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Statement by the Director

Lambertus van Zelst, Director

It is a pleasure to introduce this first issue of the CAL Annual Research Reports. This document is intended for the information of our colleagues in the fields of conservation, preservation, analytical and technological studies of cultural materials, as a reference to the research ongoing at CAL. By no means are these reports intended as an alternative to publication; they merely serve to record the nature of the various projects pursued by CAL researchers, together with an indication of actual progress in those projects.

Research is major, but certainly not the only activity at CAL. Training and education, as well as various technical/analytical and information support activities, complement research, combining into an integrated environment where individual staff members contribute simultaneously in different functional areas. This report does not reflect these other activities, outside research. In the future, we expect to include those areas as well in what then will be an actual annual CAL report.

As many other organizations, CAL is going through an internal evaluation and planning process, which is expected to come to completion shortly. The next annual report would likely reflect the outcome of that process in format and content. Rather than wait yet another year to provide this annual information, we have preferred to go ahead and produce a more limited Research Report, based on submissions by individual researchers, with only limited editing. I want however to acknowledge especially the contribution of Gail Goriesky, who acted as production editor, and worked very hard to produce a consistency of format which makes this an eminently readable report.

1993 was a successful, but not necessarily an easy year for CAL. Budget economies forced us to discontinue some programs and reduce our staff, and still make do with less in the remaining programs. However, the challenge has been met admirably by CAL's staff, as this report demonstrates clearly for the research programs. Major breakthroughs in the area of the characterization of materials properties are opening tantalizing avenues for a vastly improved understanding of the relationships between physical and chemical stability and environmental variables, which in turn may permit formulations of optimal conditions for storage and exhibit based on true quantitative theory. The application of new analytical technologies to cultural materials continues to expand dramatically our ability to interpret the past from the material record. Development and testing in conservation technology produced the formulations of new treatment materials and techniques.

On behalf of all CAL staff, I offer you this report in the hope that it will provide you with useful information on who at CAL is doing what research in areas of your and our concern. Please contact individual researchers for more detailed information on projects which raise your specific interest.
Archaeometry

Jacqueline S. Olin, Assistant Director for Archaeometric Research
Ingrid C. Alexander, Research Art Historian
Ronald L. Bishop, Senior Research Archaeologist
M. James Blackman, Senior Research Chemist
Martha Goodway, Metallurgist
Emile C. Joel, Research Chemist
Pamela B. Vandiver, Research Scientist in Ceramics

In FY 1993 the Archaeometry Section has undertaken a unique program of archaeological and art historical research which utilizes the staff and facilities of the Conservation Analytical Laboratory and the National Institute of Standards and Technology. The fields of chemistry, physics, biochemistry, materials science, archaeology and art history are represented among the staff. Collaboration with researchers from other museums and from universities is extensive and involves both national and international programs. The Smithsonian's program of Research Collaborators and Research Associates is used extensively by the staff.

The following are the research programs of the Archaeometry section:

**New World Archaeology:** The American Southwest, The Maya Region of Southern Mexico and Central Mexico, Lower Central America Projects

**Old World Archaeology:** Near Eastern Obsidian Exchange Program, Near Eastern Craft Production and Exchange Program, Program for the Archaeometric Characterization of Epigraphic and Iconographic Artifacts, Lead Isotope Ratio Program

**Materials Science and Ancient Technology**

**Historical Archaeology**

**Technical Studies in Art History**
New World Archaeology

Research emphasis within the New World Programs is given to archaeological questions concerning the prehistory of the Maya region of southern Mexico and Central America, and Central America south of the Maya (Honduras, El Salvador, Nicaragua, and Costa Rica), and the American Southwest. Data obtained through the use is physical and natural science techniques are combined with more traditional kinds of archaeological information to assist in the determination of social, economic, and ideological relationships among Pre-Columbian peoples. Pottery, with its many attributes of style, form, etc., is the major focus of analytical attention. Materials analyzed in the course of problem-oriented research are obtained from previous or current archaeological survey and excavation projects as well as through the use of national and institutional collections. Specific archaeological questions are addressed by separate teams of researchers who bring to the projects a wide variety of specialized knowledge. Within each geographic region, the individual projects contribute to a greater interpretive whole as each investigation tends to build on previous research. The individual projects within the New World Archaeological Programs, grouped below by geographical area, are lead by Ronald L. Bishop, Senior Research Archaeologist.

The American Southwest

Physical and Behavioral Sources of Variation in Hopi Pottery Production and Exchange, A.D. 1300-1890
Ronald L. Bishop, CAL
Veletta Canouts, U.S. National Park Service; Research Associate, CAL
Suzanne P. DeAtley, University of Colorado
Alfred Qoyawayma, Hopi potter and engineer, Arizona
Carroll L. Riley, Emeritus Professor, Southern Illinois University

Chemical, technological, archaeological, and detailed stylistic data on Hopi yellow-firing pottery, produced between A.D. 1300-1890, are combined with Hopi oral tradition to investigate aspects of population amalgamation and social organization on the Hopi Mesas. The following areas are investigated: (1) the scale of production; (2) shared social information; (3) covariance of technological and design attributes. Technological or compositional changes observed in the pottery as well as changes in the inferred exchange patterns are combined with contact period accounts to address changes in Hopi social organization and the impact of Spanish contact on historic Hopi society.

Chemical analyses of more than 1600 samples from Hopi vessels have been completed. Several pronounced patterns within the data reveal that, contrary to popular models, a considerable amount of yellow-firing pottery was produced at sites not on the mesas. Indeed, with exception of a strong trading relationship between Awatovi (on Antelope Mesa) and Homolovi (off the mesas, on the Little Colorado River), little evidence has been found for trade of pottery from the Hopi Mesa villages. Additional patterns within the chemically-derived data suggest that the existing patterns of Hopi ceramic production continued after Spanish contact but then were significantly altered following the Hopi revolt against the Spanish. Papers describing these research findings are being readied for publication. The interpretation of analytical findings for the post-Spanish contact period is furthered by the completion of a report that reviews information in archival sources regarding Hopi craft activities. Research effort during the forthcoming year will be devoted largely to a program of experimental firings that seek to characterize the "yellow" surface color firing technology of Hopi pottery that was used during A.D. 1300-1600, but which was subsequently lost.
Production and Exchange of Mimbres Black-on-White Pottery
Ronald L. Bishop, CAL
Veletta Canouts, U.S. National Park Service; Research Associate, CAL
Patricia Gilman, University of Oklahoma
Frederick W. Lange, University of Colorado

The classic black-on-white Mimbres vessels, which have been touring the country in several traveling museum exhibits, are some of the finest examples of ceramic art produced in the American Southwest. For a longer period than most other cultural groups of the Southwest, the people who inhabited the Mimbres Valley in southwestern New Mexico were recognized primarily by their pottery as archaeologists and art collectors filled museums with bowls and jars painted with highly stylized images. Notwithstanding the attention given these vessels, the nature of the production and exchange of this pottery remains problematical.

Compositional research has determined that differentiation among pottery producing areas can be achieved. A report of this research is under review by American Antiquity. The purpose of this research project was to analyze the range of compositional variability in the Classic Mimbres style ceramics in order to establish a baseline for determining sources of production and directionality in trade. This has been achieved. At this time, no future research on Mimbres pottery is being considered.

Development and Distribution of Zuni Matsaki Polychrome
Ronald L. Bishop, CAL
Barbara J. Mills, University of Arizona
Hector Neff, University of Missouri Research Reactor Facility
Michael Glasscock, University of Missouri Research Reactor Facility

Research is underway to assess the number and location of production centers responsible for the production of Matsaki Polychrome, the major painted ceramic produced in the Zuni area between A.D. 1400 and 1680. The ceramic was known to exist at all six Zuni occupied sites during the period of initial European exploration of the American Southwest. Importantly, Matsaki Polychrome bears decorative designs that are identical or at least highly similar to those found on Hopi pottery from the same period. During the period under investigation, information and population movements between the Zuni and Hopi regions were frequent. The research data will contribute to our understanding of social relationships among Zuni occupied villages as well as to the results and mechanisms for information exchange.

The CAL analytical component of the project is completed. Compositional analyses by Instrumental Neutron Activation Analysis (INAA) demonstrate that with a sufficient number of analyses of pottery from well controlled sampling, the difficulties of shard temper can be overcome and production differentiated among the various sites of the Zuni area. These data are being supplemented by analyses currently underway at the Research Reactor Facility of the University of Missouri. Publication of research will follow the completion of these analyses.
The Maya Region of Southern Mexico and Central America

Research into the patterns of ceramic production and distribution among the Late Classic (A.D. 600-900) Maya represents one of the most active components within the New World Programs, involving several projects and many national and international collaborators. The benefit of a large and continuously expanding analytical data base can be seen in the manner in which data generated for a specific project provides an interpretive context for another. Care is taken to continuously evaluate research progress - analytically and contextually - thereby insuring that the chemical or physical measurement data contributes to a systematized body of archaeological knowledge. Several of the projects during the past year benefited significantly by support of the Research Opportunities Fund and outside grants that permitted intensive sampling of ceramic collections located in Central America.

Classic Maya Polychrome Pottery: Styles, Provenances, and Workshops
Ronald L. Bishop, CAL
Dorie Reents-Budet, Duke University Museum of Art

Classic Maya pictorial polychrome pottery has long been recognized as one of the great ceramic traditions of the world. Unfortunately, however, many vessels with elaborate hieroglyphic texts or painted court scenes have been looted and thereby serve as little more than pleasing aesthetic objects. By combining traditional art historical methods and chemical analysis of ceramic pasts, the products of centers of Maya ceramic production are identified and located. The compositions of almost 1,700 whole vessels are compared against the corpus of approximately 9,000 chemical analyses of excavated or surface collected Maya ceramics presently curated in the SARCAR data base. The chemical characterization of excavated pottery, in addition to providing information about exchange of ceramic goods among Maya centers, permits the informational content of the vessels to be interpreted with a geographical context. The combination of paste analysis, compositional modeling, hieroglyphic translation, and structural and thematic analysis brings a new, unique body of information forward to contribute to the understanding of the development and fall of Classic Maya civilization.

Two reports, one on pottery from the Belizean-Guatemalan border area and another of a more generally synthetic nature, have been submitted for publication during the past year. A more comprehensive monograph is in preparation.

The Petexbatun Ceramic Economy Project
Ronald L. Bishop, CAL
Antonio Foias, Vanderbilt University
Arthur A. Demarest, Vanderbilt University
Juan Antonio Valdéz, Universidad de San Carlos, Guatemala

The events surrounding the historically-documented 7th century expansion of the Dos Pilas state in the Petexbatun region of northern Guatemala and its 8th century collapse are the focus of an interdisciplinary investigation. CAL-sponsored research is concerned with the nature of the relationships among Petexbatun centers during the Maya Late Classic Period as reflected by trade between the site of Dos Pilas and six other important sites in the region. Data regarding shifts in the directionality of trade among the Petexbatun sites and changes in the organization of domestic ceramic production within specific sites has been revealed by the chemical analyses of ceramics and from the detailed study of form attributes exhibited by the utilitarian wares.
Major funding for a two-year excavation program has been received for the Vanderbilt-Guatemala project from the Swedish government. Additional chemical analysis of the pottery recovered by this last year's excavation is awaiting the completion of ceramic attribute analysis. A report on the patterned distribution of fine paste ceramics recovered within the Petexbatun region has been submitted for publication. These ceramics are of special interest for they have been shown to have been made on the distant Lower Usumacinta River and appeared in the region immediately prior to the Petexbatun collapse and abandonment.

**Greater Palenque Ceramic Survey**  
Ronald L. Bishop, CAL  
Robert L. Rands, Southern Illinois University

Research is directed toward the synthesis of analytical data, generated over many years, on the archaeological ceramics of the Palenque region, Mexico. A principal objective is to determine ceramic relationships of the large Classic Maya site or Palenque, Chiapas, Mexico, often considered to be one of four "regional capitals" of the Southern Maya Lowlands, to the surrounding minor sites which are commonly regarded as economic and political dependencies of Palenque. Problems of centralization or noncentralization are investigated by a combination of approaches that focus on compositional analysis as an indication of production sources and exchange. The analytical database is extensive: approximately 1,500 thin section examinations, 2,200 neutron activation analyses, and over 700,000 semiquantitative binocular examinations, in addition to detailed analyses of form and decoration. A limited program of new chemical analyses was completed this past year to supplement existing data on past variation amongst certain jar forms recovered in the survey region.

The first monographic presentation of research findings begins with From Black to Gray to Orange: New Perspectives on the Lowland Maya Fine Paste Tradition. This monograph is scheduled to go to press by the end of 1993.

