection, as opposed to object type (e.g., moccasins), culture, or treatment date because of the importance of glass composition. Although the colorant is a relatively small percentage of the glass composition, we expect it to roughly correlate with other components in the glass, as discussed earlier. Additionally, for a conservator without access to analytical equipment, color is the main feature by which we identify beads. Twenty-one objects with red beads and 38 objects with blue beads were chosen that have records of the presence of glass disease in the conservation database and are currently located in collections storage. Many objects had more than one type of blue bead or both red and blue beads; therefore, a total of 84 bead types were surveyed.

Forty-two cultures are represented by the 52 objects, with the most objects attributed to the Kiowa, Apsáalooke (Crow/Absaroke), Niitsitapii (Blackfoot/Blackfeet), and Tlingit. The objects included bags, baby carriers, clothing, breastplates, bridles, cradleboards, earrings, dolls, necklaces, and pipe bags, among other items. All of the objects were previously cleaned with water (deionized or distilled), ethanol, or 1:1 water: ethanol. Although we initially planned on including objects with red and blue beads that had records of unstable glass but that had not been previously cleaned, we ended up excluding those objects from our survey. We did not survey them because in most cases only overall images of the objects existed, which did not provide sufficient detail to assess changes in the presence of white surface material on the beads. None of the beads on the objects have been consolidated as part of their treatment. The treatments occurred from 1994 through 2011 for exhibitions and loans by the NMAI.

4.1 SURVEY METHODOLGY

This second survey recorded information about the bead (shape, manufacturing technique, opacity, Munsell color number), materials in contact with the beads, the bead's pH, and a comparison with the previous condition. The results were then entered into a Microsoft Excel spreadsheet. The pH of the beads was measured using the same technique as described in the previous survey. Only bead types that had records of unstable glass were examined. Additionally, objects that had only three or fewer beads of the color in question were not included in the survey because the number of beads was considered too small to be a representative sample.

4.2 RESULTS AND DISCUSSION

The red and blue bead types were analyzed to look for trends in the susceptible beads as well as the effectiveness of cleaning with different techniques. Of the surveyed red bead types, 54% were red-on-white beads also known as white hearts or *cornaline d'Aleppo* (Sprague 1985; Ross 2000; Billeck 2008). The rest of the red and blue beads were made with what appears to be a single layer of glass; however, it is likely that some of the beads have a clear glass layer on the top that would only be visible with cross sectional analysis (Shugar and O'Connor 2011). Eighty-five percent of the red and blue bead types were seed or pony beads made with the drawn technique. Most of the glass beads (76%) were in contact with hide; however, 19% were in contact with fabric (two of these were in contact with both hide and fabric). Other materials were also present as substrates, including tin, basketry, fur, wood, and plant fibers. We did not notice the glass deterioration affecting the substrate, for example, by causing darkening or discoloring, or the threading material. Although the surveyed beads are not necessarily representative of the overall collection, the relative unity of the red and blue beads (mostly drawn seed beads of similar color on hide) enables comparison of treatment techniques.

4.2.1 Assessing Color Trends within Red and Blue Beads

We recorded the Munsell color number for each of the types of beads on the objects. The red beads ranged from dark red to medium red, to a dusky rose (fig. 9). Forty five percent of the red beads, however, fall in the mid-range of the Munsell chips (2.5R 3/10, 5R 3/8, 5R 3/10, 7.5R 3/8, 7.5R 3/10, 7.5R 3/12).

We expected to find mostly light blue beads affected by glass deterioration because of the inherent instability of blue beads colored by copper. The wide spread of blue beads that had unstable glass (fig. 10) surprises us. Thirty-seven percent of the bead types are in the dark blue color range. As expected, the lightest red and blue colors are not unstable, probably due to the calcium oxide used to create the paler colors.

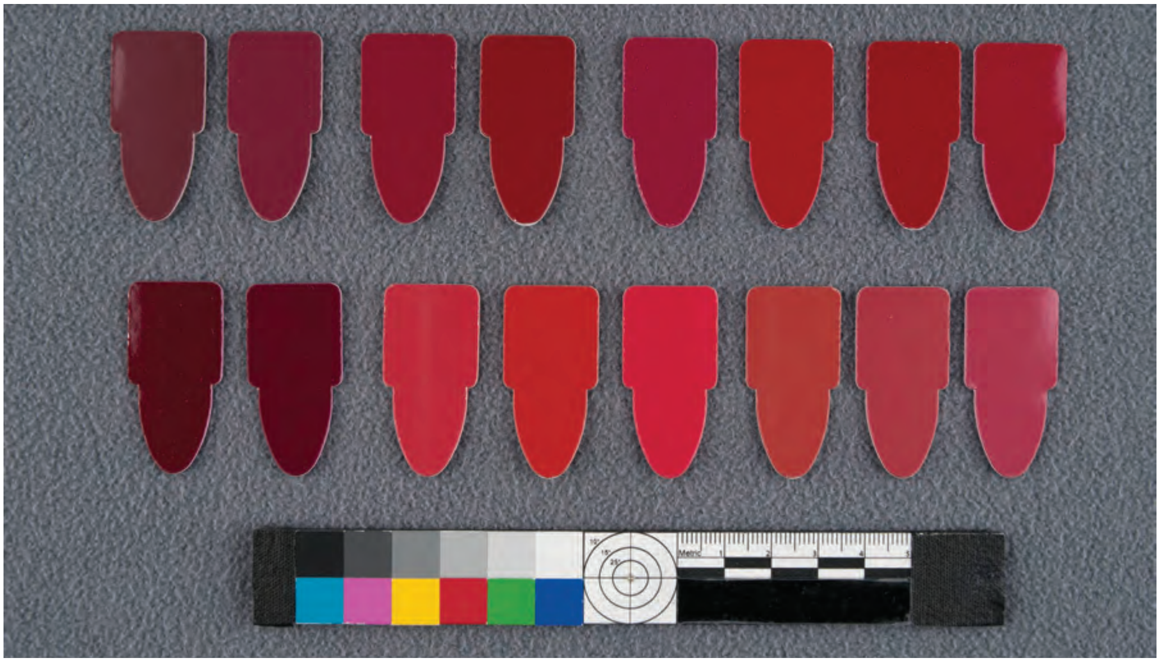

Fig. 9. Image of the red Munsell color chips that correlated with the beads that had records of unstable glass. Munsell numbers from left to right of the upper row: 5R 3/4, 2.5R 3/6, 5R 3/8, 7.5R 3/8, 2.5R 3/10, 7.5R 3/12, 7.5R 3/10, 5R 3/10. Munsell numbers from left to right of the lower row: 7.5R 2/8, 5R 2/8, 5R 4/10, 7.5R 4/10, 5R 4/12, 7.5R 4/8, 5R 4/8, 2.5R 4/8. (Courtesy of Robin O'Hern)

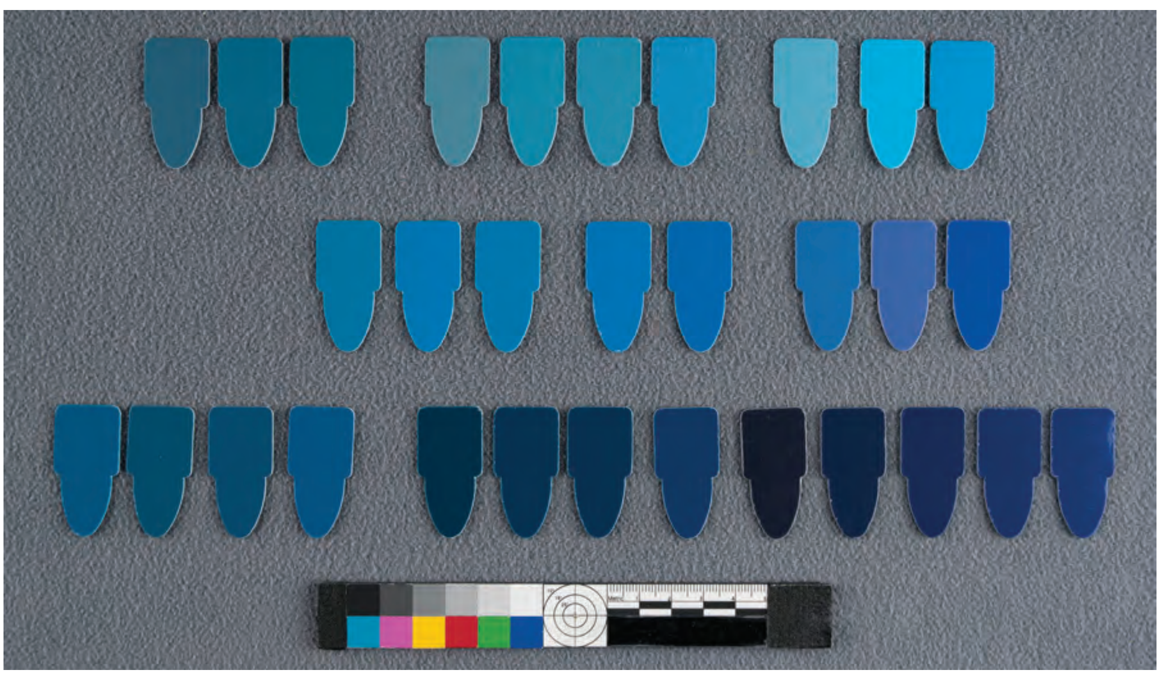

Fig. 10. Image of the blue Munsell color chips that correlated with the beads that had records of unstable glass. Munsell numbers from left to right of the upper row: 10B 4/4, 7.5B 4/6, 5B 4/6, 7.5B 5/4, 7.5B 5/6, 5B 5/6, 10B 5/8, 7.5B 6/6, 5B 6/10, 7.5B 5/10. Munsell numbers from left to right of the middle row: 7.5B 4/8, 7.5B 4/10, 5B 4/10, 2.5PB 4/10, 10B 3/10, 5PB 4/8, 7.5PB 4/8, 7.5PB 3/12. Munsell numbers from left to right of the lower row: 5B 3/8, 7.5B 3/6, 10B 3/6, 2.5PB 3/8, 2.5B 2/6, 10B 2/6, 2.5PB 2/6, 5PB 2/8, 7.5PB 2/2, 7.5PB 2/4, 7.5PB 2/6, 7.5PB 2/8, 7.5PB 2/10. (Courtesy of Robin O'Hern)

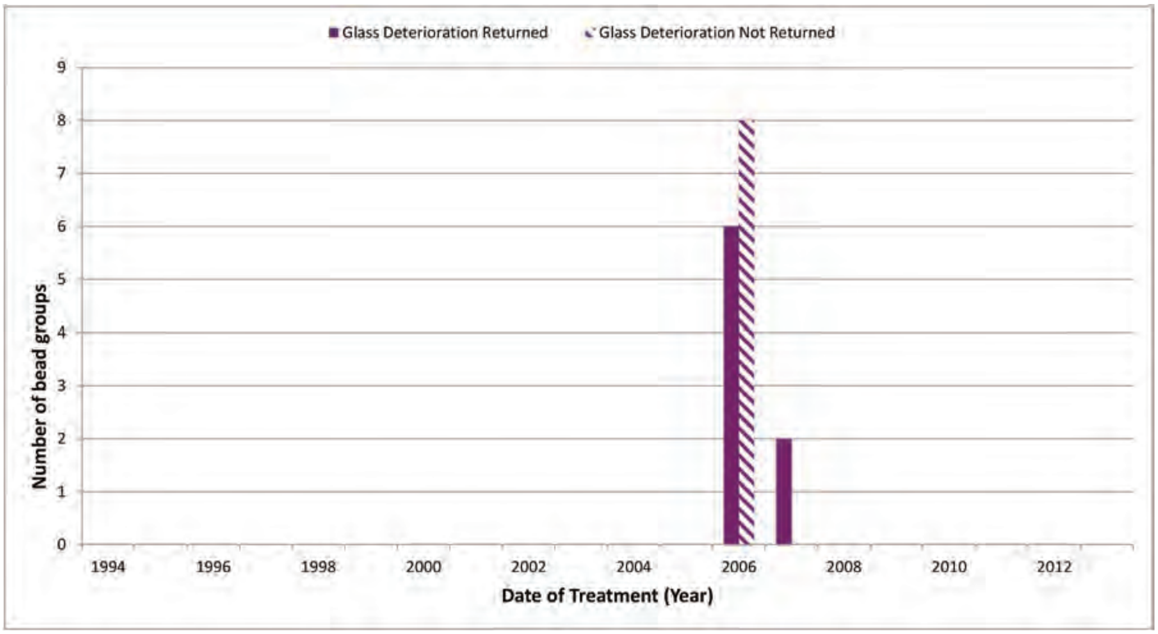

Fig. 11. Reoccurrence of deterioration on glass beads with records of unstable glass that were cleaned with deionized or distilled water (Courtesy of Robin O'Hern)

4.2.2. Does Cleaning Technique Matter?

We evaluated objects that had been cleaned 3–20 years previously. Not all the cleaning techniques were used across the same time span, which makes comparison difficult. The 16 red and blue bead types (fig. 11) that were cleaned with deionized or distilled water were all treated in 2006 and 2007 in preparation for an exhibition called Identity by Design. Half of the bead types cleaned with water have redeveloped alkaline surface salts and half of them have not over the past 7–8 years (table 2). We did not see any beads that had developed glass disease on the interior due to water wicking into the thread and creating a humid microenvironment, an issue found by Lougheed (1988). Similarly, other conservators also have not seen any facilitation of deterioration by using water to clean glass beads (Roundhill 2011).

The 21 bead types cleaned with 1:1 water: ethanol were treated over a wider period of time—from 2000 to 2009—which covers many different loans and exhibitions (fig. 12). The water component was either deionized or distilled water. Of the 21 beads cleaned with 1:1 water: ethanol, 52% of the beads redeveloped alkaline surface salts and 48% of the beads are still stable (table 2). There is not a strong correlation between duration since cleaning and redevelopment of alkaline surface salts: beads that were cleaned 5 years ago have both had glass disease redevelop and also remained stable, as have beads that were cleaned 13–14 years ago.

The 47 bead types cleaned with ethanol were treated over the widest period of time, from 1994–2011 (fig. 13). Forty-seven percent have redeveloped surface salts since cleaning (table 1). Once again, there isn't a strong correlation between duration since treatment and the redevelopment of glass deterioration; however, most of the beads cleaned in the 1990s have glass disease now. If the beads cleaned with ethanol are compared over the same period of time to the beads cleaned with 1:1 water:ethanol (e.g., from 2000 to 2009), then only 42% of the beads cleaned with ethanol have redeveloped glass deterioration. This suggests that using ethanol on its own may result in slightly fewer beads redeveloping glass deterioration; however, the surface salts will still eventually return. Further research could be done on why ethanol seems to delay the return of deterioration slightly more effectively

Table 2. Percentages of bead types per year that have had glass disease return by treatment material

Year	Number of Bead Types Cleaned with Water by Year	Percentage of Bead Types Cleaned with Water by Year that Have Redeveloped Glass Deterioration	Number of Bead Types Cleaned with 1:1 Water: Ethanol by Year	Percentage of Bead Types Cleaned with 1:1 Water: Ethanol by Year that Have Redeveloped Glass Deterioration	Number of Bead Types Cleaned with Ethanol by Year	Percentage of Bead Types Cleaned with Ethanol by Year that Have Redeveloped Glass Deterioration
1994	0	N/A	0	N/A	2	100%
1995	0	N/A	0	N/A	0	N/A
1996	0	N/A	0	N/A	2	100%
1997	0	N/A	0	N/A	1	100%
1998	0	N/A	0	N/A	2	0%
1999	0	N/A	0	N/A	1	100%
2000	0	N/A	1	100%	12	33%
2001	0	N/A	4	50%	2	100%
2002	0	N/A	0	N/A	10	40%
2003	0	N/A	2	50%	0	N/A
2004	0	N/A	2	50%	6	50%
2005	0	N/A	0	N/A	4	25%
2006	14	43%	3	100%	0	N/A
2007	2	100%	4	25%	1	100%
2008	0	N/A	2	50%	1	0%
2009	0	N/A	3	33%	0	N/A
2010	0	N/A	0	N/A	0	N/A
2011	0	N/A	0	N/A	3	33%
2012	0	N/A	0	N/A	0	N/A
2013	0	N/A	0	N/A	0	N/A
Total	16	50%	21	52%	47	47%

than the other techniques. It is possible that the ethanol has a dehydrating effect on the bead that removes some of the moisture present, which is causing the glass to deteriorate.

This second survey reinforced conclusions made during the first condition change survey. Measuring pH of beaded surfaces is critical in identifying which beads have alkaline surface salts and which are either dirty or contain culturally applied kaolin. Evaluating condition change based on an overall documentation image is very difficult. Detail photos are necessary to visually measure a change in the condition of a bead. It was the aim of the second survey to evaluate treatment methods used to remove surface salts on deteriorating beads at NMAI over a period of 20 years. The use of water, 1:1 water: ethanol, and ethanol were examined, and it was found that while there was no clear frontrunner, beads cleaned with ethanol had the lowest rate of return. It should be noted, however, that the rate of return could be influenced by more than just solvent choice/use alone. It was continually observed in the survey from 1999 that the interaction of beads with the substrate or sewing material affected the type or amount of salts present (Carroll and McHugh 2001). Additionally, the method of manufacture can affect

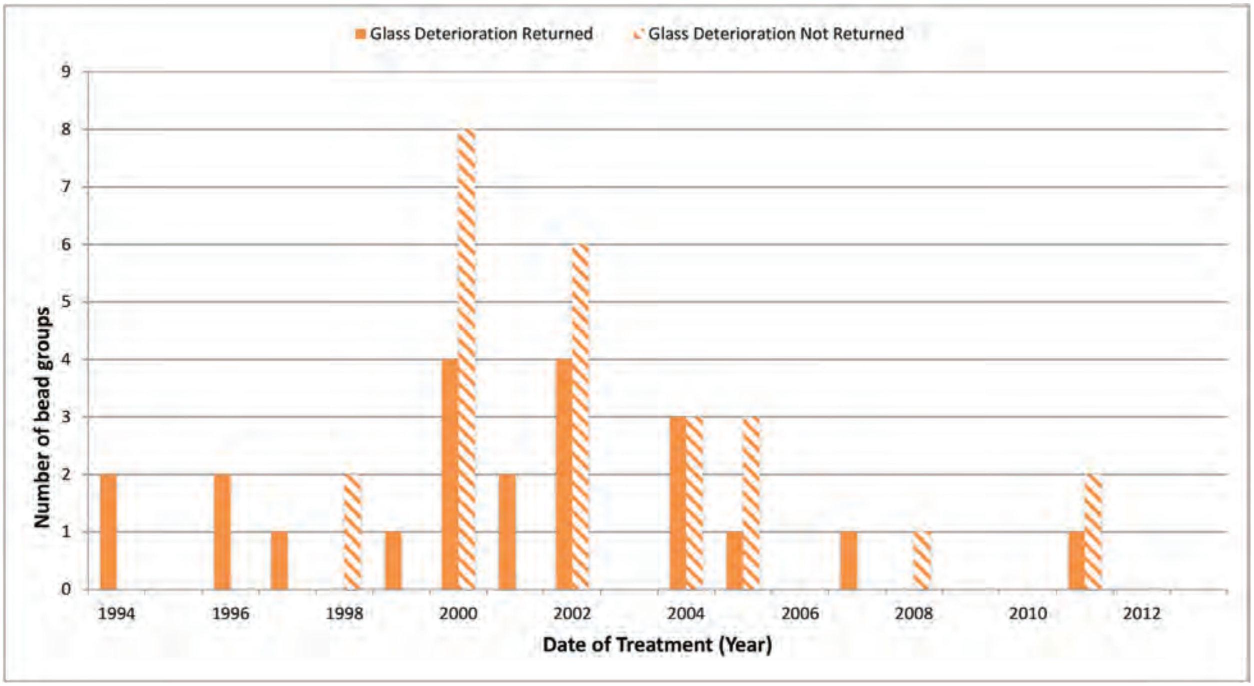

Fig. 12. Reoccurrence of deterioration on glass beads with records of unstable glass that were cleaned with 1:1 (deionized or distilled) water:ethanol (Courtesy of Robin O'Hern)

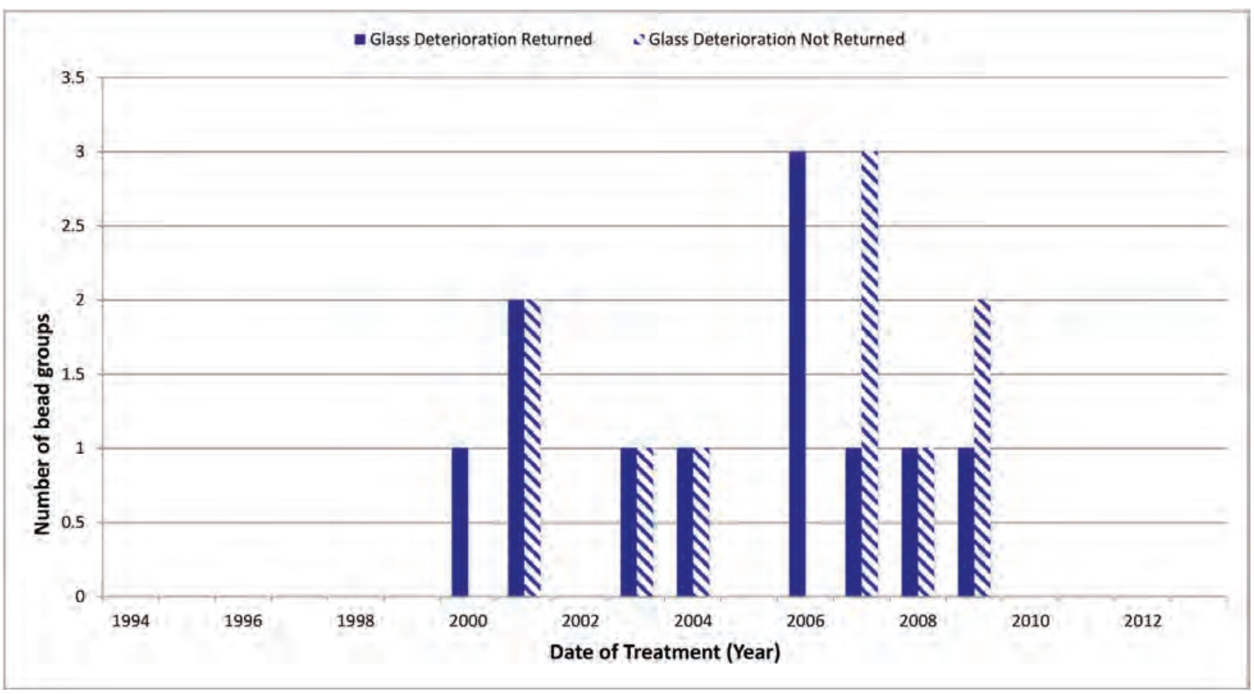

Fig. 13. Reoccurrence of deterioration on glass beads with records of unstable glass that were cleaned with ethanol (Courtesy of Robin O'Hern)

the way that glass beads deteriorate in terms of the glass composition, the direction of cracks, or the surface treatment (Sirois 1999, 85).

5. FURTHER RESEARCH

There are many different aspects of this project that merit further research. It would be beneficial to have a larger sample size of objects cleaned with the different techniques, particularly if they had more comparable date ranges. This would be best done through collaboration with another institution. We have considered surveying uncleaned objects known to have unstable glass to assess whether deterioration has progressed. The lack of detailed images makes comparison difficult, but we could resurvey only those objects that have sufficiently detailed images. Further research could also be done on why beads cleaned with ethanol seem slightly less likely to redevelop glass deterioration—does slightly dehydrating the bead during solvent cleaning help stabilize the bead? Additionally, what is the deterioration mechanism for beads whose surface accretions include oily or fatty components from the hide substrate?

It would be particularly beneficial to analyze the composition of the surveyed beads to look for additional correlations; for example, how much stabilizing calcium oxide is present in the beads and does that correlate with which have redeveloped alkaline surface salts? Or, does the alkali component (sodium oxide, potassium oxide, or lead oxide) seem to influence the deterioration of the bead? We are also interested in pursuing more information about the composition of the deteriorating black beads identified by our survey of the conservation records database because this color has received relatively little investigation.

6. CONCLUSIONS

Glass deterioration affects numerous beaded objects in the collection of the NMAI. These composite objects have conservation requirements different from unstable vessel glass or non-composite objects. The surveys found that there may be a correlation between the glass composition associated with manufacturing technique and the long-term stability of the glass. Seed and pony beads tend to make up the largest numbers of beads affected—perhaps due to the large numbers of those beads used on objects. Finally, blue, red, and black beads are the most unstable colors used on objects in the NMAI's collection.

The second survey evaluated cleaning methods and found that the results were very similar for water (50% of bead types had glass deterioration return), 1:1 water: ethanol (52% of bead types had glass deterioration return), and ethanol (47% of bead types had glass deterioration return). When the bead types cleaned with ethanol are compared over the same time with the bead types cleaned with 1:1 water: ethanol, then the rate of return of glass deterioration for beads cleaned with ethanol decreases to 42%. Revisiting these treatments was only made possible through the use of the NMAI's Collections Information System, allowing for objects containing glass disease and treatments for glass disease to be searched. Expanding the size of the survey group may offer different results; however, this project provides a foundation and a methodology in which to proceed with this evaluation. These studies confirm the importance of several conservation practices, such as recording treatment materials in reports and documenting post treatment condition with words and images, especially if the object is tagged as requiring long-term monitoring.

Glass deteriorates due to unstable composition, environmental factors, contact with substrates such as hide, and the way an object was used. Unstable glass composition is an inherent vice; therefore, distinguishing which beads might be more susceptible to glass disease is important. By assessing the distribution of unstable glass beads throughout the collection and understanding the mechanisms of deterioration, the authors aim to inform and identify beaded objects at risk of deterioration. This information can be used to assist in the long-term preservation of these important collections.

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NOTES

[1]The authors decided to record the information in separate questions so that the data could be analyzed more thoroughly. Seed and pony beads—the majority of those encountered in the surveys—are coded as Ia (undecorated tubular monochrome beads) or IIa (undecorated rounded monochrome beads) based on the Kidd and Kidd system as modified by Karklins (2012).

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ROBIN O'HERN is an Andrew W. Mellon Fellow in objects conservation at the National Museum of the American Indian (2012–2014). Robin has completed internships at the Walters Art Museum, the Straus Center for Conservation and Technical Studies at the Harvard Art Museums, Peabody Museum of Archaeology and Ethnology, the Agora Excavations of the American School for Classical Studies at Athens, the American Museum of Natural History, the Pitt Rivers Museum at Oxford University, and the Corning Museum of Glass. She received a Master of Theological Studies degree from Harvard Divinity School, where she studied religion and material culture, and holds a master of arts from the UCLA/Getty Program in archaeological and ethnographic conservation. Address: Smithsonian Institution National Museum of the American Indian, NMAI Cultural Resource Center, 4220 Silver Hill Road, Suitland, MD 20746. E-mail: OhernR@si.edu

KELLY McHUGH is an objects conservator at the National Museum of the American Indian (NMAI), where she has worked since 1996. She holds a MA in art history with a certificate in conservation from New York University's Institute of Fine Arts, and BA in art history and peace and global policy studies, again from New York University. She specializes in evolving NMAI's initiatives in collaborative conservation and in caring for the museum's contemporary art collection. Address as for O'Hern. E-mail: McHughK@si.edu

TECHNICAL STUDY OF THE BAT WING SHIP (THE HORTEN HO 229 V3)

LAUREN HORELICK, MALCOLM COLLUM, PETER McELHINNEY, ANNA WEISS, RUSSELL LEE, ODILE MADDEN

ABSTRACT

This article describes a technical study of the Horten Ho 229 V3, a unique World War II, German plywood jet affectionately called the Bat Wing Ship. The aircraft has been in the collection of the Smithsonian National Air and Space Museum since 1952 and has never been exhibited due to its badly deteriorated plywood skin. The jet has been popular with enthusiasts who believe it to be the first stealth fighter because the jet's designer is reputed to have once said he added radar-absorbing charcoal to the plywood, though no tangible evidence exists to support or refute this claim. Plans to move the fragile jet from storage for display provided an opportunity for a technical study to characterize its original, historic materials, to inform treatment approaches, and to clarify the historical record about the presence of "stealth materials." This article describes the characterization of the jet's wooden components, adhesives, paint layers, and inclusions within the adhesives by Raman and infrared spectroscopies, X-ray fluorescence spectrometry, polarized light microscopy, and X-ray diffraction. Findings were compared with historical accounts of WWII era experimental aircraft construction materials and techniques.

1. INTRODUCTION

The Bat Wing Ship is a one-of-a-kind German jet-powered aircraft that was built during World War II and now is part of the Smithsonian's National Air and Space Museum (NASM) collection (fig. 1). The aircraft is also known as the Gotha Go 229 and the Horten H IX V3 (described as the Horten in this article). The Horten is an experimental prototype designed by brothers Reimar and Walter Horten in 1945, and built by the *Gothaer Waggonfabrik* workshop (referred to as *Gotha* throughout). The designation "V3" relates to the version number of this particular airframe design. The Horten brothers had designed and built a V1 and V2, but both crashed catastrophically during test flights. They were in the middle of production of the V3 in 1945 when the Allies invaded Germany and found the *Gotha* workshop where the body of the jet was nearly complete. The wings were recovered from a different location. With twin jet engines, a plywood skin, and tubular steel framework, the Horten possesses an unconventional combination of the most advanced technologies of the time, paired with traditional materials. American and British journalists embedded with the Allied troops called the newly discovered and incomplete jet the "Nazi Bat Wing Ship" for its unique tailless (or all-wing) design for which the Horten brothers are known. The nickname Bat Wing Ship has stuck through to the present day (Myhra 2002; Shepelev and Ottens 2006; Lee 2011).

Another thing that stuck was an idea. Later in his life, Reimar Horten's aviation career was faltering. Possibly as an attempt to bolster his reputation, he promoted the idea that the Horten Ho 229 V3 was intended to be built as a stealth aircraft, which would have placed this jet's design a decade ahead of its time. Reimar Horten claimed that he wanted to add charcoal to the adhesive layers of the plywood skin of the production model to render it invisible to radar, because the charcoal "should diffuse radar beams, and make the aircraft invisible on radar" (Horten and Selinger 1983, Russ Lee translation). This statement was published in his 1983 co-authored book *Nurflügel* (which translates as "only the wing"). Although this statement refers to the never-made production model, it stands to reason that the experimental charcoal addition could have been used on the Horten Ho 229 V3 prototype. The mere mention of early stealth technology sparked the imagination

Fig. 1. The Horten Ho 229 V3 (plywood, wood, adhesives, ferrous alloy, aluminum alloy, and paint. 274 cm height, 762 cm length, 304 cm wide, with a 55.4 wingspan, constructed 1945 (NASM A1960 0324 000) (Courtesy of Eric Long, National Air and Space Museum, Smithsonian Institution)

of aircraft enthusiasts all over the world and spurred vibrant debate that is rich with conjecture and is ongoing in the aviation community; however, to date, there has been no tangible evidence to support or refute this claim.

The stealth myth has been growing since the 1980s and was invigorated when the National Geographic Channel, in collaboration with Northrup Grumman, produced a documentary called "Hitler's Stealth Fighter" in 2009. The program featured the Horten Ho 229 V3 as a potential "Wonder Weapon" that arrived too late in the war to be used (Myth Merchant Films 2009). The documentary also referred to the jet's storage location as "a secret government warehouse," which added to the mystique of this artifact. Since the airing of the documentary, public pressure has increased to remove the jet from its so-called secret government warehouse and put it on display. In fact, this warehouse is the Smithsonian Institution's Paul E. Garber Facility in Suitland, Maryland, where a team of conservators, material scientists, a curator, and aircraft mechanic has been evaluating the aircraft (fig. 2). After 70 years in storage, the plywood skin has deteriorated considerably, which complicates plans to relocate the aircraft to the museum where it can be exhibited with a more accurate interpretation.

2. MOTIVATION AND GOALS

The initial motivation for the current research was to develop a plan to safely move the jet from the Garber facility to the Steven F. Udvar Hazy Center (UHC) in Chantilly, Virginia, where it will be

Fig. 2. The Horten center section at NASM's Garber facility (Courtesy of Ben Sullivan, National Air and Space Museum, Smithsonian Institution)

exhibited. Moving the jet is complicated by its deteriorated condition (fig. 3). In particular, the plywood, which is a composite material composed of many layers of thin wood veneers bonded together with a polymeric adhesive, has suffered from water damage and fungal attack causing delamination and structural failure. The plywood is also the focus of speculation about stealth, so any attempt to consolidate the plywood before the move could interfere with characterizing the original, historic material. Curator Russ Lee was very interested to know if we could validate or debunk Reimar Horten's claim of charcoal within the plywood adhesives to create the world's first stealth aircraft; thus, the project goal expanded to include a search for physical evidence, derived from the artifact, to clarify the historical record. The comprehensive technical study also would inform the stabilization methodology before the jet's move and its eventual conservation treatment.

The jet incorporates many historic materials, but the research presented here focuses on the composite layered structure of the plywood and the search for charcoal. The technical study aimed to characterize the composite plywood panel construction, shown in figure 4. The panels that make up the aircraft's skin and underlying spacer blocks are plywood. We wanted to (1) characterize the wood species used to make the plywood veneers, structural supports, and spacer blocks; (2) identify the adhesives that bond the veneers into plywood boards and spacer blocks, and those that attach wooden structural supports to the plywood panels; (3) determine whether charcoal was added to the adhesives in concentration sufficient to make the jet invisible to radar; and (4) characterize the green protective coating found on the underside, and selectively on the top surfaces of the plywood panels.

Fig. 3. Details of delaminated plywood veneers on the tail and side of the jet (Courtesy of Ben Sullivan, National Air and Space Museum, Smithsonian Institution)

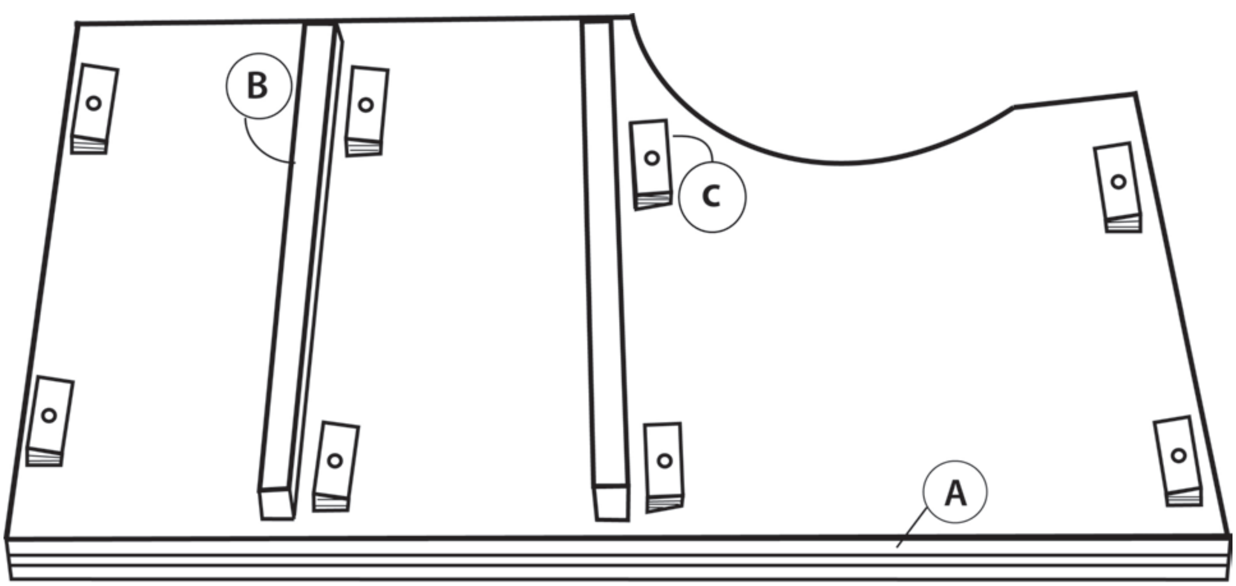

Fig. 4. Diagram of a plywood panel composed of (a) wood veneers adhered at 90 degrees to one another forming a plywood board, (b) structural supports adhered to the plywood board, and (c) spacer blocks made from wood veneers adhered together (Courtesy of Lauren Horelick)

In the conservation field, technical studies of macro-technological artifacts, such as air and spacecraft, are unusual because typically the production specifications are available. This is not the case with the Horten because it was constructed toward the end of the war when resources were scarce, supply lines were compromised, and record keeping was perfunctory. Additionally, there is no documentation from the *Gotha* workshop about material specifications. Our technical study aimed to compare physical evidence on the jet with historical wartime accounts of materials used to contextualize our findings.

3. THE HORTEN HO 229 V3: CONSTRUCTION, ACQUISITION, AND CONDITION

The Horten stands 9 ft. tall, has a 55-foot wingspan, and is 22 ft. long. It is constructed in five main sections: a center section made from a steel tubular framework that encompasses two engines, the cockpit, the landing gear, and two wings. The center section framework is covered with a plywood skin made up of multiple panels that are attached to structural wooden supports with steel hardware. Steel fairings protect the engines at the back of the aircraft and are secured over the plywood to protect the wood from exhaust heat (fig. 5). A green protective coating is present on the interior surfaces of the plywood panels and selectively on the exterior wooden surfaces. The wings are constructed of wooden structural members and plywood skin.

The exterior surface paint that we see on the Horten today dates to its postcapture history. Before the aircraft entered the NASM collection, the United States Army displayed it in 1946 at Orchard Park, which is now Chicago O'Hare International Airport. At that time, the army attached the wings to the jet, added aluminum panels to uncompleted areas, and painted the exterior gray-blue. They added swastikas to the tail and stenciled numbers on the engine fairings (Myhra 2002; Shepelev and Ottens 2006).

The National Air Museum (as NASM was called then) acquired the Horten in 1952 when there was a shortage of storage facilities. Consequently, it sat outdoors in wooden crates from 1952 until 1974, and that is where most of its condition issues originate. Extensive plywood veneer delamination, material loss, biological growth, and coating delamination are evident throughout the aircraft. The metal components are corroded, fasteners have failed, and numerous small parts are missing.

The plywood skin has presented the biggest conservation dilemma. We needed to stabilize this material before moving the jet, and conservation treatment potentially conflicted with our desire to study the plywood. The solution was to carefully disassemble the fragile metal fairings and plywood panels. Each part was carefully packed and shipped to NASM's Emil Beuhler conservation laboratory at UHC. This allowed us to study the plywood panels with their associated protective coatings in an undisturbed state.

Fig. 5. Illustration showing the (A) tubular framework with engines, (B) plywood support structure, (C) plywood skin and metal fairings (Courtesy of Arthur Bentley)

4. RESEARCH METHODOLOGY

4.1 LITERATURE REVIEW

A literature review of plywood technology was the starting point for developing a list of likely materials that we could expect to find on the Horten as well as the techniques by which they were applied. The research emphasized natural and synthetic plywood adhesives and protective coatings that were in use in Germany before and during World War II. In addition to published literature, many sources were found in the "Combined Intelligence Objectives Sub-Committee Reports" found in the Library of Congress and "German Captured Air Technical Documents," which are microfilmed in NASM's archives. The Combined Intelligence reports (ca. 1946) are summaries and full manuscripts of interviews and interrogations conducted by British and American intelligence officers who gathered detailed information about German industry and individuals of interest, including the Horten brothers. The German Captured Air Technical Documents are scientific reports from 1943 to 1946 acquired by the Allies from German factories and laboratories. These reports, largely in German, describe material property tests of plywood, wood veneers from differing species, adhesive formulations, and protective coatings.

4.2 REFERENCE MATERIALS

Reference samples of cured thermosetting urea and phenol formaldehyde resins were obtained from Georgia Pacific Chemicals. Mr. Matthias Schleinzer and Mr. Josef Griener of Bitz Co., Mr. Hans Vornlocher of Eichelsdörfer (both aircraft restoration companies), and Peter Selinger provided plywood samples made of adhesives mentioned in the literature review. Wooden elements on the Horten were compared to a set of wood reference samples prepared by wood identification experts Dr. Terry Conners, from the University of Kentucky, and Larry Osborn from the University of West Virginia.

4.3 SAMPLING METHODS

A protocol was established for removing small samples from representative and undeteriorated areas of the Horten. Samples of plywood in cross section, individual veneers, adhesives, inclusions within the adhesives, and original protective coatings were carefully recorded, numbered, and photographed with a high-resolution Hirox KH-7700 digital microscope.

Sampling the plywood was initially complicated due to the extensive deterioration, which made obtaining intact samples difficult; however, once we removed the steel fairings we discovered areas of sound wood that had been protected from the elements and chose to take our samples from there.

In our search for charcoal in the plywood adhesives, two methods were devised to extract black particles for analysis:

Method 1: The adhesive was crushed with a mortar and pestle, followed by soaking in sodium hydroxide (pH 14) for several hours to further break apart the adhesive matrix and release any inclusions. Particles were pipetted onto a glass slide, allowed to dry, and the black particles were separated out with tweezers.

Method 2: Intact samples of adhesive were prepared into thin sections (30–50 μm) by embedding the sample in clear polyester resin, followed by cutting the cured resin sample with a diamond blade saw, and polishing with Micro-mesh sheets. Samples were examined and photographed with a Nikon, Eclipse E600 POL Research Microscope equipped with a Leica DFC290 HD camera in transmitted, bright field, and under crossed polarization.

4.4 ANALYTICAL TECHNIQUES

Scientific analysis of samples and reference materials was performed at the Smithsonian's Museum Conservation Institute (MCI) and NASM using multiple techniques.

Polarized light microscopy was used to examine the Horten's adhesives, wood, paint, and black particles extracted from the adhesive. Samples were examined on glass microscope slides with a Nikon, Eclipse E600 POL Research Microscope using transmitted light in bright field and crossed polarization with a magnification range of 50–1000x.

FT-Raman spectroscopy (FT-Raman) was performed with a NXR FT-Raman module coupled to a Thermo Nicolet 6700 FTIR spectrometer (Thermo Electron Corporation, Madison, Wisconsin, USA). The NXR module was equipped with a continuous wave Nd:YVO_4 excitation laser (1064 nm), CaF_2 beam splitter, and thermoelectrically cooled InGaAs detector. Instrument control, data collection, and spectral interpretation were managed by OMNIC 7.2a software (Thermo Fisher Scientific). Laser power was chosen empirically to optimize spectral quality and minimize risk to the samples. No baseline correction or smoothing was applied.

FTIR was carried out on reference adhesives, Horten adhesives and green paint samples with a Thermo Nicolet 6700 FTIR spectrometer in attenuated total reflectance (ATR) mode with a single bounce, 45° Golden Gate ATR accessory with diamond crystal, and an electronically cooled DTGS detector. Spectra were a co-addition of 64 scans at 4 cm^{-1} spectral resolution, and were ATR corrected. Each sample was analyzed three times.

XRF was performed with a Bruker Tracer III-V handheld XRF spectrometer equipped with a rhodium anode. Spectra were collected without a filter at 40 kV for 120 seconds live time accumulation. Spectra were collected and examined with SiPXRF software followed by observation with Artax software.

XRD was used to identify the black particles in the adhesive matrix. The instrument was a Rigaku D/Max Rapid Micro X-ray Diffractometer with copper target and operated at 50 kV, 40 mA, and 2.00 kW. Samples were mounted on a glass fiber with Elmer's jell.

5. RESULTS AND DISCUSSION

5.1 LITERATURE REVIEW

The literature review provided valuable information about plywood technology. In particular, plywood production methods of German industry from 1930 to 1945 are described in the Combined Intelligence reports. These reports document that European birch was originally specified for aircraft plywood veneers, but beech was soon introduced for reasons of supply (Knight et al. 1945). The reports describe how thin veneers were created by peeling water soaked logs along the tangential plane. The veneers were dried, and a layer of synthetic or natural adhesive was applied to the tangential planes and the veneers were stacked one atop the next with the wood grain aligned at ninety degrees. Alternating grain direction created a strong, multilayered composite material and overcame the inherent weakness of wood across the grain (Perry 1942; Gordon 2006). The Combined Intelligence reports describe extensive experimentation to produce lightweight composite plywood that would have excellent performance characteristics, including resistance to moisture, biological attack, excesses in heat and cold, jet fuel, and extreme physical stresses. Protective coatings for wood that were intended to impart properties such as waterproofing, fireproofing, temperature indication, invisibility to infrared photography, resistance to petrol, and heat are also described.

Synthetic adhesives developed for aircraft plywood are described extensively in the Combined Intelligence reports. The reports indicated that phenol formaldehyde and urea formaldehyde adhesives were extensively used for plywood construction. Trade names of various types of adhesives and their chemical composition mentioned in these reports are listed in table 1. The Horten brothers were also interrogated as part of post war intelligence gathering (Blot 1945). In their interview, they give explicit details about the materials and construction of many of their tailless aircraft; for example, they went so far as to offer that the wings of the V2 were constructed with a urea formaldehyde resin with the trade name *Kauritleim W and Kauritleim WHK* adhesives (Blot 1945). Unfortunately the Horten Ho 229 V3 is not mentioned at all.

Table 1. WWII-era German Adhesive Trade Names, Chemical Composition, and Preparation

Adhesive Trade Name	Chemical Composition	Preparation
Kaurit/ Kauritleim	Urea formaldehyde	Prepared with urea formaldehyde with 10–40 % beech wood flour or potato meal.
Kaurit W Pulver	Urea formaldehyde	Prepared by 1 mol of urea and 2 mol of formaldehyde (30% solution) reacted together to form a 36% resin solution. This was concentrated by heating (65 degrees C) in [vacuum]. Then 8–10% of wood, rye, or potato flour was added to yield a mixture composed of 55% resin, 10% flour, and 35% water neutralized to pH 7 with sodium hydroxide.
Kaurit MS-Pulver	Urea formaldehyde	Prepared from *Kaurit W. Pulver*, potato meal, wood flour, and methyl cellulose.
Kaurit WHK-Pulver	Urea formaldehyde	Prepared from *Kaurit W-pulver,* and *Trolitan-Prossabfallo*, a phenolic powder prepared from rejected moldings or flash at Troisdorf, which is ground and passed through a 0.3 mm sieve.
Polystal	Poly-isocyanate resins	Made by the reaction of a di-isocyanate with a polynydroxy compound.
Polystal U II	Isocyanate resin	Mixture of toluene and hexamethylene di-isocyanate and ethyl acetate. These are mixed in the proportion of 40 parts UI to 100 parts U2 immediately before applying.
Tego-film/ Tego glue	Phenol formaldehyde	Prepared by precipitating phenol formaldehyde onto a sheet.

5.2 CHARACTERIZING WOODEN ELEMENTS

5.2.1 Plywood Veneers and Spacer Blocks

Cross sections of the Horten's plywood skin showed a composite structure whereby 5-ply plywood sheets were laid up, one on top of the other, to form a thick plywood board (fig. 6a detail of a 5-ply assembly). The veneer thickness within each one ply was measured at approximately 0.2 mm, which is consistent with historical research of wartime aircraft plywood production (Perry 1942; Lacey et. al 1945). The species of wood used for the veneers was identified as European beech (*Fagus sylvatica*) on the basis of the distribution and width of ray cells on the tangential plane, which is all that is available for observation when the sample is a thin veneer (fig. 6b). The species of wood used for the veneers of the spacer blocks was also identified as European beech from the same microfeatures observed in the tangential plane, but these veneers were rotary cut to a greater thickness (1 mm) (figs. 6c, 6d).

