Harpers Ferry Center

National Park Service
U.S. Department of the Interior

Development of a Web-Accessible Reference Library of Deteriorated Fibers Using Digital Imaging and Image Analysis

Proceedings of a Conference

April 3-6, 2003

Sponsored by the National Park Service
Harpers Ferry Center

Funded by a grant from the National Park Service and the National Center for Preservation Technology and Training

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Preface

Jane Merritt

This volume contains the papers delivered at the conference *Development of a Web-Accessible Reference Library of Deteriorated Fibers Using Digital Imaging and Image Analysis* held at the National Conservation Training Center (NCTC) in Shepherdstown, West Virginia, on April 3-6, 2003. Textile Conservator, Jane Merritt and Conservation Scientist, Judy Bischoff of the National Park Service's Harpers Ferry Center organized the conference. They received funding to support the event and this publication from the National Center for Preservation Technology and Training.

The idea to convene a meeting of specialists who would discuss the creation of a reference library of deteriorated fibers arose more than a decade ago. Initially the reference library was conceived as a resource for conservators who routinely need to identify deteriorated fiber samples that have lost their characteristic morphologies. In the intervening years technologies have developed or were improved to the point where the reference library as now conceived can be a powerful, searchable database containing digital images of fiber samples, other types of data, and all the data can be made globally accessible through the World Wide Web. The database would serve many disciplines, from conservation, to law enforcement and homeland security, to forensics.

The specialists who attended the meeting have long careers in areas that relate to the many aspects of making a Web-accessible fiber reference library a reality. They were invited to discuss their involvement in relevant fields and brainstorm about a resource that would fulfill the needs of a broad group of users. After three intensive days of presentations and discussions, the vision of the Web-accessible fiber reference library crystallized and a work plan for its creation emerged.

By the end of the meeting the participants had organized themselves into core work teams, committed to collaborating on the project. What comes next is the funding to take their ideas and create the database. The participants felt strongly that governance of the database should be guided by a not-for-profit organization and the data rest in the public domain.

This publication is the first step in the fundraising process. It demonstrates that the research and groundwork for this project has been accomplished and is worthy of support. Currently the project remains under the direction of the National Park Service while funding is sought and a non-profit organization is created to establish, manage, and operate the database.

Acknowledgments

A special note of thanks is extended to the following people for assisting with summaries and/or reviewing manuscripts:
Fenella France
Chandra Reedy
Mike Toth

Harpers Ferry staff were critical to this project. Designer, Roberta Wendel of Media Development designed this volume and offered great support and advice. Bob Grogg, Associate Manager, Media Development was instrumental to getting this volume to completion. Martin Burke, Associate Manager, Media Assets never wavered in his support.

Thanks are also due to Peggy Sandretsky, NPS Liaison, at the FWS National Conservation Training Center and Robin Hanson who contributed to the group's comfort and well-being while at NCTC.

Envisioning a Web-Accessible Fiber Reference Resource

Jane Merritt

Across disciplines textile specialists identify and compare fiber samples. Whether the work is performed to document cultural treasures or analyze evidence from a crime, fiber samples can provide valuable information to the conservator, curator, scientist, investigator, and researcher. When the samples are collected, documented, tracked, analyzed, and organized systematically, an important resource, a reference library, develops. Newly available technologies and the World Wide Web can make it possible to share this resource globally.

This three-day international meeting brings together specialists with the critical skills to envision, plan, develop, and implement a Web-accessible fiber reference library. The issues begin with the tangible fiber resource and expands into managing the information gleaned from the sample.

Conference Goals

Define the purpose of a Web-accessible reference library of fiber samples that uses digital imaging and image analysis. Create a work plan for its realization.

Conference Issues

A project as broad as creating a Web-accessible reference library of fiber samples has many issues that need to be addressed. Participants anticipated who may be users and their needs, discussed database design and development, voiced concerns about developing standardized procedures and protocols for acquiring samples, and addressed issues of governance and funding.

Conference Outcomes

After stimulating discussions, participants agreed that a Web-accessible digital library of fiber samples would have great practical use. A road map to its realization is detailed in this document.

Conference Participants

Conference participants represented a range of organizations, and a variety of skills, with expertise in textile, forensic and conservation science, conservation, knowledge management, information systems, systems integration, web design, education, textile history, and collections management.

Specialists from the following organizations participated in the meeting:

National Park Service, Harpers Ferry Center
Metropolitan Museum of Art
Cooper-Hewitt, National Design Museum of the Smithsonian Institution
Cleveland Museum of Art
Art Institute of Chicago
Museum of Fine Arts, Boston
Winterthur Museum and the University of Delaware Art Conservation Program
Trace Evidence Unit, FBI Laboratory
Laboratories and Scientific Services, Bureau of Customs and Border Protection, U.S. Dept. of Homeland Security

Forensic Investigations Division, New York City Police Department
Ohio State University
University of Delaware
University of Southampton, Winchester, UK
Centre for European studies at Monash University based in Florence, Italy
Art Preservation Services
R.B. Toth Associates
National Center for Preservation Technology and Training (NCPTT).

Conference Location

This three-day meeting took place at the U. S. Fish and Wildlife's National Conservation Training Center in Shepherdstown, West Virginia. The secluded woodland campus with residential facilities was an ideal venue for creative brainstorming, professional networking, forming work groups and developing friendships.

Conference Structure

All participants made short presentations describing their involvement in issues pertinent to the creation of a Web-accessible fiber database. Nine invited speakers addressed key issues and discussion points for the participants. Four textile students participated and assisted with note taking during the meeting.

Breakout groups and provocative, sometimes even contentious plenary sessions led to developing a purpose statement and work plan for creating the fiber reference resource.

The meeting was facilitated.

Conference Organizing Committee

Judy Bishoff
Fenella France
Robin Hanson
Kathryn Jakes
Jane Merritt
Mike Toth

Facilitators

Eunice and Sherwood Shankland
Shankland and Associates, Fairfax, Virginia

Conference Support

The conference was supported by the National Park Service, Harpers Ferry Center which received generous financial support through a grant from the National Park Service and the National Center for Preservation Technology and Training.

This publication was developed under a grant from the National Park Service and the National Center for Preservation Technology and Training. Its contents are solely the responsibility of the participants and do not necessarily represent the official position or policies of the National Park Service or the National Center for Preservation Technology and Training.

Executive Summary

The concept, principles, and elements for developing a Web-accessible, integrated database of images and data derived from the acquisition of textile fiber samples were discussed in detail during this meeting. A work plan developed at the conclusion of this international conference convened by the National Park Service, Harpers Ferry Center with support from the National Center for Preservation Technology and Training (NCPTT). It was held at the U.S. Fish and Wildlife Service National Conservation Training Center in Shepherdstown, West Virginia, USA, on April 3-6, 2003.

Participants recognized that the utility of a Web-accessible fiber reference resource will vary according to the needs of the various users. They agreed that the following goals must be addressed for the integration of an effective and sustainable fiber reference resource.

Purpose and Scope

Database Utility

A Web-accessible, digital, public domain, textile fiber reference database is needed for use as a tool and resource in the textile field for:

- Identification
- Treatment Support
- Research
- Comparison
- Education
- Training

Users

The database will be tailored for, but not limited to, use in the textile field by:

- Curators, Historians, Researchers
- Conservators and Conservation Scientists
- Textile Scientists
- Forensic Scientists
- Educators and Students
- Archaeologists
- Anthropologists
- Preservation Professionals

Content and Input

Database Content

The Web-accessible database will store and archive information associated with specific textile fibers, which may include fiber and source images, and associated data, including:

- Standardized details on ownership
- Historical context
- Standardized fiber descriptors
- Fiber treatment and environmental conditions
- Results of physical, chemical, and spectral testing and analysis

Database Input

Individual contributors will need to enter the data based on an agreed protocol, using agreed standard fiber microscopy and textile science nomenclature, with associated standardized metadata and uniform data formats. The images and data will need to be collected using agreed standard textile fiber sample mounting, sampling, and imaging methods, including visible light, multispectral, and electron imaging. Existing data entries will be included in the database or linked to it wherever efficiently possible.

Output

Users will be able to conduct text-driven searches of the database using standardized criteria and terminology in multiple fields, including:

- Keywords
- Image details
- Textile and fiber details
- History of treatment
- Contributor details and usage rights
- Scientific and conservation study results

Users will be able to access the original digital images, processed images, and the associated data on the textile fiber sample, as well as links to additional source information and existing textile resources.

Resources and Governance

Funding

Further funding will be required for the proper integration and operation of this database as an effective tool for the textile community, first on a smaller scale as a prototype, and then scaled up to a fully operational capability. Funding for additional research into standard methodologies and standards development may also be required. Initially this project will remain under the auspices of the National Park Service, then eventually to a not-for-profit organization established to manage and operate the database as a service of common concern.

Management

Since the information will be in the public domain from samples collected from objects in the possession of public and private institutions and individuals, issues regarding ownership rights and acknowledgements need to be discussed and resolved. These issues will have to be resolved to the satisfaction of the many contributors who may be from countries who have differing views about the protection of intellectual property.

Developing a Web-Accessible Reference Library of Deteriorated Fibers Using Imaging and Image Analysis

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Fiber Identification History

Development of a Web-Accessible Reference Library of Deteriorated Fibers Using Digital Imaging and Image Analysis

Meeting Program

Friday	Saturday	Sunday
Objectives: • To build a common understanding of what is going on in the field (state of the art); to acknowledge common practices and emerging trends. • To identify key issues or concerns surrounding the development and design of a deteriorated fiber database Theme: Knowledge and Methods	Objectives: • To present current and new breakthroughs in technology applications. • To identify effective ways to apply technology • To identify key working group topics (for follow up actions) Theme: Technology Tools and Practical Applications	Objectives: • To build a set of recommendation and plans of action to develop a Web-accessible reference library Theme: Building a Web-accessible Reference Library
Opening Remarks—purpose and anticipated outcomes/benefits of this conference Introductions and Exchange 1. Snap shots of the group—who is here/ the perspective they bring 2. Individual presentations 3. Group discussions—identify trends and current issues re textile deterioration (needs analysis) LUNCH BREAK Presentations: Conservation and Technology 1. Textile deterioration and standards (K. Jakes, L. Commoner, F. France, J. Merritt) 2. Database—concepts, management, and web accessibility (M. Toth, R. Hanson, D. Gilbert) Group reflection and Close	Opening—The day's flow of activities Open forum: Insights from yesterday's discussions. Technology Applications 1. Setting up your own imaging system (Software, hardware, cost) 2. Application of image analysis to fiber deterioration—J.Bischoff 3. Software applications—image analysis software—C. Reedy Break out groups and Forum LUNCH BREAK Hands—On in the Lab Image analysis Sampling; discussions of techniques and implication to building a database Group work: establish work groups (discussion-addition to morning forum results) Reflection and Close	Opening—Working Group context and instructions Working Groups Plenary reports Reflection and Next steps Conference reflection and feedback LUNCH AND CLOSING


WELCOME
DEVELOPING A
WEB ACCESSIBLE
REFERENCE LIBRAR
OF DETERIORATED
FIBERS USING
DIGITAL IMAGING
AND IMAGE ANA
MELANIE

Welcome and Opening Remarks

Taking the Resource and Making it Accessible

Jane Merritt

In 1975, ten fiber samples were removed from the different fabrics that make up the George Washington tents in the collection of Colonial National Historical Park for the purpose of fiber identification. Then Harpers Ferry Center (HFC) Textile Conservator, Fonda Thomsen, began a process that continues in the lab today and eventually lead to this meeting. She and her staff removed minute fiber samples from every textile that they treated as part of their standard documentation and treatment process. Rather than discarding the sample after identifying the fiber, they kept the mounted specimen. Each sample was labeled with the object's accession number and assigned a sequential registration number, and then it was stored in a slide box. The registration number was incorporated into the object condition and treatment report that accompanies each conservation treatment. By 1992 when I became the HFC textile conservator, this practice had created an amazing resource. More than 1,500 fiber samples existed that related to our conservation records. These contained a condition assessment of a textile before treatment followed by a full description of treatments undertaken.

This practice has been in effect for 28 years and has resulted in a reference library of deteriorated fiber samples that reflects the strengths of the textile collections of the National Park Service (NPS). Sharing this resource with others seemed obvious. Initially I thought that the fibers would be great to use as comparisons for the identification of similar deteriorated fibers. Textile conservators frequently voice frustrations when using purchased fiber reference sets as an aid in identifying fibers taken from an artifact. The samples in these sets are prepared from new fiber specimens that may not exhibit the same characteristics as the deteriorated sample sitting on the conservator's microscope stage.

There is also the fact that the sample is removed from a textile before treatment, and also before the object is returned to the park museum and put on exhibit. The level of deterioration of the sample is therefore a reference point should a new sample be taken from the textile many years later to use for a comparison. How to apply the resulting information to the routine conservation practices of treatment, storage, and exhibition could be considered.

The information recorded in the condition/treatment report and matched to the sample may help with these considerations. Harpers Ferry Center designs interpretive media for the National Park Service. Staff routinely communicate with parks across the U.S. via video recording and conferencing as well as e-mail and web techniques. It is therefore the ideal organization to begin the process of making the fiber reference library accessible to all interested disciplines and to collaborate with others to expand the resource and have it serve multiple purposes.

The tools to make the reference library accessible were acquired gradually. Computers and the World Wide Web became an integral part of life in the 1990s. The textile lab purchased a high quality polarized light microscope, Harpers Ferry Center hired Dave Gilbert as web manager, and Robin Hanson joined the textile lab as an advanced conservation fellow. Robin had a keen interest in fibers and created the architecture for a database for the reference library. Our conservation scientist, Judy Bischoff, brought a vision of image analysis to the project. Finally, the funding and support from NCPTT and the interest of each of you in sharing ideas and expertise leads us to a collaboration that could have an impact in many fields.

The variety of expertise at this meeting is amazing. Gathered together for this conference are people who identify fibers, work with small samples, treat artifacts, manage databases or systems, use image analysis, mentor students, and perform research.

Although we may approach sample analysis from different perspectives and desire different information, the dissimilarities among us will strengthen our collaboration and help us to develop a Web-accessible reference library of fibers that will be useful to all.

What are some of the outcomes for the field of conservation? Within the NPS fiber sample collection we have many 19th-century wool fibers, primarily from military uniforms, flags, and accoutrements. There are samples from more than 200 wool Civil War period uniform jackets. A study of just those fiber samples could yield information about the wear patterns and vulnerabilities of the wool, origins of the cloth and yield new information about the type of wool used for Federal versus Confederate jackets. The types of damage we see with the uniforms tend to be similar. Often there is extensive damage from insects; fibers are dry, shedding, and brittle. When you consult a condition report you may learn that the uniform found on the battlefield at Gettysburg has a damage pattern that is similar to that found on a uniform from the Antietam battlefield. Comparing the fiber slides from the two jackets and being able to quantify the damage using image analysis will bring a powerful new tool to our ability to understand and manage deterioration. A compendium of condition characteristics that relates what is observed on the macroscopic and microscopic scale prepares us to better treat and preserve our cultural heritage.

