Conservation

Analytical

Laboratory

Annual Report

1994

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Foreword

Lambertus van Zelst, Director

The beginning of fiscal year 1994 marked the tenth anniversary of the Conservation Analytical Laboratory's move from its old Mall quarters in the basement of the National Museum of American History to the then just completed Museum Support Center. With that move began a decade of program development and reorientation. Comparing the accomplishments described in the annual report before you with those of that first year, documented in Smithsonian Year 1984, dramatically demonstrates both the changes in program emphasis and the enormous growth in depth and productivity of CAL's programs. Just a few numbers illustrate the point. The FY 1984 report devoted 30 percent of its space to conservation service activities and another 20 percent to conservation science, most of which we now call analytical services. Work in the archaeometry section occupied yet another 30 percent. Information and teaching (another 20 percent) reported, besides the activities of the technical information section, mostly on lectures by CAL staff at other institutions. One course (the first, in fact) was organized at CAL, as compared to 15 in FY 1994. CAL hosted three interns, as compared to 24 in FY 1994. Most of all, comparing the two reports underscores how many new programs, answering distinct needs of the National Collections and the field in general, have been created in the last decade. Notable examples are programs on the mechanical properties of collection materials, preservation of photographic materials, modern materials, science collection materials, and biogeochemistry. Finally, in terms of research output, contrast seven articles in peer-reviewed journals or books with 43 last year.

While all of us at CAL can be proud of this performance, we also realize that the climate that allowed for the necessary resource growth has changed. The next decade will be different indeed: while developing new programs and initiatives will be essential for CAL to maintain a leadership role and fulfill its mission, we must be able to do so primarily through prudent, efficient use of existing resources. This necessity will require strict adherence to clearly formulated priorities and an increased emphasis on productivity and accountability. Thus it was appropriate that we began this next decade by planning and implementing CAL's new organizational structure, which corresponds more closely with the main elements of its mission statement.

The organization of this annual report reflects this new structure, with three program areas reporting: Research and Development, Education and Training, and Support and Collaboration. It should be recognized, however, that most of the work reported here took place under the previous management. Deputy Director Alan W. Postlethwaite retired in March 1994. His tenure at CAL will be remembered through the long-lasting benefits of his many outstanding contributions, to which he added again greatly during this year. Jacqueline S. Olin, Assistant Director for Archaeometric Research, is gratefully acknowledged for her wise and productive management and her gracious assistance with the transition to the new structure. Marion F. Mecklenburg, Assistant Director for Conservation Research, and Charles S. Tumosa, Head of Analytical Services, assumed full-time research responsibilities in May. Their fine research and management efforts, both in this and in previous years, have made great contributions to CAL's programs.

Being the Smithsonian Institution's specialized research and training facility for the preservation and technical study of collections does not restrict CAL's mandate to the

National Collections. Indeed, we are well aware of the wide diversity of our national and international constituencies, including colleagues, students, professionals in related fields, and the general public. A special effort has been made in this report to document and illustrate this diversity.

This year's annual report also reflects a new use of graphic images and photographic illustrations, as well as a new layout, all made possible by the recently installed in-house desktop publishing facility. Special thanks go to Gail Goriesky, Conservation Information Specialist, who again took responsibility for the technical production.

I want to thank all CAL staff, not only for their superb efforts and another very successful year as documented in this report, but also for their contributions to the production of this publication. The three program coordinators, Ronald L. Bishop for Research and Development, Donald C. Williams for Education and Training, and Melanie E. Feather for Support and Collaboration, spent much time and energy introducing, editing, and integrating the information into comprehensive and consistent chapters. They deserve special thanks.

And so I am proud and pleased to offer this annual report of the Conservation Analytical Laboratory's activities for the fiscal year 1994. I hope and trust that our work will be of interest to our many and diverse constituencies, and I encourage you to provide us with any ideas, comments, or suggestions that its reading may engender.

Research and Development

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Research at the Conservation Analytical Laboratory is, by its very nature, interdisciplinary. It binds specialists from different fields, such as chemistry, engineering, conservation, and archaeology, into projects focused on specific problems and on the utilization of equipment. Research programs travel along two different paths: preservation research, and collections-based research, both organic and inorganic.

Preservation research strives to enlarge understanding of how materials and composite objects deteriorate. This research generates both data and models used to formulate conditions for storage, display, and other applications that will minimized deterioration. Research projects also develop and test treatment technologies for stabilizing deteriorating collection materials. All these studies require analyses and characterizations of object materials and deterioration products and examination of the way external and internal factors, such as environmental conditions or chemical composition and physical structure, affect the nature and rate of these alteration mechanisms.

Collections-based research develops, adapts, and applies methods of analysis for the characterization of natural and cultural materials to enlarge understanding of the biological, technical, economic, social, or political aspects of past lifeways. Depending upon the specific questions asked, the scale of the investigations varies widely. Collaborations with non-CAL scholars are a critical component for many projects, permitting not only the increased benefit of greater intellectual diversity but also wider access to collections and highly specialized instrumentation. This area is further subdivided into organic and inorganic collections research.

Although their objectives differ, CAL's research programs all involve the analysis and characterization of cultural and natural collections materials and the environments in which they are curated. Specific projects are initiated by CAL staff and Smithsonian bureaus and research units, sometimes in response to suggestions made from the national and international professional community. CAL staff prepare formal proposals that describe the specific problem to be investigated, the methodology that will be employed, and the expected significance of the research. These proposals may be subjected to both internal and external review and are evaluated relative to CAL's mission priorities. Timely, peer-review publication of the research is required.

Significant accomplishments of CAL research projects during fiscal year 1994 are described below.

Preservation Technology

Mechanics Research and the Effects of the Environments

Damage to cultural and artistic objects results from both chemical reactions and mechanical responses to changes in temperature, relative humidity, and impact and vibration. Collaborative research among CAL scientists has progressed beyond the point of determining the sources and mechanisms of most environmentally induced deterioration. The effects of potentially hazardous environmental and transit conditions for most objects can now be predicted. The fundamental research direction is built upon a general theoretical model that mathematically relates externally applied forces to environmentally induced stresses in materials. This theoretical model allows the use of standard engineering test procedures to characterize the physical and mechanical properties of the cultural materials typically found in the objects of the Smithsonian's collections. This materials information then allows the development of predictive analytical models.

There are several approaches to model development. Both closed-form analysis and the numerical method are used at CAL. The most powerful form of the latter is finite element analysis, which is extensively used in engineering for the structural analysis and design of an enormous variety of structures and structural components. Constructed numerical models of museum objects can assist in determining the anticipated stress development and failure modes that result from a wide variety of environmental and transport conditions.

Mechanical Testing and Materials Characterization

Mechanical testing and materials characterization, an approach to preservation research developed by CAL researchers, requires extensive physical and mechanical data. These data, however, have not been available for most cultural materials. Thus one objective of CAL's program in mechanics research is to provide that baseline information. This program involves, in part, subjecting actual specimens of cultural materials to the expected environmental and dynamic conditions museum objects might normally encounter. In this way the required materials properties are determined as a function of the different parameters. While the kinds of materials to be tested are large, this number is small compared to the number of objects constructed using these materials. In effect, then, the initial testing of a few important materials allows for the analysis of a considerable number and variety of objects.

At CAL, 36 mechanical testers in controlled environmental chambers are running nearly 24 hours a day. CAL staff are conducting short- and long-term tests on the impact of temperature and relative humidity, the rate of loading, and effects of solvents on a very wide variety of cultural materials. These data provide the necessary materials information for constructing both the closed-form and computer models. Periodic checks on the performance and accuracy of the models are conducted by constructing and testing actual objects under different conditions to see if the experimental results agree with the analytical models.

Museum Environment Project

Maintenance of proper environmental conditions has been identified as the most important factor in the preservation of collections. Many environmental factors, including, temperature, relative humidity (RH), light, pollution, and vibration, affect the permanence of objects and materials. For example, variation in RH causes changes in the moisture content of hygroscopic materials. Since all organic materials are hygroscopic to some extent, most traditional cultural materials are subject to swelling and shrinking with moisture changes. These dimensional changes can cause structural changes in objects.

Accumulated data from several individual research projects, including the National Air and Space Museum project described below, support a general model of environmental responses of materials that argues for the relaxation of climate controls in museums, usually maintained at a constant temperature of 20 degrees C and 50 percent RH. This year a CAL staff member presented a major paper reexamining the role of relative humidity in the museum. It integrated information in the literature with results from CAL research to better define the questions related to relative humidity in the museum and the types of approaches to its control. The results suggest a redefinition of appropriate environmental conditions in museums that will secure significant savings in design, construction, and operating costs.

This challenge to the conventional environmental standards is now under review by the museum community at large. While research is proceeding, findings so far are being distributed in response to national and international requests.

NASM Annex Project

Specific projects are currently directed toward determining the allowable temperature and relative humidity fluctuations that objects in Smithsonian collections may withstand without damage. One project involves the collections of the National Air and Space Museum (NASM). This work is fairly well advanced, and CAL researchers are now able to provide environmental recommendations for the new NASM Annex proposed for Dulles Airport. Presentations on mechanics research have been given to the senior staff of NASM, representatives from the Smithsonian's Office of Design and Construction, and members of HOK, the architects of record for the NASM Annex. Data were provided to assist in setting heating, ventilation, and air conditioning requirements for the new 600,000 square foot structure. CAL staff submitted a interim report to NASM in October 1994. During the course of this research, extensive evidence was accumulated to demonstrate that significant allowable fluctuations are possible in nearly all museums.

National Center for Preservation Technology

A grant from the Center for Preservation Technology is helping to develop a more precise thermodynamic model of the mechanical properties of materials and the effects of temperature. Even though research is at an early stage, the new temperature-dependent model has been verified experimentally.

These models are important for they provide an even stronger foundation for establishing allowable RH and temperature fluctuations for museum environment. This work will also provide better insight into damage mechanisms of objects

exhibited outdoors. In addition, this research effort has applications for examining the effectiveness of very low temperature pest control and management techniques as an alternative to chemical fumigation of objects in the collections. The materials testing component of this program, using new low-temperature test facilities, is also under way.

Art in Transit

Art in Transit, a joint program of the National Gallery of Art, the Canadian Conservation Institute, and CAL, investigated the physical impact of transportation on paintings. CAL researchers examined some of the mechanical properties of typical artists' materials under different environmental conditions in conjunction with computer-based analysis of objects subjected to impact and vibration. Several workshops and research publications have resulted from the project.

Chemical Degradation Processes

Paper Aging Study

CAL's ongoing study on paper aging is designed to determine the effects of temperature and relative humidity on the rate and mechanisms of the aging of paper. It evaluates the effect of storage conditions on the permanence of paper and determines the relevance of accelerated aging conditions to natural aging. In FY 1994, analysis of a number of aged paper samples was completed and reported in an interim publication.

Studies in FY 1994 focused on the degradation process of cellulose as a function of temperature and relative humidity. Determining the rates of individual reactions for a number of different conditions of temperature and relative humidity allowed the calculation of reaction rates as a function of relative humidity as well as of activation energies (temperature dependence) for individual reactions. The distribution of reaction products as a function of aging conditions also was determined.

More samples remain to be analyzed, and new sets of aging conditions will be examined as aging chambers become available. These studies will allow the results to be extrapolated to room temperature and below with greater certainty, as well as the effects of other changes in aging conditions to be determined.

Paint Cleaning Study

The cleaning of paintings has been investigated from a number of aspects, including the effects of solvents and aqueous cleaning agents. The purpose of the research is to improve approaches to the cleaning of paintings, making it as safe as possible, by defining the possible effects and determining the ways various cleaning agents and processes act on paint films. The results of the study of the effects resin soaps on paints have been published, and preparation is underway for the next phase of the study. This phase, which will continue examining the effects of solvents on paint films, is intended to answer some questions raised by the original study.

Photographic Materials

Long-Term Storage Conditions

Research continued during FY1994 on cold storage for photographic materials. The primary objective of this research is to develop a generic, low-cost packaging method that will allow the use of conventional freezers for safe cold storage practice. External grant funds helped to purchase two freezer designs: a radiant shell-type manual defrost unit and an autodefrost unit. ACR electronic humidity and temperature data loggers and the required computer hardware and software were also purchased. Most of the necessary packaging materials were donated by various suppliers.

The results of this research have exceeded original expectations. The data loggers recorded a fundamental relationship between temperature and relative humidity that has been overlooked by the photographic industry. This discovery led to a spin-off project to study moisture content isolines of photographic gelatin.

This new project yielded an even more startling result. It was discovered that the glass transition temperature of gelatin, which is moisture dependent, can be determined from the water vapor phase equilibrium established by the gelatin in a sealed container. The determination of a hygroscopic polymer's glass transition by this method is a novel scientific approach that applies not only to photographic science but to the field of polymer science as well.

These research findings have profound implications for accelerated aging tests routinely conducted by the photographic industry. In studying aging characteristics, the industry has employed both sealed-container testing and free-hanging environmental chamber testing, and scientists have unanimously assumed that the two methods establish the same environmental conditions with regard to temperature and relative humidity. Differences in test results were believed to be caused by degradation products trapped in the sealed incubation conditions acting to catalyze more degradation. The moisture content isoline data and the revelation of the glass transition points in the research prove that the two test methods establish systematically different environments and that the glass transition may be exceeded in one type of test but not in the other. These findings, in turn, explain a great many of the inconsistencies between the two types of tests. In personal communication between CAL's photographic scientist and researchers at a major photographic company, it was learned that in the past many test results with discrepancies were discarded because the results could not be explained. The research will also have a significant impact on a current ANSI project to develop a national standard for accelerated aging tests of photographic materials.

Low-Cost Storage Systems

The original FY 1994-95 research objective to establish a low-cost packaging method has been completed ahead of schedule. A literature search revealed en equation for modeling the shelf-life characteristics of a moisture-permeable package containing moisture-sensitive food products. The equation was developed by food-packaging scientists to predict the shelf-life characteristics of moisture-sensitive foods sealed in various packaging materials. This equation directly applies to the problem at hand, correctly predicting the time required for specific moisture content rise in

photographic materials when they are packaged in moisture-barrier polymers such as low-density polyethylene and stored in conventional freezers. A generic packaging method was subsequently developed during FY1994 that allows a wide variety of photographic materials (motion picture films, sheet and roll still films, fiber base and resin coated prints, etc.) to be safely stored at subzero temperatures. The method employs two recloseable polyethylene bags - a simple moisture trap comprised of a small volume of hygroscopic materials, such as paper, mat board, or silica gel, and a cobaltous chloride moisture content indicator to show that the package is functioning safely. The design is simple to use, uses only low-cost materials, has redundant safety features, and is verifiable so that package integrity can be monitored by visual inspection.

This year's research accomplishments are significant because subzero temperature storage environments can keep photographic films and prints in excellent condition for hundreds of years. Subzero temperature storage is the best overall solution to the frequent problems of chromogenic dye stability and acetate base deterioration. These two deterioration mechanisms will destroy the majority of photographic films made in the second half of the 20th century within the next 100 years if museums and archives do not take aggressive steps to implement cold storage. The moisture content isoline data and glass transition work confirm that photographic material properties are beneficially affected by low-temperature storage, and the simplicity of the new packaging method makes it an elegant solution to the problem of moisture control during cold storage. The method eliminates the need for humidity control within the storage space, gives excellent insurance against external pollution and water damage in the event of flood or fire, and reduces energy costs to the point where the additional labor and materials associated with the packaging method are more than offset. Those who choose to adopt this new preservation method will be able to save their collections with confidence for generations to come.

Modern Materials

Polymeric Materials

The polymeric materials project seeks to develop a fully operational resource center for modern polymeric materials that will serve the Smithsonian Institution and other museums by developing historical information on the technology of modern plastics and elastomers, information on chemical aging and degradation processes, and recommendations for the treatment of objects. The primary focus is on elastomers, as they are understudied.