**Time and Change in Ceramic Production at Caracol, Belize**  
Ronald L. Bishop, CAL  
Arlen F. Chase, University of Central Florida  
Diane Z. Chase, University of Central Florida

Caracol was a major polity in western Belize during the Maya Late Classic Period, A.D. 600-900. While investigating the ceramic resources of Caracol for the ROF supported Maya Ceramic Project, it was learned that the Caracol excavation program had recovered a unique assemblage of ceramic vessels - all from primary deposits that can be well dated. For the first time anywhere, the sensitivity and precision of CAL's program of instrumental neutron activation analysis can be applied to strongly contextual and dated materials. This will permit questions of changes in the organization of ceramic production to be addressed on a temporal scale much finer than previously has been possible. As such, the project presents interesting methodological opportunities as well as substantive contributions to the understanding of Caracol's development. Over 500 samples of whole vessels, all from primary contexts were sampled in the field in Belize. An additional 50 Caracol vessels were sampled in the Department of Archaeology, Belmopan, Belize. A formal proposal for this research is in preparation.
Lower Central America Projects

Honduras, El Salvador, Nicaragua, and Costa Rica make up lower Central America - a region laying between the Maya culture to the north and those of the Andean area to the south. People, goods, and ideas clearly moved through the area. Several closely related projects have been designed to define and document strength of local cultural traditions and to seek an enhanced understanding of the nature of the changes that occurred from approximately 800 B.C. up to the time of Spanish contact. Program emphasis is upon the documentation of regional ceramic production, inter- and intra- regional contacts (as these are revealed by ceramic distributions), and the exchange of stylistic information. Close collaboration is maintained with archaeological professionals in each of the countries where they, as local experts, assist in the development of research design and sample selection.

Cultural Development and Filtration in Lower Central America
Ronald L. Bishop, CAL
Frederick W. Lange, Museum, University of Colorado

Questions pertaining to the patterns of production and distribution of pottery in southwestern Nicaragua and northwestern Costa Rica (known and Greater Nicoya) and how these patterns changed, suggesting different social or economic realignments, are being addressed by the ceramic compositional analysis. More than 1,400 analyses provide the database for current synthesis and as a guide for future research.

Research during the past year has demonstrated that a close social relationship existed between the Tempisque River Valley in Costa Rica and the valley of Lake Arenal region in the Cordillera. In addition, subregional patterns of ceramic production appear to be the case for southern Nicaragua, each "center" distributing its products south to a different region of Costa Rica. Also during the past year, the project has begun to investigate the extent of trade involving ceramic objects and the flow of technological information into Greater Nicoya from Honduras to the north. This expansion of research to the north was listed as one of the highest research priorities by the participants at the May Conferencia de Cuajiniqil, held in Costa Rica to assess the future of archaeological and ethnohistorical investigation in Greater Nicoya.

Variation in Ceramic Utilization at Ceren, El Salvador
Ronald L. Bishop, CAL
Marilyn P. Beaudry, UCLA

Ceren, El Salvador, an archaeological site buried by a localized volcanic eruption around 600 A.D., is under investigation with financial support provided by the National Science foundation. Due to the catastrophic event that ended the occupation of this village, the situation is quite different than in many archaeological projects where the artifacts recovered are those that were discarded, left behind, or taken out of circulation for special use in burials and offerings. The analytical project has compositionally characterized the entire inventory of ceramic materials that were in actual use, storage for continued use, or were maintained for recycling. In doing so, we are able to assess the nature of the production and distribution systems for ceramics that were in the households at the time the community was destroyed. These data provide information about intra-community patterns that are usually difficult or impossible to obtain when temporal variability is less controlled.
The analysis of 100 percent of the ceramic inventory recovery from the living surface of four houses at the time of burial has been completed. Data analysis is underway with a final project report to be presented at the November 1993 meeting of the American Anthropological Association; publication will follow.

**The Organization of Colonial Mayólica Pottery Production in the Valle de Panchoy, Antigua, Guatemala**

*Ronald L. Bishop, CAL*
*Zoila Rodríguez Girón, Universidad de San Carlos, Guatemala*
*Víctor Sandoval y Sandoval, Consejo Nacional para la Protección de la Antigua, Guatemala*

Responding to a request from the Guatemala government, we are initiating a program of instrumental neutron activation analysis of ceramics and clays related to the production of Mayólica in Antigua, Guatemala. The program will attempt to understand aspects of ceramic craft organization under the control of the Dominican and other church sponsorship during A.D. 1545-1773. The changes in that organization that were brought about by the virtual destruction by earthquakes in Antigua in 1773 will also be monitored.

Initial analytical findings have revealed multiple compositional patterns among the locally-made Mayólica pottery. These data are being compared to the modern Mayólica pottery produced by the Montiel family, whose workshop was allowed to be re-established in Antigua after the 1773 earthquakes.
The chemical characterization, using Instrumental Neutron Activation Analysis (INAA), of geological obsidian source samples and archaeological artifacts to examine the mechanisms of intra- and inter-regional procurement and exchange systems and their evolution through time in the Ancient Near East.

**The Trans-Caucasian Obsidian Project**  
*M. James Blackman, CAL*  
*R.C. Badaljan, Institute of Archaeology and Ethnography, Academy of Sciences, Yerevan, Armenia*  
*Z.K. Kikodze, Georgian State Museum, Academy of Sciences, Tbilisi, Georgia*  
*Philip Kohl, Wellesley College*  
*I.G. Narimanov, Institute of History, Academy of Sciences, Baku, Azerbaijan*

This project has sought to examine the obsidian procurement strategies employed during the Neolithic through the Bronze Age for several regions in the Republics of Armenia, Azerbaijan, Georgia, and Russia. Prior to the initiation of this project in 1988, chemical analytical data from the known obsidian sources was nearly non-existent and only about five archaeological artifacts had been analyzed. In phase I of the project, 118 geological samples, representing the 18 most important obsidian occurrences (of over 25 known occurrences), have been analyzed and are chemically distinguishable from one another. Analysis of 575 obsidian artifacts from 27 sites in Armenia, eight sites in Azerbaijan, 15 sites in Georgia, and two sites in Russia, has been completed with over 88% chemically identified with known obsidian occurrences. The artifact data so far collected, show distinctly different regional procurement patterns that appear persistent through time. The identification of a long range exchange system, during the Bronze Age, that linked obsidian sources at Gutansar in central Armenia and Mets Satanakar in southeastern Armenia, with artifacts excavated in western and southern Iran, presents the opportunity to monitor exchange in other types of goods moving out of the Caucasus during this time period.

This research has been supported by travel grants from the Academy of Sciences of Armenia and of Georgia, the Smithsonian Institution, and Wellesley College. These manuscripts are currently undergoing revision in Armenia and Georgia with expected publication in 1993 or 1994.

Phase II of this project, will attempt to complete the characterization of the seven unanalyzed obsidian sources. Based on the results of phase I, the second phase will also refine our understanding of the regional procurement strategies by expanding the number of sites in under-represented regions and targeting specific archaeological sites for more intense investigation.
The Greater Mesopotamian Obsidian Exchange Project
M. James Blackman, CAL
Frank Hole, Yale University
Michael Rosenberg, University of Pennsylvania
Bonnie Magness-Gardner, Bryn Mawr University
Gary Rollefson

This project seeks to examine, by chemical characterization, the mechanisms and evolution of obsidian exchange systems in areas to the north, east and west of the Mesopotamian heartland, through extensive examination of the obsidian artifacts from a few selected archaeological sites and by a selected sampling of obsidian collected in regional surveys. Specific hypotheses concerning the mechanisms of exchange - "down-the-line," "central place"; proposed shifts in source utilization; and projected exchange routes are being examined. Site selection has been based on geographical location and targets specific time periods, while survey sampling concentrates on areas for which no data currently exists.

Extensive sampling and analysis of obsidian artifacts from Halafian levels at the site of Umm Qseir, on the central Khabur River in northeastern Syria were conducted: 1) to examine a proposed shift in source utilization said to have occurred during this time period; 2) to assess the validity of an exchange route thought to have used the Khabur River as a route to the Levant; and 3) to evaluate a new methodology for subsampling large obsidian artifact collections. The results showed that in order to assign (at the 95% confidence level) all obsidian artifacts, in a given assemblage, to chemically defined groups, analysis of 60% of the total number of artifacts was required. At Umm Qseir this required the analysis, by INAA, of 161 artifacts. The ability to give a source assignations for the entire assemblage, allowed shifts in source utilization to monitored on a very fine time scale. The results from Halafian Umm Qseir did not verify the proposed shift in source utilization and further cast doubt on the postulated Khabur-Levant obsidian exchange route.

Work begun in 1991 to expand the time range covered for the Khabur River drainage with analysis of obsidian from the Aceramic Neolithic site for Tell Feyda was continued in 1993 with the analysis of obsidian from the Tell Brak area and from U'baid and Uruk levels at Tell Kuran. The analysis of obsidian samples from Hallam Cami, an Aceramic Neolithic site in the Tigris River drainage in southeastern Turkey were completed.

Analysis carried out on samples from pre-pottery Neolithic levels at 'Ain Ghazal in Jordan to verify the sources actually reaching the Levant was expanded with the completion of analyses on samples from the site of Tarsus in south central Turkey.
Near Eastern Craft Production and Exchange Program

Chemical, mineralogical, metallurgical, technological and stylistic characterization of craft products to examine changes in production and distribution as related to increasing economic and social complexity in the ancient societies.

Kur River Basin Project
M. James Blackman, CAL
William Sumner, Oriental Institute, University of Chicago
Massimo Vidale, ISMeO (Rome)
Petar Glumac, CAL
Vince Pigott, MASCA, University of Pennsylvania

This project, centered on the site of Tal-e Malyan in the Kur River Basin of Southwestern Iran, has attempted to take an integrated approach in assessing the impact of increasing economic and social complexity on the production and distribution of a variety of craft products. Through research designed to provide chemical, metallurgical, mineralogical, physical, technological, and stylistic characterization data, specific studies are being conducted on ceramics, stone beads, plaster, metals and slags. The ultimate goal of the project is to present an integrated picture of economic interaction and interdependence as it developed through time.

In FY 1993, work on re-evaluation and manuscript preparation of ceramic data and data from stone bead manufacture has proceeded. Sumner and Vidale spent time at CAL to facilitate this work.

Research on the archaeometallurgical characterization of metals and metallurgical slags begun in 1991, was continued with the initiation of Pb isotopic studies of lead artifacts from late 4th and early 3rd millennium contexts at Malyan. A proposal is in preparation for samples of copper based metals and smelting slags from Malyan and silver artifacts from Tepe Hissar to be submitted for analysis for Pb isotope analysis.

Khabur River Basin Project
M. James Blackman, CAL
Glen Schwartz, Johns Hopkins University
Gil Stein, Northwestern University
Harvey Weiss, Yale University
Frank Hole, Yale University

This project has concentrated on the chemical, mineralogical, and technological characterization of ceramics and clays from the site of Tell Leilan and other sites in the Khabur River drainage in northeast Syria. Over 50 source clays have been collected in the field and work progresses on levigation studies to simulate the ancient potters preparation of clays for fine ware production. Firing studies are being carried out on both levigated and "raw" clay samples to examine the effects of natural and man-induced size sorting on the firing properties and the chemistry. INAA analysis of over 200 third millennium Habur Period fine ware sherds from survey collections within a 15 km radius of Tell Leilan and from Tell Leilan itself have been completed as part of a post-doctoral research project conducted by Gil Stein. This study seeks to examine the degree of central control over manufacture and distribution of fine ware ceramics in this region. Metric, chemical, and technological analysis of a fused stack of over 25 fine ware bowls, excavated at Tell Leilan, has formed the basis for a study of ceramic craft specialization at Leilan.
In FY 1993, a preliminary investigation was begun on ceramics from Tell Raqai, third millennium site on the Middle Khabur River, to assess the utility of chemical characterization in determining local manufacture vs. importation of a variety of coarse and fine wares. Third millennium sites in this region seem to have served a special purpose as all are small in size, include extensive grain storage structures, and are located outside the dry farming region in the Khabur drainage. As no indications of ceramic production have so far been detected at the several sites excavated, is of great interest to determine if ceramics were imported to these sites. If importation is indicated, this project will attempt to determine whether the ceramics moved down the Khabur from the dry farming regions to the north or up the Khabur from sites on the Euphrates River.