Having the samples accessible over the Web means that conservators worldwide can easily consult each other about issues of damage and treatment. A successful treatment performed on the Gettysburg jacket becomes a starting point for considering treatment for the Antietam jacket. Take this idea and broaden it to include weighted silks, archaeological textiles, modern materials, and no conservator need make a treatment decision without locating a similarly degraded object to compare another conservator's approach to its preservation.

Getting to this point will take a great deal of work, funding, enthusiasm, and a lot of other things not yet imagined. What we start here today may become a model for others who work in similar disciplines. The NPS fiber reference samples were not accumulated and saved for this expanded purpose. There are inconsistencies in documentation and early sampling procedures, but we can use these samples as discussion points and a rationale for creating standards for sample acquisition and expanding the purpose of a reference library. This group consists of people who are in the position to analyze, discuss, and develop the procedures that will bring a commonality and consistency to taking future samples. And in the end, this resource will help us with our preservation efforts.

Judy Bischoff and I welcome you to this conference and express our hope for a very productive meeting. We look forward to working together and thank each one of you for attending.

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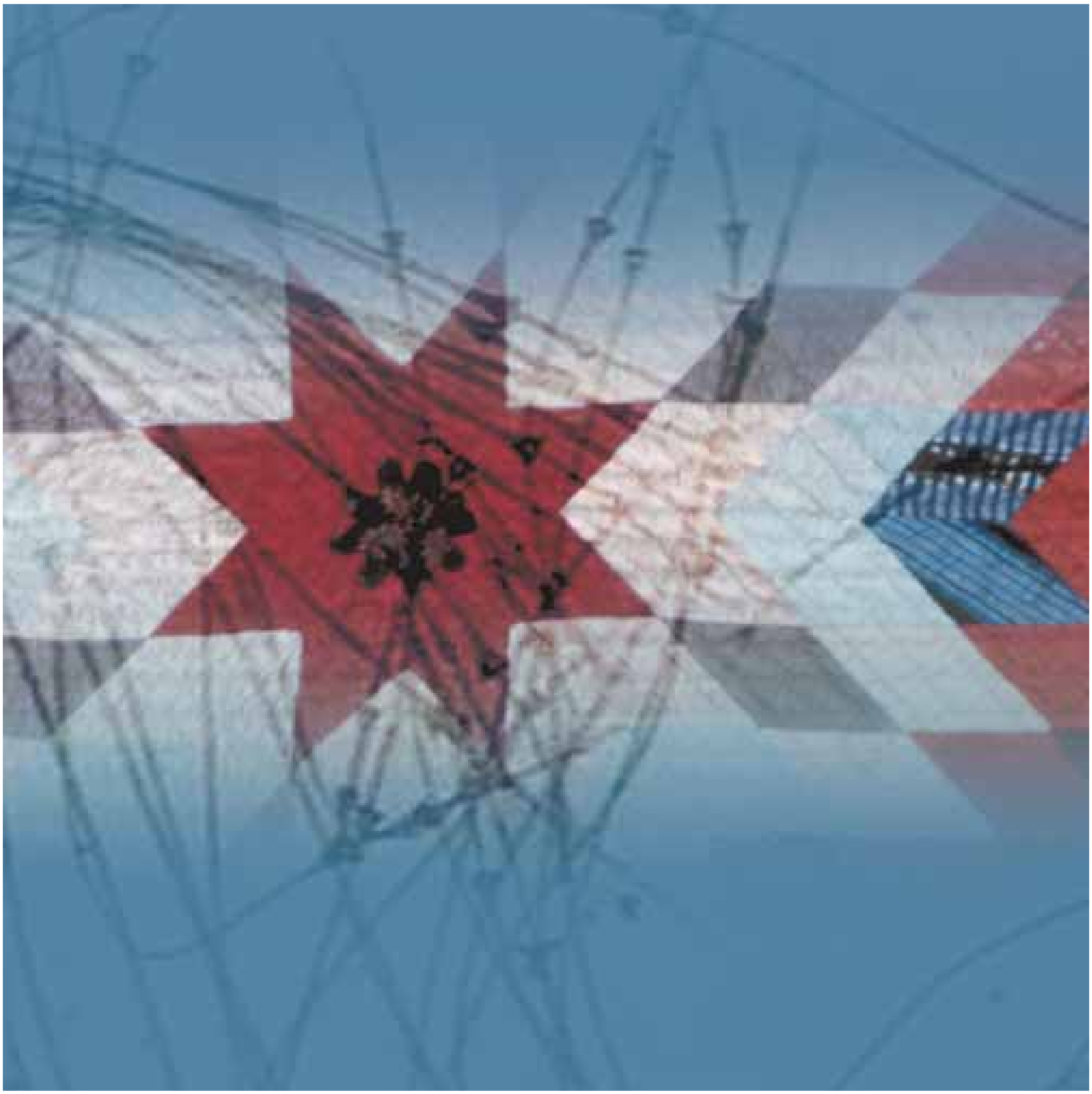
Participant Papers



What If I Am Not a Conservator? Creating a Fiber Database Which Can Also Be Used by Textile Historians and Researchers

Angharad Rixon
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Developing a Web-accessible database of fiber samples would create an invaluable tool for textile research. It is not difficult to imagine how this project would be useful to textile conservators and conservation scientists; as a source of comparative material to help identify a mysterious fiber, facilitating the discovery of how different conditions and treatments have affected similar objects, or gauging the degree of fiber deterioration through comparison with similar contexts—but what if I am not a conservator? This database has the potential to become a useful resource for all forms of research which reference textiles, and as such there is need to consider the scope of potential users. As a textile historian who has worked with both conservators and scientists, I have seen and heard about the processes and thoughts of these parties as well as those of curators and other historians. Like conservators, historians and curators are interested in the state of conservation of objects, partly because this dictates both scholarly and public access, but also because it tells us something about its history, how it has been kept and how it has survived into the present. Fiber analysis also gives us valuable insight into the physical object, which helps to place it in context: the agriculture, economics, fashion, and artisans of the world from which it came.

My work with analysis of deteriorated fibers began in 2000 while I was studying fragments of lace which were retrieved from the wreck of the Dutch East India Company ship *Batavia* which was wrecked off the coast of Western Australia in 1629. Initially this was a rather naïve study; I had thought that a comparative analysis of thread from the *Batavia* lace and other laces of similar style and period might give some scientific evidence to help solve a dispute about its origin. The study, which compared 10 samples to the *Batavia* lace, did not in fact solve the problem of the lace's origin. It did, however, raise a number of questions about the study of lace history, particularly as it revealed the possibility of linen/cotton blends in the manufacture of early laces (Rixon 2000), the use of cotton being previously thought to be evidence of a 19th-century reproduction (Earnshaw 1989). In 2001 this work was followed up with a project on the 16th-and 17th-century laces in the Powerhouse Museum, Sydney, Australia where again, the use of cotton appeared much earlier than would be expected (Rixon 2002).

The results of these projects altered my approach to the study of lace irreversibly, and I now include a fiber analysis as an integral part of any catalog entry. I work in this way partly because I believe that it is important to record faithfully all the physical details of an object and partly because I am interested to see if there are links between particular characteristics of the thread and particular periods or centers of manufacture. At this stage a full-scale development of this branch of my research is not possible, and so, I slowly continue this research by noting this characteristic when I see it.

The key element in my own fiber sampling practice is that a sample of the whole yarn is taken; this method reduces the risk of sample contamination and retains other important data about the thread as a whole. As I am interested particularly in the early use of blended threads, the possibility of contamination must be avoided at all costs; keeping the yarn intact and teasing out the end of the sample under the microscope has been the only way I have found to ensure this. Cross-sections are always made by packing the sample into a tiny hole in a steel microscope slide and carefully cutting away the excess with a razor blade; these are examined using a compound light microscope.

Longitudinal sections are always examined using a scanning electron microscope (SEM). In addition to the fiber content of the thread I also record the twist and the ply, as well as whether it is hand or machine spun. Wherever it is possible I do take one sample which is generous enough to provide all the information I require as I prefer to avoid going back to the object for re-sampling. Many would disagree with taking a generous sample, but I find it important for accuracy, and fortunately the objects I work with often have a cut end, so it is generally not too difficult to obtain such a sample.

As a student working with fiber analysis I have always worked on projects with small budgets. The positive aspect of this is that I have been involved with the entire process from selecting the objects to be analyzed, to taking the samples, to working with a technician in the SEM laboratory. Through this process I have come to realize that the individuals who take the samples and conduct the tests ultimately have control over the kind of information which is gathered. With this in mind, care must be taken not to restrict possible users of this database to those who physically take the samples, and I would suggest that this might be done by standardizing a basic set of characteristics which are to be included. In North America and Australia, museum protocol is such that it is the responsibility of conservators to conduct fiber analysis, be that for fiber identification or condition reports. But this information is also an important part of the object description and is thus important for placing the object within its historical and geographical context. Hence it is important to consider potential needs beyond one's immediate study, and certainly beyond the field of conservation.

The issues of sampling protocol and budget are not only a concern for student projects. If this database is to include the broadest range of samples possible, then the criteria which are set for sampling and analysis must take into account the varied financial means of those who own the objects. While budgetary constraints are a global issue for museums and research institutions, they can be greater in the case of private and small community collections. For comparative research to be really effective one requires a large number of samples from similar objects, some of which should have a clear provenance. Private collectors and community museums play an important role in collecting such data, and with this one must ask what types of analysis the database will include.

While SEM and infrared (IR) are techniques which are able to give us very detailed information, not all researchers are able to use or gain access to these apparatus and for many purposes a good quality photograph taken through a light microscope may be adequate. The technical protocols for the database therefore must be constructed in a way that does not exclude valuable information on the grounds of simple technology.

While conservators are often given the task of conducting scientific analysis of objects, curators have the task of selecting objects for exhibition and compiling catalogs. Because of this, they may also take a great interest in the database, both in working with conservators to establish whether an object is able to withstand exhibition and in ensuring the catalog information is as accurate as possible. With regard to further research, the involvement of curators is uncertain simply because of the pressures which institutions place upon them to produce exhibitions which will attract a large audience and thus funding. This is the element which sets the roles, and consequently the needs of curators and historians apart. While they generally share art history training, and museums were once able to conduct more research, the roles of the curator and the historian have grown apart as a result of the economic need of museums to attract a larger and more general audience for both their exhibitions and their publications.

A database such as the one proposed would be of immense use to historians as it would make primary evidence available in a form and quantity which has never existed before. Where textile historians have traditionally used comparative studies of design and technique to group objects into periods, they could now compare even the thread, the fibers from which an object is made.

Any form of comparative research requires a wide range of samples in order to have adequate data for patterns and therefore plausible theories to develop. When a comparative study involves not only seeing the object but also taking fibers from it for scientific analysis, this creates a range of practical and political problems which would be extremely difficult if not impossible to overcome. Obtaining access to handle and photograph objects can be difficult enough, and not many museums would be willing or able to allow outside researchers to take samples; as such it is a very practical idea to store images and/or samples in a form that may be made accessible to the research community.

The main concern which I have as a historian is that of keeping the project in perspective. With all of the technology we now have available to us, it is very tempting to conduct scientific analysis simply because we are able to, rather than addressing the more complex question of what it is we actually wish to know. With SEM, ESEM, IR, ANOVA… the increasing need for specialized knowledge in order to conduct such tests does create a rift between those who understand the acronyms and those who do not, rather than making valuable information accessible to all parties with genuine interest. This is not to say that the database should not be aimed at an informed audience, but rather, that the information which it contains should be organized in terms of what it tells us about the fibers, and consequently the objects, avoiding the trap of circling around the technology which was used to generate it.

In the midst of such jargon, the standardization of terminology becomes an important issue and one which is of particular interest to me. In recent years there have been moves to standardize the language and cataloging procedures for textiles and costume in Western Europe, particularly Italy. The focus has been on creating a language which is completely descriptive, giving a name to each of the elements which one might come across so that consistency may be established across the field. This rather taxonomical approach has two major advantages; the first being that it solves problems which arise where there are multiple names for the same element, or when one name can be applied to a number of different elements, and the second being that simple descriptive terms are more easily translatable into other languages.

The issue of language, or translation is not merely one of moving from English to French, or German to Japanese, but rather one of ensuring compatibility across fields of study, creating a language which encourages understanding rather than inhibiting it. This is of particular importance for fields like lace history where the traditional terminology has had a tendency to be somewhat romantic and often rather vague. This might seem appropriate in the case of lace history, but it does no good to create confusion unnecessarily, as this limits the utility of the knowledge to a very specific and generally small audience. It is not the function of this database to analyze the information which is within it, but to present raw information which might then be used as a comparative resource in a number of contexts. Therefore it should be searchable by a number of fields including fiber, object, technique, period, and origin, using terms which are as descriptive and universal as possible.

Textiles are part of our everyday experience; there are few material histories which maintain such a global level of cultural importance, and they are connected to innumerable areas of study: fashion and decorative arts, art history, politics, trade and economic history, archaeology and anthropology, just to begin. Textile objects have an extraordinary ability to carry and preserve cultural information, and in conserving those objects there is a responsibility to make this knowledge, which they give us, accessible to those who will be able to read and use it; indeed, it is the only real justification for their conservation.

With a full assessment of the possible and desired outcomes, and carefully set criteria which reflect these, this will be a very exciting project. While this is a large and complex project which will require the support of a number of institutions as well as individuals, it must be remembered that the central idea is one of simplicity and extreme practicality. With ever increasing cuts to museum funding and higher demands on our time, it makes perfect sense to store and share the information we collect with others in our field. Whether for conservation, scientific, historical or other research purposes, the great value of this database will be as a comparative resource. The existence of a database of fiber samples has the potential to make an enormous amount of comparative data available to researchers, and thus to become an invaluable resource for all involved with the study of textiles.

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Fibers, Microscopy, Digital Imaging or Image Analysis at the Winterthur Museum

Joy Gardiner
Textile Conservator/Assistant Director of Conservation,
Winterthur Museum

As the textile conservator at the Winterthur Museum, Garden & Library, Winterthur, Del., my involvement with fiber microscopy is two-fold. I work with the approximately 20,000 textiles in the collection that are used for research and exhibition. My other responsibility is as a teacher of graduate students in the Winterthur/University of Delaware Art Conservation Program. Currently, a fiber sample collection does not exist nor is there any involvement with image analysis.

Most work with the Winterthur Museum textiles involves the identification of natural fibers as the scope of the collection ranges in date from 1640–1860 (items made and/or used in America). There are some items in the study collection and in the library that go beyond those dates and are comprised of synthetic fibers. The graduate students who are majoring in textiles and spending their second year in the textile lab have treatment assignments that include objects from other institutions as well as Winterthur's own collection. This is to ensure that they experience working with textiles from a wide variety of dates and regions. Generally, much of our fiber identification is done from longitudinal samples with transmitted light on a stereo-binocular microscope at 100–250X.