During FY 1994 NASM's collection of airplane tires was a subject of research. This collection represents many years of manufacture, although many of the tires are of similar materials, such as natural rubber blends. The collection is not kept at constant temperature or in any protected atmosphere, and it shows evidence of oxidation. The tires are not on any kind of mounts and are also in danger of deformation from weight.

Storage tests used a natural rubber blend as a model material. This rubber is carbon filled and is similar in composition to many of the tires. Trials in which the material was kept below freezing and measured for crystallization indicated that this rubber blend - and, presumably, NASM's tires - will crystallize rapidly at low temperatures. Crystallization is accompanied by a significant increase in stiffness, which might protect the tires from deformation.

Room temperature mechanical trials of the model material provide a baseline for low-temperature trials in FY 1995 that will help quantify potential benefits of cold storage for this and similar collections.

Magnetic Media

The magnetic media project studies the chemical and mechanical deterioration of magnetic media (cassette, 8-track and reel-to-reel audio recordings, videotape, and computer tape) to define the kinetics of these deterioration reactions and the effect of relative humidity and temperature on their rates. These data will be used to generate assessment methods, treatments, and storage conditions for audiotapes and videotapes, which represent a rapidly growing section of the Smithsonian's holdings, including oral history collections, wildlife recordings, computer-generated scientific data from the Smithsonian Astrophysical Observatory, and collections data bases.

A literature review revealed that only a few experiments have been done on the tape binder in its final form; most work was done on a non-cross-linked model. Curators at the Smithsonian Institution Archives and the Library of Congress indicated a lack of knowledge of material composition of tapes in their collections, due partially to lack of documentation. Based upon the data gathered, it does not appear that the age of tape can be used as a good guideline for determining when it should be copied.

Most magnetic media are presently stored at room temperature. Various real-life samples have been assembled and characterized. Additional materials have been requested from manufacturers, and negotiations are continuing with one company for both research materials and an exchange of current research information. A testing method was developed for the Fourier transform infrared spectroscopic microscope. The results of preliminary tests of artificially aged materials compare well, qualitatively, with naturally aged materials. The current test procedure may be modified for a general survey of magnetic media collections.

Natural History Specimen Preservation

The alarming decrease in biological and anthropological diversity in the world has led to a concomitant increase in the collecting of specimens to document the cause of these changes. Preservation of these new collections as well as the existing reference collections housed in the Smithsonian Institution is critical not only for the scientists who study them and visitors who view and learn from them but also for their application to such diverse industries as agriculture, biotechnology, and medicine. CAL has initiated several new projects to determine why existing collections are deteriorating and how specimens can be better and more efficiently prepared and preserved for study. CAL scientists also are contributing to research use of these collections by utilizing specimens as controls for the study of shell and collagen deterioration.

On focus of study is the storage of collections in fluids, primarily those stored in alcohol solutions. There are about 1.5 billion fluid specimens worldwide, and these are growing at a rate of about 50 million per year. An investigation has begun to determine why and how these specimens are deteriorating by analyzing the fluids in which specimens are stored.

Mammals Stored in Fluid

Approximately 60 samples of mammal specimens from the Abbott Collection at the National Museum of Natural History, an early collection, were prepared separately for analysis by gas chromatography, gas chromatography - mass spectrometry, and the amino acid analyzer. Tests have revealed amino acids in solution, evidence that the mammal specimens are deteriorating. The amino acid profiles indicate a general protein loss as well as some structural protein loss. Lipids in these solutions are being hydrolyzed.

Other Taxa Stored in Fluid

Fluid samples also were collected from preserved millipedes, tarantulas, marine snails, squid, spiders, bird heads, octopi, fish, land snails, and freshwater snails. For these species, all samples of fluid contained proteins that have leached into the storage medium. The mix of amino acids found indicates they are most probably derived from the general deterioration, or break-down, of muscle and other organs in the specimens. While it is obvious that the specimens are slowly dissolving, no rate of loss can be assigned on the basis of these data.

Enzyme Cleaning of Skeletons

Faunas that the museum collector can sample for fresh skeletal specimens are declining because of local protective legislation and the deterioration of habitats. Some faunas no longer exist in natural habitats and are found only in already existing collections. Consequently, the maximum utilization of museum skeletal material is increasingly important.

Current techniques for the preparation of skeletons are costly and time consuming and can result in the destruction of delicate bone processes. CAL research in

enzyme cleaning describes a new skeleton preparation technique that not only improves the quality of the preparation but also saves effort, time, and money.

The enzyme trypsin was chosen for the preparation of delicate (small bird carcasses and Philippine swiftlets) and difficult to clean (fresh dolphin bones) skeletal material. Swiftlet and dolphin samples were macerated with varying trypsin concentrations and pH 7.6 buffers in differing amounts of solution and at different temperatures. Microscopic examination of approximately 200 dolphin and bird bones indicated that no softening or erosion of the surface occurred. Subsequent ultrasensitive amino acid analysis confirmed the lack of deleterious effect of the cleaning process, revealing no changes to the important structural proteins of bird and dolphin bones.

Spongin

King Philippos II, father of Alexander the Great, died in 336 B.C. and was buried in Vergina, Macedonia, northern Greece. In his tomb were bath utensils for his death journey. Among these was a sponge that was analyzed for any changes in amino acid content and the presence of polysaccharides. (Sponges are known to contain a polysaccharide component closely associated with spongin.) The analyses were conducted to determine the state of preservation of this sponge, presumably gathered from the Mediterranean Sea, which had been "stored" in an underground tomb for 2,300 years at high humidity. Although the sponge samples were somewhat friable, they could be identified as belonging to the genus Hippospongia, a common commercial sponge from the Mediterranean.

Spongin, the protein of which sponges are composed, is closely related to collagen, the structural protein of mammals. Amino acid analysis indicated that relatively few bonds had been broken in the original molecules. Only about 10 percent of the amino acids were completely hydrolyzed and existed in the free state; the remainder were still linked in the peptide bonds of proteins. The amino acid composition of this sponge resembled that of spongin and also was similar to modern samples from the same area of the world. In addition, carbon, hydrogen, and nitrogen (CHN) analysis determined that the CHN ratio fell within the values expected for proteins, indicating that the sponge was composed primarily of protein and not a combination of protein and polysaccharide.

What is remarkable is that this material not only had not crumbled completely during its 2,300 years of interment at high humidity but also that it retained sufficient morphological and chemical features to be identified.

Protein Chemistry

Studies are being conducted on glutamic acid, one of the most abundant and stable of the amino acids found in the proteins of bone and egg shell. Preliminary results indicate that those proteins that hydrolyze in solution may be partially stabilized by lactam ring formation of N-terminal glutamic acid. Heating studies of dry proteins to explore this phenomenon also indicate a high degree of stabilization linked to glutamic acid. More than 400 samples have been analyzed to explore this phenomenon. This research may have implications for the storage of natural history specimens.

Other amino acids and their deterioration products are being explored for their utility in providing both a time and temperature history for old specimens. Samples from the glutamic acid study were supplemented by approximately 100 samples from specimens that have reactions with a substantially different activation energy. Conceivably, a benefit of the present research findings might be in the development of a new dating technique.

Organic Collections Research

Biogeochemistry research at CAL expands understanding of molecular preservation in the fossil record and seeks new methods of using collections as informational reservoirs of preserved ancient biomolecules to address questions of paleoclimate, paleodiet, and paleopathology.

Kents Cavern Project

The Kents Cavern project is a geochemical study of a middle to upper Paleolithic fauna and the surrounding cave matrix. The cave, located in southern England in the county of Devon, was excavated in the 1860s by William Pengelly, and the materials recovered, under study in this project, are from the Smithsonian's National Museum of Natural History and the Troquay Museum in England. The purpose of the study is to determine the extent of organic preservation in the Paleolithic period and reexamine the radiocarbon dates from the sits; to ascertain whether dietary and climatic information is retained in the stable isotopes of these materials; to measure the individual amino acid isotopic signatures and assess the usefulness of this information at this time depth; to investigate the possibility that ancient DNA is preserved in these fauna; and to compare trace element (strontium and barium) paleodietary information with stable isotopic interpretations.

For FY 1994, radiocarbon dates from both the organic (collagen) and inorganic (apatite) phases of Kents Cavern fauna were obtained. While the purified collagen yielded radiocarbon ages consistent with both faunal types and previous dates, the carbon in the enamel apatite exhibited evidence of exchange with modern carbon. Molecular preservation of collagen, the major protein in vertebrate calcified tissue, was highly variable in the Kents Cavern fauna. However, substantial amount of collagen was recovered from 80 individuals, and light stable isotope measurement from herbivore and carnivore collagen carbon and nitrogen exhibited the predicted trophic relationship. The carnivores, primarily hyenas, were enriched in both the heavy isotope of carbon and nitrogen relative to the herbivores (primarily rhinoceros and horses). Subtle and previously undefined degradation processes have altered total collagen carbon and nitrogen isotopic values, a conclusion based on the biochemistry of the ancient collagens, the lack of isotopic "space" for omnivores between the herbivores and carnivores, and the carbon isotopic values of the individual amino acids of modern Kents Cavern collagens. DNA was extracted, and a portion of the mitochondrial genome was PCR-amplified, from rhinoceros bone. The removal of low-molecular-weight degradation products was found to improve the amplifications of ancient DNAs. In sum, this project represents the most complete description of molecular preservation at this time depth, some 40,000 years ago.

The Lingula Project

The focus of this study is an animal that belongs to the little-known phylum Brachiopoda, called *Lingula*. *Lingula*, a "living fossil," is one of the (if not *the*) oldest genera on Earth with a continuous fossil record and living members. In terms of shell morphology, this animal has undergone little change since the Cambrian period. Although *Lingula* was once widely distributed, today it exists only in a small area of the Pacific; the only U.S. species (*Lingula reevii*) is found in Kaneohe Bay, Hawaii. Because of its intertidal habitat, *Lingula* has been severely affected by increases in human population on several islands, especially Japan. The need for

biologically based study of *Lingula* is strong not only from a biogeochemical standpoint but also from a mineralogical one.

This animal has survived all the major extinction events of the past 500 million years, yet the physiological adaptations that have permitted this persistence are not well known. The shell of this inarticulate Brachiopod is unique, based on chitin and hydroxylapatite with a complex, protein matrix. Thus 100 million years before vertebrates evolved, the biological mechanisms necessary for the deposition of hydroxylapatite were in place. The major protein in the shell has been purified and partially sequenced at CAL, and two polyclonal antisera have been raised to date. Whether there are similarities underlying the mechanisms of vertebrate and invertebrate calcium phosphate biomineralization is not known, but one of the best comparative invertebrate models is *Lingula*. The long-term goal of this project is to use light isotope data (both organic and inorganic) to interpret present and past plankton utilization and to derive past ecological information in the form of paleotemperature and atmospheric oxygen content.

In FY 1994, isotopic analyses of carbon, nitrogen, and oxygen were completed for both *Lingula reevii* (Hawaii) and *Lingula unguis* (Japan). These data set the stage for an isotopic analysis of ancient lingulids that have been collected from five sites in the Cambrian deposits of Wisconsin. In modern shell material, there was substantial intertissue variation in both carbon and nitrogen isotopic values. The difference in the stable carbon isotopic values between the shell organic matter and the periostracum-lophophore might well be due to the contribution of the contribution of the isotopically light chitin carbon in the shell. More difficult to explain is the nitrogen shift toward the heavier isotope in the lophophore compared to the shell organic matter and the relationship between shell size and the nitrogen isotopic values. The small standard deviation in the oxygen isotopes from shell carbonate apatite will be a useful indicator of authenticity in the future analysis of ancient shell material.

Four months of manual dissection have produced gram quantities of ancient shell material from the Wisconsin collections that will form the basis of the comparison of modern and ancient isotopic values and biochemistry.

Human Stable Isotopic Values and Interpretations of Ancient Diets

From the first application of stable isotope values to interpretations of paleodiet, it has become clear that an understanding of how, isotopically, food gets translated into bone collagen and bone apatite is necessary and that both collagen and apatite isotopic values can be altered by time and burial.

Ten years ago, a model was advanced that attempted to explain the translation of diet carbon isotopes into bone collagen and apatite. This model relied exclusively on the concept of routing (diet protein preferentially goes to collagen), and energy, described as carbohydrates and fats, is disproportionately represented isotopically in the carbon dioxide associated with the hydroxylapatite of bones and teeth. Five human skeletal collections from the National Museum of Natural History and other museums have formed the basis for the present interpretations of ancient diets.

In FY 1994, the paleodietary and paleoecological interpretations of the archaic Windover site in east-central Florida were published. More than 180 individuals and

more than 80 human brains were found at the site. Based on carbon and nitrogen isotopic values in human and faunal collagens, these ancient humans were obtaining foods primarily from the estuaries, and floral species suggest a seasonal use of the burial site. In contrast, the Sully site in South Dakota was inhabited by maize- and bison-eating peoples, and the infants of the Sully site exhibited the nitrogen isotopic signature of mother's milk in their bone collagen.

The range of carbon and nitrogen isotopes in these populations demonstrates that interpreting the amount of maize utilized by an archaeological population as compared to the other non C-3 isotopic inputs from either marine or terrestrial sources cannot be done with any degree of accuracy by using whole collagen or apatite values. The addition of sites like Sitio Sierra from a recent excavation in Panama will allow further development of quantitative approaches to paleodietary questions (e.g., how much maize or seafood was in the diet). In collaboration with Marilyn Fogel of the Geophysical Laboratory of the Carnegie Institution of Washington, CAL researchers will continue to pursue the contribution that molecular dissection and on-line gas chromatography-isotope ratio mass spectrometry can contribute to interpretations of paleodiet.

Inorganic Collections Research

Provenience or Sourcing of Raw Materials or Artifacts

Artifacts were not always produced where they were found. Knowing the location of the sources for the artifacts, or even knowing that a given group of artifacts was produced from the same source materials, greatly increases the artifacts' value for investigating the political, economic, and social relationships of a society in the past. The general procedure for attributing at artifact to a source consists of determining a characteristic profile or "fingerprint" of chemical concentrations in CAL's Instrumental Neutron Activation Analysis (INAA) program or lead isotopic abundances in the Lead Isotope Mass Spectrometry Program. The sample profiles are compared for their compositional similarity, with similar specimens interpreted as products made from the same raw materials. Depending on the requirements of the research, the source for the raw materials may refer to a geographical subregion, to a specific site, or even to the products of a single workshop. The attributions made possible by the compositional data provide the base from which historical or social reconstructions are made.

When applicable - and permissible - collections of the Smithsonian Institution from a central part of the research effort. Collections from the Freer Gallery of Art, National Museum of African Art, National Museum of American History, National Museum of the American Indian (before it became a Smithsonian museum), and the Natural Museum of Natural History have been utilized in CAL research. Even when other collections provide part, or all of the specimens being analyzed, similar specimens in the Smithsonian benefit by a expanded interpretive context.

The analytical data and the accompanying descriptive information (e.g., traditional archaeological attributes) are deposited into the Smithsonian Archaeometric Research Collections and Records (SARCAR) data base. This data base encompasses the analytical data produced in the course of CAL projects as well as those obtained from other research facilities. The SARCAR data base not only protects the scholarly community against the loss of unique data accumulated by scarce resources but also expands the research base for CAL projects.

Neutron Activation Analysis Program

The Conservation Analytical Laboratory maintains a research facility located at the National Institute of Standards and Technology (NIST), Gaithersburg, Maryland, consisting of two automated sample changers and four gamma detectors with associated electronics. The facility provides high precision multielement chemical data for use in a wide range of chemical characterization research projects conducted by CAL staff, fellows, and research collaborators. CAL has the only continuously funded research facility of its king operating in the United States and one of the few in the world. With this continuous support, CAL can engage in collections-based research projects that require the accumulation of extensive sets of data over several years. Short-term projects, such as those associated with training as part of CAL's postdoctoral fellowships, are also carried out as appropriate.