5.2.2. Structural Supports

The structural supports are solid lengths of milled wood; the species was identified by observation of the wood in the transverse section, and the regular, radially aligned arrangement of cells indicates that the material is softwood. The presence of resin canals immediately narrowed the species identification to one of four genera-*Picea, Larix, Pinus,* and *Pseudotsuga* (Spruce, Larch, Pine, Douglas-fir). The distribution of resin canals and associated cells, and the abrupt transition from early to late wood were also of diagnostic value (figs. 7a, 7b). Lemon-shaped cross-field pits were also observed in the

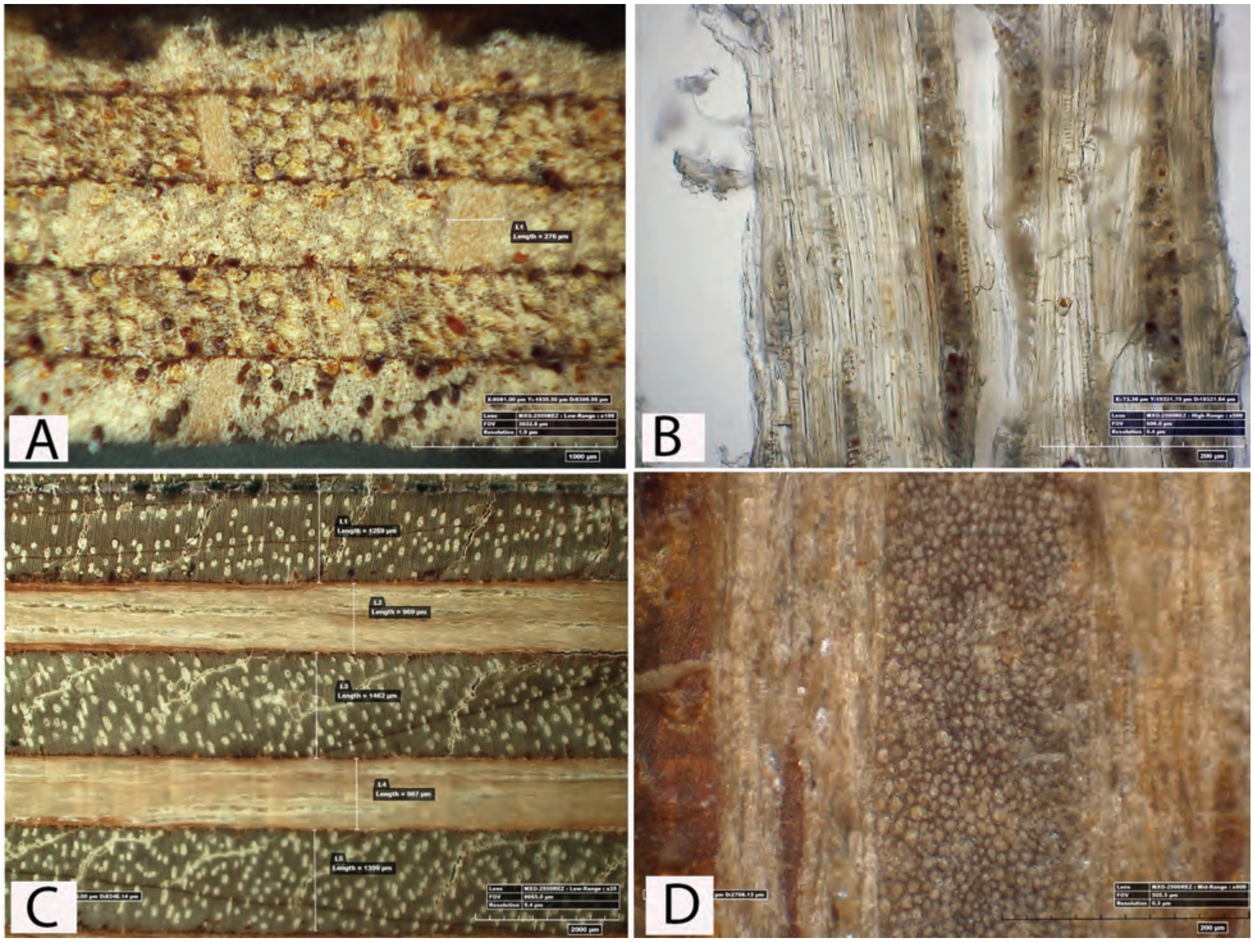

Fig. 6 (a) Detail cross section of the Horten's plywood skin showing the construction of a 5-ply board, (b) tangential view of the veneer showing the diagnostic ray width and distribution, (c) cross section of spacer block construction with 1 mm thick veneers, (d) tangential view of spacer block showing a diagnostic ray (Courtesy of Peter McElhinney)

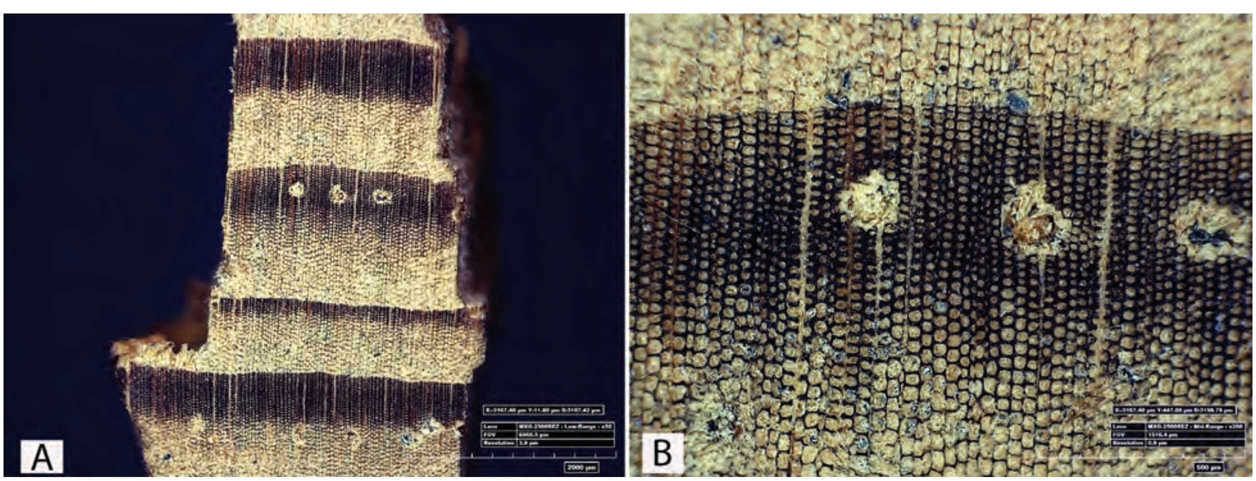

Fig. 7 (a) Transverse view showing regular, radially aligned arrangement of cells and abrupt transition from early to late wood, (b) detail of resin canals in transverse plane (Courtesy of Peter McElhinney) lumber sample (known as fenestriform pits) in combination with dentate walls in the ray tracheids, both of which are characteristic of Scots pine (*Pinus silvestris L.*).

Although historical research helped narrow down either European beech or silver birch (*Betula pendula*) as the two most likely species of wood that could have been used for the plywood veneers, the choice of Scots pine for the structural supports is somewhat unusual, as it does not appear to be a widely recognized aircraft wood. Spruce is typically preferred for wooden aircraft structural members, primarily for its excellent strength-to-weight ratio. The natural habitat range for spruce in Europe includes all but the most Southern regions of Norway, Sweden, and Finland, and would therefore appear to have been available to the Germans at the time of production. It is unclear at this time why this particular species of pine was selected over spruce, other than as a result of material shortages prevalent toward the end of World War II (Markwardt 1930).

5.3. CHARACTERIZING ADHESIVES

5.3.1 Adhesive Along the Structural Supports and Spacer Blocks

A thick adhesive bead is found consistently around the structural supports and gluing together the spacer blocks. This adhesive is hard, brittle, and black; however, under the microscope, the samples have multiple, colorful inclusions (figs. 8a–8d). Samples taken from varying locations around the jet's

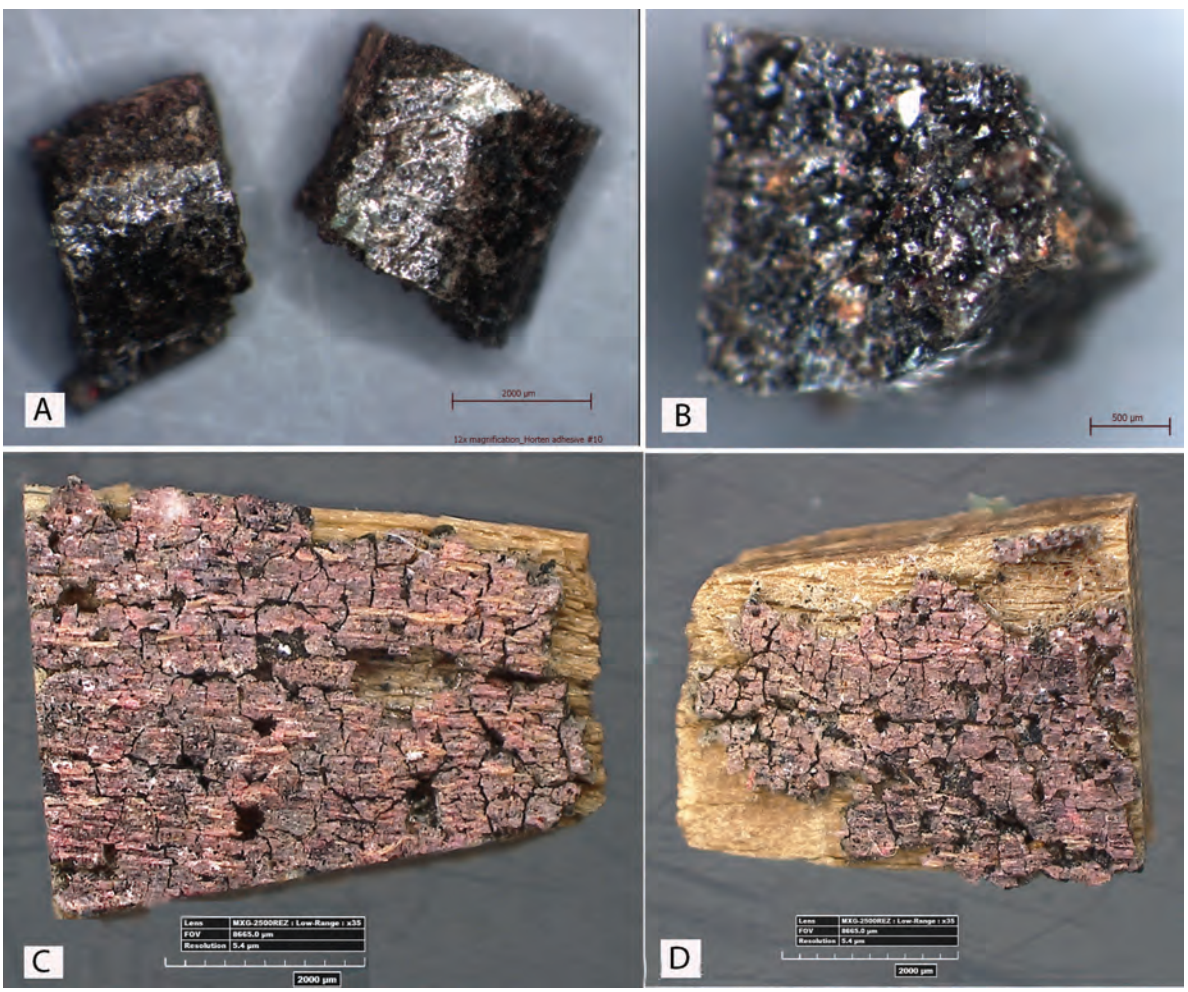

Fig. 8 (a)(b) Adhesive samples from around the structural supports, and (c)(d) pink and black material is the adhesive layer used to form the spacer blocks (Courtesy of Lauren Horelick and Anna Weiss)

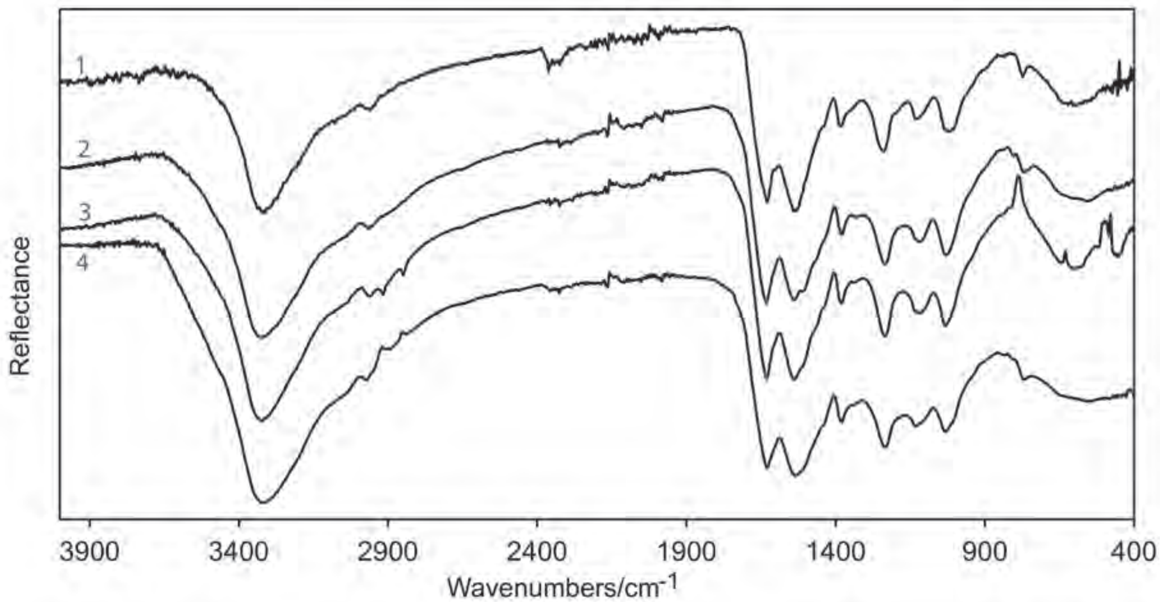

Fig. 9. Spectrum (1) Georgia Pacific cured urea formaldehyde reference spectrum; spectrum (2–4) adhesive from structural support locations from sample numbers 8, 3, and 10 (Courtesy of Lauren Horelick and Odile Madden)

structural supports were characterized with FTIR and generally resulted in a consistent match with one another and with the reference sample of cured urea formaldehyde (fig. 9). Although there are subtle variations between the Horten samples and a modern reference of urea formaldehyde, spectra share peaks at 3314, 1630, 1541, 1380, 1240, and 1019 cm^{-1}. Other physical characteristics, such as insolubility to a variety of organic solvents, resistance to strong acids, but weakness to strong bases increased our confidence that the adhesive bead is urea formaldehyde (Eckelman 1997).

The adhesive binding the spacer block veneers was also identified using FTIR as urea formaldehyde. Figure 10 compares the adhesives found within four different spacer blocks veneers to the reference spectrum of urea formaldehyde.

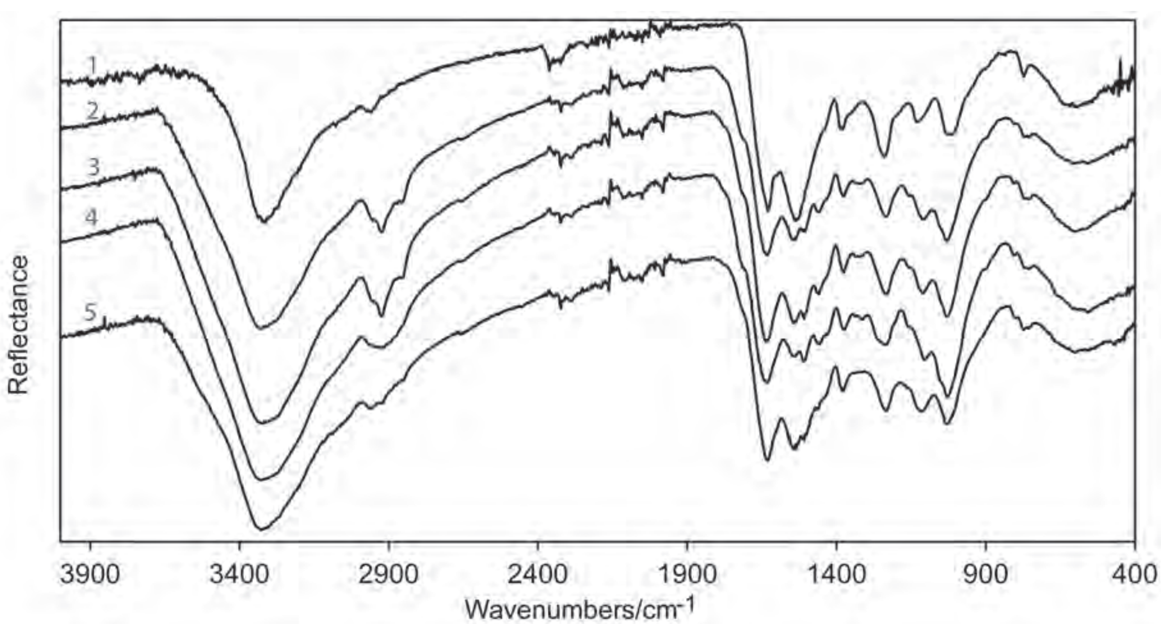

Fig. 10. Spectrum (1) cured urea formaldehyde reference spectrum from Georgia Pacific Chemicals; spectrum (2–5) adhesives holding together four different spacer blocks (Courtesy of Lauren Horelick)

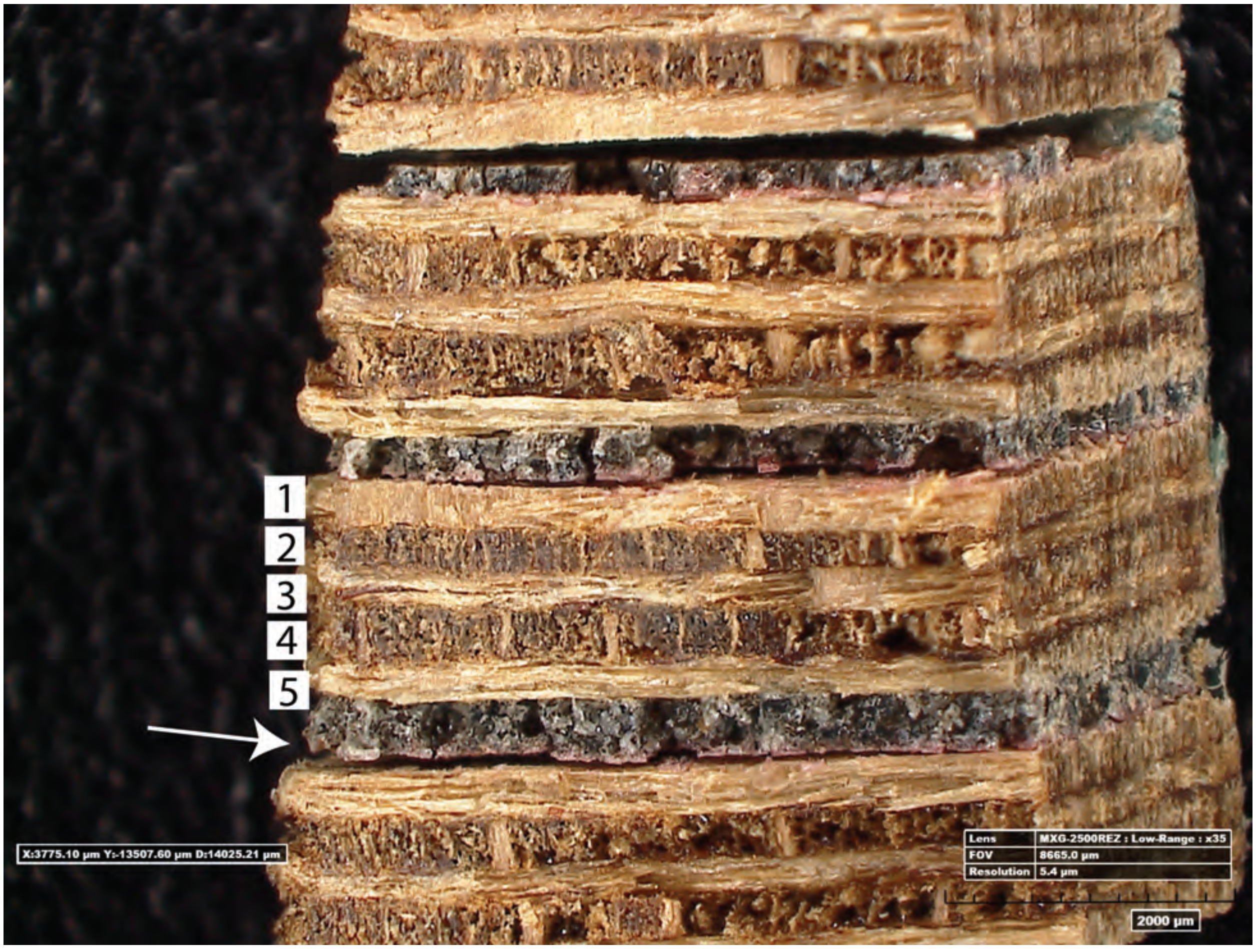

Fig. 11. Annotated cross section of Horten plywood showing the layering (1–5) of 1-ply boards that are adhered together with a thin, translucent amber colored adhesive. Each of the 1-ply boards is composed of approximately 20 veneers. The white arrow points to the thick, black colored adhesive layer that joins the 5-ply assemblies to one another. (Courtesy of Peter McElhinney)

5.3.2. Adhesives Used to Create the Plywood Boards

Cross sections of plywood show a layered structure of 5-ply sub-assemblies stacked one on top of the other with a thick black adhesive, as seen in figure 11. The individual 5-ply sub-assemblies, composed of many thin veneers, are adhered with a thin layer of a translucent amber material. Each 1-ply board is composed of approximately 20 veneers. Attempts to peel apart these veneers and the boards to separate the amber colored adhesive layer resulted in barely usable, tiny fragments of the amber colored material with wood still strongly adhered. FTIR spectra were dominated by the signal of cellulose and were not diagnostic for the amber material. With FT-Raman spectroscopy, we were able to analyze an intact cross section by focusing the laser on the amber adhesive layer. The resulting spectrum shared many diagnostic peaks with a reference sample of phenol formaldehyde (fig. 12). Peaks that were not attributed to phenol formaldehyde were consistent with cellulose in the adjacent wood. Phenol formaldehyde is further characterized by its translucent amber color and historic use as plywood adhesive (Perry 1942; Sutton 1963).

In between the 5-ply assemblies is approximately 0.3–0.5 mm thick black material that shared similar color, texture, brittleness, and distribution of inclusions as the adhesives found in between the spacer blocks and around the structural supports. The thicker layer was identified with FTIR, again resulting in a match with the reference sample of urea formaldehyde.

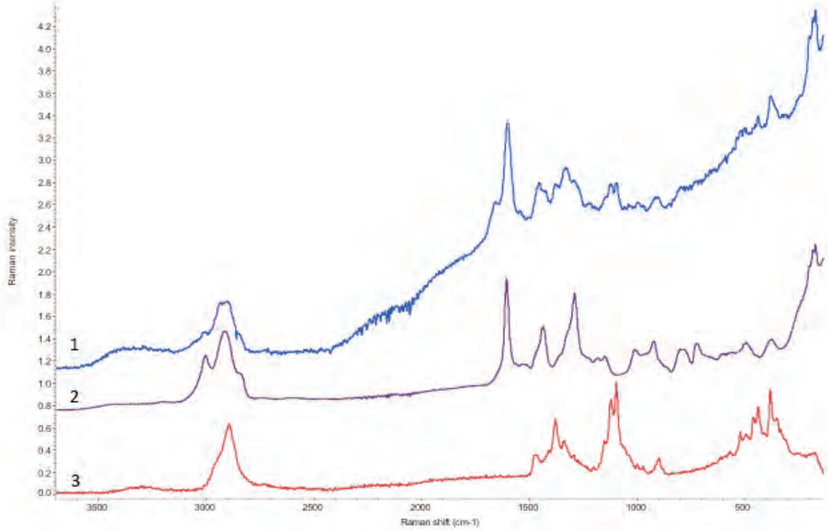

Fig. 12. Spectrum (1) is the amber colored resin layer, (2) reference spectrum of phenol formaldehyde from Georgia Pacific Chemicals, and (3) reference spectrum of cellulose powder (Courtesy of Odile Madden)

Adhesives listed in table 1 and used on historic plywood samples provided to the project by German aircraft restoration companies were characterized with FTIR and Raman in an attempt to correlate these specific materials with those on the jet. Although this work is still in its preliminary phase, comparative spectra of *Kaurit WHK* (a urea formaldehyde–based thermosetting adhesive) and the urea formaldehyde–identified adhesives on the jet revealed many similarities. Figure 13 shows a spectrum from each adhered wood component (in between the spacer blocks, in between the plywood boards, and around the structural supports) compared with *Kaurit WHK*. Although further characterization of the *Kaurit WHK* is needed to conclusively connect the use of this material with what is on the Horten, the spectra in figure 13 suggest a correlation.

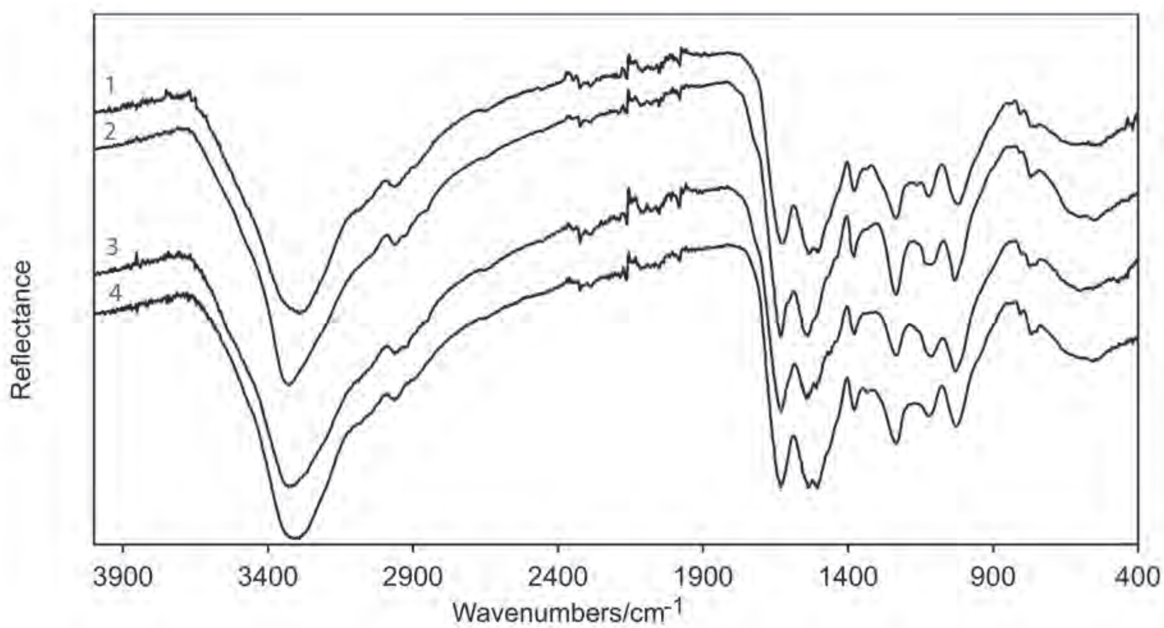

Fig. 13. Spectrum (1) is of *Kaurit WHK* adhesive sample compared with the black adhesive found consistently to match the urea formaldehyde reference sample from locations around the jet. Spectrum (2) is the adhesive from in between the 5-ply assembly. Spectrum (3) is the adhesive from the spacer block. Spectrum (4) is the adhesive used around the structural supports. Spectra 2–4 show close similarities to the *Kaurit WHK.* (Courtesy of Lauren Horelick)

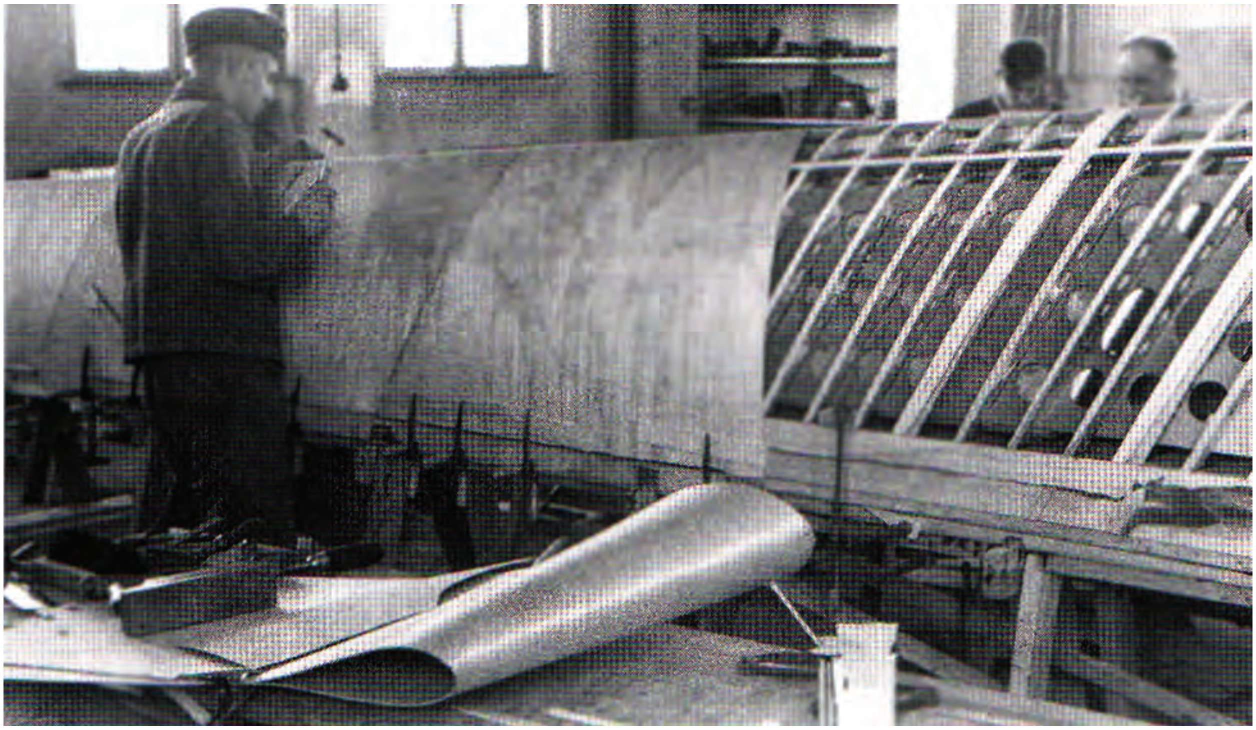

Fig. 14. Image of Horten workers assembling V2 wings. Note the plywood veneer in the foreground and the row of C-clamps at the edge of the wing under construction. (Courtesy of Myhra 2002)

The discovery of urea formaldehyde as an assembly material in three separate locations strongly suggests this as the adhesive material choice of the *Gotha* workshop for assembling the Horten. The FTIR and Raman spectra of the adhesives found within the plywood skin illustrate the use of pre-fabricated phenol formaldehyde bonded 5-ply plywood. *Gotha* workshop craftsmen must have added 5-ply boards to cover over the framework, layer by layer, to achieve the desired thicknesses using urea formaldehyde in between each board's layer. Historical references to urea formaldehyde's use for aircraft indicate its application as a liquid with a working time of up to 4 hours after mixing. It will cure at minimum room temperatures of 70°F, although the quality of the bond is improved and its cure accelerated by the application of heat up to 140°F (Nichols 1943). Historic images of Horten workers assembling the wings of the V2 show the use of clamps and jigs as opposed to ovens or presses (fig. 14).

5.4 SEARCHING FOR STEALTH MATERIALS

The adhesives and wood identification research was somewhat straightforward in both designing a methodology and obtaining results. Searching for the stealth materials was less so. Reimar Horten stated that he wanted to add charcoal to the adhesive layer of the plywood skin, but as we discovered, there are two adhesive layers used to form the plywood skin. The phenol formaldehyde plywood boards were ruled out as a layer to investigate due in part to their pre-fabrication, the absence of inclusions in the adhesive layer, and the fact that phenol formaldehyde does not readily accept filler material (Perry 1942). The consistent use of urea formaldehyde by the *Gotha* workshop suggested this was the only layer in which charcoal could be added. Urea formaldehyde's properties include its ability to accept fillers and extenders, which is consistent with our samples showing multiple inclusions. In particular, we noted suspicious black particles in the adhesive matrix, clearly visible with optical microscopy. Two different methods were devised to isolate these black particles for characterization, which were thin sections and dispersions, as seen in figures 15a–15f.

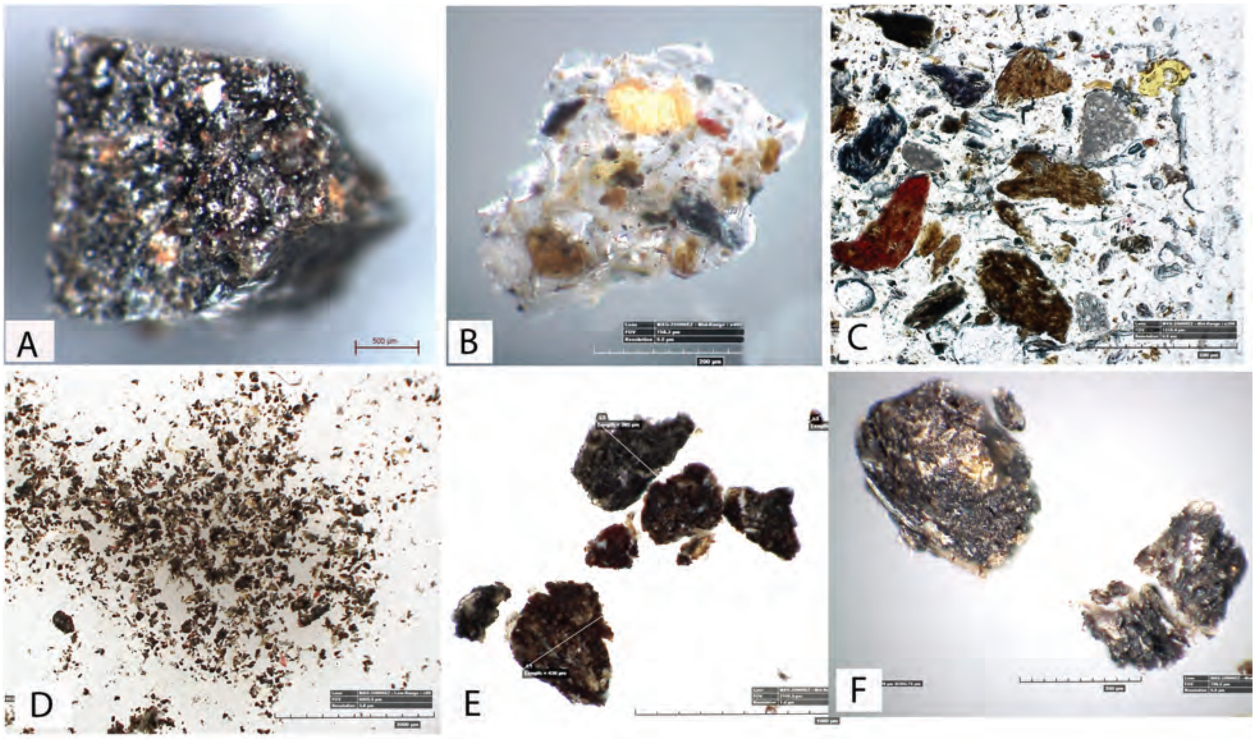

Fig. 15 (a) Adhesive along the structural supports before any manipulation, (b) adhesive once it has been crushed with a mortar and pestle, (c) thin section of adhesive, (d) dispersion of the adhesive, (e) isolated black particles showing measurements between 1 and 436 µm, (f) isolated black particles measured at 200 µm (Courtesy of Anna Weiss and Lauren Horelick)

Under the microscope, the black particles range in size from 1 to 436 µm. They are irregular, rounded, and opaque overall, whereas some particles exhibited red, gray, and blue hues around the edges. With PLM some of the particles were anisotropic, which is not a characteristic of charcoal, according to the particle atlas (McCrone Atlas of Microscopic Particles 2012). Observation of the thin sections with PLM revealed inclusions within the black particles that were anisotropic, appeared fibrous, and exhibited interference colors. Comparatively, charcoal is both isotropic and completely opaque at sub-micron sizes. The thin sections also permitted us to see the location and density of distribution of the black particles within the adhesive matrix. Figure 15c shows a scattered distribution of these particles, as opposed to a cohesive and dense layer.

XRD resulted in an amorphous pattern, which does not rule out the presence of charcoal. With FTIR the black particles resulted in a spectrum showing clear peaks, which is atypical for charcoal, which can block infrared light without producing spectral bands (fig. 16); however, depending on how the charcoal was processed, it will produce a spectrum (Cohen-Ofri et al. 2006; Esteves et al. 2013). In the spectrum of the suspicious black particles, we see a peak attributed to cellulose and hemicellulose at 3300, 2918, and 1029 cm^{-1}. The peak around 1700 cm^{-1} is the C=O bond that may be from oxidation. The peaks around 1600, 1500 and 1250 cm^{-1} relate to a phenolic, whether it is from lignin, a natural phenolic in the wood, or from the presence of a phenolic resin is uncertain (Ellen Nagy of Georgia Pacific Chemicals, personal communication 2014). The FTIR spectrum suggests that rather than discrete particles of charcoal within the adhesive matrix we are finding oxidized, or very aged, wood.

The Combined Intelligence reports state that after 1940 shortages of raw casein and dried blood as plywood adhesives forced the use of *Kaurit* exclusively, which could be extended by adding 10 to 40%

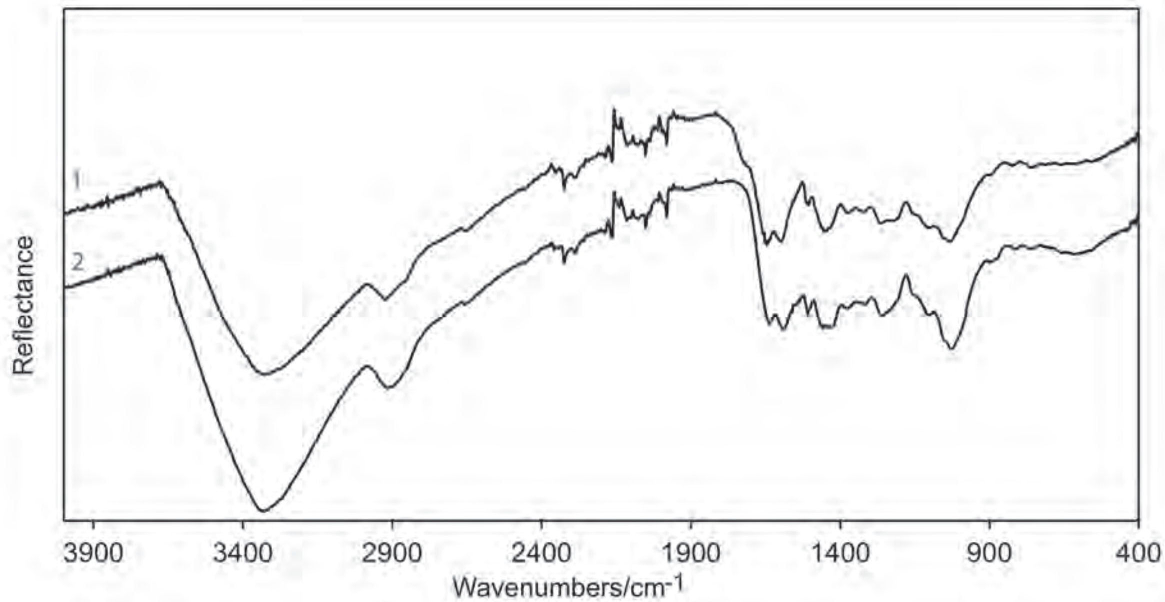

Fig. 16. FTIR spectra of black particles from two different adhesive locations on the jet. Spectrum (1) is from black particles extracted from the adhesive located in between the plywood; spectrum (2) is the black particles extracted from the adhesive around the structural supports. (Courtesy of Lauren Horelick)

beech wood flour or potato meal (Knight et al. 1945; Palmer et al. 1945). Although more study is needed to fully characterize the *Kaurit*, it may be possible that the black particles we see in the adhesive matrix could relate to oxidized beech wood flour thereby explaining the peaks for cellulose, hemicellulose, and the presence of phenols in the spectrum of the black particles.

The search for charcoal as the stealth material at this stage in the research appears inconclusive; however, a more macro view of the problem can be seen in the plywood cross sections, where there is a marked absence of a thick layer of anything except the adhesive. A cohesive and measurable layer of radar absorbing charcoal in between the plywood would suggest a concentrated effort at experimenting with stealth materials. Despite our best efforts to either validate or debunk Reimar Horten's claim, the fact remains that we have a dilemma of scale in pursuit of identifying this material. The problem of looking for something tiny, like charcoal particles, within something huge, like a jet, is that it opens the door for speculative thoughts about looking and sampling in the right or wrong location. We characterized a material within the plywood adhesive that shares many commonalities with charcoal, but is not clearly and definitively charcoal. Reimar Horten's published statement in the 1980s about wanting to add charcoal to the production model is also not to be overlooked, as a production model was never fabricated, only our prototype.

5.5 CHARACTERIZING THE GREEN PAINT

Our final goal for the technical study was to characterize the green paint, found on the interior and selectively on the exterior of the plywood panels. The green paint is obscured on the exterior surfaces with over paint applied in 1946 by the United States Army; however, some wooden surfaces that were covered by metal fairings exhibited untouched green paint that we speculated was some kind of protective coating (fig. 17). This particular green tint was rather unusual, even among veteran NASM restoration specialists experienced in working with German aircraft. We, therefore, set about characterizing this paint and sought out historic references that might describe its purpose.

Fig. 17. View of Horten tail section with the metal fairing removed, revealing plywood coated with green paint (Courtesy of Eric Long, National Air and Space Museum, Smithsonian Institution)

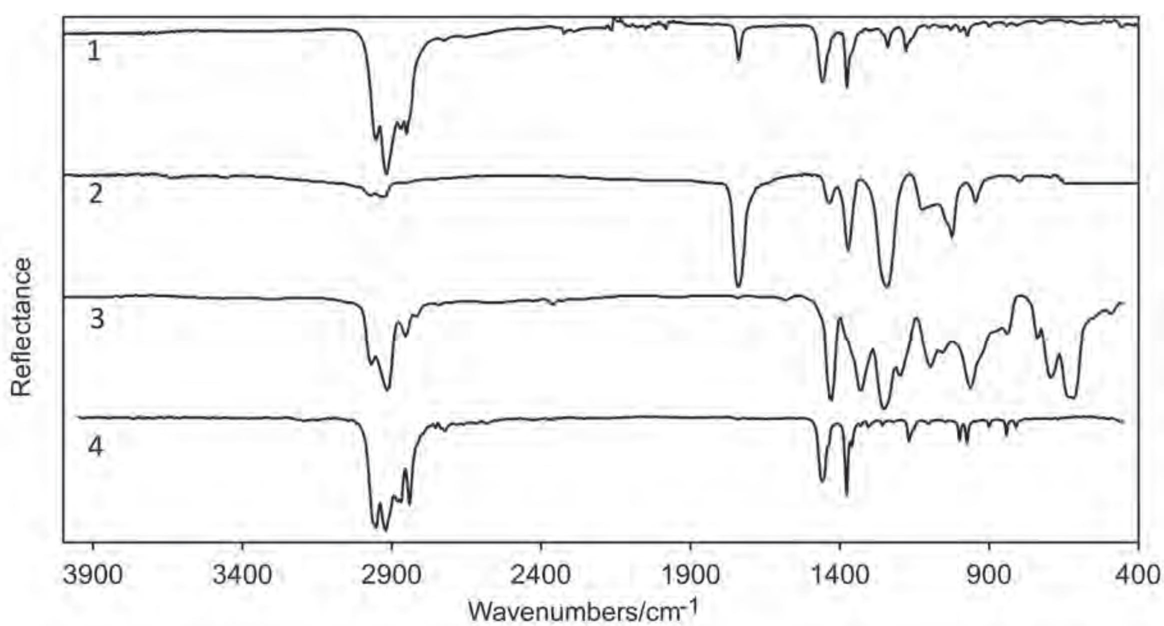

Fig. 18. FTIR Spectrum (1) is the paint binder extracted from the green paint; spectrum (2) is a reference spectrum for PVAC; spectrum (3) is a reference spectrum for PVC; spectrum (4) is a reference spectrum for atactic polypropylene. (Courtesy of Odile Madden)

Preliminary analysis with FTIR of the green paint suggests that the paint binder is a combination of polypropylene, PVC, and PVAC (fig. 18). Chlorine was detected with XRF along with chromium, zinc, and iron. No pigment particles were seen under PLM.

We have since found evidence that fireproof paint based on PVC was developed in Germany during this time. A *Gotha* glider is reported to have been painted with a green fireproof product composed of cellulose acetate and PVC. This paint was supplied under the general trade name "Herbolid" and contained a PVC-based additive called "Vinoflex" (Merrick and Kiroff 2004). "The stability of this resin depended on after-chlorination being pushed as far as it would go to give a product 60 to 66% total chlorine" according to subjects of an interrogation. The subjects also offered their poor opinion of "[its] fireproofing properties on wood, where the weight ratio P.V.C/cellulose was very low" (Palmer et al. 1945, 6). FTIR spectra of the green paint from the Horten more closely resemble a combination of PVC with PVAC and polypropylene, rather than the cellulose acetate described by Merrick and Kiroff, but the possibility that the green paint was a fireproofing coating is tempting given its location in what would have been the jet's hottest areas.

6. CONCLUSIONS

The technical study provided valuable and concrete evidence of the jet's fabrication and materials. The study has identified the use of beech and Scots pine as the major wooden components and urea and phenol formaldehyde as the adhesives holding the plywood skin together. We have tried to make some correlations with specific German World War II adhesives, finding some striking similarities although nothing conclusive. Although the presence of charcoal as a stealth ingredient appears unlikely, the opportunity to investigate the adhesive matrix revealed a microcosm of additives and inclusions, which can be seen as an artifact of materials availability of the time. The characterization of the green PVC-based paint and its links to the development of fireproof paints reveals the extent to which experimentation in the coatings industry was driving material advancements. All of the results from the technical study provided insights to the material choices of the *Gotha* workshop, which speak to an economy of wartime availability, along with an unusual combination of experimental and traditional material use.

Characterization of the different materials in the technical study allowed us to investigate their physical properties and correlate their deterioration in salient ways; for example, the plywood delamination that we see is consistently located the urea formaldehyde layers, which has less resistance to weathering than phenol formaldehyde–bonded panels (Perry 1942). Discussions about proposed materials and techniques to consolidate the plywood veneers was informed by our research into urea and phenol formaldehyde, which are both cross-linked resins and therefore insoluble in a variety of organic solvents. A literature review of adhesives used for wood consolidation illustrated that many conservation materials do not have all the perfect properties that we desire, and an effective yet reversible treatment may not be possible. The focus has shifted toward materials that would consolidate friable wood effectively and impart structural security without affecting the paint layers. The wood identification part of the technical study informed our decision to use beech wood veneers to replace areas of loss, as this material will have the same mechanical properties of adjacent layers.

Consideration for how far to take the conservation treatment of the Horten is informed by the curator's interest in exhibiting it in an unrestored, but stabilized state and allowing it to show its age, history, and character. Extant paint and the original plywood skin will be preserved while we aim to stabilize these materials to impart a cared for appearance. Various camps of aircraft enthusiasts will have differing ideas about how they think the Horten should look, although there is a growing trend to exhibit unrestored aircraft. The public links ideas of authenticity with the concept of irreplaceable, which is what the Horten is. We hope the level of study applied to understanding the original historic materials of this aircraft will encourage similar research on other unrestored technological artifacts.

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SOURCES OF MATERIALS

Micro-Mesh Cushioned Abrasives
Micro-Surface Finishing Products, Inc.
1217 West Third St.
PO Box 70
Wilton, IA 52778
www.micro-surface.com

Clear Casting Resin
Douglas and Sturgess, Inc.
1023 Factory St.
Richmond, CA 94801
www.douglasandsturgess.com

LAUREN ANNE HORELICK has a BFA in Sculpture from the San Francisco Art Institute, a BA in art conservation and anthropology from the University of Delaware, and an MA in archaeological and ethnographic conservation from University of California at Los Angeles (UCLA)/Getty Conservation Master's program. Horelick's research interests include studying the effects of adhesives on cultural materials and the use of fluorescent labeling techniques to track consolidants. She is currently an objects conservator at the National Air and Space Museum. Address: National Air and Space Museum, Steven F. Udvar-Hazy Center, 14390 Air and Space Museum Pkwy. MRC 326, Chantilly VA 20151. E-mail: Horelickl@si.edu

MALCOLM COLLUM has been the chief conservator at the Smithsonian National Air and Space Museum since 2008. Trained as a conservator of fine art, he applies the same preservation philosophies and methodologies utilized in the art world towards the conservation of historic technological artifacts. He has a BA from the University of Minnesota and an MA and Certificate of Advanced Study in Art Conservation, from SUNY, Buffalo, New York. Further studies were conducted at the National Museum of Science and Industry, London, England and at the Philadelphia Museum of Art. In 1996, Collum took a position at the Henry Ford Museum and Greenfield Village where he became senior conservator and was responsible for the automotive, aviation, horological, paintings and scientific instrument collections. In his current position at the National Air and Space Museum, he works with conservators, curators, and restoration specialists to devise appropriate preservation methodologies for aerospace artifacts in the national collection. His goal is to highlight the benefits of technical analysis and conservation research and to merge this work into the more traditional realms of restoration. He has conducted numerous seminars, written several articles and frequently lectures on ethical concerns and other unique issues related to preserving historic technology. Address: as for Horelick. E-mail: CollumM@si.edu

ODILEMADDEN is a research scientist at the Smithsonian's Museum Conservation Institute and heads their growing modern materials research program. She holds a PhD in Materials Science & Engineering from the University of Arizona, a master's degree in the history of art and archaeology and an Advanced

Certificate in Conservation from New York University, and a bachelor's degree in Italian and Art History from the University of California at Los Angeles (UCLA). Her research focuses on the technology, materials science, preservation, and environmental impacts of synthetic and natural polymer composite materials, as well as Raman spectroscopy and the challenge of pesticide residues on museum artifacts. Address: Museum Conservation Institute, 4210 Silver Hill Rd, Suitland MD 20746. E-mail: MaddenO@si.edu

PETER McELHINNEY studied conservation of organic materials at Camberwell College, University of the Arts, London, before completing a two-year postgraduate Andrew W. Mellon Foundation Fellowship in Objects Conservation at the Smithsonian Institutes National Museum of the American Indian. He is the current Postgraduate Fellow in Conservation of Museum Collections at the Smithsonian, National Air and Space Museum. Research interests include the conservation of organic materials, and the application of emerging technologies in the conservation process. Address: as for Horelick. E-mail: pjbmcelhinney@yahoo.co.uk

ANNA WEISS holds a master's degree in artifacts conservation from the Queen's University Art Conservation Program in Kingston, Ontario, where she conducted research on nanosilica coatings for outdoor sculpture and monuments. She is also interested in public outreach, emergency response and salvage, and the development of treatment methodologies for technological material culture. She is currently a Post Graduate Fellow working at the Smithsonian, National Air and Space Museum. Address: as for Horelick. E-mail: amarie.weiss@gmail.com

RUSSELL LEE earned a BA at Southwest Texas State University and an MA in American history at George Mason University. Lee curates the collections of sailplanes and gliders; ultralights and hang gliders; amateur-built sport aircraft; and Japanese aircraft from World War II at the National Air and Space Museum. Lee's book, *Only the Wing: Reimar Horten's Epic Quest to Stabilize and Control the All-Wing Aircraft*, began with research he conducted to support treatment-loan of four all-wing Horten sailplanes to the Deutsches Technikmuseum Berlin in 1994. Address: Smithsonian National Air and Space Museum, PO Box 37012, NASM, Rm. 3312, MRC 312, Washington, DC 20013. E-mail: LeeR@si.edu

ANIMATION CELS: CONSERVATION AND STORAGE ISSUES

KRISTEN McCORMICK, MICHAEL R. SCHILLING, MIRIAM TRUFFA GIACHET, JOY MAZUREK, HERANT KHANJIAN, TOM LEARNER

ABSTRACT

An analytical survey was conducted of animation cels in the Walt Disney Animation Research Library (ARL) collection, made for animated films from 1929 to 2003, that addressed three main topics: (1) characterization of cel polymers and plasticizers; (2) assessment of cel degradation in storage; and (3) assessment of cel degradation and microenvironments in passe-partout mounts.