When warranted, more in-depth methods and instrumentation are available to the staff and students. As an example, during the 2002–03 academic year, graduate students Yadin Larochette and Anne Peranteau were examining textile fragments from the underwater archaeological site of the 1798 shipwreck in the Delaware Bay of the H.M.S. *De Braak*, now in the collection of the Delaware State Museums. The fragments were removed from the site by a private salvage expedition without notation of their context. Fiber identification and weave structure analyses were undertaken by the students to try to determine more information on the use and original ownership of the textiles.

In addition to analysis of longitudinal samples in transmitted light, the students took gelatin scale casts, immersed samples in mineral oil to reveal medulla patterns, made cross-sections, stained bast fibers with phloroglucinol stain (0.25g phloroglucinol, 15mL distilled water, 15 mL methanol, 15 mL concentrated hydrochloric acid), and requested scanning electron microanalysis conducted by Dr. Jennifer Mass, associate scientist in Winterthur's Scientific Research and Analysis Laboratory. The information gained from the samples identified the fibers as wool and rabbit. Most interesting was that one of the samples contained sheep's wool and hair from a species of the genus *Llama*, such as alpaca. This discovery fits in with the history of the ship that shortly before the *De Braak* sank, it had captured a Spanish ship laden with goods from the South American colonies.

Winterthur is fortunate to have a well-equipped Scientific Research and Analysis Laboratory (SRAL) which can help to confirm instrumentally what is observed microscopically. For example, the question arose regarding the fiber content of a set of gauze bedhangings, which were described apocryphally as being composed of piña or pineapple fiber. Microscopy of longitudinal samples in transmitted light indicated that the fiber was silk. To confirm this, small samples of warp and weft were analyzed using Fourier transform infrared spectroscopy (FTIR) and the best match was a reference spectrum of silk. SRAL has compiled a reference library of FTIR spectra of a McCrone set of reference fibers.

Digital imaging is only just beginning to be used with fiber microscopy, mainly by the graduate students for incorporation into reports. However, the textile lab is currently in the process of ordering a new polarizing light microscope with a digital imaging camera and monitor. The software system being considered contains a database which would be used to start to catalog our samples.

The History of Fiber Sampling at The Art Institute of Chicago's Department of Textiles

Lorna Filippini
Associate Conservator, with **Eva Schuchardt,**
Conservation Scientist, Textile Department,
The Art Institute of Chicago

Microscopic examinations of objects and fiber sample collecting began in 1968 when Curator of the Department of Textiles, Mrs. Christa Thurman, brought the first stereomicroscope to the Department of Textiles. A collection of coverlets selected for an exhibition and catalog were amongst the earliest group of textiles whose fibers were sampled. During the 1970s, a collection of Nubian textiles on loan from the Oriental Institute of the University of Chicago were sampled for fiber identification under a polarizing light, with many fibers examined using an electron scanning microscope. The museum's microscopist, Inge Fiedler worked with Mrs. Thurman identifying these fibers for a publication on the Nubian textiles.

Textile Object Examination Records were established in 1980. All new acquisitions, as well as textiles selected for treatment and exhibition have since been examined by stereomicroscope.

Department of Textile's Object Examination Records cataloging includes:

Materials Identification
Materials Data
- Element Type
- Element Function
- Element Color
- Element Fiber Identification
- Make-up/Construction
- Element Diameter
- Thread Count
Structural Analysis
Measurements
Condition Reports
Treatment Records
Exhibition and Storage Records
Fibers Sampled for Polarizing Light Microscopy

While fibers from most objects are examined with a stereomicroscope, some fibers are sampled for identification under a polarizing light microscope. The reasons fibers are sampled for polarizing light examination fall into four groups:

Identification

Many synthetic fibers as well as bast fibers cannot be distinguished under the stereomicroscope. Degraded fibers whose identification is obscured by condition are often sampled for identification by a polarizing light microscope. Fibers whose identification is obscured by dye saturation, surface impregnation, or surface finishing treatments are sampled. Finally, fibers may be sampled for identification under polarizing light due to the experience limitations of the examiner.

Cataloging Verification

Polarizing light examination is often used for verification when stereomicroscope identification differs from that supplied by manufacturer's label or weaver's/artist's notes or cataloging. Verification is also sought when stereomicroscope identification challenges established cataloging, standing research, published information, dating, or place of origin of an object.

Sampling for Comparative Study

A systematic sampling of laces was conducted in conjunction with a 1984 grant for cataloging the lace collections of The Art Institute of Chicago. Over 1,200 pieces of lace received dating, typing, full structural descriptions, and condition reports. Systematic sampling of laces by type, century, and country of origin was conducted in order to compare possible fiber features that could be used to identify similar objects; collect examples of fibers used to produce known lace types, and compare fiber from various sources, a particular time period or place such as Flemish vs. Italian linens of the 16th century (figure 1).

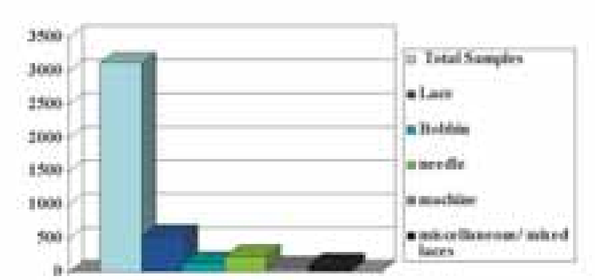

Figure 1. Lace samples in database

Correlations have yet to be made. Systematic sampling of metallized synthetic films and metallic foils encased in synthetic films was conducted in order to identify materials and thread constructions manufactured and in use during the 1950s-70s.

Sampling for Subclass Identification

Animal hair such as camelid (alpaca, vicuna, llama and guanaco); goat (cashmere, mohair); sheep; rabbit; etc. were sampled for differentiation. While these samples have yet to yield the information we had hoped, it has been made clear that we are in need of a more complete reference slide collection and that this identification requires additional time and experience.

Threads of gilt-animal-substrate have been sampled for identification of substrate source as vellum, leather, gut, or parchment. These samples proved difficult and will also require more reference slides and greater experience to distinguish.

Wild silk threads were sampled in hopes of identifying the species of the source moth. To date, this identification has not proved successful.

Of the more than 11,500 objects in The Art Institute's Textile Collection, spanning the world and dating from 200 BCE through present day, approximately 2,280 objects have been sampled; 1,582 objects have single samples, with the remaining objects having from two to as many as 55 samples. The distribution of objects sampled adequately reflects the collection's distribution of objects through the centuries (figures 2 and 3).

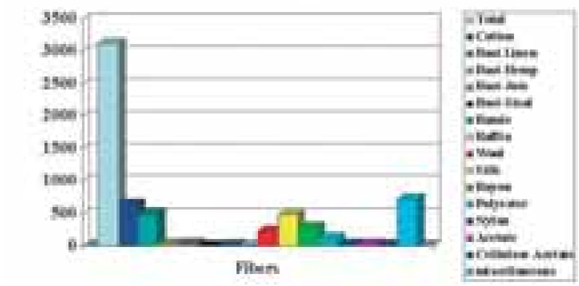

Figure 2. Fibers represented by collected samples

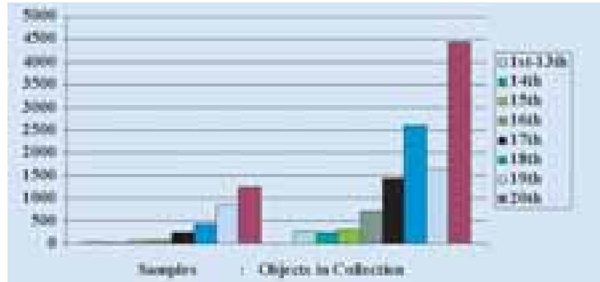

Figure 3. Distribution over centuries

Sampling Practices

The conservator and textile laboratory staff do all sampling for the purpose of fiber identification. Two factors dictate sampling practices. First, sample size and site are selected to be the least destructive possible. Second, samples are taken from fibers in the best state of preservation to facilitate identification. Common sample sites are along outer unfinished edges, seams, hems, edges of losses and element floats on reverse face. Usually full threads or yarns are taken, but occasionally sampling techniques include teasing fibers from intact yarns and partial sampling of yarn elements from various places in multi-element yarns. These sampling procedures present several drawbacks. Sampling from seams and hems yield larger samples but the condition is generally better than the object as a whole. Samples from outer edges, fringes, and along edges of loss may not be complete, usually show more wear, and may not be representative of the fiber's general condition. Samples from reverse face floats may have picked up stray fibers. Teasing, perhaps the core from a wrapped yarn may not get fiber from all fibers present and taking portions of a multi-element yarn from different sites may keep the yarn intact but may be an incomplete sampling. Lastly, small samples tend to be the least destructive to take and these may not be adequate for cross-sections and any additional chemical tests—a complaint often registered by the microscopist.

Samples and Fiber Identification Records

All samples are labeled with object reference number; object's title, date and place attribution; thread element type, function and color; as well as the sample number out of the total number of samples taken from the object. Currently sample site is not noted.

Samples are permanently mounted to glass slides, currently in Meltmount (a thermoplastic mounting media from Cargille Laboratories, Inc., Cedar Grove, NJ). The slides are similarly labeled. Slides are stored on metal trays in wooden slide cabinets. Any portion of the sample that remains is kept in its original glassine envelope. Fiber identification record sheets have sections for description, comments and measurements on morphology, optical properties, microtome sections, red plate tests and photographic records. These sheets are placed in an object's conservation files and are entered into a FileMaker Pro database.

While working on this presentation it has become clear that our choice of database, while relatively easy to use, is limited. Entry consistency is necessary for accurate sorts and searches. Searches for samples of uncertain identification entered as "possibly," "probably," or "most likely" were lost due to qualifiers. Consistency of entry order is also necessary for multi-fiber samples. Sorts using object dates also posed some difficulties. Dates that span BCE through CE (entered in the database as BC to AD) are lost. Date entry in a mixed word and numeral format do not sort out with entries using exclusively numerals—third quarter of 18th century versus 1751-1775.

As of mid March 2003, some 3,118 samples were entered into the database. All existing fiber Identification Record Sheets were reviewed before entering the records into the database. Many records of samples from objects with accession numbers from 1970 through the mid 1990s have not been reviewed and entered.

Expectations for an Online Database of Degraded Fibers

Preparation of this presentation allowed serious thought as to the benefits of producing, the uses for, and future possibilities of an online database of degraded fibers. In establishing this database, the field of textile conservation could establish standard sampling and sample labeling methods. Standard terms for micro level fiber damage could be developed. A scale of object condition relative to fiber condition could be established that could be used to determine handling, light levels, exhibition, and loan policies. Lastly, there is the hope that someday a fiber sample's condition could be used as a predictor of future object damage.

Fiber Analysis at The Art Institute of Chicago

Inge Fiedler
Microscopist, Conservation Department
Eva Schuchardt,
Conservation Scientist, Textile Department,
The Art Institute of Chicago

At The Art Institute of Chicago, textile fibers are routinely identified from textile objects in the collection, as are the fabric supports from paintings when they are being sampled for paint or medium analysis (1). Due to the limited amount of sample material that is usually removed from art objects, the fibers are primarily mounted for longitudinal viewing in a permanent mounting medium and identified by polarized light microscopy (figure 1).

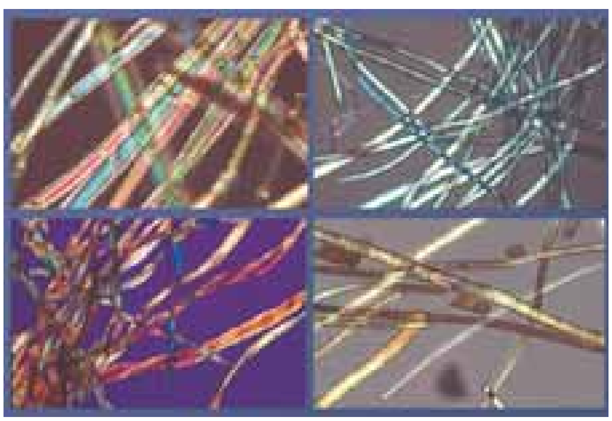

Figure 1. PLM longitudinal views of Nubian textiles fibers.

The results of the analysis are incorporated into a FileMaker Pro database for each sample. Information includes fiber type, a brief description as to the fiber's characteristics, it's diameter size range, color (whether the fiber is naturally pigmented or dyed), lumen or medulla structure and a brief description of its shape (if a cross-section is prepared). Optical characteristics, such as type of extinction, birefringence, and refractive index relative to the mounting medium, are noted, as is the overall condition of the fiber. When conducted, chemical tests and their results are included as well.

Because of the number of fiber samples that are analyzed routinely, most are not fully classified. Cross-sectional or chemical analyses are not done for every sample, only those that may require further analysis if optical microscopy is inconclusive. The majority of fiber samples identified are also not photographed routinely, although this will change once the lab obtains a digital camera and images can be transferred more readily in to the database. When cross-sections are made, they are mounted using a Jolliff plate using mercerized embroidery yarn as the filler material. Samples are positioned in the center of the filler threads that have been spread apart after they have been pulled partially through the small hole (figure 2).
Once the sample is in place, all the fibers are pulled through and the excess threads are trimmed on both sides of the plate with a sharp Teflon coated razor blade. The mounted sample is then examined under the microscope and the side with the best cut is mounted on a glass microscope slide, taped along the edges to keep it in place,

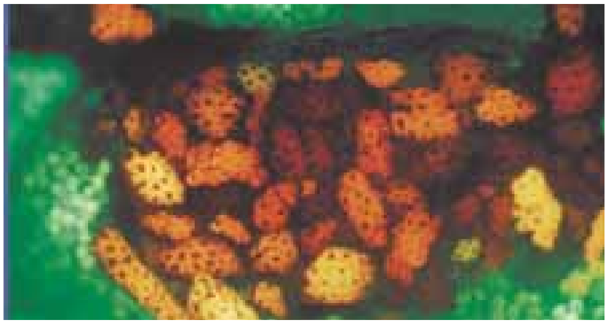

Figure 2. Jute (Red Star, 328 wrapping, Hooven & Allison)

and then viewed by transmitted light. Cross-sectional views are useful since they show a characteristic cell shape for each type of natural fiber and a typical shape for synthetics. Certain chemical tests are performed when necessary, such as the phloroglucinal/HCL test which is useful to differentiate bast fibers. Occasionally Shirlastain dye tests are also conducted which have proved useful for manufactured cellulosic fibers and synthetic fibers and films.