In the past year more than 2,100 archaeological samples have been analyzed in support of several major CAL research projects. These projects have included studies of Classic Maya pottery, Pre-Columbian and historical Hopi pottery, Pre-Columbian Peruvian ceramics, Bronze Age and Iron Age ceramics from Gordian in Turkey, medieval Islamic ceramics and stonepaste ware, and ceramics from the Indus Valley in Pakistan and the Oman Peninsula.

Hopi Yellow Ware Project

Trace element analysis of approximately 1,700 Hopi yellow ware ceramics, representing production between A.D. 1300 and 1850, has been completed. These chemical data are being combined with colormetric measurements, archaeological information, detailed stylistic analysis, and Hopi oral traditions to study aspects of Hopi social organization and population amalgamation on the Hopi mesas. Close collaboration with members of the Hopi tribe and an educational outreach component, at the Hopi high school and to Hopi students in residence at CAL in previous years, constituted novel aspects of this research project.

The project began with the Fewkes Collection of the Smithsonian's National Museum of Natural History and was extended to include Hopi pottery from museums in Arizona, New Mexico, California, Illinois, and New York. Whole vessels, important for the stylistic analysis, are linked through the chemical data to collections of recently excavated ceramic fragments. The latter form the provenienced ceramic compositional profiles against which the whole vessels are compared.

Contrary to current archaeological interpretation, yellow-firing pottery was produced at many locations throughout the Hopi tribal lands, not just on the mesas. For many of the pottery-making villages, extensive exchange is not documented except for the products from Antelope mesa. Ancient villages along this most eastern of the mesas traded pottery south to the Little Colorado River and to the east, into the land of the Zuni and beyond. Prior patterns of ceramic production continued into the time of Spanish occupation but were significantly altered following the Hopi revolt against the Spanish.

During FY 1995 the project will focus on controlled firing experiments to determine the basis of the yellow-firing color - a technology that has been lost since the mid-17th century.

Research in the Maya Area

Ongoing collaboration with several archaeological programs of excavation in the Maya area continue to contribute to an expanding INAA data base of Late Classic (A.D. 550-850) Maya painted pottery. As new projects for determining locally produced and imported pottery for sites throughout the Maya lowlands continue, the data base grows in utility for these individual projects and for determination of the source of production for the nonprovenienced, but elaborately painted, Maya elite pottery.

The region about the site of Nakbé, in the northern department of the Petén, Guatemala, was a focus of analytical investigation in FY 1994. Previous interpretation of INAA data had suggested the general region as a probable source of manufacture for vessels of a codex-like black-brown line on cream pottery, a style that until recently was known only from nonprovenienced museum objects. The compositional data have now demonstrated that the codex-style pottery was produced in the general Nakbé region. The considerable time depth recovered at the site has also provided the opportunity to document the technological changes in ceramic production that occurred during earlier periods.

In another analytical effort, the fourth year of research on the Guatemalan-Vanderbilt University Petexbatun project included fieldwork to gather raw clays from the locations about the ancient regional capital of Dos Pilas and various deposits along the Pasión and Usumacinta rivers. This project draws heavily upon the data in the SARCAR data base for a regional context within which the INAA data from the Petexbatun pottery can be interpreted. This research took on new significance with the discovery that a certain fine paste ceramic, Chablekal Fine Gray, was imported into certain Petexbatun sites from the region of Palenque, to the north. This finding will alter existing interpretations of events immediately prior to the virtual abandonment of the central Petén - the so-called Maya collapse. As the Palenque region has been the focus of INAA for more than 20 years, the new data will be useful for interpretation from the standpoint of both the producing area and the consumer.

Painting the Maya Universe

Classic Maya elite painted polychrome pottery is one of the great ceramic traditions of the world. The vessels carry images of the Maya worlds of the living and the dead, often with hieroglyphic texts that record historical narratives or encode information about whom the pottery was made for or by. Unfortunately these nonprovenienced vessels are better known in museums for their aesthetic qualities than for their archaeological value. A major component of CAL's research in the Maya region has been the use of the Maya data base, consisting of more than 12,000 analyses, for the attribution of these vessels. The importance of this work was reinforced during the past year with the touring of the exhibition *Painting the Maya Universe*, organized by Maya ceramics project collaborator, Dr. Dorie Reents-Budet, Curator of Pre-Columbian Art at the Duke University Museum of Art. Vessels drawn from national and international collections were chemically attributed to production loci within the Maya region, permitting the styles, themes, and hieroglyphic texts to be interpreted within a geographic context.

The research, catalog, and presentation have been heralded as achieving a new level of scholarly achievement in the study of Maya ceramic art. Previously displayed at Duke University, Los Angeles Museum of Art, and the Museum of Fine Arts in Boston, the exhibition concludes at the Yale University Museum of Art in April 1995. Only 90 of the more than 1,700 whole vessels analyzed by the project were included in the exhibition. A more inclusive monograph is in the initial stages of preparation.

Pikillacta Project

This project focuses on the Andean Middle Horizon (ca. A.D. 540-900) state-level society known as the Wari and one of its provincial administrative centers, Pikillacta. Following a detailed attribute analysis of ceramics from Pikillacta and several sites in the environs, INAA was carried out on approximately 180 pottery samples to determine patterns of regional production and exchange. The analyses were completed in FY 1994, leading to their summarization during FY 1995. Several of the sites surrounding Pikillacta were found to have been centers of production for ceramics previously believed to have been present simply as trade items. Findings such as this will be incorporated into a doctoral dissertation by Mary Glowacki, Brandeis University.

Mid-Asia Project

One highlight of this year's research involved a continuation of the study of the manufacture and exchange of ceramics between sites on the Oman Peninsula and sites located in modern Iran and Pakistan during the late third millennium B.C. This research, in collaboration, with Dr. Sophie Mery, Centre National de Recherche Scientifique, Art et Archéologie, has sought to combine mineralogical data from thin-section analysis and chemical data from INAA to establish the area of manufacture and subsequent exchange of ceramics across this broad region.

An earlier stage of this research projects demonstrated the indigenous Omani production of fine black-painted redware, originally believed by most archaeologists to have been imports from across the Gulf of Oman in south-central Iran. The current investigation has extended this research to include ceramics that are stylistically the same as the wares found in Harappan contexts in Pakistan and India. The combined mineralogical and chemical data demonstrate conclusively that the majority of these ceramic types were indeed imports from across the Gulf of Oman. This information has helped to verify an active over water trade network during the third millennium B.C. Further, comparison of the chemical data generated in this study with chemical data in the SARCAR data bank for ceramics and bangles from the cities of Harappa and Mohenjo-Daro has established the source of the clay to be the Indus River alluvium at of south of the ancient city of Mohenjo-Daro.

A single Indus-style ceramic piece did not match the chemical composition of the rest of the ceramic collection analyzed in this study. This piece was, however, identical both chemically and mineralogically to ceramics found on the Oman Peninsula, but not of the Indus style. This finding leads to the possibility that Omani potters were producing sophisticated copies of Harappan ceramics thought, until now, to be beyond their technological ability. Further research will begin in 1995-96 to investigate this early example of technological transfer.

Islamic Glazed Frit Project

The Islamic project involved the examination by chemical characterization of 131 medieval Islamic glazed stonepaste (frit) sherds, some lustered, from the site of Gritille in southern Turkey. The current thought in Islamic ceramic history holds that the decorative technique of lustering was highly restricted, proprietary technology and that the production of such luxury ceramics was limited to a few production centers located throughout the medieval Islamic world from which all of these wares were exported. To assess the validity of this hypothesis, the project focused on excavated ceramics from the small provincial site of Gritille, which represents the end of the line in the distribution system. The analysis showed that nine chemically distinct groups were represented in the Gritille stonepaste ceramics and that lustered sherds were present in most of these groups. During the time period represented by the Gritille sherds, if current thought holds, only one production center, located in Syria, should have been supplying lustered stonepaste wares to the region. This was not the case. Luster technology must have been much more widespread than previously thought. This study proposes that production, rather than being centralized, was dispersed among a number of regional and provincial centers. Thin-section analysis of a selected sample is currently being carried out to clarify the picture further.

Arslantepe Sealing Clay Project

Continuing research focuses on the sealing and accounting practices in a region of the upper Euphrates River in Turkey during the late fourth millennium B.C. It involves the chemical analysis of a carefully selected sample of 123 clay sealings (from a total of about 1,800 sealing fragments) found together in a single archive at Arslantepe. The study was initiated to see if differences in raw material utilization could be detected and to attempt to identify sealings on non-local objects. The chemical data fell almost exclusively into three large chemical groups. Since the seals impressed into the clay crosscut the chemical groups, with the same seal being used to seal objects in each of the groups, the sealing operation was shown to be a local accounting operation. The three clay groups appear to be clayey marls, with most of the chemical difference due to calcium carbonate dilution.

When the clay sealings were correlated with the type of object being sealed, a pattern became clearly defined. The higher carbonate-lower clay, least plastic chemical group was used to seal objects where the seal was supported by the object. The lowest carbonate-highest clay, most plastic chemical group was used to seal objects where the seal was affixed to the side of the object. The medium plastic chemical group was used to seal objects where the sealing was partially supported. This specificity of composition with sealing types has two possible explanations. Either an individual or group of individuals was responsible for sealing all types of objects, with three batches of prepared sealing clay present for selection depending on the object being sealed, or, more likely, individuals specialized in sealing certain types of objects and developed clay compositions appropriate for the object.

Lead Isotope Program

In many areas of the world metals take second place only to pottery in the study of contacts between social groups or cultures. Data derived from lead isotope analyses have been shown to be highly effective for identifying the source of ores used in bronze and copper artifacts. Research projects carried out by the lead isotope program uses isotope rations determined on a National Institute of Standards and Technology's thermal ionization mass spectrometer designed for high precision measurements. Access to the NIST facility is provided through the collaboration of Dr. Robert D. Vocke, CAL Research Collaborator.

Studies of Nigerian Bronzes and Comparative Samples

The study of Nigerian bronzes centers about the collections of the National Museum of African Art to determine the sources of the copper alloys used in the major casting centers of Nigeria. The objects represent 1,000 years of copper metalworking traditions in Nigeria (7th-19th century A.D.) and reflect the different cultural influences introduced through contact with traders from Europe and other regions in Africa. The sampling of material for analysis extends to other museum collections, from Europe, Nigeria, and the United States, as necessary to address expanding questions about the source of ores used to produce the bronzes and the changes in exploitation modes over time. Dr. Frank Willett, Research Fellow at the Hunterian Museum, Glasgow, Scotland, is a CAL research collaborator for this project.

This year emphasis was placed on locating specimens and acquiring samples from objects representing the Igbo-Ukwu (8th-10th century A.D.), Ife (ca. 11th-14th century A.D.), and pre-and post-contact Benin periods. Almost 200 samples, covering the major periods of metal casting in Nigeria, have now been acquired. The Igbo-Ukwu and Ife samples are especially important, as very few objects from these periods exist outside of Nigeria.

The lead data obtained thus far for the Igbo-Ukwu samples fall into two very distinct artifact groups, indicating a possible change in raw materials. The Ife objects also fall into two isotope groups that were distinct from two Igbo groups.

Contemporary with the Igbo-Ukwu period are samples from various types of copper alloys excavated in Marandet, Niger. Samples of 11th-12th century brass rods, excavated in Ma'aden Ijafen in southern Mauritania, were also analyzed. The samples represent a hoard of 2,000 such objects abandoned in the desert, probably intended for major casting centers in West Africa such as Ife. Although data from these copper alloyed rods show very high probability of matching various European sources, in view of the lack of sufficient lead isotope data from African ore sources it would be premature not to consider the mining areas of North Africa as possible sources.

The lead isotope ratios for Benin bronzes might be difficult to interpret, due to the possibility that multiple sources were used for the lead or that the bronzes were resmelted. However, early results of the analyses on these objects proved that although the Benin bronzes were cast over a period of four centuries during which metal was imported from a number of the major European countries, the lead isotopic data tend to form groups even more tight than the earlier, compact Ife (pre-Benin) clusters. Nations trading metal to Benin over the period of Benin bronze

production may have exploited only a few source regions, such as Belgium and Germany. A compilation of European lead isotopic data is under way (see below), supplemented by newly analyzed ore samples. These data may resolve some of the questions pertaining to the source of materials used to manufacture the Benin bronzes.

Spanish and Spanish Colonial Glazed Ceramic Artifacts

Excavated Spanish ceramics from Spain and the New World were analyzed in FY 1994 to determine the provenience of the lead used to produce the glazes. The project uses data previously acquired through CAL research projects and non-CAL data from an assembled European data base. Lead analysis of glazes from 16th-17th century sherds from the royal monastery at San Clemente in the San Vicente district of Seville were added this year.

Earlier research indicated at least two Spanish sources for the lead. Spanish Artifact Group 1 appears similar to the lead composition found in some Spanish ores and is distinct from Spanish Artifact Group 2, which contains no Spanish ore data. The probable sources of the lead in this second group of artifacts may be from ore deposits in Belgium and Germany. It is not surprising that ores from Belgium and Germany would be represented in Spanish artifacts from the 16th century, because these areas were an integral part of one empire at the time.

Lack of sufficient lead data from relevant Spanish ore sources renders assignment of Spanish artifacts to Spanish sources problematic. This dearth of data has been addressed by analyzing ore samples obtained from the Smithsonian's National Museum of Natural History Mineral Sciences Department, ores obtained from Spanish geologists, and a compilation of data in the geological literature. At present, however, a significant number of artifacts remain unassigned to the characterized Spanish or Belgian-German sources.

Recently, lead isotopic data have been obtained from newly published studies of Spanish and Portuguese ore deposits. Nevertheless, the lead isotope composition of the glazes in Spanish Group 1 is unique among Spanish artifacts and does not correspond with other European ores in CAL's data base. The probable sources may have been narrowed to two possible regions - mining areas north of Seville, and isotopicaly similar regions in North Africa, particularly Moroccan deposits. Current analyses will continue to pursue the more accurate determination of ore source for the many Spanish artifacts yet unassigned.

Geological Ore Samples from Western and Central Europe

One aspect of the lead isotope program focuses on locating analytical data already derived at laboratories throughout the world. These data, when of acceptable precision and accuracy, are continuously added to CAL's growing data base. To date, more than 1,700 entries have been made of isotope ratios of European ores.

Isotopic values taken from the literature may pose difficulties, for the determinations might not be based on the same reference standard or may suffer from insufficient precision. The effective use of these data, therefore, require that new analyses be carried out on selected samples to evaluate the precision and accuracy.

The newly acquired published data on Spanish ores have greatly augmented the amount of analytical data available, permitting the identification of several different and distinct isotopic ore groups covering the regions of Cartagena, Almeria, and Linares and the pyrite belt from southwestern Portugal to the Heulva district of Seville.

The recent lead data on French ore deposits comprise more than 600 data entries on the regions in the Massif Central, Massif Armorican, the Vosges, the Pyrenees, the French Alps, Maures, Corisca, Haut-Allier, and Limousin. Preliminary statistical analyses of these lead data have generated numerous isotopic fields, some of which considerably overlap others. Presently, work is in progress to exclude (e.g., lead measurements on radiogenic ores), reevaluate, and refine many of these lead isotope groups. These statistically derived isotope groups will be used to help determine the source of raw materials for artifacts manufactured in these historic mining regions.

Inter-comparison Study

The lead isotope program emphasizes measurements of high precision and accuracy through thermal ionization mass spectrometric analysis. In FY 1994 CAL responded to a request from Wim Devos, University of Ghent, to reanalyze glaze samples from ceramics excavated from medieval contexts in southern Belgium (Ardennes). His lead isotopic data, obtained by inductively coupled plasma mass spectrometric analyses (ICP-MS), formed the basis for an inter-comparability study of the two techniques.

Five semidigested samples were submitted for analysis. Lead was separated by anodic electrodeposition and analyzed. The data on the glazes from Devos's analyses and from CAL's analyses were strikingly different. All of the CAL-NIST data were sufficiently consistent to indicate that the glazes were from the same lead source. These data also agreed with the published data from Belgium sources. These conclusions, however, are not readily apparent in the lead data from Ghent. At present, it does not appear that the ICP-MS technique can deliver the precision and accuracy of the thermal ionization mass spectrometric technique.