**Islamic Glazed Frit and Calcareous Earthen Ware Project**

*M. James Blackman, CAL  
Scott Redford, Georgetown University  
Jessica Hallett, Freer Gallery of Art*

The technology of manufacture of tin-lead glazed medieval Islamic lustered frit and calcareous earthen ware has been considered to be so complex as to preclude its general manufacture. Consequently several investigators have proposed a limited number of production centers, located throughout the medieval Islamic world, from which all of these wares were exported. To attempt to assess the validity of this hypothesis, the project has focused on the site of Gritille in southern Turkey. While having little probability of being a producer of these wares, Gritille represents the end of the line in the distribution system. Glazed wares from Gritille will be compared with wares attributed to one or the other proposed production center based on stylistic grounds. Published analysis of these wares from some of the proposed production sites will be used for comparison. Chemical characterization of 198 frit and earthen wares have been completed; thin section analysis of a selected sample will begin this year; and a proposal is being written to examine the lead isotopic composition of these wares. An expansion of this study with the analysis of about 90 samples from in and around the southern Iraqi production center at Basra was begun in FY 1993.

**Midasia Ceramic Project**

*M. James Blackman, CAL  
Sophie Mery, CNRS (Paris)  
Rita Wright, New York University*

This project focuses on ceramic production and distribution during the 3rd millennium in southeastern Iran, southern Pakistan, southern Afghanistan, and on the Oman Peninsula. Ceramics from Shahr-i Sokhta in Sistan, Mindigak in Afghanistan, and Hili on the Oman Peninsula have been extensively sampled. Petrographic analysis (S. Mery) and chemical analysis (M.J. Blackman) have been completed. The manuscript for a second publication concerning the manufacture and distribution of incised gray wares was prepared during a three week visit to CAL by S. Mery and R. Wright in 1992 and is being further refined in 1993.
Archaeometric Characterization of Epigraphic and Iconographic Artifacts

The chemical, mineralogical, stylistic and epigraphic examination of tablets, seal impressed clays, and other clay objects to approach problems of exchange in perishable items, and to monitor administrative activities, both inter and intra site.

Tal-e Malyan Sealing Clay Project
M. James Blackman, CAL

This project has involved examination of seal impressed clays from late 4th to late 3rd millennium strata at Tal-e Malyan. A manuscript titled: "Chemical Characterization of Sealing Clays from Tal-e Malyan and its Implications for Monitoring Administrative Complexity" has been prepared for submission.

Arslake Sealing Clay Project
M. James Blackman, CAL
Marcella Frangipane, Rome

Research on sealing clays at Tal-e Malyan and at Tepe Gawra demonstrated the ability to track information flow within a single archaeological site, with both sites displaying periods of primarily parochial administrative concentration and other periods of where external contacts proliferated. At Tal-e Malyan, examination of Proto-Elamite tablets documented the movement of accounting tablets from craft/domestic area of the site to a monumental building about .9 km away. The Tal-e Malyan research also showed a marked change in the use of sealings between the early 3rd and late 3rd millennium. The earlier sealings were 95% of local clay indicating use in local accounting activities. The late 3rd millennium sealings were about 50% local and 50% foreign clays indicating a greatly increased use of sealings to account for goods in transit between locations. The Arslantepe project is designed to extend the examination of sealing and accounting practices to the region of the upper Euphrates River during the late 4th millennium. This project focuses on the chemical analysis of a sample of 140 sealings (from a total of about 1,800 sealing fragments) found together in a single archive at Arslantepe. Analysis was begun in 1992.

The Northern Mesopotamian Tablet and Sealing Project
M. James Blackman, CAL
Harvey Weiss, Yale University

This project involves the examination of tablets and seal impressed objects from northern Mesopotamia. The studies at Tal-e Malyan and Tepe Gawra both suffered from a lack of controlled clay samples from the region around the sites. As a result little could be said about the extent of the external contacts during the periods of increased external activity. Based on a major characterization of geological clay source samples from the Khabur River and its tributaries in northern Syria, this project is aimed at producing a chemical and mineralogical data base upon which studies of ceramic production and distribution and of information flow through the analysis of administrative artifacts can be based. To date some 50 clay source samples have been collected and are in the process of analysis. Artifact analysis has so far concentrated on the 3rd and 2nd millennium levels at the major urban center of Tell Leilan. The Leilan research seeks to increase our understanding of Leilan's relationship with its hinterlands through a collaborative study of the combine iconographic, epigraphic and chemical information in the sealings and tables. The long term goal of this research is to include several other contemporary sites to give the study a regional perspective.
Lead Isotope Analysis of Eastern Mediterranean Artifacts and Black Sea Ores: Production and Exchange, 3800-1500 B.C.
Emile C. Joel, CAL
Edward V. Sayre, Research Associate
Aslihan Yener, Research Collaborator

This project has investigated the specific factors and processes that generated one of the most sophisticated metal industries in the Eastern Mediterranean in the 4th and 3rd millennia B.C. It has long been acknowledged that the highland regions of Anatolia were among the earliest environments in which metallurgy developed. Questions about the emergence of these operations and the impact of this metal industry upon different subsystems of Anatolian society are issues being answered through an interdisciplinary study of the sources and exchange of metals. The method involves obtaining analytical information about the techniques of manufacturing metals and delineating the sources of metals as a prerequisite to understanding more complex relationships. The technique for provenance determinations involves the use of lead isotope analysis on ores and artifacts.

A part of this multi-phase project, a group of ore specimens collected by Yener from various mining sites in mountainous areas of the Black Sea coast of Anatolia and a number of excavated Bronze Age archaeological samples were analyzed for their lead isotopic composition by CAL staff at the National Institute of Standards and Technology (NIST). The prior lack of sufficient data from this area hindered the isotopic characterization of the Black Sea region. However, combining the new data with similarly published data from others in the field has created a sufficient body of isotopic analyses which has now formed the basis for satisfactory statistical analysis. Such analysis shows that the overall body of data can be divided into separate isotopic regions within the geographical areas studied. The degree of overlap between these isotopic groups and all of the published data for Eastern Mediterranean metal source sites is still being considered. The probabilities of Eastern Mediterranean Bronze Age artifacts of newly analyzed and previously published objects matching the isotopic fields of these groups are also being recalculated and reevaluated at this time.

An earlier phase of the project has already provided insights into understanding one major subsystem in Turkey by isotopically defining a specific ore field, the Taurus Mountain mining region. It was the process of analyzing these ore deposits that led to the discovery of the much sought after tin of antiquity in Anatolia. The discovery of Kestel, the tin mine, has led in turn to Goltepe, a miners' smelting settlement and now a mortuary chamber inside one of the abandoned mine shafts which dates to the 3rd millennium B.C.

We are in the process of preparing several manuscripts on the results of our analyses of the Black Sea ores and corresponding artifacts. One is to be presented at the International Archaeometry Symposium in Turkey in 1994. A preliminary paper on our findings was presented last year at the International Archaeometry Symposium in Los Angeles. We have had to respond to one last reply to the paper "Statistical Evaluation of the Presently Accumulated Lead Isotope Data from Anatolia and Surrounding Regions." "Evaluating Further Observations" by P. Budd, et al deals with all of the replies generated by our statistical paper and our corresponding reply will end this published debate on lead isotopes and statistical methods. It is expected to appear in the 1993 Fall issue of Archaeometry.
Materials Science and Ancient Technology

Programs of Research include:

The Materials Science and Ancient Technology area is divided into research programs which include Paleolithic pigments and ceramics, Pathways to Pottery: plaster and ceramic technologies, Southwest Asian Specialized Technologies of the Third Millennium B.C., Oriental Glazes, Islamic Fritwares and Their European Counterparts, Early Bronze Age Mining Project, Tell es-Sweyhat Metal Project, Traditional Abrasive Project, Bell Founding Project, and Links of DeSoto Mail. They are led by Pamela Vandiver, Senior Research Scientist in Ceramics, and Martha Goodway, Metallurgist.

In conjunction with these programs and others in the Archaeometry program, the Materials, Art and Archaeology Discussion Group meets bimonthly. Student projects relating to these areas are regularly supported both in terms of teaching and supervision of and collaboration with local student and post-doctoral fellows in research projects.

The program in materials science and ancient technology is responsible for technological characterization of ancient materials, reconstruction of their technology(ies) of production and use, and interpretation of their cultural and/or artistic significance. We use the paradigm of modern materials science in that we attempt to measure the structure, composition and properties of ancient artifacts in order to discover their raw materials, processing and performance characteristics. We attempt to distinguish raw, processed and weathered materials and to reconstruct their history of selection, fabrication, use-wear and post-depositional change. Ancient processes or the critical parts of these technologies are replicated and often compared with similar modern technologies. These empirical studies may involve single artifacts or site-specific groups of artifacts, and they involve on-site collection of comparative materials to be used as a baseline against which to measure the archaeological sample. Subjects of these investigations concern the identification of the physical bases of appearance, the constraints and variability of raw materials, the methods and sequences of manufacture, the physico-chemical envelope of processing parameters and the rate limiting steps in the practice of a technology. We attempt to characterize and reconstruct ancient technologies, such that interpretations of technological complexity, cultural and/or technological constraints, craft organization and specialization are made more probable. To interpret when a structural change in a technology may reflect a cognitive or behavioral change involves careful evaluation, within a special environment and archaeological context, of a particular technology as a corpus of decisions and activities of which only fragmentary materials culture remains.

Ceramics are defined as inorganic oxides subjected to a pyrotechnology and include such classes of materials as pigments, plasters, glazes, glasses, enamels, metallurgical slags and clay-based products. Metals are inorganic non-oxides subjected to a reduction technology and subsequent post-depositional oxidation. Such complex materials require study by a multi-method and multi-disciplinary approach. To characterize internal macrostructure, xeroradiography and x-radiography are employed. To characterize microstructure, we use optical microscopy, scanning electron microscopy and Vicker's hardness testing. To measure composition, x-ray fluorescence, energy dispersive x-ray analysis and wavelength dispersive microprobe analysis are used. To identify phases present in a multi-phase assemblage, the techniques of x-ray and electron diffraction are used. To characterize thermal history, differential thermal analysis, thermogravimetric analysis, refiring tests and electron microscopy are useful. From
microstructure and microcomposition, optical and mechanical properties are hypothesized; replicas are made and tested.

**Paleolithic Pigments and Ceramics**  
*Pamela Vandiver, CAL*  
*Bohuslav Klíma, Archeologicky Ustav, Czechoslovakia*  
*N.D. Praslav, Institute of Material Culture, Paleolithic Archaeology Section, Russia*

Paleolithic pigment and ceramic technologies at Dolni Vestonice and Pavlov in Czechoslovakia, and Kostienki I-1 in Russia date between 26,000 and 23,000 B.P. Colored minerals excavated at these sites have a range of color from black, red and orange to yellow and white. These sites date to about 10,000 years prior to the decorative use of pigments on cave walls. Are these minerals suitable as pigments? What processing do their microstructures and compositions imply? Are functions other than use as pigments probable? Reference collections of pigments from other sites such as Lascaux, Arcy-sur-Cure, Mas d'Azil and others for which the processing is known are used for comparison in addition to on-site collections of geological references materials from Dolni Vestonice and Kostienki. Another set of reference materials is being studied from the cave of Le Cosquer near Marseille, France and dated to 17,000 B.P. in collaboration with Jean Clottes.

The ceramic technologies from these two sites have been characterized, and our main goal this year has been to detail and understand the relationships between the two crafts of ceramics and pigment processing. In addition, a database has been used to compare to artifacts in the National Museum of Natural History (NMNH). Two articles on mortars and palettes in the NMNH collections are in press co-authored by Richard Potts and Michael Petraglia.

**Pathways to Pottery: Plaster and Early Ceramic Technologies**  
*Pamela Vandiver, CAL*  
*Olga Soffer, University of Illinois*  
*Sahara Makoto, Nara National Cultural Properties Research Institute*  
*Gary Rollefson, San Diego State University*  
*Eugene Farrell, Fogg Museum, Harvard University*  
*Andrej Danjnowski, Fogg Museum, Harvard University*  
*Jean Clottes, Ministry of Culture, France*

This project aims to investigate the Old World pottery techniques and their precursors to identify the trajectories of development and to understand how they differed from place to place. In Southwest Asia plasters were fabricated into vessels, decorative objects and figurines prior to the development of a clay-based technology with differences in the technology through successive periods among different artifact types. In Japan, hunting-and-gathering Jomon peoples made vessels, probably for cooking, using a specialized technology but having great difficulty controlling raw materials.

Results of the study were published with Olga Soffer in *Archaeology* and as a chapter in the book *Lascaux Inconnu*, as well as a study of Neolithic Chinese pottery from Liangzhui with Farrel and Danjnowski given as a paper at the International Conference on Ancient Ceramics in Shanghai, China. An article on the ethnographic remains of plaster production is in preparation with G. Rollefson, as well as papers on two other aspects of this problem.
Southwest Asian Specialized Technologies of the Third Millennium B.C.