At present, analytical techniques such as scanning electron microscopy (SEM) have been used only for special projects. This is mainly because The Art Institute does not have any analytical instruments in-house and therefore utilizes outside consulting laboratories for analysis. A detailed study of ancient Nubian textile fibers was conducted in collaboration with The Oriental Institute at the University of Chicago using the university's SEM to aid in the identification of very deteriorated fibers. The SEM has proven extremely helpful in identifying fibers and also determining their overall condition.

To aid us in the identification of textile fibers, we have compiled a handbook, which comprises information acquired from the literature and personal experience, and contains photomicrographs of cross-sectional views made from The Art Institute's reference collection. The handbook is divided into natural and synthetic fibers and includes information as to fiber class, country of origin, how fibers are manufactured, identification characteristics, and physical and chemical information. We hope to include longitudinal views of all of the fibers in the near future and continually seek information to incorporate into the handbook that would aid us in fiber identification. We are also very actively acquiring additional samples to expand our fiber reference collection. Reference fibers are permanently mounted as longitudinal samples and cross-sections to help us in the identification and comparisons to unknowns.

The museum has recently been awarded a grant from a private foundation to purchase an infrared spectrophotometer with a microscope (micro-FTIR) which will expand our analytical capabilities and allow us to analyze fibers, in particular synthetic fibers, some of which are not readily identified by polarized light microcopy. This method will also enable us to identify many of the dyestuffs used for textiles and other works of art.

Note

1. See summary by Lorna Filippini for a discussion on sampling precedence and procedures in the Department of Textiles.

Fiber Analysis in the Support of Exhibitions, Teaching, and Research at the Cooper Hewitt, National Design Museum

Lucy Commoner
Textile Conservator, Cooper Hewitt,
National Design Museum

The Cooper Hewitt, National Design Museum, New York, N.Y., is a museum of decorative and applied arts with a collection of over 250,000 objects spanning 23 centuries. The curatorial departments, which reflect the strengths of the collections, are Drawings and Prints, Wallcoverings, Textiles, Product Design and Decorative Arts, and the Library and Archive.

The textile collection is made up of over 30,000 pieces, from 200 BCE to the 21st century. The bulk of the collection is Western, 5th-20th centuries, with the most common textile materials being natural and early synthetic fibers.

With a small staff and a demanding exhibition and loan schedule, most of the work in the textile conservation lab is focused on supporting the textile department in the exhibition of the collection and in the preservation of the collection in storage. Microscopy is just one of the many functions of the lab. Fiber microscopy takes place most often at the request of a curator, either in-house or at a borrowing institution in preparation for an exhibition. It is also performed for the purpose of teaching interns and classes, and there is the occasional opportunity for pure research.

Fiber identification results are recorded in The Museum System (TMS), a museum-wide database, and in the lab's own database that includes images (FileMaker Pro). The lab also maintains a sample file of fibers for record and research purposes. Of particular interest in my own research are bast fibers, metallic fibers of all types, and early mercerized cotton. For fiber identification, an Olympus BX50 polarizing microscope outfitted with phototube for a camera or video camera is used. The video camera is connected to a monitor and a Mac G4 computer. The video camera is useful for teaching as well as for recording fiber images. A Sony video printer produces high quality dye-sublimation prints captured by the video camera. Both the camera and video printer are used on the polarizing light microscope and on a stereo-zoom microscope (Olympus SZX9), which magnifies up to 60 times. The stereo-zoom microscope is used to study and record textile structures and conditions.

An example of the applied use of fiber microscopy at Cooper Hewitt is as follows: A 17th-century slit tapestry woven band from colonial Peru (figure 1) was requested for loan to the Metropolitan Museum of Art's upcoming exhibition, "Colonial Andes." The curator was very interested in fiber identification in order to confirm the textile's placement in colonial Peru.

Figure 1. Tapestry-woven band, 17th century, Peru, Cooper Hewitt Museum, 1902-1-374A.

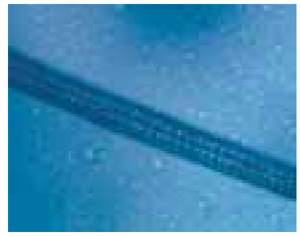

Figure 2. Weft, rabbit hair from1902-1-374A.

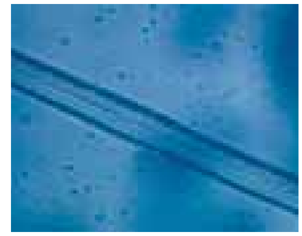

Figure 3. Weft, scale cast of rabbit hair from 1902-1-374A.

The results of the fiber identification showed two different types of threads (figures 2 and 4). In the areas of colored weft, spun European hare (domesticated rabbit, genus *Oryctolagus*) was found rather than the native rabbit of Peru (genus *Sylvilagus*). This finding however, does not exclude the possibility that European hares were imported into Peru during the Colonial Period. A scale cast of the same fiber (figure 3) was used to confirm that the fiber was not viscacha or chinchilla, more common fiber-producing animals from the region. In addition, cross-sections were performed to confirm the identification of the rabbit hair. The lab has recently purchased a new Leica microtome that will eventually replace the more primitive methods that we have been using for producing cross-sections. Another unusual find was the composition of the white weft area, which is a combination of cotton fibers spun with goose feathers (figure 4). Fiber microscopy was an important analytical tool in this investigation. Although the results neither confirmed nor put into question the characterization of this piece as Colonial Andean, fiber identification is a critical component of the ongoing research on the textile. Further research will be needed on the species of rabbit and goose that were present in Colonial Peru.

Figure 4. Weft, cotton and goose feathers from 1902-1-374A.

Identification of Ethnographic Plant Fibers in the Collections of the Arts of Africa, Oceania and the Americas, Metropolitan Museum of Art

Christine Giuntini
Textile Conservator, Metropolitan Museum of Art

As a textile conservator for the Arts of Africa, Oceania and the Americans (AAOA) at the Metropolitan Museum of Art, New York, I am very interested in the issues surrounding the identification of deteriorated fibers. This topic is important to me because the museum has a large and significant collection of ethnographic fibers, that are often not well understood or documented. When the museum acquired the Michael C. Rockefeller Collection in the late 1970s, its holdings of archaeological and ethnographic textiles and objects constructed from unusual fibers increased dramatically. This collection is now housed within the Department of the Arts of Africa, Oceania and the Americas. Among the holdings of the department are fiber ensembles from Oceania and West Africa; ethnographic and archaeological weavings from Central Africa and Precolumbian Peru, as well as a variety of composite objects from these non-western cultures that use plant fibers as the support or carrier for other materials.

Since the museum is charged with the interpretation, preservation, and presentation of these objects, it strives to record cataloging information accurately. However, typically plant fiber identification has been a weak point in the cataloging process. The AAOA catalog database often identifies such materials generically—“plant fiber” rather than “raffia,” for example. The most common reason for the generic identification is the cataloger’s lack of familiarity with the many types of plant fibers used by the low latitude archaeological and ethnographic cultures represented in the collections. In addition, positively identified comparative material is scarce. To be useful, comparative materials should be grown, harvested, and processed in a manner similar to that of the artifact fiber.

An object usually enters the museum with some sort of materials identification, the accuracy of which is highly variable, depending to a great degree upon the acquisition circumstances. Any one of a diverse group of individuals—the owner, dealer, field collector, curator, conservator, or registrar—could have made the preliminary fiber identification. In the past, the initial fiber identification was rarely checked by microscopic examination and/or comparison with known samples; therefore, the initial assessment often became part of the cataloging information. Needless to say, the more specific the identification, the greater the chance for error. Typically, when the cataloging identifies a fiber specifically, it does not include the source of the identification or the instrumentation technique(s)—if any—used to make the identification. It is small consolation that many other institutions contend with similar fiber identification issues.

When textiles and fiber objects are examined as part of a conservation treatment plan or in preparation for exhibition, fiber attributions may be reexamined as time and budget considerations allow. Like many textile conservators, I have taken short conservation-focused microscopy classes for fiber identification. These classes usually focus on the plant and animal fibers most commonly found in western artifacts.

A large proportion of the AAOA collections are made up of the more readily identified cellulose and protein fibers such as cotton, wool, camelid, or silk. Microscopic identification of these fibers is usually, but not always, straightforward due to unique fiber-specific morphological characteristics. There remain, however, many types of plant, animal, and synthetic fibers—all of which can pose considerable identification challenges. Most problematic have been the leaf and bast fibers in the AAOA collections.

Authorities on fiber identification have acknowledged the difficulties involved in identifying bast and leaf fibers. They emphasize the problems encountered when the fibers are deeply dyed or are in a degraded and/or desiccated state. In those situations, it is often not possible to distinguish between leaf and bast fibers (1). As conservators and other researchers have become more sophisticated in their understanding and interpretation of these objects, they have also become more reluctant to make precise fiber identifications.

Figure 1. Photograph by Lester Wunderman. [detail, Kanaga dancers, 1972-75] courtesy The Metropolitan Museum of Art, NY. The Photograph Study Collection, AAOA. Gift of Lester Wunderman, 1996 (1996.458.60).

A brief case study concerning two African fiber artifacts will be presented in order to focus on the difficulties encountered while trying to identify and compare the plant fibers used in their construction. Both artifacts come from the same geographic area—the Bandiagara escarpment and Séno plain in Mali—a demanding landscape of steep cliffs and arid Sahel, east of the inland delta. The land was once home to an ancient people called the Tellem, although the Dogon now occupy this region. Art historians, archaeologists, and ethnographers have long tried to understand the relationship between the Tellem and the Dogon (2).

The first artifact is a Dogon *kanaga* masquerade ensemble (figure 1), worn by a man at a *dama* ritual, honoring a deceased member of a Dogon community. This complete costume is believed to have been fabricated for a *dama* witnessed by the collector in Mali in the mid-1970s. It was given to the museum in 1987 (1987.74 a-I) and consists of a wood mask with fiber hood; a bead, shell, and cotton cloth vest; two short fiber overskirts—one orange and one yellow; two mixed orange and yellow fiber armbands; a long brown plaited underskirt and indigo dyed cotton trousers. None of the fiber attachments was in good condition, but the yellow and orange dyed fibers could be manipulated minimally without causing damage. The brown underskirt was, in contrast, in an advanced state of deterioration. The fibers felt hard and dry; bits of fiber shattered when the skirt was moved for the examination. At the time of the initial examination in 1987, the differing condition of the fibers was attributed to the action of some agent used on the fibers during the dyeing process.

The second fiber artifact, a woman's modesty apron or *cache-sexe* (figure 2) was also collected in Mali and given to the museum in 1998 (1998.478.4). It is a rare archaeological find from the high dry caves located within the Bandiagara escarpment. Although it seems very stiff and heavy, specialists have concluded that a fiber girdle (now missing) once secured it around the waist of a woman. These modesty aprons are considered to be among the earliest of artifacts found in the caves and have been dated from the 11th to the 12th century (3).

Figure 2. *Cache-sexe* collected in Mali now in the collection of the Metropolitan Museum of Art.

These two artifacts, the first ethnographic and the second a rare archaeological find, are separated in time by approximately 1000 years. The survival of organic archaeological materials in West Africa is unusual and an examination of the materials and technology used in the construction of these two artifacts presented a unique opportunity for studying and comparing both the fibers and fiber technology in use in this area over time.

Following the usual conservation protocols, details of the various fabric structures and construction techniques used in the creation of the *cache-sexe* and the masquerade ensemble were recorded along with an assessment of condition. It was during these examinations that several questions arose. It became increasingly obvious that the fibers used by the Dogon in the construction of the plaited underskirt of the ensemble were different from the fibers used in the construction of the short overskirts. The fibers used in both the under and overskirts were unevenly processed. Areas of finely separated fibers lay beside fibers still bound together with other plant material and the visual appearance of these incompletely retted areas was distinctively different in the under- and overskirts. In addition, there were small patches of what seemed to be epidermal tissue attached to the fibers and this tissue had also distinguishing surface characteristics. The tissue attached to the dark dyed fibers of the plaited underskirt was smooth, light colored and waxy in appearance (figure 3). The tissue attached to the orange and yellow skirts was dark and fibrous (figure 4).

In contrast, the fibers used to construct the *cache-sexe* had been highly processed (figure 5). The fibers appeared to have been well separated from the remaining plant material; and then tightly spun and plied into yarns. In spite of the degraded and powdery nature of the individual fibers, the *cache-sexe* could still be examined. Its cohesiveness is entirely due to the high degree of yarn spin and ply as well as the subsequent tight inter-working of the elements.

Figure 3 top. Tissue attached to dark dyed fibers of the plaited underskirt.

Figure 4 right. Tissue attached to orange and yellow skirt.

From the start, it was obvious these particular fiber identifications were going to be difficult to undertake, given my limited experience with ethnographic plant fibers and the high degree of degradation of all the fibers. The ethnographic and art historical literature indicated that the Dogon were both secretive about the methods used for the creation of ritual ensembles and unreliable reporters. Adding to this confusion, secondary sources often supplied contradictory information or they incorrectly reported Dogon words for the fibers used in the making of the costumes. Possible fiber candidates would have to be established by conducting a well-organized search of the published literature (4). The search for information about Dogon fibers proved to be a painstaking labor, but various authors independently reported that sansevieria fibers (*Sansevieria guineensis*) were used for the dark dyed underskirts and hibiscus fibers (*Hibiscus cannabinus L.*) were used for the short overskirts (5). The fiber used to construct the Tellem apron was identified as the inner bark of a species of baobab tree (*Adansonia digitata*) (6). Of the various plants reported in the literature, these three fiber identifications seemed to come from the most reliable sources. Unfortunately, none of these sources included the instrumentation or techniques used to establish the fiber identifications.

Figure 5. Example of processed fibers used to construct the *cache-sex*.

Following one of the common sense protocols outlined in the conservation literature, the rotation test proved to be useful in confirming that the Dogon overskirts were made with some type of "ethnographic" plant fiber, rather than the cultivated flax or ramie fibers. The fibers of the overskirts clearly rotated in the clockwise direction (twist toward the left). Unfortunately, no rotation was discernable in the underskirt, despite several attempts to wet the fiber and observe its behavior upon drying. The *cache-sexe* fibers were too degraded to wet.

Studying pictures of these tropical plants and gathering botanical information including descriptions of their anatomy, growing conditions, harvesting, and processing were very useful steps toward understanding them. In the beginning, the Internet was the most expedient method of obtaining images and horticultural information about the plants; periodicals and books provided additional photographs, illustrations, and information. However, the ability to navigate the classification system is essential for gathering accurate and current information on plant anatomy. The botanical classification system is not immutable and different types of plant professionals use variations of the classification system. Many plants have more than one species name; a plant may have a common name as well. Typing in a common name doesn't necessarily yield a result when using a botanical search engine such as that found on the Royal Botanic Garden, Kew website (7).