Ancient Technology

Ceramics (including plasters, pigments, glasses, glazes, metallurgical slags, and clay-based products) and metals are complex materials that retain within them, in some degree, their manufacturing history. This history and its cultural significance are a focal point of CAL research. Subjects of investigation concern the identification of the physical bases of appearance, the constraints and variability of raw materials, the methods and sequences of manufacture, the processing parameters, and the use of artifact properties to interpret cultural function. Critical portions of the ancient technologies may be replicated and compared with analogous modern practices.

The structure and properties of artifacts are intrinsically measurable, independent from the human behavior that produced them. Use and function are, however, explicitly part of the human realm and reflect both individual and group behavior. For culturally significant interpretations, these areas must be considered together.

The Potter's Wheel in Ancient Southwest Asia

Research on the forming and finishing methods used in pottery production in mid-fourth through first millennia B.C. Iran, Iraq, Syria, Turkey, and Egypt show that the use of the potter's wheel has been misinterpreted. Reconstruction of sequences of manufacture using fractography, texture analysis, and radiography demonstrate that the potter's wheel was used for small vessels. Larger vessels were created by various combination of hand building, rotary forming, and finishing.

Strategies for employing the wheel for different ware and form classes of pottery vary with site. In the Euphrates-Tigris drainage, where the clay is easily worked, the wheel was used for sculpture, pottery, architectural details, and other products. At Amuq, in Syria, as well as at the Iranian sites studied, the wheel continued to be used only for small-sized vessels until the second millennium B.C. Obviously, there are many possible explanations for such technological differences. Current research, leading to the completion of the analytical phase of the project, involves an extensive set of ceramics from several sites. Macroscopic and low-power microscopic traits, such as wiping and wheel markings, alignment of porosity, and the evidence of joints with manufacturing sequences in whole vessels from each site have been recorded. Xeroradiography of the sherds will be completed during FY 1995. A new interpretation of the potter's wheel for mass-production in ancient Southwest Asia will follow completion of the project.

Glass Beads of Nippur

Beads from the Akkadian period (ca. 2350 B.C.) site of Nippur in Iraq have been the subject of extensive analytical investigation. Among the artifacts studied are two beads that are the earliest recovered from ancient Southwest Asia. One is a soda-lime-silicate composition with 30-micron calcium-silicate crystals, evidence of an unusually long heat treatment. The other is a lead-silicate, copper green composition with six phases present, including calcium-magnesium silicates and yellow lead-stannate; the latter was previously thought to be a glass colorant first used in Roman times. These beads, along with other glass materials and the remains of furnaces, have revealed a complex pyrotechnology that may have a developmental link to the processing of metal.

The Nippur research has be conducted as part of a larger effort to reconstruct the late-third-millennium ceramic and glass technology. The Nippur phase of the investigation has been completed and a final report submitted for publication.

The Wright Flyer

The Wright Flyer, which first flew at Kitty Hawk on December 17, 1903, is presently on display at the National Air and Space Museum. The 8 weight percent copper-aluminum alloy of the crankcase represents the first aerospace application of an aluminum alloy and one that, with few modifications, is still in use. When the fine structure of this aluminum was studied by transmission electron microscopy in collaboration with Frank W. Gayle at NIST, Guinier-Preston (GP) zones were observed, indicating precipitation hardening. Replication of the 1903 alloy showed that these zones result from casting into a preheated sand mold. The discovery of precipitation hardening in aluminum had been credited to Alfred Wilm, who first published his work in 1911, so this finding represents an important correction to the history of technology. Higher magnifications revealed additional very small GP zones in areas of low copper concentration where they had not been predicted according to the current literature. The GP zones have been interpreted as evidence of ambient temperature precipitation occurring over the 90 years since the first flight.

Early Mining at the Great Orme

A recent discovery on a headland in northwest Wales has led to the reassessment of the trade in bronze in northern Europe during the Early Bronze Age. A mine of that date has been discovered at Great Orme, and ores from the mine are the subject of CAL research. Its extent underground, limited only by the ancient water table at 250 feet, indicates a very much larger supply of copper in the British Isles than had been supposed and suggests the direction of the bronze trade may have been to, rather than from, the Continent during this period. In a collaborative program with Great Orme Mine Ltd. and the University of Liverpool, CAL is characterizing the ores to test this possibility. An initial selection of small finds and ores has been sectioned and analyzed. Seven ore or bronze metal samples from the mine have been analyzed by lead isotope analyses. The results of the analyses were compared to lead isotope data from the geologic literature on Welsh ore sources. Isotope ratios for two galena and an azurite sample appear to be similar to the copper ores found in Parys Mountain and the Mendips region of Wales but fell outside the normal distribution of those characterized isotopic ore groups. However, the lead isotope composition of the bronze fragments excavated from early levels in the mine show close similarity to the ore samples from the Mendips and southern Wales regions.

Update on Harpsichord Wire

The Smithsonian has an important collection of historical musical instruments. Among these are wire-strung instruments such as harpsichords and clavichords, some sufficiently robust to be played in concert. The original wire of these instruments was, however, an ephemeral part, subject to wear, fracture, and replacement. During conservation of Smithsonian harpsichords tiny fragments of early wire were recovered, and these were the subject of long-term research in CAL during the 1980s.

Wire for restringing the Smithsonian's instruments authentically has been drawn to specifications developed from this research. The brass wire has already found international acceptance with harpsichord makers and musicians. The iron wire has been reproduced courtesy of Nippon Steel Corporation. During FY 1994 specifications were submitted, wire received, and the iron strings on the Dowd Blanchet copy rewired by Scott Odell of the National Museum of American History, for a long-term trial. The stringing of instruments that require other string strengths is being scheduled. Several instruments with the new wire have now been played in concerts at the Smithsonian.

Art Historical Research

Technical studies of historical or cultural materials are limited in significance if they are not tied to other types of information that might exist about the object of study. Previous CAL research using neutron-induced autoradiography to study the composition and structure of paintings by various artists produced data in the form of radiographic images. Research is presently under way to extract the information contained in the autoradiographs and place it more fully within the context of the artist's life and work.

Image Processing of Radiographic Images

For the first time, autoradiographs and x-radiographs have been examined by image processing. Alexandre Winter, an intern from the Ecole Nationale Supérieure des Télécommunications, conducted the first study of images of Albert Pinkham Ryder's *Tempest* (1890s) with image processing. Images scanned at Dupont De Nemours EI & Co. were mosaiced and examined at the National Air and Space Museum's Center for Earth and Planetary Studies. Both the x-radiograph and one of the autoradiographs were processed. Winter corrected distortions that occurred in the images during scanning, thus improving their legibility. The imprint of the stretcher was removed in the x-radiograph by using a filter. He also created various zoomed images, including those of Prospero and Miranda, two figures in the painting, for comparative work. An internship funded by Paris Telecom permitted Thomas Rey, also and intern from the Ecole Nationale Supérieure des Télécommunications, to continue the imaging processing. His work included making zooms of the figures of Ariel and Caliban and making the first attempt at filtering-out the canvas weave.

The Paintings of Thomas Cole

American painter Thomas Cole is considered the founder of the Hudson River School. While strolling through the valley of the Hudson River, he jotted down sketches of the landscape that would later be transformed into paintings in his studio. After the initial study of the underdrawings of the paintings at the National Museum of American Art and the Corcoran Gallery of Art, Washington, DC, CAL staff examined the paintings at the Wadsworth Atheneum, Hartford, Connecticut, the largest Cole collection.

During the National Museum of American Art's exhibition of Cole's work, *Thomas Cole: Landscape into History*, 58 additional paintings were studied. Underdrawings were discovered that ranged from simple, delicate outlines to detailed underdrawings of buildings. One of the most extraordinary finds was the detailed architectural drawing found beneath Cole's *Oxbow* (1836) at the Metropolitan Museum of Art. Here, the extensive underdrawings proved to be initial attempts to paint Consummation of Empire (1835-36). A historical analysis of this painting, compared against the newly discovered underdrawings is now being carried out.

Education and Training

Education Coordinator / Senior Furniture Conservator
Donald C. Williams

Senior Conservators
Mary W. Ballard
Carol A. Grissom
Dianne van der Reyden
Melvin J. Wachowiak

Conservators
Harriet (Rae) F. Beaubien
Jia-sun Tsang

Educational programs at CAL continue to evolve, building on established successes by reaching out in new projects to constituents. All CAL professional staff can contribute to any of the program's major emphases: internships, courses and workshops, public outreach, and publications.

Internships and fellowships at CAL span a wide variety of educational levels and academic disciplines. Whether the visitor is a postdoctoral fellow in materials science, a graduate student in conservation, or a pre-program or summer intern in conservation, there is a common emphasis on enhancing the students' understanding of artifact characterization or preservation.

Courses and workshops are often a focal point for the professional communities related to the work at CAL. Through both long-term programs and short-term or one-time events, courses provide concrete applications of research implications and the principles of professional practices. This year saw the emergence of an archives policy and practices series (RELACT), along with the more established Furniture Conservation Training Program (FCTP), and numerous short courses on topics such as stain removal and exhibition materials. Some of CAL's curricula are focused on the established preservation professional, others are available to anyone interested in the topic.

CAL staff are extremely active in presenting their work outside CAL to both professional and other organizations. In addition, this program area has begun an ongoing series of instructional videos for collection caretakers and has planned and hosted a lecture series on artifact characterization for students at a local high school.

Conservation treatment of artifacts allows CAL staff to develop new techniques or adapt old approaches to the problems of preservation and restoration. It also provides and excellent opportunity to teach the conservation profession to interns and visiting students, whether advanced or beginner. In most cases the treatment procedures developed at CAL are published in the conservation literature and presented at professional conferences.

Conservation treatment is included in this section for the final time. In the future the three distinct components of treatment will appear in their proper context given the new administrative structure of CAL: treatment development will be a Research and

Development function, treatment execution will be under Support and Collaboration, with only treatment-based training and publication remaining under Education and Training.

The future promises to be challenging as CAL staff continue to emphasize education through additional instructional and scholarly videos, specialized and interdisciplinary internships and fellowships, an active publications program, secondary school outreach, and public presentations to an ever-expanding interested professional and public audience.

Internships and Fellowships

The Conservation Analytical Laboratory offers internship and fellowship opportunities at several academic levels, including a variety of artifact, preservation, and conservation treatment specialties. CAL's commitment is to enhance the experience of the intern, whether the internship is an introduction to conservation or an advanced fellowship providing specialized technical training. This year CAL hosted 24 interns or fellows from more than a dozen states and several foreign countries, who joined the staff for differing periods of time.

Within a broader commitment to internship training, CAL offered four dedicated appointments in response to the special needs of emerging conservation and preservation disciplines. Under the auspices of the Objects Conservation Laboratory, CAL offers two archaeological conservation opportunities, one for a graduate student intern, the other for a postgraduate fellow. These students, along with the conservators, formed the core of CAL's program, which includes both on-site conservation and research and related projects in the CAL laboratories. The Paper Conservation Laboratory hosted similar level interns in archival conservation. The graduate student intern and postgraduate fellow engage in a number of projects in conjunction with archival and special collections within the Smithsonian, and research and treatment projects in the CAL laboratories.

Fellows, Interns, and FCTP Students with Appointments at CAL During FY 1994

Patrick Albert (University of Toronto) completed his second year in the Furniture Conservation Training Program.

Holly Anderson (SUNY-Buffalo Art Conservation Program) began her term as a graduate archives conservation intern with the Paper Conservation Laboratory.

Jennifer Barr was a pre-program volunteer intern in paper conservation for three months during the summer, rehousing the National Museum of Natural History Fish Illustration File collection.

Katherine Elizabeth (Liz) Brown (University of Michigan) was a full-year, volunteer pre-program intern in the Furniture Conservation Laboratory working on a variety of restoration and woodworking (fabrication) projects. She was accepted into the SUNY-Buffalo Art Conservation Program.

Terry Childs (Brown University) was a postdoctoral fellow in materials analysis, studying the historic metallurgical technologies of central Africa.

Sue Ann Chui (Vassar College) was a full-year pre-program intern in the Paintings and Furniture Conservation Laboratories, working on a variety of treatments (both painting and furniture) and woodworking (fabrication) projects. She was awarded a fellowship to study fresco conservation in Florence, Italy.

Tania Collas (SUNY-Buffalo Art Conservation Program) began her term as a graduate intern in archaeological conservation in the Objects Conservation Laboratory.

John Courtney (East Caroline University) completed his second year in the Furniture Conservation Training Program.

Patricia Griffin (Conservation Center, Institute of Fine Arts, New York University) was a research associate in the Objects Conservation Laboratory. She completed work on the plastered skulls from 'Ain Ghazal.

Katherine Holbrow (University of Delaware, Winterthur Art Conservation Program) was a graduate intern in archaeological conservation in the Objects Conservation Laboratory. She conducted research and treatment projects in the laboratory and fieldwork in Pakistan and Honduras.

Somya Abdel-Khaled Ibrahim (Textile Conservator, Egyptian Museum, Cairo) spent five months in the Textiles Conservation Laboratory, working on archaeological textiles.

Emily Kaplan (Art Conservation Programme, Queen's University) was a postgraduate archaeological conservation fellow in the Objects Conservation Laboratory. She conducted research and treatment projects in the laboratory and fieldwork in Pakistan and El Salvador.

Paul Koenig (Purdue University) completed his second year in the Furniture Conservation Training Program.

Naomi Kroll (Rice University) was a full-year pre-program intern in the Objects and Furniture Conservation Laboratories, contributing to treatments on both archaeological and wood artifacts and woodworking (fabrication) projects. She was accepted into the Art Conservation Program, Conservation Center, Institute of Fine Arts, New York University.

Mark Kutney (Pennsylvania State University) completed his second year in the Furniture Conservation Training Program.

Charles Jeffers (Jeff) Moore (Roger Williams College) completed his second year in the Furniture Conservation Training Program.

Rebekah Njaa (Minneapolis Institute of Art) was a 10-week summer intern in textiles conservation, working on the Civil War flag project.

Allison Payne (University of Texas) began her term as a full-year pre-program intern in the Paintings and Furniture Conservation Laboratories.

Thomas Rey (Ecole National Supérieure des Télécommunications, Paris) was an engineering student working on image processing of x-radiographs and autoradiographs using facilities at the National Air and Space Museum.

Andrew Robb (University of Delaware, Winterthur Art Conservation Program) began his term as the postgraduate fellow in paper conservation, specializing in photographic materials.

Kendra Roth (SUNY-Buffalo Art Conservation Program) was a 10-week summer intern in objects conservation, working on the 'Ain Ghazal statuary cache.

Ginger Russell (Virginia Commonwealth University) was a volunteer undergraduate intern in the Furniture Conservation Laboratory, spending three months on the treatment of an 18th-century English japanned clock.

Erin Sears (University of Missouri) was a 10-week minority intern in archaeology researching phytolithic material from Classic Maya pottery. She returned as a full-year intern on the same project.

Laura Steward (Harvard University, trained in Florence) was a third-year archives conservation intern in the Paper Conservation Laboratory, researching chromolithographic printing techniques. She co-authored a paper presented at the Book and Paper Group meeting, American Institute for Conservation.

Marie Svoboda (SUNY-Buffalo Art Conservation Program) began her term as a postgraduate fellow in archaeological conservation in the Objects Conservation Laboratory.

Heather Tennison was a pre-program volunteer intern in paper conservation for three months during the summer, rehousing the National Museum of Natural History Fish Illustration File collection.

Fei Wen Tsai (Columbia University Archives Preservation Program) was an advanced fellow in archives conservation, conducting research characterizing Chinese papers and contributing to treatment, survey, and collections care projects from various Smithsonian Institution archival and special collections.