FTIR was helpful in differentiating the main polymer types: cellulose nitrate, cellulose diacetate, cellulose triacetate, and polyester. The majority of the cels were made from cellulose diacetate before 1981, and cellulose triacetate thereafter. Pyrolysis-gas chromatography/mass spectrometry (Py-GC/MS) identified a number of distinct plasticizer mixtures–primarily triphenyl phosphate mixed with phthalates–in the diacetate and triacetate cels. Estimates of the acetyl content by gas chromatography/mass spectrometry, which assessed the degree of substitution in the cellulose acetate cels, revealed that few cels showed evidence of hydrolysis. Levels of acetic acid vapor produced by cels in storage vaults at the ARL, as measured by A-D Strips, confirmed that few cels were at risk. Finally, the concentration of acetic acid vapor in passe-partout mounted cels for traveling exhibition, as measured by GC/MS and A-D Strips, was minimal.

Animation cels represent a unique and important cultural legacy of the 20th century. This study revealed that cellulose acetate cels have a range of compositions, which ultimately may affect their stability. Further research is needed to find optimum storage environments that reduce the rate of hydrolysis of the cellulose acetate without damaging the ink and paint layers.

1. BACKGROUND

Hand-drawn animation, which began as an art form in the early 20th century, was made possible by advances in the plastics industry. In traditional hand-drawn animation, each moment in time was captured onto a thin, transparent sheet of plastic called a cel. Characters or objects were meticulously drawn in ink onto the front of the cel; colors and details of the characters were then painted onto the verso. Once completed, each cel was placed face up on a painted background to position the character or object into a scene and photographed sequentially. Played back on a movie projector, the progression of photographs in a sequence created the illusion of motion. It took an average of 1440 photographs of individual animation cels to capture 1 min on film. The process required an enormous amount of time, effort, and resources to complete a full-length animated feature. Although animation today is almost entirely done on computers, a rich legacy of stories and beloved characters from our childhood was created.

Only a few plastics possessed physical properties suitable for use as animation cels. The plastic needed to be sturdy enough to hold paint layers, but pliable enough to manipulate it onto the animation pegs, which aligned the character in position for the camera frame. It also needed to be colorless and transparent, essentially disappearing on the screen, so that the characters were perceived to exist in the background environment. Cellulose nitrate was the first polymer used for cels, but its inherent flammability and tendency to yellow, wrinkle, and evolve corrosive nitric acid over time caused severe problems. Cellulose acetate, another cel polymer, was much less flammable, but was susceptible to photodegradation, hydrolysis (with the release of acetic acid), wrinkling, discoloring, and shrinking. Cels today are made from polyester (Mylar), which exhibits good mechanical and chemical stability, but because its polished surface is difficult to wet by traditional gum-based paints, synthetic paint media such as vinyl or acrylic are preferable.

Walt Disney recognized the historical value of artwork from his films, including elements that are not seen on screen; hence, early in the evolution of The Walt Disney Studios, he established a repository for the animation artwork in the basement of the Ink and Paint building on the studio lot called the "art morgue," after a term used in the newspaper business for a location where old files and notes were retained. All aspects of the animation process were retained and preserved there: painted animation cels and backgrounds, animation drawings, story sketches, layout drawings, character sculptures, and visual development paintings. It is a working collection regularly utilized as a source of inspiration and education for the animation staff. The collection currently comprises over 65 million pieces of animation artwork, mostly works on paper. It continues to grow with each production both in physical and, more recently, digital assets; approximately 10% of the collection consists of animation cels.

Given the growth of the Walt Disney Studios and the long history of the animation artwork collection, it should come as no surprise that, over the years, the storage location has changed several times, and along with it, the environmental conditions within storage. For instance, the original basement location of the Art Morgue had no special controls on the storage environment, and much of the collection was kept in metal filing cabinets. In 1989, the collection was relocated to air-conditioned storage areas in the Walt Disney Animation Research Library (ARL). Since 1999, the collection has been stored in vaults fitted with museum-standard security and HVAC systems, along with a staff dedicated to care for it. The environmental conditions are set to 62–65°F and 50% (+/– 2%) relative humidity. Cels are interleaved with 2 mil polyethylene sheets and kept in archival boxes. It is worth noting that exposure to light in every storage location has been limited, and that newer cels have spent proportionally more of their lifetime in environmentally controlled conditions.

The Image Permanence Institute has studied extensively the effects of storage on the useful lifetimes of acetate film, and established the IPI Storage Guide for Acetate Film with recommendations on temperature and relative humidity levels for the preservation of the material (Reilly 1993). The guide recommends reducing the temperature and relative humidity in storage environments to slow the rate of hydrolysis of acetate film. With some exceptions, the cel collection appears to be in remarkably good condition. The most commonly observed conservation concerns for cellulose acetate cels are buckling, discoloration, and off-gassing of acetic acid; therefore, the climate-controlled storage vaults at the ARL are helping slow down the rate of hydrolysis of the cels.

To learn more about the relationship between deterioration phenomena and composition, the Getty Conservation Institute and the Walt Disney ARL initiated a project in 2009 to study the plastic substrates of animation cels. Individual cels from various Disney productions were analyzed using multiple techniques to investigate three main areas: (1) characterization of cel polymers and plasticizers; (2) assessment of cel degradation in storage; and (3) assessment of cel degradation and microenvironment in passe-partout mounts.

2. ANALYTICAL METHODS

An important component of this research was to better understand the range in composition of the cels in the ARL collection versus production date. This involved measuring several key parameters using various noninvasive and invasive analytical techniques and procedures: polymer type, plasticizer content, plasticizer distribution, and the degree of acetylation (Giachet et al. 2014; Truffa Giachet et al. 2014).

An A2 Technologies portable FTIR equipped with a diamond/zinc selenide attenuated total reflectance probe (FTIR-ATR) was used for noninvasive identification of the polymers in 110 cels dating from 1929 to 1988. The ATR probe was placed directly onto the cels during measurement. Analysis of samples taken from a second set of 75 cels, dating from 1934 to 2003, was performed in transmission mode using a Bruker Hyperion 3000 FTIR microscope with a liquid-cooled MCT detector and Opus software version 6.5. Analysis was performed over a spectral range of 600–4000 cm^{-1}, using a wave number resolution of 4 cm^{-1} and 64 scan accumulations. The sample preparation consisted of flattening the cel fragments on a diamond window using a metal roller.

Invasive tests were conducted on samples from 75 cellulose acetate cels dating from 1931 to 2003. Plasticizers were identified using pyrolysis-gas chromatography/mass spectrometry (Py-GC/MS). Small discs of cels (~0.5 mm in diameter) were pyrolyzed at 550°C using a Frontier Laboratories 3030 microfurnace pyrolyzer, and analyzed with an Agilent 5975C inert MSD/7890A GC/MS on a 30 M × 0.25 mm × 0.25 μm DB-5MS UI column with a Frontier Laboratories Vent-Free Adaptor. The GC method was 40°C for 2 min, 20°C min^{-1} to 320°C; helium carrier at 1 mL · min^{-1}. Plasticizers were identified on the basis of their mass spectra, and peak area percentages were calculated for each. Only plasticizers present above 5 area percent were reported. Plasticizer content was measured by extracting 1 mg pieces of cels in a 1:1 mixture of ethanol and hexane, and weighing the solid polymer residue after decanting drying.

The degree of acetylation of the cellulose acetate polymer was measured by aminolysis using pyrrolidone, which converts the acetyl groups to acetylpyrrolidine. The polymer residue remaining after extracting the cels with 1:1 ethanol:hexane was used in this test instead of the cels, since the contribution of plasticizers to the total weight of the cels would result in a systematic measurement error. In this procedure, 200 μL of pyrrolidine were added to the polymer residue (from 0.3 to 0.9 mg) in a crimp-top vial. The vial was heated at 80°C for 18 hours, with vortex mixing after 3 hours and again after 18 hours. After cooling, the solutions were analyzed on an Agilent 6890/5973 inert GC/MS with a Frontier Laboratories Ultra ALLOY 1 capillary column (30 m × 0.25 mm × 0.5 μm) and Vent-Free Adaptor. The GC method was: 80°C for 1 min, 20°C · min^{-1} to 195°C, 120°C · min^{-1}. to 300°C and 2.3 min isothermal; helium at 0.4 m · s^{-1}; split injection at 280°C with a 50:1 split ratio. The acetyl content of the samples was evaluated using a linear calibration curve forced through zero from standard solutions of acetylpyrrolidine ranging from 1000 to 10,000 ppm in pyrrolidine. The percent acetyl content is calculated using equation 1:

(1) % acetyl = 38.02 × (ppm acetylpyrrolidine) × (mL pyrrolidine) / (μg cellulose acetate)

The degree of substitution expresses how many of the three hydroxyl groups on the cellulose ring are acetylated. The relationship between % acetyl and the degree of substitution is shown in equation 2 (Loo et al. 2012):

(2) DS = (3.86 × % acetyl) / (102.4 − % acetyl)

A small number of cellulose acetate production cels displayed in passe-partout mounts for a 2006 travelling exhibit were examined in this study (table 1). A VICI Pressure-Lok precision analytical syringe inserted into the sealed package was used to remove 2.5 mL of the enclosed air space, which was then analyzed for acetic acid using an Agilent 6890/5973 inert GC/MS on a 20 M × 0.18 mm × 1.0 μm DB-624 column with Vent-Free Adaptor. The GC method was: 30°C for 1 min, then 20°C min^{-1} to 90°C; helium at 59 cm s^{-1}; and splitless injection at 150°C with 60 s purge-off time.

Art-Sorb from selected 2006 passe-partout mounts (samples 1, 3, and 4 from table 1) was extracted with ethanol and tested for acetic acid using an Agilent 689ON/5973 GC/MS on a 25 M × 0.2 mm × 0.2μm INNOWAX column with Vent-Free Adaptor. The oven program was 80°C for 2 min, then 10°C · min^{-1} to 260°C; helium set to 44 cm · s^{-1}; and splitless injection at 260°C with 60 s purge-off time.

Table 1. Animation Cels in Passe-Partout Mounts from 2006

1. Cinderella cel setup: Mice-making dress
2. Sleeping Beauty cel: Sleeping Beauty in the forest with animals
3. The Little Mermaid cel setup: Ariel and Eric
4. Alice in Wonderland cel setup: Mad Hatter and Teacup
5. Sleeping Beauty cel setup: Squirrel in forest
6. Alice in Wonderland cel: Tweedle Dee and Tweedle Dum
7. Alice in Wonderland cel: Cheshire Cat

Table 2. Plasticizers Identified in Cellulose Acetate Animation Cels

Plasticizer	CAS Number	Abbreviation
Dimethyl phthalate	131-11-3	DMP
2,2,4-Trimethyl-1,3-pentanediol diisobutyrate	6846-50-0	TXIB
Diethyl phthalate	84-66-2	DEP
Methyl carbethoxymethyl phthalate	85-71-2	MCMP
Ethyl carbethoxymethyl phthalate	84-72-0	ECMP
Dibutyl phthalate	84-74-2	DBP
Bis(2-methoxyethyl) phthalate	117-82-8	DMEP
Triphenyl phosphate	115-86-6	TPP

3. TEST RESULTS FOR CELS IN ARL STORAGE VAULTS

Table 2 lists information about the plasticizers detected in the cels by Py-GC/MS. The plasticizer content of cellulose diacetate cels ranged from 12 to 21%, whereas for cellulose triacetate the range was from 8 to 14%. These results show that plasticizer represents a significant proportion of cellulose acetate cels.

Tables 3 and 4 list the plasticizer compositions of cels made from cellulose diacetate and cellulose triacetate, respectively. It was discovered that multiple formulations of plasticizers were used in the cels,

Table 3. Average Plasticizer Compositions for Cellulose Diacetate Cels

		Peak Area Percentages						
Production Date(s)	**Plasticizer Group**	**TPP**	**DEP**	**MCMP**	**TXIB**	**DMEP**	**ECMP**	**DMP**
1937	A		91					7
1940	B		39	57				
1949	C	56	28				11	
1940–1981	D	55	43					
1967–1974	E	47	13		35		5	
1970	F	50				39		6

Note: The numbers of cels tested by Py-GC/MS within each of the plasticizer groups are: A (1), B (2), C (1), D (33), E (6), F (2).

Table 4. Average Plasticizer Compositions for Cellulose Triacetate Cels

		Peak Area Percentages			
Production Dates	**Plasticizer Group**	**TPP**	**DMP**	**DBP**	**DMEP**
1983–2003	G	71	27		
1995–2001	H	53		47	
1985–1986	I	88		5	6
1994–2000	J	88			11
1989–2002	K	97			

Note: The numbers of cels tested by Py-GC/MS within each of the plasticizer groups are: G (14), H (3), I (5), J (3), K (5).

and moreover that some formulations were more common than others. For instance, in the CDA cels, the most common formulation was triphenyl phosphate with diethyl phthalate, whereas in the CTA cels the most common formulation was triphenyl phosphate mixed with dimethyl phthalate. Triphenyl phosphate functions in cels both as a plasticizer and a flame retardant. The earliest CDA cels tested contained no TPP, whereas TPP was the sole plasticizer in some of the more recent CTA cels. In all, six groupings of plasticizer composition were identified in the cellulose diacetate cels (table 3), and five groupings of plasticizer composition were identified in the cellulose triacetate cels (table 4). The variation in plasticizer formulation may be due to the material being sourced from different commercial manufacturers, as well as the experimental process in the cellulose acetate production, considering that each manufacturer may have attempted to perfect their own formulations.

The results listed in tables 5, 6, and 7 show the number of cels tested from each production, their corresponding polymer type, and plasticizer group. The FTIR analyses revealed a number of important

Table 5. Polymer Types and Plasticizer Groups for Cels from 1929 to 1942

Title	Production Date	Plasticizer Group (# of cels)	# of CN Cels	# of CDA Cels
The Skeleton Dance	1929	—		2
Barnyard Olympics	1932	—	20	
Flowers and Trees	1932	—		1
King Neptune	1932	—	3	
Two Gun Mickey	1934	—		1
Three Little Wolves	1936	—		1
Snow White	1937	A (1)	13	2
Fantasia	1940	B (2)	3	14
Pinocchio	1940	D (1)		2
Dumbo	1941	—		2
Bambi	1942	D	1	1

Note: Polymer types were identified by bench-top and/or portable FTIR instruments, and plasticizer groups for CDA and CTA cels by Py-GC/MS. Comparatively, more cels were tested by FTIR than by Py-GC/MS; thus, where no number appears in parentheses after the group letter in the plasticizer group column for a production, the same number of cels were analyzed by both bench-top FTIR and Py-GC/MS. When a number is listed after the group letter for a production, the number signifies the number of cels that were analyzed by Py-GC/MS.

Table 6. Plasticizer Groups for Cellulose Diacetate Cels from 1943 to 1981

Title	Production Date	Plasticizer Group (# of cels)	# of CDA Cels
Saludos Amigos	1943	—	1
Three Caballeros	1944	—	4
Song of the South	1946	D	1
Adventures of Ichabod and Mr. Toad	1949	C	1
Cinderella	1950	D	2
The Brave Engineer	1950	—	2
Alice in Wonderland	1951	D (2)	33
Peter Pan	1953	D	1

(Continued)

Table 6. Plasticizer Groups for Cellulose Diacetate Cels from 1943 to 1981—*(continued)*

Title	Production Date	Plasticizer Group (# of cels)	# of CDA Cels
Lady and the Tramp	1955	D	2
The Sleeping Beauty	1959	D	2
101 Dalmatians	1961	D	2
The Sword in the Stone	1963	D	2
Mary Poppins	1964	D	2
The Jungle Book	1967	D, E (1, 3)	4
Winnie the Pooh and the Blustery Day	1968	E	1
The Aristocats	1970	F	2
Bedknobs and Broomsticks	1971	D	2
Robin Hood	1973	D	3
Winnie the Pooh and Tigger Too	1974	D, E (1, 1)	2
Pete's Dragon	1977	D	2
The Rescuers	1977	D	2
The Fox and the Hound	1981	D	4

Note: See note given for table 5.

Table 7. Polymer Types and Plasticizer Groups in Cels from 1983 to 2003

Title	Production Date	Plasticizer Group (# of cels)	# of CTA Cels	# of PE Cels
Mickey's Christmas Carol	1983	G	2	
The Black Cauldron	1985	G, I (1, 2)	5	2
The Great Mouse Detective	1986	I	3	
Oliver and Company	1988	G	2	
Who Framed Roger Rabbit	1988	—	2	10
The Little Mermaid	1989	G, K (1, 1)	2	
The Prince and the Pauper	1990	G	2	
The Rescuers Down Under	1990	G	2	
Beauty and the Beast	1991	G	1	
Aladdin	1992	G	1	
The Lion King	1994	J	1	
Pocahontas	1995	H, K (1, 1)	2	
The Hunchback of Notre Dame	1996	K	1	
Hercules	1997	J	1	
Mulan	1998	G	1	
Tarzan	1999	K	1	
The Emperor's New Groove	2000	H	1	
Fantasia 2000	2000	J	1	
Atlantis	2001	H	1	
Lilo and Stich	2002	K	1	
Brother Bear	2003	G	1	

Note: See note given for table 5.

findings. Four types of polymer were identified in the cels: cellulose nitrate (CN), cellulose acetate (CA) in the form of cellulose diacetate (CDA) and cellulose triacetate (CTA), and polyester (PE). CN was identified only in films produced between 1932 and 1942 (table 5), yet CDA was identified in some of these productions, even as far back as 1929. This runs counter to the prevailing assumption that CN was the only polymer used in cels until the 1940s (Saracino 2006). Next, in productions from 1943 to 1983, cellulose diacetate was the only polymer used (table 6). Cellulose triacetate was identified in productions dating from 1986 to 2003 only (table 7). Some polyester cels were used in two productions: *The Black Cauldron* and *Who Framed Roger Rabbit*. It should be noted that all cels in the ARL collection for productions dating after *The Little Mermaid* (1989) are, in fact, replicas of original computer animation artwork that were made for internal usage; thus, because production date was shown to be insufficient for determining polymer type, analysis is needed for accurate identification.

The degree of substitution results ranged from 2.0 to 2.6 for CDA cels (35–41% acetyl), and 2.8–3.0 for CTA cels (43–45% acetyl). It is encouraging that the CDA cels, which as the oldest in the collection are the ones that have spent proportionally less time in ideal storage conditions, still remain in the diacetate form. The wider variance of acetyl content in the CDA cels may be due to the effects of hydrolysis, but also from variation in the polymer manufacturers' original formulations and manufacturing technique. CDA is produced by making CTA which has a degree of substitution of 3, then partially hydrolyzing it to form CDA. Considering the number of parameters that would affect the rate of hydrolysis, such as pH and water content, this process may have been difficult to control carefully.

It was evident that the GC/MS test method, which was developed for measuring the acetyl content of wood fibers, worked remarkably well on the microsamples of cellulose acetate polymer residue obtained from solvent extraction of plasticizers in the cels. The method was found to be simple, rapid and accurate (Truffa Giachet 2014).

4. ASSESSMENT OF CEL DEGRADATION IN STORAGE

Of the many indicators of cellulose acetate degradation, perhaps the most noticeable in cel storage cases is the odor of acetic acid, formed by hydrolysis and off-gassing. A-D strips, developed by The Image Permanence Institute (IPI), are a reliable tool for identifying so-called Vinegar Syndrome in cellulose acetate film and in other forms of cellulose acetate (Image Permanence Institute 2001). A-D strips turn from blue to green to yellow with increased concentration of acetic acid. Depending on the environmental conditions, a strip placed directly on a CA object will change color within a certain period of time if acid is detected. A-D strips measuring 1–2 ppm indicate some degradation of the object has occurred, so the object may require closer monitoring. Objects giving measurements of 3–5 ppm are at a higher risk of vinegar syndrome, and may be close to the autocatalytic point at which the degradation process accelerates exponentially (Image Permanence Institute 2001).

To examine the effects of storage environment on the cels, A-D strips were used to monitor cels in storage vaults at the Walt Disney Animation Research Library. These were deployed in eight locations in four different storage vaults. These were placed directly on CA cels of varying age (1940–1988) that exhibited varying degrees of warping and discoloration. After 8 hours, all the strips appeared unchanged except for the strip placed on a cel from *Bambi* (1942), which showed a slight color change toward green. After an additional period of 88 hours (96 hours in total), the strip on the *Bambi* cel measured an acetic acid level of 1–2 ppm. In addition, three samples from 1950, 1959, and 1968 each showed a very minor shift in color (measuring <0.5 ppm). After a final period of 240 hours (336 hours/2 weeks in total), the strip on the *Bambi* cel measured an acetic acid level of 3–5 ppm. In addition, the three samples from 1950, 1959, and 1968 each shifted slightly more toward green to a level around 0.5 ppm.

5. ASSESSMENT OF CEL DEGRADATION AND MICROENVIRONMENT IN PASSE-PARTOUT MOUNTS

Passe-partout mounts, typically used for works on paper to produce a microclimate for the artwork inside of a mat package, are used routinely at the ARL for displaying cels on loan to museum exhibits.

The mounting process starts with hinging the artwork as desired, generally with Japanese tissue hinges attached using methyl cellulose or wheat starch paste, onto 8-ply acid free mat board. On the verso of the mat board, a sheet of Art-Sorb is applied with 3M ATG 987 Adhesive Transfer Tape. A Sud-Chemie Performance Packaging humidity indicator card is also adhered to a visible corner of the Art-Sorb. A sheet of .003 mil polyester is cut to fix the size of the mat board. The passe-partout package is then assembled placing the layers one by one face down on each other starting with the UV acrylic (Plexiglas), then the matted artwork with the Art-Sorb backing, followed by a sheet of polyester. The layers are sandwiched together using Scotch 845 Book Tape. The tape attaches to the front edge of the acrylic glass and continues along the side of the packet taking in all the layers wrapping around to the polyester sheet on the back. A bone folder is used to press out all air bubbles along the tape to create as airtight of a seal as possible. The passe-partout package is then placed in a frame with an archival foam core backer. A small window is cut out of the foam core to facilitate reading the humidity indicator card. The color changes of the humidity indicator card are recorded periodically. Figure 1 shows the layout of the passe-partout packages.

In 2006, the ARL loaned production cels to an exhibit entitled *Walt Disney: Il Etait une Fois* (*Walt Disney: Once Upon a Time),* which compared Walt Disney animation artwork to classical European artwork. The passe-partout mounted cels travelled to the first two venues of the exhibition, the Grand Palais, Paris, and the Musee des Beaux Arts, Montreal, before being removed from the tour. On returning

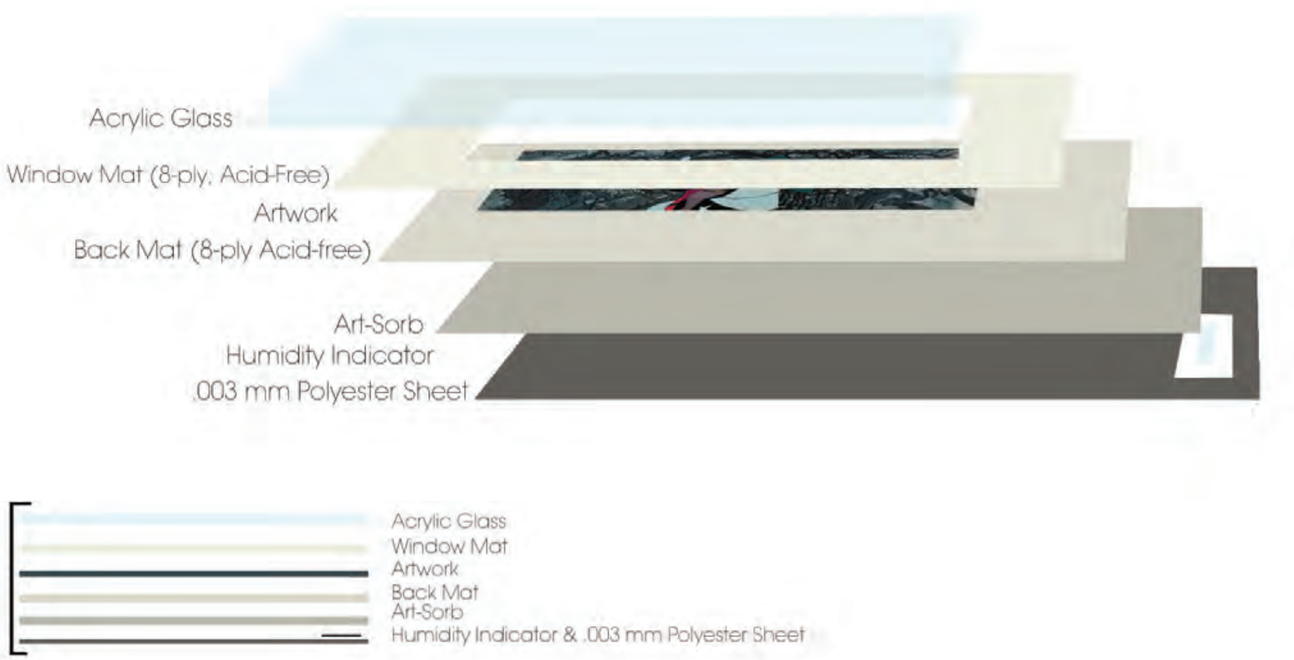

Fig.1. Schematic of passe-partout packaging for animation cels (Courtesy of Kristen McCormick)

to the ARL, most of the cels were unframed and reintegrated into the collection; however, it was noticed that paints on a few cels exhibited delamination and microcracking, so it was decided to keep these cels in their passe-partout mounts for eventual scientific investigation. In this study, the passe-partout packages for each of the damaged cels was investigated to test for acetic acid in the entrapped air, and to determine if acetic acid may have been adsorbed by the Art-Sorb.

All of the tests showed minimal amounts of acetic acid present in the passe-partout packages from 2006. The color of A-D strips (placed within the passe-partout packages in 2014, then resealed and observed for 30 days) remained unchanged in all the packages throughout the observation period. In GC/MS analysis of the entrapped air in each passe-partout mount, the concentration of acetic acid present was well below 0.8 ppm (estimated to be < 0.1), which is consistent with the A-D strip results. Moreover, no acetic acid was detected in the ethanol extracts of the Art-Sorb from the CA cel mounts; however, it is interesting that DMP and DEP plasticizers were detected in the Art-Sorb from the Cinderella cel mount, and camphor plasticizer was detected in the Art-Sorb from a CN cel from *Snow White and the Seven Dwarfs* (1937). These results show that Art-Sorb is capable of removing vapor from certain plasticizers from storage environments. Over time, this may affect the behavior of the enclosed plastic object (Richardson et al. 2014; Shashoua et al. 2014).

6. CONCLUSIONS

The results of this study illustrate the value of multiple analytical techniques for characterizing the four polymers used in cels and their additives. Noninvasive FTIR is a good technique for in situ identification of polymer types, and detailed information about plasticizers is obtained by Py-GC/MS. Because it is possible that the rate of hydrolysis may be affected by the plasticizer composition, especially for cels that lack TPP (Tsang et al. 2009), plasticizer identification is useful. The GC/MS method for measuring acetyl content showed no evidence of advanced hydrolysis in the cels.

Although the current storage environment employed at the Animation Research Library is beneficial to the cel collection, A-D strips revealed slight off-gassing of acetic acid from one of the oldest cels tested. A broader survey with A-D strips would be needed to identify other cels at increased risk of developing vinegar syndrome and to establish an assessment of the state of the collection. Although all cels inevitably are moving toward vinegar syndrome, a small subset of the collection is likely at higher risk; therefore, identification and subsequent isolation of those cels would be desirable to prevent accidental acceleration of hydrolysis in lower risk cels stored in close proximity.

No evidence was found, using A-D strips and GC/MS analysis of gas samples from passe-partout mounts made in 2006, that the mounts enhanced the degree of hydrolysis of the enclosed cels; therefore, the mounts do not appear to have contributed to the observed delamination and cracking of cels' paints. To better understand the risk factors contributing to degradation of animation cels while on loan, however, additional study needs to be conducted on the packing methods and orientation of the framed artworks within the crates, as well as changes in microenvironment during transit.

The challenge for preventive conservation of animation cel collections is that storage temperatures and relative humidity levels which increase the useful lifetime of the cellulose acetate sheets may negatively impact the inks and paints by causing cracking and delamination. Finding ideal environments for the mixed media of animation cels will require extensive additional studies, especially developing a thorough understanding of the mechanical response of paint layers and their plastic supports to changes in temperature and relative humidity. As caretakers of this unique 20th century art form, such research is essential if we hope to preserve animation cels for future generations.

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KRISTEN McCORMICK is manager of Art Collections and Exhibitions, Walt Disney Animation Research Library. She has been at The Walt Disney Company for over a decade and a half where she has been responsible for the safe keeping, care, and transport of a broad range of artworks from African Art to Animation Art. In her current role, she oversees the care of the Walt Disney Animation Collection that comprises over 64 million pieces of artwork, from all facets of the production process including storyboard drawing, visual development, layouts, backgrounds, animation drawings, and animation cels. McCormick is also responsible for the traveling exhibitions and loans for this collection, and has extensively toured works around the world, including Taiwan, Korea, Australia, Japan, and throughout Europe. In addition, she is a customs broker and has considerable experience handling CITES and Fish and Wildlife special import and export protocol. Address: Walt Disney Animation Research Library, 1400 Flower Street, Glendale, CA, 91201. E-mail: kristen.mccormick@disney.com

MICHAEL R. SCHILLING is senior scientist and head of the materials characterization group at the Getty Conservation Institute. He began his career at the GCI in 1983. He earned his BS and MS degrees in chemistry from California State Polytechnic University, Pomona. His group is involved in studies of a broad range of traditional and contemporary museum objects, including Asian lacquers, animation cels, and contemporary art. Address: Getty Conservation Institute, 1200 Getty Center Drive, Suite 700, Los Angeles, CA 90049. E-mail: mschilling@getty.edu

MIRIAM TRUFFA GIACHET In 2011, Miriam obtained an MSc in science and technology applied to the cultural heritage at the University of Torino with a master thesis in chemical and physical characterization of photographic material. In 2012, she spent a year as visiting scientist at the Getty Conservation Institute working on the diagnostic analysis of composition and degradation of animation cels from the Walt Disney Animation Research Library. Her research interests include characterization of artistic materials by spectroscopy, colorimetry, chromatography and thermal analysis. Address: Via Belbo, 14 – 12060 Bossolasco (CN), Italy. E-mail: miriam.truffagiachet@gmail.com

JOY MAZUREK is assistant scientist at Getty Conservation Institute. She has worked as an assistant scientist at the GCI since 1998. She specializes in the identification of organic materials by gas chromatography/mass spectrometry. She obtained her master's degree in biology, with emphasis in microbiology from California State University Northridge, and a BS degree in biology from University of California, Davis. Address: as for Schilling. Email: jmazurek@getty.edu

HERANT KHANJIAN received his undergraduate degree in chemistry from California State University, Northridge. His research interests involve the study of organic media in paintings, sculptures and decorative art pieces using FTIR, Py-GC/MS and HPLC. He is currently an assistant scientist at the science department of the GCI. Address: as for Schilling. E-mail: hkhanjian@getty.edu

TOM LEARNER is head of science at Getty Conservation Institute. He has a PhD in chemistry (University of London, 1997) and a diploma in conservation of easel paintings (Courtauld Institute of Art, London, 1991). At the GCI, he oversees all scientific research being undertaken by the Institute and develops and implements projects that advance conservation practice in the visual arts. Prior to this appointment, he was head of modern and contemporary art research at the GCI for 7 years, having spent 10 years as a senior conservation scientist at the Tate Gallery in London. Address: as for Schilling. E-mail: tlearner@getty.edu

MANAGING CONSTRUCTION-INDUCED VIBRATION IN THE MUSEUM ENVIRONMENT

ANNA SEROTTA, ANDREW SMYTH

ABSTRACT

In the spring of 2012, The Metropolitan Museum of Art began a large-scale renovation of galleries, offices and storage areas in The Costume Institute, which is located directly below the galleries of the Egyptian Art Department. Vibration from construction activities poses a serious risk to museum objects, and the fragile nature of objects in the Egyptian galleries makes this collection particularly vulnerable. To safeguard the collection, a project team including curatorial, collections management, and conservation staff, in collaboration with a group from the Department of Civil Engineering and Engineering Mechanics at Columbia University, worked together to assess the risk to the collection on an object by object basis and developed a range of preventive conservation strategies. This paper will discuss the methods and procedures that were developed not only to protect the artworks but also to allow visitors continued access to as much of the collection as possible during the work period.

Before the renovation, tests were carried out to determine the amount of vibration that would be caused by the demolition of both structural and nonstructural elements in the construction zone. Different tools and demolition methods were tested in various locations to assess which would create the least vibration; at the same time, techniques for mitigating vibration were evaluated. The article discusses the implementation of these mitigation solutions, which included isolation of objects and pedestals with Sorbothane and other vibration-dampening materials. Testing also revealed that shelf design and pedestal shape and material contributed significantly to the degree of vibration amplification. Case studies will be presented that illustrate the response of particular installations to vibration and specific solutions devised for each scenario. For some objects, isolation was not possible; deinstallation decisions and logistics will be presented.

During initial testing, a monitoring system to measure vibration levels and to automatically communicate this information to the project team was developed; this system, which used wireless communication, was implemented throughout the effected galleries before the start of demolition. Automated alerts were sent via e-mail or SMS (text) message to the project team when defined vibration velocity thresholds were exceeded. The corresponding vibration event signals were recorded on a central server for reference and review. The vibration sensors were placed on gallery floors, directly on objects, or on shelves and pedestals and display case decks. The rationale for the general vibration thresholds used in the project, which were adjusted depending on the sensor location and context, is discussed. The quantitative feedback provided by the vibration monitoring system was augmented with daily observation and regular hands-on assessment of vibration levels throughout the two-year project.

Although much information was gained through limited initial testing, the actual construction project often produced unexpected vibration and consequently mitigation solutions had to be adapted. Preliminary observations about the response of objects, installations, and the building itself to various demolition and construction activities will be shared. The dynamic nature of the construction project required great flexibility, and constant dialogue between all members of the project team, the construction department, and contractors was essential to the overall success of this project.

1. PROJECT OVERVIEW AND CHALLENGES

From the spring of 2012 until the end of 2013 The Metropolitan Museum of Art conducted a large-scale renovation of The Costume Institute, which is located directly below the galleries of Egyptian Art. The project included a complete renovation of Costume Institute storage spaces, gallery spaces, offices, and conservation labs and involved the demolition of both structural and non-structural elements and the installation of new walls, ductwork, and architectural features.

To safeguard this very fragile, ancient art collection, a project team including curatorial, collections management, and conservation staff worked together with the museum's construction department in collaboration with a team from the Department of Civil Engineering and Engineering Mechanics at Columbia University. The main goals of the project team were to assess the risk to the collection from construction-induced vibration and to develop a range of preventive conservation strategies. This article serves as a preliminary description of the project for timely dissemination. A more comprehensive article manuscript is in preparation from the authors together with other key project team members.

The area above the construction work zone consisted of 27 galleries housing over 20,000 objects, which are, on average, between 2000 and 4000 years old. Objects in the collection are both organic and inorganic, representing the full spectrum of materials used in ancient Egypt including stone, metal, ceramic, glass, basketry, linen, and wood; extremely fragile organic materials such as mummies, ancient foodstuffs, and dried flowers are found throughout the collection. There are other factors contributing to the vulnerability of these objects. Many are made of composite materials, such as plastered or painted wood, and they often contain ancient joins such as wooden dowels, ancient glues, or rawhide ties. As this is an archaeological collection, much of which came to the museum in the early 20th century, many objects contain old restoration materials, which are often undocumented. For these reasons, the collection of Egyptian art is one of the most fragile collections the museum, and the interaction between the various components of the objects when exposed to vibration was of particular concern for the project team.

The gallery installations themselves also presented a challenge. Many of the installations are old, dating to the late 1970s and early 1980s; and some of the large and very fragile objects have not been moved since they were put on display decades ago. Additionally, a large part of the collection is housed in study-storage galleries, which contain thousands of objects. About 90% of the collection is on view, and there is only permanent storage space for the remaining 10% of the collection.

Given these challenges, it was critical at the outset to assess how vulnerable these objects and installations would be to construction-induced vibration so that appropriate preventive strategies could be implemented.

2. WHY DO VIBRATIONS MATTER IN THE MUSEUM CONTEXT?

Vibrations can be the cause of damage to objects during short or long-term exposure. These can cause increased stresses (bearing, bending, shear, etc.) that can damage objects. Because vibrations are a type of cyclic loading, they can cause fatigue damage (like a paper clip that snaps after bending it back and forth). Vibrations can also cause the growth of existing cracks.

2.1 VIBRATION BASICS

Although it is beyond the scope of this short article to provide a comprehensive review of the basics of mechanical and structural vibrations, an extremely brief summary of some fundamental elements is useful to provide a framework for the discussion. Numerous texts, for example Rao (2004), are available, which cover the fundamentals of vibrations. Anything that has mass and some flexibility (the reciprocal of stiffness) can vibrate. The frequency at which things tend to vibrate is related to the square root of the stiffness over mass; for example, for a given stiffness of a shelf, extra mass will make it vibrate at a lower frequency, and vice versa.

In the context of a museum under construction it is, of course, not just shelves which vibrate, but everything from the building itself, responding to impact and other demolition tools, all the way down to vibrations occurring within an object. It is, however, useful to focus on the simple (and yet, in the museum context, intrinsically important) example of the cantilevered shelf, as shown in figure 1a. If the wall to which it is attached is vibrating vertically with displacement $x_s(t)$ then we might be interested in how much the shelf vibrates $x_{tip}(t)$. In general, these will not be equal.

The surprising thing to the uninitiated is that the shelf vibrations may be much larger than the exciting wall vibrations. This is due to the well-known resonance condition that occurs when the exciting frequency is near the natural frequency of the shelf. This is shown in the amplification plot (fig. 1b) for

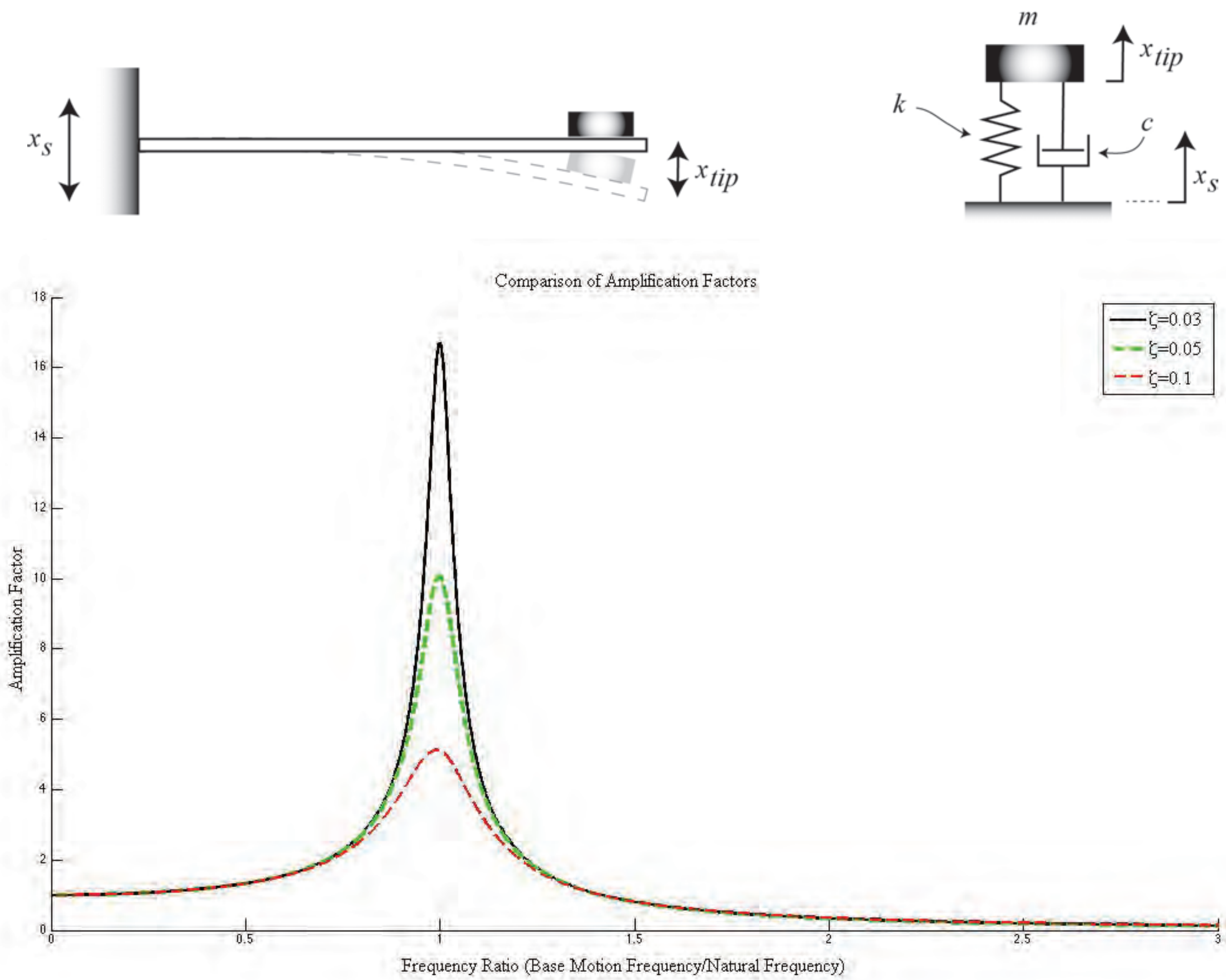

Fig. 1 (a) Schematic of simple cantilevered shelf system with vertical wall excitation, (b) The amplification of a simple "single degree of freedom" dynamic system due to harmonic excitation. The horizontal axis in the graph is a ratio of the harmonic excitation frequency to the natural frequency of the system. (Courtesy of Andrew Smyth)

the same shelf with different values of inherent energy dissipation (or damping). Notice that even for a relatively large damping value of 0.1, the response can be five times as large as the excitation displacement. As the frequency of excitation goes higher above the natural frequency of the shelf system, the response starts to drop significantly. This idea will be used later.

One of the key consequences of this is that when considering all of the objects and mounts, and pedestals (all of which have their own natural frequencies and damping values), it becomes challenging to anticipate an acceptable level of input excitation because it is hard to anticipate the respective responses of the objects.

2.2 VIBRATION THRESHOLDS

For practical matters, however, it is important to have some reference values to use as guidance to judge vibration levels and to distinguish between the excitation (in the museum context at the floor or in the wall) vibration and the response vibration levels. Velocities are often used as a standard for vibration levels for a variety of reasons. Note, however, that accelerometers (which measure accelerations) are typically used to make measurements. To start, one may consider a review of vibrations standards such as that presented in S.S. Rao's textbook (2004) *Mechanical Vibrations* highlighting different vibration standards including a discussion of human perception thresholds. According to ISO 2631, the human perception curve begins at about 1 $mm \cdot s^{-1}$ at low frequencies. There is also an ISO DP4866 standard that has a minimum threshold starting at 3 $mm \cdot s^{-1}$ for building structural damage.

Although this article does not delve into a detailed comparison of different standards that have been used, one may simply say that one should be cautious when borrowing from standards that were developed for very different contexts to primarily protect single-family homes from damage due to construction blasting vibrations. Many of these permit an increase in velocity threshold above 10Hz. See, for example, Johnson et al. 2013.

In a hypothetical comparison, one may have a situation where a single story house (for which many of the standards were designed) and museum objects are far apart; for example, a single-story house might be expected to have a natural frequency in the 4–12 Hz range, whereas a museum object or mount may have a natural frequency in the 20Hz range; one can see that it may be ill-advised to permit more energy in an area ($>$ 10Hz) where amplification may be the greatest for the object or object mount. Not knowing exactly where the amplification may be greatest for our museums and our objects is why measurements are made.

3. DEVELOPING STRATEGIES FOR VIBRATION MITIGATION AND MONITORING

To better understand the effects of different tools on this specific building with objects displayed as they were, a series of pilot tests were performed before the demolition and construction phase of the project. These pilot tests were initially planned by the museum's construction department to provide more information about the building and were conducted at different locations throughout the work zone. The goal of the project team was to determine the amount of the vibration that would be caused by the demolition of both structural and nonstructural elements in the area of the Costume Institute, and different tools and demolition methods were tested in various locations to assess how much vibration each would produce. Additionally, this testing helped identify which installations in particular were more susceptible to vibration and provided an opportunity to test mitigation and monitoring strategies.

3.1 MEASURING VIBRATION IN THE GALLERIES

The vibration measurement instrumentation used for the pilot phase was very similar to the setup for the demolition and construction phases, although pilot testing was primarily done during time when the museum was closed, so aesthetic considerations were not important. During the actual construction phase, a wireless system of data communication was employed.

Figure 2 illustrates a schematic of the monitoring network. Accelerometer sensors were connected to wireless data acquisition nodes, as seen in figure 3, which would communicate with a central processing server over the museum's own wireless network. Data were analyzed in real-time and when thresholds, which had been established from the pilot testing phase, were exceeded, automatic warnings were sent via e-mail and text message to key individuals on the engineering, construction, and conservation staffs. Typical alert thresholds were in the 1 or 3 $mm \cdot s^{-1}$ range. Note that these were not necessarily thresholds that would cause work stoppage, but were used as levels that would trigger alert messages that were reviewed in the appropriate context, and which, in turn, led to different actions being taken. Alert thresholds were often programmed for different sensors depending on their location (e.g., floor or shelf) and the perceived fragility of nearby objects. Wireless nodes were installed throughout the

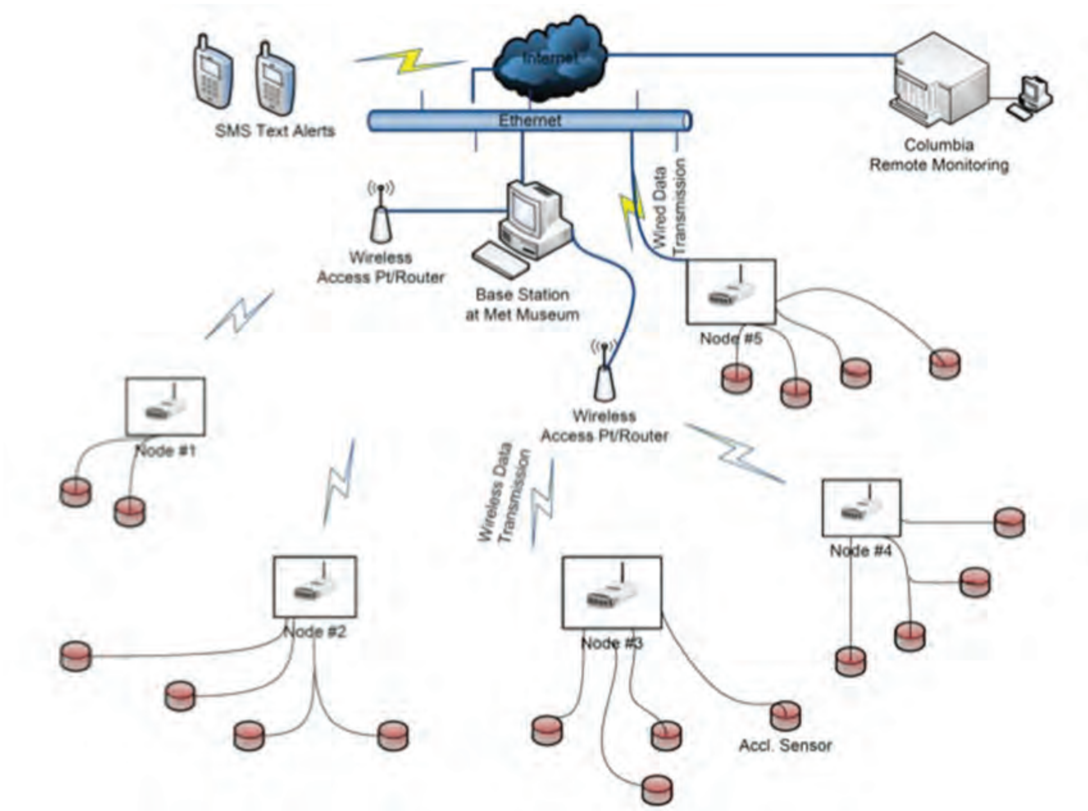

Fig. 2. Schematic of wireless monitoring network developed by Columbia University team (Courtesy of Andrew Smyth)

Fig. 3. Wireless data acquisition unit with sensors attached (Courtesy of Andrew Smyth)

Fig. 4. Sensor placement during pilot testing (Courtesy of Andrew Smyth)

galleries above the work zone for the duration of the project; sensors were often positioned on or near fragile objects or installations that might amplify vibration. Additionally there were some "roaming" units used by the museum staff to concentrate on specific areas as the demolition and construction activities moved from area to area. Wireless nodes were often installed in the light attics above the cases to utilize power from the lighting system. Case lights were switched on and off at set times each day, so that the monitoring system was running well in advance of the contractors' work day.