An amalgam of these issues came up while collecting information on Genus *Sansevieria*. It has been shifted back recently into the reinstated Order *Asparagales* from *Liliales* and therefore was put into Family *Dracaenaceae*. However, the conservation, horticultural, and ethnographic sources we consulted place sansevieria into Family *Agavaceae* (and therefore remaining in Order *Liliales*) (8). When these changes had been sorted out finally and Genus *Sansevieria* located, Species *guineensis* did not appear in some of the sources. Time spent on what could be a wild goose chase to find accurate anatomical information can become an insurmountable barrier to progress.

A visit to the herbarium at the Bronx Botanical Garden, to view specimens of sansevieria and hibiscus helped to solve this problem. Although neither plant had a specimen that had come from Mali or an adjacent West African country, I did discover that the plant I knew as *Sansevieria guineensis* from the ethnographic sources was the same plant that is called *Sansevieria hyacinthoides* in the current botanical classification system. Seeing the dried sansevieria leaves did reinforce the speculation that the remaining epidermal tissue on the dark overskirt was from a plant similar to the dried sample. The hibiscus plants did not include a thickened stem and no conclusions about our artifact could be drawn from an examination of the herbarium specimen.

The next step was to acquire reference samples, no easy task, considering the country of origin was Mali. AAOA has been building a small documented collection of reference fibers, and specimens are acquired by various means, usually through travel abroad. Both sansevieria and hibiscus fibers have some commercial applications; both are processed for use as cordage. In this application, hibiscus is known as kenaf and sansevieria as bowstring hemp. Acquiring samples of cordage seemed a sensible alternative, but up to this time reliable sources have not been located. The American Kenaf Society was persuaded to send a dried sample of kenaf stem. However, several attempts to separate long fibers from the desiccated sample proved unsuccessful.

In the event that documented reference samples would be made available, microscopic specimens of the three artifacts were prepared and examined. If the field reporters are correct, the most likely fiber source for each artifact comes from a different part of the plant: leaf (sansevieria), bast (hibiscus), and inner bark (baobab). Since the kinds of cells and their arrangement within the plant structure varies according to the part of the plant from which they come, it might be possible to generally confirm that the artifact fibers do indeed come from those parts of the plant.

All the specimens were examined on a stage microscope at 100X and 400X. Water was floated under the cover slip and after the examination the samples were allowed to dry before storing. Cross-sections of the Dogon fibers were also prepared. Textbook descriptions of the differing arrangements of cell structures in bast, leaf and inner bark fibers were studied. Although there were some distinguishing features on all our specimens, they did not appear to be very similar to any of the generalized illustrations or specific photo-micrographs found in these books. It was not possible to draw any definite conclusions by way of these comparisons. When well-documented comparison specimens become available, this very interesting study of Dogon and Tellem fibers can continue.

When I was invited to participate in this Fiber Database Conference, the unfinished Dogon fibers project immediately came to mind. After a long and often frustrating search to identify unusual fibers, I would have the opportunity to discuss these difficulties with other conservators and scientists who have struggled with similar issues. Perhaps some of these colleagues would also have access to samples of these exotic fibers. Building a fiber database will expand our understanding of and ability to identify artifact fibers because we will be able to share samples and observations.

Preservation plans for textiles and fiber objects are almost never contingent upon fiber identification, yet these plans are greatly impacted by the assessment of the overall condition of that fiber. In other words, it commonly has been more important to be able to identify the different types and degrees of fiber deterioration, than it is to identify precisely the fiber. The building of a broad fiber database may eventually give us the ability to make connections between microscopic surface details and condition on a macroscopic scale, so that we can make more precise condition assessments. But as important, the identification of these little-studied "ethnographic" fibers will contribute critical data toward understanding the relationship between the archaeological record and historical cultures.

Notes

1 See, for example, Goodway, Martha, 1987. Fiber Identification in Practice. *Journal of the American Institute for Conservation* 26(1): 31. Also, Florian, Mary-Lou E. , Dale Paul Kronkright and Ruth E. Norton, 1990. *The Conservation of Artifacts Made of Plant Materials*. Malibu: The J. Paul Getty Trust, p. 57.

2 Ezra, Kate, 1988. *The Art of the Dogon: Selections from the Lester Wunderman Collection*. New York: Metropolitan Museum of Art, pp. 26-28.

3 Bolland, Rita, 1991. *Tellem Textiles: Archaeological finds from Burial Caves in Mali's Bandiagara Cliff*. Translated by Patricia Wardle. Amsterdam: Tropenmuseum, p. 28.

4 The department was fortunate to have as an intern in the Spring of 2001, a graduate student, Susan Brown, who was interested in culling the extensive published literature on the Dogon with an eye to fiber identification. I wish to thank Susan (MA, Museum Studies Program, FIT, SUNY), who pursued the literature for allowing me to use her report for this discussion.

5 Brown, Susan, 2001. Unpublished compilation and critique of the published literature on the fibers used by the Dogon for the preparation of ritual ensembles.

6 Bedaux, Rogier M.A. and Rita Bolland, 1989. Vêtements féminins médiévaux au Mali: les cache-sexe de fibre des Tellem. *Basler Beiträzur Ethnologie* 30: 25.

7 http://www.rbgkew.org.uk

8 I wish to thank the staff at http://plantsdatabase.com for helping me locate the most up to date information on plant anatomy. L. Watson and M. J. Dallwitz (1992 onwards). The Families of Flowering Plants: Descriptions, Illustrations, Identification, and Information Retrieval. Version 14th December 2000. http://biodiversity.uno.edu/delta/'.

Knowledge Management at Harpers Ferry Center, National Park Service

Jan Gauthier
Deputy Associate Manager, Knowledge Archives and Training, Harpers Ferry Center

Harpers Ferry Center (HFC) develops and produces interpretive media for the National Park Service (NPS). Included in our many projects are visitor center exhibits, films and videos, publications, wayside exhibits, interpretive plans for parks, and historic furnishings reports. Well equipped conservation laboratories perform conservation treatments on museum objects and do scientific research and material analyses. The NPS History Collection, Art Collection, NPS Reference Library, and Photographic Collection are also located at HFC.

Our vision at HFC is that every person finds a personal connection to the preservation of his or her natural and cultural legacy. We value creativity, teamwork, flexibility, professionalism, integrity, and inclusion. Our staff of approximately 200 people is made up of conservators, museum specialists, exhibits specialist, curators, interpretive planners, park rangers, cartographers, writers, editors, librarians, exhibit planners, designers, producers, project managers, and business management professionals.

In our organization knowledge is created and it needs to be managed on two levels. Internally we need to manage the media projects we design and develop. Externally we share standards and best practices on how to develop and produce media to build NPS media capacity.

In doing this we have identified that:

- Intellectual capital (or knowledge) resides in both tacit form (human education, experience and expertise) and explicit form (documents and data).
- Knowledge is a fluid mix of framed experience, values, contextual information, and expert insight that provides a framework for evaluating and incorporating new experiences and information.
- Knowledge develops over time, through education, experience, family, media, and work
- Knowledge management is the development of strategies and structures for maximizing the return on intellectual and information resources.
- Knowledge management depends on both cultural and technological processes of creation, collection, sharing, recombination, and reuse.

- New value is created by improving the efficiency and effectiveness of individual and collaborative knowledge work while increasing innovation and sharpening decision-making.
- Bringing people together with different knowledge and experience is one necessary condition for knowledge creation. “Knowledge chaos”—large, complex pool of ideas to create knowledge can be an important tool in creating and sharing knowledge in a community of practice.

By identifying the need for a manager of Knowledge Archives, HFC has made the commitment to look at the current processes that exist to support knowledge management for the organization.

We are continuing to look at systems and processes needed to create understanding and support in the effort to capture and share the most critical learnings from the work that we do and to create processes and situations where knowledge transfer can occur—workshops, training, technical reports, meetings, discussions, individual learning, mentors, development, and lessons learned during the design and development of media products.

By taking the lead in developing a Web-accessible fiber reference library, HFC continues to bring together people as resources to better preserve our cultural heritage.

Analyses at the U. S. Bureau of Customs and Border Protection

Kathleen Mulligan-Brown
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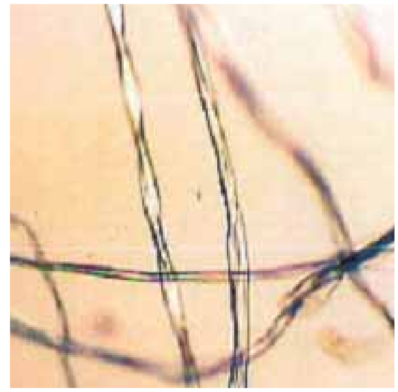

Figure 1. PLM is one process used to identify cotton.

The Department of Homeland Security Bureau of Customs and Border Protection (BCBP) includes the former U.S. Customs Service, which is responsible for the enforcement of tariffs imposed by the U.S. Government. These tariffs are set by the United States International Trade Commission in conjunction with other government agencies and published in the "Harmonized Tariff Schedule of the United States" (HTSUS) (2003). This 5-inch thick document dictates the tariffs imposed on the broad range of goods imported into the United States.

To support the various U.S. ports of entry in tariff decisions, the BCBP has 7 laboratories, each covering a laboratory service area. The Savannah Laboratory covers an area stretching from Pennsylvania to Florida. The laboratories perform a range of services including: Analysis of Commodity Samples, Mobile Operations outside the laboratory, Forensic Analysis, Scientific Advice for Customs Officers, and Commercial Gauger and Laboratory Accreditation and Inspection. Many of these analyses are conducted on textiles and similar commodities in support of Customs Officers. The Savannah Laboratory in Savannah, Ga., performs a range of textile analyses, including tests of water resistance, analyses of fiber content, determination of the method of manufacture, knitting methods, comparisons of pile versus non-pile materials, and analyses of commercial fraud cases. Testing and scientific analysis in support of these analyses frequently include identification of the textile or fiber, including its composition and construction, as well as physical tests. Physical testing includes measurement of mass and yarn count, as well as tests for water and abrasion resistance.

Tests are conducted on a range of textiles covered in the HTSUS, including wearing apparel, both knitted and woven, (HTSUS chapters 61 and 62, respectively). They are also conducted on yarns, which are made up of silk (HTSUS Chapter 50), wool and fine animal hair (HTSUS Chapter 51), cotton (HTSUS Chapter 52), vegetable fibers (HTSUS Chapter 53), man-made filaments (HTSUS Chapter 54), and man-made staple fibers (HTSUS Chapter 55). Shoe uppers are measured (HTSUS Chapter 64) for the external surface area of the upper, and entire shoes are disassembled to determine the composition of the component materials (leather, textile, and/or plastic, etc.) by weight.

Figure 2. Detail of knit structure.

Figure 3. Detail of net structure.

Figure 4 & 5. Microscopy of animal hairs.

Microscopy is used in the laboratories for the identification of fiber, the type of weave structure, and the type of knit or net (figures 1, 2, and 3). Both polarized light microscopy and scanning electron microscopy (SEM) are used to study the fibers. SEM is particularly useful for the study of the scales on hair fibers (figures 4 and 5). Microscopy is also used to study the composition of wickerwork, including willow, rattan, and bamboo (figures 6, 7, and 8).

Images are captured digitally and analyzed on computer workstations utilizing standard hardware and software: Dell Optiplex GX240 computer loaded with Image Pro Plus v. 4.5, HP ScanJet 6100C scanner, Sony Digital Photo Camera (DKC-5000), and Leica DM/LM microscope. Image analysis includes studies of the external surface area of footwear, wool grading, and thickness of coatings. Man-made fibers are also measured for tex, or linear density.

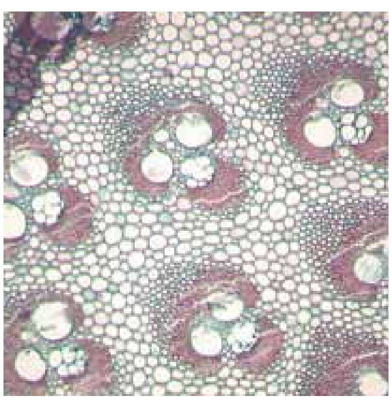

Figure 6. Detail of bamboo.

Figure 7. Detail of willow.

Figure 8. Detail of rattan.

Image analysis is also used to measure the length of fibers, which are first positioned under a cover slip and imaged, with the fiber then digitally traced to measure the total length. The same fibers that are traced for length are collected and weighed as a group. The tex or decitex can then be calculated.

The Savannah Laboratory utilizes a range of additional testing techniques to assess textiles. This includes infrared spectroscopy to perform qualitative analysis of plastics, polymers, chemicals, and fibers. Weight analytical testing is also performed on a range of textiles, utilizing a textile conditioning chamber or a conditioning room.

The Savannah Laboratory, utilizing a standardized laboratory protocol also tests the water resistance of textiles. Equipment used by Customs Officers at ports of entry, as well as commercial gaugers, are tested and/or inspected by our staff.

The Savannah Laboratory also analyzes related fibrous materials, such as wood and paper. Wood studies include microscopic evaluation of wood samples to study vessels, parenchyma, rays, inter-vessel pitting, and fibers. Paper studies include tests for fiber identification, composition, grammage, and coatings. Printing processes are also studied microscopically to determine methods of printing, such as by the electrostatic or flexographic process.

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Standardization of the Database

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Criminalist, New York City Police Department,
Forensic Investigations Division

In the year 2002, the six analysts in the hair and fiber unit of the New York City Police Department processed 1,325 items from 339 cases with the production of numerous samples. The numbers of samples (tape lifts and slides) depended upon several factors, including the circumstances of the crime and the items submitted. Hairs are the primary focus of examinations as investigators often subsequently pursue DNA analysis. Due to the ease of image acquisition and improvements in the technology, digital imaging is being used increasingly to document the evidence.

The types of microscopes used for fiber examinations include stereomicroscopes, polarized light microscopes, comparison microscopes, fluorescence microscopes and phase contrast microscopes. A scanning electron microscope is also available. In addition, chemical data are derived from a Fourier transform infrared spectrometer (FTIR) with a continuum microscope and color analyses are conducted with a micro-spectrophotometer. Many of the microscopes have trinocular heads for camera mounting.

The cameras currently being used include the Nikon Coolpix 995 and the Kodak Professional DCS 760C, both of which were selected for their versatility and resolution capabilities. The Nikon camera may be mounted on a tripod or a microscope, while the Kodak camera may be used on a tripod or on a copy stand. Only cameras with .TIFF file storage format may be used for documenting forensic evidence. Limited image processing is permissible with Adobe Photoshop.

Major reforms in forensics began in the late 1990s with the establishment of governing committees, standardized procedures, and accreditation programs. The primary objectives were the development of quality control and quality assurance methods to ensure the timely and consistent analyses of forensic evidence. The accreditation of the New York City Police Department Laboratory was mandated by the New York State Commission on Forensic Science.