Gitta van der Outen (graduate in paper conservation trained in Florence) served as a three-month volunteer intern in paper conservation, participating in a paper preservation video and an object treatment.

Amy Venzke (Beloit College) was a three-month summer intern in the Textiles Conservation Laboratory, working on the Civil War flag project.

Courses

CAL offered 15 courses in FY 1994, which were attended by approximately 350 people from wide-ranging personal and professional backgrounds, coming from 27 states and 6 foreign countries. In addition, more than 100 Smithsonian colleagues from most bureaus attended, and nearly all CAL professional staff participated in teaching, collaborating with 33 visiting faculty.

CAL courses and training events have a variety of emphases. In addition to two long-term curricula - the Furniture Conservation Training Program (FCTP) and the new Research, Libraries, and Archives Conservation Task Force Program (RELACT) - there are several individual courses and workshops with a range of constituents and durations, from week-long specialized topic courses for advanced professionals to relatively non-technical introductory and overview courses for collection caretakers. While most CAL courses were open to outside participants, some were developed to meet specific needs of the Smithsonian staff.

The FCTP is a unique graduate-level program designed to allow practicing woodworkers and restorers to pursue advanced midcareer development and reorient their professional activities. Responding to a clear need for a larger professional community of furniture conservators, the FCTP was initiated in 1986. Program students come to CAL for four two-week graduate seminar classes per year over a three-year period; each course is worth four academic credits. The complete Program concludes with a one-year full-time internship in a recognized furniture conservation laboratory or studio. FCTP students are individually enrolled in the Independent Master of Arts degree program of Antioch University and receive an M.A. in furniture conservation at the completion of their studies. This year, the FCTP again held four two-week courses. Five FCTP students were joined by a large number of conservation professionals and other visiting student attendees for these sessions. Most of the instruction was by CAL and other Smithsonian staff, but 20 expert faculty from industry and the conservation discipline also provided valuable insight and support.

Another area within the preservation discipline to which CAL is responding is the need for trained specialists in preserving and conserving archival collections. In addition to the two dedicated internships in archives preservation, a five-event series was developed by the Paper Conservation Laboratory for RELACT. The series was attended by about 25 collections managers, archivists, curators, and others, from the National Air and Space Museum, National Museum of American Art, National Museum of Natural History, National Postal Museum, Smithsonian Institution Archives, Smithsonian Institution Libraries, and other Smithsonian entities and included lectures by Paper Conservation Laboratory staff, other Smithsonian conservation staff, and visiting professionals. RELACT is the foundation for developing further curricula and training opportunities for archives specialists.

Courses Offered by CAL During FY 1994 were:

1. *Fumigation with Argon*, October 7-8, 1993 (20 attendees)

This closed course was offered to Smithsonian staff to establish protocols and procedures for treating insect-infested objects, sculptures, paintings (frames, stretchers), and textiles with non-reactive argon gas. The instructor was a specialist who previously developed special techniques for treating infested artwork.

2. *Structural Conservation of Furniture* (FCTP course 6), November 1-12, 1993 (20 attendees)

The causes and treatment of structural deterioration were surveyed, including technology and practice of consolidating degraded structural materials, the ethical concerns of reconstructing and reproducing objects for interpretation or utility, and reconstructing upholstery supports. This course included a week-long advanced wood-carving workshop.

3. *Mildew on Textiles*, December 10 and 13, 1993 (73 attendees in two sessions)

The course reviewed the life cycle and function of microorganisms, the dangers of these microorganisms and the likelihood of adventitious ones on fabrics. The consequences of these microorganisms upon both natural and synthetic fiber substrates were explained.

4. *Preservation Priority Surveys for Paper-Based Collections* (RELACT), December 16, 1993 (25 attendees)

This session dealt with methods of surveying collections of diverse archival materials and ways those collections can be compared. Terms such as value, use, risk, and exposure were defined, and a simple one-page form that permits a numerical ranking of the preservation needs for each collection was presented. Several surveys, taking only a few minutes each, were demonstrated for and undertaken by participants on-site in Smithsonian collections.

5. *Random Sampling Surveys for Paper-Based Collections* (RELACT), January 13, 1994 (25 attendees)

The session centered around what to do after a collection is targeted for preservation actions. A sampling survey can provide statistically accurate assessments of collection needs by surveying a specific percentage of collection items, selected randomly by computer. A computer program can then sort, correlate, and graph the findings. An example was demonstrated.

6. *Coatings for Furniture Conservation I* (FCTP course 7), February 7-18, 1994 (18 attendees)

This was the first of a three-part set of courses with a unified curriculum, offered in three two-week sessions. Coatings I introduced the history and technology of transparent coatings, the history of wood finishing, solubility theory, and the analysis, deterioration, and conservation of historic coatings.

7. *Coatings for Musical Instruments*, March 14-18, 1994 (10 attendees)

This week-long course, primarily for violin makers and restorers, was presented for the second year. Coatings history and technology were reviewed, as were analysis, deterioration, and conservation of historic coatings on musical instruments.

8. *Conservation of Photographs: Mid-career Training for Book and Paper Conservators*, February 1-4, 1994 (17 attendees)

The course provided an updated overview of photographic print materials and their preservation and conservation. Topics such as the relaxation and flattening of distorted surfaces, inpainting, consolidation of flaking binder, and repair of tears and losses were thoroughly covered in slide lectures and demonstrations. Practical work by course participants followed. Techniques for the display and storage of photographs were also discussed, and a disaster recovery workshop was included.

9. *Preventive Care Programs for Photographic Collections* (RELACT), February 3, 1994 (10 RELACT attendees; 17 photograph conservation course attendees)

The course presented an outline for planning preservation of photographic collections. Topics included organizing collections, identifying photographic processes and photograph deterioration, housing and holdings maintenance, reformatting, and conservation treatment.

10. *Coatings for Furniture Conservation II* (FCTP course 8), April 11-22, 1994 (8 attendees)

Coatings II, the second of FCTP's three-part set, emphasized evaluation of appearance, laboratory safety and design, and the technology of transparent colorants used in coatings processes.

11. *Case Study: Random Sampling Survey and Rehousing of the Warshaw Collection of Business Americana at National Museum of American History* (RELACT), April 28, 1994 (20 attendees)

Using an important collection as an example, the course illustrated the techniques of surveying mixed-media collections. Materials and techniques used to rehouse the collection were demonstrated.

12. *Preventive Care Projects at the Smithsonian Institution Libraries* (RELACT), May 26, 1994 (20 Smithsonian attendees)

This course outlined various preservation projects such as rebinding of books, reformatting, cold storage of master copies and use of reference copies, box making, establishment of criteria for selection for treatment, collection maintenance procedures, access policies, disaster preparedness, and staff training.

13. *Exhibition Materials*, June 21-23, 1994 (53 attendees)

This course covered evaluating, selecting and utilizing materials in the display of artifacts. Changes and developments in exhibition practices and materials were reviewed to alert exhibition designers to potentially harmful combinations of exhibition materials. Scientists and conservators discussed the use of metals, glass, plastics, textiles, paper, plastic additives, pest control measures, formaldehyde, and toxic residues.

14. *Coatings for Furniture Conservation III* (FCTP course 9), August 1-12, 1994 (18 attendees)

The third coatings course focused on painted finishes, such as polychrome sculpture, decorated furniture finishes, and consolidating and inpainting surfaces. Included were pigment history, technology, and identification; the history of painted furniture; the deterioration and treatment of panel paintings; the history, technology and conservation of urushiol (oriental lacquer); and the treatment of painted wooden objects.

15. *Stain Removal: Theory and Practice*, September 6-8, 1994 (10 attendees)

This course was designed primarily for textiles conservators with a particular interest in removal of accidental soiling and staining of porous materials, principally fabrics. A review of surfactants, solvent systems, and reagents was followed by discussions of the most common adventitious stains. Toxicity, material safety data sheets, and the relative benefits of proprietary mixtures were discussed. Topics of particular interest were the interrelationship of fiber type to detergent system and stain adsorption; the chemistry of colorants (dyes, pigments, food and fungal colorants) and the chemistry of their removal; and the limitation of cleaning systems as a function of the condition or previous history of the object.

CAL and Visiting Faculty During FY 1994

The number or numbers in parentheses at the end of each entry indicate the course or courses taught.

Mark Anderson, Associate Furniture Conservator, Winterthur Museum (2)

Gordon Anson, Exhibitions Conservator, National Gallery of Art (13)

Mary T. Baker, Ph.D., Research Organic Chemist, CAL (6, 10, 13, 14)

Mary W. Ballard, Senior Textiles Conservator, CAL (1, 3, 13, 15)

Susan Blaine, Preservation Officer, Smithsonian Institution Libraries (12)

Robert Blanchette, Ph.D., Professor of Plant Pathology, University of Minnesota (3)

Bronson Brown, Office of Environmental Management and Safety, Smithsonian Institution (10)

Edward Cooke, Ph.D., Montgomery Professor of Decorative Arts History, Yale University (14)

Mary Lou Davis, Furniture Conservator, Southbridge, MA (14)

Claire Dekle, Book Conservator, Smithsonian Institution Libraries (12)

David DeMuzio, Senior Furniture Conservator, Philadelphia Museum of Art (2)

Debra Derby, Photograph Conservator, Philadelphia, PA (8, 9)

Michael Dresdner, Director of Research and Design, Martin Guitar Company (6)

W. David Erhardt, Ph.D., Senior Research Organic Chemist, CAL (7, 13)

Timothy Geran, Ph.D., Research Scientist, CIBA Corporation (10)

Melanie Gifford, Research Scientist, National Gallery of Art (14)

Wallace Gusler, Director of Conservation, Colonial Williamsburg Foundation (2)

Richard Harold, Ph.D., HunterLab Corporation (10)

Ted Hatfield, Lt. Col., Chief of Microbiology Division, Armed Forces Institute of Pathology (3)

Walter R. Hopwood, Organic Chemist, CAL (6)

Samuel Hudson, Ph.D., Professor, Department of Textile Engineering, Chemistry and Sciences, North Carolina State University (3)

Nora Kennedy, Photograph Conservator, Metropolitan Museum of Art (8, 9)

Robert Koestler, Ph.D., Research Scientist, Metropolitan Museum of Art (3)

Gregory J. Landrey, Furniture Conservator, Winterthur Museum (2)

James Martin, Paintings Conservator and Director of Analytical Services, Williamstown Regional Conservation Center (10)

Mark H. McCormick-Goodhart, Senior Research Photographic Scientist, CAL (8)

Marion F. Mecklenburg, Ph.D., Senior Research Scientist, CAL (6)

Robert D. Mussey, Furniture Conservator, Boston, MA (6)

Debbie Hess Norris, Photograph Conservator, University of Delaware (8, 9)

Michael Sandor Podmaniczky, Associate Furniture Conservator, Winterthur Museum (2)

Heasoon Rhee, Ph.D., Senior Research Chemist, International Fabricare Institute (3, 15)

Mervin Richard, Exhibitions Conservator, National Gallery of Art (13, 14)

Arno Schniewind, Ph.D., Forest Products Laboratory, University of California (2)

Vanessa Simmons, National Museum of American History Archives Center Preservation Officer (11)

Elizabeth Simpson, Ph.D., Bard Center for the Decorative Arts, New York (2)

Janice Stagnitto, Book Conservator, Smithsonian Institution Libraries (12)

Gary Sturm, Collections Manager, Division of Musical History, National Museum of American History (2, 7)

Jonathan Thornton, Art Conservation Program, SUNY-Buffalo (14)

Jia-sun Tsang, Paintings Conservator, CAL (6, 7, 14)

Charles S. Tumosa, Ph.D., Senior Research Chemist, CAL (6)

Dianne van der Reyden, Senior Paper Conservator, CAL (4, 5, 8, 9, 11, 12, 13)

David W. von Endt, Ph.D., Senior Research Organic Chemist, CAL (6)

Melvin J, Wachowiak, Jr., Furniture Conservator, CAL (2, 6, 7, 10, 14)

James Wermuth, Preservation Technology Associates, Newport, RI (2)

Donald C. Williams, Senior Furniture Conservator, CAL (2, 6, 7, 10, 14)

Richard Wolbers, University of Delaware, Winterthur Art Conservation Program (14)

Public Outreach and Special Projects

CAL staff use many avenues to inform colleagues and the public about the principles of collections care and characterization and the nature of CAL's programs and projects. In addition to internships and courses, CAL staff frequently give lectures at professional conferences and to civic groups. A special effort was made in FY 1994 to begin new ventures and modify old ones to reach broader audiences.

In FY 1994, CAL contracted with a local video production company to begin creating a series of broadcast-quality educational videos on collection care for both lay and professional audiences. Two videos were started this year. The first, developed by the Furniture Conservation Laboratory, was "Furniture Care and Maintenance," aimed at non-professional furniture collection caretakers. Filming took place in the spring of 1994 at the Surratt House Museum in Clinton, Maryland, with the cooperation of the Maryland-National Capital Parks and Planning Commission, and in the CAL Furniture Conservation Laboratory and the studios of CinemaSound Productions. Editing and soundtrack recording were done during the summer. Production for this 27-minute video was completed in September 1994. Currently, a companion booklet is being written, and distribution of the package will begin in FY 1995.

A second instructional video, tentatively titled "Rescuing Records: Recognizing Value and Problems," from the Paper Conservation Laboratory, is an introduction to preserving paper-based collections. Filmed during the summer and fall of 1994 at CAL and several sites, including the National Museum of Natural History Fish Illustration File and Botany Illustration collections and CinemaSound Production studios, the project is in the final editing and soundtrack stage.

Other special projects include a pilot secondary-level program to introduce selected local high school students to the process of studying artworks at CAL, and participation in developing the first-ever CD-ROM dedicated to the technical study of art. "Introduction to Technical Studies for Secondary Students," a pilot program for ten local high school students, consisted of six sessions with CAL staff. The curriculum was designed to introduce basic scientific and historical methods used to study works of art. Hands-on workshops gave the students an introduction to the instruments and methodologies used for research in this field.

In collaboration with the Direction des Musées de France, the Laboratoire de Recherche de Musées de France (LMRF) produced the CD-ROM "Art and Science" in February 1994. This is the first multilingual CD-ROM devoted to the technical studies of paintings and manuscripts. CAL staff, along with approximately 15 project participants, selected 500 images from 120 artifacts (from several thousand possibilities) to illustrate the 150 key words selected by the participants. The participants wrote texts to accompany the images, and those texts were then translated by the participants into eight languages. CAL staff translated texts from German, Italian, and French into English. This project was funded by the French Ministry of Culture.

In addition to these presentations and projects, CAL conservators responded to hundreds of inquiries for information from allied professional colleagues and the general public. To better fulfill this function, CAL staff have begun to update existing and create additional "Guideline" brochures that will contain information on specific

topics relative to artifact care and preservation. The initial phase of this project will conclude in FY 1997, with ongoing editing and development as necessary.

Finally, CAL hosted the Annual Conference of the Association of Graduate Training Programs in Conservation (AGTPC) in April 1994. This was CAL's first opportunity to host the meeting since joining the AGTPC in 1989. In addition to an initial day of presentations by AGTPC students, there was a lively banquet and a second day of lectures by established professionals on the topic "Preserving Research Collections."

Conservation Treatment and Development

CAL conservators conduct conservation treatments and technical studies as part of their educational and research responsibilities. Projects often serve as learning experiences for interns, fellows, Smithsonian staff and other students. They also serve as prototype studies in developing treatment or evaluation procedures for particularly difficult problems or unusual artifacts.

- Furniture Conservation
- Objects Conservation
- Paintings Conservation
- Paper Conservation
- Textiles Conservation

Furniture Conservation

The emphasis on training and education reduced the conservation treatment projects in the Furniture Conservation Laboratory. However, CAL furniture conservators and National Museum of American History Division of Engineering and Industry staff jointly received a Smithson Grant for the research and treatment of an 18th-century fancy-painted English tall case clock. The extensive treatment is being executed under CAL direction by contract conservator William Lewin. The novel treatment and materials research have led to several lectures and one publication.