Pamela Vandiver, CAL
John Merkel, Institute of Archaeology, University of London
McGuire Gibson, University of Chicago
Aslihan Yener, CAL
Mark Fenn, CAL
Leopold May, Chemistry Department, Catholic University
William Hornyak, Physics Department, University of Maryland
Andreas Hauptmann, Bergbau Museum, Germany

The third millennium B.C. in Southwest Asia marked a period of tremendous technological change including metallurgical, ceramic and glass processing. This project aims to identify and characterize these technologies and to understand the cross-craft and cross-cultural exchanges of technology. Several individual studies are the basis of this project. With Aslihan Yener, study of ceramic and slag from tin processing crucibles excavated at Goltepe, Turkey, has established the processing parameters of metal production, since replicated on-site. Two publications are available, *American Journal of Archaeology* and *Materials Issues in Art and Archaeology*, Vol. III, and a third is in press in *Archaeometry* on the TL-dating of the crucibles.

With McGuire Gibson, a study of 3rd millennium glass bead making at Nippur has been conducted, showing the highly variable nature of an incipient technology with ties to both later soda-lime-silicate technology and to then-current tin and lead processing technologies. This study is being rewritten for *Science*.

With Mark Fenn, study of a bead technology using a copper-silicate glaze on quartz has been published. Replicate melts show a more complex technology was practiced than originally shown through analysis alone. This study is being continued as replicate melts studied by ESR to determine whether copper substitutes on calcium sites in the glass structure.

The three glass compositions will be melted this summer in a furnace in which John Merkel simultaneously smelts copper. We will study the conditions of temperature and atmosphere which simultaneous produce glass and copper metal. Residues on the sandstone refractories will be studied to determine conditions for the production of copper green glaze, similar to that found on third millennium B.C. copper smelting furnaces in Wadi Feinan, Jordan.

Ceramic sickles and other tools are commonplace on sites such as Nippur. A study of the technology and use-wear of these tools from a single period Uruk site near Nippur has been completed in order to understand the context of production and the processes of production and use. We wish to know whether manufacture and use are patterned, and, if so, how they might be standardized. A collection of clay resources from this quite homogeneous, alluvial area of Iraq has been assembled which is being compared to the sickles to determine how resources were used, and whether the strengthening mechanism of the ceramics is dependent on processing.
Oriental Glazes, Islamic Fritwares and Their European Counterparts
Pamela Vandiver, CAL
Zhang Fukang, Shanghai Institute of Ceramics
Sun Jing, Shanghai Institute of Ceramics
Louise Cort, Freer and Sackler Galleries of Art
Shelly Sturman, National Gallery of Art
Daphne Barbour, National Gallery of Art
John Carswell, Sotheby's, London

Oriental glazes are some of the most beautiful and technically advanced of pre-modern ceramics and were imitated in other parts of Asia as well as Europe using local materials and local technological practices. Our aim is to isolate the imitative technological processes and to understand the effects of constraints of local raw materials, styles of technology, and the nature of the visual effects. Understanding the visual properties of these glazes requires investigation of the submicron structures responsible for their optical appearance, including those structures which result from nucleation and crystal growth, liquid-liquid immiscibility, decomposition reactions and stability or reactant phases. Current research involves 8th-10th century white and green glazed wares from the Sori kilnsite in Korea, from the same period the early Sanage kiln in the Mino-Seto area of Japan. Ceramics from the Plummer temmoku collection from Fujian, Guanwares from Ongquan and Phoenix Hill in Hangzhou, Cizhow overglaze enamels, Karatsu wares of 16th century Japan, and Korean porcelains of the early Koryo dynasty in Korea have also been studied. An extensive collection of Islamic fritwares and three examples of Saint-Porchaire ware from the National Gallery of Art have also been studied.

Five publications are in press and two others are in preparation. Papers on guan, temmoku and a Sri Lankan assemblage were presented at the Fourth International Symposium on Ancient Ceramics in Shanghai, November 1992.

The Development of the Potter's Wheel in Southwest Asia
Pamela Vandiver, CAL
Robert Henrickson, CAL

Funding from the Scholarly Studies program has allowed continuation of a regional study of the development of the potter's wheel in Southwest Asia. Vandiver's doctoral dissertation found no evidence of use of a potter's wheel prior to 3200 B.C. based on a study of 25 sites and 40,000 sherds. Several collections will be surveyed using optical microscopy to catalog traces of wheel manufacture and xeroradiography to determine the angle of the average alignment of internal pores compared with that of near-horizontal throwing ridges. A typology of manufacturing methods is being constructed. Replicative tests of various speeds and types of potter's wheels have been carried out, and this data base is being used to interpret results from sites dating to the second, third and fourth millennia B.C. The collaboration of many scholars has been gratefully received in order to permit this study, including William Sumner, Henry Wright, C.C. Lamberg-Karlovsky, Mary Voigt, Robert Dyson, Jr., Bennett Bronson, Cuyler Young, Jr., and Harvey Weiss in the US as well as Annie Caubet of the Louvre Museum.
Early Bronze Age Mining Project

*Martha Goodway, CAL*

*Dr. Joan J. Taylor, University of Liverpool*

*Tony Hammond, Great Orme Mine, Ltd.*

*Andrew Lewis, Great Orme Exploration Society*

*Dr. Rob Ixer, University of Birmingham*

The trade in metals in Europe, particularly in northern Europe, has presented archaeologists with considerable difficulties of interpretation since the British Isles during the Early Bronze Age displayed greater wealth than could be accounted for by the known early resources. The discovery at Great Orme, near Llandudno in Wales, of a copper mine that has been dated by C14 to this period and the largest such mine known in Europe offers an opportunity to study mining practices at this early date and possibly to source metal from its ore. Materials from this mine are available from sealed, well-dated contexts. Some small metal finds and samples of ore from the great cavern are already under study in CAL, and Dr. Taylor will return in June to collaborate in completing the proposal.

Tell es-Sweyhat Metal Project

*Martha Goodway, CAL*

*Dr. Thomas A. Holland, The Oriental Institute, Chicago*

Lead can be smelted under the most primitive conditions. Certainly it is the most easily smelted metal of antiquity, yet it rarely appears in objects in early contexts. One of these is Tell es-Sweyhat, a third millennium site in Syria. Field identification of small metal finds included bronze, silver and possibly lead. Initial assessment of 38 samples submitted to CAL by Dr. Thomas A. Holland has already indicated that four objects, a pin, an earring, a ring, and a small frog shape, are lead. Silver objects, which usually accompany lead ones, do not appear among these samples. Because of their early date isotopic ratios of the lead objects offers the possibility of identifying the source of the ore and thus illuminating patterns of trade. The remaining samples are copper or copper alloy objects or fragments that are being studied for evidence of deliberate alloying and fabrication techniques in use at this period.

Traditional Abrasive Project

*Martha Goodway, CAL*

*Michael A. Constable, Birmingham Museum of Science and Industry, England*

Other than hone stones there appear to be a lack of information in the archaeological literature on materials used as abrasives in finishing metal. However traditional craft methods are still being used in the Jewelry Quarter of Birmingham, England. There a river sand was being used until recently to polish silver objects. A sample of this abrasive was examined in CAL and chalcopyrite was identified by x-ray diffraction as its major component. Chalcopyrite is one of the chief ores of copper and if found in an archaeological context might be interpreted as evidence of copper smelting. A paper has been prepared for publication in an archaeological journal that suggests care in making such a conclusion in the absence of other evidence of smelting.

Michael Constable, a Keeper in the Industrial Machinery section of the Birmingham Museum of Science and Industry has been able to discover that the sand analyzed came from the River Trent and was known in the art metalwork trade as Trent sand. It is now outlawed as a health risk so it is proving difficult to track down the sources of supply, which with the other data collected including references to its use in traditional
metalworking, are to be incorporated into a joint paper on Trent sand and its use for consideration by Historical Metallurgy.

**Bell Founding Project**
*Martha Goodway, CAL*
*Massimo Vidale, Centro Scavi Is. M.E.O., Rome*

After the introduction of cannon in warfare bells were routinely used as an available source of the bronze required to cast them. Both bronze bells and cannon must be cast in metal of high purity, as free of lead as possible. Since no 12th century bells are known to have survived in Europe, waste material from bell-founding pits are our only source of information on the control of alloying and the purity levels achievable at the time. Such a pit was discovered adjacent to the medieval church at Venosa in southern Italy and was excavated by Massimo Vidale. The materials from this bell founding operation now in CAL include several samples of bronze. Some of these are obviously spills, and one is of 'flash,' the metal which when molten flows between parts of the mold and freezes there. These bronze samples have been examined and have somewhat differing microstructures due to differences in cooling rate. Modern bell metal is alloyed with great care to avoid the presence of lead because this tends to deaden the sound. The alloys from the bell pit are high tin bronze as expected, but also contain lead. Corrosion products are also under study, with some results, such as copper formate, requiring further confirmation before the identifications can be published.

**Links of DeSoto Mail**
*Martha Goodway, CAL*
*Charles R. Ewan, DeSoto-Apalachee Project*
*Herbert Bump, Florida Department of State*
*Robert Smith, The Tower of London*
*Dr. Alan Williams, University of Manchester*

The site of De Soto’s winter encampment of 1540 was discovered in Tallahassee in 1987 and excavation of the site has recovered a number of links of mail armor. It is thought that the De Soto entrada in Florida of 1529-1543 heralded the end of mail as effective armor. About twenty of the links recovered were made available for study in CAL. Earlier research in this lab on music wire established that the selection of high phosphorus iron for wire making was standard practice by 1677. The practice can be inferred, from alterations in the dimensions of musical instruments, to have been applied to music wire perhaps as early as 1600. Earlier evidence depends on finding well dated samples of wire, and this is very difficult to do. In the case of mail armor that constantly requires repair it is not always evident which links were replaced, or when. Links from an excavation such as this one, which is exactly dated, avoid this problem but present others.

The excavated links are heavily corroded. In some cases corrosion is complete. The corrosion product contains elements from the soil which in settlement sites is usually contaminated with phosphorus, so analysis of the corrosion product for phosphorus is unreliable. There are no published studies of corroded links, nor of corroded wire. Several procedures, including sequential sectioning of the links, have been developed in search of remnant areas of sound iron.

Though initial examination of two iron links revealed phosphide inclusions in one, further links sectioned so far have not produced as definitive results. About half the available links have been sectioned so far and some have proved to be totally mineralized. The
hope that the mineralization, which does preserve evidence of drawn structure, also preserves iron phosphide inclusions in a morphologically recognizable way has not been realized. The effort is now focused on sectioning to locate sound metal in these links for analysis of iron.

Oriental Glazes, Islamic Fritwares and Their European Counterparts - Roman Lead Glazing
Ted Pena, Research Collaborator
Pamela Vandiver, CAL
Emile C. Joel, CAL

This is a study of the early history of lead glazing in the Roman Empire based on a set of 38 samples excavated by T. Pena from the Palatine Hill in Rome. These samples were derived from about two tons of unglazed pottery. These are lead glazes found on cups, bowls and ewers from two periods. The periods represented are early Imperial ware, late 1st-3rd century A.D. and middle and late Imperial ware, 4th-5th century A.D. The results from visual observations, petrographic and neutron activation analyses have shown that the bodies relate to those found from several areas within Italy and just over the border in Albania. The lead glaze wares are of local Italian manufacture, one group coming from Ravenna on the northeast coast. The glazes contain lead concentrations as high as 60-70%, so lead isotope analyses were performed on five samples. Our preliminary results show very close agreement between four of the five which represent samples from both periods and indicates that at least two different sources of lead were utilized. Our present European database contains very little ore data from Italian sources. We have approximately 19-20 samples of ores from central Italy submitted by R. Brill which we hope to analyze in the near future. It is also possible that T. Pena will be able to collect local ore samples while in the field this summer for lead analysis.
Historical Archaeology

Statistical Evaluation of the Lead Isotope Data on Geological Ore Samples from Western and Central Europe

Emile C. Joel, CAL
Edward Sayre, CAL Research Associate
Robert Vocke, Research Collaborator, NIST

We have created an extensive database of the published lead isotope determinations on geological ore samples from Western and Central Europe. Lead isotope analysis has never been fully applied to provenance studies of European artifacts or to the distribution of metal that resulted from trade with other regions for several reasons. First, the belief that artifacts from this period would contain lead from a variety of sources due to the natural and mechanical mixing of ores and recyclable metals and secondly, bivariate plots of the isotopic fields generated in the past overlapped and created difficulties in distinguishing between ore sources known to have been used in ancient times. Thus far, we have been concentrating on those regions suggested in the literature as possible sources of metal during post-medieval and renaissance periods of European history. The amount of data derived from published geological studies has been enormous. We have assembled well over one thousand measurements and more is forthcoming. In areas where geological lead studies are negligible, we attempt to locate ore samples and perform the lead isotope measurements in our laboratory. One of the possible sources for samples we have investigated is the Mineral Science Department in the Smithsonian's National Museum of Natural History and we have obtained samples of ores from Portugal and Spain, areas for which little geological lead data exists.