The Commission responsibilities include:

- Facilitating improvement of the quality and delivery of forensic services between laboratories, law enforcement, and other criminal justice agencies
- Maintaining a forensic laboratory accreditation program
- Monitoring forensic laboratory compliance with accreditation standards

- Establishing and supporting Technical Working Groups (TWG Disciplines: Evidence collection, Fiber analyses, Digital imaging, etc.)

Working groups have been established at the local, state and federal levels to continually evaluate and improve individual laboratories with regard to the procedures of other laboratories and improving technologies. These groups meet periodically to re-evaluate their objectives.

The responsibilities of the working groups include:

- Establishing uniform analytical protocols
- Promoting uniform quality assurance procedures
- Identifying qualification standards for analysts
- Maintaining proficiency and currency of laboratory procedures and personnel
- Providing technical consultation services

Standardization resources include the American Society of Crime Laboratory Directors (ASCLD), FBI-Scientific Working Group for Materials Analysis (SWGMAT), ASTM International, and the International Organization for Standardization (ISO). These organizations provide guidance and support for laboratories seeking to achieve and maintain accreditation with the establishment and maintenance of standard operating protocols.

Since forensic laboratories have been functioning with standard operating protocols for years, they may serve as a guide for this fiber study project. For analytical results to be comparable, the analytical methods must be consistent. Standard operating protocols may be used to establish methods for image and data acquisition, information storage and retrieval, and end-user capabilities. At a minimum, the protocols should include sections on terminology, analytical selection, quality assurance, documentation, and references. Analytical selection includes direction in equipment and instrument selection, sample preparation techniques, and analytical sequence. The protocol should also have an official procedure for revisions.

Protocols must be adaptable due to potential changes in resources. The availability of qualified personnel, laboratory equipment, and suitable samples and standards dictates that protocols require minor revisions over time. The protocols should also be written to permit alternative analytical methods in extenuating circumstances. In addition, technological and scientific advances in analytical methods and digital imaging will motivate modification, but adherence to the accepted protocols should be encouraged until an official procedural change is instituted.

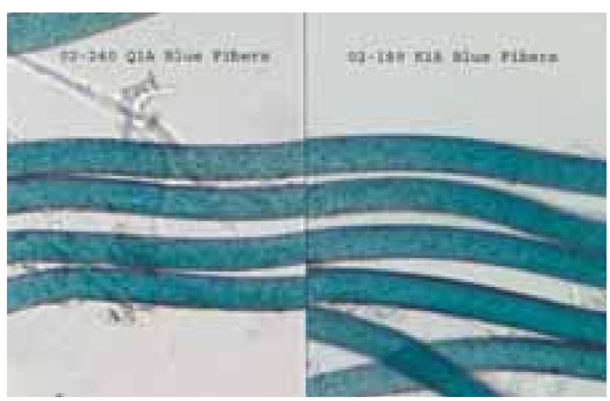

Figure 1. Detail of knit structure.

It should be taken into consideration that this project involves many different occupational disciplines, many of which are non-scientific, with varying expectations of the final product. However, the scientific method, involving a series of experiments and observations, is being employed to evaluate the success or failure of the preservation methods. It is anticipated that people concerned with fiber deterioration primarily will consult the database to evaluate and employ the optimum methods for preservation, depending upon the specific fiber content of the artifacts. The database should be initiated with the experimentation and collection of data on readily available, non-deteriorated fibers to establish the baseline, which will operate as a gauge for the degree of fiber deterioration in the artifact fibers. It must be emphasized that the method of analysis must be reproducible for the results to be comparable.

The presentation concluded with a hit-and-run homicide case study, which included digital images of a fiber comparison between fibers recovered from a suspect's automobile windshield and a victim's jacket. The poor quality photo of the fiber comparison, taken with a video/digital camera (figure 1), illustrated the necessity of not sacrificing quality for economy in purchasing digital cameras. Rather it is necessary to research and purchase the best equipment for the available funds. It is also necessary to establish a minimum acceptable resolution for images in the proposed database with consideration of storage capability and end-user accessibility.

The photos (figures 2 and 3) of the jacket sleeve and physical fit between the piece of fabric (from the automobile windshield) and the jacket hole were taken with the Nikon Coolpix 995. Optimum available resolution in digital image acquisition is critical for the end-user viewing of the significant details.

Figure 2. Victim's jacket sleeve.

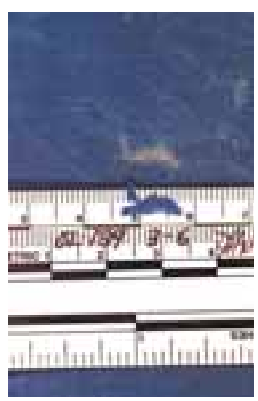

Figure 3. Sharp image of piece from victim's jacket sleeve retrieved from auto windshield taken with Nikon Coolpix 995.

The FBI Laboratory's Automotive Carpet Fiber Database

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The forensic analysis of fibers is based on the theory that whenever two people come into contact, material will be exchanged. This theory is known as the Locard Exchange Principle. This theory applies not only to fibers, but also to hair, soil, paint, wood, feathers, glass, and building materials. By examining this type of evidence, forensic scientists attempt to determine whether an association exists between two people based on trace evidence.

The typical techniques used in the forensic analysis of fibers include the following: visible light microscopy, polarized light microscopy, fluorescence microscopy, micro-spectrophotometry (color analysis) and infrared spectroscopy. Other techniques may be conducted as needed. Fibers are mounted in a semipermanent mounting medium with a refractive index of approximately 1.525 for all analyses except infrared spectroscopy, in which fibers are removed from the mounting medium. The most important technique is visible light microscopy, which allows both identification of polymer type and characterization of microscopic characteristics.

Certain fiber types lend themselves to rapid identification of their end use based on the microscopic characteristics. Carpet fibers are one such type. The relatively large size, the cross-sectional shape, and the polymer type are all factors which allow one to identify the end use of these fibers. When a carpet fiber is found on an item of evidence from a crime scene, it may allow the forensic scientist to give some lead information to the law enforcement officers investigating a case. If the carpet fiber from the crime scene can be searched against a database and a possible match is found, the forensic scientist can give the investigator the information regarding the possible source of the carpet fiber. This may be enough information for the investigator to obtain a search warrant in order to conduct a search and obtain the samples needed for the forensic scientist to conduct a comparison.

The Trace Evidence Unit of the FBI Laboratory uses an automotive carpet fiber database. It is not, unfortunately, complete, and methods of acquiring new samples are being analyzed continuously. The database consists of carpet samples of known origin, i.e., the make, model, year and if possible, the Vehicle Identification Number are known for each sample. All samples are mounted on a glass microscope slide in a mounting medium with a refractive index of approximately 1.525. A reference sample of each fiber mounted on a glass microscope slide must be maintained so that a direct comparison with a crime scene sample can be conducted.

The database consists of all the known information regarding the carpet fiber as described above. In addition, information from microscopic analysis is also maintained in the database, in order to facilitate searching of the database. The additional information that is collected from each fiber type is as follows: diameter (micrometers), cross-sectional shape, gross color, delustrant level, voids and inclusions, and generic/sub-generic polymer type. In the future, additional information will be incorporated into the database such as infrared spectroscopy data and microspectrophotometry data, both of which will be searchable. In addition, a digital image of the fiber will be included in the database.

Some problems that we have had to face in the design of the database are the descriptors for the additional information obtained from the microscopic analysis. The problems we encountered and the solutions we decided upon are described for each of the following:

Diameter. Since most carpet fibers are not round, it is not a simple task to measure the diameter. There is no standardized method for measuring the diameter of a fiber that is not round. For a forensic fiber examiner, the diameter is of critical importance when one is considering calculating the birefringence of the fiber. The birefringence is important in the identification of the polymer type used. Therefore, the measurement of fiber diameter must correspond to the amount of polymer the light passes through when calculating the retardation on the polarized light microscope. For carpet fibers, this is almost never the same as if one were to measure from one outside edge of the fiber to the other. Therefore, it was necessary to adopt a standardized method for measuring diameter in carpet fibers. This standardized method of measurement is of crucial importance since one of the most used search criteria for querying the database is fiber diameter.

Color. While color may seem to be an easy quality to assign to a fiber, in actuality, it is one of the more subjective aspects of fiber analysis. What one-person calls light red, another may call pink. The subjective nature of assigning color makes it very difficult to use this criterion to search the database. The solution we found to this problem was to be as general as possible, i.e., blue, brown, and red. By assigning only a general color, it allows all fibers within that color group to be searched. However, in combination with other search criteria based on other microscopic characteristics, the field can be narrowed down sufficiently to a manageable number of possible matches.

Delustrant Level. As with diameter and color, the possible descriptors for delustrant level can be very subjective. The solution was to again use very general terms such as none, slight, moderate, and heavy. However, even with these general terms, there can be some overlap and therefore confusion. Therefore, delustrant level is not used commonly as one of the search criteria when querying the carpet fiber database. Rather, it is used as a confirmation once a match is made based on a search using other criteria.

Voids and Inclusions. These characteristics are imparted intentionally by the fiber manufacturer or are artifacts of the manufacturing process. They are useful microscopic characteristics in the comparison process, but are difficult to assign non-subjective descriptors. Therefore, we simply document the presence or absence of voids and inclusions in the database.

In summary, the FBI currently uses an automotive carpet fiber reference collection and database. By careful selection of descriptors and field names, this database allows us to search quickly a large number of samples and retrieve a relatively small number of samples that require actual analysis with the microscope. In the future, we anticipate being able to add additional information regarding the sample, such as color measurement data (micro-spectrophotometry) and infrared spectroscopy data. The addition of these data will enable us to further refine the number of possible matches within the database; thus decreasing the amount of time needed to conduct the microscopic analysis and comparison.

The Fiber Database as a A Web-Accessible Tool for Teaching and Research

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My background is in analytical and biological chemistry. I was drawn into conservation science fortuitously when the Textile Conservation Centre (TCC) moved from Hampton Court to Winchester to become affiliated to the University of Southampton in 1999. I am involved with the three sections at the TCC, Studies and Research, which has responsibility for the two-year MA in Textile Conservation, the recently instigated Arts and Humanities Research Board funded Research Centre for Textile Conservation and Textile Studies, and the commercial arm Conservation Services.

An Educational Resource

My initial interest in a fiber database stemmed from my textile science teaching role. In the MA we highlight an informed approach to conservation, and place some emphasis on understanding the composition and behavior of textile materials. An electronic database would be a valuable educational resource, to complement the practical experience of the students in fiber identification by light microscopy and supplement a "permanent" slide collection, so I was keen to learn more about the NPS Web database when I came across it during a search a year or two ago. I was all the more intrigued by the notion of its extension to a conservation resource of aged materials.

While decisions on conservation and display may be predicated on the physical state of an artifact, it is of course seldom possible to determine the crucial parameters directly for a historic textile, but we might be able to establish correlations with measurable factors. Light microscopy could provide some guide elements, though the value of the approach presupposes that we can construct an appropriate and sufficiently comprehensive reference library.

A Reference Library

The idea of extending a fiber image database in a broader conservation context complements my research interests in the application of vibrational spectroscopy. We are collating a fiber spectral reference library, which might prove an essential complement to an image database. Currently, our spectral database is simply a collection of named fiber spectra and is used for identification of the fiber type (figure 1). For chemically dissimilar fibers spectral peak matching is quite successful, either visually, or more efficiently using automated sub-routines (which may involve spectral processing such as taking first or second derivatives). However, for chemically similar fibers, for example the range of plant fibers, this has proved inadequate. Nonetheless, where the direct approach does not work quite so well distinction is still possible by comparing characteristic peak ratios, which reflect subtle chemical differences.

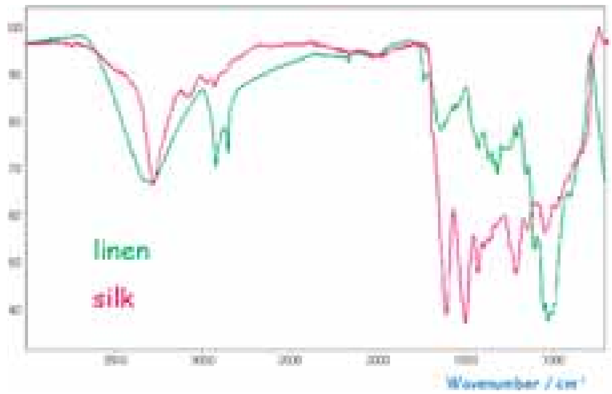

Figure 1 The infrared attenuated total reflectance spectra of linen and silk fibers.

A current project concerns the analysis of a 200 year old sail. Not surprisingly, it is a linen cloth, as evidenced by spectroscopic analysis and also microscopy (figure 2). We now have yarn from a number of damaged areas, and are proceeding to comprehensively characterize the fibers. Our records will include light and scanning electron micrographs, tensile test results, acidity measurements, and spectroscopic analyses. We are particularly keen to build up a reference library of such complementary data, which we will use to predict the likely behaviour of historic fibers to support informed custodianship.

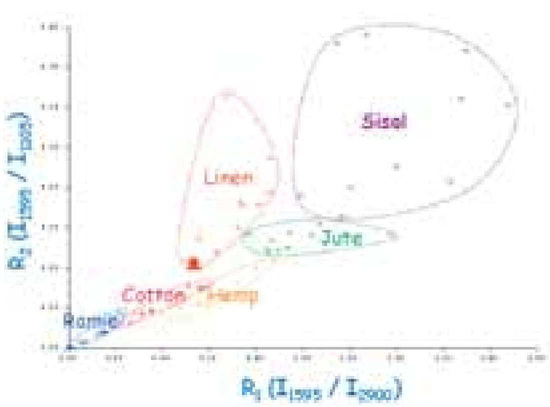

Figure 2 Peak ratio plots for the infrared attenuated total reflectance spectra of various plant fibers, with the data point for a 200 year old sailcloth overlaid.

For now accepting that this is worthwhile, what criteria should we bear in mind when assembling such a library? First we must be clear about the purpose of the library and thence its scope. In our case it was initially a simple identity aid, though now we are extending the brief to encompass characterization of the state of deterioration. We must also consider the progressive development of the database, suggesting selectivity, and the criteria for selection of the entries; we need to consider the representative nature of specimens, sampling considerations are a significant issue as are the value of aged surrogates. Besides incorporating information from historic textiles, data for material subjected to well-defined ageing regimes would add immeasurably to the value of the database.

To make the connection we must have the requisite complementary information, so that morphological descriptors of fibers should be accompanied by mechanical properties, including perhaps subjective handlability of fabric, and further microstructural and chemical information would be really useful.

We also need to think about the required resolution or sensitivity of fit: in relation to conservation decisions is a simple coarse scale sufficient?
We may wish to prioritize our compilation, at least first dealing with what we consider the core, though there may be pragmatic constraints.
Since my particular concern is with natural fibers, these were the nucleus of the spectral library, though we are now adding data for artificial fibers.
Sub-categorization not only clarifies the coverage but also conveys manageability.