Work has continued on CAL-sponsored development of commercially viable surface coating products for museum professionals and the general public. A patent application is being prepared. It is the intention to have these products produced and distributed under a Smithsonian product license.

Several treatments were executed by interns under the direction of the furniture conservators. A folding "safari" chair designed by Gustav Klimt from the Cooper-Hewitt collection was cleaned, and the transparent coating inpainted to diminish disfiguring marks on the surface. The replacement of a major loss from a small Egyptian bier (National Museum of Natural History) was fabricated, attached, and inpainted for visual unity. A 19th-century grained chair was consolidated and inpainted to compensate for losses of the paint layers. Finally, a walnut desk from the Renwick Gallery underwent extensive surface treatment, including the fabrication of replacements for areas of loss and extensive inpainting on the top, which was scarred and disfigured by cigarette burns and coffee and food stains.

Objects Conservation

Conservation of archaeological objects remains the focus of treatment and study activities for the objects conservators, interns, and fellows. The principal treatment project for FY 1994 was the continued assembly and documentation of the "Ain Ghazal plaster statuary cache from Jordan.

An objects conservator and the archaeological conservation interns engaged in on-site conservation programs at three archaeological sites with long-standing association with CAL: Harappa, Pakistan; Joya de Cerén, El Salvador; and Copán, Honduras. These programs are supported by grants from the Kress Foundation. Planning and administering these projects are nearly a full-time activity for one conservator. Thousands of objects were treated, and laboratories were set up by CAL conservators at the sites. Additional treatment and technical studies were conducted in the CAL laboratories on selected artifacts from the sites, including a project studying the desalination of samples from Harappa.

The ongoing treatment at CAL of the pigment remains from a Pre-Columbian painted gourd from Joya de Cerén initiated a technical study of other painted gourds from the site. The work was supported by a grant from the Smithsonian's Research Opportunities Fund. Another technical study involved the characterization of a ceramic-textile sherd from Petexbatun, Guatemala.

Other activities included the examination of 12 zinc statues on the Helsinki Cathedral prior to treatment, consulting with Smithsonian's Office of Design Central regarding the treatment by contractors of the sculpture *Columbus Protecting Science and Industry* atop the Arts and Industries Building, and further consulting with ODC about the exterior stone repair study of the Patent Office Building. CAL objects conservators collaborated with Freer/Sackler Galleries staff on the Indus Valley exhibition (scheduled for 1997) in both treatment and training activities, and assistance was provided to the Belize Department of Archaeology in establishing a conservation laboratory, a project supported by the Getty Conservation Institute.

Paintings Conservation

A pair of 19th-century National Museum of American History folk art paintings, *Portrait of Girl with Hat* and *Portrait of Girl with Hoop*, were examined and treated. Staff removed restoration oil-resin varnishes without affecting the underlying thin glazes and scumbles.

An additional 19th-century folk art painting, *Portrait of Woman and Child*, which was severely crackled, underwent detailed examination. Because the painting had never been treated, it provided an excellent opportunity to study the nature of the cracks in the paint layers through microscopic observations and chemical testing. The cleaning treatment of this painting was begun at the end of the year.

Treatments on several easel paintings from the Division of Armed Forces History, National Museum of American History, were completed. *The Effect of the Long-Range Gun, Paris*, required a tear repair, cleaning, lining, and inpainting. The frame was reinforced to accommodate the new, heavier stretcher. *When Brave Men Meet* and *Allies* were also treated and their frames reinforced. *Civil War Battle Scene* required the removal of old facing tissue, superficial cleaning, and varnishing. A similar treatment, with the addition of a minor canvas repair and restretching, was necessary for *General Pershing and the American Troops, July 14, 1919*.

Along with Hirshhorn Museum and Sculpture Garden staff, CAL staff studied Frank Stalla's *Arundal Castle* (1959) to identify the water-soluble components in the moisture-damaged painting. The painting was put on the "no lending" list. A ca. 1863-65 National Museum of American History collection painted textile, *Regiment Color Flag* by Horstmann Brother, was investigated with Suzanne Thomassen-Krauss, textiles conservator, National Museum of American History, to develop a strategy for consolidating flaking gilded paint without affecting other sensitive components of the flag. The painted flag was scheduled for inclusion in the "Smithsonian Treasures" exhibit in Japan.

Mrs. J. Cropper (1793) and *General John Cropper* (1792), by Charles Willson Peale (National Museum of American History), were the focus of a study to characterize the surface coating, preliminarily identified as cross-linked isobutyl-methacrylate, a widely used contemporary restoration varnish resin. The solubility of this coating relative to the paint layers underneath is problematic, and this project will contribute to the field's understanding of the coating and its removability.

Paper Conservation

The primary emphasis during FY 1994 was on preventive conservation and initiating and testing collections care protocols. Collection surveys, involving more than 25 Smithsonian archival and research collections, established comparative, pan-institutional, preservation priorities and solutions for more than 100,000 items in Smithsonian collection. A holdings maintenance - preventive conservation care room was set up by CAL for the National Museum of Natural History Anthropological Archives at the Museum Support Center Anthropology Conservation Laboratory. Smithsonian staff were trained in storage rehousing, using supplies purchased with a Smithsonian Research Resources Grant.

CAL staff consulted with numerous representatives of Smithsonian collections. Projects included designing a comprehensive program for preservation of National Museum of Natural History Plains Indian drawings, providing collection maintenance guidance for the National Air and Space Museum and the National Postal Museum, and consulting with the Archives of American Art about processing and duplication systems.

Treatment for a severely damaged Chinese woodblock print from National Museum of Natural History was completed. The project required the development of techniques for humidifying and flattening the print using a floating screen and polyester film.

Several technical studies were conducted. One project characterized genuine vegetable parchment papers, providing data on color, gloss, opacity, and strength before and after aging for three different examples. Another project focused on problems found in Asian papers. Scanning electron photomicrographs showed the presence of phytoliths, indicating the presence of straw fibers. This is the first time these fibers have been recorded in paper. These silica-covered fibers appear to be responsible for poor bonding properties that have led to extreme deterioration of some Chinese papers. This project included a comparative study on the effects of various humidification systems for flattening paper with sensitive media.

A final project characterized modern water-borne media (mixtures of acrylics with watercolor, gouache, tempera, and casein). Fourier transfer infrared spectra of 11 brands indicated a wide variation of binders and additives. Because gouache can be very friable, artifacts with it are not normally recommended for travel. However, a modern "gouache" painting that is actually gouache mixed with acrylic might be stable enough for travel restrictions to be lifted.

Textiles Conservation

The Textile Conservation Laboratory engaged in a wide range of Smithsonian collections based conservation treatments and technical studies. Treatment and examination of an archaeological silk manuscript continued on behalf of and in the facilities of the Freer/Sackler Galleries. Summer interns contributed to studies of the Star-Spangled Banner for National Museum of American History Division of Conservation, along with the Division's Civil War buntings project, which documented, unfolded, cleaned, and rolled a number of flags in preparation for long-term storage. CAL staff prepared preliminary notes for treatment of the Star-Spangled Banner. CAL staff designed and supervised treatment for a 50-pound button quilt recently acquired by the National Museum of American Art. At CAL, a contract conservator carried out the treatment under the direction of CAL staff. Exhibition designers at the National Portrait Gallery were assisted by the treatment and mounting of a Japanese flag from World War II.

Experimental work was begun on a mordant question associated with Pre-Columbian South American dyeing. CAL staff also completed a major report for textile conservators regarding pigment printing, which cannot be cleaned by traditional methods.

Support and Collaboration

Scientific Support Coordinator/Conservation Scientist
Melanie E. Feather

Analytical Chemist
Camie S. Campbell

Senior Conservator, Paintings
Roland H. Cunningham

Conservation Information Specialists
Gail L. Goriesky
Ann B. N'Gadi

Organic Chemist
Walter R. Hopwood

Research Chemist
Emile C. Joel

Computer Network Administrator
Cheryl D. Sultzer

The Support and Collaboration Group is comprised of specialists from a wide variety of disciplines including the physical and natural sciences, conservation, and library science. Staff members provide analytical and technical support to all CAL research and education programs, to conservation and curation programs in other Smithsonian bureaus, and, on occasion, to other museums and government agencies. The staff of this group also maintain all general-use scientific equipment at CAL. In coordination with the CAL research and education programs, larger collaborative projects with other Smithsonian bureaus are undertaken. Technical information services are provided for all CAL programs, other Smithsonian bureaus, other museums and government agencies, outside conservation professionals, and the public. The production and distribution of CAL publications is also a function of this group.

The Support and Collaboration Group is organized in two programs: Analytical Services and Technical Information. A summary of new and upgraded scientific equipment follows the descriptions of the two programs.

Analytical Services

The Analytical Services staff operate and maintain a large number of analytical instruments and perform or assist with analytical chemistry techniques to support CAL research and education programs and to provide assistance to other Smithsonian bureaus and, occasionally, other museums and government agencies. Instrumental support offerings include Fourier transform infrared spectroscopy (FTIR), gas chromatography-mass spectrometry (GC-MS), scanning electron microscopy with energy dispersive spectroscopy and wavelength dispersive spectroscopy (SEM-EDS-WDS), ultraviolet-visible spectrophotometry (UV-VIS), xero-radiography, x-ray diffraction (XRD), x-ray fluorescence (XRF), and x-ray radiography.

During FY 1994, the analytical staff performed more than 3,000 analyses. About 23 percent of them were done to assist other Smithsonian bureaus and government agencies. The accompanying bar graph illustrates the distribution of these analytical services.

Analyses Performed for Units (other than CAL)

Freer/Sackler Galleries	58
Hirshhorn	62
NASM	14
NMAfA	36
NMAA	23
NMAH	100
NMAI	4
NMNH/MSC	222
NPG	24
OEMS	6
Renwick Gallery	6
FBI	10
Govt. of Puerto Rico	23
State Department	102
National Gallery of Art	7
Walters Gallery of Art	11

Within CAL, analytical support has been provided for conservators, scientists, fellows, interns, and visiting scholars. Assistance for the Objects Conservation Laboratory included work on pigments from Copán, the 'Ain Ghazal figurines from Jordan and related consolidation samples, Guatemalan ceramics, and an Islamic tile. For the Paintings Conservation Laboratory, six whole paintings and a number of painting cross sections were examined. Assistance for the Paper Conservation Laboratory included studying valentines, coated paper, parchment papers, and Chinese paper. Textile conservation projects involved fibers, dust from the Star-Spangled Banner, salts from a glass sheet touching a Tibetan textiles, clothes from an archaeological

burial, and samples from a silk manuscript. Materials science research studies using expertise from the Analytical Services staff included samples from Apollo 11, corrosion from Saturn V, rubber from a B-29 aircraft, photographic film and storage packages for film, painted Petén ceramics, Usulután resist-ware, Zuni ceramics, jadeite, clays, pigments, a Usolsk bowl, kapsels (fortepiano parts), coins, gold-silver-sulfide corrosion products, bones, shells, and eggs.

Analytical Services staff also contributed to many Smithsonian projects outside of CAL, primarily to assist the conservation efforts of staff conservators and curators. Assistance to the Freer/Sackler Galleries included analysis of bronzes and pigments. Hirshhorn Museum and Sculpture Garden work included bronze corrosion from sculptures and several painting cross sections. Some filmy accretions found on vertical glass surfaces and brown deposits found in one of the storage pods were analyzed for the director of the Museum Support Center (MSC). Spacesuit gloves once worn by Michael Collins, now at the National Air and Space Museum (NASM), were radiographed to determine the position of the model hands within the gloves. Assistance to the National Museum of African Art (NMAfA) included analysis of corrosion from wax, bead fragments, a wrought-iron staff head (*Horse and Rider*), and a knife blade. Samples from the National Museum of American Art (NMAA) included those from four paintings by Henry Ossawa Tanner and those from 19th-century silhouette portraits of celebrities. National Museum of American History (NMAH) staff members requested assistance with a large variety of items, reflecting their collections. These included two 16th-century iron cannons, several flags, a replica of the *Statue of Liberty* for examination before and after travel for the recent Japanese exhibition, the plaster statuette *Checkers/Up at the Farm* by John Rogers (also for the Japanese exhibition), 19th-century factory gates from Philadelphia, German spoons, and a viola by Aegidium Klotz. A black coating on a house totem was examined for the National Museum of the American Indian (NMAI).

Like NMAH, the National Museum of Natural History (NMNH) presented CAL with a wide variety of objects to be examined. These included paper from herbarium specimens; asbestos insulation and samples of ceramics exposed to asbestos contamination; forensic samples of teeth, bones, and numerous powders; blue crystals found on an Egyptian mummy that were identified as vivianite; and corrosion from brass brackets used in exhibition cases. Coated papers and a silhouette drawing were examined for the National Portrait Gallery (NPG). The Renwick Gallery submitted a secretion from a salon wall paining for analysis. Assistance was also provided to the Office of Environmental Management and Safety (OEMS) in the analysis of corrosion found in a sprinkler system.

CAL also assists other government agencies as needed, and on occasion, other museums. Such organizations often lack the analytical facilities and staff expertise to perform certain examinations and analyses. A Pre-Columbian gold crown was examined for the Federal Bureau of Investigation (FBI). In addition, samples of metal and corrosion from *The Expanding Universe* sculpture were studied for the State Department. Other metal and corrosion samples from the sculpture *Raíces* were analyzed for the government of Puerto Rico. A discolored stone tablet was examined for the Walters Art Gallery in Baltimore, Maryland. CAL assisted the National Gallery of Art (NGA) with an examination of three bronze metal samples from the National Gallery in London.

As part of CAL's public outreach mission, students from the St. Columba School in Oxon Hill, Maryland, visited CAL. They attended lectures and demonstrations by several staff members and participated in hands-on sessions with some of the analytical equipment. The students examined various samples that related to their science studies at school.

Technical Information

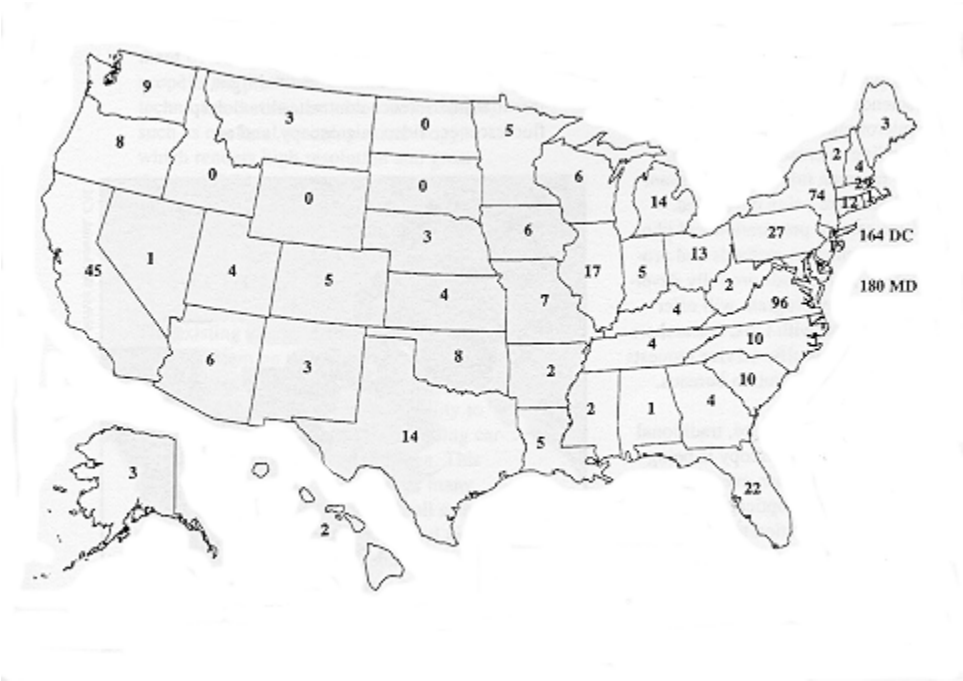
The Information Office is the center of CAL's public outreach programs. The staff assist conservators, scientists, and students within CAL, at the Smithsonian Institution, and from national and international organizations (as far away as Croatia and Kenya) in finding technical and professional conservation-related materials and assistance. The Information Office also serves as the public inquiry center for conservation and general scientific information in the Smithsonian. Staff members conduct data base searches, maintain an up-to-date reprint file, answer questions on conservation-related issues or refer the inquiries to someone who can, and distribute CAL publications, including *Approaches to Pest Management in Museums* and *A Primer on Disaster Preparedness, Management, and Response: Paper-Based Materials*. The staff also conduct official tours of CAL laboratories for visiting scholars, professionals, and dignitaries.