3.2 OBSERVATIONS MADE DURING PILOT TESTING

During the pilot testing, sensors were placed on the floor, on pedestals and shelves, and on the objects themselves with Mylar barriers (fig. 4).

During the pilot testing phase, the data were analyzed directly on a laptop "dashboard" by the Columbia team on site, and real-time vibration data were communicated to the project team, who used their hands to correlate numerical data with what they actually felt on pedestals and objects.

Some general observations were made during the pilot testing, which helped the project team and contractors to select the tools and methods that would produce the least vibration while still being able to accomplish the task at hand. Large vibrations were recorded due to heavy impact tools such as sledgehammers and crowbars, and it was agreed that these tools would not be used in the demolition process. In contrast, a light chipping gun produced generally acceptable levels of vibration, and instead of shooting anchors into ceilings for piping, a high-speed coring drill produced much less vibration. As expected, cantilevered shelves used to display small objects in many galleries significantly amplified vibrations.

3.3 VIBRATION MITIGATION STRATEGIES

3.3.1 Isolation with Sorbothane

Along with recommendations for equipment and methods, the pilot testing also provided valuable information on vibration mitigation strategies. One of the steps taken to reduce the potential of damage to the artifacts was to decrease the natural amplification of the vibrations that occur in the art.

Fig. 5. Testing Sorbothane isolation during pilot tests. Sorbothane pads are installed under the coffin bottom but not under the lid. Vibration responses were measured in both the coffin bottom and lid, and also in the floor. (Courtesy of Andrew Smyth)

Fundamentally, this involves the mechanical decoupling of the vibration source (often the floor) from the object by means of a very soft viscoelastic layer, which performs as a kind of filter. This was accomplished by introducing Sorbothane, a viscoelastic urethane polymer that comes in a variety of hardnesses and thicknesses. The core concept of how Sorbothane works is that it provides a soft layer that mechanically tends to isolate the object it supports. From a vibrations perspective, this has the effect of creating a low natural frequency system with a frequency (if properly designed) significantly lower than the excitation frequency. The result is a substantially decreased object response motion.

Figure 5 demonstrates the use of Sorbothane to decrease the response vibrations in a standing coffin base when excited by a 30 lb. chipping gun removing concrete fireproofing on a beam just beneath the floor.

The response of this coffin was compared with vibration levels in the adjacent floor and in the lid of the coffin, which had not been isolated with Sorbothane (fig. 6).

The objects were exposed to vibration from the chipping gun for a short duration, and the response vibrations were recorded. In this instance, Sorbothane was a decidedly effective isolator: the velocity reduction between the floor and the isolated coffin base was approximately 75–80%. Other objects isolated with Sorbothane also performed well during the probes, showing vibration reduction factors of 3, 4, and 5 with the appropriately designed Sorbothane pads, and these results encouraged wider use of the material.

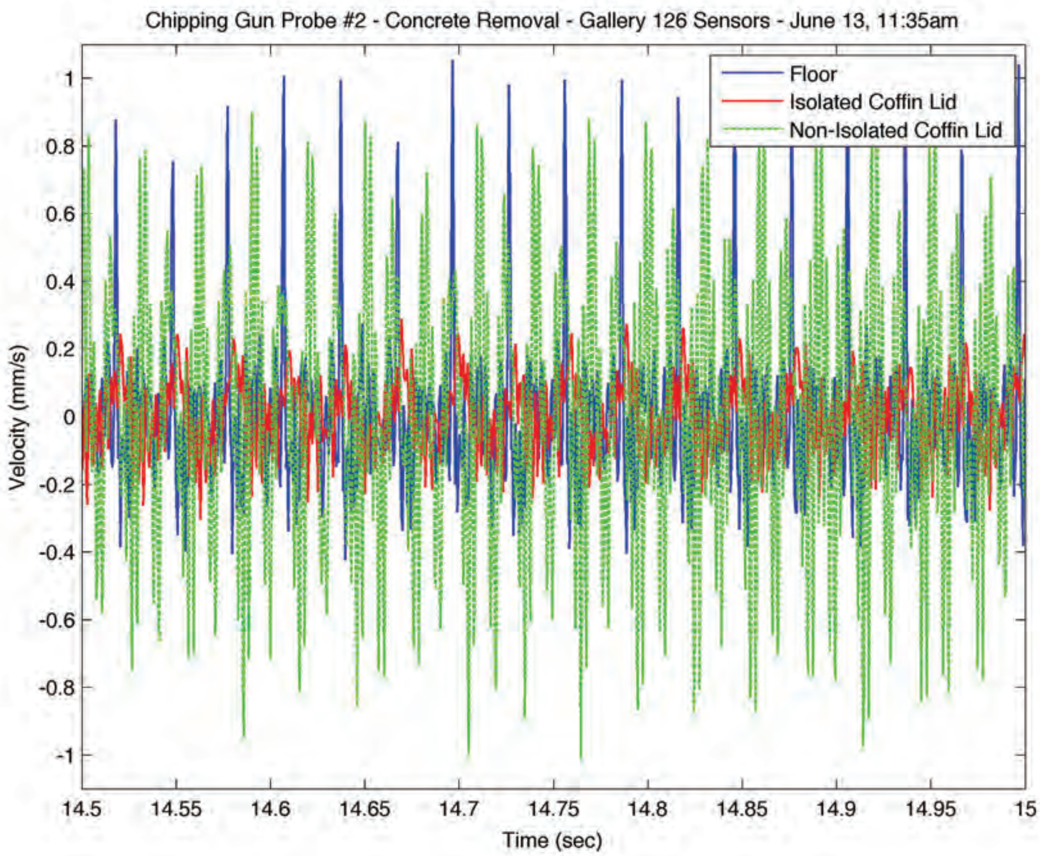

Fig. 6. A comparison of the response of the floor, with a nonisolated coffin lid and a similar neighboring coffin (Courtesy of Andrew Smyth)

The project team installed Sorbothane under a variety of objects and pedestals, particularly in galleries above areas slated for structural demolition. One pad was typically placed in each corner of the base of the object or pedestal, although rectangular bases often required additional pads below their longer edges. To ensure good performance, it was important to achieve an even distribution of weight on all pads. If an even distribution of weight was not possible because the bottom surface of the object was uneven and the object had no pre-existing base, boards of high density polyethylene (HDP) were inserted between the object and the Sorbothane pads (figs. 7a, 7b).

Choosing the correct pads for the specific object is critical, and the wrong choice can actually make things worse; for example, the system cannot be softened too much, otherwise the Sorbothane will creep: flattening over time, which renders it useless. The Columbia University team developed a customized simple software tool for the museum conservators so that they could appropriately design their Sorbothane pads for each object. This allowed them to insert maximum pad thickness (for aesthetic reasons) and provided limitations on the strain level to prevent creep. The software was created as a design tool to help museum staff determine pad dimension and property selection. The resulting calculations match those of the manufacturer-created software tool, which could be used in a trial-and-error mode to achieve the same results.

Pedestals, rather than individual objects, were isolated when the objects themselves were particularly fragile or when the objects themselves were not heavy enough to properly compress the Sorbothane pads. (Recall that because one is trying to create low natural frequency systems when performing isolation, it is important to have a relatively large mass to stiffness ratio.) One group of fragile, lightweight objects was effectively isolated by increasing the weight of each object with a steel

Fig. 7. (a) Sorbothane pads were installed in each corner of the HDP board and (b) the object was placed on top of the HDP board (Courtesy of Anna Serotta)

plate base. These objects, painted wooden models from the tomb of Meketre (MMA 20.3.9-.13), were previously installed on pedestals whose mushroom-shaped structure precluded effective isolation; the bases of these pedestals were relatively narrow and the additional height of the Sorbothane pads would have positioned the objects too close to the top of their case. New, shorter pedestals were designed and the objects were reinstalled on Sorbothane pads on top of these pedestals, with a steel plate positioned between each object and its Sorbothane pads. This new configuration, shown in figure 8, enabled the effective isolation of the models and allowed these highly popular objects to remain on view for the duration of the project.

This mitigation method had to be further modified for another group of objects in the same gallery, the Meketre boats (MMA 20.3.1-.6), which sit on glass cantilevered shelves. As with the Meketre models, deinstallation of these objects was seen as a last resort because of their importance, popularity, and fragility. Sorbothane pads were tested under one of the Meketre boat models during the pilot tests, and the vibration responses of the isolated boat and shelf were measured. The cantilevered shelves acted as

Fig. 8. (a) Sorbothane pads installed under steel plates (Courtesy of Andrew Smyth); (b) the Meketre models isolated on their new pedestals (Courtesy of Gustavo Camps)

a low-pass filter for the input vibrations, effectively filtering out much of the high-frequency component. Not surprisingly, those low frequency input vibrations were amplified, rather than dampened by the Sorbothane pads, where the response of the isolated boat is significantly greater than that of a nonisolated boat. In this case, where low-frequency vibrations were expected, alternative steps had to be taken to reduce the magnitude of the response vibrations. The solution developed by the project team was to install a support leg in the front corner of each shelf, as seen in figure 9. The legs helped elevate the natural frequency of the shelf support system and thus reduced shelf movement and, in addition, the Sorbothane pads installed between each leg and the shelf served to further dampen vibration. This system was tested and found to satisfactorily reduce the vibration experienced by the fragile boats.

Steps were also taken to mitigate vibration in entire galleries. In the same gallery containing the Meketre boats and models, a tuned mass damper was installed. This consisted of two large weights (in

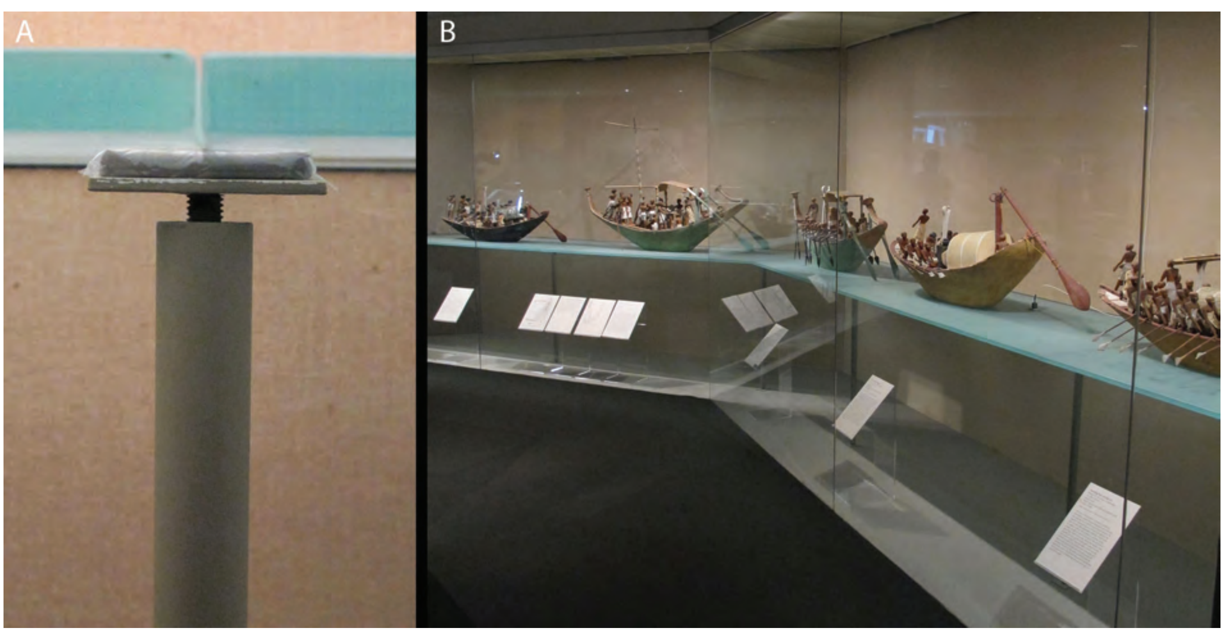

Fig. 9. (a) Sorbothane pads inserted between support leg and glass shelf; b) Support legs with Sorbothane pads at their top ends were installed under cantilevered glass shelf with Meketre boats (Courtesy of Andrew Smyth)

this case granite pedestals) placed onto Sorbothane pads in the center of the gallery. The Sorbothane/ weight system was tuned to coincide with floor vibration frequencies so that during construction the vibration of these weights would dissipate the energy of the floor vibrations. This system was tested and found to be another effective vibration dampening solution. Lower-cost versions of the same system were installed in closed galleries using cast concrete blocks.

3.3.2 Other Mitigation Strategies

Although the project team generally found Sorbothane to be a useful tool for vibration mitigation in the galleries, there were many objects whose size, shape, weight, or mounting system prevented effective isolation with Sorbothane. In such cases, objects were often protected from vibration in situ with other cushioning materials, such as polyester batting, polyethylene foam and tissue. These padding materials were installed in both galleries that would be closed for the duration of the project and in galleries that would remain open. In some cases, an entire shelf was covered with polyester batting and the objects were reinstalled over a tissue layer to protect particularly delicate materials from catching on the batting fibers. Although these materials are not particularly designed for vibration isolation, they proved to be very effective at cushioning and protecting small, lighter objects.

Another solution for protecting small, light objects was to reinstall entire shelves on trays made from thick archival blueboard and thin polyethylene foam, as shown in figure 10. These trays were given

Fig. 10. Small objects reinstalled on foam trays (Courtesy of Anna Serotta)

Fig. 11. Bumpers installed in a closed study gallery to prevent objects from walking off of shelves (Courtesy of Anna Serotta)

additional foam rims, which prevented vibration from causing especially light objects from walking off of shelves.

Because making and installing thousands of tiny objects on to the foam trays was time consuming, in closed galleries, bumpers made of Ethafoam tri-rod were often substituted (fig. 11). Bumpers were used only in cases where the objects were not particularly fragile and where the major concern was the objects walking off of their shelves.

Although many of the strategies developed were repeatable for a variety of object types, risk assessment and mitigation planning had to be carried out on an object-by-object basis, taking into account the structure and condition of the object, the mounting/installation system, and the type of demolition/construction work to be performed in that area.

3.3.3 Storage Solutions

For many objects, vibration mitigation was not possible. Either vibration in a particular area was deemed too high for effective isolation, or the mounting system or object itself prevented isolation. Additionally, the implementation of mitigation strategies was time-consuming, and the scope of objects needing protection widened as more information was gleaned about the vibration behavior of the building, installations, and objects; thus, for many objects, deinstallation was the best solution.

To accommodate the deinstalled objects, the Egyptian rotating exhibition space was converted into a temporary storage space. On the basis of the initial tests, specific objects that could not be safely isolated were slated for deinstallation, but the project team was also concerned about vibrations that might be stronger than that produced during the tests or any unexpected behavior of objects and mounting systems when exposed to vibration. To plan for any unanticipated deinstallation, the shelving size and layout of this temporary storage space was planned to accommodate a large range of objects.

It was decided to close all of the study galleries for the duration of the project and to use them as in situ storage; most objects in these galleries were rehoused with the cushioning materials described in section 3.3.2. Door plugs and scrims were created to block entrance to these spaces. The scrims were printed with a note explaining why the gallery was closed. Keeping the objects that could be safely nested in the galleries allowed the team to reserve precious storage space for the objects that did need to be moved, and minimized unnecessary object movement.

4. MONITORING AND COMMUNICATION DURING CONSTRUCTION

Although the accelerometer monitoring system was able to give us information about vibration levels in very specific locations, in-person monitoring was also required for the duration of the project. As demolition work progressed, it was noted that vibrations were often very localized and would be registered only by a sensor in the immediate area of the impact; therefore, it was critical to closely monitor locations without sensors when demolition or construction work was being carried out in these areas. Conservation and Egyptian department staff members also routinely took a hands-on approach to monitoring, particularly during structural demolition or when work was being carried out below particularly fragile objects. Team members used their hands to feel how the objects themselves were responding to vibration, noting which objects amplified vibration levels and adjusting mitigation strategies accordingly.

Additionally, Egyptian department staff members performed a daily visual check of each gallery. Before the start of demolition, conservators identified especially fragile objects in each gallery and wrote a guide for the monitoring team that outlined both general considerations and specific issues of concern in each gallery. Many fragile objects were also photographically documented before and during project. Staff members conducting the daily monitoring alerted the project team members with any concerns, and condition issues were addressed by members of the conservation staff.

Regular monitoring was particularly important for objects like some of the more fragile coffins, which were not able to be isolated with Sorbothane or other cushioning materials. The configuration of the mounts of these coffins (cantilevered shelves or four-legged brass stands) made the installation of Sorbothane pads complicated, and it was decided that handling these extremely fragile objects, all of which are constructed from multiple pieces of ancient wood with friable gesso and paint layers, could potentially cause more damage than vibration. As these coffins were not directly over areas where structural demolition was planned, it was agreed that they would be closely monitored for the duration of the project; if vibration levels exceeded acceptable limits for a sustained period of time or if the team determined the safety of the objects to be compromised, then the solution of leaving them in place would be reevaluated. Before the start of demolition work, conservation staff members carried out an object-by-object condition assessment, documented fragile surfaces with high-resolution photos, and also carried out some minor consolidation treatments of particularly friable surfaces. White paper was put under objects in closed galleries to better observe any powdering or flaking paint or wood, and a tuned mass damper was installed in the gallery.

Demolition work began in April 2012. Work was divided in to three phases: “heavy demolition” (removal of structural elements), “light demolition” (removal of nonstructural elements), and construction (installation of new elements). Faced with time constraints and thousands of objects remaining to isolate or deinstall, the project team worked with the contractors and the construction department to devise a seven-phased solution for light demolition activities, which were slated to begin first. Rather than working in multiple areas simultaneously, the contractors would work in one area at a time, completing the work in one area before moving on to the next. This phasing plan helped the project team to focus mitigation and monitoring efforts.

The museum’s construction department provided the project team with continually updated work scopes and plans, and also with the tools we needed to communicate with the contractors. The team prepared an internal schedule for responding to alerts and for communicating with the contractors. It was agreed that no work would occur outside of regular museum staff hours so that any incidents could be dealt with by the appropriate personnel.

5. SUMMARY AND CONCLUSIONS

Overall, this multifaceted project spanned approximately 33 months, from initial planning meetings in February 2011 to the official completion of the construction project in December 2013. The first round of pilot testing commenced in June 2011 and preparation of the collection followed immediately after and lasted through the spring of 2012, with additional mitigation activities undertaken as needed for the duration of the vibration-creating work, which lasted until August of 2013.

Over the course of the project, over 14,000 objects were isolated with Sorbothane or other support materials or moved to storage. Vibration mitigation with Sorbothane was highly effective, although correct installation was found to be critical, and the performance of the material over time had to be carefully monitored. When Sorbothane isolation was not appropriate, Ethafoam, batting, tissue, and other cushioning materials were also found to be effective at dampening vibration.

Although approximately two-thirds of the collection usually on display was off-view (a large percentage of this number being objects in the study collections), many collection highlights, such as the Meketre boats and models, were able to remain on view for the duration of the project. The extensive use of Sorbothane in the Late New Kingdom and Third Intermediate Period coffin galleries allowed these large, fragile objects to remain in place despite their proximity to major structural demolition. Objects in closed galleries were often able to be protected in situ, alleviating the inherent risk in transporting fragile objects and allowing the team to conserve valuable storage space.

No major damage to any artwork was incurred from vibration. As expected, the most prevalent condition issue was minor crumbing and powdering of friable wooden substrates and gesso layers. Debris was documented and removed by conservation staff, and additional treatment was carried out when necessary. Despite the support leg solution for the Meketre boat shelf, demolition work below this area produced vibration levels that were higher than expected, causing the failure of an old join in one wooden figure.

Perhaps the most dramatic incident was the migration of small objects on a cantilevered shelf in one of the study galleries. Work under this area produced significantly more vibration than anticipated, causing objects on shelves directly above to be significantly displaced. Fortunately, these objects were prevented from walking off of the shelves by previously installed Ethafoam tri-rod, and more fragile objects were protected with tissue and foam supports.

Throughout the testing, preparation, and construction phases of the project, museum staff learned a great deal about how objects and installations respond to vibration, and also how vibrations travel and change within the architecture of the building. Several critical observations were made about the behavior of particular installations and, in future, the project team might advise against placing particularly fragile objects on vibration-amplifying cantilevered shelves and Plexiglas pedestals, particularly if vibration-producing activities are anticipated. Vibrations were frequently stronger than anticipated (often stronger than vibration levels recorded during the probes) and sometimes traveled in unexpected paths, being dampened or amplified by the various materials in gallery floors and walls. The same type of work or tool could produce different vibration levels from one area to the next, and occasionally vibration traveled significant horizontal and vertical distances. On the other hand, some construction activities resulted in very localized vibration that was often not detected by nearby sensors. Unforeseen vibration events also arose, as one might expect, from incidents in the construction zone and from regular museum activities, such as opening case doors, rigs driving through the galleries, or visitor traffic and accidents.

Real-time vibration data communicated by the sensors were critical to the project team's ability to respond to vibration events in the galleries, but for the aforementioned reasons, and because the objects themselves sometimes amplified vibration, monitoring could not be done through numerical data alone. In-person observation was a critical component of the project; this, in combination with the extensive preparatory work, was a considerable strain on the available workforce and required significant coordination efforts.

In general, the project's success was largely thanks to effective communication between museum staff, engineers, and contractors. The work schedule changed frequently, and all parties needed to remain flexible. Weekly meetings, regularly distributed work schedules, and constant dialogue ensured that demolition and construction work could move forward while ensuring the safety of this important collection.

ACKNOWLEDGMENTS

The authors would like to thank the other members of project team–Isabel Stünkel (assistant conservator, Egyptian Art), Ann Heywood (conservator, Objects Conservation) and Elizabeth Fiorentino (collections manager, Egyptian Art)–for their incredible efforts, and Diana Craig Patch (curator-in-charge, Egyptian Art), Dorothea Arnold (emeritus curator-in-charge, Egyptian Art), Lawrence Becker (Sherman Fairchild conservator in charge, Objects Conservation) for their tremendous support. This project was a success due to the combined efforts of many individuals from The Metropolitan Museum, RCDolner LLC, and The Columbia University Department of Engineering and Engineering Mechanics. Enormous thanks to Eddie Graziano of RCDolner LLC; Luisa Ricardo Herrera of the Construction Department; Sergio Salerno, Dennis Kelly, Seth Zimiles, and Jeffery Hall, the Egyptian Art technicians; Emilia Cortes, conservator, Textile Conservation; Debbie Schorsch, conservator, Objects Conservation; Rebecca Capua, assistant conservator, Paper Conservation; Adrian Brügger, Patrick Brewick, Raphael Greenbaum and Manolis Chatzis of the Columbia University Department of Civil Engineering and Engineering Mechanics; and many others from Egyptian Art, Objects Conservation, Construction, Buildings, the Ratti Center, Design, Scientific Research, IS&T, Digital Media, Visitor Services, the Director's Office, Security and RCDolner LLC.

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Thickett, D. 2002. Vibration damage levels for museum objects. *ICOM Committee for Conservation preprints.* 13th Triennial Meeting, Rio de Janeiro. London: James & James Ltd. 1: 90–5.

SOURCES OF MATERIALS

Sorbothane (aka. Ultra-Soft Polyurethane) in a variety of thicknesses and durometers
McMaster-Carr
PO Box 440
New Brunswick, NJ 08903
732-329-3200
www.mcmastercarr.com

Ethafoam, Acid-free Tissue, Mylar, Blue Board (Heritage Courrugated B-Flute Board) and Pellon (non-woven polyester batting)
Talas
330 Morgan Ave.
Brooklyn, NY 11211
212-219-0770
www.talasonline.com

Ethafoam Tri-rod (aka. GripStrip Backer Rod)
Weatherall Company, Inc.
106 Industrial Way
Charlestown, IN 47111
877-275-2739
http:/weatherall.com

Accelerometers
PCBPiezotronics, Inc.
3425 Walden Avenue
Depew, NY 14043-2495
800-828-8840
www.pcb.com

High Density Polyethylene Sheets
McMaster-Carr
PO Box 440
New Brunswick, NJ 08903
732-329-3200
www.mcmastercarr.com

ANNA SEROTTA graduated from the Conservation Center, Institute of Fine Arts, New York University, in 2009, where she majored in objects conservation with a focus on archaeological materials. After graduating, Serotta completed a fellowship in the Sherman Fairchild Center for Objects Conservation at the Metropolitan Museum of Art. Between 2010 and 2014, Serotta held the position of Contract Conservator and then Assistant Conservator in the Sherman Fairchild Center for Objects Conservation at the Metropolitan Museum of Art, working predominantly with the Egyptian Art collection. In addition to her museum work, Serotta participates regularly in archaeological fieldwork; currently, she is the senior field conservator at the Met's excavations at Dahshur in Egypt and New York University's excavations at Selinunte in Sicily. She is also an adjunct professor at the NYU Conservation Center, where she coordinates and lectures in a short course in archaeological field conservation and co-teaches a course on conservation documentation. Address: 40 Sidney Place, Apt 2B, Brooklyn, NY 11201. E-mail: aserotta@gmail.com

ANDREW SMYTH is a professor of civil engineering and engineering mechanics at Columbia University with a primary research focus in dynamics and structural vibrations. Prof. Smyth received his ScB and AB degrees at Brown University in 1992 in Civil Engineering and Architectural Studies respectively. He received his MS in civil engineering at Rice University in 1994, and an MS in electrical engineering (1997) and a PhD in civil engineering (1998) at the University of Southern California. He joined Columbia as an assistant professor in 1998. In 2007, he was a visiting researcher at the Laboratoire Central des Ponts et Chausées, Paris. He is the recipient of the ASCE Walter L. Huber Research Prize and was awarded an NSF CAREER award. He serves on the editorial board of the *ASCE Journal of Engineering Mechanics* and in 2011 was elected to serve on the Board of Governors of the ASCE Engineering Mechanics Institute of which he was named a Fellow in 2013. He also is a member of the Executive Committee of the US Panel on Structural Control and Monitoring. He serves as the chair of the Smart Cities Center at Columbia's Institute for Data Science and Engineering and is also the director of the Carleton Strength of Materials Laboratory at Columbia. Address: Department of Civil Engineering and Engineering Mechanics, 610 S.W. Mudd Bldg., MC4709, Columbia University, New York, NY 10027. E-mail: smyth@civil.columbia.edu

INTRODUCTION TO THE JOINT OBJECTS AND ARCHITECTURE SESSION PAPERS

SUZANNE DAVIS

The final six papers in this volume come from a joint session of the Architecture and Objects Specialty Groups. Jennifer Correia, program chair for ASG in 2014, and I had a shared goal in our selection of these papers: we wanted to explore the liminal space between our two disciplines. This space is hard to define, but recognizable to many conservators. It is a place where traditional professional boundaries dissolve, where "objects" are part of structures, and structures are treated as objects. It is also a place where the objects of our work exist in landscapes and cityscapes ,not museums. Whetherthese "objects" are archaeological temples or modernist monuments, they are situated in active communities whose needs and desires are as important as the heritage we conserve.

These papers focus on built and natural heritage in a variety of dissimilar locations: the banks of the Nile River; Colombia; Lake Tahoe; Los Angeles, California; and a small city in the Midwest. What these papers all share is collaborative, innovative research and problem solving in the frontier between objects and architectural conservation.

CONSERVATION OF INSCRIBED SANDSTONE FRAGMENTS AT LUXOR TEMPLE IN EGYPT

CASESTUDY

HIROKO KARIYA

ABSTRACT

Since 1995, the Epigraphic Survey of the Oriental Institute, University of Chicago, known as Chicago House has been carrying out conservation of inscribed sandstone fragments in Luxor Temple, Egypt.

Over the last 18 years, the project went through various phases in order to meet the most immediate needs on site. The original focus on documentation, treatment, and condition monitoring of about 2000 registered fragments quickly evolved to include emergency protection of additional 40,000 unstudied, inscribed fragments. After the emergency protection of the fragments was achieved, the project focus shifted to site management including stabilization of temple walls by reconstruction and providing public access to the collection by creation of an open-air museum.

This article discusses challenges such as managing a massive amount of semiportable artifacts with limited resources, balancing protection with public access and working with a community heavily reliant on the tourist industry. In addition, it includes the ongoing impact of Egypt's 2011 revolution on the community surrounding the site as well as on our conservation approach.

1. INTRODUCTION

1.1 LUXOR TEMPLE FRAGMENTS

The city of Luxor, known as Thebes (pharaonic *Waset*) in ancient times, is located approximately 700 km south of Cairo. Luxor Temple, on the east bank of the Nile, was mainly built during the reigns of Amenhotep III, Tutankhamen, and Ramses II in the 14th and the 13th centuries BCE. The temple was constructed from large sandstone blocks decorated mainly in painted raised relief, as shown in figure 1.

Traces of historical defacement, restoration, and alteration are present on some blocks. When the temple was reduced to a quarry for building materials in late antiquity, the blocks were cut to small sizes for reuse in the foundations of mud brick superstructures in the immediate vicinity. The latest of these were occupied into the late 19th century. In the 1880s and 1890s Georges Daressy, working for the Egyptian Service d'Antiquités, cleared all post-antique stratigraphy down to the ancient levels. When this happened, the ancient fragments faced reuse again, this time as fill in the construction of the Nile "*corniche*" (or embankment road); however, the inscribed fragments discovered during excavations by the Egyptian Antiquities Organization along the Avenue of the Sphinxes in front of the temple during the 1950s and 1960s were retained by them in the Luxor Temple precinct. Following excavation, these fragments were stored directly on damp ground contaminated with soluble salts (fig. 2).

1.2 EPIGRAPHIC SURVEY

In the late 1970s and throughout the 1980s, the fragments were studied by Chicago House, which collected and documented about 2000 inscribed fragments and established their original provenance within the Temple and sites elsewhere. They were registered and moved onto nine "*mastabas*" (or platforms) with damp-proof courses created using a bituminous membrane to resist the capillary rise of the ground water. These platforms were purpose-built for long-term storage of fragments in the

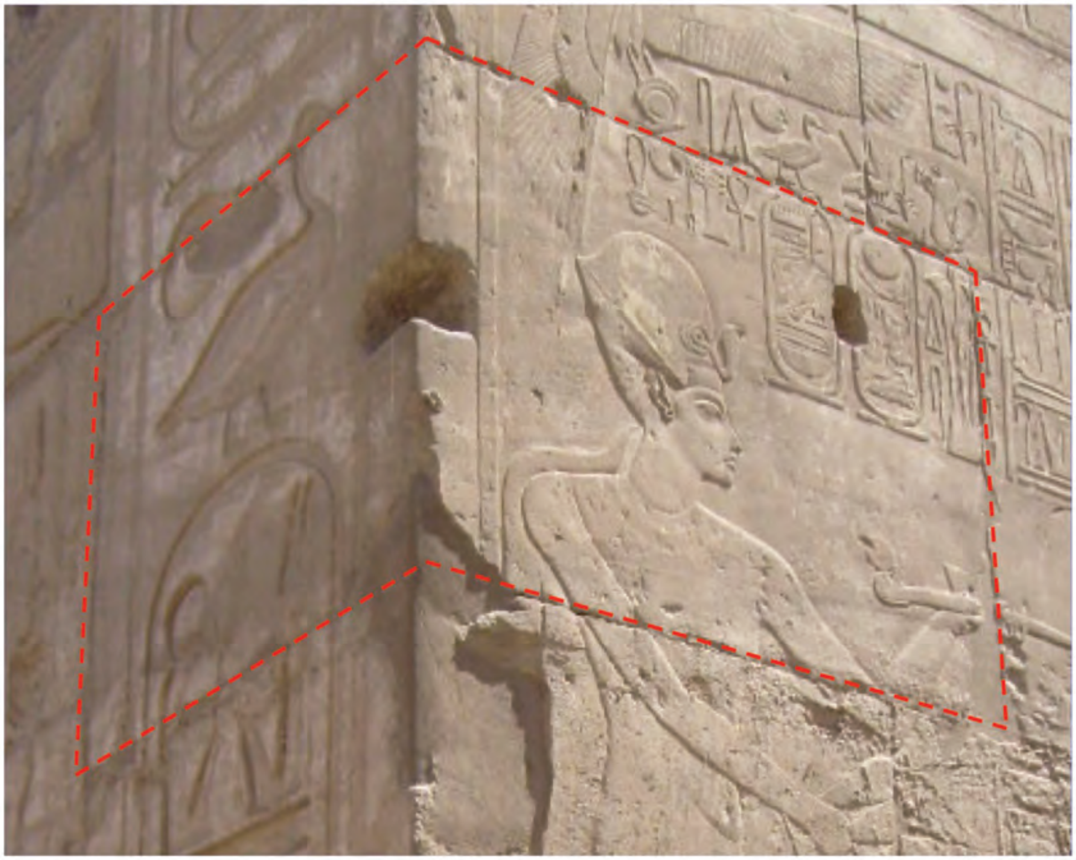

Fig. 1. Original sandstone blocks in intact wall (Courtesy of Hiroko Kariya)

Fig. 2. Sandstone fragments after excavation (Courtesy of Lanny Bell)

southeast corner of Luxor Temple. This main storage area came to be known as the Luxor Temple "blockyard."

1.3 SANDSTONE

According to XRD carried out in 1998 by the Engineering Center for Archaeology and Environment, Cairo University, the sandstone is composed of mainly quartz with traces of clay minerals such as kaolinite, goethite, albite, and oligoclase.

Although the specific provenance of the fragments has not been determined through petrological study, historically comparable sandstone in ancient Thebes has been studied and identified as originating from Gebel el-Silsila, located some 40 km north of Aswan along the Nile Valley. This so-called Nubian sandstone was widely employed as a building material in Upper Egypt (or southern Egypt) from the middle of the 18th Dynasty (1539–1295 bce), including many buildings in Luxor such as Karnak Temple and Medinet Habu. The sandstone at Luxor Temple was probably procured from this quarry.

1.4 INSCRIPTION MATERIALS

The sandstone blocks are mostly carved in raised relief on surfaces perpendicular to the natural sedimentary strata of the stone. Many carved surfaces are finished with a thin fine gypsum (calcium sulfate) preparatory layer for subsequent painting. There are traces of coarse gypsum mortar and original architectural features such as holes for dove-tail clamps on uninscribed surfaces (and sometimes on inscribed surfaces from reuse).

The original gypsum preparatory layer has minor traces of quartz and calcium carbonate impurity, whereas a thin layer applied over the original paint for ancient restoration or reuse is often found to be a mixture of calcium sulfate and calcium carbonate, common in later periods.

Traces of pigments and/or a preparatory layer are preserved on about a third of the registered fragments. Pigments were identified by the author using a polarizing light microscope and/or microchemical spot tests in Luxor. These pigments include Egyptian blue (calcium copper silicate), red ochre (iron oxide), and yellow ochre (iron oxide), all commonly used pigments in ancient Egypt. They are often found mixed with calcium sulfate with minor quartz inclusions to create a lighter shade; for example, calcium sulfate is mixed with Egyptian blue to create light blue; with red ochre to create a reddish skin color; and with yellow to create a yellowish skin color. In addition, a greenish blue pigment consists of Egyptian blue and yellow ochre.

2. DETERIORATION PHENOMENA

Limited analysis to identify the substrate and determine deterioration causes as well as the effectiveness of treatment was carried out by the Engineering Center for Archaeology and Environment, Cairo University. The majority of the study on materials and deterioration was based on visual examination under low magnification on site as well as simple "low-tech" testing such as microchemical spot tests and/or use of indication strips. Long-term monitoring provided the most useful and realistic information to determine treatment and protection approaches.

2.1 GRANULAR DISINTEGRATION

The main problem of the fragments is granular disintegration due to the loss of natural binding media such as clay minerals, especially along vulnerable bedding planes. An early stage of granular disintegration can be seen in figure 3, while figure 4 shows advanced disintegration of the same block.

Fig. 3. Fragment with early stage of granular disintegration along bedding planes, 1983, (Courtesy of Susan Lezon)

Fig. 4. Same fragment in advanced stage of disintegration, broken into 2 pieces, 2007, (Courtesy of Hiroko Kariya)

This deterioration can be accelerated by the movement of soluble salts due to environmental fluctuation as the fragments were exposed to the ambient outdoor environment since excavation. This could result in the total disintegration of the stone over time.

2.2 SOLUBLE SALTS

While reused in foundations, many fragments were exposed to contamination by human and animal organic waste as well as the natural salinity of the local soil. It is reported that rapid population growth in the Luxor area and the construction of the Aswan High dam in 1970 accelerated the contamination of local ground water. It should also be noted that sandstone samples from Gebel el-Silsila contained chloride and nitrate ions; thus, soluble salts in fragments could originate from not only the burial environment but also from the original quarry site.

An XRD analysis indicated that a sample collected from deteriorated stone contained a mixture of sodium chloride (halite) and/or sodium nitrate. A total of 96% of samples collected from 107 fragments detected chloride, nitrate, or sulfate ions by qualitative and/or semiquantitative tests (microchemical spot tests and/or indicator strips). Both chloride and nitrate were more common than sulfate salts. Many samples, especially those collected from actively deteriorating stone, contained a higher quantity of chloride than nitrate ions. It is difficult to determine the behavior of a mixture of salts as they have a wide range of equilibrium relative humidities.

Significant concentrations of soluble salts were detected at least 9 cm below the surface of deteriorated stone, even though the physical disruption may only affect a few millimeters of the surface. Samples collected at 1.5 cm intervals from a single drilled hole (from decayed uninscribed fragments) showed that the concentration of chloride ions is high, extending almost equally through the depth to at least 9 cm, whereas that of nitrate ions decreases as the depth increases (for an unidentified reason).

2.3 OTHER TYPES OF DETERIORATION

In addition to the deterioration described earlier, deteriorated surfaces can be pitted by minor occasional rain. Pigments are friable due to loss of binding media. Some paint layer(s) are flaking off from the preparatory layer or the stone surface due to lack of adhesion. Emergency consolidation of inscribed surfaces, possibly with diluted polyvinyl acetate emulsion, carried out in the 1970s caused surface darkening due to exposure to the outdoor environment. In addition, since this consolidant did not deeply penetrate to bond the deteriorated area and relatively intact core, it caused surface exfoliation as the consolidant shrunk. Other types of deterioration were also present, such as staining from nearby construction sites and cracking and breaking due to improper handling and poor storage conditions.

3. CONSERVATION PROJECT

The current conservation work was started as a four-year funded project in 1995 by my predecessor, John Stewart. I joined the team in 1996 and have been working every year since then (between 3 weeks and 4.5 months per season) except for 2003 when the second Iraq war started.

3.1 TREATMENT OF REGISTERED FRAGMENTS

The principal objective of this initial conservation project was the stabilization of about 200 of the most seriously deteriorating fragments. These were selected from the 2000 registered fragments. The most effective methods were identified through testing of potentially appropriate conservation materials on site. The project also included documentation, monitoring, and protection of the remaining 1800-registered fragments.[1]

3.1.1 Stone Consolidant

After limited analysis, discussions with conservators working in Luxor, satisfactory results from the 1986–88 treatment, and various field tests including application methods, curing time, environmental condition for application, etc., the inorganic consolidant tetraethoxysilane (TEOS) or Wacker OH (and later Wacker OH100) was selected for use in consolidation of the sandstone fragments. It provides proper strength with minimal or no darkening, desirable penetration, retreatability, and chemical and physical compatibility and stability in outdoor environments. It was also locally available.

Wacker OH is a stone strengthener based on tetraethoxysilane with a neutral catalyst (dibutyltindilaurate). It is a one-component ready-to-use system and does not contain water repellent. Wacker OH comes as a 75% solution in acetone and methyl ethyl ketone (MEK). Later, the formula was changed to “solvent-free” (or “straight”) ethyl silicate and sold as Wacker OH100 (or SILRES BS OH 100.)

TEOS reacts with atmospheric humidity as well as moisture within stone pores. It releases alcohol and forms silicic acid gel, which eventually converts into silicon dioxide (SiO_2).

$$Si(OCH_2CH_3)^4 + 4H_2O \xrightarrow{\text{catalyst}} Si(OH)^4 + 4CH_3CH_2OH$$
$$Si(OH)^4 \rightarrow SiO_2 + 2H_2O$$

Specific environmental conditions are required during application and curing to achieve optimum results. The environmental conditions recommended for application by the manufacturer are as follows: temperatures between 10 and 20°C (50–68°F) and the relative humidity (RH) above 40%. It requires approximately 2–3 weeks to cure, depending on prevailing environmental conditions. Repeated treatment may be required on severely deteriorated surfaces, in 3–4 week intervals (or longer as it is observed that TEOS could stay hygroscopic for months after curing.)

3.1.2 Application and Curing

Chicago House's field season usually takes place between mid-October and mid-April. Annual environmental conditions in the shade in Luxor range from 6 to 56°C (mean 26°C) with relative humidity between 0 and 87% (mean 33%). These conditions are often outside of the recommended range of application and curing of the consolidant. As the climate is generally unfavorable for the use of the consolidant outdoors for most of the year (except for a few early morning hours between December and February), a simple microclimate environment was created to maximize treatment time.

A microclimate "tent" for movable fragments was built over an unfinished storage platform filled with sand (used as a sandbox to support uneven fragments). The tent (approximately 6 m (l) × 1 m (d) × 1.35 m (h)) was constructed from a wooden frame (later replaced by an aluminum frame) covered with cotton-backed plastic sheeting (with the cotton side facing out). Figure 5 shows a drawing of the tent's construction.

The interior of the tent was divided into three sections using plastic sheeting. Water may be sprayed in the tent to raise RH days before treatment if necessary. In the sandbox, selected fragments were placed (over a polyethylene isolating sheet) with the surface to be treated facing up to permit maximum penetration of the consolidant. In most cases, only one face was treated at a time.

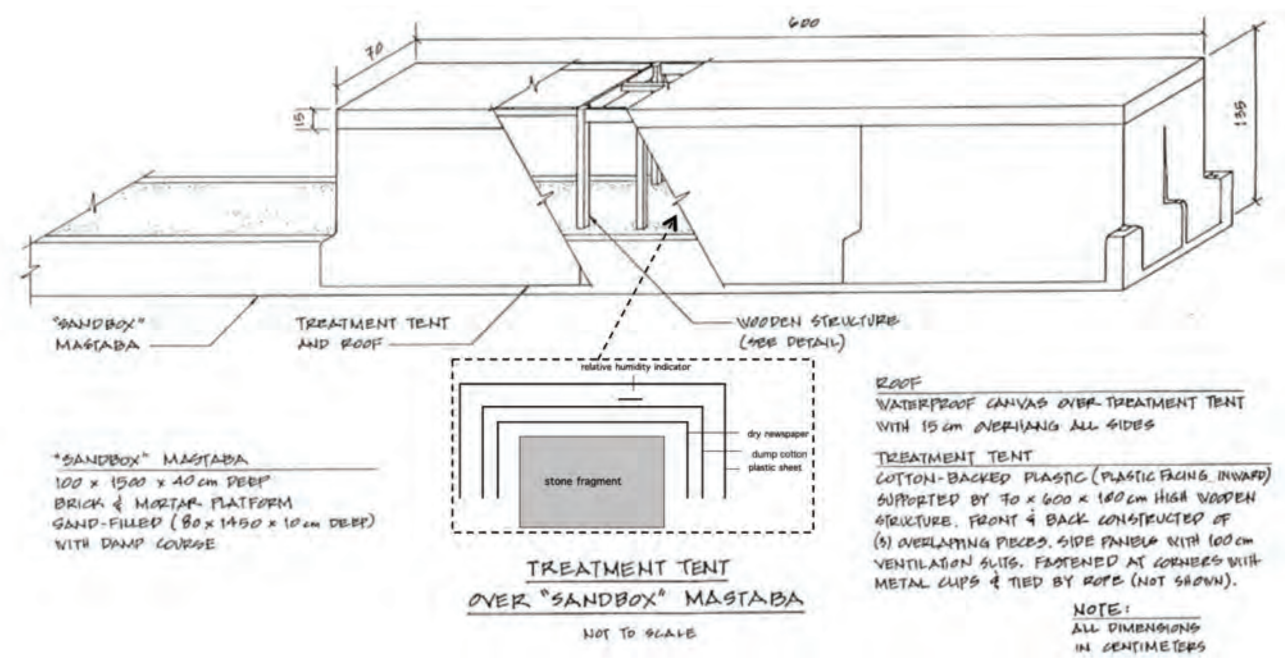

Fig. 5. Original microclimate treatment tent (Courtesy of Margaret De Jong) and microclimate set up for portable fragment (Courtesy of Hiroko Kariya)

After testing various application methods including pipet-dripping, spraying, brushing, immersing, and capillary absorption, the consolidant was generally drip-fed, using disposable polyethylene pipettes onto deteriorated stone surfaces until fully saturated. In the case of severely deteriorated surfaces, dripping the consolidant could cause surface loss or pitting; thus, it could only be fed into the margins of the decayed area by capillary absorption.

Each treated fragment was covered with multiple layers of dry newspaper as separation from the slightly damp cotton sheet placed above. Exposure and transfer of newsprint ink to the consolidant was tested before usage to confirm no dissolution of the ink. These layers provide sufficient moisture for the consolidant's chemical reaction, without mobilizing soluble salts within the stone. The fragment was then covered with a plastic sheet (not tightly sealed). The RH level of the environment of treated fragments was carefully maintained between 40 and 60%.[2]

The consolidation was carried out within one section of the tent at a time. Once completed, the section was closed to reduce evaporation and contain solvent fumes within it. The solvent's fume concentration around treatment sites was measured using self-indicating dosimeters for MEK, one of the components in Wacker OH. On the basis of this measurement, access to the treatment areas was restricted by personal communication as well as strategically placed signs and ropes.

During curing, distilled water was occasionally sprayed in the tent and/or the cotton sheet cover. After about 3 weeks, the covers on the fragments were removed. After one additional week, the tent was opened to ventilate for a few days. The condition of the fragments was then examined and recorded. Temperature and RH in the tent were recorded using a small digital hygro-thermometer (and later datalogger) and entered in the database described in detail below.

This treatment method provided the most simple and efficient design for treatment of portable irregular fragments. This method maximized the space and time available by minimizing handling fragments, and effectively contained solvent fumes. Two tents were constructed in the blockyard. About 50 fragments can be treated in one tent depending on their size. One cycle of the treatment takes about 4 weeks including microclimate preparation, documentation, transportation and setup of fragments, and curing time.

In the case of consolidation of immobile stone such as large blocks and wall fragments in situ, treated surfaces were first covered with plastic sheets that were perforated in areas corresponding to the treated areas. This was followed by application of cotton sheets lightly dampened with distilled water. The perforated plastic sheet allowed for the movement of water vapor from the sheet to the treated surface of the stone, but prevented direct contact. The cotton sheets were further covered with a solid plastic sheet to prevent rapid drying and inhibit the rapid evaporation of the consolidant. The entire surface area was then draped with a canvas sheet as a sunshade.

These fabric sheets and membranes were held in place on the wall by wooden battens fastened into modern wall joints by means of removable plastic screw plugs. Figure 6 shows a drawing of the microclimate set up for treatment of standing walls.

3.1.3 Desalination

The behavior of specific soluble salts in the fragments in a given environment will have an important bearing on their future stability. Because treated fragments must remain in the uncontrolled ambient climatic conditions of Luxor Temple, it is likely that consolidation will only retard the deterioration process, unless fragments can be effectively desalinated (Bradley and Hanna 1986). The presence of soluble salts in the stone may also affect the curing properties of the consolidant. One study showed that Wacker OH does not form a continuous film over salt crystals (Berry and Price 1994). Another study suggests that consolidation should be carried out only if followed by desalination because the consolidation could accelerate salt efflorescence formation (Miller 1992); however, at least in the case of Luxor Temple fragments, salt efflorescence was rarely caused by the consolidation and curing process.