Discussion Points for Developing a Web-Accessible Fiber Database

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My involvement with identifying fibers began in 1989 with my training by Walter McCrone as a conservation student at New York University. I knew then that fiber identification would be an important part of my future career in textile conservation. Indeed, it has been an increasingly significant part of my work. I have worked on fiber identification for private clients, institutions, and colleagues, and I have taught workshops for the New York Microscopical Society as well as a full course every fall for my graduate students at the Fashion Institute of Technology (FIT). As Chair of the Museum Studies Costume and Textiles department, I teach conservation science courses and occasionally consult with the Museum at FIT on fiber identification questions.

All of my above mentioned involvements require identification of historic fibers, sometimes originating from quite severe physical circumstances or past treatments (4th century BCE burial site remains, or weighted silks, for example) in which their morphological features have been changed or distorted over time. Such fibers often do not match any reference slides or pictures that usually only illustrate perfect examples of newly produced fiber types, thus extending the time necessary to complete an identification. The usually poor condition of historic fibers becomes an impediment in the teaching of fiber identification to my graduate conservation students, thus I hope that the database will include deteriorated fibers in their set of reference samples. Such a suggestion would mean that those fibers selected for inclusion into the database be of known age and origin, and have had a systematic method of condition rating associated with them.

My own personal research interests tend to be focused on modern fibers such as the early regenerated cellulosics of the 20s and 30s as well as the modern related Lyocell fibers, and the slightly later regenerated proteins of the 40s and 50s. This is also related to the holdings of the Museum at FIT which houses one of the largest collections of late 19th and 20th century fashion items for which I do occasional fiber identification. I am also interested in modern coatings, which range from early wrinkle-resistance, mothproofing, and flammable treatments to the modern holographic treatments on Versace fabrics, and how they affect the optical properties of fibers, thus possibly affecting their identification. The history of the use of delusterants is also interesting and may play a role in the identification of fibers.

When I was asked to participate in the discussion concerning the formation of a uniform Web based fiber identification database, I was very pleased to think that such a helpful tool was going to be developed. I have recently purchased an Olympus DP 12 digital camera for my lab at FIT and was poised to develop some sort of limited database for my own students. As I began to think about the design and content of such a database I was overwhelmed by what I felt were the minimum numbers of necessary categories of information for each fiber that such a database needed to contain, both for the descriptive side as well as the condition status side, to be useful. The development of a standardized vocabulary alone will be time consuming though extremely important. As is well known, man-made fibers can be quite challenging to identify due to their lack of unique morphological characteristics and at the same time their complexities of chemical make-up as seen in bicomponent fibers and microfiber production with odd cross-sectional shapes. They therefore will sometimes require more complex microscopical techniques for identification, such as the use of refractive indices, 530nm plate tests, as well as the use of additional spectrographic or other analytic techniques. The opportunity to include the results from those types of analyses into a fiber database, I believe, will be key to its ultimate usefulness.

Other standardization issues will be the need to develop uniform sample taking protocols as well as those for the longitudinal and cross-section slide preparation. Image capturing techniques, resolution issues, and access are all additional open design elements that will need to be worked out as this project moves forward. For myself, in my role as a teacher of fiber identification, I will need a database that is easy to learn as classroom time is limited.

I am extremely excited by the prospect of one day using a fiber database, equipped with vetted historic fibers in varying states of deterioration and hope that my input as both a future user and as an educator will be useful.

Development of Two Conservation-oriented Online Databases

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In the last several years, the Internet has become an essential resource for the compilation and dissemination of information. Its availability and breadth allows researchers worldwide to collaborate, develop databases, and share information. Within the conservation field, two databases, IRUG (Infrared and Raman Users Group) and CAMEO (Conservation and Art Materials Encyclopedia Online) have become important searchable information resources. The origination of these two collaborative Internet databases will be presented briefly here.

IRUG spectral database is a compilation of over 1000 infrared spectra for cultural materials. This includes spectra for natural products (oils, waxes, resins, proteins, carbohydrates, dyes, minerals), synthetic materials (adhesives, coatings, paints, dyes) and other products (corrosion, salts, polymer additives) in digitized (JCAMP.dx) and hard copy formats. The collection was started in 1993 through spectral contributions from several individuals and institutions. In return for adding at least 10 spectra, each contributor was provided with a copy of the compiled collection in both hard copy and digitized formats. Each contributor retained copyright for his or her spectra. The IRUG membership has formed into a non-profit organization whose goal is to share information and data on the infrared and Raman analysis of works of art. The organization has worked together to develop spectra standards, edit submissions, obtain grants, and place the database on the Internet.

CAMEO is an electronic database that compiles, defines, and disseminates technical information and images on the distinct collection of terms, materials, and techniques used in the fields of art conservation and historic preservation. CAMEO was developed at the Conservation and Collections Management Department at the Museum of Fine Arts, Boston and placed on the Internet as a resource for the conservation field. With the aid of voluntary contributors, this database has grown into a comprehensive resource that consolidates the textual and visual information on museum materials. CAMEO contains more than 10,000 records. Each term was selected based on its having been mentioned in art, conservation or related scientific literature (journals, books, catalogs, etc.). Entries include materials such as pigments, minerals, binders, coatings, adhesives, fibers, dyes, solvents, reagents, corrosion inhibitors, woods, pollutants, pest control agents, and storage materials.

Both of these databases were developed originally as collections of data and information digitally organized using the FileMaker Pro database.

Funding support from the National Center for Preservation Technology and Training (NCPTT: funded both IRUG and CAMEO), the Samuel Kress Foundation (funded IRUG), CertainTeed Corp. (funded IRUG), and the Institute of Museum and Library Services (funded CAMEO) was obtained to expand and develop the databases online as free, interactive, searchable reference sources.

Development of a Web-Accessible Reference Library of Deteriorated Fibers Using Digital Imaging and Image Analysis

Proceedings of a Conference April 3-6, 2003

Keynote Papers

Creating a Standard Vocabulary for Defining Levels of Deterioration

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Quantification of deterioration must reflect changes in mechanical properties, not just changes in visual appearance. Assessment of the loss of mechanical properties identifies the changes in the chemical structure of textile fibers. In order to standardize mechanical measurement of deterioration, attributes intrinsic to the fiber type must be characterized to track changes. Textile degradation manifests itself as an observable change in a natural attribute, or the appearance of a new feature. These new features can include fractures, soiling, and biological damage. Deterioration can be attributed to many factors: effects of real-life textile usage, environmental effects, and the effects of treatments and exhibition or storage conditions. Use of a controlled vocabulary of deterioration is fundamental to assessing the mode of fracture, as manifested by a fracture type associated with a cause. Standardization is essential, and allows the database to be used comparatively by various parties. Fiber characteristics can then be linked to changes in the textile so that the micro—macro linkage between conservation treatments and observations relates to events at the fiber level. Microscopic imaging and tensile testing must provide useful macroscopic information. While quantification is necessary to define levels of deterioration, standard terminology is imperative to provide useable information.

Introduction

In order to create a useable database, a standardized vocabulary is essential to enable searches with established criteria, comparative analyses, and relevant data. While deterioration in the past has largely been determined by visual assessment, it is the loss of mechanical properties associated with the textile item and its function that gives a direct manifestation of the relationship between mechanical and chemical degradation. The most important characteristic of textile fibers is their mechanical properties, more specifically the tensile properties, since these reflect changes from forces applied to the fiber. Since mechanical characteristics define the overall changes that have taken place during the life of the historic textile, tensile properties provide a valuable mechanical assessment of handling characteristics, which are an important consideration for understanding deterioration of all textiles. When structured into a yarn or a fabric, the textile fibers are dependent upon the relationship between the structural arrangement of the textile and the individual fiber properties. Understanding the properties of yarns and fabrics necessitates knowledge of the fiber properties. Yarns and fabrics are limited by the component fiber properties, since the yarn strength will not exceed the total maximum strength of the fibers from which it is assembled.

The condition of a textile is entirely dependent upon its history. Previous influences can include the manufacturing processes, mechanical damage due to use as a textile and subsequent treatments, and conditions to which it has been exposed. Exposure to light, water and consequent moisture fluctuations, pollutants, extreme temperatures, and general soiling are all causes of deterioration that are likely to have had an effect upon the textile. Display and storage conditions are factors that should also be addressed for museum textiles.

Since deterioration is an ongoing process, one of the challenging aspects of creating both the database and a standardized vocabulary is the concept that this is a "living" database. Assessing deterioration means monitoring and tracking changes in fibers. Longitudinal studies on existing samples in the database have the potential to provide extensive useful information. Horizontal comparative studies of similar fibers will assist the comparison of samples from different time periods to interrelate the effects of environment, storage, display and general deterioration from textile usage during its working lifetime. In addition, the value of some characteristics and tracking data may only become clear over time and use of new technology. The fracture morphology of individual fibers by scanning electron microscopy (SEM) can illustrate the effect of past influences on the textile. Fiber fracture is a direct visual manifestation of physical changes. The information gained regarding the history of the textile can also help develop suitable conservation decisions. Massa et al. (1980) measured both fiber strength and fracture morphology by SEM for Egyptian mummy keratin fibers dated at 1500-4000 years old. The fibers were found to have similar tensile properties and distinctive fracture morphology comparable to more modern aged textile fibers. These studies provide invaluable information about the effects of environmental conditions. In addition, they impart important comparative data relating to the rate at which certain environmental parameters can cause rapid deterioration of more contemporary textiles when not controlled.

Standardizing the Evaluation of Deterioration

An accurate description and definition of deterioration requires the determination of the fiber characteristics to be measured and assessed. These attributes should be specific fiber morphological characteristics intrinsic to the particular fiber type. For example: measurable wool features include scales, elliptical shape, axial ratio 1.1-1.3, diameter range of 15-50μm, length characteristic of the breed; cotton includes the characteristic twisted ribbon shape, with a diameter range of 10-30μm; and linen fibers include the characteristic cross-sectional nodes, and polygonal fiber shape.

Achieving this standardization requires people with expertise in particular fiber types, who can recognize and are familiar with assessing changes in key attributes. The use of digital imaging to assist the measurement protocols will be a useful technology transfer to the textile conservation field, with the input of professionals in the field of textile research. Features that contribute to changes in fiber mechanical properties such as strength and extensibility, as opposed to just changes in visual appearance, must be quantified, accurately described, and captured as key attributes.

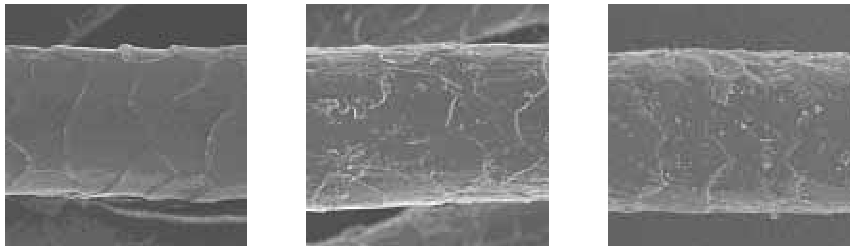

Figure 1. Wool Fibers – left to right: new wool, artificially aged, naturally aged (France 2000).

Deterioration Criteria

To evaluate the deterioration of a fiber attribute, it is necessary to note the presence or absence of a feature, and in conjunction with this, an observable measurable change in the feature. Using the characteristic features of wool fibers as an example, this could refer to the presence or absence of scales. Changes in the dimensions of the feature as a discernable change could relate to scales, length of the fiber, as well as changes in the diameter of the fiber. It should be noted that in relation to these changes, the observer needs to be aware of the normal coefficient of variation (CV %) of such attributes—in the case of wool this can be up to 60% CV for diameter variability—both between fibers, and along the length of the same fiber. Hence expertise in assessing the natural variation in fibers versus manifestations of deterioration is critical.

The appearance or presence of a new feature is also evidence of degradation, and/or the presence or influence of agents of deterioration. Such features can include micro-fractures in the fiber, cracks, soiling (particulate and organic), and evidence of biological activity. Micro-fractures can be due to fatigue and constant loading on the fibers, or evidence of a degradative cause such as relative humidity (RH) fluctuations. Changes in RH are important, since fluctuations cause small changes in fiber dimensions. RH changes over many years or due to an unstable environment can slowly generate microscopic flaws in the textile fibers. This becomes of greater concern as the artifact ages and becomes more susceptible to damage. These micro-flaws may propagate planes of weakness that exacerbate fiber fracturing. This lends credence to the common concern and recommendation for maintaining relative humidity at a constant level. Modern fracture mechanics has established that macroscopic breaks or cracks are initiated from microscopic flaws. Gamez-Garcia (1999) observed that repeating small surface mechanical deformations in keratin fibers produced micro-voids and axial cracking of the fibers. Cycling RH to create regain changes of 10% showed a marked effect on the extensibility of photo-aged wool (France & Weatherall 1999). Erhardt et al. (1995) acknowledged that damage to cottonwood materials might be related to repeated small tangential deformations caused by changes in relative humidity. Hansen et al. (1992) refer to brittleness as a reduction in the ability to elongate before breaking. They note that both medieval and modern type vellum can be considered more brittle at lower relative humidity levels.

Fractures are a direct manifestation of forces imposed upon the fiber. The appearance of elements that are not part of the fiber structure (soiling and biological debris) are evidence of environ-

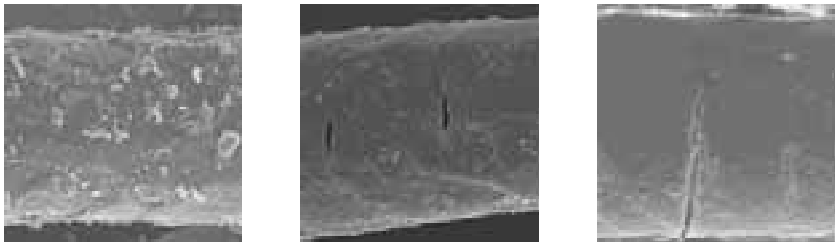

Figure 2. Examples of Environment Influences on wool–left to right: soiling, micro-fractures, cracking (France 2000)

mental influences. Soiling can create degradation due to abrasive particulate matter that either abrades the surface, or embeds and creates planes of weakness in the fiber structure. The size of the particulate is important in relation to the damage potential. Organic soiling can be subtler, in that the potential often remains unrecognized. Daniels (1984) notes that the slow oxidation of organic material at room temperature (autoxidation) is probably the most important non-biological cause of degradation. Due to free radical formation, a chain reaction continues, resulting in the formation of peroxides. Feller (2002) notes that the point at which this process begins is difficult to determine. It is often after the artifact has become brittle or fragile that the rapid damage becomes apparent, and at this point it may be too late for the item to be preserved effectively.