The focus of this project is to apply multivariate and probability statistical analysis to further refine the isotopic fields generated by the lead data. We have been very successful in this endeavor. The geological lead ore data obtained from the literature was first evaluated on several factors to determine its comparability to the data produced by our laboratory before inclusion into the database. The factors reviewed included measurement methods, standardization procedures, measurement error and instrumentation biases, geographical areas of study and their relevance to archaeometric provenance studies of artifacts. Statistical evaluation of the data has demonstrated that differences in lead isotope composition do occur within the political boundaries of some individual countries and it is possible to determine the origins of some of the artifacts manufactured there and distributed elsewhere. The geology of Europe is very complex and overlapping does occur between areas having similar geological characteristics. However, if one eliminates the present political boundaries, functional regions are distinguishable.

Spanish and Spanish Colonial Ceramics

Emile C. Joel, CAL
Jacqueline S. Olin, CAL
Edward V. Sayre, CAL Research Associate
Robert Vocke, Research Collaborator, NIST

Spanish artifacts excavated in Spain and the New World were reexamined to determine their provenance in relation to the newly determined European ore sources. We decided to trace the origins of the lead used in these 16th century Spanish artifacts to test the validity of the European ore fields and to illustrate the effective use of the lead isotope database. Some of the lead data used in this study were from a previously published
study conducted at our laboratory on glaze samples taken from majolica from Spain and from Spanish colonial sites in the New World. The original study successfully demonstrated that majolica produced in Mexico could be distinguished from those produced in Spain and are characteristic of the lead isotopic composition found in Mexican ores.

The published lead data on Spanish majolica formed three distinct groups: a Mexican group and two distinct groups comprising of majolica excavated from Spain and Spanish colonial sites. The data from the two latter groups were used in our present study which also included the published lead data on samples from artifacts excavated from Salvador Island in the Bahamas, one of the possible sites of Christopher Columbus' landing in the New World. Also included were the data from the analyses of glazes from the sherds excavated by K. Deagan, University of Florida, from the site La Isabella in the Dominican Republic and in addition samples of glazes from sherds excavated from Islamic contexts from Portugal and Spain.

The lead data from these two studies again formed two very distinct isotopic groups and were compared to the lead isotope data from European ore sources. One group, found to be similar to ores located in southwestern Spain and Portugal, overlapped slightly with ores found in Sardinia and France. The other Spanish artifact group closely matched ores from the Low Countries (Spanish Netherlands), several regions in Germany and overlapped slightly with some ores from France. Probability statistical analyses of individual objects showed higher probabilities for lead glazes originating from Iberian sources in group 1 and from Belgium and German sources in group 2. However, the metal objects such as the 15th century Spanish coins, had equal probabilities between regions or to the mixing and recycling of metal. Our results are consistent with the historical evidence which documents the extensive trade in metals and other materials between these regions. The results of this study were presented by E. Joel at a symposium on "Trade and Discovery: The Scientific Study of Artifacts from Post Medieval Europe and Beyond" held at the British Museum in November 1992.

Presently, we are preparing a manuscript for publication which will only address the provenance of lead glazed pottery from 15th and 16th century contexts in Spain, and from Spanish colonial sites in the New World. We are also considering adding new analyses to our present data from objects that have been studied using neutron activation analysis to compare trace elements in addition to lead isotope characterizations. The results from this investigation will provide a model for future studies on the provenance determinations of lead containing artifacts of European origins and will provide a baseline whereby artifacts of unknown provenance can be compared. This study represents the first in a multi-phase series of studies to determine the provenance of artifacts from other European regions, e.g. French, English, Italian and Dutch lead glazed ceramics utilizing the European ore database.

**Lead Isotope Studies of Nigerian Bronzes and Comparative Samples**

*Emile C. Joel, CAL*

*Edward V. Sayre, CAL Research Associate*

*Frank Willett, Research Collaborator, Hunterian Museum, Scotland*

*Stuart Fleming, MASCA*

*Robert Vocke, Research Collaborator, NIST*

The source of metals used in casting Nigerian "bronzes" has been the topic of several analytical investigations and previous studies have been only partially successful in answering this fundamental question. The objects represent one thousand years of...
copper metalworking traditions in Nigeria and reflect with time the different cultural influences acquired through contact with traders from Europe and other regions in Africa. Trace characterization of these objects using lead isotope and elemental analysis will provide us a better understanding of the socio-economic ties that existed between such diverse cultures. Identifying the precise region or the different regions of metal acquisition used at different times in the casting of the Benin bronzes and other early period Nigerian objects will provide information on the interregional and the trans-Atlantic trade that developed during the medieval and post medieval periods in European history in addition to much needed insight on the production and distribution systems for metal trade throughout these regions.

An archaeometric proposal for lead isotope determinations on Benin bronzes and related objects was submitted last year to study objects from several collections here and abroad. It was suggested that the Benin proposal be broken down into three main components. The first phase would be the assemblage of European ore database, the second phase would consist of the study of related European artifacts which could be used to augment the European artifact database. Both of these have been described in the preceding projects. The final phase would be the analyses and study of the Benin and other Nigerian bronzes and their relationships to European and African sources of metal.

Several potential collaborators have been proposed to aid in the study of Benin bronzes, namely Frank Willett, Senior Honorary Research Fellow, Hunterian Museum, University of Glasgow; Bryna Freyer of the National Museum of African Art; and Stuart Fleming, MASCA. Professor Willett's experience in the field spans 30 years and his knowledge on the archaeological and art historical context of the objects is considered invaluable. His familiarity and pioneering use of analytical methods in many of his earlier studies is unique among scholars of African art. A short term visitors grant was sought and obtained for F. Willett to visit CAL for two weeks in January 1993. Thus far, Professor Willett's contributions to our initial study has been extremely beneficial and has helped to establish a viable 3-5 year prioritized research effort of considerable interest to the international community in an area that has long been ignored.

The analyses of samples from objects excavated by Thurstan Shaw and submitted by R. Brill will be completed this period as well as some prioritized samples by F. Willett. The results from these analyses will be viewed as an useful indicator for considering and confirming the local utilization of raw materials. Lead isotope data from objects excavated from contemporary European sites in the Old and New Worlds showed remarkable isotopic similarity to the Benin bronzes. A preliminary lead isotope study comparing Benin bronzes with other Nigerian bronzes and African and European ore sources and artifacts was the subject of a CAL seminar in November 1991 by E. Joel and demonstrated that the lead isotopic fields of several European regions agreed well with the published literature as possible sources of the imported metal. Preliminary statistical evaluation of newly acquired data on Benin bronzes from Willett and Fleming in addition to our own shows two very distinct groups which relate well to European ore sources.
Technical Studies in Art History

Examination of the Working Methods of the American Artist, Thomas Cole
Ingrid Alexander, CAL

This examination of some of the works of the artist Thomas Cole will focus on an investigation of the graphic style of his underdrawing. Thomas Cole is arguably the most important painter of the Hudson River School. He produced numerous drawings which earned him a reputation as an accomplished draftsman. Once he embarked on painting in oil, his technique embraced the romantic scenery of the Hudson River valley and the grandeur of the area.

The research into Cole's working methods examines his drawings on paper and the underdrawing in several works. Although a few studies of this important American artist have investigated the underdrawing, no systematic studies have yet been undertaken. Thus far, 21 paintings have been examined with infrared reflectography. Ten were found to be underdrawn. These paintings were from the National Museum of American Art, the Corcoran Gallery and the Wadsworth Atheneum. The information from research carried out at the Cleveland Museum of Art by Christina Currie on Schroon Mountain and View of Florence was included in this study.

The project has uncovered Cole's particular style of underdrawing which is both at times meticulous for architectural elements and quixotic for features such as light, clouds and atmosphere. Figures are usually not underdrawn and pencil seems to be the sole underdrawing tool.

Network of Art Research Computer Image SystemS in Europe
Ingrid Alexander, CAL
in collaboration with Direction des Musées de France, Laboratoire de recherche des musées de France, et al

A consortium of 17 cultural institutions have come together to produce a CD ROM "Art-Science" within the Narcisse project. The project is organized under the aegis of the Commission of the European Community (DGXIII) within the framework of the project IMPACT I 178. A databank of technical photographs and radiographs of works of art is being made. Numerous images from the various institutions have been scanned at very high resolution. These images are accompanied by a multilingual glossary. Each of the paintings and manuscripts within the project are described through "Commentaries" which are presented in eight languages. The past three meetings of the group serve to standardize the entries and correlate translation.
Conservation Research

Marion F. Mecklenburg, Assistant Director for Conservation Research
Charles S. Tumosa, Head of Analytical Services
Mary T. Baker, Research Organic Chemist
Camie S. Campbell, Chemist
W. David Erhardt, Research Organic Chemist
Melanie Feather, Conservation Scientist
Walter Hopwood, Organic Chemist
Mark McCormick-Goodhart, Photographic Scientist
Noreen Tuross, Research Biochemist
David von Endt, Research Organic Chemist

In addition to developing and conducting major research programs that benefit the entire Smithsonian institution, the Conservation Science section also assist the CAL staff conservators in their research efforts. Other members of the staff make up the analytical services group. They provide timely chemical analyses of materials to the entire Smithsonian Institution as well as CAL researchers.

The following are the research programs of the Conservation Science section:

- Biogeochemistry
- Degradation Mechanisms of Traditional Artist's Materials
- The Mechanics of Materials and Structural Analysis
- The Modern Polymeric Materials Program
- Natural History Specimen Preservation
- The Photographic Science Program
- Analytical Services Group
The Biogeochemistry Program

The Kents Cavern Project funded by the Walcott Fund
Noreen Tuross, CAL

One hundred and fifty light isotope analyses were performed on the faunal material from the Kents Cavern collection. These analyses make this paleolithic assemblage the most thoroughly studied collection at this time depth (30,000 to 50,000 years B.P.). Several interesting things about this collection have been discovered. The number of faunal bones and teeth from Kents Cavern in museum collections has been grossly underestimated and certainly numbers many ten's of thousands. In the journal of the original excavator, William Pengelly describes a seventeen year excavation that removed tens of thousands of pieces of bone from this cave. The original Pengelly journals were examined at the Torquay Museum in England and the collection was sampled extensively, including whole hyena and equid mandibles and dentition: invaluable for distinguishing between ontogenetic and true trophic level differences in the isotopic and elemental analyses. The Torquay Museum has also entrusted the human remains, including the oldest radiocarbon dated *homo sapiens* in Europe that was found at Kent's Cavern. It is critical to redate this sample using accelerator mass spectrometry, collaborating with the Oxford Radiocarbon Laboratory in the collagen preparation of these human remains.

Sampling of the Kent's Cavern collection at the National Museum of Natural History was completed, and more than 200 pieces were identified by Melinda Zeder. Isotopic analyses (organic carbon, organic nitrogen, inorganic carbon and inorganic oxygen) have been completed on approximately one hundred and fifty well preserved samples, and these data were presented at the Oxford Ancient Bone Conference in July 1993. A paper is accepted in *Journal of Archaeological Science* entitled "Preservation of trophic and climatic information through isotopic signatures in fossil mammals from Kent's Cavern" by H. Boucherens, M.L. Fogel, N. Tuross and M. Zeder that will report the preliminary results detailed below.

Demonstration of Several Biochemical Markers of Trophic Placement and the Preservation in the Information from the Paleolithic

Three separate isotopic analyses discriminate between herbivores and carnivores: 1) $[\delta^{15}N]$ values in bone collagen show an enrichment in the heavy isotope of nitrogen in carnivores, supporting the hypothesis that enrichment of nitrogen isotopes increases up a food chain (Schoeninger and DeNiro, 1984); 2) $[\delta^{13}C]$ in bone collagen are consistently depleted in herbivore collagen relative to carnivore collagen by a small 1-2 permil.; 3) the difference between organic and inorganic (tooth apatite) stable carbon isotopic values also separates herbivores and carnivores. The inorganic trace element analyses of these same bone samples are in progress, and will test the hypotheses regarding discrimination of barium and strontium in herbivores and carnivores. The demonstration of differing trophic levels utilizing independent isotopic (and perhaps, elemental) data indicates that a new level of analytical rigor can be brought to paleodietary analyses, and allows us to proceed to the next challenge: relative omnivory. The evolution of omnivory (e.g., in the case of hominids, what was the first omnivorous group?) and the amount of meat in diets are questions that occur in many contexts.
Terrestrial Climate Models and the Use of $^{18}O$

The oxygen isotopic values were obtained from the CO$_2$ that is trapped in the lattice of mineral, apatite of enamel. This oxygen from the apatite is thought to be in equilibrium with body water during the life of the organism and the isotopic composition on body water closely correlates to changes in environmental water (Luz and Lolodny, 1985). Finally, enamel is thought to hold the in vivo isotopic values far better than the less crystallized tissue, bone.