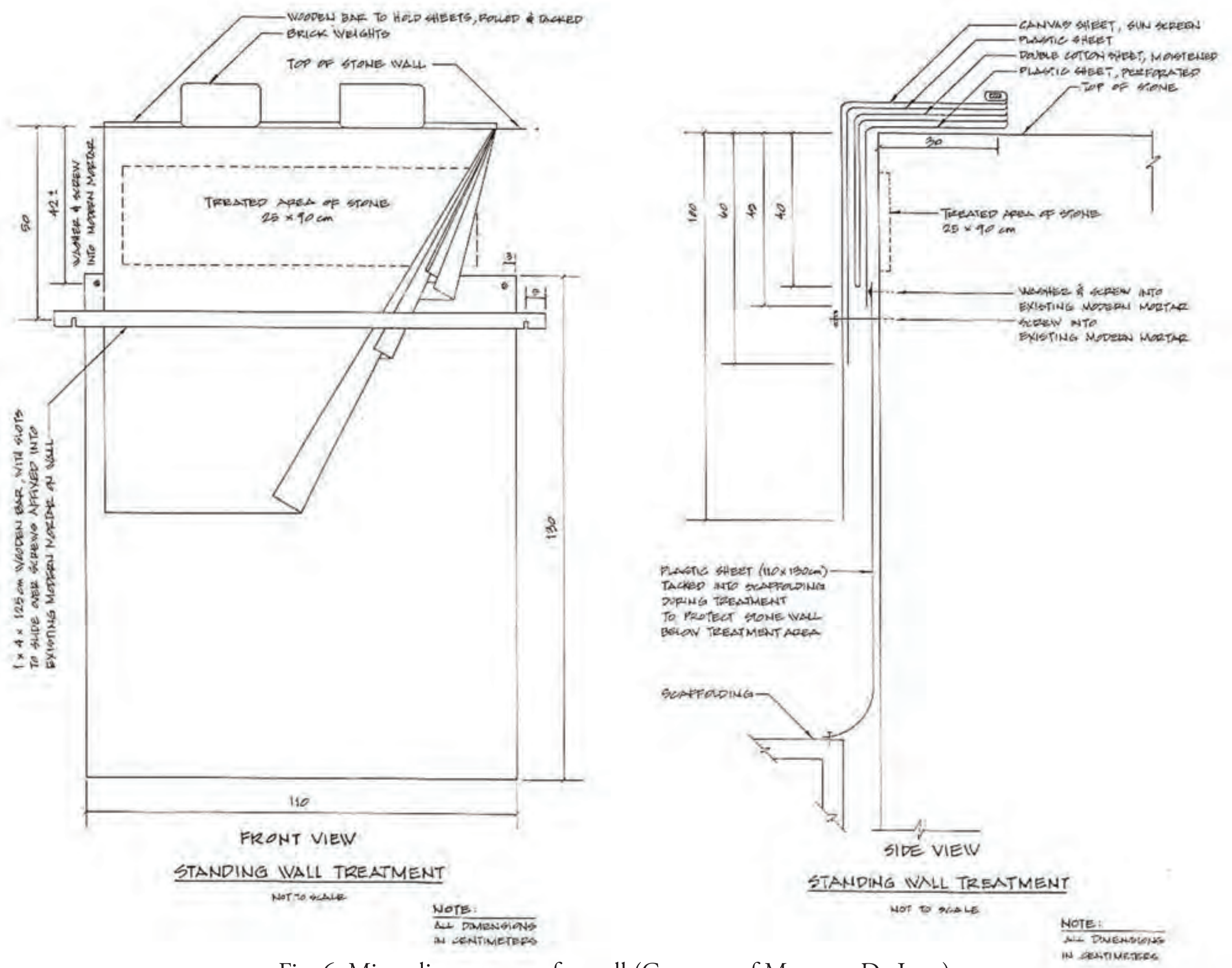

Fig. 6. Microclimate set up for wall (Courtesy of Margaret De Jong)

Desalination testing was carried out by the author. Most sample fragments (including both treated and untreated pieces) that were desalinated by immersion or poulticing with various materials appeared to have promoted or activated movement of soluble salts and, thus, resulted in more deterioration than undesalinated fragments. After monitoring desalinated and undesalinated fragments, it was decided desalination would be performed only on limited numbers of fragments because it is difficult to effectively desalinate fragments. Partial or incomplete desalination appeared to promote salt activation. It is also difficult to protect pigments and a preparatory ground layer during desalination. With limited facilities and materials, it is not realistic to plan desalination of a large number of fragments. Instead, the condition of the treated fragments is annually examined and recorded. Desalination was performed on a small number of fragments with continuous salt deterioration and fragments with past or present salt damage that were to be reconstructed on temple walls (as it would be difficult to access them once reconstructed.)

3.1.4 Treatment Results

About 79% of consolidated surfaces showed improvement. At least 12.5% of fragments remained in the same condition (or show no or negligible improvement) after treatment and 8.5% of the treated surfaces continued to deteriorate after a short period of time despite treatment.

The consolidant was not always applied in a single cycle of treatment (one application cycle.) Approximately 49% of treated fragments required retreatment; 44% required second or third applications; and 5% required more than four applications of the consolidant. If retreatment was not carried out in a reasonable period, deterioration resumed. Because the treatment requires about 4 weeks, it sometimes took several seasons for completion of treatment for one fragment, especially if multiple applications were required.

There was no distinction in stone type between successful and unsuccessful cases of the treatment according to visual examination. Also, there was no difference in the environmental conditions (outside the treatment tents) during treatment and curing. Furthermore, no significant difference was observed in the content of soluble salts and the initial depth of deterioration. The unsuccessfully treated fragments have, however, larger areas of deterioration (more than 20% of their surface area) when compared to the successfully treated fragments.

Approximately 10% of treated surfaces showed darkening during posttreatment examination. The darkening was not related to any specific stone type. An unfavorable curing environment may be responsible for this problem in part. In most cases, however, darkening disappeared after a year or two. A single excessive application of the consolidant could cause darkening of the stone surface. Darkening seemed to be minimized when the stone was not over saturated. Consequently, it proved better to treat a fragment several times rather than oversaturating the stone at once with a single application of the consolidant.

3.1.5 Database

A database (using the software FileMaker Pro) was developed to facilitate monitoring of the treatment and annual condition assessment (fig. 7).

This database can provide information on various aspects of treatment such as the amount of consolidant applied, its application environment, the number of applications, darkening, changes in posttreatment condition, etc.

3.1.6 Summary

In summary, the consolidation using TEOS significantly improved the condition of most deteriorated fragments in the given environment. The following advantages and disadvantages are noted while using this consolidant on site.

The advantages include physical strengthening, high penetration, minimal or no darkening, chemical and physical compatibility with sandstone, retreatability, ease of use, and local availability. The disadvantages include its slow curing process, possible multiple applications required, difficulty in creating a desirable treatment environment for application and curing, unknown long-term stability

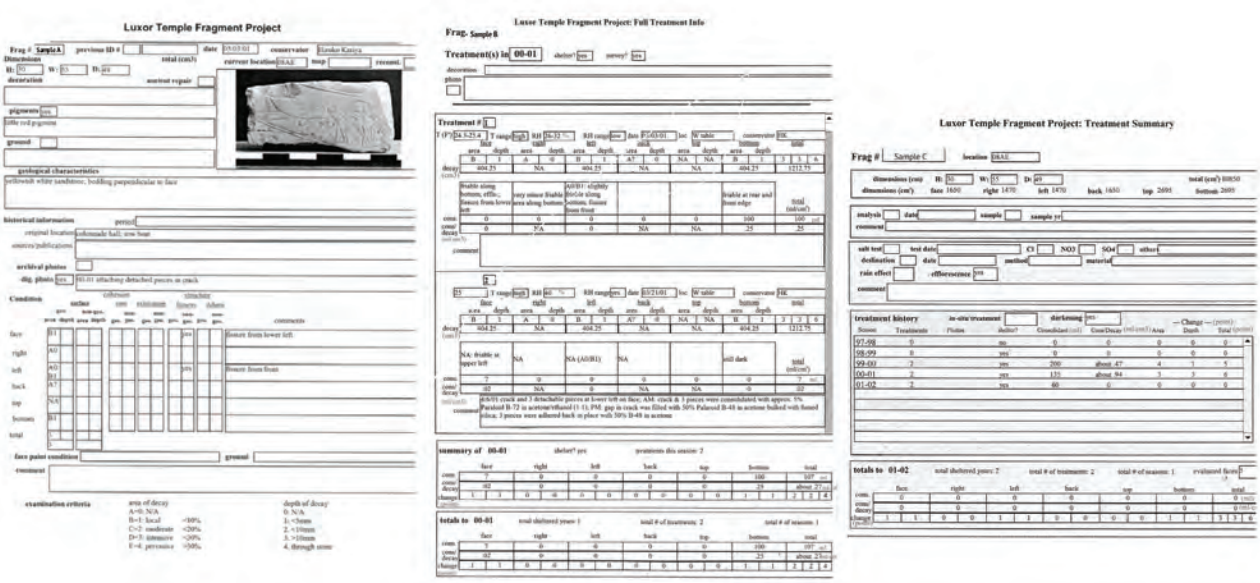

Fig. 7. Database sample forms; examination (left), treatment (center), summary (right) (Courtesy of Hiroko Kariya and Harold Hays)

(especially with the presence of soluble salts), brittleness of bonding between mineral grains, limited strengthening for properties for coarse stone with large pores (large distance between grains), high cost, and toxicity, requiring proper personal protection (which can be uncomfortable in the intense heat). It should be noted that although some fragments were treated in slightly less than ideal conditions, no difference in resulting strength was observed. Importantly, the long-term effectiveness of TEOS is of concern especially if soluble salts remain in the stone; however, the few deteriorated fragments treated in 1986–88 were not desalinated. They were left in an uncontrolled environment. After 25 years, they are still in a largely stable condition. Long-term monitoring of the condition of the collection is necessary to appraise the real efficacy of this particular combination of materials and treatment methods.

3.2 EMERGENCY PROTECTION AND DATA MANAGEMENT

While focusing on the 2,000 registered fragments, we witnessed some unregistered inscribed fragments that were still sitting on the soluble salt contaminated ground completely disintegrating into piles of sand. Also, construction around Luxor Temple uncovered hundreds of fragments that were added to our collection. Consequently, we shifted our goal to emergency protection of tens of thousands of unstudied, inscribed fragments.

We built about 200 additional damp-proof platforms. Because most of the blockyard has never been excavated, platforms were built to be temporary, nonsolid structures. They consist of brick walls filled with sand and topped with a damp-proof course, bricks, and mortar. Some fragile fragments were protected in various temporary shelters such as plastic-lined wooden boxes, shelves, and aluminum frames draped with durable "tent" or "sail" canvas sheets because we are not allowed to keep artifacts under lock and key. Very few fragments still in situ were reburied. More than 40,000 inscribed fragments were moved onto the platforms in the vicinity of the original wall locations whenever possible, as seen in figure 8.

During this process, the fragments were sorted by categories, mainly according to historical periods. Various miscellaneous fragments from the Middle Kingdom (the 20th century bce) to modern

Fig. 8. After sorting and storing of fragments on damp-proof platforms (Courtesy of W. Ray Johnson)

Islamic times were found among the piles. Some fragments were reconstructed on platforms to promote their comprehension. Designated numbers were given to registered fragments. These were applied to the surface using a durable, permanent outdoor marker, Valve Action Paint Marker, that was selected after testing of various markers. Also, a simple FileMaker Pro inventory database was created to manage the massive quantity of data.

3.3 SITE MANAGEMENT

After emergency protection and general sorting of the fragments, we shifted our goal once again to the structural stabilization of the temple wall, site management, and promotion of public access to the collection.

3.3.1 Reconstruction (Structural Stabilization)

Although the original locations of many fragments were identified, only a small portion of the fragments can be returned to their original place because they do not directly join the remaining walls. Because the middle section of the wall was at ground level before the excavation, it was more accessible in the intervening centuries to people seeking to quarry temple blocks for reuse, and thus these blocks are often missing. Moreover, the ground-level position of these blocks made them most susceptible to deterioration.

In 2004, we were urged to stabilize part of the wall in the Colonnade Hall of Amenhotep III. The result is a unique example of the integration of structural engineering, conservation, masonry work, and Egyptological research. During his annual inspection, a structural engineer, Conor Power, identified the wall as one of two structurally dangerous sites at the temple. As many as 48 fragments originating from this wall were located, stabilized, and used as part of the structural reinforcement of the wall, as shown in this reconstruction drawing (figure 9).

Locally fired bricks and lime mortar were used instead of stone to build the main support; this reduced weight and also enables insertion of any fragments discovered in the future. Figure 10 shows this brick core.

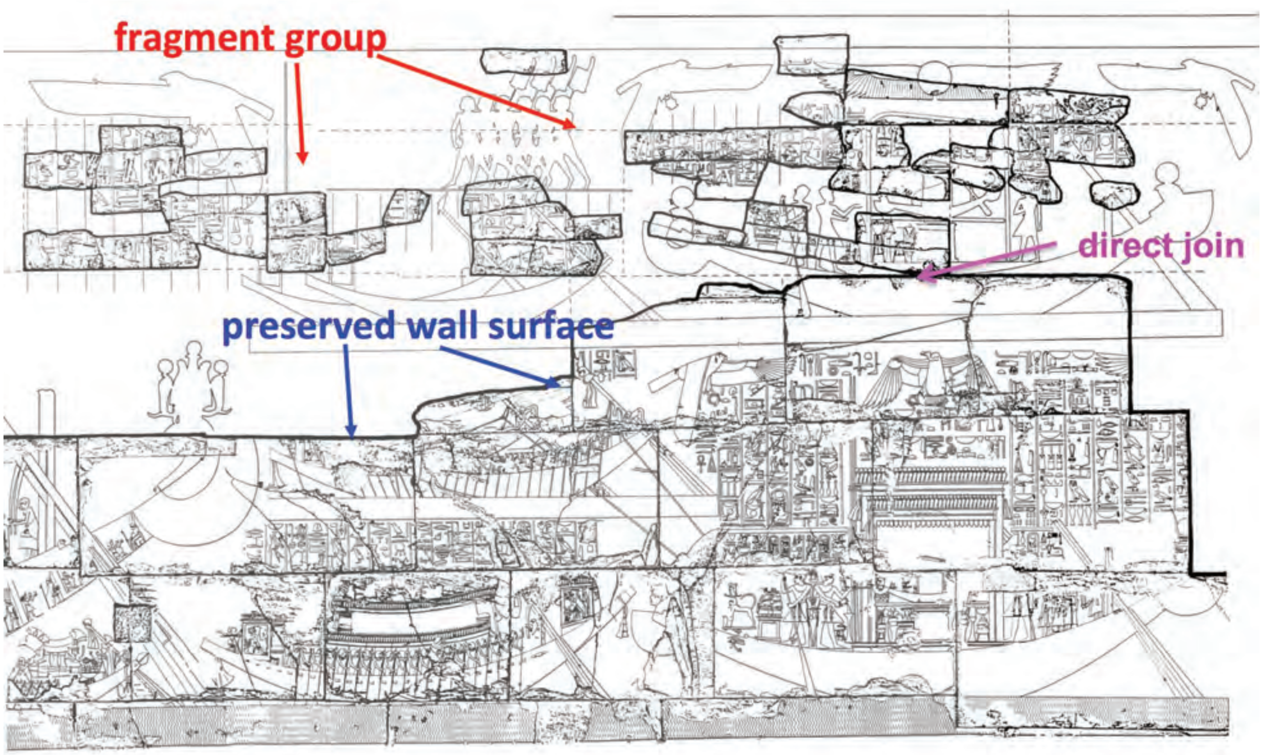

Fig. 9. Reconstruction drawing of the east wall in the Colonnade Hall of Amenhotep III (Courtesy of W. Ray Johnson and Carol Meyer)

Fig. 10. Brick core to support unstable wall (Courtesy of W. Ray Johnson)

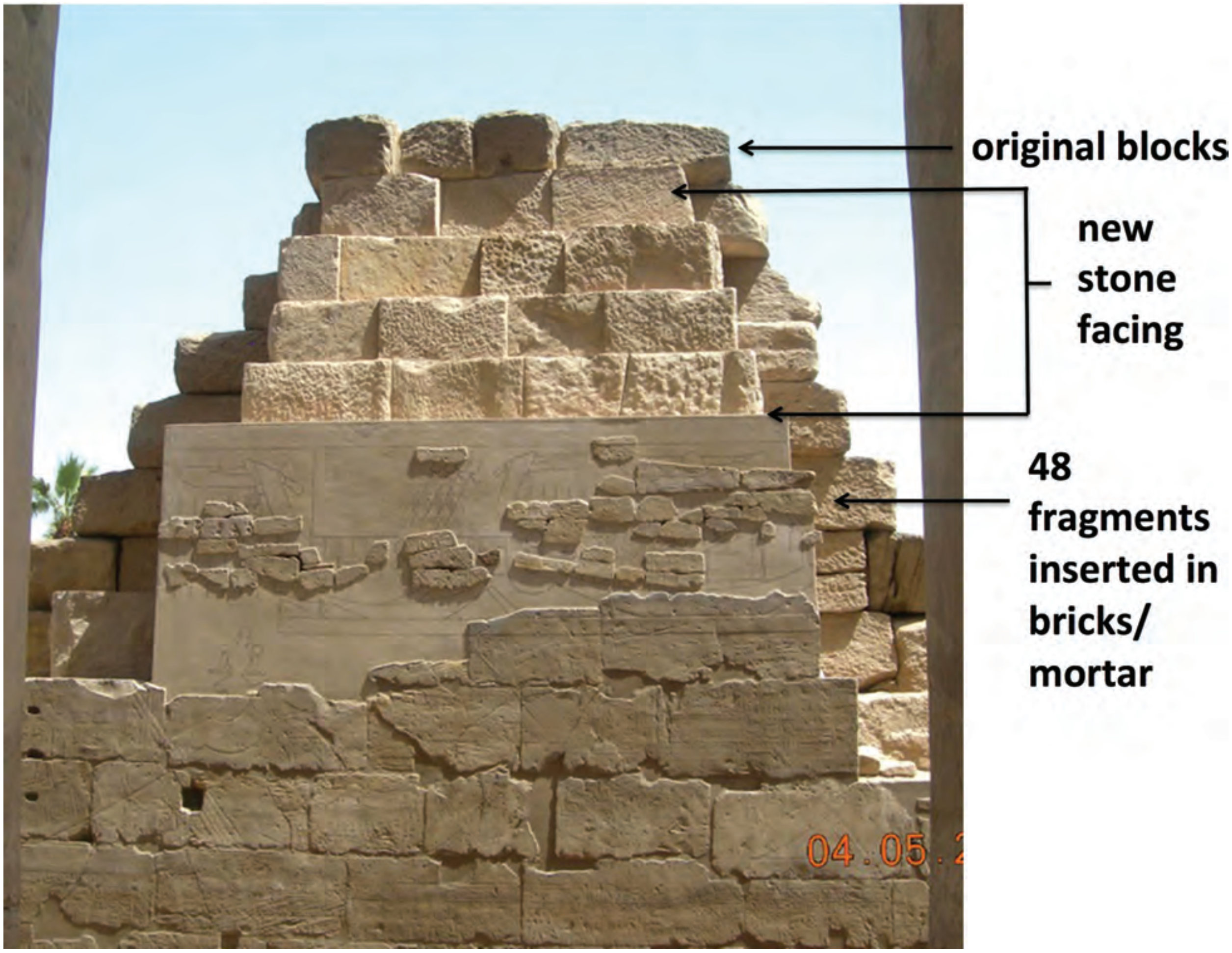

Fig. 11. Wall after reconstruction (Courtesy of Hiroko Kariya)

As hydraulic lime is not locally available in Egypt, lime mortar was mainly used. Proper mixtures were selected by a mason depending on areas of use. The 48 extant fragments, including one small piece to join the wall, were inserted in the brick matrix, whereas the upper section of the brick support was faced with sandstone slabs imitating the original stone blocks (fig. 11). Finally, missing sections between the fragments were compensated with minimal line drawings using acrylic paint (selected after testing). The fragments preserve part of the great Opet Festival river procession inscribed during the reign of Tutankhamun, specifically the great riverine barge of the god Khonsu.

Throughout the project, we trained local staff in tasks such as the proper slaking and preparation of lime mortar. Because we are not allowed to bring any heavy mechanical equipment into the temple, the work was carried out manually, just as in ancient times.

This work served as a prototype for the reconstruction of another wall in the Sun Court of Amenhotep III. As many as 111 fragments (including five newly discovered fragments in 2009) originate from 16 large blocks identified by Chicago House in the 1970s. This wall was structurally stable, but twice as many original fragments were used. Of these, 27 fragments were reconstructed in 1986–88. Reconstruction of an additional 82 fragments was completed in 2010. Reconstruction of the remaining two fragments was purposefully kept for the future because of their location. The fragments preserve a depiction of the great bark of Amun-Re and a pile of offerings set up in the court, flanked by figures of Amenhotep III. The wall also presents examples of historical defacement, restoration and alteration; the bark was carved by Amenhotep III, hacked by Akhenaten's agents, restored by Tutankhamun, appropriated by Horemheb (who erased Tutankhamun's name and added his own), and was finally enlarged by Sety I, who added a restoration inscription.

3.3.2 Open-Air Museum and Site Management

With an increased number of visitors to the temple, another phase of the project began in 2007. Although the blockyard had been closed to the public, we strongly believed that many of the fragments could serve as a great educational tool. Our work focused on providing public access to part of the blockyard in the form of an open-air museum. The central idea of the open-air museum is to create a chronological, art historical, and stylistic chain of examples of inscribed fragments from the Middle Kingdom to modern Islamic times with brief explanatory signs in Arabic and English.

In addition to this educational purpose, the project embodied site-management goals. Because visitors to Luxor Temple generally walk through the narrow north–south axis (especially in the hypostyle hall and antechambers in the south) and back the same way, opening this part of the temple significantly eased the flow of visitors (fig. 12).

Fig. 12. New public access added by open-air museum (Courtesy of Hiroko Kariya)

Fig. 13. Luxor Temple open-air museum and storage area (Courtesy of W. Ray Johnson)

Before the construction, part of the blockyard was filled with modern rubble and trash. As always, the project began by negotiation with the local authorities. All structures were built to be temporary to allow possible future excavation. A majority of the work was manually conducted as heavy equipment is not allowed within the temple. Non-Egyptologists made the initial selection of the display fragments from among the 40,000. We aimed to select fragments that would capture the eye and imagination of the public; thus, our choices were based on wider considerations than scholarly significance alone. Our director, Dr. W. Ray Johnson, later chose historically and stylistically significant pieces from among this group. During their transportation, fragile surfaces were temporarily protected by facing with tissue and/or fabric and cyclododecane. Some fragment groups were reconstructed on the display platform; however, no fragments were directly mortared. They were dry-set in bricks and mortar fill, thus preventing the mobilization of soluble salts and enabling later insertion of any fragments. Losses were compensated by simple line drawings.

In the open-air museum, 200 m of paved paths were created along 12 thematic platforms on which over 300 fragments are displayed, as seen in figure 13.

In addition to the chronological display, the museum includes a group of fragments to highlight the unique features and conservation issues of the blocks, a rotating display with specific themes, and finally a viewpoint for the site of the Roman tetrastyle. The blocks are illuminated by spotlights every evening, keyed to the overall temple lighting system as the temple opens at night.

This project exemplified the integration of various specialties including conservation, Egyptological or curatorial work, design and collections management, and engineering and masonry construction work. We made every effort to use local resources including manpower and materials. Whenever possible, we trained local workmen and used large amounts of recycled materials for construction. In the interest of sustainability, we felt it was more important to use simple, accessible, low-cost materials and regularly replace them than to use more aesthetic, durable imported materials that might become hard to obtain in the future.

Originally, we struggled to balance protection with public access; however, we found that the paved pathway with its railing was adequate and perhaps even more effective in keeping visitors from straying than any “no entry” signs. In addition, as soon as the fragments were displayed, people started to pay respect to these long-neglected fragments. This also brought challenges. The more people see value in the fragments, the more we became responsible for their security. Small portable pieces were braced with metal straps. We also made a visual inventory list for the temple's inspectors to help them to monitor the collection.

Early ideas for an audio guide were abandoned after considering the reaction of the local guides to potential competition with their services. Instead, our director gives the local guides an annual on-site training, which informs and encourages them to bring their tours. In addition, an online catalogue is currently being prepared for visitors interested in more detailed information about the site.

4. IMPACT OF REVOLUTION AND ONGOING TURMOIL

In February 2011, the Egyptians overthrew 30 years of dictatorship through revolution. This was completely unexpected for us. It was the middle of the fieldwork season, and events in Cairo took us by surprise. Although some missions were evacuated, most Chicago House staff remained working on site during the entire months of the revolution.

Although southern Egypt, including Luxor, turned out to be relatively peaceful with some minor incidents, it was a long, uncertain time with a lack of reliable information or sometimes no information at all. The resignation of Hosni Mubarak did not end the period of uncertainty. Turmoil including looting and theft of antiquities throughout Egypt continues to date.

4.1 IMPACT OF REVOLUTION

During this period, some of the immediate and direct impacts on missions working in Egypt included decreased site security, delays in granting work permits due to the constant changes in government personnel, difficulty of planning work, and lack of basic necessities such as fuel and electricity. Security was a major consideration to individual foreign staff, host institutions, and funding sources. We observed the difficulty of planning future, long-term work, retaining professional staff due to uncertainty of schedules, and the emotional impact on local staff.

Luxor with a population of about 600,000 holds many ancient sites such as Karnak and Luxor Temples on the east bank and Valley of the Kings, Medinet Habu, and Colossi of Memnon on the west bank. It has been a UNESCO World Heritage Site since 1979 and its economy largely relies on tourism. Consequently, Luxor's experience over the past 3 years is somewhat unique even for Egypt.[3] The lack of tourism could mean reduced resources for site maintenance. This experience urged us to review our site conservation program. We needed to ensure the sustainability of the site without our presence, especially at the open-air museum.

4.2 EMERGENCY RESPONSE

In January 2014, I returned Luxor for the first time after the 2013 military take-over. Our assigned inspector, who was one of many young, enthusiastic people hired after the revolution, was excited about participating in the maintenance program.[4] He set up three meetings with his colleagues for me. Through these meetings, I discussed with almost 40 inspectors, including the chief inspector of the temple, common problems such as the improper behavior of visitors (i.e., climbing monuments, etc.) and site maintenance challenges such as equipment repairs and trash and weed removal. These problems became more serious due to lack of maintenance personnel after the revolution. We brainstormed solutions such as public outreach (training local guides, lectures at local schools, greeting tour groups at entrance, etc.) and comprehensive signage to reduce improper behavior by visitors (proper visitor conduct signage at entrance, pictogram signs, etc.), installing physical blocking of access (railings, walls, signs, etc.), and systematic inspection and collaboration with Chicago House local staff for maintenance. I was open to all suggestions, but tried to keep our final trial program simple, realistic, and low cost.

On the basis of their suggestions, in the 2014 season we installed pictogram signs and replaced some ropes with metal chains that are considered to be more respected by local visitors. I also came up with a trial program for the off-season this year. Although not completely independent from Chicago House, this trial program will lay the foundation for independent off-season maintenance. We stocked some consumable materials such as light bulbs for off-season use. A simple checklist in English and Arabic was provided, which will be used during a regular walk-through by inspectors. If necessary, they will report issues requiring attention to one of two inspectors who volunteered to be point persons. They will then contact Chicago House, which will send local staff to repair or provide replacement material. A suggestion notebook was also provided for noting comments by any temple staff for discussion.

4.3 FUTURE PLAN

Next season, we will review the trial program. Signage indicating proper visitor conduct will be installed at the entrance. Also, a workshop on site sustainability with our inspectors may be proposed. Finally, in the future, I hope to reach a formal agreement on responsibilities between Chicago House and the temple staff, and eventually to shift full responsibilities to the temple staff.

5. CONCLUSIONS

We have been lucky to be able to continue the project for 18 years. We tried to meet the needs of the project and the interests of available funding sources. For a project like this, it is important to be flexible to meet any unexpected needs on site. Utilizing local resources is a major factor in our success. It is not only cost effective but also helps us build mutual trust and strong cooperative relationships with the community and local professionals. Increasing public access and education promotes understanding and respect for the site as well as its artifacts. This was one of the most significant outcomes of the project.

Finally, the 2011 revolution (and ongoing turmoil) was a wake-up call. We are still uncertain and adjusting our work as the situation changes; however, the revolution and Egypt's transformation consistently reminds us of the importance of a systematic, practical, and sustainable site management program.

ACKNOWLEDGMENTS

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NOTE

1. A final report was submitted to American Research Center in Egypt (ARCE). See "Luxor Temple: Conservation of Luxor Sandstone Block Fragments, Luxor Temple Egypt" by H. Kariya and J. Stewart, February 1, 2004. ARCE Egyptian Antiquities Project.

2. To identify the range of RH, white salt crystals typically found on fragments (containing chloride and nitrate) were sampled from five fragments. A small amount of the samples was exposed to microclimate with RH adjusted at approximately 20–30%, 40%, 50%, 60%, 70%, 80%, 90%, and 100%. The samples were monitored to determine their dissolution RH. After a few days, it was observed that one sample was dissolved above 70%, two above 80% and two above 90%. This indicates that the common white salt crystals may be mobilized at RH above 70%.

3. In 2011, 14 million tourists came to Egypt and about 9.4 million in 2013 (many to the Red Sea only). In 2011, Egypt obtained approximately $18 billion from tourism revenue which is 12% of GDP. By 2013, the share of tourism in GDP dropped to $5.9 billion. About 12.5% of national employment relies on tourism, and this is much higher in Luxor. (sources: Middle East Institute; *BBC News; Al Ahram; The Guardian*)

4. The number of temple staff significantly changed since the revolution. As of March 2014, in Luxor Temple, there are 64 inspectors (including over 30 hired post-revolution after a long-term hiring freeze as a result of protest by temporary staff); 38 guards (there used to be 65 guards, now reduced by attrition); approximately 20–25 conservators; about 10 cleaners (day shift only).

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SOURCES OF MATERIALS

ACR, SR-002 SmartReader 2 T/RH Logger
Herzog/Wheeler & Associates
2183 Summit Avenue
St. Paul, MN 55105-1051
651-647-1035

Chloride Test Kit Model PSC-DR Code 4503-DR
LaMotte Company
802 Washington Avenue, PO Box 329
Chestertown, MD 21620
410-778-3100
www.lamotte.com/en/

Cyclododecane
Kremer Pigments Inc.
228 Elizabeth Street
New York, NY 10012
212-219-2394; 800-995-5501
www.kremerpigments.com

Digital MAX-MIN Thermometer/Hygrometer
Preservation Equipment Ltd.
Church Road, Shelfanger, Diss
Norfolk, IP22 2DG, UK
+44 0 1379 647400
www.preservationequipment.com

Dist WP Waterproof Conductivity Meter
Merck Ltd.
Merck House, Poole,
Dorset BH15 1 TD, UK
+44 0 1202 669770

Gastek Dosi-tube No. 152D (Methyl Ethyl Ketone)
SKC Ltd, 11 Sunrise Park
Higher Shaftesbury Road
Blandford Forum
Dorset DT1 8ST
+44 0 1258 480188
www.skcltd.com

LaMotte Multi-Range Conductivity Meter (model DA-1)
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Chestertown, MD 21620
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Merckoquant Nitrate Test/Sulphate Test
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Polyethylene Pipet Graduated 5 ML
Sigma-Aldrich Corp
St. Louis, MO
314-771-5765
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Quantab Chloride Test Strips
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P. O. Box 389
Loveland, CO 80539-0389
800-227-4224
www.hach.com

Valve Action Paint Marker
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Elk Grove Village, IL 60007-5746
800-621-4025
www.markal.com

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Wacker-Chemie GmbH,
Geschaftsbereich S, Hans-Seidel-Platz 4,
D-81737 Munich, Germany
+49 89 629-0
www.wacker.com/cms/en/home/index.jsp

HIROKO KARIYA was trained as an objects conservator at the Conservation Center, Institute of Fine Arts, New York University. She has worked in the Conservation Department, Brooklyn Museum, and other museums in the United States. She has also worked on various archaeological sites including the Athenian Agora in Greece, Kaman-Kalehoyuk in Turkey, Mut Temple, Karnak Temple, and Valley of the Kings in Egypt. She is currently in private practice as an objects conservator working in museums and on archaeological sites. She has been a project conservator for the Epigraphic Survey of the Oriental Institute, University of Chicago in Luxor since 1996. She also works as a consultant at the Qatar National Museum in Doha, the Pennsylvania-Yale-Institute of Fine Arts in Abydos, Egypt, New York University Expedition to Abydos, Egypt, for Waseda University at Abusir in Saqqara Egypt, The Metropolitan Museum of Art and the Michael C. Carlos Museum, Emory University in Malqat, Egypt, and for UNESCO Egypt-Waseda University in the Valley of the Kings, Egypt. Since 2009, she has also worked as a conservator for special projects for Harvard University's Archaeological Exploration of Sardis, Turkey. Address: 509 Morgan Dr, Lewiston, NY 14092-1105. E-mail: hkariya@aol.com or hkariya8@gmail.com

THE CULTURAL PRODUCTION OF TOURISM AT LAKE TAHOE: EXPLORING HOW CULTURAL HERITAGE PRESERVATION IS IMPACTED BY TOURISM

CATHERINE E. MAGEE

ABSTRACT

This article explores the connection between tourism and cultural heritage preservation by examining the formation processes of hybrid tourist/cultural heritage landscapes. As heritage conservation professionals, we use scientific investigations and research to better understand material culture and how to best preserve it, but education and scientific illumination are just two end results of our work. Our work, the real end result of what most of us do, is for tourists, enticing people to visit our museums, national parks, archaeological sites, and historic buildings both in reality and virtually. We are involved in the cultural production of tourism and tourist sites, although we may not conceptualize our work in this way.

This article explains and explores this connection between tourism and cultural heritage preservation. Specifically, it examines the impact tourism had and has on the cultural heritage of the Washoe Tribe of Nevada and California by investigating the cultural landscapes of Lake Tahoe, United States.

1. INTRODUCTION

Our work as heritage professionals is part of an extensive community of people dedicated to the preservation of tangible and intangible heritage. We help ensure the preservation of cultural heritage, and conservators have a unique and intimate relationship with the objects we conserve, regardless of whether the object is a building, landscape, or sculpture. This extensive and comprehensive understanding of objects enables conservators to uncover little known aspects of an object's manufacture and use that can reveal connections between cultures. These discoveries, so extensively documented, become part of an object's cultural interpretation. Conservators recognize this unique relationship and responsibility because it is likely their interactions with the object will shape the object's long-term preservation and contribute to the scientific, academic, and cultural understanding of the object. We as conservators see our work in cultural heritage institutions as contributing to these intellectual pursuits, often with the catalyst for our work being museum exhibits or the preservation of buildings, sites, and monuments. The public then visits these venues, where conservators have aided in the public's interaction with and potential interpretation of that cultural heritage.

The concept proposed in this article is to consider who the end users of our work are, and how the end users or consumers of our work inform the preservation decisions we make. Many conservation professionals see the scientific and academic study of objects as the primary products of their work. But much of our work ends up being presented to the public, and its educational components are high on the list of end products of our work. In the end, the visiting public, or tourists, are the largest consumers of our work. We as heritage professionals, however, do not necessarily recognize or think of our work within the broader context of tourism. Indeed many of the preservation decisions conservators and heritage preservation professionals make are impacted by tourism and play a part in the cultural production of tourism. Additionally, in the ever increasing incorporation of our work within the concept of sustainability, it is critically important to recognize that our work is an integral part of the tourism network.

2TOURISM AND SUSTAINABILITY

Sustainability is most often identified with ecological principles and the impact humans have on the environment. Yet sustainability is an encompassing concept dealing with sociocultural, economic, and environmental concerns. It is the combination of all of these aspects that create a truly sustainable approach. Tourism impacts sustainability in each aspect and is an inherently consumptive process as practiced today.

Although the act of tourism dates back millennia, the academic study of it and its definitions is a relatively new field. Once the stance of defending tourism as an activity that deserves serious academic attention was established, tourism was soon examined as an activity that has global sociocultural, economic, and environmental impacts (Hall and Page 1999; Hall and Page 2009). Tourism has both positive and negative impacts and is widely promoted as a development tool and economic panacea, bringing much needed international currency to depressed local economies. Yet tourism can be a force for endangering and altering traditional local cultural practices and values, bringing outside influences and practices to communities worldwide. Tourism can be a force for good, promoting global peace and cross-cultural understanding; yet it can also be a force aiding in the subjugation of indigenous people, who often earn low wages in tourist sites. Tourism can be promoted as sustainable, yet eco-tourism can still deplete precious local resources such as water and divert it to tourists and away from locals, and it can be the mechanism or impetus that introduces invasive species into an ecosystem.

Tourism is a major formative and reciprocal process, impacting the places and people visited as well as impacting the tourists themselves (Urry 1990). Tourism's sphere of influence is global; it infiltrates all aspects of culture—socially, environmentally, visually, ethnically, ethically, and aesthetically. Tourism shapes culture and creates its own culture. This co-production of people, places, and things is reflected in our everyday lives because tourism is pervasive. In our postmodern world, tourism is conducted daily, and by simply engaging in our daily routine we too can become tourists in reality or virtually (MacCannell 1976; Urry 1990). The academic literature is replete with definitions of tourists and tourism, subdividing tourism into groups and types that are too numerous to list here. Tourism is studied across disciplines including: geography, anthropology, sociology, psychology, hospitality, and marketing. Broad tourism categories that are most applicable for heritage professionals include heritage tourism, cultural heritage tourism, eco-tourism, sustainable tourism, adventure tourism, and mass tourism; but a case could be made for many more tourism categories. This is because our work in heritage preservation is cross-disciplinary and has multiple permutations that overlap with other tourism categories such as dark tourism. This is exemplified by the recent work of conservators working with genocide victims to help to create an environment for cultural healing through preserving items that include human remains, aiding in establishing museums, and installing exhibits. This work is done in places dealing with the aftermath of cultural genocide and is a powerful example of how our work encompasses the broader aspects of cultural sustainability while being part of tourism. These places may now be primarily visited by genocide survivors, but also serve as places of cultural memory and can be visited or used by others. Our work as heritage professionals is manifested in many ways, and all these potentially have ties to the multiple expressions of tourism.

3. TOURIST/CULTURAL HERITAGE LANDSCAPES

As briefly described above, there are many rich avenues to explore the links between tourism and cultural heritage preservation. Heritage—built and natural, tangible and intangible—is typically segregated for effective management, ease of categorization, and implementation of preservation strategies. Yet this is an artificial division in how people perceive and actually interact with cultural heritage. The term "cultural landscape" is an answer to this, and it was first recognized by the United States National Park Service in 1981. The

United Nations Educational, Scientific and Cultural Organization officially sanctioned the cultural landscape in 1992 as a designation of cultural heritage that "represent combined works of nature and of man" (Alanen and Melnick 2000, 8). I would add to this definition an additional layer of meaning, that of an ethnographic landscape as defined by Hardesty. He explores how ethnographic landscapes have different meanings imparted to them by the different culture groups interacting with them (Hardesty 2000). Combining these two definitions creates my definition of a cultural heritage landscape, and this is the designation I prefer over cultural landscapes. My current research analyzes cultural heritage landscapes, large and small, to explore how tourism impacts cultural heritage preservation, resulting in what I have termed the hybrid tourist/cultural heritage landscape.

The formation of these hybrid tourist/cultural heritage landscapes occur globally and will be explored via the landscapes of Lake Tahoe, United States (see figs. 1, 2) as these are the focus of my current research.

Fig. 1. Map of the Great Basin (Courtesy of Wikipedia, http://en.wikipedia.org/wiki/Great_Basin)

Fig. 2. Map of Lake Tahoe (Courtesy of A Great Place to Stay.Net, http://agptspics.homestead.com/TAHOELOCATIONMAP.html)

Like other cultural heritage landscapes, they have been shaped by man and nature, have different meanings to the people interacting with them, and have undergone and will undergo continual changes due to tourism. Tourism has and continues to shape the cultural heritage landscapes at Lake Tahoe. I am specifically examining how the original culture group at Lake Tahoe, the Washoe Tribe of Nevada and California, was impacted by tourism, and how this is expressed in the cultural heritage landscapes of Lake Tahoe today, creating hybrid tourist/cultural heritage landscapes.

Visitors to Lake Tahoe may not initially or easily recognize the impact the Washoe people had and have on their experience of the Lake Tahoe landscapes; the influence is discernable, but not always in obvious ways. Euro-American settlement of Lake Tahoe and tourism had strong and irreversible impacts on the Washoe people culturally, economically, socially, and environmentally. The landscapes at Lake Tahoe today represent this reciprocity of influences. My goal is to highlight how tourism in particular played a role in shaping the Washoe people's cultural heritage traditions and interaction with Lake Tahoe landscapes, and in turn how the Washoe people shaped tourism and tourists' landscapes at Lake Tahoe. This interaction over time resulted in the hybrid tourist/cultural heritage landscapes that are valued and protected at Lake Tahoe today. In this article, I will examine two case studies to highlight different landscape formation processes. These case studies exemplify multiple aspects of what constitutes hybrid tourist/cultural heritage landscapes.

3.1 AN OVERVIEW OF SETTLEMENT AND TOURISM AT LAKE TAHOE

In order to understand the changing Lake Tahoe landscapes, one needs to have a sense of the patterns and processes of settlement and tourism; therefore a brief history of the Washoe people and Euro-American settlement of the Lake Tahoe Basin will be outlined. Although the Lake Tahoe Basin's entire shoreline has been affected by Washoe and Euro-American settlement and tourism, specific places, people, and activities will be highlighted as they represent the overall patterns or point to particularly significant events. The discussion particularly emphasizes the sociocultural impacts of settlement and tourism development at Lake Tahoe, highlighting the impact of tourism on the Washoe people who become a tourist product and producer of tourism.

For thousands of years, Lake Tahoe was known only to the Native Americans of the Sierra Nevada, and primarily the Washoe people. Their name for Lake Tahoe is *Da ow a ga*, and it is the center of their physical and spiritual homeland (The Washoe Cultural Office 2009). Lake Tahoe was bypassed by the earliest European and American explorers owing to the difficulty of the terrain and the formidable barrier of the Great Basin. It was first mapped by John C. Frémont in February of 1844, who without the aid of a Washoe guide, it is said, would have likely perished in the Sierran winter (James 1915; The Washoe Cultural Office 2009). Lake Tahoe was overlooked by the rush of miners seeking to strike it rich in California in 1849 and seen as an obstacle to the reverse-migrating California miners lured by the promise of new riches in the Nevada Territory's 1859 Comstock Lode. When entrepreneurs serving the masses of miners who were headed for Virginia City turned their attention to Lake Tahoe, they realized that a full service hotel along its shores could be more than just a way station on a wagon road (Scott 1957). This sparked early tourism, Euro-American development was established, and the mechanisms altering Lake Tahoe landscapes were set in motion (James 1915; Scott 1957; Downs 1966; Nevers 1976; Goin et al. 1992; Obermayr 2005; Makley 2011).

3.1.1The Washoe People

The Washoe people, *Wa She Shu,* have always been at Lake Tahoe. Their creation legend places Tahoe at its center, where they as a people began (Downs 1966). The Washoe people's creation myths, spiritual beliefs, mythologies, and their social, economic, and cultural well-being all radiate from Lake Tahoe (Downs 1966; Nevers 1976; Hinkle and Hinkle 1987; Makley 2011). Thousands of years of use of Lake Tahoe as their seasonal meeting, hunting, and gathering place left little physical evidence on the landscape except for depressions in large rock platforms, known as bedrock mortars, that were used for grinding foraged nuts, seeds, and dried fish (Rucks 1995; Obermayr 2005). The Washoe's physical presence on the landscape was minimal, although today their physical impact on the landscape is being further explored by examining how they managed ecosystems (Taylor and Beaty 2005). To this day, Lake Tahoe is infused with meaning specific to the Washoe. According to Downs, many Washoe place names result from the legends of the twin weasels *Damalali* and *Pewetseli* and their encounters with other miraculous creatures including Water Babies, who are linked to shaman. The most sacred place in all the Washoe lands is on the eastern shore of Lake Tahoe: Cave Rock, or *De'ekwadapush*. This is the Washoe's religious center, where shaman would receive spiritual guidance through meditation and rituals (Downs 1966; Nevers 1976; Makley and Makley 2010).

Not only does Lake Tahoe nurture the Washoe spiritually, but in the past it sustained them physically as well; the Lake Tahoe Basin was part of their seasonal hunting and gathering grounds (fig. 3).

Lake Tahoe was too cold and snow covered for year-round habitation, so the Washoe people would move up into the Lake Tahoe Basin beginning in spring, with entire family groups settling annually in their ancestral camps near the shores. The Washoe were a small group of people dispersed across the Sierra front and western Great Basin during most of the year because their lands were a difficult environment for subsistence. The annual gatherings at Lake Tahoe were not just to gather food for the winter, but also

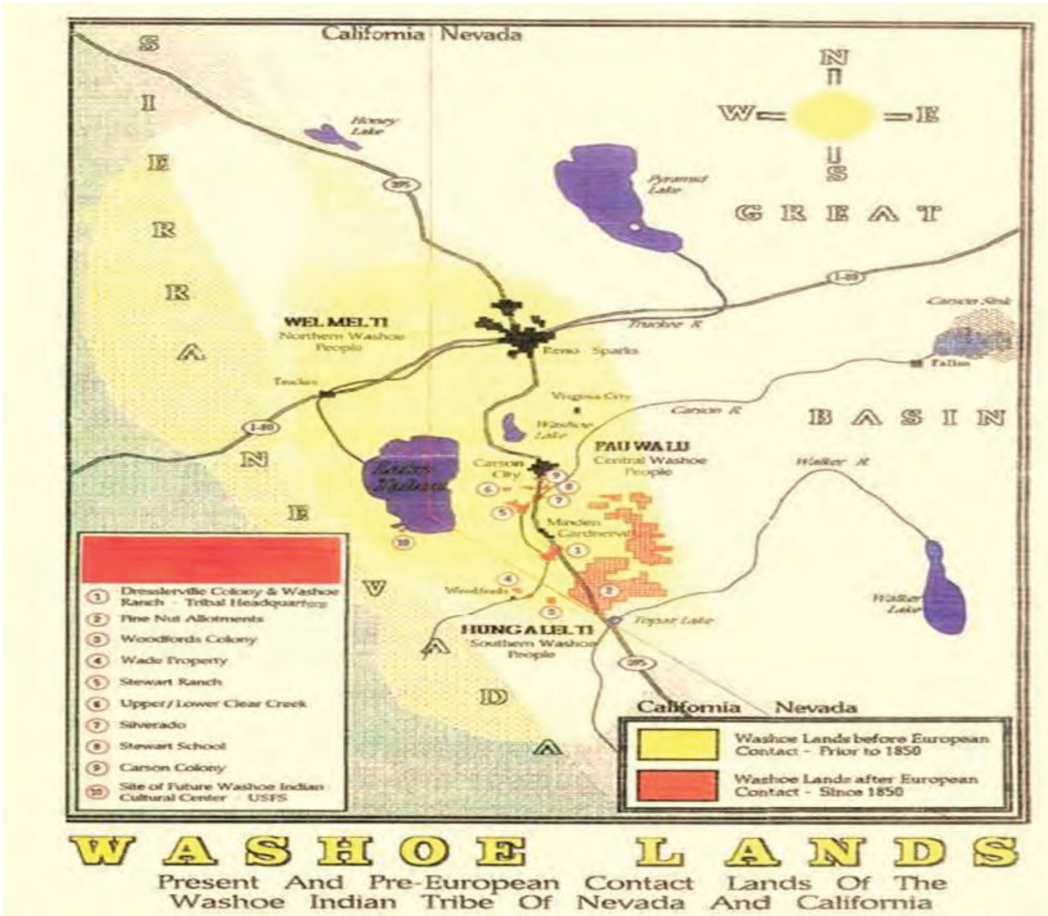

Fig. 3. Map of Washoe lands, present and pre-European Contact Lands of the Washoe Tribe of California and Nevada (Courtesy of the Washoe Tribe of California and Nevada)

a time to reaffirm social bonds and reconnect extended families. Thus, Lake Tahoe landscapes were at the center of social networks for the Washoe. As fall and winter descended, so did the Washoe people, returning to valleys and smaller family units (Downs 1966; Nevers 1976; D'Azevedo 1993a). When Euro-Americans began to settle in the Lake Tahoe Basin in the 1850s, they seriously disrupted Washoe cultural traditions socially, economically, and environmentally.

Euro-Americans and the Washoe people collided at Lake Tahoe beginning with the "discovery" of Lake Tahoe by Frémont in 1844. Over time, Euro-Americans gained control with the result that the Washoe people were marginalized and discriminated against as they lost control over their lands. Their traditional lands were taken by, given, and sold to Euro-American settlers resulting in the Washoe people becoming a landless tribe by 1863 (Nevers 1976). Not until the Federal Government created a reservation for the Washoe people in the Carson Valley and in Reno, Nevada, in 1917, did the Washoe regain some rights in the eyes of the Federal Government authorities. The Washoe's cultural practices were attacked and demeaned by Euro-Americans, reflecting the racist attitudes of the time (Nevers 1976; Makley and Makley 2010). By the turn of the 20th century, the Washoe thought they were becoming extinct as their small numbers continued to dwindle and their traditional cultural practices were attacked and suppressed (Nevers 1976; D'Azevedo 1993a; The Washoe Cultural Office 2009). Never fully removed from their lands and cultural practices, the Washoe fought and are still fighting to regain the use of traditional lands. They recently won a legal battle to close Cave Rock to rock climbers, who the Washoe tribe viewed as desecrating their most sacred of places (Taliman 2002; Makley and Makley 2010). The Washoe tribe now manages one of the oldest tourist resorts on Lake Tahoe, Meeks Bay Resort. They have regained access to the lakeshore and adjacent meadows, enabling the cultivation of traditional plants and the maintenance and teaching of Washoe cultural practices (Taliman 2002; Makley and Makley 2010).

3.1.2 Euro-Americans

Early Euro-American settlement in the Lake Tahoe Basin was first sparked by discovery of gold in the nearby Sierra foothills of California in 1848 and the Comstock silver strike in Virginia City, in the Nevada territory, in 1859 (fig. 4).

Lake Tahoe is between several emigrant trails and wagon roads built to the south and north of the Lake Basin, but few fortune seekers focused on Lake Tahoe itself (Obermayr 2005). The Lake Tahoe Basin was sparsely settled by Euro-American squatters in the 1850s, before the discovery of silver in the adjacent Virginia Range. At first the squatters settled in areas that were provided for their use, near meadows with the native hay to feed cattle as in Lake Valley south of Lake Tahoe or in Glenbrook on the eastern shore (Scott 1957; Strong 1984; Hinkle and Hinkle 1987). The Washoe people took note of the squatters, as they had of the fur trappers and early immigrants, but "(f)or the most part Washo[e] life seems to have gone unchanged" (Downs 1966, 74). At this point the Washoe, their cultural practices, and their access

Fig. 4. Map of major mines of the California Gold Rush (1–7) and Comstock Lode (8) (Courtesy of The American Experience, Public Broadcasting Company, http://www.pbs.org/wgbh/amex/goldrush/map/)

to their lands had been little impacted by Euro-American settlement. This changed as thousands of miners reversed their migration from the California gold fields and flowed east along the wagon roads, lured by the 1859 Comstock silver strike in Virginia City (Scott 1957; Hinkle and Hinkle 1987). As traffic increased so did wagon road construction. With the new influx of people, transportation systems improved and expanded, and entrepreneurs expanded roadside hostelries and built new lakeside accommodations (Hinkle and Hinkle 1987; Obermayr 2005).