The staff of the Information Office answered 651 inquiries from conservation professionals and the public in FY 1994. They also referred 373 inquiries to be answered by CAL conservators and scientists. Such work involves discussing the inquiry with the person initiating it to determine where to route the question, assigning the request, preparing an informational packet to send out, and checking with the person initiating the inquiry to make sure his or her needs were met. In FY 1994, the Information Office encountered a wide variety of questions and problems, including how to display a seven-foot wooden clipper ship, how to restore a hobby horse, how to preserve hides treated with arsenic, and how to clean silver prior to long-term storage. Referrals for radiocarbon dating services were also made.

Data bases used in the searches include the Conservation Information Network (CIN), Internet, Smithsonian Institution Research Information System (SIRIS), and CAL Archives. Searches during FY 1994 have included the following topics: Mayan textiles, red gold, freezing and cotton, conservation assessment programs, silica gel, acrylic and Plexiglas mounts, ink clarification, mummies, fatty acids and copper alloys, Persian composite art, painted wooden artifacts, poultices, outdoor public sculpture, ethics of 20th-century art conservation, treatment of cobalt and cobalt alloys, adhesives on archaeological textiles, petrified wood buildings, use of enzymes in restoration of paintings, Chinese papermaking and Chinese paper, conservation and cleaning of rubber, storage of photographic materials, vacuum suction table, James Abbott McNeill Whistler's paint box, glass matrix pigments, arsenic in natural history collections, cleaning silver, cleaning of ancient bronze and copper coins, gilding on silk, tracing paper, stamps, manufacture of pigments with lakes, desalination, Spanish Colonial *santos* (carved wooden statues of saints), American gravestones, color measurement, chromatography, phosphine, hot melt adhesives, lead oxidation, lighting on artwork, ebonized finishes on wood, petroglyphs, faience, conservation of aluminum sound recordings, azurite and malachite in paintings, care and maintenance of bronze statues in saltwater air, consolidation of degraded shellac, copal resin, climate control in tropical areas, framing techniques, static electricity and textiles, shell corrosion, earthquake damage prevention, ceramic analysis, glue sticks, Oddy tests, feather treatment, and halon.

Requests on availability and location of reprints come to CAL from throughout the United States and around the world. The CAL Information Office is one of the few places where copies of many conservation and conservation-related publications can be found. If the item is not in the CAL reprint file, the Information Office tries to locate a copy.

The accompanying United States map shows where technical and public inquiries, data base search requests, and reprint requests originated (total of 876). Internationally, 148 such inquiries and requests were received.



Work has also begun on improving CAL's "Guidelines," informational brochures on specialized conservation topics. The "Guidelines" will be revised, edited, and printed in a standardized form. The "Guidelines" will also, in the future, be produced in standardized format, using an in-house desktop publishing program. So far, general guidelines on conservation-related addresses, sources for conservation materials, and time capsules have been updated. Informational publications from other sources (such as other conservation professionals and product suppliers) are being evaluated to determine if they might be of use to researchers, conservators, and the public.

New or Upgraded Scientific Equipment

CAL added or upgraded several pieces of research and computer equipment during FY1994 with funds provided by the Smithsonian Institution Research Equipment Pool and the Smithsonian Institution Computer Pool. These purchases substantially added to CAL's microscopy, analytical, environmental monitoring, and computing capabilities.

Microscopy

The microscopy equipment at CAL is undergoing major expansion and updating. A new microscope (with accessories) for materials science research, a Leica DMRX Research microscope, has become the heart of this expanding microscopy program. Methods for research microscopy relevant to CAL's mission are being developed. These include sample preparation and photographic documentation methods and protocols. After these methods are fully developed, the microscopy program will offer general collaboration with CAL researchers and assistance with specific service requests to other Smithsonian Institution bureaus.

In the field of materials science, traditional optical (visible light) microscopy is being used to a greater degree than ever before. The reasons are simple: optical microscopy provides sufficient resolution to answer most questions and also provides a context for further analytical procedures. The techniques of optical microscopy have, until recently, been somewhat forsaken in the conservation laboratory. But a combination of techniques, many of them nondestructive, shows great promise for conservation applications, CAL's research microscope is currently configured for transmitted and incident light (bright- and dark-field), polarized incident and transmitted light, differential interference contrast, ultraviolet fluorescence, video microscopy, and an analog-to-digital interface for image analysis and measurement. This research microscopy allows researchers to analyze systematically materials, including coatings, paints, organic supports (wood, paper, textile), metals, ceramics, composites, and photographic and magnetic media. Documentation is simplified and reproducible. The photographic image is permanently imprinted with data generated by a microprocessor-controlled three-camera system. A dedicated high-resolution video camera can videotape or provide a means to collect images for analysis and measurement by computer processing. The microscope is the platform for a number of other techniques that can be added in the future, such as confocal scanning microscopy, which renders high resolution and great depth of field in unprepared (even live tissue) samples.

Analytical

The existing energy dispersive spectroscopy (EDS) system on the CAL scanning electron microscope (SEM) was upgraded, expanding the EDS detector capability to low atomic number elements, including carbon, oxygen, fluorine, and nitrogen. This capability allows the resolution of many ambiguities in the analysis of small samples, such as corrosion products and pigments. It increases the elemental analysis capability of the SEM, already one of the most commonly requested analytical tools at CAL.

Environment Monitoring

Two two-stage dew-point meters were purchased to support the environmental experimental research at CAL. Such research must be accurately monitored with respect to temperature and relative humidity. CAL researchers have found that reliable and accurate environmental monitoring is possible only with dew-point meters that can sample the ambient air without changing the moisture content.

Computing

A Dell OmniPlex Pentium 90 MHz computer was purchased for the mechanical testing program. This computer is used for the refinement of models pertaining to the effects of environmental conditions on cultural materials.

Staff

Ingrid C. Alexander, Research Art Historian. B.A. (1971) Emmanuel College; M.F.A. (1975) Villa Schifanoia, Italy; Ph.D. (1990) Catholic University of Louvain, Belgium. Areas of interest: the study of the historical and technical development of European and American paintings; scientific analysis of painting materials and techniques.

Mary T. Baker, Research Organic Chemist. B.S. (1980); Ph.D. (1986) University of Connecticut. Areas of interest: magnetic media, primarily videotape; natural and synthetic modern rubber; archeological rubber; synthetic coatings and modern paints; chemical and physical studies of modern polymers, primarily plastics.

Mary W. Ballard, Senior Conservator, Textiles. B.A. (1971) Wellesley; M.A. and Diploma in Conservation (1979) Institute of Fine Arts, New York University. Areas of interest: textile preservation, storage, and treatment.

Harriet (Rae) F. Beaubien, Conservator, Objects. B.A. (1972) Beloit College; M.A. (1976) University of Chicago; Diploma in Conservation (1986) Institute of Fine Arts, New York University. Areas of interest: archaeological objects, on-site conservation; decorative arts.

Ronald L. Bishop, Research Coordinator/Senior Research Archaeologist; Manager, Smithsonian Archaeometric Research Collections and Records (SARCAR). B.A. (1965) San Francisco State University; Ph.D. (1975) Southern Illinois University. Areas of interest: archaeology of Meso- and Central America; ancient materials characterization; exchange systems; quantitative methods.

M. James Blackman, Senior Research Chemist. B.A. (1965), M.A. (1970) Miami University, Oxford, OH; Ph.D. (1975) Ohio State University. Areas of interest: archaeological materials characterization; exchange systems; production technology and organization, Old World and Middle East.

Camie S. Campbell, Analytical Chemist. B.S. (1987) Howard University. Areas of interest: chemical analysis of art objects and archaeological materials.

Roland H. Cunningham, Senior Conservator, Paintings. B.A. (1962) New York University. Additional studies: Institute of Fine Arts, Conservation Center, New York University. Areas of interest: inorganic characterization of paints, pigments and archaeological materials; technical studies of artists' materials and techniques on canvas, panel paintings, and polychromed wood sculpture.

W. David Erhardt, Senior Research Organic Chemist. B.S. (1972) University of Miami; Ph.D. (1977) University of Maryland. Areas of interest: identification and chemistry of archaeological and historic organic materials; the museum environment; degradation processes; accelerated aging; the cleaning of paint films.

Loretta E. Ester-Clark, Administrative Support Assistant. Certificate (1981) Prince George's Community College. Additional studies: (1993) Prince George's Community College. Responsibilities: payroll, timekeeper, staff travel coordinator, fellows and visiting scientist secretary.

Melanie E. Feather, Scientific Support Coordinator/Conservation Scientist. B.A. (1984) Franklin and Marshall College; M.S. (1986) University of Michigan. Areas of interest: application of electron and x-ray techniques to the study of art objects, archaeological material, and other museum specimens.

Mary L. Garbin, Conservator, Objects. B.A. (1961) and M.A. (1970) University of California at Los Angeles; Diploma in Archaeological Conservation (1973) Institute of Archaeology, London University. Areas of interest: technology and conservation of leather, especially historic leather.

Martha Goodway, Metallurgist. S.B. (1958) Massachusetts Institute of Technology. Areas of interest: archaeometallurgy; the study of the traditional technologies of mining, smelting, refining, and forming of metals and their by-products in Europe, Egypt, and Southwest Asia; the metals of music.

Gail L. Goriesky, Conservation Information Specialist. B.A. (1969) Michigan State University; additional studies University of Mannheim, Germany; San Francisco Art Institute; San Francisco State University; Goethe Institute, Rothenburg o.d. Tauber, Germany. Areas of interest: desktop publishing.

Carol A. Grissom, Senior Conservator, Objects. B.A. (1970) Wellesley College; M.A. (1974) Oberlin College. Areas of interest: sculptures in bronze, stone, zinc, plastic, and wood.

Walter R. Hopwood, Organic Chemist. B.S. (1966) University of Pittsburgh. Areas of interest: synthetic polymers and effects of commercial products on conservation treatments, museum display and storage; carbohydrate gums.

Emile C. Joel, Research Chemist. B.S. (1977) University of the District of Columbia. Areas of interest: application of mass spectrometric techniques to provenience studies of archaeological and historical materials through lead isotope analysis.

Francine T. Lewis, Training Program Assistant. Certificate (1980) University of the District of Columbia; Certificate (1984) Prince George's Community College. Responsibilities: education and training liaison, training budgets, travel coordinator, internship liaison.

Mark H. McCormick-Goodhart, Senior Research Photographic Scientist. B.S. (1976) Rochester Institute of Technology. Areas of interest: modern and historical photographic materials and processes; conservation of photographs; electronic imaging and image evaluation.

Marion F. Mecklenburg, Senior Research Scientist. B.S.C.E. (1970), M.S. (1972), Ph.D. (1984) University of Maryland. Areas of interest: mechanical properties of solid materials and the effects of environmental factors such as temperature and moisture; computer modeling of structures under static and dynamic loadings.

Ann B. N'Gadi, Conservation Information Specialist. B.A. (1987) University of Oregon; M.L.S. (1992) University of Maryland. Additional studies: Westminster College; University of Pittsburgh. Areas of interest: anthropology and archaeology; computer applications for information science and retrieval; Internet applications.

Jacqueline S. Olin, Senior Research Chemist. B.S. (1954) Dickinson College; M.A. (1955) Harvard University. Areas of interest: the use of physical and chemical methods of dating, studying provenience and ancient technology; Spanish and Spanish Colonial ceramics.

Alan W. Postlethwaite, Deputy Director. B. Met. (Hons.) (1944) Sheffield University, England; S.M. (1949) Massachusetts Institute of Technology. Areas of interest: laboratory management; museum pest control and fumigation practice; application of science to the study and prevention of deterioration in materials and objects.

Jocelyn D. Sellers, Office Assistant. Certificate (1992) Prince George Community College; certificate (1995) Bowie State University. Responsibilities: Office of the Comptroller liaison, procurement liaison, data entry.

Beverly M. Smith, Assistant to the Director. Certificate in Nursing (1971) American University; A.A. (1984) Center for Independent Studies. Responsibilities: EOE Officer; budget forecasting, budget administration; office manager; liaison for human resources, fellowships and grants, sponsored projects, plant services, design and construction.

Cheryl D. Sultzer, Computer Specialist. B.S. (1984) Morgan State University; B.S. (1993) University of Maryland. Responsibilities: computer applications, networking, communications, training on new software or changes to the network.

Jia-sun Tsang, Conservator, Paintings. B.S. (1974) Bowling Green State University; M.S. (1985) University of Delaware. Areas of interest: artists' materials and techniques; characterization and surface cleaning of painting varnishes; modern painting media and varnishes.

Charles S. Tumosa, Senior Research Chemist. B.S. (1966) St. Joseph's College; Ph.D. (1972) Virginia Polytechnic Institute and State University. Areas of interest: analysis of trace materials; mechanical and materials properties of modern materials; tsarist Russian coins and medals.

Noreen C. Tuross, Research Biochemist. B.A. (1973) Boston University; B.S. (1975) Trinity College; M.A. (1978) Bryn Mawr College; Ph.D. (1985) Brown University. Areas of interest: biomineralization with an emphasis on shell proteins in inarticulate brachiopods; molecular preservation in subfossil vertebrates and invertebrates; archaeometric uses of protein and DNA in subfossil bone.

Dianne van der Reyden, Senior Conservator, Paper. B.F.A. (1975) Virginia Commonwealth University; M.A. (1979) and Diploma in Conservation (1980) New York University; Certificate in Paper Conservation (1981) Fogg Art Museum, Harvard University. Areas of interest: technology of specialty papers found in art, archives, and library collections, including transparent, coated and dyed papers; development and evaluation of conservation treatments for paper and photographs.

Pamela B. Vandiver, Senior Ceramic Scientist. B.A. (1967) Scripps College; M.A. (1971) Pacific Lutheran University; S.M. (1983) and Ph.D. (1985) Massachusetts Institute of Technology. Areas of interest: the analysis, reconstruction, and explanation of conservatism and innovation in craft technologies and material culture, especially Paleolithic ceramic, soft stone, and pigment use; Neolithic plaster and pottery techniques; early glass; slag and glaze technology in Eurasia using the methodologies and techniques of archaeology and materials science; site resource survey.

Lambertus van Zelst, Director. Ph.D. (1971) University of Amsterdam, The Netherlands. Areas of interest: development and application of chemical and physical methods for the technical study and analysis of art objects and archaeological materials.

David W. von Endt, Senior Research Organic Chemist. B.A. (1960) Columbia Union College; M.S. (1966) University of Maryland; Ph.D. (1974) Howard University. Areas of interest: application of organic chemistry to problems in museum conservation and archaeology and to the study of natural organic compounds; chemical dating of archaeological bones and teeth.

Melvin J. Wachowiak, Jr., Senior Conservator, Furniture. B.S. (1981) Springfield College; M.S. (1989) Winterthur Museum, Art Conservation Program, University of Delaware. Areas of interest: history, characterization, and surface cleaning of coatings; wood technology and anatomy; microscopy; training.

Donald C. Williams, Education Coordinator/Senior Conservator, Furniture. B.A. (1985) University of Delaware. Areas of interest: furniture finishes and colorants.

Vernetta M. Williams, Administrative Officer. B.S. (1954) Howard University. Responsibilities: financial transactions, procurement, and property accounting.