In the Kents Cavern collection the $\delta^{18}O_{\text{smow}}$ values range from 21.0 to 26.9, however, we observed a distribution of values that clusters around 26‰. We would suggest that these data indicate that the majority of the fauna lived during the subarctic conditions of the middle Devensian cold phase 30,000-40,000 years ago. Equally interesting are the few oxygen values in the 21-24‰ that indicate lower mean annual temperatures during the life of these animals. It is likely that these values represent animals from the late Devensian, a time when arctic conditions and major glaciations occurred over the British Isles. We propose to test this hypothesis by radiocarbon dating the oxygen isotopic end members. Further, we wish to complete the stable oxygen analysis on the lower breccia fauna, animals that date to a much earlier time perhaps as much as 350,000 years ago.

The Lingula Project funded by a Scholarly Studies Grant

Noreen Tuross, CAL

Two major pieces of work were accomplished on the Lingula project: 1) large collections of Cambrian-age specimens were collected from five sites in Wisconsin. Participating in the collecting were Nigel Hughes, NMNH; Sandy Carlson, University of California, San Diego; Annette Richer, University of Mainz; Herve Boucherans, Carnegie Institution of Washington; Marilyn Fogel, Carnegie Institution of Washington; Jerry Gunnerson, Madison, Wisconsin; and, Noreen Tuross. The collections were made from Cambrian sandstones and include two genera of linuloids. These specimens will form the basis for the ancient molecules work in the second year of the Scholarly Studies Grant. 2) an extensive survey of carbon and nitrogen isotopes in modern Lingula from Hawaii and Japan has been completed. Within tissue variation is very small in each population, but intertissue variation is substantial especially in nitrogen isotopes.

This variation between tissue results from biochemical differences, and the chitinous tissues have distinct isotopic values. The stability of carbon and nitrogen isotopes in a given tissue for a population is a solid foundation upon which to build interpretations of trophic placement of ancient linguloids. In the coming year online gas chromatography/mass spectrometry of individual amino acids from ancient linguloids will proceed at the Carnegie Institution of Washington. In FY 1994 funding will be requested from the National Geographic Society in order to do a larger collection of the food web in Kaneohe Bay, Hawaii. Securely placing Lingula in its contemporary food chain is essential for interpretations of ancient brachiopod diets. The long term goal of the dietary aspects of this work is to understand if a plasticity in food source exists in the presence of long term morphological stability in Lingula. More simply, the zooplankton that are the apparent food source of Lingula today, did not exist in the Cambrian, yet modern and fossil Lingula are virtually identical in size and shape.
Smaller Projects

1. **Blood on Stone Tools** (collaboration with Rick Potts, NMNH, and Ian Barnes, University of Bradford, England)
   The ability to find and source (type) blood on experimental stone tools was carried out by ELISA assay. Stone tools were prepared from source rock at Olorgesalie, Kenya and used in goat butchery. This study demonstrated the presence of very small amount of blood on these experimental tools, and further demonstrated the possibility of determining the origin of the blood residues. However, there were major caveats offered in these results which have been written up for the *Journal of Archaeological Science*.

2. **Organic Pottery Residues** (with short-term visitor, Richard Evershed, University of Bristol, England)
   Over one hundred amino acid analyses were performed of experimental and archaeologically recovered pot shards. This protein based information was compared to the lipid data previously published by Richard Evershed. There was a consistent pattern of amino acids which gave complimentary data to the lipid analyses. This manuscript is in preparation.

3. **Effects of Microbial Degradation on the Isotopic Values in Bone**
   (collaboration with Marilyn Fogel, Carnegie Institution of Washington)
   Through a process called an enrichment culture, pig bone of known isotopic composition was subjected to microbial and fungal decay from soil microorganisms. Both the organic and inorganic isotopic compositions in were altered by culture activity. The change in organic isotopic values is consistent with lipid degradation, and the change in inorganic carbon isotopic values is consistent with exchange of CO\textsubscript{2} in the environment. Nitrogen isotopes did not vary with exposure to culture. These data were presented at the Ancient Bone Meeting at Oxford University in July, and will be reported in a publication from that meeting.

4. **Organizing Committee of the Ancient DNA Meeting**
   The Second International Ancient DNA conference was held October 7-9 at the Ripley Center of the Smithsonian. The sponsoring Smithsonian entities are the Conservation Analytical Laboratory, the National Museum of Natural History, the Smithsonian Tropical Research Institute and the Office of the Assistant Secretary for Research.
The Degradation Mechanisms of Traditional Artist’s Materials

Paper Aging Project
W. David Erhardt, CAL

Color changes in the samples prepared so far were measured and the results published and presented at the 10th Triennial Conference of the International Council of Museums Committee for Conservation. The results were quite interesting, showing that the factor which correlated most closely with color change was dew point, rather than temperature or relative humidity. This has interesting ramifications for the approaches which should be taken in optimizing storage for library and archival materials.

Analysis of the degradation products of the samples has begun. Enough samples have been analyzed to show that the data can be used in the calculation of reaction rates, activation energies, and the effect of relative humidity. These analyses will continue.

Measurements of the physical properties of the samples also is underway. The initial results show that aging of the samples results in changes in breaking strength, rather than modulus. This means that the aged samples are weaker, rather than stiffer or brittle. This is in contrast to many reports in which aged paper is often described as "brittle."

The results of the physical, chemical and optical measurements will be examined for correlations. The results so far appear very promising.

Paint Cleaning Project
W. David Erhardt, CAL

The work conducted with Dr. Judy Bischoff on the effects and mechanisms of action or resin soaps on oil paint films resulted in several publications. The work showed that many assumptions as to the mechanism of action and effects of the resin soaps were either incorrect or incomplete, especially regarding the roles of the components of the mixtures. This work has resulted in apparent changes in the way that these mixtures are formulated and used. It is not anticipated that any further work will be conducted on aqueous surfactant mixtures while the formulations are still in transition. Further work on this project will again focus on the effects of organic solvents rather than aqueous mixtures.

The Mechanics of Materials and Structural Analysis
Marion F. Mecklenburg, CAL

Mechanical Testing Program

The long range materials testing program has expanded considerable from paints, textiles, photographic gelatin, and adhesives to epoxy systems, degraded paper (cellulose), film base materials such as polyester and acetate, and woods. This required the modification and reconstruction of some equipment to handle larger and stronger specimens. The newly modified equipment is performing well and the wood research, with the assistance of Mel Wachowiak from the furniture conservation laboratory, is answering may of the questions regarding the environmentally induced forces in a large variety of woods.
The mechanics of materials research has entered an advanced phase where distinction can be made as to the elastic and plastic behavior of the materials. This is important since it is possible to show that environmentally induced plastic deformation can lead to early structural failure of objects composed of these materials.

**Computer Modeling**

This year significant advances were made in computer modeling of the structural behavior of cultural objects. The methodology was transferred to photographic materials with refinements that allowed increased effectiveness in computer usage. Specifically, it is possible to use the computer models to predict the mechanical response of structures to the environment, but to also provide a verification of the experimental measurements of the mechanical properties of the materials. This year, the modeling of photographic materials resulted in the current revision of the ANSI standards for the storage of photographic materials. This is clearly a demonstration of the effectiveness of this approach to the research of cultural materials.

The most recent version of the Finite Element Analysis software, ANSYS (version 5.0), has just been received and this version incorporates modifications that were the result of research and suggestions supplied by CAL to Swanson Analysis Inc., the supplier of the software.

**Shock and Vibration Studies**

This area of research has been extremely active in FY 1993 since it is very much a part of the mechanical properties program. Where much research in this area is conducted using environmental parameters, the dynamic studies examine both the effects of the environment and high rates of loading. These tests usually take a fairly short time and materials characterizations can proceed rapidly. A second component of this research is the actual analysis of structures subjected to shock and vibration. This area is conducted using ANSYS, the computer model software. One aspect of this area of research is specific applications. Working with Al Bachmeier at the Garber facility, preparations are being made to ship the "Vin Fiz," an early Wright Brothers flyer to Japan. The primary concerns are potential adverse effects of shock and vibration during transit. The solution is a shipping container that is its own suspended trailer. Current plans call for installing shock, vibration and environmental monitors in the shipping crate.
The Modern Polymeric Materials Program

Modern Materials
Mary T. Baker, CAL

Elastomers

This study investigated the effect of cold storage on the elastomeric materials in the Smithsonian’s space suit collection. Thermal analysis had shown in the previous year that oxidized rubber would crystallize in the same manner as unoxidized rubber, although slightly more slowly. It also indicated that the rubber decrystallizes at a temperature between 25-30°C above that at which it was crystallized.

This year, several deaccessioned suits were sampled for elastomers and the percent crystallinity determined. All were above 25% crystalline; many were as high as 45%. After decrystallization at 50°C, the samples were recrystallized at subzero temperatures, to determine if the trend noted on the non-suit rubber samples could be repeated. The results from this year, along with further analysis of previous data were interesting, and can be summarized in two basic points:

1) The rate of crystallization is further accelerated by exposure to heat before storage. Tests in nitrogen and oxygen showed that the rubber experienced an annealing effect as a result of time spent at elevated temperature. When the rubber had the opportunity to oxidize, the two factors (oxidization and annealing) competed, the oxidization slowing the crystallization rate and the annealing effect accelerating it. Under the study conditions, the effect of oxidization was stronger, causing a general suppression in rate. The bottom line of this result is that plain oxygen-free storage of rubber artifacts, as suggested by other studies, while it will slow oxidation, will accelerate room-temperature crystallization of the rubber if the artifacts are ever exposed to higher temperatures (as in most warehouses). This is not immediately hazardous to the rubber, but will make it stiffer due the crystallization, and since the crystals are formed at room temperature, the stiffness can only be removed by exposure to high temperatures, such as around 45°C (115°F).

2) The elastomers in the suits are both highly crystalline (after only 20-25 years of storage at room temperature and above) and highly crystallizable. Although the elastomers require several hours at 45-50°C to be decrystallized, when they were recrystallized at -7°C, they then required only about 11°C for decrystallization. This suggests that the suit materials have a smaller difference in de/re-crystallization temperatures than the rubber samples originally used last year. If this result holds true for the majority of the samples which will be taken in the next year as part of the planned collection survey (by the Garber Facility), it will firmly define the amount the temperature at which suits are presently stored (13°C) should be reduced.
The alarming decrease in biological and anthropological diversity in the world has led to a concomitant increase in the collecting of specimens to determine the cause of these changes. Preservation of these new, as well as the existing reference collections housed in our institution, is critical not only to the scientists who study them, and the public who visits and learns from them, but also for 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 to better and more efficiently prepare and preserve specimens for study. CAL scientists also are contributing to the research use of these collections by using specimens as "controls" for the study of shell and collagen deterioration.

One of our greatest concerns at this time is the storage of collections in fluids, primarily those stored in alcohol solutions. It is estimated that there are about 1.5 billion fluid specimens worldwide, and these are growing at a rate of about 50 million per year. These collections are a major source of preserved material used for a wide range of ecological, biological, histological, taxonomic and biochemical studies. They constitute a major portion of the record of our earth's biodiversity.

CAL has begun an investigation into the deterioration which is occurring in existing collections by analyzing the fluids in which specimens are stored to determine why and how they are deteriorating. Current studies indicate that specimens are slowly dissolving in these solutions, and that better preservation conditions need to be found for the future.

**Mammals Stored in Fluid**

Briefly, it can be stated that lipids, as evidenced by mass spectral and gas chromatographic analysis, are being hydrolyzed and removed from Abbott Collection (an early NMNH collection) mammal specimens, and are present in the storage medium. Proteins are also deteriorating in mammals as evidenced by amino acids in solution. The amino acid profiles indicate a general protein, as well as some structural protein loss.

**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 which have leached into the storage medium. The "mix" of amino acids which were found indicates they most probably are derived from the general deterioration, or breakdown, of muscle and other organs in the specimens. In other words, portions of all the specimens studied are slowly dissolving, although 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 dwindling because of local protective legislation and the deterioration of habitats. Some faunas no longer exist, and are found only in already existing collections. Consequently, maximum utilization of museum skeletal material is gaining in importance.

Current techniques for the preparation of skeletons are costly, consume much time, and can lead to the destruction of delicate bone processes. This research 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, Philippine Swiftlets), or difficult to clean (fresh dolphin bones) skeletal material. Swiftlets and dolphins were macerated with or without trypsin and pH 7.6 buffer in differing amounts of solution, at different temperatures, and differing trypsin concentrations. Microscopic examination of both dolphin and bird bones indicated that no softening or erosion of the surface was induced by the test conditions. Ultra-sensitive amino acid analysis of all the samples confirms the observations above, and indicates that there are no changes to the all important structural proteins of bird and dolphin bones.