The Tahoe Basin was quickly seen as a resource to be exploited by Euro-Americans for their mining industries. Cattle ranches were established, the lake was commercially fished, and water, a precious commodity in the arid adjacent lands, was employed for drinking, agriculture, and the industrial saw mills of the timber industry. The original growth forests in the Tahoe Basin were cut down as the forests closer to Virginia City were destroyed. The Tahoe Basin was almost completely denuded of its forests by 1900. Yet during this time, in what we would consider an industrial wasteland and ecological disaster area, tourism was thriving due to Lake Tahoe's undeniable beauty as well as the foresight of timber barons, who were looking for their next exploitation of Lake Tahoe through tourism.

As Euro-Americans settled in Lake Tahoe, the Washoe attempted to retain their cultural practices, although access to their land and the lakeshore became increasingly difficult as properties were built and fenced (Nevers 1976). By the mid-1880s the lakeshore was ringed with lumber operations and dotted with hotels, inns, and camps as well as summer homes (James 1915; Scott 1957; Pisani 1977; Strong 1999). The Washoe adapted and integrated to some extent into late 19th and early 20th Euro-American dominated society (Downs 1966; D'Azevedo 1993a). One way the Washoe people retained their presence in their ancestral lands was by becoming part of the tourist landscapes at Lake Tahoe. The Washoe worked with the Euro-American settlers at Lake Tahoe as employees, including as domestics in the tourist industry at hotels and in summer homes (Nevers 1976). Employing expert knowledge of the lands and using their skill and expertise in hunting and fishing, some Washoe became hunting and fishing guides. Traditional basketry was altered by Washoe artists to be sold to tourists, and tourism was in full swing by the turn of the 20th century.

In summary, Washoe lands were overtaken by Euro-American settlement, and their culture was nearly eradicated economically, ecologically, and socially. Access to their lands was continually limited and restricted, the productivity of their hunting and gathering grounds plummeted, and their cultural traditions were impaired. The Washoe were marginalized, but they never fully disappeared from Lake Tahoe landscapes. They were impacted by Euro-Americans, but worked to retain their cultural traditions, if not in the same form as pre-Euro-American settlement. One way the Washoe retained their presence at Lake Tahoe was by becoming part of the tourist landscape. Tourism can shape the culture and material cultural traditions of a people. That co-produced material culture can then be so strongly identified with a people and place that it infuses the place with associated meanings, enabling the formation of multiple types of hybrid tourist/cultural heritage landscapes.

3.2 CAVE ROCK, DE'EK WADAPUSH

The first example of a hybrid tourist/cultural heritage landscape examined is Cave Rock on the Eastern shore (fig. 5).

The Washoe name *De'ek wadapush* means rock standing gray, and Cave Rock can be seen from almost any point on Lake Tahoe shoreline. It is *the* most sacred site in all the Washoe lands, and the Washoe still believe that the proper use of Cave Rock is necessary to maintain the health and welfare of the Washoe and non-Washoe alike (Makley and Makley 2010, 2). As discussed earlier, Cave Rock has been a site of spiritual and ritual pilgrimage for centuries for Washoe shaman. This form of tourism, the sacred pilgrimage, is seen in multiple cultures. It imbues a place with significance and has the potential to physically impact a site. Cave Rock has seen damage, but this is associated with tourism and visitation

Fig. 5. Cave Rock from the South (Courtesy of Renalto)

beginning with Euro-American settlement of the Lake Tahoe Basin in the 1850s. This damage included blasting highway tunnels through the revered rock, mostly eradicating the sacred caves the Washoe Shaman used. Before becoming part of the historic Lincoln Highway (today US 50), the first "rock" transcontinental highway built in the United States, Cave Rock was part of the Bonanza Wagon Road that enabled travelers to reach the Virginia City silver mines more easily from the California gold fields. Originally the wagon road was a wooden trestle-supported bridge cantilevered over the lake side of Cave Rock (fig. 6). This structure was augmented with rock revetments to accommodate automobile traffic on the Pioneer Branch of the Lincoln Highway (Franzwa 2004).

The first tunnel blasted through the rock occurred in 1931. A second tunnel was bored through the rock in 1957 to accommodate the increased traffic flow on a now four-lane Highway 50 (Obermayr 2005; Makley and Makley 2010). All construction was undertaken without consideration of the significance of Cave Rock to the Washoe people.

Cave Rock also became a worldwide Mecca and a preeminent site for sport rock climbers beginning in the 1980s (Makley and Makley 2010). Not only did the sport climbers physically defile the rock face with their anchors hammered into the rock, the names of many of the climbing routes are culturally offensive to most people outside the rock climbing culture. One route includes a profanity in the name, "Shut the ___ up and Climb" (Makley and Makley 2010, 5). Additional desecration came with tourists building fires, writing graffiti, littering, and using the remaining cave as a toilet. The Washoe would not use their defiled sacred rock until fairly recently, following their successful 2003 lawsuit that banned rock climbing. Strict enforcement of this only came in 2008 (Lake Tahoe Basin Management Unit 2008; Makley and Makley 2010). The Washoe were also instrumental in having Cave Rock

Fig. 6. Cave Rock from the south prior to tunnels ca. 1910 (Courtesy of the North Lake Tahoe Historical Society)

considered for designation as a Traditional Cultural Property on the National Register of Historic Places (NRHP). It was found eligible for inclusion in 1996 but is not yet listed. This partial victory is bittersweet. To accomplish even this, the Washoe needed a sympathetic head of the US Forest Service and had to demonstrate additional layers of significance beyond being a sacred and religious site for their people (Makley and Makley 2010). The proposed NRHP designation for Cave Rock is based on its paleoenvironmental and archeological resources, its role as a long-term historic transportation corridor, and its importance for telling the story of the Washoe People at Lake Tahoe (National Trust for Historic Preservation 2013).

Cave Rock has both been altered and imbued through time with original cultural associations and use, as well as subsequent and continued use by tourists, creating one type of hybrid tourist/cultural heritage landscape. The previous discussion highlights how a landscape feature can be shaped by cultures and by tourism. With this concept explained, I would like to explore another example of the formative and reciprocal processes tourism has on cultural heritage preservation.

3.3 DAT SO LA LEE

Tourism not only impacted the sociocultural and environmental aspects of the Washoe, but also impacted the Washoe economically and directly influenced their material culture traditions. The evolution of Washoe basketry from utilitarian objects to sculpture has had a continued and profound influence on the basketry tradition. This evolution is tied to Lake Tahoe, Carson Valley, the tourist industry, and the Washoe artists whose mutual influence from 1895 to 1935 created the artistic traditions on which Washoe basketry is judged today (Cohodas 1979). To highlight the reciprocal relationship between tourism and the

Fig. 7. Dat So La Lee with two of her *degikup* (Courtesy of the North Lake Tahoe Historical Society)

Washoe's cultural heritage, I will discuss an iconic type of Washoe material culture, the *degikup* basket, and its most famous creator, Dat So La Lee (fig. 7).

Dat So La Lee is a world-renowned artist and is widely considered one of, if not the, greatest American Indian basket makers (Cohodas 1979; Kort and Sonneborn 2002). Dat So La Lee's baskets are famed worldwide, bringing in near-million dollar prices from collectors and museums.

Her work has been exhibited globally and she has been the focus of numerous scholarly and popular publications. She was instrumental in promoting the artistry of Washoe basketry, and her influence paved the way for contemporary and future acclaimed Washoe artists. She is also a product of tourism; she is a tourist creation and a creator of tourism. She represents the reciprocal nature of tourism and the socioeconomic impacts tourism can and does have on cultural traditions.

3.2.1 Dat So La Lee and Her Patrons

Multiple stories about how Dat So La Lee became a famed artist are mostly inaccurate and have conflicting details and impossible timelines. It is nearly impossible to tease out accurate facts about her transformation from Dabuda to Louisa Keyser to Dat So La Lee. The reason for this is her patronage by Abraham and Amy Cohn. They are the reason we know so much about Dat So La Lee and her baskets, because they kept detailed records of her baskets in ledgers, but they are also the primary reason for the inaccuracies (Cohodas 1992).

Dat So La Lee was born Dabuda sometime in the early or mid-1800s in the southern Washoe lands. Her first husband Assu died, and she eventually moved to Carson City, Nevada, where she married her third husband, a half-Washoe man named Charlie Keyser, taking the name Louisa Keyser (Cohodas 2005). She became a domestic servant for the Cohn family and this is where her tourist creation myth began. It is said that Abe Cohn's wife, Amy, first noted Louisa Keyser's remarkable basket weaving skill, bringing it to the attention of her husband who ran a local emporium. Another version notes that Louisa Keyser approached Abe Cohn to sell basket-covered bottles. In either case, the Cohns recognized her remarkable talents and made a deal with Louisa Keyser that gave them exclusive rights to sell her baskets in return for free room and board for life for her and her family. The Cohns built a house for her and her family, adjacent to theirs, in Carson City, Nevada. From then on, 1895–1925, Louisa Keyser's baskets were sold exclusively at the Cohn's Emporium in Carson City, Nevada, and during the summer at the Cohn's tourist shop, the Biscose, on the shores of Lake Tahoe in Tahoe City, California. For the remainder of her life, Louisa Keyser's work was solely focused on making baskets for the Cohns and their curio shops.

The Cohns possibly renamed Louisa Keyser around 1899. They promoted her new name, Dat So La Lee, whose meaning was derived from the Washoe language for "wide-hips," as part of their marketing strategy for her (Bibby 2010; Nevada Women's History Project 2014). Dat So La Lee was the name used by the Cohns in all their promotional material, yet Dat So La Lee's baskets, so carefully catalogued by the Cohns, are each labeled with LK (Louisa Keyser) followed by the number in chronological order. Her professional name, whatever the origin, was used as a marketing strategy to sell an image as well as distinguish her from her contemporaries. The other contemporary Washoe weavers, many of whom the Cohns represented, had Anglo sounding names. Using a name ostensibly derived from the Washoe language gave Dat So La Lee more credibility as a Washoe weaver. This tied her image to Native Americans and particularly to the Washoe people. The association with "Indians" had positive and negative aspects. On one hand it lent authenticity to her work as being made by a real Native American. On the other hand, the conflicting and contradictory attitudes the Euro-Americans had toward Native Americans ascribed negative connotations to a Native American name. Cohodas points to the fact that the Carson City Newspaper articles at that time only featured two Washoe tribal members with any regularity. One was a political leader and mostly favorably represented. The other was Dat So La Lee, who was represented as childish, churlish, dirty, fat, uneducated, and naïve in some articles (Cohodas 1992). In others, Dat So La Lee was represented as an unsurpassed artist whose baskets were of such high quality as to be sold for exponentially more than those of her contemporaries (Cohodas 1992). This dichotomous representation is in keeping with the attitude Euro-Americans had about Native Americans, the "noble versus savage Indian." An additional layer of ascribed identity is the Victorian aesthetic and attitudes of the time. Amy Cohn was Dat So La Lee's main image promoter and brought Dat So La Lee to lectures and meetings. Yet many newspaper articles about Dat So La Lee reference her in conjunction with Abe Cohn (Cohodas 1992). These reports, of a childish and argumentative Dat So La Lee, place her in the caricaturized role of a Victorian wife according to Cohodas (2005). This relationship is highlighted by a newspaper article from the Carson City News noting a fight between Abe Cohn and Dat So La Lee about a corset, and how she was mad that it did not make her look like more svelte Western women (Carson City News 1911). Beyond her ascribed identity being reaffirmed, however, the article also shows a woman who clearly had a say in her life. She was not simply being exploited by the Cohns, she was an active if not equal participant in her image creation.

Dat So La Lee's artistry is singularly responsible for the *degikup* (pronounced "day-gee-coop") basketry type, elevating it from a handicraft into a work of art. This basketry type remains iconic of Washoe basketry today and of Dat So La Lee. The *degikup* was also part of the Cohns promoted mythology for Dat So La Lee. Although it may be based on a traditional Washoe basketry type, its altered shape and designs are inventions of Dat So La Lee (Cohodas 1982). Additionally the fanciful names of her designs were co-produced by the Cohns and Dat So La Lee, as some of the stories of the designs claim she saw them in visions or dreams (Cohodas 1979). Amy Cohn is noted for fabricating a traditional history, function, and meaning for the *degikup* that were created by Dat So La Lee (Cohodas1992). Through their marketing and promotion, the Cohns influenced scholarship about Washoe basketry at the time and this has continued to color scholarship today. Otis Mason's 1904 publication *American Indian Basketry*, based on a report he made to the Secretary of the Smithsonian in his capacity as the head of the Department of Anthropology, US National Museum, referenced the help he received from Amy Cohn about the Washoe and their basketry technology and naming. The book features baskets from Amy Cohn's collection as well as photographs of Dat So La Lee and her baskets (Mason 1988; Cohodas 1992).

The *degikup* does potentially have early Washoe cultural associations, described as a small, nearly spherical "traditional mortuary and ceremonial vessel," yet no known *degikup* predate those made by Dat So La Lee (Cohodas 1982).The traditional use of the *degikup* as a mortuary item customarily buried with its weavers could account for its lack of representation in the Washoe material culture. But scholars led by Cohodas surmise "…the *degikup* was the product not of a long indigenous development for ritual function, but instead of an aesthetic choice by an innovative artist at a specific point in time" (Cohodas 1979, 6). The point in time when Dat So La Lee wove was when Washoe cultural traditions were under assault from Euro-American settlement of the Washoe homelands. The Washoe's hunting and gathering way of life was impaired and in danger of becoming extinct along with the people (D'Azevedo 1993b). Many Washoe adapted to Euro-American settlement as a means of survival (Downs 1966). The first and foremost innovative artist was Dat So La Lee, whose mastery, skill, and innovation in weaving led her to re-create and continually evolve the *degikup* basketry form. In reality she created a new basketry form that was no longer associated with food collection or other cultural traditions, but with artistry. She transformed the *degikup* into sculpture (Cohodas 1979).

Dat So La Lee's reputation as the preeminent Washoe basketry artist eclipses other contemporary Washoe weavers due to her skill and to her promotion by the Cohns. Not only were her baskets marketed, so was Dat So La Lee. Dat So La Lee was promoted in photographs, in tourist postcards, Emporium pamphlets, in guidebooks, and as an actual tourist attraction. She traveled with the Cohns to arts and craft fairs nationally, and during the summer she worked and lived in Cohn's Lake Tahoe curio shop in Tahoe City, California (Cohodas 1979, 1992). She wove baskets in the front window and on the front steps of both Cohn's shops as a display or enticement for people to enter. The Tahoe City curio shop, the Biscose, was conveniently located adjacent to the luxurious Tahoe Tavern Hotel and the train depot that brought visitors from the transcontinental railroad to Lake Tahoe.

Dat So La Lee and her baskets are as much iconic figures of Lake Tahoe and Tahoe City today as they were when she was alive. Dat So La Lee is still being promoted and reimagined as a tourist draw. A recent exhibition at the *North Lake Tahoe Historical Society* of her miniature baskets from the Amy Cohn collection drew thousands of visitors (Bibby 2010). Her image continues to be used in tourist promotions including placemats featuring historic women associated with Lake Tahoe juxtaposed with contemporary tourist images of Tahoe City. Dat So La Lee is often described, and some sources inaccurately translate her name, as "Queen of Washoe Indian Basket Makers" (Gigli 1974; Karen Atkinson Studio 2014).

4. CONCLUSION

The previous discussion highlighted a Washoe woman who is both produced via tourism and is a producer of tourism at Lake Tahoe. During her lifetime, Dat So La Lee produced an appreciation for Washoe cultural traditions, and she produced a new type of Washoe material culture, the *degikup* and its associated designs. Today she remains an important part of the preservation of Washoe cultural traditions through her artistic acclaim, promotion of the Washoe basket making tradition, and transformation of it from a utilitarian craft into an artistic tradition iconic of the Washoe people today. Dat So La Lee and the Washoe material culture she created remain an actively preserved and promoted part of the Lake Tahoe cultural heritage landscape, and they represent a different aspect of the hybrid tourist/cultural heritage landscape from Cave Rock. Cave Rock has been physically altered by the processes of tourism, yet it represents a place imbued with multiple cultural associations. Its contested use through time is interwoven with its original spiritual and religious associations for the Washoe people. Cave Rock remains a tourist site and is being actively preserved because it has multiple cultural associations, including tourism. Both examples of Washoe cultural heritage represent different expressions of the hybrid/tourist cultural heritage landscapes that are actively preserved at Lake Tahoe today. By becoming aware of hybrid tourist/cultural heritage landscapes and learning to examine their formation, we conservators can become better, more informed stewards of the heritage we work to preserve.

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CATHERINE MAGEE holds a doctorate in Geography from the University of Nevada Reno. She received her MS in objects conservation from the Winterthur Museum/University of Delaware Art Conservation program. She has worked in Asia, Central America, the Mediterranean Basin, and North Africa as an archaeological conservator on both terrestrial and marine sites. She lived in Washington, D.C., for 15 years and worked at the Smithsonian Institution and in her own conservation business. Her doctoral research explored the reciprocal relationship between cultural heritage preservation and tourism. Her main research interests are local and native groups reclaiming authority over their cultural heritage landscape from tourist use, media in production of culture heritage sites, and analysis of cultural heritage landscapes. Address: 2540 Pioneer Drive, Reno, NV 89509. E-mail: catherinemagee@hotmail.com (preferred); cmagee@unr.edu

CONSERVATION REALITIES AND CHALLENGES AT ARCHAEOLOGICAL AND HISTORICAL SITES IN COLOMBIA: SEEKING SUCCESS BY CONSIDERING THE CONTEXT

MARÍA PAULA ÁLVAREZ

ABSTRACT

This article introduces the idea that political and social realities have an important impact on conservation practice and sustainability for cultural heritage. This concept is illustrated through three case studies from my work at archaeological and historical sites in Colombia. The first case study is the *Fuente de Lavapatas*, an important pre-Columbian site in the archaeological park of San Agustín, a UNESCO World Heritage site. Despite great public interest in the site and careful research to inform a long-term management plan, a political decision was made and no further resources were allocated for its preservation. The second case study discusses how community involvement can positively transform a site and contribute to its conservation. It presents educational, research, and conservation efforts in the archaeological park of Facatativá, a nature reserve that includes rock shelters with pre-Columbian pictographs. The third case study relates to monuments in public spaces in Bogotá. While social conditions are negatively impacting monument conservation, recent political decisions have been made that have led to better conservation and outreach community practices. Considering these projects and events, it is clear that the preservation of cultural heritage is not only driven by deterioration factors such as the environment and human and biological activity, but also subject to deterioration factors resulting from the social context. Preservation is also highly vulnerable to political decisions. Understanding the impacts of decisions made in those contexts and the ability to anticipate the outcomes of these decisions can lead to better heritage management and the implementation of more sustainable conservation projects.

1. INTRODUCTION

The topic of sustainability was highlighted in my experience several years ago when I moved from conservation to planning and management concerns, opening my mind to aspects of decision making other than strictly technical ones. To illustrate this, I have chosen three examples, two of them taken from my experience with Colombian archaeological parks, and the third one related to historical monuments in a big city, taking Bogotá as an example. Each case demonstrates, in very different ways, the impacts of political and social contexts on sustainability and practice in cultural heritage preservation.

First, I will show how complex political realities affect decision making for the development and implementation of conservation projects, and how those realities may lead to heritage sites becoming self-regulated. An example of this is the *Fuente de Lavapatas*, in the archaeological park of San Agustín, a UNESCO World Heritage Site.

Then, I will show how constraints imposed by the political and social context open different possibilities for conservation practice. An example of this is the mandatory cleaning of pictographs in the Archaeological Park of Facatativá, prompted by a request from the community that opened the possibility to integrate conservation, archaeology, and educational issues.

The third case shows how ongoing, public, political protests in Bogotá forced the implementation of different strategies that included education, participation, and conservation. The selection and application of an anti-graffiti coating was carried out recently as a result of these efforts.

2. CASE STUDY 1: FUENTE DE LAVAPATAS

2.1 BACKGROUND

The *Fuente de Lavapatas* is located in the Archaeological Park of San Agustín, in the department of Huila in southern Colombia (fig. 1). It is considered a Property of Cultural Interest and protected by the UNESCO World Heritage designation.

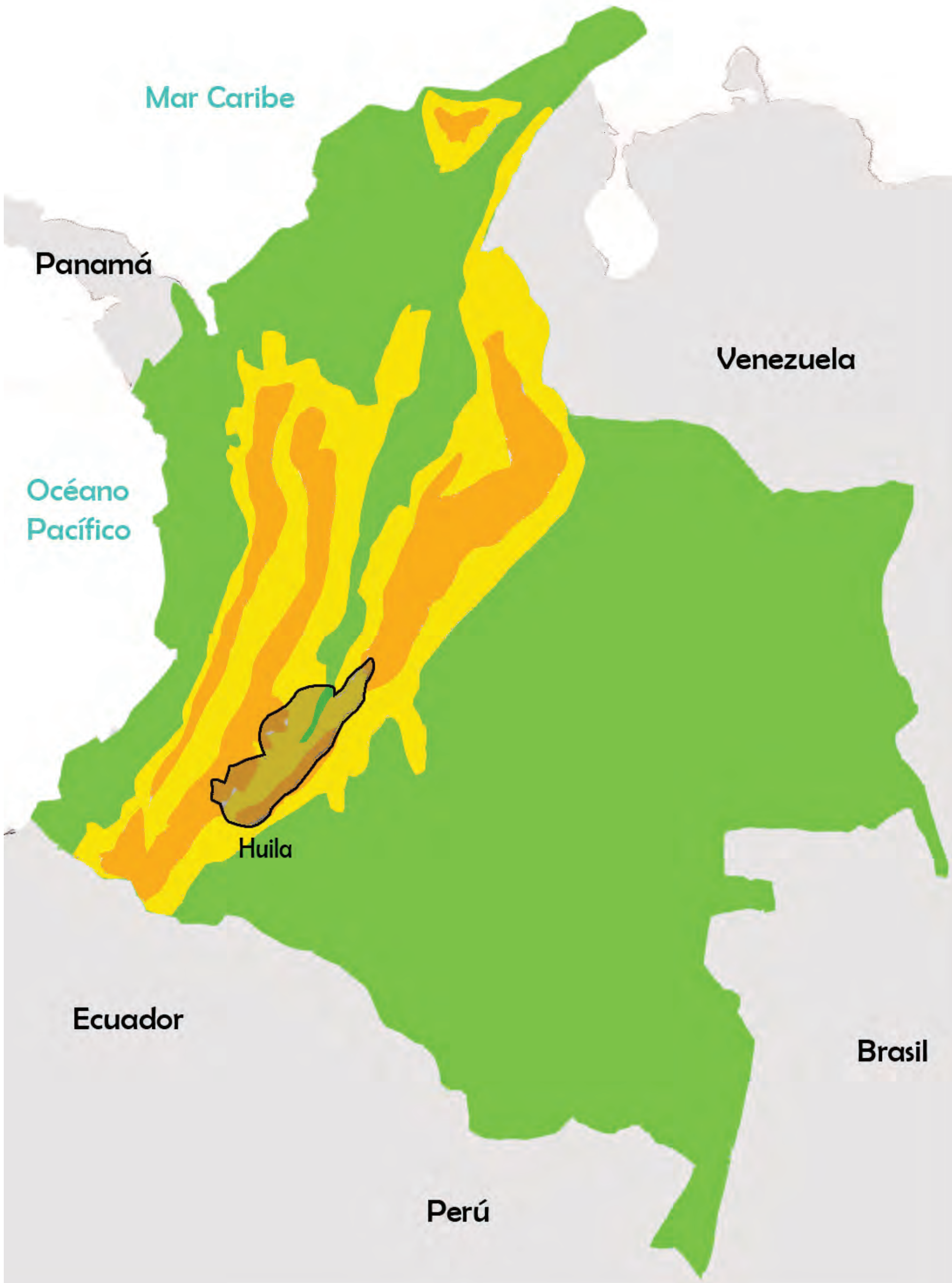

Fig. 1. Map of Colombia with the department of Huila indicated in gray. The Archaeological Park of San Agustín is located in the south of Huila. (Courtesy of M. P. Álvarez)

Fig. 2. *Fuente de Lavapatas* drawing by Luis Alfonso Sánchez from the archaeological commission headed by José Pérez de Barradas (7/10/1937) (Courtesy of ICANH)

The *Lavapatas* fountain was built by pre-Columbian sculptors of the Upper Magdalena region, sometime between the ninth century bc and the ninth century ad, in the sloping bed of the Lavapatas creek. The fountain is formed by a series of complex channels and wells that determine the direction of the water flow. As seen in figures 2 and 3, these channels define, mark, and highlight human and animal sculptures such as lizards and snakes.

The predominant forms are located in the north and central sections and are protected by a shelter covering an area of 20.2 × 21.7 m. Other carved forms and channels, which are less significant, are located outside of this covered area.

Since its discovery in 1937, the fountain has been unceasingly admired. It is a favorite place for visitors. Since 1937, both researchers and stakeholders have been attentive to the preservation of the site, expressing their concern over the loss of the carved shapes. In response to this concern, studies and analysis have documented the state of conservation of the fountain at different times. The studies made between the seventies and nineties were not carried out regularly or systematically and therefore do not allow a proper assessment of the level of the loss of the sculptural forms, the degree of deterioration of the stone, the effect of water, the environmental conditions, nor how much the presence of the shelter affects the fountain (Álvarez et al. 2012).

As seen in figure 4, the first shelter over the *Lavapatas* was directly attached to the site causing some damage to the stone. The current shelter (fig. 5), a metallic structure covered with acrylic, was installed in the eighties.

Fig. 3. View of the *Fuente de Lavapatas,* Archaeological Park of San Agustín, Colombia (Courtesy of C. Bateman)

Fig. 4. First shelter with structure directly attached to the *Lavapatas* (Courtesy of Duque, ICANH Archive 95ii 0191)

Fig. 5. Shelter installed in 1984 and present at the site currently (Courtesy of C. Bateman)

2.2 PRESERVATION OUTCOME

In order to respond to the conservation concerns that had not been resolved, a team of four conservators (including myself), one geologist, one microbiologist, and one graphic designer met between 2008 and 2012 to develop the Integral Conservation Project of the *Fuente de Lavapatas*. This group of professionals was hired by the Colombian Institute of Anthropology and History (ICANH) to carry out the project.[1]

The study provided a new understanding of the deterioration processes impacting the *Lavapatas* fountain (Alvarez et al. 2012, 92). It not only identified and documented the current conditions, but also considered the fountain's treatment history, local weather conditions, and geological and physical properties of the stone. This information completed what was missing from previous studies and allowed us to have a more comprehensive picture of what was happening on this site.

The review of historical treatments was done in order to understand changes that the site has experienced since its discovery in 1937. Different protective systems and water flow and canalization systems were studied, as well as previous documentation and conservation studies carried out from 1971 to 2007.

During a period of more than 6 months, local weather conditions were studied, measuring relative humidity and temperature inside and outside the shelter, and taking surface temperature measurements of the rock (fig. 6).

Fig. 6. Surface temperature measurements as part of the weather conditions study (Courtesy of A. Miro)

Those measurements allowed us to understand that the current shelter mitigates the impact of environmental conditions such as solar radiation, relative humidity, and temperature on the rock of the *Fuente*. However, the current shelter is inadequate because it leaks and has structural damage. The shelter conditions should be monitored and in the future it should be repaired.

The geological study was done in situ through the macro-description of the rock, the evaluation of capillary absorption, the documentation of fractures, and hardness of the surface, and in the laboratory through the study of samples taken from different areas of the fountain illustrating different states of conservation. Petrographic, microprobe SEM, infrared spectroscopy, and x-ray diffraction analyses were carried out allowing the understanding of the discontinuous and heterogeneous nature of the *Lavapatas* volcanic tuff, illustrated in figure 7.[2]

Fig. 7. Discontinuous and heterogeneous nature of the *Lavapatas* volcanic tuff (Courtesy of H. Jacobsen)

Samples from the areas surrounding the fountain were analyzed in two German stone conservation laboratories. After the mineralogical characterization of samples was carried out, the following physical properties were determined: water absorption, ultrasound speed, hydric expansion, porosity, thermal expansion, tension bending strength, and Young's modulus of elasticity. Snethlage and Wendler (1995) and Sasse and Snethlage (1996) methodologies were used.

A detailed observation of the site allowed us to establish the most significant damage to the stone: cracks, damage caused by the previous shelter, detachments, and disintegration.

The biodeterioration studies identified lichens, mosses, selaginellas and hepatics, microalgae, total aerobic bacteria, filamentous fungi, sulfur-reducing bacteria, nitrifying and total coliforms, and fecal organisms. For biodeterioration control, the evaluation and selection of several biocides was carried out. Biocides characterized by rapid degradation of the biocide, minimal toxicity, minimal bioaccumulation, and effectiveness at low concentrations were given preference. 1R3-Rocima 363 and Preventol CD-601, which are based on isothiazolinones and orthophenylphenol, were selected for use on the stone of the fountain (Villalba in Alvarez et al. 2012).

Consolidants to be used in disintegrated areas were also evaluated. The methodology proposed by Snethlage, Wendler, and Sasse (Snethlage and Wendler 1995; Sasse and Snethlage 1996) was followed. Five sequences in which ethyl silicates were used in different manners were evaluated. Two different ethyl silicates (Remmers KSE 300 and elastified Remmers KSE 300 E) were tested. Furthermore, the effect of two products, one that should minimize hygric dilatation (Remmers Antihygro) and a product that ought to improve adhesion to the surface (tartaric acid 0.14% diluted in alcohol), was examined (Jacobsen in Álvarez et al. 2012).

Additionally, the Integral Conservation Project of the *Fuente de Lavapatas* suggested further research in the following areas:

- Identification of a consolidant grout to repair detached stone fragments
- Treatment and management of the water flow in the *Lavapatas*
- 3D scanning
- Implementation of a monitoring program for environmental conditions and deterioration of the rock

2.3 THE INFLUENCE OF THE POLITICAL CONTEXT IN CONSERVATION

The studies carried out between 2008 and 2012 demonstrated the need to apply biocides and consolidants. Because the ICANH did not have qualified professionals to evaluate processes and ensure they meet international standards and contribute to the future conservation of this important site, outside expertise was requested. In March 2012, Dr. Gottfried Hauff, dean of the Stone Conservation Program of the Fachhochschule Potsdam, and Dr. Eberhard Wendler, author of several publications on stone conservation and an international expert on volcanic tuff, were called to consult on the project. They determined that our study provided accurate information that allowed a good understanding of the site conditions. They completed their analysis with observations about the presence of water, noting that water has the greatest impact on the conservation of the site. They recommended testing the silicate-based consolidants and biocides on samples of the same type of stone before starting treatment, and initiating a monitoring program of the samples and the ongoing deterioration processes in the *Lavapatas* over a period of 2 years (Álvarez and Jacobsen 2012).

In 2013, the conservator of the park, concerned about the continuity of the project, worked on monitoring the environmental conditions and deterioration of the *Lavapatas* rock (Rincón 2013).Yet in the same year, the leadership of ICANH made a politically motivated decision to only continue with the 3D scanning portion of the project. Unfortunately, ICANH did not invest in the monitoring phase, nor any of the other recommendations put forth by the international experts, and so with this decision the ICANH essentially brought an end to the Integral Conservation Project of the *Fuente de Lavapatas*.

Conservation studies carried out for the *Fuente de Lavapatas* in the past did not provide relevant information because they were carried out every 10 years without ensuring continuity. This caused significant loss of detailed information and many wasted efforts. Today, as in the past, conservation initiatives for the *Lavapatas* seem to be headed for the same dismal fate.

In 2014, this important site remains in the same condition as it has been for decades. It continues to be subject to deterioration by natural factors and damage caused by undocumented maintenance activities performed by park workers. There is not a complete monitoring program that can inform decision-making activities and ensure the conservation of the site.

The *Lavapatas* conservation project is an example of the lack of sustainability of conservation processes in Colombia. It shows how much political decisions affect the continuity and effectiveness of conservation projects.

To ensure the sustainability of conservation projects, they should be considered priorities for the institution. This must be translated into the allocation of economic resources in the future. If persons occupying management positions change, the institution must honor the commitment to support those projects.

After illustrating the negative impacts of political context in conservation, the following examples will show how much conservation can be positively influenced by the political and social context.

3. CASE STUDY 2: ARCHAEOLOGICAL PARK OF FACATATIVÁ

3.1 BACKGROUND

The Facatativá nature reserve, which was declared a national archaeological park in 1946, is a very beautiful and heavily visited place located 36 km from Bogotá. It is known for having more than 20 rock shelters as seen in figures 8 and 9, with approximately 60 pre-Hispanic pictographic panels and 5 painted portraits of prominent citizens done in 1915. The area was used as a recreational park for years, during which time the pictographs were not protected in any way. The pre-Columbian heritage values were never appreciated or presented to the visitors.

Fig. 8. Panoramic view of the park's central area with the rock shelter of Los Presidentes and rock shelter 18 (Courtesy of M. P. Álvarez)

Fig. 9. Pictographs from Facatativá Archaeological Park (Courtesy of M. P. Álvarez and L. Castillo)

The use as a recreational park allowed several practices that directly led to deterioration of the pictographs. A great number of the pictographic panels were covered with graffiti, inscriptions, and scratches, and, occasionally, bonfires were lit under the rocky shelters. Some examples of this deterioration can be seen in figure 10.

In 2003, the ICANH hired me and a team of conservators to treat one of the pictographic panels: panel 16 (Álvarez 2003). The project was to continue over the course of several years. In 2004, conservation treatment on panels 19 and 20 was carried out (Álvarez and Martínez 2004). In 2005, panels 20a and 20b were treated (Álvarez and Martínez 2005). Unfortunately, after each intervention was

Fig. 10. Bonfire stains, salts, dirt, inscriptions, and graffiti on panel 20E in 2013 (Courtesy of L. Castillo)]

completed, we had to return to previously treated panels (16 and 19) because new dirt, graffiti, inscriptions, and scratches appeared.

Clearly, our efforts and the efforts of ICANH to conserve the pictographs were not sustainable. ICANH realized that a different strategy was required, so in 2005 they encouraged us to design an archeological management plan for the park. As the first management plan for an archeological park in Colombia, it included an integrated diagnosis of the site considering historic, legal, and administrative aspects; cultural values, documentation, the state of conservation of the pictographs, and aspects of education and interpretation.

The plan established the zoning and use regulations for the park. Recommendations included the protection of the panels with fencing, the construction of a path for visitors, the archaeological study of the site, and the development of education and interpretation activities. Additionally, the proposal underscored the need for documentation and treatment of the existing pictographic panels (Álvarez et al. 2005).

We began the fundraising process, which initially included funding for the conservation of 10 panels. Even after 2 years of advocacy in political and cultural institutions, however, it was not possible to find financial support for implementing the recommended activities.

In 2007, people from the community of Facatativá, who were concerned about the state of the pictographs, filed a legal action against the government and succeeded. As a result, the institution in charge of the management of the site since 1974, Corporación Autónoma Regional (CAR), had to complete necessary actions for the appropriate protection of this archaeological heritage. This was done with the approval of the institution in charge of the conservation of archaeological heritage, ICANH.

The work started with the installation of fences in 2009 and the approval of the methodology for the conservation of 41 pictographic panels. In 2013, administrative arrangements were approved, and the National University was contracted to implement archaeological contextualization, conservation of 41 pictographic panels, and community outreach in the Archaeological Park of Facatativá (Rodríguez et al. 2013). Currently I am coordinating the conservation component of the project, working with a team of eight conservators and seven assistants, five of them from Facatativá.

3.2 PRESERVATION OUTCOME

Conservation and documentation activities for 41 pictographic panels started on July 31, 2014, and was planned to finish in December 2014. The following activities were carried out for each pictographic panel:

- Photographic documentation
- Compilation of previous documentation
- Description and graphic documentation of pictographs
- Documentation and identification of damage. This is supported by laboratory analysis of salts, stains, and biodeterioration.
- Assessment of the condition of the pictographs
- Treatment proposal supported by cleaning tests approved by ICANH
- Conservation treatments
    - Cleaning: As seen in figure 11, steam, brushes, erasers, sponges, and solvents were used. In some special cases a motor-tool and microsand blasting was required.
    - Consolidation of pictograph's paint layers, and ground and paint layers from the 1915 painting (fig. 12).
    - Inscriptions, graffiti, and scratches that could not be eliminated during the cleaning process had to be covered with silicate chalks. For the 1915 paintings, the retouching technique of *acquasporca* was used.

Fig. 11. Conservation activities carried out on different pictographic panels during 2014 (Courtesy of G. McCormick and M. P. Álvarez)

- Before and after photographs and graphic documentation of pictographs were used to evaluate the effectiveness of the treatments.
- Community outreach activities
    - Participation in academic events
    - Guided site visits to groups of people of all ages and backgrounds (school children and their teachers, university students and professors, heritage professionals, civil servants, municipal employees, national and international park visitors) as seen in figure 13.
    - A leaflet was designed and printed and is distributed to park visitors.
    - A video and a publication with the results of the project are being developed.

By the end of 2014, this project will have delivered to institutions and the community more than 1000 m^2 of documented and conserved stone surfaces with hundreds of pre-Hispanic pictographs, and paintings of five prominent citizens from 1915, making it the biggest rock art conservation project in Colombia.

Because the archaeological survey contributed to the understanding of rock art and offered interesting information about the history of the region, this project can also be considered enlightening. It shows evidence of site occupation from the pre-ceramic period that may date from 3000 years ago.

Additionally, this is one of the few examples in the country where archaeologists and conservators have had the opportunity to work together, to show visitors an interdisciplinary way to address a heritage site.

3.3 SOCIAL INFLUENCE IN CONSERVATION AND PRESERVATION

This example shows how a legal action started by the community can result in a very important project that is not only achieving rock art conservation, but also contributing to the understanding and dissemination of information about Facatativá archaeological heritage.

Fig. 12. Consolidation of paint layers on the 1915 painting in 2014 (Courtesy of M. P. Álvarez)

Fig. 13. Visitors to the archaeological excavations in September 2014 (Courtesy of C. Leiva)

It also demonstrated that because cultural heritage is protected by Colombian law, if an institution is charged with the protection of a heritage site, conservation responsibilities cannot be neglected.

Apart from the legal action started by the community in 2007, there have been several local initiatives that have led to educational activities on the site in the past 9 years. Groups of park guides and "Vigías de Patrimonio Cultural" have consolidated in Facatativá contributing to appreciation of the local cultural heritage.[3] These groups are informing park visitors and developing educational and interpretive activities with local populations, mainly children and young adults, for example, the educational program Ie Cho Zhusgoskua Semillero de Investigación Vacatatyba developed during 2014 by Fundaciónen Tierra de Sombras.

These local initiatives have been strengthened by workshops organized between 2006 and 2007 by ICANH. Additionally, international rock art seminars organized by Grupo de Investigación de Arte Rupestre (GIPRI—a nongovernment rock art research group) and funded by local municipal and regional governments have taken place twice at Facatativá.

Some Colombian indigenous groups have always considered Facatativá a sacred place. Recently formed indigenous communities of the highlands of Cundinamarca and Boyacá, who are heirs to ancient indigenous communities, have now taken up the practice of their religious ceremonies in the park, celebrating Mother Earth and their ancestors, recalling the importance of this site.

Efforts undertaken by ICANH during 2003 and 2007, and by the local community through the legal action of 2007; educational activities carried out since 2006; and the indigenous communities' appropriation have clearly resulted in more visibility for the archaeological site and the involvement of other institutions. In the past 2 years, the municipal government and the National Foundation for Archaeological Research have supported other projects for the documentation and study of materials from the Facatativá pictographs (Muñoz et al. 2013).

The local government became responsible for the management of the park in 2012. It is now actively engaged with the ongoing projects. The park is receiving considerable financial resources because it receives nearly 70,000 visitors a year. Because of the bureaucracy of local public authorities, however, the park administration has not yet managed to increase the budget for security and fence maintenance. These are critical aspects that should be considered in order to improve management and heritage protection. Past mistakes should not be repeated. If these management issues are not resolved, the cultural heritage in the park could be at risk again.

4. CASE STUDY 3: MONUMENTS IN PUBLIC SPACES IN BOGOTÁ

4.1 BACKGROUND

On the topic of contemporary and historic heritage, I will describe a negative situation generated by the political and social context of Bogotá (population 8 million) that has affected monuments in the city's public spaces. Ironically, this situation has also generated possibilities for developing conservation research and community outreach activities.

Bogotá's public spaces are constantly tagged with graffiti. There are many different types of graffiti: some with political content, others with social content expressing interpersonal feelings or displaying sports affinities, while still others are purely artistic expressions.

The graffiti movement has appeared in force in Bogotá in recent years and today is recognized as an important component of urban culture. The hip hop movement considers graffiti an artistic component of their culture. This artistic expression is expanding, invading public spaces and affecting public monuments. The District Institute for the Arts (IDARTES) has organized forums and roundtables with the graffiti activists to identify spaces where they can continue their practice (fig. 14), thus achieving a "truce" with this community.

Recently in Bogotá, the responsibility for the care of monuments in public spaces was transferred from the Urban Development Institute (IDU) in charge of public works, to the local cultural heritage institution: the District Institute for Cultural Heritage (IDPC).

Fig. 14. Graffiti corridor from Calle 26, Bogotá (Courtesy of M. P. Álvarez)

The IDPC has involved conservation professionals in the study, documentation, restoration, and maintenance of monuments in public spaces. Following IDARTES initiatives, it is developing activities with graffiti activists and citizens in an effort to make them understand that monuments in public spaces should be preserved.

This is a great improvement that has benefited the monuments and the conservation field. Expertise and experience in stone and metal conservation now support maintenance of the monuments, and several efforts have been made to identify sustainable conservation solutions.

4.2 PRESERVATION OUTCOME

A large percentage of the affected monuments, or at least their pedestals and bases, are made of sandstone. Sandstone is a granular rock, so once graffiti is applied, the paint penetrates the surface and removal of graffiti becomes extremely complicated. Solvent mixtures and products for the removal of graffiti are not completely effective and it becomes necessary to use abrasive methods, as seen in figures 15 and 16. This is not considered the most appropriate procedure to do repeatedly on stone. Often the graffiti reappears almost immediately after the surfaces have been cleaned.

While coordinating a project for the maintenance of some of the most representative monuments of the city in 2013, we proposed the use of anti-graffiti coatings to the IDPC. We felt this was advisable based on the frequency of necessary graffiti removal.

In Colombia there was no research being done on this topic. The IDPC decided to support a research project studying anti-graffiti products made in Colombia, or imported but easily accessible in the country. The research evaluated more than 10 commercial products (from water repellents to coatings) from three different manufacturers: Islecar, Hidroprotección, and Nanoword. Acrylic polymers and silicone-based products with hydrophobic characteristics were tested on sandstone. The selected product, Recubridormade by Islecar, is a dispersion of acrylic polymers. It worked well because it did not change the rock's color or gloss, and it sustains the removal of at least two layers of graffiti while still providing protection to the stone. Moreover, the local manufacturer could ensure its availability. The manufacturer recommended a brush application of three layers of the product in order to achieve a better protection of the local sandstone (Logreira 2013).

The selected product was applied to five sandstone monument pedestals and bases after conservation procedures were carried out. The conservation activities included the following:

- Cleaning of stone surfaces
- Removal of graffiti with chemical and mechanical methods


Figs. 15 and 16. Graffiti removal at *Jimenez de Quesada* monument with abrasive sandblasting and other abrasive methods. Restoration process carried out in the second semester of 2013 (Courtesy of A. Logreira)

Fig. 17. *Simon Bolivar* monument before the first conservation treatment carried out in 2013 (Courtesy of M. P. Álvarez)

- Treatment of joints, fissures, and fills. Considering that the selected product is hydrophobic, joint and fissure fills were very important to minimize future conservation problems.
- Stone repairs and replacements

The *Simon Bolivar* and the *Jimenez de Quesada* monuments are two of the monuments to which Recubridor was applied. They are located in the historical heart of the city. The *Simon Bolivar* monument stands in the middle of the Plaza de Bolivar, which is surrounded by the cathedral and other important buildings, such as the National Capitol building, the Supreme Court building, and the Mayor's Office building. This main square and all the buildings surrounding it are made of sandstone and offer multiple surfaces to graffiti artists. It is a place where political and social protests very often take place (fig. 17).

The *Jimenez de Quesada* monument is located in a square surrounded by the country's oldest university, a main street, and some old cafes. This area is considered the birthplace of one of the most recognized soccer teams in the country (Santa Fe team).

The anti-graffiti coating was applied to buildings surrounding the Plaza de Bolivar, and to the *Simon Bolivar* and the *Jimenez de Quesada* monuments. Figures 18 and 19 show the *Jimenez de Quesada* and *SimonBolivar* monuments after their conservation in 2013.

The application of the anti-graffiti coating allowed a more effective second cleaning of the sandstone surfaces in Plaza de Bolivar and the *Jimenez de Quesada* monument, contributing to improved conservation of these stone materials (Álvarez and Logreira 2013).

Fig. 18. *Jimenez de Quesada* monument with anti-graffiti coating after its conservation in the second semester of 2013 (Courtesy of A. Logreira)

Fig. 19. *Simon Bolivar* monument with anti-graffiti coating after its conservation in the first semester of 2013 (Courtesy of M. P. Álvarez)

After the *Jimenez de Quesada* monument was cleaned for the second time and the anti-graffiti coating was applied, the Santa Fe rival team fans (Millonarios team) painted their shield on the monument. Then the Santa Fe fans offered the IDPC their help to clean the monument. This was done with their help and under the supervision of a professional conservator, showing an interesting example of cooperation.

Considering the vulnerability of the Plaza de Bolivar, another strategy has been implemented for the protection of the *Simon Bolivar* monument. When news of upcoming political protests or demonstrations is known, IDPC staff covers the monument with a plastic liner specifically designed with the color and pattern of the monument pedestal. After demonstrations are over, the graffiti-covered liner is removed and cleaned, and can be used again. This is a simple procedure that has improved conservation sustainability.

4.3 POLITICAL AND SOCIAL INFLUENCE IN CONSERVATION

The previous examples illustrated several situations that Bogotá has experienced. On the one hand, Bogotá is the capital city of a country with many social and political problems. Citizens should have the freedom to express their complaints through graffiti. On the other hand, this practice has covered historic walls and monuments. The authorities of the city are recognizing graffiti as an element of urban culture and have assigned public spaces for graffiti artists. Bogotá is also a city where art and heritage issues have gained importance in the last decades. This is illustrated by the allocation of economic resources for conservation and preservation of monuments in public spaces.

The situation of monuments in public spaces is very challenging. Most of them are in very bad condition and are not appreciated by the common citizen. Thanks to IDPC's recent efforts, there is hope for the future.

Conservation professionals are finding sustainable solutions such as the use of anti-graffiti coatings on monuments or linings that protect against graffiti attacks during political protests and demonstrations. Their effectiveness depends on an ongoing monitoring effort.

IDPC has been working on the dissemination of information about monuments and efforts undertaken for their preservation.[4] This is being done with the help of the local media, such as newspapers, radio, and TV news, and also with focus groups. In 2014, IDPC proposed an "Open Doors Restoration" journey for a group of graffiti activists and soccer fans during which conservators explained their work while carrying out the conservation of the *Ricardo Palma* monument. This is an ongoing outreach effort that needs to be extended to other populations.

Community involvement and education are activities that require time, continuity, and economic resources that are not currently available. This year the IDPC is trying to secure funding for monument preservation through the program "Adopt a Monument" that seeks to involve the private sector in this responsibility.

5. CONCLUSIONS

Through the examples of the *Fuente de Lavapatas*, the Facatativá pictographs, and monuments in public spaces in Bogotá, we can see how social and political issues affected preservation efforts in different ways.

In the case of the *Fuente de Lavapatas*, recent documentation and conservation studies demonstrated that some carvings in the fountain are at risk. It also showed that monitoring was a critical prerequisite to making effective conservation decisions. Nevertheless, since 2013 no more funding has been allocated for the study or conservation of this site. The leadership of ICANH does not consider the preservation of the *Fuente de Lavapatas* a priority, illustrating how much preservation issues are affected by political decisions. In order to ensure continuity of conservation projects, institutions must consider them a priority, stand by their commitments to maintain them, and allocate the economic resources required for their preservation.

The case of the archaeological park of Facatativá illustrates how important community participation and civilian supervision are for heritage preservation. In recent years, several active young members of the community and rock art researchers have been developing and implementing documentation, educational, and interpretive activities with the pictographs. The legal action of 2007 resulted in the CAR paying for the protection and conservation of the pre-Columbian pictographs and the archaeological study of the site undertaken between 2013 and 2014. This resulted in the rediscovery of the site's archaeological and historical values. Thanks to the involvement of indigenous communities, the site has recovered its spiritual value and today it is not only a recreational park but also a sacred site, which recalls the importance of Mother Earth and the ancestors. Today, the current administration of the park should embrace community commitment and invest in security concerns and fence maintenance in order to ensure the protection of the pictographs. It should avoid repeating past mistakes that did not take into account the different values of the site.

Finally the case of monuments in public spaces of Bogotá shows how much the social and political context that affects preservation can be managed and slowly changed. This change required political commitment from local government, funding from public and private sources, and the implementation of several strategies that can improve conservation outcomes and community outreach. These strategies are as follows:

- Technical aspects such as the use of anti-graffiti coatings and protective linings for the monuments
- Social actions involving communities (such as graffiti activists and soccer team fans) in conservation and educational activities
- The dissemination of projects carried out by the IDPC for the study, conservation, and maintenance of monuments in public spaces to a broader population through TV channels, radio, and newspapers
- Funding for these projects that involves the private sector in cultural heritage protection

It has become clear to us that the preservation of cultural heritage is subject to political and social contexts, not only to widely acknowledged deterioration factors such as the environment, human, or biological activity. Understanding these forces, taking them into account, and being able to anticipate the resulting outcomes can lead to better heritage management and more sustainable practices for the preservation of monuments and sites.