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Vandiver, Pamela B., Daphne S. Barbour, and Shelley G. Sturman. "Technical Appendix II: The 'Saint Porchaire' Ceramics," In *Western Decorative Arts, Part I: Medieval, Renaissance, and Historicizing Styles, Including Metalware, Enamels and Ceramics*, by Rudolph Distelberger, Alison Luchs, Philippe Verdier, and Timothy H. Wilson, pp. 264-280, Washington, DC: National Gallery of Art and Cambridge University Press, 1994.

Vandiver, Pamela B., Daphne S. Barbour, Shelley G. Sturman, David Ilan, and Maud Spaer. "An Early Glass bead from Tel Dan, Israel," *Israel Exploration Journal*, vol. 44, no. 4 (1993): 230-234.

van Zelst, Lambertus. "Fine Art Examination and Conservation," In *Kirk-Othmer Encyclopedia of Chemical Technology*, 4th Edition, pp. 853-900, New York, NY: John Wiley & Sons, 1994.

von Endt, David W. "The King and I: A Sponge from the Tomb of Phillipos II," *Carnegie Institution Yearbook*, p. 80, Washington, DC: Carnegie Institution of Washington, 1993.

von Endt, David W. "The Analysis of Fluids from Mammalian Type Specimens," *Collection Forum*, vol. 10 (Spring 1994): 45-54.

Wachowiak Jr., Melvin J., Donald C. Williams, and William Lewin. "Conservation of an 18th Century English Japanned Surface," In *Lacquerwork and Japanning*, pp. 27-29, London: United Kingdom Institute for Conservation, 1994.

Presentations by Staff

Alexander, Ingrid C.
"Painting Techniques and Materials from Ancient Times to the Present," lecture to "Materials Science of Art and Cultural Objects," Johns Hopkins University, Baltimore, MD, March 1994.

"Impact of Early Netherlandish Painting on Italy," lecture to the Faculty of the Arts, Tel Aviv University, Israel, April 1994.

Baker, Mary T.
"Ancient Mexican Rubber Artifacts and Modern American Spacesuits: Studies in Crystallization and Oxidation," lecture to Materials Issues in Art and Archaeology IV, Materials Research Society, Cancun, Mexico, May 1994.

Ballard, Mary W.
"Your Catastrophe Has Already Been Selected for You," lecture to the Textiles Section of the Mid-Atlantic Association of Museums conference, "Conservation Dialogue: What Collections Managers Need to Know," February 1994.

"Tropical vs. Temperate Conservation," lecture to the Conservation Center, Institute of Fine Arts, New York University, at Cooper-Hewitt Museum, February 1994.

"Insects and Wool Textiles," lecture to the MOVE Crew, National Museum of Natural History, February 1994.

"Museum Textile Conservation," lecture to the International Fabricare Institute, Silver Spring, MD, May 1994.

Beaubien, Harriet F. (Rae)
"The Preacquisition History of Archaeological Collections," lecture to the Anthropology Department MOVE Crew, Smithsonian Institution, Washington, DC, April 1994.

"'Low-Tech' Methods for Characterizing Materials in the Field," lecture to Materials Issues in Art and Archaeology IV, Materials Research Society, Cancun, Mexico, May 1994.

Bishop, Ronald L.
"The Petexbatun: A Ceramic Compositional Isolate among the Classic Maya," lecture to the International Congress of Americanists, Stockholm, Sweden, July 1994.

"Science, Art, and the Pre-Columbian Past," lecture to the Pre-Columbian Society of Washington, Washington, DC, December 1994.

Bishop, Ronald L., Veletta Canouts, Roland H. Cunningham, and Dorie Reents-Budet
"Ceramic Technology, Composition, and Archaeological Interpretation: Examples from the Americas," lecture to the Eighth Cimtec World Ceramics Congress, "Ceramics Heritage," Faenze, Italy, June 1994.

Erhardt, W. David
"Paper Aging Research," lecture to the Conservation Forum of the Graduate School of Library and Information Science, The University of Texas at Austin, Austin, TX, November 1993.

"Scientific Principles of Conservation," lecture to the International Centre for the Study of the Preservation and the Restoration of Cultural Property (ICCROM), Rome, Italy, February 1994.

"Paints Based on Drying Oil Media," lecture to the "Painted Wood: History and Conservation" meeting, Williamsburg, VA, November 1994.

Erhardt, W. David, and Marion F. Mecklenburg
"Accelerated vs. Natural Aging: Effect of Aging Conditions on the Aging Process of Paper," lecture to Materials Issues in Art and Archaeology IV, Materials Research Society, Cancun, Mexico, May 1994.

Goodway, Martha
"Metallurgy in the Museum," lecture to the Arkeologisk museum i Stavanger, Stavanger, Norway, February, 1994.

"Current Issues in Archaeometallurgy," lecture to Stockholm University, Stockholm, Sweden, March 1994.

"Metals," lecture to Anthropology 212 course, "Metals and the Identification of Natural Fibers," George Washington University, Washington, DC, May 1994.

"Great Orme Mine Project and the Guinier-Preston Zones in the Wright Flyer Aluminum," lecture to the Historical Metallurgy Society Annual Conference, Sansea, Wales, September 1994.

Goodway, Martha, and Frank W. Gayle
Seminar on the aluminum of the Wright Flyer, National Institute of Standards and Technology (NIST), Gaithersburg, MD, February 1994.

Goodway, Martha, and Joan J. Taylor
"The Great Orme Mine and the Re-Evaluation of European Early Bronze Trade," a lecture to the 95th Annual Meeting of the Archaeological Institute of America, Washington, DC, December 1994.

Grissom, Carol A.
"Diagnosis, Treatment Decisions, and Documentation: An Objects Conservators' Point of View," lecture to National Association of Corrosion Engineers Meeting, "Dialogue/94, Coatings for Outdoor Metals Used in Artistic and Historic Works," Baltimore, MD, July 1994.

Mecklenburg, Marion F.
"Art in Transit," a two-day workshop, Oberlin College, OH, November 1993.

"Current Research in Art in Transit and the Effects of the Museum Environment," lecture to the American Association of Museums Annual Meeting, Seattle, WA, April 1994.

"Recent Advances in Research on the Determining Allowable Fluctuations of the Museum Environment," lecture to the National Gallery of Art, Washington, DC, April 1994.

Mecklenburg, Marion F., Charles S. Tumosa, and Jonah D. Erlebacher
"The Mechanical Behavior of Artists' Acrylics Paints under Equilibrium Conditions," lecture to the Polymers in Museums Symposium, American Chemical Society, Washington, DC, August 1994.

Mecklenburg, Marion F., Charles S. Tumosa, and Mark H. McCormick-Goodhart
"A General Model Relating Externally Applied Forces to Environmentally Induced Stresses in Materials," lecture to Materials Issues in Art and Archaeology IV, Materials Research Society, Cancun, Mexico, May 1994.

Mecklenburg, Marion F., Charles S. Tumosa, and Nicholas Wyplosz
"The Effects of Relative Humidity on the Structural Response of Selected Wood Samples in the Cross-Grain Direction," lecture to Materials Issues in Art and Archaeology IV, Materials Research Society, Cancun, Mexico, May 1994.

Mecklenburg, Marion F., Nicholas Wyplosz, and Charles S. Tumosa
"The Mechanical Properties of Crossed-Grain Wood with Varying Relative Humidity," lecture to the American Institute of Conservation Conference, Nashville, TN, June 1994.

Mery, Sophie, and **M. James Blackman**
"Indus Ceramics on the Oman Peninsula," lecture to the World Archaeological Conference III, Delhi, India, December 1994.

Olin, Jacqueline S., Emile C. Joel, Edward V. Sayre, and Robert D. Vocke
"The Probable Sources of Lead in Some 15th-16th Century Spanish Artifacts," poster at the 29th International Archaeometry Symposium, Ankara, Turkey, May 1994.

Steponaitis, Vincas, **M. James Blackman, and Hector Neff**
"Large-Scale Patterns in the Chemical Characterizations of Mississippian Ceramics," lecture to the Southeastern Archaeological Conference, Lexington, TN, November 1994.

Tuross, Noreen C.
"Ancient DNA in Bone," lecture to the 2nd International Ancient DNA Meeting, Smithsonian Institution, Washington, DC, October 1993.

"Ancient Biomolecules," lecture to the Evolution Seminar, California Institute of Technology, Pasadena, CA, December 1993.

"Macromolecular Preservation in Ancient Bone," lecture to the Dinosaur Meeting, Purdue University, Indianapolis, IN, May 1994.

"Archaeological Artifacts and Biomolecule Affliction: A Test of Cleaning and Implications for Excavation," lecture to Materials Issues in Art and Archaeology IV, Materials Research Society, Cancun, Mexico, May 1994.

"Protein and DNA Preservation in Ancient Bone," lecture to the Ancient DNA Symposium, Evolution Meeting, Atlanta, GA, September 1994.

"Paleodietary and Paleoenvironmental Isotopic Data from Kents Cavern," lecture to Fourth Advanced Seminar on Paleodiet, Banff, Canada, September 1994.

van der Reyden, Dianne
"Maximizing Minimum Resources for Paper-Based Collections by Integrating Preventive Care, Research and Training Programs," lecture to American Culture and Conservation Fellows from Winterthur Conservation Program, University of Delaware, February 1994.

"Art or Archives?" lecture to the Association of Graduate Training Programs in Conservation Annual Conference, "Preserving Research Collections," Washington, DC, April 1994.

"Genuine Vegetable Parchment Paper: Characterization of Some Chemical and Physical Properties before and after Aging," lecture to Materials Issues in Art and Archaeology IV, Materials Research Society, Cancun, Mexico, May 1994.

"National Park Service Workshop for Archivists," a two-session event including "Identification of the Enemies of Archives-Preservation of Archives and Manuscript Collections" and "Stabilizing Archival Collections," Tucson, AZ, May 1994.

"Technical Study of a Sam Francis 'Gouache' Wedged between Glass," lecture to conference, "Modern Materials, Modern Problems," Tate Gallery, London, UK, June 1994.

"Repair of Pop-Up Books and Other Mechanical Chromolithographs," lecture co-authored with graduate archives conservation intern Laura Steward, American Institute for Conservation Book and Paper Group Specialty Session, Nashville, TN, June 1994.

"Maximizing Minimum Resources: An Ounce of Prevention," poster at the International Institute for Conservation (IIC) Preventive Care Conference, Ottawa, Canada, September 1994.

van der Reyden, Dianne, and Mary T. Baker
"Genuine Vegetable Parchment Paper and the Effects of Accelerated Aging on Some Physical and Chemical Properties," lecture to Materials Issues in Art and Archaeology IV, Materials Research Society, Cancun, Mexico, May 1994.

Vandiver, Pamela B.
"Art, Science and Technology in Ancient Cultures," lecture to the MIT Club of Washington, The Castle, Washington, DC, October 1993.

"China as an Altered Landscape: The Relation between Pottery and Agriculture," lecture to the American Anthropological Association, Washington, DC, November 1993.

"The Art, Science and Technology of Ancient Material Culture," lecture to AT&T, Bell Laboratory, Murray Hill, NJ, December 1993.

"The Origins of Ceramics in the Upper Paleolithic Period at Dolni Vestonice, Czechoslovakia," lecture to the Centre Nationale Recherche Scientifique Conference, Terre Cuite et Societe, Nice, France, November 1993.

"Corinthian Amphora," lecture to the Archaeological Institute of America, December 1993.

"Corrosion of Synthesized Glasses and Glazes as Analogs for Nuclear Waste Glass Degradation," lecture to the Fall Materials Research Society Meeting, Boston, MA, December 1993.

"Materials Science of Ancient Artifacts," lecture to the Materials Science Club of New York, Brown University Club, December 1993.

"Interactions among the Crafts of Copper Smelting, Glass and Glaze Manufacture in the Bronze Age of the Ancient Near East," American Society for Metals, Mid-Atlantic States Chapter, December 1993.

"Paleolithic, Neolithic, and Urban State Cultures," lecture to the interdisciplinary program in History and Life Sciences, Chantilly High School, January 1994.

"Paleolithic Pigment Processing Reconstructed from Artifacts in the National Museum of Natural History Collections," Paleoanthropology Seminar, National Museum of Natural History, Washington, DC, March 1994.

"The Use and Reuse of Window Glass at Sardis," lecture to the Archaeometry Conference, Ankara, Turkey, May 1994.

Vandiver, Pamela B., and Robert C. Henrickson
"The Potter's Wheel in the Ancient Near East," lecture to the Archaeological Institute of America, Washington, DC, December 1993.

"Traces of Pottery Production," lecture to the Archaeometry Conference, Ankara, Turkey, May 1994.

"The Origins of Ceramics at Dolni Vestonice," lecture to the "Ceramics Heritage," Eighth Cimtec World Ceramics Congress, Faenze, Italy, June 1994.

Vandiver, Pamela B., and Blythe E. McCarthy
"Glazes from Nippur," lecture to the Archaeological Institute of America, Washington, DC, December 1993.

"Corrosion of Glazes from Nippur, Iraq," lecture to the Eighth Cimtec World Ceramics Congress, "Ceramics Heritage," Faenze, Italy, June 1994.

Vandiver, Pamela B., and Olga Soffer
"Upper Paleolithic Ceramics at Pavlov, Czechoslovakia," lecture to the Society of American Archaeology, St. Louis, MO, April 1994.

von Endt, David W.
"The Preservation of Insects in Fluid," lecture to the Entomology Collections Network, Entomological Society of America, Purdue University, Lafayette, IN, December 1993.

Wachowiak, Melvin J., Jr.
"Conservation of an 18th Century English Japanned Surface," lecture to the Conference on Japanning and Lacquerwork, Tate Gallery, London, UK, November 1993.

"Comparative Approaches to Working Wood: East vs. West," lecture to Yale University Symposium on Materials Culture, "Wood," New Haven, CT, April 1994.

Williams, Donald C.
"Furniture Care and Preservation," lecture to the Fort Ward Museum, Alexandria, VA, October 1993.

"Furniture Conservation in the Museum," lecture to the Smithsonian Institution Research Associate's Program course "Antique Furniture," February 1994.

"From Log to Lumber," lecture to the Yale University Symposium on Material Culture, "Wood," New Haven, CT, April 1994.

"In Search of the Perfect Polymer," lecture to the American Chemical Society Symposium "Polymers in Museums," Washington, DC, August 1994.

Grants

Smithsonian Institution Funding

Computer Pool, $4,350

- Dell OmniPlex Pentium 90 MHz computer, $4,350

Research Equipment Pool, $80,707

- new research microscope, $45,886
- upgrade of energy dispersive spectroscopy (EDS) system, $19,443
- two two-stage dew-point meters, $15,378

Williams, Donald C. and Carlene Stephens

- "Treatment of an English Japanned Clock," James Smithson Society, $16,000

Tuross, Noreen C.

- "Tropic Placement of *Lingula reevii*," Abbott Endowment Fund, $5,000

Tuross, Noreen C. and Melvin J. Wachowiak

- "Molecules on the Edge," Collections-Based Research Fund, $5,000

van der Reyden, Dianne

- "Research, Libraries, and Archives Collections Conservation Task Force (RELACT)," Research Resources Program, $17,000

External Funding

Beaubien, Harriet F. (Rae)

- "Archaeological Conservation Internship Program," Samuel H. Kress Foundation, $4,600

Mecklenburg, Marion F. and Charles S. Tumosa

- "The Development of General Guidelines for Setting Safe Allowable Temperature Fluctuations for Museums, Historic Sites, and Cultural Collections," National Center for Preservation Technology and Training grant, $39,000

Tuross, Noreen C. and Melvin J. Wachowiak

- "Blood on Stone Tools," National Center for Preservation Technology and Training grant, $40,000

van Zelst, Lambertus and Carol A. Grissom

- "Development of an Evaluation Methodology for Stone Cleaning Damage Assessment," U.S. National Park Service contract, $40,000