New Techniques for Studying Specimen Deterioration

A new research thrust is being developed which involves fundamental studies of the chemical deterioration of proteins and their constituent amino acids. It is felt that one of the primary modes of stored-specimen deterioration (and its inverse, preservation) is the result of internal-to-the-specimen chemical reactions, as well as the reactivity of the specimen with its environment, whether a fluid or the components found in air. An understanding of this fundamental chemistry will allow a better description of deterioration processes, and as a consequence, provide a basis for the development of more chemically rational preparation and storage methods.

The above approach will be extended to include not only proteins, but other major classes of compounds found in natural history specimens: fat, carbohydrates and, especially, nucleic acids.

- For instance, initial experiments are currently underway to examine the stability/deterioration processes of fats in mollusks, egg shells and bone.
- Also, research is being conducted with P.E. Hare to develop improved techniques for amino acid analysis so that more reliable, and, especially, more complete analyses can be collected rapidly for the natural history projects, because many analyses will be conducted. Asparagine and glutamine cannot be determined by conventional methods since they are converted to aspartic and glutamic acids during preparation procedures. We have developed a pre-column derivatization technique for amino acids which, along with non-destructive preparation techniques will allow us to determine D- and L- asparagine and glutamine directly.
- These methods currently are being refined, and will be used to assess the state of preservation of museum specimens, projecting useful specimen lifetimes, and developing methods to improve preservation and long term storage conditions.
- In addition, new studies are being conducted on one of the most abundant and stable of the amino acids - glutamic acid. Preliminary results indicate that those proteins which hydrolyze in solution may, in fact, be partially stabilized by lactim 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. Research is being conducted to further explore this phenomenon. This research has implications for the conditions of storage of natural history specimens.
- The reactions with glutamic acid mentioned above, this time extended to include other amino acids and their deterioration products, are also being explored with
the object of providing both a time and temperature history for old specimens, which should result in a stand-alone dating technique.

- A study of the variable reaction rate kinetics of aspartic acid in mollusks (see below under "Short-Term Dating," completed in 1992), is now being extended to a study of racemization of all the amino acids found in egg shells. Hundreds of analyses have already been completed, and this preliminary data is being compiled to establish chemical pathways, and the kinetics of these reactions.
- The deterioration reactions of proteins also are being extended to a study of why and how aged protein adhesives remain stable, or fail. As a corollary, the analysis of binding media (potentially protein) for Southwest American Indian rock art has been requested by the Anthropology Department, University of Texas.
- Preliminary experiments are being conducted on the stability (and deterioration) of the major collagen from sponges - spongin.

**Short-Term Dating**

The proteins of all living creatures are composed exclusively of L-amino acids. After death, some of the L-amino acids changes to the D- form through a process termed racemization. New studies on aspartic acid racemization in land snails have determined that the initial rate of racemization is extremely high. This rapid initial rate presents the possibility of using this phenomenon as a high-resolution dating method for young materials. This is of particular interest because radiocarbon generally cannot be used for dating the last 350 years. For this reason, museum mollusk collections were used as a source of material of known age with which to evaluate the age predictive ability of D/L aspartic acid ratios. The dates of collection of these samples ranged from 1881-1949.

These shells showed a progressive increase in the D/L aspartic acid ratio with increasing age, to a value of 0.093 in the 110 year old specimens collected in 1881. These results indicate an average racemization rate of 1%/22 yr, and indicates that the age of a shell sample can be estimated within ± 10 years.

Recently, the experiments have been extended to bird egg samples, which also were found to have a high aspartic acid racemization rate. For instance, a net racemization of ca. 1% per 35 years was indicated for an egg shell sample about 330 years old. The method is useful for biogeographical studies, and could also be applied to dating of various deposits in nature (including archaeological material) and should provide good time resolution for the post-1650 A.D. period not covered by radiocarbon.
Research on the mechanical properties of photographic materials continues. During 1993, the stress analysis for Cibachrome print film was refined by using computer modeling to back solve for the emulsion properties. The refinements gave a remarkable improvement in accuracy. Even large scale deflections in specimens where anti-curl coatings had been removed from the product were correctly predicted. The new results showed that the earlier reported levels of stress in photographic emulsions had been conservatively estimated and that the actual levels caused by low relative humidity were about 25% higher.

The research on physical properties, combined with the "time out of storage" table that was developed last year show the chemical kinetics relationship between storage temperature, humidity, and time out of storage sparked a healthy debate as to the soundness of the current American National Standards Institute (ANSI) specification for photographic film storage. The ANSI document IT9.11, had just been revised to mandate low relative humidity storage in 1991. The CAL research has, in effect, forced ANSI committee members into a swift revision of the revision! As a newly elected member of the committee (December 1992), considerable man hours have been devoted to this task in 1993. Committee members met in December 1992, again in March 1993, and a final meeting takes place in October 1993. A new draft was circulated and revised further during the course of the committee work. The final revision has recently been completed. It allows for higher relative humidity levels (up to 50%RH) and compensation for chemical stability by lower storage temperature. The October meeting is to vote approval of the final draft. It is anticipated that the new standard will be published in 1994. It should also be noted that the ANSI standard very often drives revisions to the International Standards Organization (ISO) documentation. This work is a major step forward in terms of how photographic storage standards should be established. The final draft allows the archivist significantly greater flexibility in specifying suitable storage conditions, and encourages the use of reduced temperatures to significantly increase the life of a photographic collection.

Work has also progressed on the subject of photographic cold storage implementation. Conflicting guidelines in the conservation literature make the use of conventional freezers very impractical for this purpose due to restrictive packaging and moisture conditioning procedures. Moisture equilibrium experiments conducted over the past two years are now beginning to yield important information. The research strongly suggests that the presently recommended moisture control procedures are inaccurate or incorrect and that the guidelines for cold storage can be greatly simplified. This research will continue into the next fiscal year. A grant proposal was recently submitted to the SI Women's Committee to fund more of this research. The goal is to publish a clear set of guidelines that make the implementation of cold storage for photographic materials much more practical.

Finally, research work was initiated during the summer 1993 regarding "the vinegar syndrome" in photographic films made with acetate supports. This new research is admittedly in the formative stages. However, a literature review prompted the research activity because it showed that a serious number of discrepancies exist between the bulk chemical models proposed for deacetylation of the film support and the manner in which the film actually fails on archives' shelves. Although a number of research groups have
been investigating this serious issue, it is clear that a more comprehensive view of the problem must take into account the physical and chemical interaction of the photographic emulsion layers with the deteriorating acetate film base.
Analytical Services Group

Charles S. Tumosa, Head
Camie S. Campbell, Chemist
Walter R. Hopwood, Analytical Chemist
Melanie E. Feather, Conservation Scientist

The operation and maintenance of a large number of instruments and devices are required of the staff. Additions to the equipment have included, continuing upgrades to the XRD unit as well as a new UV-VIS spectrophotometer. A new small low KV x-ray unit has just been purchased. The requests coming in have become more sophisticated and the analytical services staff have now become more partners in research than technical support. Technical communications with the National Air and Space Museum (NASM), the National Gallery of Art (NGA), the National Museum of African Art (NMAfA), the National Museum of American History (NMAH), the National Museum of Natural History (NMNH), the Sackler Gallery, the National Museum of American Art (NMAA), as well as the Textile Museum in Washington, Catholic University, the Library of Congress, Folger Library, the U.S. Navy, and the National Park Service were part of the technical information and service provided. Total testing by Analytical Services has been approximately 5,000 tests per year, with almost 30% of this testing done for non-CAL sources.

Research

Research has been conducted along several diverse lines. In pure research the investigation of mechanical properties of various paint, epoxy resins and hide-glue films has been undertaken under the direction of M.F. Mecklenburg. These have concentrated on the measurement of physical property changes (e.g., thermal expansion, moisture expansion) as well. The investigation of the mechanical properties of wood and parchment has also been started. The parchment research, undertaken with the Library of Congress, is directed to the study of the behavior of certain old documents, notably the Dead Sea Scrolls. Nicholas Wyplosz, a French student, has been working on the mechanical properties of wood. An ongoing research project of Melanie Feather and Walter Hopwood is the analyses of pigments, binders, inks and corrosion products associated with a series of 14th century documents of the Knights of Malta.

Historical research into the Russian use of powder technology of platinum coinage is continuing. Further experiments are continuing on the gold-silver-sulfide question and on XRD of copper fatty-acid corrosion products. Pigment identification on Mayan pottery fragments is continuing.

Involvement with the research projects of other groups has lead to work/consultation on several projects:

1. Examination of a Russian silver bowl from the 14th century
2. Examination of an alleged chalice from the American Southwest
3. Examination of site matrix from a South African hominid site
4. Xeroradiography of ceramics from numerous sites with P. Vandiver and R. Hendrickson
5. Xeroradiography of the 'Ain Ghazal figurines
6. Pigment and corrosion identification on the murals at the Lincoln Memorial
7. Examination of trace ions in paper from the Clementine Collection of Catholic University
8. Examination of deposits on materials from African Art
Staff Conservators Research Program

In addition to the six core research areas, there are another five areas of research undertaken at CAL:

**Furniture**
*Donald C. Williams*, Senior Furniture Conservator
*Melvin J. Wachowiak*, Furniture Conservator

**Paper**
*Dianne van der Reyden*, Senior Paper Conservator

**Paintings**
*Roland H. Cunningham*, Senior Paintings Conservator
*Jia-sun Tsang*, Paintings Conservator

**Objects**
*Carol A. Grissom*, Senior Objects Conservator
*Harriet F. Beaubien*, Objects Conservator

**Textiles**
*Mary W. Ballard*, Senior Textiles Conservator

The conservators at CAL have different responsibilities that the conservation science staff. They treat objects, train conservators and interns, conduct conservation research, present papers and publish both research and conservation treatment findings. In each of the conservation laboratories, a different emphasis is placed on the responsibilities. For example, the conservators in the furniture conservation laboratory commit a considerable proportion of their time to the training of conservators in the Furniture Conservation Training Program. On the other hand, the paper conservation laboratory has a strong research bias. The research summaries then, provide information on the research programs only, and do not reflect the efforts gone into training, treatment, lecturing and writing done by the conservators for the fiscal year 1993.
Furniture

Gels as Organic Solvent Reservoirs for Treating Degraded Coatings
Don Williams, CAL

This project revolved around the development of a new treatment for degraded coatings on a wooden surface which are:

1. Inappropriate and/or damaging to the object
2. Extremely fragile, thus not manipulatable by mechanical means, and
3. Very sensitive to organic and aqueous liquids.

In other words, coatings so fragile that they could not be touched by anything solid or liquid without damaging them. We needed to remove enough degraded over-varnish to diminish its deleterious effects, simultaneously revealing the underlying decorative polychromy.

Using isopropanol gelled with polyacrylic acid, not as a contact poultice but as a solvent vapor reservoir, we could control the solvation process further, removing the varnishes safely and relatively quickly. During the initial exposure the fumes consolidated the thermoplastic paint and varnish. After consolidation the procedure was repeated for a much shorter timed exposure. Although the coating system had identical solubility throughout, we were able to exploit yet another property of materials, that is, they cannot occupy the same space. The vapors softened the varnish only so deep. By using a dull scalpel, we could them aggressively scrape off only the softened portion without worrying about "biting" into the still-hard lower layers.

We began with two dozen layers of varnish, compiled to a thickness between 0.75-1.00 mm, and ended with an extremely thin remaining layer which diminished the threat to and revealed the decorative polychromy. This treatment yielded a more stable presentation surface and an appearance closer to the intentions of the maker.

Surface Coating Materials
Mel Wachowiak, CAL

Two wax polish formulations were developed and reviewed for patentability. The final application is underway. Licensing and income distribution are to be negotiated.

One formulation is a wax resin paste and the second is an emulsion. The wax resin paste will be ideal for museums and collectors. The emulsion polish should be ideal for the mass consumer market. Both are easy to use and are composed of materials of known, stable chemical and physical properties. Future work will involve formulations that can be sprayed or colored. Other components will be changed to produce different properties.
Paper

Pigment-Coated Papers Research Project
Dianne van der Reyden, CAL

Pigment-coated papers, which are the support for many book and photograph collections, have special properties that render these papers susceptible to damage and conservation treatments. Several research projects were designed to 1) determine manufacturing processes for both hand-and machine-made coated papers, 2) identify deterioration problems, 3) catalog, test, and develop treatment procedures, and 4) characterize paper coating compositions (by SEM/EDS and FTIR) and appearance properties (by SEM imaging of surface structure and quantitative measurements of color and gloss), in order to evaluate changes that might occur following application of solvents used in conservation treatments to clean and stabilize documents. For a preliminary project, sample papers were hand-coated with combinations of calcium carbonate, zinc oxide and barium sulfate in binders of gum, glue, and acrylic resin, and tested for the effects of four solvents - water, ethanol, acetone, and toluene - applied three ways - immersion, poultice (diatomaceous earth), and suction disk - to each of the papers. The results indicated that, among other things, the aqueous poultice applications used in this study could cause cracking of some pigment-coated surfaces, especially the machine-coated sample. A second, statistical, study was designed to provide reliable data on the effect of two treatments that have been used for cleaning dirt, stains, or accretions from coated papers, namely aqueous immersion and blotter-poulticing, followed or blotter-drying. Findings indicate that SEM imaging revealed more surface disruption and reduction in gloss in the blotter-poulticed and blotter-dried samples, suggesting that this treatment, which has been used in the past, should be avoided with highly glossy papers.