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NOTES

1. ICANH is the institution in charge of the protection of the national archeological heritage.

2. Tuff (from the Italian *tufo*) is a type of rock consisting of consolidated volcanic ash ejected from vents during a volcanic eruption.

3. This is a program sponsored by the Ministry of Culture to train local citizens in the knowledge and appreciation of their cultural heritage, who work on outreach activities with the community. http://vigias.mincultura.gov.co/Lists/EntradasDeBlog/Post.aspx?ID=11 (accessed 12/14/14).

4. www.patrimoniocultural.gov.co/patrimonio-material/monumentos.html (accessed 12/14/14).

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Dow Chemical Company
1-899-4474369
www.dowmicrobialcontrol.com

Preventol CD-601
LANXESS Material Protection Products
www.protectedbylanxess.com

RemmersKSE 300, elastified RemmersKSE 300 E, Remmers Antihygro, tartaric acid 0.14% diluted in alcohol
Remmers Baustofftechnik
Bernhard Remmers Strasse 13
49624 Löningen
041 05432/83-0
www.remmers.de

Recubridor
Islecar Group
Carrera 76 no 71-75
Bogotá, Colombia
0571 7028991
www.islecar.com/

Nanoflex TPM 100
Nanoword
Paseo de la Reforma 250 Esquina con NizaPiso 8. Col Juarez del Cuauhtémoc
0055 36007774
www.nanodepot.com

MARÍA PAULA ALVAREZ has worked for 15 years in the study and conservation of Colombian archaeological parks. She is currently the conservation coordinator of the National University project in the Archaeological Park of Facatativá (Contract 847-2012 CAR-UN), and director of several District Institute for Cultural Heritage (IDPC) projects related to the conservation and study of outdoor sculpture and historical facades. She holds a graduate degree in conservation from the Externado de Colombia University and a master in World Heritage at Work from the Torino University. She directs Corporación Proyecto Patrimonio Bogotá, Colombia, and teaches in the conservation program of the Externado de Colombia University. Her primary interests are stone conservation and heritage management research. Address: Cra5 no 28-30 apt 201, Bogotá, Colombia. E-mail: cproyectopatrimonio@gmail.com, mpalvarez2001@yahoo.com

THE DEVELOPMENT OF TREATMENT PROTOCOLS AT THE WATTS TOWERS CONSERVATION PROJECT

FRANK PREUSSER, BLANKA KIELB, SYLVIA SCHWERI-DORSCH, CHRISTINA FISHER, MARIANA RUIZ, ISRAEL CAMPOS

ABSTRACT

This article provides a review of current and past conservation practices and the development of new treatment proposals for the Watts Towers. The Italian immigrant Sabato (Simon) Rodia built the Watts Towers in the backyard of his house. They consist of 17 interconnected structures, each constructed of a steel core covered with cement stucco and embedded decorative elements. The two largest structures reach a height of 99.5 ft. (30 m). Rodia built the Towers from 1921 to 1954. He did so without assistance and without scaffolding. The Towers are located in the Watts district of Los Angeles County.

A team of conservators, scientists, and research assistants from the Los Angeles County Museum of Art has been working on the review of current and past conservation practices, and the development of new treatment proposals for the Watts Towers since January 2011. After reorganizing and rehousing the extensive treatment archives, the first comprehensive environmental and physical monitoring program in the history of the Towers was established. This program was further expanded when, in 2013, a team from the UCLA Department of Civil and Environmental Engineering joined the effort of Los Angeles County Museum of Art.

This monitoring and measurement program resulted in a significantly improved understanding of the response of the Towers and their individual elements to a variety of environmental stresses, including solar radiation (heat), vibration and deformation due to wind and seismic activities, and corrosion of the metal substrate. It also provided an explanation for the repeated failures of many of the repairs carried out over the past 50 years.

Based on these findings, we are evaluating improved repair and maintenance procedures that promise to be of greater durability, using the recent advances made in building science and the concrete industry. To date, materials that have undergone laboratory and outdoor exposure testing, and that are now applied to the monument on a limited test scale, include elastomeric crack fillers, polymer amended mortars, architectural adhesives, and penetrating water repellents.

Currently we are also evaluating different approaches to corrosion protection, including migrating corrosion inhibitors and embedded sacrificial anodes.

1. INTRODUCTION

The Watts Towers (fig. 1) were built by the Italian Immigrant Sabato (Simon) Rodia in the backyard of his house in the years from 1921 to 1954. They consist of 17 interconnected structures, with the tallest reaching a height of 99.5 ft (30 m). They are owned by the State of California and are currently administered and operated by the Department of Cultural Affairs of the City of Los Angeles. They are located in the Watts district of Los Angeles County.

On December 10, 2010, the City of Los Angeles and the Museum Associates (dba LACMA) signed a Professional Services Agreement for preservation and conservation services. Under this agreement LACMA's Conservation Center was to

- Assess the City's existing conservation and preservation plan for the Watts Towers as embodied primarily in the *Preservation Plan* and *Maintenance and Restoration Guide,* prepared for the State of California by The Ehrenkrantz Group in 1983, and the *Evaluation and Conservation of Fissures Report* and *Documentation Synthesis and Materials Research Report*, prepared by the Architectural Resources Group (ARG) in 2004 and 2006, respectively;

Fig. 1. *Watts Towers*, Sabato (Simon) Rodia, steel, cement, and embedded ornament, 30 m, City of Los Angeles Department of Cultural Affairs; view from the North side (Courtesy of Frank Preusser)

- Conduct periodic inspections and undertake minor repairs and restoration;
- Conduct tests to evaluate new materials and techniques for the repair of cracks and spalls and for the adhesion of loose or detached decorative elements.

Recurring cracking of the concrete shell and ongoing losses of decorative ornaments are the most visible signs of the deterioration of the Towers. This has been going on since the beginning, and it has been reported that Simon Rodia himself carried out repairs while he was still constructing the Towers. Since he abandoned the Towers in 1954, there have been numerous repair campaigns (1960–1969, 1979–1985, 1987–1994, 1995–2001, and 2001–2005). During these campaigns a variety of mortar formulations and synthetic resins were used, and large sections of the steel supports were replaced. Unfortunately, the cracks reappeared in many of the repaired areas after relatively short periods of time and the loss of decorative ornaments continued. Close inspection of the Towers reveals that most repairs are "repairs of repairs." In 2005, N. J. Bud Goldstone lamented that "*In each* (repair *sic*) *period there have been cracks and new cracks in original Rodia cement and in repairs of every material used to date*" and "*All else is failing*" (Goldstone 2005).

Before considering any alternative to the repair materials and techniques used in the past, it proved necessary to first determine the causes of the deterioration of the monument and the reasons underlying the failures of past interventions.

2. CONSTRUCTION TECHNIQUE AND MATERIALS

Simon (Sabato) Rodia constructed the Towers from 1921 to 1954, when he abruptly abandoned them and moved to Northern California. He built them without a scaffold and had no assistants. He had no design drawings and frequently changed design elements. The Towers consist of 17 interconnected structures with the tallest reaching a height of 99.5 ft. (30 m). Details of the history of the Towers and their construction can be found in Goldstone and Goldstone (1997).

Each segment of the Towers consists of a central steel element covered by wire mesh. Rodia then applied a cement plaster (figs. 2, 3) and embedded decorative ornaments while the plaster was still wet (fig. 4).

The steel elements were tied together with wires; Rodia did not bolt or weld them together. In later restorations bolting and welding became common, making the structure stiffer (fig. 5).

Fig. 2. Cross section of element from the Towers (Courtesy of Kimberly Blanks)

Fig. 3. Cross section of element from the Towers (Courtesy of Blanka Kielb)

Fig. 4. Embedded decorative ornaments (Courtesy of Frank Preusser)

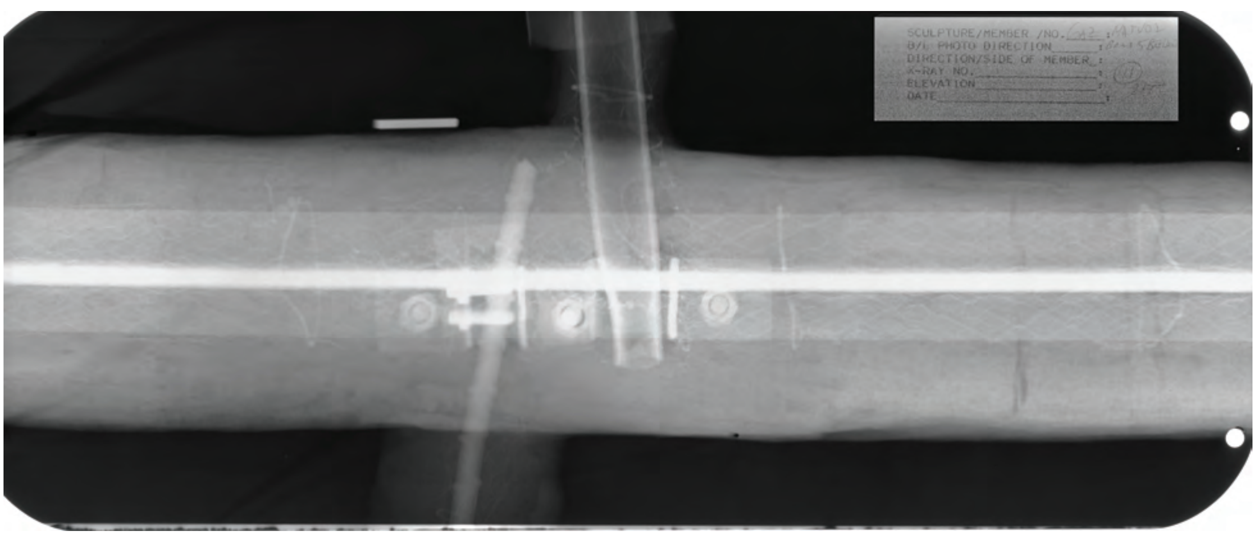

Fig. 5. X-radiograph of bolting (Courtesy of Los Angeles Department of Cultural Affairs)

3. CAUSES OF DETERIORATION

Some previous studies suggested that solar radiation (heat) and vibrations and movements caused by wind forces and seismic events might be the main causes of the development of cracks and loss of ornaments. The cracks then would provide access to water and cause subsequent corrosion of the steel supports. No technical studies were carried out to test the different hypotheses, with the exception of a short study by ANCO Engineers (ANCO Engineers Inc.1989). This brief study confirmed that crack movement is related to temperature fluctuations.

A review of the treatment records of the past four decades revealed that the treatments were governed by the assumption that the deterioration of the Towers is predominantly caused by the corrosion of the steel supports. This led to large-scale steel replacement campaigns and repairs with traditional cement mortars, epoxy resins, and epoxy-cement mortars. Many of these repairs only lasted a short time, less than 2 years, before new cracks formed. The failures were both adhesive and cohesive (figs. 6–8). Adhesive failure, which is the separation of the repair material from the old mortar, typically

Fig. 6. Adhesive failure of repairs (Courtesy of Blanka Kielb)

Fig. 7. Adhesive and cohesive failure of repairs (Courtesy of Blanka Kielb)

Fig. 8. Loss of cement cover over epoxy repair, adhesive failure of repair (Courtesy of Frank Preusser)

occurred in traditional repair materials such as portland cement, which often failed at the bond-line, and in repairs consisting of a thin cement fill applied over an architectural epoxy paste, which failed adhesively at the cement/epoxy interface. Cohesive failure, which consists of cracks within the repair material, can be found in both epoxy and traditional cement repairs because they are too rigid to accommodate the movement of the sculptures.

3.1 MONITORING OF THE TOWERS' RESPONSES TO ENVIRONMENTAL STRESSES

As a first step in developing a restoration protocol, we decided to determine the effect of environmental stresses on the Towers. Before embarking on an ambitious monitoring program, we did a preliminary study consisting of:

- Installation of an on-site weather station
- Plaster bridges over existing cracks
- Mechanical crack monitoring devices over existing cracks
- Low-cost battery operated accelerometers
- Spot temperature measurements with a laser thermometer

These devices provided us with the following necessary information for a more sophisticated monitoring program:

- Many of the existing cracks are moving (some plaster bridges broke within less than two weeks) (fig. 9). The cracks vary in width from less than 1 mm to 3 or 4 mm.
- Strong winds create g-forces on the Towers comparable to moderate earthquakes
- Temperature differences between the cement plaster and the decorative elements are substantial

Based on this preliminary information we expanded the monitoring program by adding:

- Electronic displacement transducers with data-loggers (fig. 9).
- Thermal imaging using a FLIR E60bx camera.

In January 2013, a team from the UCLA Department of Civil and Environmental Engineering joined our monitoring effort. They installed a tilt meter and an accelerometer on the Center Tower and later added a Wind Observer 2 to measure wind speed and direction, and turbulences in direct proximity of the Tower. They also installed two displacement transducers over existing cracks.

Fig. 9. Plaster bridge and two different types of displacement transducers (Courtesy of Blanka Kielb)

This joint monitoring program resulted in the following major findings:

- Most of the monitored cracks open and close on a daily basis: the cracks close when the sun heats up the concrete and open when the concrete cools down. The movement is smaller than would be theoretically predicted on the basis of the thermal expansion coefficient of the concrete. This is most likely due to the thermal expansion and contraction of the steel core which creates opposite forces.
- Because of the one-sided heating and expansion of the columns, the towers also lean away from the sun (to the north and west) on a daily basis with an approximate displacement of 1 in. at the top of the Center Tower. This results in daily tensile forces on the south and east legs and compressive forces on the north and west legs. Once the sun sets, the Towers return to their original position.
- Confirmation that strong winds (25–30 mi./hour) create g-forces that are comparable to moderate earthquakes. An 11 mi./hour wind creates temporary displacement of approximately 3 in. at the 100 ft. level.
- Vibrations resulting from strong winds or from seismic events occasionally lead to irreversible widening of cracks.

Comparison of a high-resolution laser scan of the whole monument with data from a measured survey conducted in the 1980s showed no permanent displacement of the three tall towers. A ground penetrating radar survey of the floor also showed no changes since 2004.

3.2 REPEATED FAILURES OF PAST REPAIRS

Based on the results of the monitoring program and direct observations on the monuments, one can attribute the failures of past repairs to the following causes:

- Use of rigid repair materials (cement-based and epoxy resins) that could not respond to the thermal and mechanical movements without cracking.
- Application mistakes such as improper surface preparation, lack of pre-wetting, and insufficient wetting after application of cement-based mortars. This led to clearly visible cold joints and adhesive failures between new and old concrete (figs. 6, 7).
- Use of combinations of incompatible materials, such as cement mortars on top of epoxy fills without the use of a bonding agent (fig. 8).
- Use of materials not designed for outdoor use, such as some acrylic resins and cellulose nitrate adhesives that have been used to readhere decorative ornaments.

4. DEVELOPMENT OF NEW REPAIR APPROACH

When discussing the repair and maintenance of the Towers, one has to accept:

- Movement (thermal and structural) as status quo and
- The need for regular retreatment as status quo.

It is our goal to extend the time period between major treatment campaigns (requiring scaffold) from currently only a few years to a period of 20–25 years.

The main goals are as follows:

- Minimize the number of new cracks forming
- Keep water away from the steel cores
- Minimize the loss of decorative ornaments

Since movement has to be accepted as a fact, a successful treatment has to accommodate that movement. The old saying that "any structure develops cracks where it needs them" also applies to the Towers. For repairs to be durable, they need to have flexibility. We therefore decided to explore the use of elastomeric crack fillers (ECFs; expansion joint fillers) for narrow cracks and polymer-modified mortars (PMMs) for larger repairs.

As added protection against future steel corrosion, we are also exploring the application of migrating corrosion inhibitors (MCIs) and penetrating water repellents.

For the stabilization of the decorative ornaments, we realized that we would need a variety of architectural adhesives for the different applications, including a silicone contact adhesive for reattachment of ornaments to cement and an epoxy adhesive for rejoining and consolidation of broken glass and tile fragments. All of them have to be reasonably stable in the outdoor environment of Southern California.

4.1 NARROWING DOWN THE CHOICES

There is a great selection of ECFs, PMMs, water repellents, and architectural adhesives on the market. We made our initial selection based on published data and communication with manufacturers and colleagues. We then obtained samples which we applied to concrete plates that we cast and to commercial concrete tiles and blocks. These samples were then exposed in the laboratory to temperature and humidity cycles, and UV radiation. A similar set was exposed on-site on an exposure rack (fig. 10).

Fig. 10. Exposure rack (Courtesy of Blanka Kielb)

While the samples were aging, we evaluated the working properties (workability) of the different products including, but not limited to, their setting time and the possibility of adding pigment for color-matching.

Based on the results of the laboratory and outdoor exposures and the workability tests, we were able to reduce the number of products to one ECF, four PMMs, and three adhesives, as shown in table 1.

Out of eight PMMs initially evaluated, four were eliminated from further consideration on the basis of rapid setting, high initial shrinkage in workability tests, and pronounced adhesive cracking in tests plates subjected to accelerated aging and prolonged outdoor exposure. The PMMs selected for continued evaluation performed best in the following categories:

- Minimal initial shrinkage
- Good working properties (i.e., ease of placement and finishing)
- Minimal adhesive and cohesive cracking in accelerated aging and outdoor exposure tests

These include two PMMs by BASF with relatively higher compressive and tensile strengths for repairs to load-bearing elements such as columns and posts. We also selected a carvable mortar by Edison Coatings Inc. suitable for shallow, nonstructural repairs, and a low-compressive strength mortar by Rapid Set that can be feather-edged and is ideal for reinforcing broken or fragile edges around ornaments.

Past treatments had primarily utilized acrylic resins such as Paraloid B-72 and, occasionally, polyurethane adhesives, epoxies, and cellulose nitrate for ornament reattachment. Many of these treatments have failed over the span of 10–20 years. Our main criteria for evaluating adhesives were durability in an outdoor environment, flexibility to accommodate thermal movement, UV stability, workability, and appearance when applied under transparent glass, particularly green bottle glass which is ubiquitous on-site.

Table 1: Products Initially Chosen for Evaluation

Material Type	**Manufacturer**	**Product Name**	**Application**
PMM	BASF	MASTEREMACO N 1500 HCR Vertical Overhead Mortar	Deep repairs in load-bearing sculptural elements
PMM	BASF	MASTEREMACO N 400 Repair Mortar	Deep repairs in load-bearing sculptural elements
PMM	Edison Coatings Inc.	Custom System 45	Shallow, nonstructural repairs
PMM	Rapid Set	WunderFixx	Ornament edging
ECF	Dow Corning	790 Silicone Building Sealant	Crack filling
ECF	Dow Corning	795 Silicone Building Sealant	Crack filling
Adhesive	Dow Corning	3145 RTV	Reattachment of ornament to cement
Adhesive	HXTAL	NYL-1	Glass-on-glass/tile-on-tile joins
Adhesive	Silicone Solutions	Low-viscosity series: 6001-T, 6001-T3, 6604 M, and 6004 M	Low-viscosity silicone adhesives for ornament consolidation

Eighteen adhesives, including eight epoxies, five silicones, three aliphatic polyurethanes, and two urethane acrylates, were evaluated for application behind ceramic, glass, and shell ornaments. Silicone adhesives performed best in terms of workability and thermal and UV stability, showing the following characteristics:

- Excellent adhesion after accelerated thermal cycling and outdoor exposure
- No noticeable discoloration under accelerated UV exposure
- Minimal saturation of the cement substrate
- Ease of application and cleanup

The urethane acrylate adhesives were discontinued from further testing after initial workability tests showed that they cured too quickly in an outdoor environment and were difficult to clean up. Many of the epoxies and aliphatic urethanes tested were disqualified on the basis of long cure time, poor/inconsistent adhesion to cement in accelerated thermal and outdoor aging tests, and/or yellowing under prolonged UVA/UVB exposure.

Our final selection of adhesives includes the Dow Corning 3145 adhesive/sealant for use as a contact adhesive for detached glass, ceramic, and clamshell ornaments; a series of injectable silicones of varying viscosities by Silicone Solutions (6604 M, 6004 M, 6001-T, and 6001-T3) for injection behind ornaments and into cracks; and HXTALNYL-1 for the stabilization of tight glass-on-glass joins. Of the epoxies tested, HXTAL showed the least oxidative and UV-catalyzed yellowing, performed best in thermal cycling, and was one of the top performers in outdoor exposure tests.

We evaluated a total of eight expansion joint fillers/building sealants for crack repair, including three polyurethanes, one polyurea, and four silicone sealants. Our evaluation criteria included workability, adhesive peel strength, aesthetic integration, and prolonged outdoor exposure. The silicone-based sealants performed best in terms of:

- Ease of application and cleanup
- Adequate working time for a two-layer joint design
- Excellent adhesion to the cement
- Highest expansion/compression capability

While the polyurethane sealants performed well in workability and adhesion tests, we eliminated them from further consideration due to their lesser movement capability and life expectancy of 7–10 years, as compared to 20–25 years for silicone-based sealants. The polyurea sealant was disqualified because it performed poorly in adhesion tests, had a short working time, and was difficult to manipulate. Our final candidates, the Dow Corning 790 and 795, were selected due to their superior workability and availability in small cartridges and an assortment of base colors to facilitate color-matching.

Finally, as part of our strategy to reduce water ingress and slow the corrosion rate of the steel armature, we assessed the performance of six water repellents. Our evaluation was based on pre- and post-treatment water absorbency measurements on cast cement plates and depth of penetration tests. Because of the strict VOC regulations in Southern California, we had to exclude one water repellent, Protectosil CHEM-TRETE 40D, that performed well in the initial tests. Another well-performing water repellent, Wacker SILRES BS 1701, was eliminated due to its incompatibility with the Dow Corning 790 sealant. A third product was disqualified on the basis of poor depth of penetration. This left us with three products for further evaluation:

- Protectosil CHEM-TRETEBSM400-BA (VOC-compliant)
- Wacker SILRES BS 290 (dilutable in VOC-exempt solvent, parachlorobenzotrifluoride)
- Dow Corning Z-6689 (dilutable in VOC-exempt silane solvent)

4.2 IN SITU TESTING

After we narrowed down the number of products under consideration, we decided to start a program of in situ testing, carrying out limited repairs in areas of failed previous repairs. The main purposes of the in situ tests are as follows:

- Develop and refine the best application procedures for our selection of materials and prepare standard operating procedures for different circumstances.
- Identify any problems that may exist with the proposed repair strategies and adjust the procedures accordingly.
- Evaluate the performance of these test repairs through long-term monitoring. Ideally this monitoring should last at least 2 years (past repairs appear to have failed within an 18-month period).

To date, in situ testing has resulted in a number of important findings:

- PMM repairs should always be executed with a bonding agent. Repairs without a bonding agent tend to show adhesive failure between the repair mortar and the old cement stucco. We are expecting the PMM repairs to fail at some point and develop cracks. However, we want the repairs to fail cohesively so that they can be repaired in the future using an ECF instead of having to remove the whole mortar repair (as we have to do now with the old repairs). We are planning experiments with designed cuts, hoping to be able to influence the location of the new cracks to make future repairs easier.
- The PMM curing behavior is significantly altered by the addition of certain pigments. We therefore started experimenting with mineral silicate paint for the aesthetic integration of the repairs.
- Epoxy resin repairs are abundant at the Towers and the ECF DC790 does not adequately bond to one type of epoxy previously used. Even the application of a manufacturer recommended primer could not overcome this problem. DC795 together with a manufacturer recommended primer allowed us to overcome this obstacle.

While we continue the in situ testing and monitoring of PMM and ECF repairs, we are now expanding this program to address other aspects of the overall repair and preservation plan. We are also evaluating the effectiveness of the latest generation of surface-applied, amino-based MCIs to mitigate corrosion in the steel armature. MCIs reduce the rate of corrosion induced by chloride ingress and carbonation by forming a protective film in both the anodic and cathodic areas. Test applications of Cortec MCI-2020 on fragments of the Towers that had been removed (replaced) in the past were quite successful, and we are beginning in situ testing, consisting of:

- Corrosion potential measurements before MCI application, using a copper/copper sulfate half-cell
- Application of the MCI by brush or infusion
- Corrosion potential measurements 4 weeks after MCI application and then every 6 months.

We also selected areas of the monument for the test application and monitoring of the water repellents that passed our initial test and comply with the California VOC regulations.

5. COMPATIBILITY TESTING

Since the final restoration plan will involve many steps and a variety of materials, we also had to verify that individual materials and their solvents (if applicable) are compatible and do not adversely affect each other.

Our compatibility tests showed that the DC790 adhered poorly to one of the epoxy resins ubiquitously used in past restorations, Sikadur 23, a low-modulus structural epoxy adhesive. To resolve this issue, we performed off-site adhesion tests using the ECF in combination with an adhesion promoter, Primer P, which is an alkoxysilane resin-based primer recommended by Dow Corning for use on masonry surfaces. While the Primer P performed well, it was discarded because it contains an alcohol component that inhibits the cure of the DC790 if there is not sufficient time between primer and sealant application.

We therefore tested another ECF, DC795 Silicone Building Sealant, in combination with the adhesion promoter DC 1200 OS Primer for use in repair areas that contain Sikadur 23. The DC795 has similar working properties to the DC 790 and is available in 11 base colors. Off-site adhesion tests between the DC795 and Sikadur 23 have shown promising results with the OS 1200 Primer.

Another compatibility issue was identified between the DC790 and two Wacker water repellents, the BS 1701 and BS 290 (diluted in ShellSol D-38), both of which caused swelling and loss of elasticity in submersion tests. While the BS 1701 was eliminated from further evaluation, we found that we can substitute the ShellSol D-38 with anhydrous ethanol as a diluent for the BS 290 without any adverse effect on the DC790. Further testing is still needed to evaluate the compatibility of the ECF with our low-VOC solvent alternatives for water repellents, the parachlorobenzotrifluoride and silane solvents.

6. FUTURE WORK

Quite a lot remains to be done before the treatment and maintenance plan can be finalized. We still need to fully evaluate the MCI and the water repellent, and develop a long-term monitoring and maintenance plan.

7. CONCLUSION

A multiyear monitoring program has resulted in a far improved understanding of the causes of deterioration of the Towers. The cracking of the cement cover is predominantly caused by structural movements due to heat, wind, and seismic activities. Once cracks are formed and water can reach the steel cores, corrosion adds to the deterioration factors. The loss of decorative ornaments is mostly caused by differential thermal expansion and contraction, weakening the bond between the ornaments and the cement. Vibrations caused by strong winds accelerate the process.

To achieve a long-lasting restoration, one needs to plan a combination of treatments consisting of crack repairs, corrosion protection with MCIs, and the application of a penetrating water repellent. Materials used for crack repairs and adhesives used for ornament stabilization and/or reattachment should be flexible to accommodate structural movements and stable in an outdoor environment. We have identified and tested a range of materials and developed treatment protocols.

Continuous monitoring and maintenance will also be essential for the long-term preservation of the Towers.

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SOURCES OF MATERIALS

MASTEREMACO N 1500 HCR Vertical Overhead Mortar (BASF Corporation), MASTEREMACO N 400 Repair Mortar (BASF Corporation), Rapid Set WunderFixx (CTS Cement Manufacturing Corporation)
White Cap Construction Supply
(800) 944-8322
www.whitecap.com/shop/wc/home

Custom System 45
Edison Coatings Inc.
3 Northwest Dr.
Plainville, CT 06062
(860) 747-2220
www.edisoncoatings.com/index.html

790 and 795 Silicone Building Sealants (Dow Corning Corporation)
Smalley & Company
2358 E. Walnut Ave.
Fullerton, CA 92831
(714) 441-4100
www.smalleyandcompany.com/default.aspx

Dow Corning 3145 RTV MIL-A-46146 Adhesive/Sealant
Ellsworth Adhesives
W129 N10825 Washington Dr.
Germantown, WI 53022
(800) 888-0698
www.ellsworth.com/Home/

HXTAL NYL-1
Talas
330 Morgan Ave.
Brooklyn NY 11211
(212)219-0770
http://talasonline.com/

Low-viscosity series: 6001-T, 6001-T3, 6604 M, and 6004 M
Silicone Solutions
338 Remington Rd.
Chuyahoga Falls, OH 44224
(330) 920-3125
http://siliconesolutions.com

Cortec MCI-2020
S.M.A.R.T. Distribution
5521 Oak View Dr.
Mainville, OH 45039
(513) 602-5944

Protectosil CHEM-TRETEBSM 400-BA (Evonik Degussa Corporation)
The Sherwin Williams Corporation
(800) 524-5979
http://protective.sherwin-williams.com/

Wacker Chemie AG SILRES BS 290
Brenntag Solutions Group
5083 Pottsville Pike
Reading, PA 19605
(623) 302-0031
www.brenntagsolutionsgroup.com/en/

Dow Corning Z-6689
NEXEO Solutions
5200 Blazer Pkwy
Dublin, OH 43017
(877) 587-2950
www.nexeosolutions.com/

FRANK D. PREUSSER received his PhD in chemistry in 1973 from the Technical University in Munich, Germany. From 1973 to 1983, he was the head of the scientific laboratory of the Doerner Institut in Munich. From 1983 to 1993, he worked at the Getty Conservation Institute in Los Angeles where he held the positions of director of scientific research, head of publications, associate director for programs, and acting co-director. Since 1993, he has worked as an independent conservation consultant in the areas of collections environments, architecture, and archaeological sites, as well as in the scientific examination of works of art and archaeological objects. From 1995 to 1999, he was guest professor at the Tokyo National University of Fine Arts and Music, teaching the scientific examination and conservation of works of art and artifacts. He is presently the senior conservation scientist at the Conservation Center of the Los Angeles County Museum Art. Address: Senior Conservation Scientist, Conservation Center, Los Angeles County Museum of Art, 5905 Wilshire Boulevard, Los Angeles CA 90036. E-mail: fpreusser@lacma.org

BLANKA KIELB is a graduate of the Queen's University Program in art conservation, where she earned a master of art conservation degree in paintings, and currently resides in Los Angeles. Her professional interests include treatment of painted surfaces with a focus on wall paintings and architectural interiors. Blanka has contributed to a number of large-scale projects, including the treatment of historic ceilings and murals in the U.S. Capitol Building, The Secretary of War Suite in the Eisenhower Executive Office Building in Washington, D.C., and most recently, decorative painting in the Mission San Miguel. In 2010, Blanka taught an undergraduate internship at the University of Delaware Program in Art Conservation, and in January 2011, she co-directed a University of Delaware study abroad program in Peru aimed to provide UD undergraduates with hands-on experience in the documentation and treatment of wall paintings. Address: Assistant Conservator, Conservation Center, Los Angeles County Museum of Art, 5905 Wilshire Boulevard, Los Angeles CA 90036. E-mail: bkielb@lacma.org

SYLVIA SCHWERI-DORSCH is an objects conservator active in Los Angeles since 2008. A graduate of the Institute of Fine Arts Conservation Center of New York University, she has contributed to numerous archaeological, decorative arts, and architectural projects. Prior to joining the Watts Towers team in 2011, she worked at a historic preservation architecture firm in Los Angeles, advising on various preservation issues. Other recent projects include the Mission San Miguel (Griswold Conservation Associates), University of Chicago's Oriental Institute Epigraphic Survey in Luxor, and Stan Hywet Hall & Gardens house museum (with the Intermuseum Conservation Association of Cleveland). A member of AIC CERT, she has been deployed to Haiti and the Midwest on collections disaster relief. Address: 6103 Alcott St, Los Angeles, CA 90035. Email: sschweri@gmail.com

CHRISTINA FISHER is an objects and architectural conservator and contemporary artist based in Los Angeles. She received her MFA in Sculpture from Virginia Commonwealth University in Richmond, Virginia, in 2007. She was trained in objects and architectural conservation by John Griswold. She first trained as junior conservator at the Norton Simon Museum of Art from 2007 to 2009, then as conservation technician at Griswold Conservation Associates from 2010 to 2012. At GCA, Christina contributed to small- and large-scale projects ranging from ancient to contemporary art. She has been working for the Watts Towers Conservation Project for 2 years, testing materials and treatment procedures and contributing to monitoring activities. Address: Assistant Conservator, Conservation Center, Los Angeles County Museum of Art, 5905 Wilshire Boulevard, Los Angeles CA 90036. E-mail:cfisher@lacma.org

MARIANNA RUIZ received her bachelor's degree in fine art with a minor in mathematics from Mount St. Mary's College. Upon completion of her degree in May 2011, she held various positions as a mathematics and fine art-workshop instructor throughout Los Angeles County. She has also worked as a studio and gallery assistant for LA-based artist Mara De Luca, Jeremy J. Quinn Architecture and Design, Mexican artist-in-residence LauraHernandez, the José Drudis-Biada Art Gallery, and the Robert Berman Fine Art Gallery in Santa Monica. In 2012, Ruiz joined the Los Angeles County Museum of Art as a research assistant on the Watts Towers Conservation Project, conducting preservation treatments and documentation for the conservation and long-term maintenance of the site. E-mail: art.ruizmariana@gmail.com

ISRAEL CAMPOS is currently pursuing a degree in fine arts at the University of Wisconsin, Madison. Working primarily with print media, he is interested in exploring the fusion of traditional print methods with digital processes. He served as master printmaker printing a piece that was exhibited at the Madison Museum of Contemporary Art and assisted maintaining Laurie Beth Clark's performance project for the 2013 Wisconsin Triennial. He will be teaching Intro to Digital Forms for the 2014–2015 academic year. E-mail: icampos@wisc.edu

THECOLUMBUS CHALLENGE

RICHARD McCOY

ABSTRACT

In this article, I describe the challenges of leading strategic planning for the conservation, preservation, and management of a world-renowned collection of Modern architecture, landscapes, and public artworks in Columbus, Indiana. This article focuses on the importance of public engagement in the project. Specifically, it describes how preservation efforts were documented and shared with the community. It also highlights efforts to engage stakeholders in defining shared values and a vision to care for the community's unique design heritage. It documents my accomplishments with the project thus far and describes my vision for the future.

1. INTRODUCTION

In June of 2013 I signed a 1-year contract to begin working for the City of Columbus, Indiana, out of the City's Columbus Redevelopment Commission. Working directly with the Mayor of Columbus and others, I was to create and lead a new planning effort for caring for the world-renowned architecture, landscape architecture, and public art that had been built in Columbus after World War II. For the sake of consistency, I will call all of this cultural heritage simply, and perhaps too generally, "cultural resources."

Looking back on the signing of this contract, I realize now how ambitious it was. In many ways it was unrealistic in that it was designed to solve a complex citywide challenge in less than 12 months. I was hired to focus on an area of downtown that was recently designated a "Cultural District." The "Columbus Arts District" (CAD) is one of only five Cultural Districts that Indiana has recognized since starting the program in 2008. These districts are meant to promote exploration of and participation in the arts and humanities through cultural experiences that are unique to communities, while also supporting community life and economic vitality. This recognition does not come with any financial benefits, nor does it protect resources from demolition. Instead it confers an honorific designation on a city. Through this designation, the City of Columbus is working to focus interest on creating a vibrant cultural core, one that works to align many of the community and cultural organizations. At the same time, the city is leveraging the internationally recognized cultural resources that have made Columbus a popular destination for visitors.

Working within the CAD, my project focused on three primary goals: identify and increase knowledge of cultural resources, assess conditions of cultural resources, and encourage voluntary preservation of them. More generally I was hired to lead public participation in this effort and create a "preservation plan" or process that could be used by the City of Columbus. The terms of the contract were broad enough that my role could evolve from being a project-based consultant to one that was more generally available in the community, similar to a staff position in City Hall.

In this article I describe the development of this project, the challenges I faced, the processes developed, and the outcomes that were achieved. I wrote this paper and presented it at the 2014 AIC Annual Meeting as a kind of personal journey.

Further, this article focuses on the process and outcomes of my work. Specifically, I want to share with readers my belief that public engagement and vision are crucial for successful preservation projects. Through this project, I want to demonstrate my process for putting that belief into action and to share the goals and outcomes that resulted from this kind of public, stakeholder conversation. My aims were to revitalize the town's commitment to its design heritage and to begin an ongoing conversation that will both preserve and sustain Columbus's commitment to great design.

2. BACKGROUND (COLUMBUS, INDIANA)

Columbus is famous for its architecture. At one point in the 1990s, the American Institute for Architects (AIA) ranked it as sixth in the nation for architectural innovation and design, right behind New York, Chicago, Boston, San Francisco, and Washington, D.C. However, by most other standards, Columbus is a little town in the middle of nowhere, and in my opinion not enough people know of it. The city population is just under 45,000 with the nearest metropolises being Indianapolis and Louisville, each about an hour away.

Columbus truly is unlike any other place in the world, with more than 100 buildings, landscapes, and works of public art designed by internationally recognized masters. There are buildings by Eliel and Eero Saarinen, Harry Weese, Myron Goldsmith, Robert Venturi, and I.M. Pei, to name a few; landscape architecture designed by Dan Kiley, Michael Van Valkenburgh, and Jack Curtis; and public art designed by Henry Moore, Jean Tinguely, Robert Indiana, Dale Chihuly, and others. All of these projects were created within a fairly traditional context of 19th and early 20th century American design, and they are surrounded by the contemporary American and often corporate architecture common throughout small towns of the Midwest.

The story of how this remarkable collection of Modern design was created in a small Indiana town starts in the early 1940s. Led by industrialist J. Irwin Miller, along with a variety of community stakeholders, an idea emerged after World War II: if Columbus were to become a great place to work and live, forward thinking and planning should be undertaken with a kind sensibility that has become a community tradition. This sensibility starts with finding a way for the community to work in a public–private partnership to develop solutions that are broadly and mutually beneficial. The town fathers also relied on local corporations to share the responsibility of shaping the town. The idea was always to make Columbus an excellent place to live, work, and play, and ultimately also a place that was distinct and contemporary.

Today, in a slightly different way, many communities of all sizes are interested in making cities more visually interesting and distinctive. The buzzword for this kind of development or redevelopment is "placemaking"; the notion that interesting places are key to creating communities that attract the best and brightest work forces and make cities lovable, fun, and livable. There have been countless studies and books written since the 1940s that articulate the economic and cultural benefits of creating distinctive communities, but no other city has done it in a way that approaches Columbus.

To guide my work, I looked back to one of the quotations that Miller favored from the Latin historian Tacitus: "The good life is one lived in praiseworthy competition with one's ancestors." I believe Miller, like Tacitus, meant that we can and should always improve on what our ancestors did, and that we should not rely on our ancestors' ideas to shape our lives or our future. We should seek solutions that fit our time, context, and are sustainable. This kind of thinking points to a future that is informed but not directed by the past; we should not allow the past to reach out of the grave to direct the future. Instead, we should establish a kind of trust that future generations will rise to the challenge and make the best decisions for their own time.

The first, and still one of the greatest projects that embodies this line of thinking, is the construction of First Christian Church (originally Tabernacle of Christ), which was designed by Eliel and Eero Saarinen (with interior help from Charles Eames) and completed in 1942 (fig. 1). It is a building that is widely considered to be the first Modern church in America, and today stands to represent the core idea of this "praiseworthy competition" that Miller embraced.

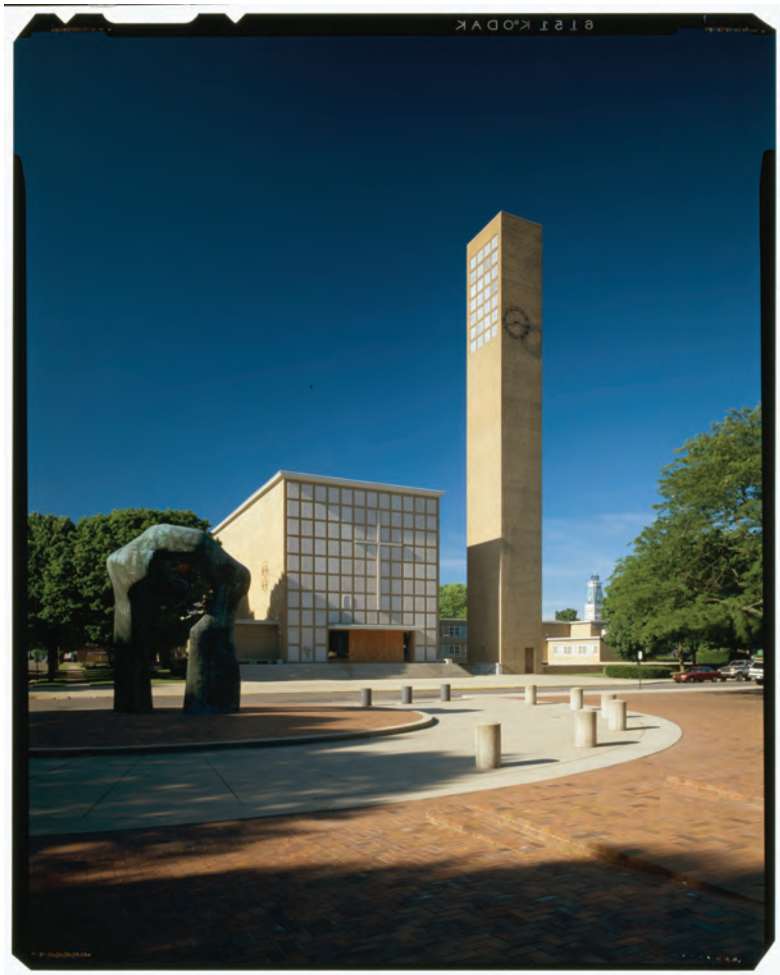

Fig. 1. Eliel and Eero Saarinen, First Christian Church, 1942 with Henry Moore, *Large Arch*, 1969 in the foreground (Courtesy of the Library of Congress, Prints & Photographs Division, Balthazar Korab Archive at the Library of Congress)

Before Saarinen was selected to create this church, another architect was chosen. This architect had in fact created drawings and a model that proposed a new church building to be built in a neo-gothic style. The architect fell ill, however, and a replacement had to be found. This misfortune turned into an opportunity; it allowed Miller and his family to personally convince Saarinen and the church board to work together on the project. At the time, Saarinen and his family were living in Bloomfield Hills, Michigan, where he was helping to develop the Cranbrook Academy. In Columbus, beyond making a building that has served its congregation for nearly 75 years, Saarinen and the church board created a building of such importance that it was recognized in 2001 as a National Historic Landmark.

The young Miller and Eero Saarinen also forged a friendship that would last the rest of Saarinen's life. Their relationship ultimately produced three other projects in Columbus and a Miller family project in Canada. The connection to Saarinen's office continues today in Columbus through the work of Kevin Roche John Dinkeloo Associates and many other architectural firms that worked with or were trained by the Saarinens.

From the 1940s until 2009, there were 69 Modern buildings constructed in Columbus, many of which had Modern landscapes, public artworks, and often highly realized interior designs directly incorporated into the overall project. Just under half of these projects were built with the help of funding from the Cummins Foundation, the nonprofit arm of Cummins Inc., a Fortune 200 diesel engine manufacturing company that J. Irwin Miller's family created and that he personally led to international success. Cummins' global headquarters is in Columbus, and the company remains the largest employer in the city, by far.

Cummins funding of design projects came in a remarkable way in that the company's foundation agreed to support the construction of new buildings for publicly owned and nonprofit agencies by paying for the architectural fees of the project (these fees usually equal about 10%–20% of the total project). They had one stipulation for this gift: in order to receive the funds, the architect had to be chosen from a list provided by the foundation. This allowed the foundation to promote young architects who were excellent designers of great potential. Over a span of more than 50 years, this program provided nearly $20 million in grants to the community (the program stretched to Bartholomew County, of which Columbus is the county seat). Many of the architects used their projects in Columbus as opportunities to vault them to bigger and better projects of global significance. The Cummins Foundation "Architecture Program" continues today.

Seven buildings in Columbus have been designated National Historic Landmarks; this is just under 20% of the total landmarks in the state of Indiana. Also, the Columbus Area Visitors Center offers year round tours of the community that focus on the Modern architecture, Mr. Miller, and the Architecture Program. The community is frequently recognized in major media publications not only for its design heritage, but also for its strong economy. The internationally recognized success of Columbus and the Architecture Program has yielded a beautifully designed environment, but it has also, and perhaps more importantly, clearly proven to be successful in attracting top talent to work in the city and in fostering the ongoing development of excellent schools, parks, and churches.

Theodore Prudon, president of the board of directors at Docomomo-US, an international organization dedicated to the preservation of Modern architecture, aptly summed up what makes Columbus unique following his 2014 visit to Columbus. In e-mail correspondence with me while I was completing research, he wrote, "It's a kind of museum of Modernism, American-style: a conscious collection of buildings as design objects, but in use. I don't think there's another example out there in the US, or in the world, for that matter, that matches Columbus."

3. CURRENT CHALLENGES

Recently, however, a unique set of challenges around the design heritage has begun to surface: how does the community continue to use these cultural resources while at the same time preserve, conserve, and manage themin to thefuture ?There are questions about whether the community is still interested in building new projects that are as progressive and architecturally challenging as in the past. In many ways the city finds itself at a crossroads. The last significant project in Columbus designed by a major architectural firm and funded by the Cummins Foundation is "The Commons ,"which was completed in 2011 (fig. 2) .

The project was designed by the Boston-based architectural firm Koetter Kim & Associates and operated by the city as a park. The building contains a 600-seat performing arts space; Jean Tinguely's 1974 kinetic masterpiece, C*haos No. 1*; and the town's busiest playground, which features the "Luckey Climber," a 35-ft. play structure. In 2014 it was announced that the Cummins Foundation Architecture Program was funding a new project, signaling that the foundation is committed to continuing this program.

Since the early 2000s, however, the financial landscape of Columbus has shifted considerably. The city's greatest benefactors, the Miller family, once known as the "Medicis of the Midwest," have a dramatically reduced role in the community. This family has been in Columbus since the 19th century and shaped key parts of community's vision, but both J. Irwin and his wife Xenia recently passed away. In

Fig. 2. Koetter Kim & Associates, The Commons, 2011, which features the citytter rgest indoor park. (Courtesy of Hadley Fruits)

2009, the Miller children donated their Eero Saarinen-designed family home (fig. 3) to the Indianapolis Museum of Art, which now operates it in conjunction with the Columbus Area Visitors Center and provides daily tours of the home and throughout the town.

The Miller's family banking institution, Irwin Union Bank & Trust, closed during the 2007–2008 financial crises. The family's Irwin-Sweeney-Miller Foundation ended its gift-giving operations recently, after donating tens of millions to the community over the span of nearly 60 years. There are no Miller family members living in Columbus today. Two other significant foundations, the Arvin Foundation and the Irwin Union Foundation, recently terminated their gift-giving operations.

There are other changes afoot in Columbus. Many of the buildings that formed the town's design legacy have undergone programmatic changes. One example is Eero Saarinen's 1954 landmark Irwin Union Bank, now operated by Cummins. The building was beautifully remodeled to become the "Irwin Conference Center" and now serves Cummins employees. Other buildings are also set for programmatic change in the coming years. Further, the Miller family's bank, Irwin Union Bank and Trust (fig. 4), which closed in 2008, had a half dozen banking branches throughout the community, all designed by Modern architects, including Harry and Ben Weese, Paul Kennon, Deborah Burke, and others. These buildings are now under different ownership and one, designed in the 1960s by Fisher and Spillman and located in Taylorsville, was destroyed in late 2014. Additionally, many of the great Modern buildings are now 50 years old and in varying need of physical repair.

Fig. 3. Eero Saarinen, Miller House, 1957, with interiors by Alexander Girard (Courtesy of the Library of Congress, Prints & Photographs Division, Balthazar Korab Archive at the Library of Congress)

Fig. 4. Eero Saarinen, Irwin Union Bank and Trust Company, 1954 (Courtesy of the Library of Congress, Prints & Photographs Division, Balthazar Korab Archive at the Library of Congress)

4. THE HEART OF THE PROJECT

With this internationally significant context and current state of affairs in mind, I beganmy project. I was new to the city and carried with me a background in fine art conservation and expertise as a generalist in materials. I hadno training in architectural design, historic preservation, or city politics. My greatest asset was that in my previous work in museums I had been at the forefront of exploring the intentions by which contemporary artists make projects. More basically, I have always been interested in from what and how culture is made.

When I was negotiating the contract for this work, I argued that it was my lack of traditional experience in historic preservation and architecture that would allow me to explore and potentially arrive at new solutions to this complex challenge. My nontraditional background, a history of doing primary research, a good set of conversation skills, and a deep interest in Columbus formed the core of my approach to the project.

Living in Indianapolis, I started the work as an outsider, a non-Columbus resident who had been hired by the mayor to work on a Columbus challenge. I recognized that the most important thing I needed to do was learn the community's traditions and values. I therefore began my project by developing relationships with key stakeholders in the community and beyond, those people and organizations who have the most direct involvement with or interest in the cultural resources in the CAD. I engaged arts and community leaders, historic preservation agencies, and potential funders with the goal of understanding and explaining the challenges that Columbus is facing. I wanted the process to be as open as possible. I wanted to learn from the community and ultimately work to create a process and a plan *with the community* instead of creating it for them. Although I had been initially contracted to create a preservation plan, I learned that a traditional preservation plan would not fit the traditions and values of the community. To have the city dictate the terms of preservation to the community was not the right approach.

At the same time, I wanted to connect this project to allied organizations and to research comparable communities within the state. I looked at Indiana communities of similar size and scope as Columbus, including Bloomington, Carmel, Fort Wayne, and West Lafayette. While none of them have the design heritage of Columbus, each of these cities has a historic preservation commission that operates out of city hall to preserve locally designated buildings and districts. These commissions can dictate the terms of rehabilitation and expansion of designated buildings and control the look of new development in areas. They often work in collaboration with the Indiana Division of Historic Preservation & Archaeology and nonprofit foundations dedicated to preservation. There are more than 50 cities and towns in the state that have Historic Preservation Commissions.

From my personal relationships and discussions in the community, and from working within and around City Hall, I realized that trying to create a historic preservation commission in Columbus would be problematic and not a helpful first step toward better preservation planning. Also I had no experience running one or setting one up! More importantly, even if the correct expertise could be applied, trying to create a new historic preservation commission in a city that has never had one would unnecessarily burden the initial steps of addressing the challenges to which I was most dedicated. The project would quickly become overrun with city politics.

Most importantly, establishing a historic preservation commission in the city would shift the dynamics of the very *process* that had allowed great buildings and design projects to be made in Columbus. It would shift the balance of power to city government and away from the community. The process that helped create the buildings relied on a natural set of public–private partnerships that formed around particular challenges.

I recognized that this lack of a historic preservation commission is in fact a significant part of the history and traditions of the community and, although there are no empirical data to support my argument, the 19th and early 20th century buildings in Columbus appear to be as well preserved as in any comparable town with a well-functioning historic preservation commission. This is in large part because of how the community traditionally worked and planned together. There are a variety of excellent and early examples of the community working to improve the 19th and early 20th century buildings, including an innovative project in 1964 led by Alexander Girard that cleaned up and painted the facades of the buildings on the main street of town, Washington Street. In some ways this project altered the historic character of the buildings, which by the 1960s were dirty and grimy, but it also allowed them to be seen in a new way and inspired business development downtown at a time when many similar cities were seeing dramatic business decline.

The Columbus community cares about its cultural resources, and there are a number of significant organizations in the city that have a stake in this care. For a town of 45,000, there are a remarkable variety of organizations that have direction connections to the cultural resources, including:

Bartholomew County Historical Society (http://bartholomewhistory.org)

"The mission of the Bartholomew County Historical Society (BCHS) is to collect and preserve Bartholomew County artifacts, photographs, and documents."

Bartholomew Consolidated School Corporation (http://www.bcsc.k12.in.us)

Nearly all of the schools in Bartholomew County have been built using the Cummins Foundation Architecture Program.

City of Columbus (http://www.columbus.in.gov)

Columbus Area Arts Council (http://www.artsincolumbus.org)

"Formed in 1972 as the Driftwood Valley Arts Council and renamed Columbus Area Arts Council in 1989, the Arts Council is a public, non-profit corporation supported by private donations, the City of Columbus, the Indiana Arts Commission, and the National Endowment for the Arts."

Columbus Area Visitors Center (http://www.columbus.in.us)

"The Visitors Center actively markets the uniqueness and advantages of the Columbus/ Bartholomew County community while engaging and educating visitors, overnight guests, and residents."

Columbus Indiana Architectural Archives (http://www.columbusarchives.org)

"The mission of the Columbus Indiana Architectural Archives is to collect, conserve, preserve, and promote the use of records that document the architecture, engineering, and arts associated with the built environment of Columbus, Indiana and Bartholomew County."

Columbus Museum of Art and Design (http://www.cmadart.org)

"CMAD, in collaboration with other local arts organizations, seeks local and national financial support to fund and display unique exhibits in venues throughout Bartholomew County."

Cummins Foundation Architecture Program (http://www.cummins.com/architecture-program)

"The program has become a major economic asset to the worldwide headquarters for Cummins Inc. More than 50 projects have been sponsored by the Cummins Foundation and numerous other significant works of architecture in the community have been privately commissioned. The resulting partnership between private and corporate resources devoted to design has created a critical mass of buildings that have captured national and international attention, attracting 40,000 to 50,000 visitors each year."

Indiana University Center for Art + Design (http://design.iub.edu/iucadc/)

"Indiana University has formed a partnership with the Community Education Coalition of Columbus to establish a center in downtown Columbus that will specialize in teaching art and design."

A nonmembership based, preservation organization, "Preserve to Enjoy Inc." also existed in Columbus until the early 2000s when it was subsumed into the Bartholomew County Historical Society. This organization was primarily focused on preserving homes from the turn of the 20th century.

Many towns of this size and scale have a fraction of these organizations. While no formal study has been completed on the number of nonprofit cultural organizations in Columbus, there are an equal amount of specialized organizations in other sectors of the community. The creation of so many organizations in this town was likely the result of two factors: the community wanting to find solutions to particular challenges and a significant amount of financial support for creating discreet solutions and organizations. In some ways it may be a handicap to have this many organizations and stakeholders sharing responsibility for cultural resources, as the responsibility becomes less focused and perhaps even diluted among the various groups.

The end result is that there is no singular entity focused on the care of the design heritage and individual cultural resources in the community. Without such focus, it is challenging to create a constituency of individuals who are dedicated to the care of the cultural resources, and it is potentially easy for those resources to lose either their significance in the community and/or elements of the original design intentions that first made them so intriguing.

Recognizing the complexities of the design legacy in Columbus, as well as the limitations of the organizations in place to help manage and care for the cultural resources, was the most obvious first step in understanding the challenges facing cultural heritage preservation in the town. The next step was to define how a new effort could begin to address these challenges directly. Such an effort should help to build relationships, earn trust, and begin to grow a constituency that could then find consensus for a way to move forward. Further, with such an effort underway, more formalized preservation resources and expertise could be brought to bear on individual challenges and larger planning needs.

To better understand the cultural resources in the community, I chose to inventory and complete a survey of those within the CAD. My aim was to identify the research resources and organizations in the community that would be most helpful in this challenge.

The area that the CAD covers is basically downtown Columbus (fig. 5). This area was selected by the current city administration and the community because it includes many of the cultural resources and downtown merchants and businesses; it makes up a cultural core of the city.

For many years the Columbus Area Visitor Center has published a guidebook about the significant buildings and works of public art in the entire county, but there does not appear to have ever been a systematic categorization or physical examination of them, even in such a discreet area as the CAD. This kind of inventory was needed, and to accomplish it I split the cultural resources into two conceptual groups: public artwork, and buildings and landscapes. Using a basic approach, a few part time subcontractors and I systematically identified, examined, and documented the existing resources. We also identified the ones that no longer exist. For the public art this process was based on my previous conservation working methods, and for the buildings and landscapes I devised a system based on a data and assessment process used by the State Historic Preservation Office and County Assessors.

Because I wanted a larger sample size for the public art, I also looked far beyond the CAD and surveyed all of the public artworks in Bartholomew County. Some of the sculptures were surveyed in the 1990s as part of Historic Preservation's Save Outdoor Sculpture! Project (http://www.heritagepreservation.org/sos/index.html). With data collected by the Visitors Center and the Arts Council, we identified 113 public artworks in the county and discovered a few with regional significance that had not been identified previously, including a work by Jerald Jacquard, a sculptor who worked throughout the Midwest.

Instead of simply making a closed database for this inventory, we created a database using Google Docs (a free, web-based office suite offered by Google) and then partnered with the Public Art Archive (http://www.publicartarchive.org), "a national effort to increase public awareness and stewardship of public artworks," to publish our inventory in their online database and mobile app (fig. 6).

Because we created the data and images in a way that is interchangeable, we also uploaded the records to CultureNOW (http://www.culturenow.org), another online project that "dedicates itself to

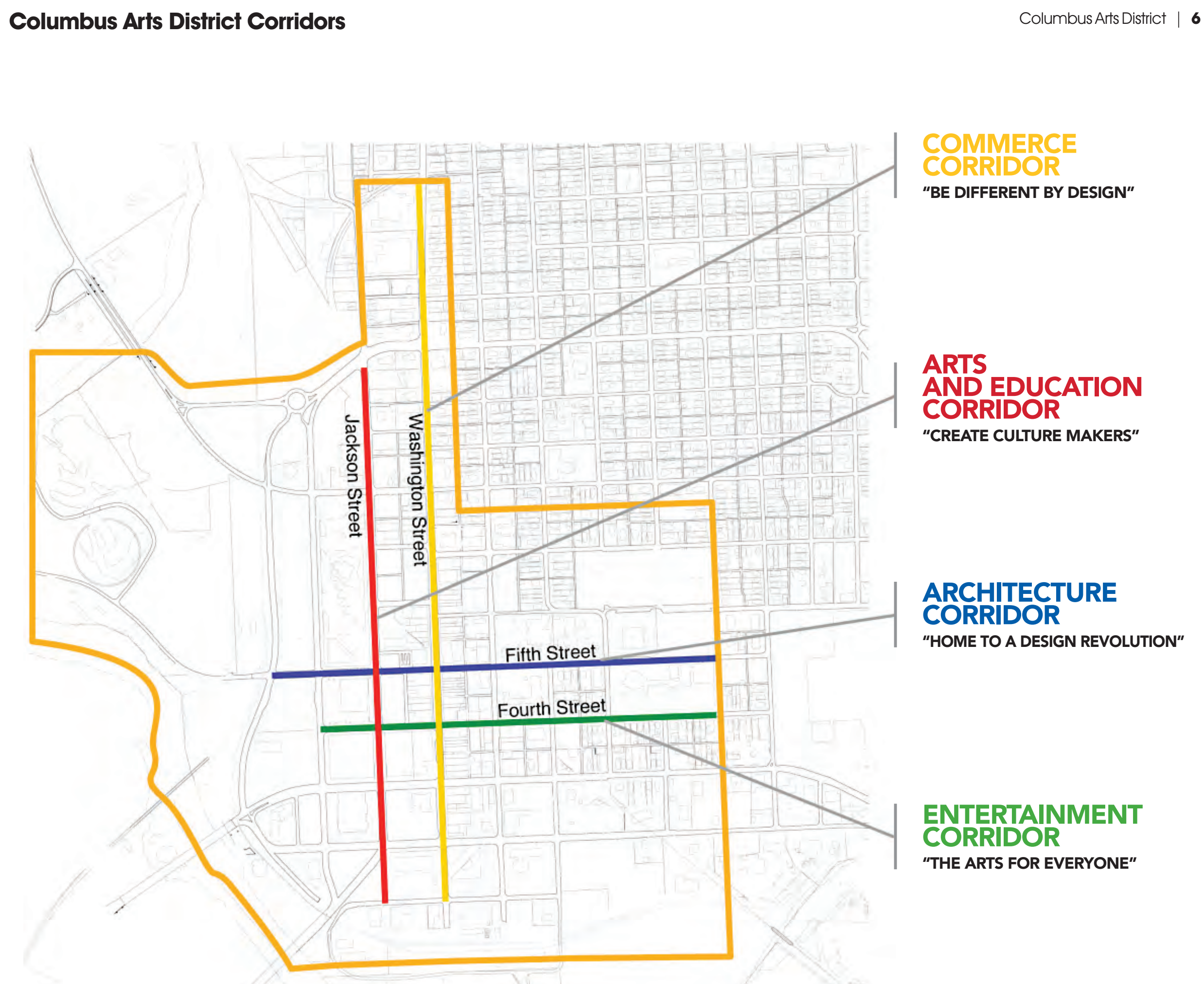

Fig. 5. Map of the Columbus Arts District (Courtesy of the City of Columbus)

celebrating our vast cultural environment as a gallery that exists beyond museum walls through cultural tourism and arts education." Finally, we published the inventory of public art in Wikipedia with precise latitude and longitude coordinates. We also created brief condition assessments of artworks owned by the city or county.

The purpose of publishing this information online in so many places (and making the database and images in Google Docs accessible online) is primarily to make this information easily findable from a Google search. This is an attempt to accomplish the first step in preservation: to recognize that something exists and to have the basic facts about its existence. I believe the first step in caring for cultural resources, and in particular public art, is knowing that it exists and then recognizing the context in which it should be understood. I believe that in the 21st century "knowing" starts with Google, so my goal for this project was to place highly accurate information in as many places as possible. I wanted to make information about the public art in Bartholomew County very easy to find.

Surveying the public art in town came naturally as I have a history of caring for outdoor artworks. Surveying the buildings and the landscapes required me to learn a different system and set of resources. Given the time constraints of the project, I created a simple and efficient method to complete this work. In addition to the data provided by the Visitors Center and the Arts Council, we relied heavily on two

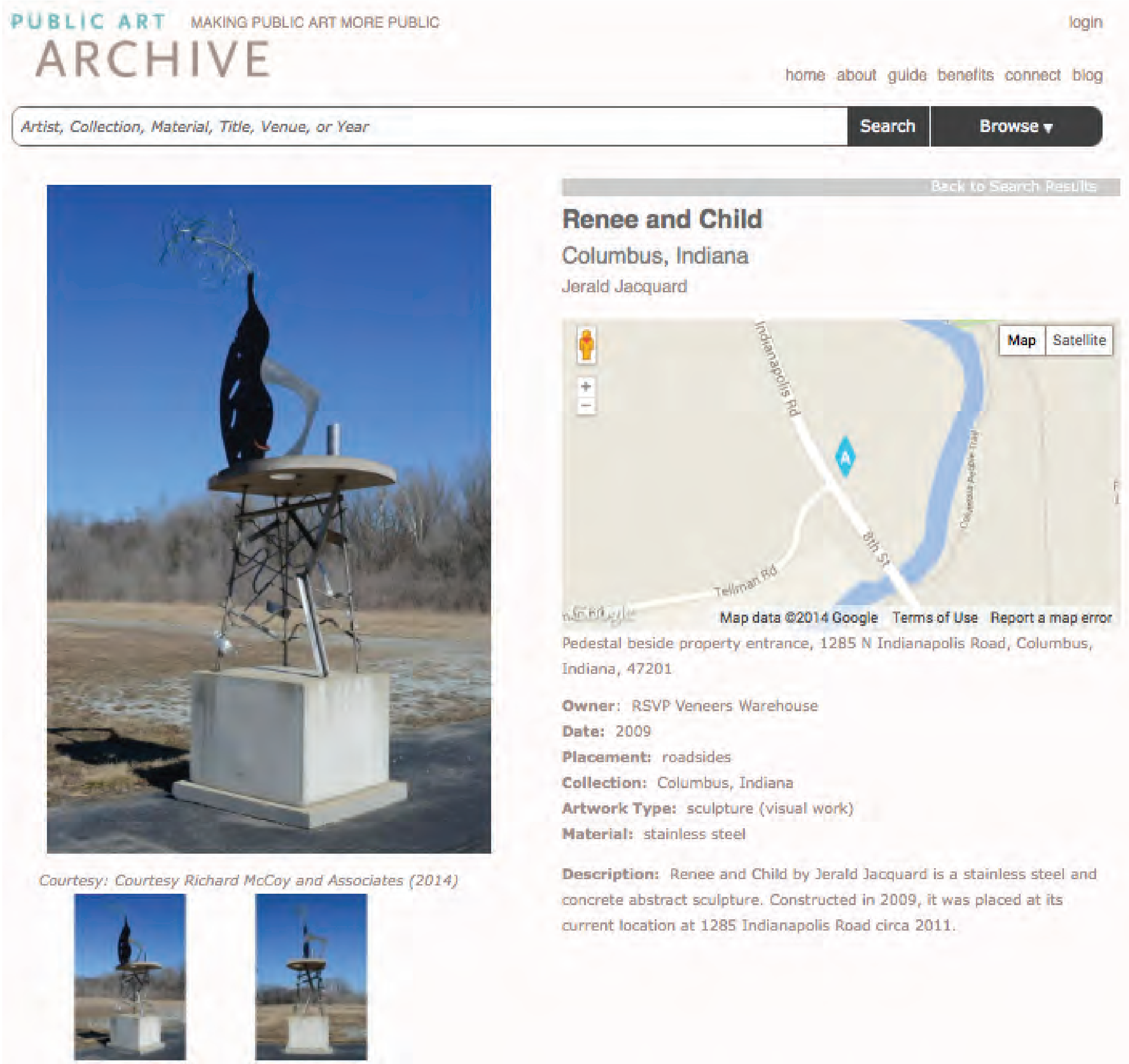

Fig. 6. Screenshot of Public Art Archive database with record of Jerald Jacquard, *Renee and Child.* (Courtesy of Public Art Archive)

countywide inventories of cultural resources that were completed by Indiana's Department of Historic Preservation and Archaeology (one in 1980 and the other in 2012) and on information from the office of the Bartholomew County Assessor. We created a database of nearly 450 properties. This included all of the Modern properties, even if they are not located in the CAD. We completed a basic inventory of all these properties using Google Docs to store our database and images, and we provided a basic rating for the condition or degree of ongoing maintenance visible from the sidewalk. This assessment is at best superficial. The process was simple and limited; it was not meant to produce a true architectural survey that would meet the demands of an architect or historic preservation professional. It was meant instead to activate the project, to begin a visible process that the community could see happening, and to produce a basic understanding of the resources within the CAD.

Using our new data set, we then selected all of the Modern buildings and 70 properties that were deemed "Outstanding" resources in the 2012 DHPA inventory. We also scoured the Internet for existing and historic images of the resources and cataloged these within Google Docs, giving each file a corresponding number that relates to a cultural resource. These data and corresponding images were published in the CultureNow web project and mobile app. With this targeted sample we began to create a working database that includes each significant cultural resource, and therefore a place to which we can add future research and information.

Whenever we completed significant research on a building or project in the CAD, we created an encyclopedic article about the project and published it in Wikipedia, the free online encyclopedia. Wikipedia is the fifth most used website in the world, and articles in it are usually among the very top search results for any given topic. Further, the information that is contained within Wikipedia uses a Creative Commons license that allows anyone to share and reproduce the information in whatever format, so long as it is properly attributed. In this way our work is a donation of knowledge to the nonprofit Wikimedia Foundation and an effort to make good information as widely accessible as possible. While this kind of information sharing can be scary for some preservation professionals, it opens the door for information to become highly interoperable and therefore more visible to any community in the world.

For example, we created an article about the Cleo Rogers Memorial Library (see fig. 7), which was designed by I.M. Pei and dedicated in 1971, and one about the Henry Moore sculpture, *Large Arch*, which stands in the Library Plaza.

All told, we created or significantly updated more than 15 articles about cultural resources in Wikipedia. Not only did this make our work and project more visible, but it also shows a way forward in terms of publishing research about cultural heritage in a free and widely available format.

We also created two videos that are published on ConservationReel.org, a project funded by the Samuel H. Kress Foundation which aims to "present video on art conservation and collections care in an online resource intended for museum and conservation professionals, students, and interested members of the general public." One video is an interview with the Roland Wetzel, director of Museum Tinguely in Basel, about the preservation of Jean Tinguely's masterpiece, *Chaos I* (in The Commons, http://conservationreel.org/video/talking-chaos-roland-wetzel). The other video is titled "The

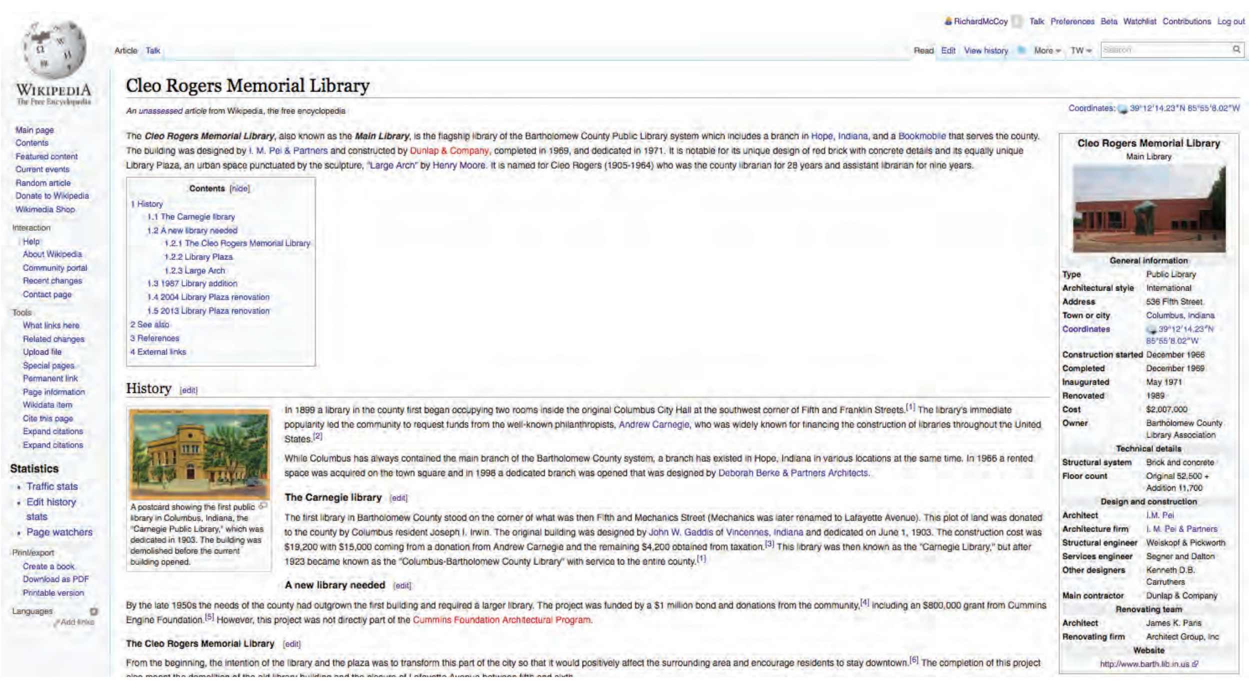

Fig. 7. Screenshot of Wikipedia article about I.M. Pei library in Columbus (Courtesy of Wikipedia)

Making of the Bartholomew County Veterans Memorial: A Conversation with Maryann Thompson" (http://conservationreel.org/partner/richard-mccoy-associates-inc). Thompson built the memorial with her then partner, Charlie Rose.

In addition to publishing this information online, the data and many other associated reports and projects were shared directly with the City of Columbus, the Columbus Redevelopment Commission, and others. Additional public outreach included a variety of online and print articles about this project, and I also spoke about it to many community organizations.

In experimenting with ways to present information about cultural resources online, I am attempting to show how we can use contemporary resources and contemporary methods to care for the cultural resources of Columbus. In this way, even my initial presentation at AIC and this article are an act in addressing the challenges of the city. It is an effort to both broaden the network of those who can help care for the design heritage of the community and to seek good solutions. I am searching for ways to find solutions to problems that fit the context of the 21st century, while deeply respecting the past. After all, if we are to be successful in caring for the cultural resources in Columbus (and everywhere) far into the future, we should be looking for ways to make this work relevant in our time.

5. THE FUTURE

Columbus is a visionary community, one that has continually looked to the future and found unique ways to solve its challenges. The challenge of caring for the design heritage of Columbus must be seen in this visionary context A community-based solution mustbe sought, one that maintains a public – private balance of power. In Columbus the architecture, landscape architecture, and public art projects were often, even usually, created through public–private partnerships, in many cases using individually dedicated committees, boards, or groups for each project.

Clearly, there is much research and work that could be done in Columbus to study the history of the town's formation and the resulting design heritage. However, the city is no longer interested in leading this effort. My contract was not extended for another year, and no effort has been made to continue this project in City Hall.

Through my work I have tried to establish some of the historical context that made this town great. I have also defined the challenges that Columbus must face in the near future if it wants to continue to both preserve and build on its legacy of creative projects designed with excellent architects. It is clear that the financial landscape has changed significantly. So, then, what is the next step in continuing this legacy? What is the best way to promote new projects while at the same time manage the programmatic and physical changes in existing buildings?

To look at this question from a community perspective, I created an event dedicated to thinking about the future of Columbus design heritage, the "Columbus Conversation." This event featured a free lecture by noted Modern expert, Theodore Prudon. It also included a half-day public panel session that featured talks from the president of Indiana Landmarks, Marsh Davis; a noted Columbus-based architect, Louis Joyner; and me. This event was generously supported by the Efroymson Family Fund, an organization that is dedicated to community improvement in Indiana. Prudon's lecture was video recorded and is available online at ConservationReel.org ("Modern Architecture as Heritage" by Dr. Theodore Prudon, http://conservationreel.org/video/modern-architecture-heritage-dr-theodore-prudon).

The final session of the "Columbus Conversation" event was a community discussion moderated by the former assistant editor of the local newspaper, Harry McCawley, who led a conversation with many stakeholders and community leaders (fig. 8). The outcome of this discussion was a community consensus that Columbus needs to create a nonprofit organization dedicated to caring for cultural resources, a group that has a constituency dedicated to the same cause.

Fig. 8. Harry McCawley stands and listens to architect William Scarborough talk about the future of Columbus. (Courtesy of Hadley Fruits)

Today, I am working on just such an initiative.

In November of 2014 I signed a contract with Heritage Fund, the Community Foundation of Bartholomew County, to continue exploring the Columbus challenge. With financial support from prominent corporations, foundations, and individuals within the community, we have at least 2 years of funding in place to continue this work. The goal is to generate a grassroots effort that will explore and identify the best way to create a nonprofit organization dedicated to caring for the county's design heritage. Ultimately, this might include the consolidation of cultural organizations that are dedicated to overlapping causes.

The current Heritage Fund project is called "Columbus Design Landmarks." This organization has three main goals, which are as follows:

1. Develop and manage a voluntary design review process for landmark projects;
2. Seek funds through grants that support caring for landmark projects;
3. Create advocacy and educational projects for and about landmark projects.

Already we have made significant progress. It is clear, however, that the first goal will be the most challenging. Our strategy is to further the legitimacy of the project through community leadership. This leadership will create trust within the community, and that trust will result in a shared, revitalized commitment to Columbus' design heritage. My work to advocate and educate about Columbus Landmarks continues with the same methods and purpose.

Perhaps most importantly, I am working to create *fun* projects that focus on community's design heritage. For example, we are hosting special educational days where community members can learn about the operation of *Chaos 1*. During National Preservation Month, we have "Ye Olde Tyme Architectural Bike Ride," a tour of significant 19th and early 20th century buildings and the City Cemetery. This approach recognizes the need to engage the next generation of Columbus in this preservation challenge, while continuing to find ways to keep the design heritage of Columbus relevant.

This is a living city, after all, and not a place destined to become a living history museum, or a site surrounded by mothballs.

There is plenty more to come with this project!

RICHARD MCCOY is an arts and design consultant in the state of Indiana who helps cultural institutions, government agencies, architectural firms, and individuals create novel approaches to manage contemporary challenges in cultural heritage. He is owner of Richard McCoy and Associates Inc., which operates as a team of specialist consultants dedicated to solving cultural heritage challenges. Based in Indianapolis, McCoy has an established history of writing for digital and print publications, teaching in graduate programs, and creating innovative web projects. He is adjunct faculty in Johns Hopkins University's Online Museum Studies Program and frequently serves on boards and committees. Address: 3271 Washington Blvd., Indianapolis, IN 46205. E-mail: richardsmccoy@gmail.com

PRESERVATION PLANNING AND MID-CENTURY MODERN MATERIALS: TOOLS TO PROMOTE STRATEGIC AND SUSTAINABLE BUILDING CONSERVATION

LACEY BUBNASH AND KATIE HORAK

ABSTRACT

The conservation of Mid-Century Modern building materials and architectural features can be challenging and unpredictable because of the experimental and nontraditional nature of many materials. Preservation planning tools such as Historic Structure Reports and Cultural Landscape Reports can provide a framework for identifying and prioritizing architectural repairs and conservation treatments. Using preservation planning to approach material conservation can prevent the loss of historic fabric and promote sustainable and fiscally responsible treatment options.

The Village Green, also known as Baldwin Hills Village, provides an exemplary case study for how preservation planning tools can effectively manage architectural conservation on a large scale over a long period of time. Built between 1941 and 1942, The Village Green is nationally recognized as a pivotal and progressive experiment in multiple-family housing. The product of architects and planners Reginald John, Lewis Wilson, Edwin Merrill, Robert Alexander, and Clarence Stein, the site has been designated as a National Historic Landmark with 162 contributing structures. Architectural Resources Group completed a Historic Structure Report and Mills Act application for The Village Green in 2010, which was awarded a Mills Act Property Tax Abatement Program contract from the City of Los Angeles. The completion of a Cultural Landscape Report for the property was completed in 2013.

Mid-century Modernism was a design movement, roughly spanning 1930 through 1970, that reflected the development of 20th century industrial societies and the rapid growth of cities. The Modern era was a time of rapid technological and scientific advances, resulting in the wide introduction of many new and inexpensive, but often experimental materials. Design features were frequently changed or adapted with the intent to improve living or working conditions. The Village Green is a product of 20th-century mass production techniques, new building materials, and progressive theories of housing design and urban planning. Special consideration may be needed to provide conservation treatments that are in keeping with those materials and philosophies, and proactive preservation planning tools can efficiently address potential issues.

This article discusses the completion of this series of planning documents and how conservation decisions were approached within the process. It focuses on planning tools and documents, decision-making criteria for maintenance, conservation and repair, and specific Modern materials that pose special challenges.

1. INTRODUCTION

Planning is a critical step in any successful conservation process, but is a particularly critical step when dealing with architectural materials on a large scale and architectural materials of varying quality. Planning and management strategies function best when they are long term and comprehensive. Routine maintenance tasks are absolutely necessary to prevent deterioration and damage to a historic resource. But those maintenance tasks, even if limited to a minimal schedule, can cumulatively alter the visual appearance and historic character of a building or site. Timely and well-executed maintenance activities will sustain the historic character and integrity of a site over time, but are most effective when planned well in advance.

This article provides an overview of several preservation planning tools and incentives used commonly in the architectural world, primarily through the lens of a Mid-Century Modern case study in Los Angeles. The conservation of Modern building materials and architectural features can be challenging and unpredictable because of the experimental and nontraditional nature of many materials used, making preservation planning even more critical for the continuation of historic character.

2. THE VILLAGE GREEN

The Village Green is a 68-acre garden apartment complex in the Baldwin Hills neighborhood of Los Angeles. Originally called Baldwin Hills Village, the site is recognized as a pivotal and progressive experiment in multiple-family housing. It has 95 residential buildings containing 629 apartment units, an administration building, and numerous garage structures. The property is notable for its site plan, which boasts acres of common green space to be enjoyed by all residents. As seen in figure 1, each building faces a small "finger court" and has lateral access to the main green, which is an expansive central lawn that is the nucleus of the complex.

Parking and vehicular access are restricted to the perimeter of the site plan, completely separating pedestrian activity from vehicular traffic.

The product of notable architects, planners, and landscape architects Reginald D. Johnson, Lewis E. Wilson, Edwin E. Merrill, Robert E. Alexander, Clarence S. Stein, and Fred Barlow, Jr., the Village Green has been recognized for its exceptional significance with designation as a National Historic Landmark (in 2001) and as a Los Angeles Historic-Cultural Monument (1977), as well as listing on the National Register of Historic Places (1993). It is widely considered to be the culmination of the work and ideas of Clarence Stein, the leading proponent of the Garden City Movement in the United States.

The site plan for The Village Green drew from Clarence Stein's 1929 Radburn Plan, which featured the following Garden City Planning Principles:

- Use of superblock site planning
- Specialized roads planned and built for one use instead of shared uses
- Complete separation of vehicular from pedestrian traffic
- Houses turned around to face pedestrian zone
- Park as a backbone of the site plan

The site plan epitomizes the Garden City Planning Principles listed earlier. Buildings are oriented to and around green spaces and pedestrian paths, while garages and vehicular access are limited to the edges of the site. The massive superblock site has no internal vehicular traffic. Construction on Baldwin Hills Village was begun in February 1941 and continued through December 1942. The cost of the

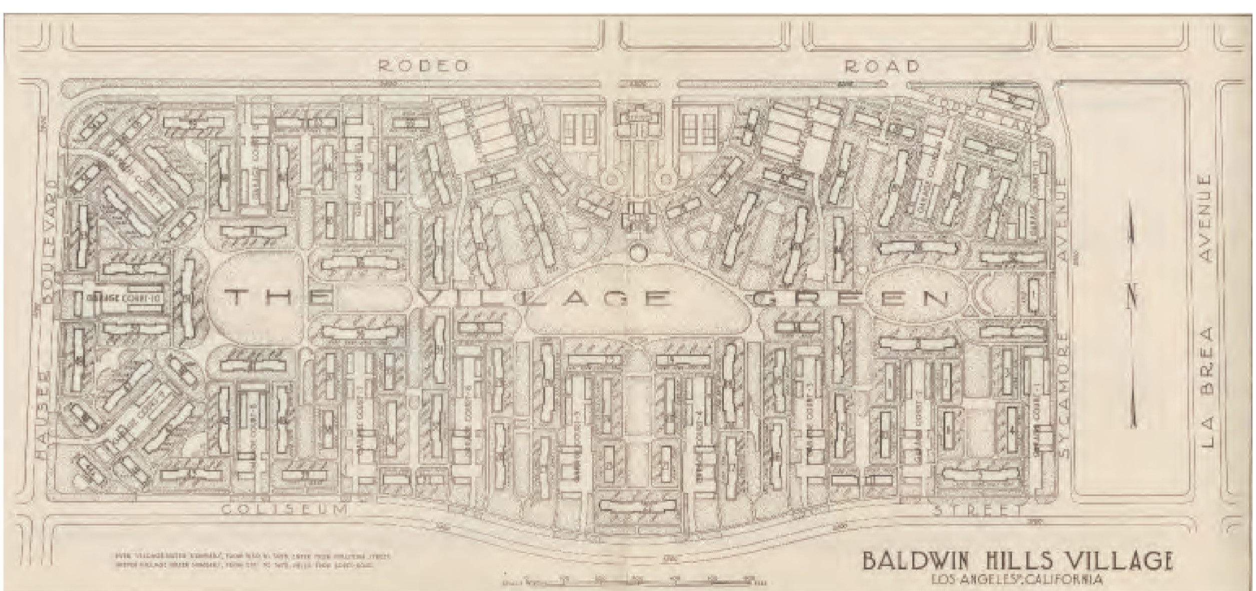

Fig.1. The site plan of Baldwin Hills Village as it existed upon completion (Courtesy of Cornell University Archives)

Fig. 2. 2008 view of typical Village Green building façade (Courtesy of Lacey Bubnash)

project was approximately $3.3 million. Franklin Delano Roosevelt's new Federal Housing Administration provided critical financing by insuring $2.6 million worth of mortgages. The local contracting firm of Marks–Charde began the work, but was replaced by the Herb Baruch Construction Company after the beginning of World War II.

The style of the buildings, now characterized as Vernacular Mid-Century Modern, was originally described as "contemporary California architecture" in the *Los Angeles Times*. The simplicity of the style was typical of the era, but it also illustrates the designers' goal of creating cost-efficient housing that focused more on spatial layout than on high-style architectural design.

The long, sleek lines of the building facades are reinforced by long spans of stucco finish and wide eaves, as seen in figure 2.

Balconies and ground floor patios break up the flat look of the facades, and the placement of steel casement windows and wood doors provides a visual rhythm. Private patio spaces are enclosed by wood fence walls, hedges, or brick walls. Secondary spaces, including garage courts and laundry drying yards remain intact and fully separated from residential zones.

Notable events in the history of the Village Green include a flood in 1963, after the Baldwin Hills dam located in the hills above the site broke. Parts of the complex were flooded, causing damage to multiple buildings and a large section of the landscape. All damage was repaired, but some small changes did occur, particularly to some landscape features. Between 1972 and 1977 the complex was converted from rental housing to condominiums. During the conversion period, many buildings were renovated and some small changes made, particularly to windows and doors, but the overall character of the complex remained the same.

3. HISTORIC STRUCTURE REPORTS

A Historic Structure Report (HSR) was prepared for the Village Green Owners' Association (VGOA) in 2009–2010. A full copy of the report can be downloaded from <villagegreenla.net/Village_Green_HSR.pdf>. The HSR follows standards for HSRs identified by the National Park Service, and includes the following components: a narrative developmental history of the property; a summary of significance; a physical description of the site and buildings; an assessment of existing conditions; materials conservation recommendations; the recommended approach to treatment per the *Secretary of the Interior's Standards*; and recommendations for continued use, configuration, treatment, and further study.

The impetus for the HSR was twofold: The Village Green Owners' Association was looking for guidance regarding the appropriate care, preservation and maintenance of the property; and the document would be submitted to the Los Angeles Department of City Planning's Office of Historic Resources as required, supporting documentation for the application for a Mills Act Property Tax Abatement contract. The HSR was written to provide an essential planning tool for the historic site, not simply a research report to be shelved. The primary goal of the document was to be practical; it must provide clear recommendations and it must create guidelines or framework for consistent decision-making for future work. The document forms the foundation from which preservation and related decisions will be made.

Although The Village Green benefits from many layers of historic designation and the protection that each affords, a comprehensive preservation plan or comparable planning document had never been completed until 2010. As a generally well-maintained residential property, the homeowner's association that manages the site had not previously seen long-term preservation planning as a priority. But as Los Angeles civic policy has become more encouraging of historic preservation over the past decade, the significant opportunities presented by completing relevant planning documents became more apparent to VGOA leadership.

Challenges faced in preparing the HSR were primarily related to the large size of the site and numerous contributing structures located within it. The site benefits from a vast amount of photographic and written documentation, which greatly aided in completing the HSR efficiently. Of particular importance to the project was photography from the Robert Alexander archive at Cornell University, and the Julius Shulman archive at the Getty Research Institute, which thoroughly depicts the property as it has appeared throughout its history. In addition, a number of previous studies completed about The Village Green were consulted, including the National Register of Historic Places nomination and the National Historic Landmark nomination.

Even with the strong background information available, extensive fieldwork was still necessary. As a large site containing nearly a hundred residential buildings and dozens of additional support structures, the systematic documentation of existing conditions was a challenge to the project team. Using existing site plans, the team divided the property into groups on the basis of building floor plans, of which there are eight variations that are repeated throughout the site. In figure 3, each of the floor plan types can be seen indicated in a different color.

This consolidated the work substantially; for instance, each building plan type was described only once, reducing the number of architectural descriptions from nearly 100 to fewer than 10. Each building was then thoroughly investigated for conditions and materials failures; the documentation of these conditions was categorized by building type, which helped to present findings in an organized and systematic manner.

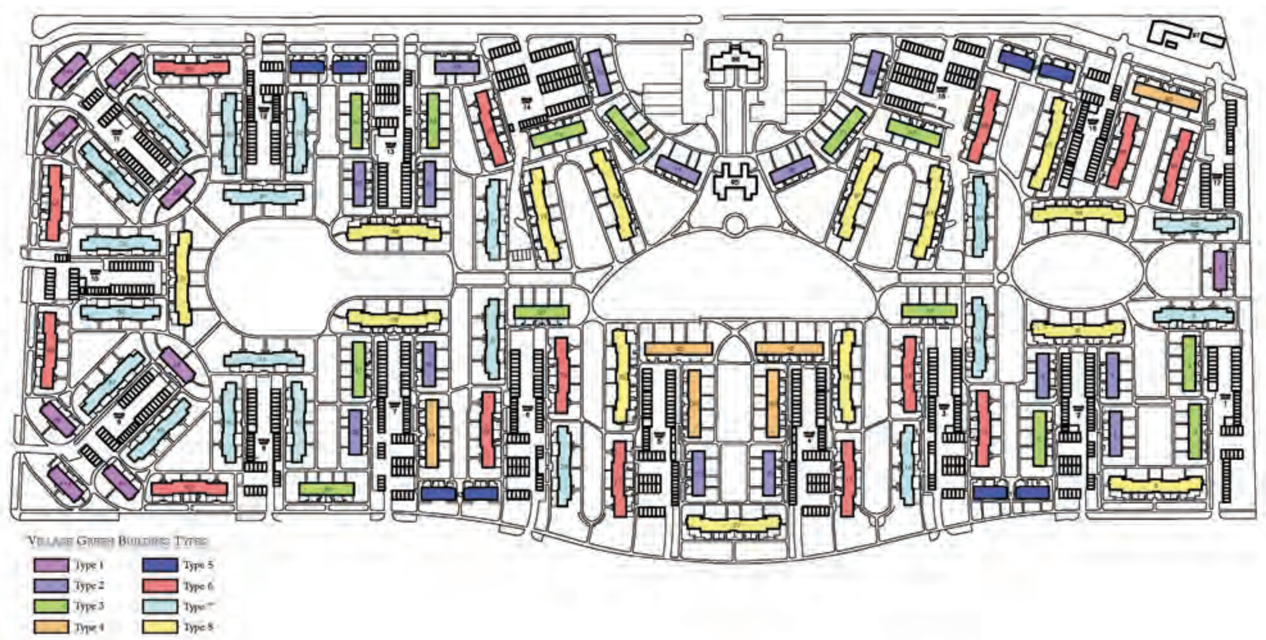

Fig. 3. Village Green site plan with each building plan type identified in a different color. (Courtesy of Architectural Resources Group)

Fieldwork was primarily carried out over a two-month period, with additional follow-up visits periodically scheduled during the several-month-long report-writing period. Survey tasks were structured as having either a general focus, or by building type (as described in the previous paragraph). For example, after focusing on documenting and describing the overall character of the site, team members in the field worked to fully document the exterior of one of each residential building type. Secondary and ancillary buildings were also surveyed.

To limit intrusion to residents and accelerate the fieldwork process, only selective interiors were visited by the project team. The goal of the interior fieldwork was primarily to document floor plan layouts and historic finishes where they remain. As private spaces, residential interiors will not be as closely guided by the recommendations in the HSR, and unit owners will retain the ability to renovate their homes.

An important component of any HSR is the identification of character-defining features. A character-defining feature is an aspect of a building's design, construction, or detail that is representative of the building's function, type, or architectural style. For an important historic resource to retain its significance, its character-defining features must be retained to the greatest extent possible. An understanding of a building's character-defining features is a crucial step in developing a rehabilitation plan that incorporates an appropriate level of treatment.

At The Village Green, character-defining features were identified both at site and individual building levels; for example, the spatial arrangement of buildings clustered around a central green space is character-defining, as are stucco wall finishes and steel windows. Additionally, great care was taken to identify materials and character-defining features that are unique to the Mid-Century period and that may require special attention. These materials were differentiated from materials that are currently mass-produced and easily replicated. For example, the plywood that was used throughout the site was identified as appropriate for replacement in kind, while other less readily available materials like the historic steel windows, light fixtures, and Louvrex glass were identified as candidates for retention and repair with conservation treatments.

The HSR provides a clear roadmap for property owners regarding areas of deterioration, alterations to the original design of the buildings (such as replacement doors and windows), and prioritized list of work recommendations. The recommendations were divided into three categories: safety and security measures; building maintenance; and rehabilitation. These items were then listed in terms of high, medium, and low priority, which helped inform the 10-year work plan required for the Mills Act application. All recommended treatment and work items meet the *Secretary of the Interior's Standards for Rehabilitation*.

The HSR enabled The Village Green to be awarded a Mills Act contract, which not only presents a financial benefit to property owners but also enables the completion of rehabilitation work heretofore beyond the monetary means of The Village Green Owners' Association. The completion of work described in the HSR and in the Mills Act 10-year work plan will, over time, improve the conditions of the site and buildings and restore many original features that have been lost. This is a public benefit on both a local and national scale; The Village Green is nationally acclaimed and its future protection and rehabilitation ensures its survival for future generations of residents and admirers.

Additionally, the Village Green is one of numerous garden apartment communities in Los Angeles. Because of their low-density nature, many are threatened with redevelopment. The investment that the Village Green property owners have made with the completion of an HSR, the award of a Mills Act and the ongoing rehabilitation of the property make it a model to all garden apartment communities. It conveys the fact that rehabilitation of these types of properties is not only possible but also can been extremely successful and offer financial benefit to property owners. The HSR itself is available to the public online and can thus provide a model for the systematic documentation of properties of similar size and scale and their rehabilitation in accordance with the *Secretary of the Interior's Standards.*

4. CULTURAL LANDSCAPE REPORTS

The HSR focuses on the built environment of the Village Green; a recommendation of the HSR was the completion of a Cultural Landscape Report (CLR), which was prepared in 2012 and focuses on the care, treatment, and preservation of the historic landscape. The full document was not available online at the time of writing but may be available in the future. Planning for landscape issues is equally important to architectural issues, particularly if sustainability is an issue under consideration. Before completion of the CLR, there were no clear standards for treatment of landscape features at the Village Green, particularly with regard to maintaining the historic character of the site.

A CLR provides guidance for issues inherent to any designed landscape, including treatment of trees, grass, and sidewalks. Although landscape features require maintenance and rehabilitation just like buildings and structures, they are more often overlooked or misunderstood. The Village Green landscape retains its essential character, but over time changes, often poorly documented, had occurred throughout the site. Some large-scale landscape modifications were made after the 1963 flood, and many plantings were added when the site was converted to condominiums in the 1970s. A CLR was needed to clarify what landscape features are historic and identify plant maintenance and replacement priorities for the future; for example, by identifying nonhistoric plants that require frequent watering, those plantings can be targeted for replacement with historically appropriate, drought-tolerant plantings to reduce water usage throughout the site. Specifically the original landscape, as completed in 1941, had many more areas of ground cover. Today, most of those areas have been converted to grass, which requires more water than most ground-cover plantings. Restoring ground cover in a smart way will reduce water usage and restore the site to its original appearance.

Additionally, the Village Green site has matured to the point that many original trees are suffering from old age. A guiding document was needed to identify treatments for trees with mature canopies that may no longer reflect the original design intent; for example, sun and shade conditions created by the landscape must also be managed as part of a tree maintenance program. Although building maintenance at the Village Green has generally always occurred under the control of facilities managers, some landscape features, such as individual trees and flower beds, have received care or attention from residents as well. The CLR presents design and maintenance priorities in a systemic and consistent manner and provides guidance on issues (like individual flower beds) where resident opinions likely vary.

5. MILLS ACT

The Mills Act Historical Property Contract Program allows qualifying owners to receive a potential property tax reduction and use the savings to help rehabilitate, restore, and maintain their buildings. The Mills Act is the single most important economic incentive program in California for the restoration and preservation of historic buildings by private property owners. Enacted in 1972, the Mills Act legislation grants participating local governments (cities and counties) authority to enter into contracts with owners of qualified historic properties who actively participate in the restoration and maintenance of their properties to receive property tax relief. The City of Los Angeles adopted local Mills Act legislation in 1996. Since then, over 600 properties have benefited from the program.

A formal agreement, generally known as a Mills Act or Historical Property Contract, is executed between the City of Los Angeles and the property owner for a revolving 10-year term. Contracts are automatically renewed each year so that the term of the contract always extends for 10 years. Property owners agree to restore, maintain, and protect the property in accordance with specific historic preservation standards and conditions identified in the contract. Periodic inspections by city and county officials ensure proper maintenance of the property. The City may impose penalties for breach of contract or failure to protect the historic property. The contract is transferred to new owners if the property is sold, and is binding to all successive owners.

A Mills Act contract for the Village Green was executed in 2010. With 629 individual condominium units, it is the largest Mills Act contract in the county of Los Angeles. Major work items that will need to be completed in the coming years include a complete reroofing of all buildings (totaling an estimated $2.6 million); corrective measures for buildings with settlement issues due to soil subsidence ($50,000 for consultation with a structural engineer and unknown cost for recommended work); stucco repair and painting of all building exteriors (estimated $3.2 million); and repair of the brick walls at rear patios (estimated $1.2 million). Because extensive planning documents have been completed for the site, these projects are all clear in scope, size, goals, and expectations. All future projects will benefit from previous recommendation and design guidelines created in the HSR and CLR documents. These documents encourage appropriate methods which retain the site's integrity and historic significance.

Mills Act funds can also support restoration projects; for example, a proposed project includes a historic paint analysis at the Village Green to identify original paint colors. Historic film footage indicates that the original finish colors may have been much brighter than the current paint scheme. This project will likely be completed after more immediate, remedial repairs are finished. Another restoration project includes a mural in the administration building that has been damaged and covered. Mills Act funds can be used to conserve the mural at a future date. Other scheduled Mills Act projects include tree pruning, landscape maintenance, sewer repairs, plumbing replacement, replacement of nonhistoric windows and doors, and general maintenance of the buildings, landscape, and site.

The benefits of the Mills Act go beyond simple cost savings. Although the Mills Act does not specifically reward sustainability, using Mills Act funds for projects that will reduce energy or water use provides a double benefit to Village Green ownership. Too often construction projects occur without owners fully realizing the long-term implications of improvements, new systems, or other architectural or landscape alterations. The 10-year planning cycle required by the Mills Act, coupled with the long-term recommendations laid out in the HSR and CLR, guarantee that all future projects at the Village Green will be well-conceived and unlikely to have unintended consequences.

6. CONCLUSIONS

There must be a balance between change and continuity for a historic site to remain useful and relevant. Change is unavoidable in any material, building, or site exposed to human contact and typical weathering. The key to successful, long-term preservation of any historic site is to highlight the continuity of character-defining features while acknowledging some level of change. Finding this balance between preservation and continued use is greatly aided by planning documents like HSRs and CLRs, which identify both opportunities for change and priorities for preservation.

ACKNOWLEDGMENTS

We would like to recognize The Village Green Owner's Association for their stewardship of the property and leadership of the HSR, CLR and Mills Act projects.

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LACEY BUBNASH is an architectural conservator at Architectural Resources Group (ARG), an architecture, planning, and conservation firm in San Francisco, California. She has a comprehensive background in architecture, historic preservation, and architecture conservation, and specializes in existing conditions assessments and construction documents and construction administration for architecture conservation. She also serves on the board of the Northern California Chapter of DOCOMOMO US. Lacey holds an undergraduate degree in architecture and has a master of science in historic preservation from Columbia University. Address: Architectural Resources Group, Pier 9, The Embarcadero, Suite 107, San Francisco, CA 94111. E-mail: l.bubnash@argsf.com

KATIE HORAK is an architectural historian and historic preservation planner based in Los Angeles, California. In addition to being a senior associate at Architectural Resources Group in Pasadena, Katie is an adjunct lecturer in the University of Southern California's School of Architecture where she teaches a course in historic site documentation. She also serves as the president of the Southern California Chapter of DOCOMOMO US. Katie holds an undergraduate degree in fine arts and has a master of heritage conservation from USC. Address: Architectural Resources Group, 8 Mills Place, 3rd Floor, Pasadena, CA 91105. E-mail: k.horak@arg-la.com

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