Chromolithographic Paper Research Project
Dianne van der Reyden, CAL

The Smithsonian Institution has one of the largest collection of "mechanical," embossed, die-cut chromolithograph prints or cards, which are important as representations of two major innovations of the 19th century: the increase in mass communication through the exchange of cards in the Penny Post, and the development of mass color printing through chromolithography (the precursor to color photography, and the patents for which were destroyed during WWII). Because of their composite nature consisting of poor quality paper, coatings, and varnishes, these objects are particularly susceptible to adhesives and cracking, flaking, and staining, as well as to conservation treatments. A project was designed to study the effects of water on glazed chromolithographs: SEM/EDS and FTIR analysis of a selection of historically authentic, glazed chromolithographs, indicated compositions primarily of clay and blanc fixe (barium sulfate) and casein, a composition significantly different from modern chromolithographic papers, but similar to photographs. Treatment testing indicated that some aqueous applications (such as brush versus poultice) could cause opening of cracks and additional cracking of glazes.

Transparent Papers Research Project
Dianne van der Reyden, CAL

Contemporary transparent or tracing papers, forming the support for architectural and other technical drawings found in archives, libraries and museum collections, are produced by specially formulated furnish compositions and manufacturing formation
procedures, which make these papers reactive to solvents used in conservation treatments. Four research projects were designed: the first project focused on identifying modern transparent papers using FTIR, UV microscopy, SEM/EDS, and GC-MS. A second project documented the effects of accelerated aging on the properties of modern transparent paper. A third project evaluated the effect of several humidification and flattening techniques (using, for instance, ultrasonic or Gore-Tex humidification, and suction table or blotter press flattening) for transparent papers. A fourth project aims to evaluate the effects of four commonly used stain-removal solvents (water, ethanol, acetone, and toluene), applied by three different treatment techniques (immersion, suction, and poultice), on several coated and transparent papers. The effects of the various treatments were evaluated by examination of changes in texture, porosity, and distribution of materials in surface and cross-section samples (using SEM/EDS); in distribution, disruption and migration of organic binder (using UV microscopy); and of properties of tensile strength, opacity, and gloss. Findings indicated that 1) contemporary transparent papers can be characterized as transparent either by fiber processing (overbeaten natural tracing papers) or by sheet processing, using acid immersion (vegetable parchment papers); supercalendering (imitation parchment papers); or coating (vellum or prepared tracing papers); 2) aging resulted in the greatest change in color, opacity, and strength for a natural transparent paper sample; 3) solvent treatments resulted in the greatest increase in opacity in a prepared transparent paper; and 4) various humidification treatments resulted in the greatest gloss, transmission, and dimensional changes in an imitation parchment paper.

A collaborative project with Winterthur and CCAHA conservator Lois Price is underway, using SEM and FTIR to analyze 19th century tracing paper sample books for a monograph on photomechanical processes found in research, libraries and archives collections.

To characterize papers transparent by immersion in acid, analysis including fiber microscopy, microchemical staining, SEM/EDS, FTIR, colorimetry, and gloss and mechanical properties measurements characterizing three different types of parchment paper (before and after aging) was undertaken by three "pre-program" summer interns with science backgrounds (Antoinette Owens, a MS candidate in Materials Science, Interdisciplinary Studies at Johns Hopkins; Melissa Todd, a graduate of Oberlin College with a BA in Chemistry; and Cecile Politte, in Chemistry and Art History at Duke University). The results have not been evaluated or compared to those for other forms of transparent papers yet.

**Parchment Skin Research Project**

*Dianne van der Reyden, CAL*

For a course on parchment conservation, SEM/EDS analysis was used to compare parchment skin and parchment paper, finding that although cross-sections were unexpectedly similar, elemental analysis was naturally quite different. However, more importantly, it was discovered that 10 samples of new parchment skin have relatively high levels of chlorine (which, used as a bleach with paper, might have been used as a disinfectant with parchment skin), while older parchment samples, from the eighteenth and early nineteenth centuries, had very low levels of chlorine, if any. This information is important not only for general analysis to distinguish parchments from different periods, but also in the context of whether sampling of the Yale's Vinland Map is warranted or not with respect to the map's authenticity.
The painting, A Reading, by T.W. Dewing, owned by NMAA was autoradiographed at NIST. Samples were taken for embedding, sectioning and SEM-EDS analysis of inorganic constituents. Information was used for analyses of materials and interpretation of the artist's technique.

Extensive work was performed using the rotary microtome to prepare samples for photomicrography and SEM analysis in order to extract as much inorganic information as possible and still retain enough of the sample for further study. These techniques have been adapted to archaeological smelted tin samples, canvas fibers, silver samples, vellum, parchment, skin and samples of photographic support material samples where only very small pieces are available. Samples were cut into approximately 2x3 mm sections and wrapped in aluminum foil packets under magnification. The packet's edges were crimped and embedded in an experimental, quick setting, thermoplastic medium. FTIR analysis indicates no contamination of embedding material using these techniques.

Epoxy mounts were designed and fabricated to support irregular copper artifacts so that the artifacts could be positioned at any desired height and surface disposition within the same mold, prior to epoxy embedding under vacuum for sample preparation.

FTIR, UV-Vis microscopes and GC-Pyrolysis from the FBI Forensic Laboratory were used in a study of the paint binder of alkyd paint from a group of de Kooning paintings from the Hirshhorn Museum.
Objects

**Plaster Analyses Relevant to the 'Ain Ghazal Sculptures**
*Carol Grissom, CAL*
*Patricia Griffin*
*A.E. Charola*

DTA, XRD, SEM, and thin-section petrography have been used in an attempt to determine the temperature to which calcium carbonate rock was heated prior to making plaster for the prepottery neolithic sculptures found at 'Ain Ghazal, Jordan.

**Aging of Conservare OH**
*Carol Grissom, CAL*
*A.E. Charola*

Samples of the 'Ain Ghazal plasters which have been consolidated and aged for different periods of time (from several months to seven years) have been examined with the scanning electron microscope to determine if any changes are visible in the consolidant over time. No differences have been observed which cannot be attributed to the application of different quantities of consolidant.

**Ancient Meso-American Pigment Identification**
*Harriet F. Beaubien, CAL*
*Holly S. Lundberg*

Samples of pigments used to decorate artifacts and architecture found at excavations at Ceren, El Salvador, and Copan, Honduras, have been identified by x-ray diffraction. Further work in this area is anticipated in order to achieve a better understanding of pigments used in ancient Meso-American cultures.

**Consolidation of Unbaked Clay Tablets**
*Anne V. Liegey*

Samples of salt-laden ancient and laboratory-made unbaked clay tablets were consolidated with an acrylic resin or an alkoxysilane solution and water washed to remove the salts. Desalination of the alkoxysilane-consolidated ancient tablets was successful, but none of the laboratory-made tablets were intact after submersion in water.

**Comparison of Medium Pressure Water and Walnut Shell Blasting of an Outdoor Bronze Sculpture**
*Carol Grissom, CAL*

Areas on the statue of Freedom from the U.S. Capitol which had been test cleaned by blasting with walnut shells or water at three pressures (2000, 4000, and 6000 psi) were photographed with magnification (6x, 12.5x, and 31x) before and after cleaning. The photographs taken at the lower magnifications proved to be useful in determining the degree and uniformity of corrosion removal with the different methods.
Textiles

Textile Conservation Research
Mary Ballard, CAL

Two major research reports were presented this fiscal year. Both reported on the nature and cause of interactions between cleaning agents commonly utilized in textile conservation and their long-term effects on the completed ["conserved"] textile object: one series of work developed the concept of chemical interaction between silk and surfactant; the other, reported the cause of out-gassing on glass from framed textiles. These research projects have important implications for future conservation treatments and for existing treatments across the United States. The treatment of silk has a bearing on both antique and modern silk textiles and garments. The silk and surfactant work was a joint project with the International Fabricare Institute; the glass deposit residue work was conducted under the supervision of senior textiles conservators at CAL and the Cooper-Hewitt by post-graduate fellow Susan Heald.

On-Going Research

At the Textile Conservation Group's Symposium on the Use of Adhesives and Consolidants in Textile Conservation, January 21-22, 1993, Mary Ballard and Paul Czubay presented "The Removal of Crosslinked Synthetic Latex from Carpets: Theory and Practice." This presentation explained the theoretical and practical difficulties in removing latex adhesive from the back of an oriental carpet. It was the only presentation which delineated the problems associated with the removal of an adhesive from a porous surface, i.e. a textile. All the other speakers discussed putting the adhesive on the object. While this presentation completed file CAL #4786-B, the broader and more troublesome issue of latex removal for 19th century hooked rugs remains. Bayou Bend, Houston Museum of Fine Arts has loaned such an object for the development of a prototype treatment.

Ten days in October were spent in Indonesia, in Java, primarily in Jakarta and Solo. Samples of natural dyeings were obtained together with information on the source of the dyestuff, the extraction methods, the dyeing methods and techniques. Two research institutes were visited, one in the Yogyakarta [Balai Besar Penelitian dan Pengambangan Industri Keriganan dan Batik, Departemen Perindustrian] and another in Bogor [Pusat Penelitian dan Pengembangen Biologi] as well as the Bogor Botanical Gardens. The purpose of the trip to Indonesia was to collect samples of natural dyeings for research. Indonesian Natural Dyes/Bahan Celup Alam Indonesia compiled by P. Yosep Subagiyo and Mary Ballard requires practical data in addition to the literature review carried out in FY 1992. Standard dyeings were obtained. The mordants on these dyeings were confirmed with SEM and EDS. Camie Campbell identified sucrose and ammonium aluminum potassium sulfate as some of the products used in Solo for mordanting. The samples have been labeled and set aside for additional testing. A portion of the samples were given to Dr. Helmut Schweppe for analytical confirmation. The new UV-VIS spectrophotometer at CAL is expected to help significantly in this work. The ci35 Weatherometer will also be employed.

Another field of on-going research involves the treatment of sulfuric acid treated 19th century American silk flags, as compared to the treatment of weighted silk.
Fellows and Interns

Jose Aguirre (University of California, Berkeley), summer intern with Emile Joel and Jacque Olin.

Marina Delaney (New York University), Paintings fellow with Ron Cunningham and Jia-sun Tsang.

Kathy Evans (University of Wisconsin, Madison), summer intern with Noreen Tuross.

Patricia Griffin (New York University, Institute of Fine Arts), third year archaeological intern.

Beverly Johnson, volunteer from the Carnegie Institution of Washington, with Noreen Tuross.

Thuy Le (Thomas Jefferson High School for Science and Technology), intern with Pamela Vandiver.

Holly Lundberg (University of London, Institute of Archaeology), postgraduate archaeological conservation fellow.

Anne Liégey (University of Paris - Sorbonne), conservation intern in the Objects Laboratory.

Annette Owens (Johns Hopkins University), summer intern with Marion Mecklenburg and Dianne van der Reyden.

Joanna Pessa (Tulane's Sophie Newcomb College), summer intern in the Textiles Laboratory.

Cecile Politte (Duke University), summer intern in the Paper Laboratory.

Arati Raghavan (Thomas Jefferson High School for Science and Technology), intern with Pamela Vandiver.

Christine Richardson (University of Alberta), summer intern in the Textile Laboratory.

Ginger Russell (Virginia Commonwealth University), summer intern in the Furniture Laboratory.

Dana Seaman, summer intern with Noreen Tuross.

Karen Stamm (University of London, Institute of Archaeology), summer intern in the Objects Laboratory.

Melissa Todd (Oberlin College), summer intern in the Paper Laboratory.

Julie Tu (Harvard University), undergraduate intern in archaeometry.
**Julie Unruh** (Queen's University, Conservation Programme), summer intern in the Objects Laboratory.

**Alexander Winter** (Ecole Nationale Superieure de Telecommunication [ENST], Paris), intern with Ingrid Alexander.

**Nicholas Wyplosz** (European High Institute for Chemistry of Strasbourg, France [EHICS]), summer intern with Charles Tumosa.
Publications