All textiles are subjected to a diverse range of influences. Critical information for conservators and curators is determining changes attributable to museum conditions and treatments. While some textiles may have been subjected to little more than mechanical action during their history, others may demonstrate results of many influences, including light, heat, and moisture. The previous history combined with exhibition and storage conditions can make it difficult to ascertain the main cause of degradation from this cumulative effect. Assessing fracture surfaces under scanning electron microscopy (SEM) has provided greater opportunities to determine the specific causes of textile degradation. This fracturing can also be observed by a trained eye under a high magnification microscope, showing changes from normal more fibrillar fracture surfaces, where the internal structure of the fiber can resist break, to increasingly smooth fractures as the fiber deteriorates, relating to a weakened interior structure. Due to the characteristic brittleness of aged fibers, any deformation of the fiber is more likely to cause it to break, i.e. tensile force, bending, shear, and twist. Providing the knowledge for the conservator or curator to prioritize, monitor, and control causes of deterioration is a critical tool for extending the life of fragile textiles.

Quantification of Deterioration

One of the critical factors for developing a useful deteriorated fiber database is the information that establishes the relationship between the microstructure and the macrostructure. Changes in fiber morphology should relate to the yarn and the textile fabric. Quantification of fiber characteristics relates to the changes in attributes native to that fiber, as well as changes due to the presence of other degradative environmental influences. Using wool as an example, while aspects such as scale, diameter and length dimensions can be measured; the next step should be to assess the relative proportion of a particular fiber characteristic present on a microscope slide. Changes in morphology, such as fractures commensurate with deterioration, could be assessed in terms of the ratio of smooth versus fibrillar breaks. At the yarn level, the number of fiber breaks in a specific yarn length could be noted, as well as the types of fiber breaks for a skilled assessor. The amount of yarn thinning, surface flattening, distortion or set of yarn shape, or loss of twist, are all features that provide a quantification of the deterioration. The consistency or range of fiber and yarn characteristics in the textile is also important for evaluation.

At the macro level, years of experience allow conservators to subjectively appraise the textile fabric through a visual and tactile assessment. The ability to objectively quantify these hand assessments and relate fabric characteristics to fiber or micro level deterioration terminology could provide a great benefit to textile examinations. Systems such as the KES-F system (Kawabata evaluation system for fabrics) have been employed for many years in the fabric industry to define objective measurement of previously subjectively assessed fabric parameters. These include parameters of surface properties, warp, weft, and shear properties, tensile, bending, and compression properties. Supplementary information regarding fabric weight, thickness, and count would add to visual assessments, such as areas of loss, and flattened yarn crowns in the structure. These visual assessments could also be quantified through image processing. This would create a more comprehensive overall assessment of the textile deterioration, while allowing fiber characteristics to be linked to observed and measured changes in the textile fabric. Utilization of existing textile and conservation standards and terminology where possible; e.g. American Society for Testing and Materials (ASTM), and American Institute for Conservation (AIC), would assist the ease of data transfer. Standardizing the terminology is also critical to create useable information. A workable standardized vocabulary is required to effectively transfer useable practical information from scientist to conservator and curator. The microscopic imaging must provide useful macroscopic information and translate to workable information at the macro level.

Linking the Causes of Deterioration to the Vocabulary

Causes of deterioration need to be defined in terms of their effects upon textile fibers. The causes of deterioration can be defined in three broad categories.

Real-life Usage

The first type relates to the effect of real-life usage in textile materials—commonly referred to as "wear and tear." The mode of deformation of the textile composite and hence the fibers, includes tensile load, torsion or shear forces, as well as bending or flexion, twisting, elongation, and abrasion. Fatigue refers to a repeated loading over a long period of time, at a lower level than required for immediate failure. This is one of the most common reasons for deterioration and reduced mechanical stability in aged textile fibers.

Environmental Factors

The second category consists of the effects of environmental factors. These include visible light and ultraviolet radiation, temperature, water, oxygen, and biological. The most damaging environmental factor for textile fibers is visible light.

Table 1. Causes of Deterioration

Real-life Usage in Textile Materials	Environmental Factors	Effects of Treatments and /or Conditions
Tensile forces	Visible light	Aqueous Cleaning
Torsion or shear forces	Ultraviolet radiation	Non-aqueous Cleaning
Bending and flexion	Water	Humidification
Twisting	Oxygen	Rotation
Elongation	Temperature	Display Orientation
Abrasion	Biological	Light source
Fatigue	Soiling	– daylight
Compression	- particulate	– artificial sources
Expansion	- organic	(tungsten, florescent, LED)
Friction	Autoxidation	Relative Humidity
	processes	Extreme temperature

Observation has shown that dyed textiles fade and change color on exposure to light. British Blue Wool Standards comprise eight blue wool standards graded from 1 (very low light fastness) to 8 (very high light fastness), and were originally developed to monitor daylight. The usual light in museums is generally ultraviolet (UV) filtered daylight, and/or some combination of artificial light sources. Horie (1990) noted that blue wool standards with poor light fastness are faded by both visible and UV radiation, while the higher number standards are only faded by shorter wavelength components of the radiation. Standards 6 and 7 were shown to be unreliable when UV was excluded. Since most museum lighting is UV filtered, these standards do not provide an accurate measure of the real damage. Fading does not necessarily indicate changes in the textile fiber structure. While there may be slower initial textile substrate deterioration compared to dye fading, this may be reversed later in the life of the textile. Research has shown that in some aged textiles, there appears to be a photo-protective effect from specific dyes, when compared with un-dyed fabric in the same textile (France 2000). Information in the database offers potential as a key input for determining effective preventive conservation techniques, particularly relating to environmental conditions.

Effects of Treatments and/or Conditions

Effects of treatments and/or conditions are the third type of deterioration causation and are often the least researched and most important influence on textile fibers. Conditions relate closely to the environmental factors noted above, but gain more attention when they can be controlled or at least monitored, as in museum and historic house environments. Monitoring allows an assessment of which agent of deterioration is the most damaging, and presents opportunities for greater control and modification of the environment. Sadly, many decisions are cost-driven, so having the information to assess and prioritize risk allows more efficient allocation of resources, as well as ensuring that exposure of the artifact to degradation processes is minimized. An important consideration is whether stabilization of the condition alone can confer a benefit (France 2002), including issues such as orientation of the textile on display from hanging to flat with creep and stress release, or long-term gradual humidification of the textile as opposed to wet cleaning. Some textiles such as tapestries, provide a rich source of information regarding light degradation when fiber samples from the front are compared with ones from the back that have not been exposed to light. With lighting, information should include not only the level measured (lux or footcandles) but also the light source. The spectral distribution may differ meaning that the same number of footcandles could have more damaging incident energy. The context is also important; for example historic houses, which have more daylight versus artificial light, and issues regarding rotated textiles versus those on permanent display. The RH stability is another critical environmental factor, as well as whether there are extreme changes in temperature.

Testing and Analysis

Treatments have tended to follow standard protocols, and often the effects of these are not known until many years later. Testing on small samples of fibers to assess the effects of the treatment provides knowledge during or prior to the textile undergoing treatment. Mechanical tensile testing makes available information regarding any changes in textile strength which is important for handling and display options. Single fiber analyses reduce the amount of sampling required from a textile, with the benefit of minimal impact on the artifact. As yarns tend to fail through a combination of factors, defining the stress-strain properties of single fibers from the yarn allows a more comprehensive representation than simply breaking the yarn. A statistically significant sample can usually be obtained from a 2-inch yarn fragment (depending upon skilful extraction of fragile fibers). Research has shown samples to be similar even over large artifacts. A large amount of information can be gained from a very small sample. An approach ensuring the full range of fiber strengths was measured would be to sample from both a damaged area and an intact area of the textile. In some instances noting the range of the results may be just as important as the average value of the sample fibers. Noting data such as warp and weft, as well as location, are critical to assessing the deterioration and provide valuable monitoring information. Determining the effects of treatments also suggests issues regarding sampling. Before and after sampling provides more relevant information when half of the same sample yarn is tested and imaged. Tracking changes for the database after a number of years allows longitudinal studies and follow-up of the effects of not only the treatments, but also the environmental conditions to which the textile has been exposed. This may be critical for assessing manipulation of the textile.

As fibers deteriorate the load at break is reduced. However the changes in fiber strain (or elongation) is essentially the "canary" of tensile properties, since the effects of various conditions and treatments most profoundly affect fiber elongation (France 2000). This research has also shown that a wide variety of treatments on new wool have a similar effect, ranging from fireproofing to aqueous and non-aqueous cleaning treatments, as well as RH cycling. Most textiles have been used to varying degrees when they arrive at the museum, with the textile already in a deteriorated condition. Determining this level of degradation through tensile testing allows for appropriate handling and treatment options to be followed.

Terminology of Deterioration

The durability of textiles is a major concern to consumers from a practical perspective. A textile specialist can see that the changes are due to the deterioration of the fibers in the fabric. The common modes of fracture that relate to all the previously noted causes of deterioration include tensile, shear, combination, and flexion. These tend

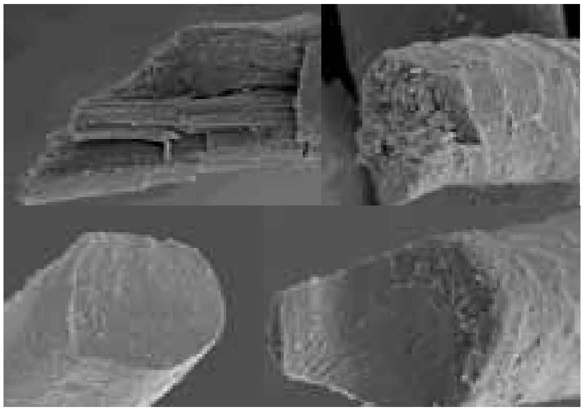

Figure 3. Fracture Types – from left clockwise: fibrillar, step, concave and smooth (France 1999-2000).

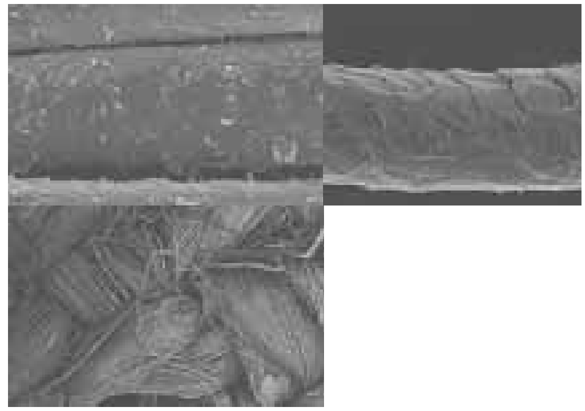

Figure 4. Examples of Effects of Treatments and Environmental Deterioration–from left clockwise: removed particulate matter, treatment cracking, biological debris, yarn crown flattening (France 2000).

to present as specific types of fracture, such as fibrillar, step, concave and smooth. While many variations of fractures can be seen, experience shows that each fracture will show features that correlate with a specific grouping. SEM and high power microscopy allow examination and identification of these fracture surfaces.

In their simplest form, tensile fractures show breaks perpendicular to the fiber axis. When the fiber structure can dissipate the stress, a fibrillar type fracture results. As the fiber deteriorates, the fracture surface changes to a step type fracture, where a clear break through part of the fiber is combined with a more fibrillar section where the fiber is resisting the break. This may also reveal or result from micro-fractures and planes of weakness, as seen with dimensional changes due to RH fluctuations. As deterioration continues, the internal network of the fiber becomes more cross-linked and rigid, with less flexibility to distribute stresses throughout the fiber structure, and a smoother concave shaped fracture results. Very deteriorated fibers portray a smooth flat surface, commensurate with the increased brittleness of the structure, similar to the way glass breaks. In terms of environmental parameters, light degraded fibers present smooth fracture surfaces.

Fatigue, which is degradation due to repeated loading, tends to show a combination of tensile, shear (breaks diagonal to the axis of the fiber) and flexion. The initial stages of flexion or repeated bending of fibers demonstrates a series of small cracks on the outside curve surface of the fiber, generating a series of areas of weakness in the fiber. Other causes of deterioration, such as soiling and biological sources, are clearly visible due to the presence of new features on the surface of the fibers. In some cases particulate matter can be seen exacerbating crack formation due to lodging in small cracks on the surface and being embedded in the fiber. The indentations left from this type of damage can be shown by imaging the fiber to assess the efficacy or otherwise of cleaning treatments. Examining changes due to treatments may reveal weakening due to cracking, or removal of soiling without further damage. Monitoring the textile while it is on display can reveal the effects of environmental influences. If the assessment reveals an increase in the number of smooth fiber fractures, this could be indicative of photodegradation. If larger samples are available, the extent of mechanical wear at the yarn and fabric level can also be imaged to assess the amount of yarn crown flattening, patterns of fiber loss, cohesion of yarn structure, and evidence of fatigue breaks in the weave structure.

Conclusion

The underlying basis of a database is the capability to locate and correlate relevant information. While this was once based solely on keywords, now it is more frequently dependent on searchable embedded data. These in turn are critically dependent upon standardization of the vocabulary for many people with a range of professional backgrounds to effectively search, compare and use the database. Defining a protocol and method of assessing deterioration provides an essential tool for all textile specialists—to compare and contrast database samples, to acquire controlled environmental conditions, to upgrade conditions of storage and exhibition areas, and to obtain and utilize knowledge of the effects of treatment from previous work when the resources are not available for them to do so themselves.

Preventive textile conservation extends the life of a textile through the best care available. This involves decisions regarding exhibition and storage conditions, monitoring and controlling the environment, and treating or cleaning the textile. The information necessary to make these informed decisions is critical. By linking the "micro-level" fiber structural changes to the "macro-level" textile handling and exhibition requirements, useful knowledge is generated. Sampling protocols are necessary since if location, conditions of storage and display, treatments and any other historical data is not collected and retained, analyses of changes only provide one frame of the whole picture. People who provide the samples may not want to reveal deterioration issues related to mishandling or inoperative or malfunctioning equipment and environmental control systems. However, information such as this may be critical to gain funding for conservation requirements, if it can be shown that the deterioration of textiles is due to specific factors.

Defining levels of deterioration of textile fibers with a standardized vocabulary requires knowledge of changes associated with deterioration that is reflected in the terminology. The deterioration relates to changes in intrinsic features of the fibers as well as new features, usually associated with environmental influences. Standardization is essential for a database to be used easily and efficiently by all interested parties. Through this deterioration database, the utilization of new technology and textile expertise, will serve to integrate science and conservation to advance and benefit textile preservation.

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Considerations Regarding Sample Acquisition for a Web-Accessible Fiber Reference Library

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Material identification is fundamental to the work of textile preservation and interpretation. Conservators routinely remove minute fiber samples from textiles as part of the documentation and treatment process. Many practitioners also accumulate exotic fibers for reference. Conservation joins many other fields in the practice of material identification through sampling. This paper explores the process of sample acquisition, preparation, and archiving in the field of textile conservation in an effort to highlight the need to standardize protocols for a Web-accessible fiber reference library.

Introduction

The American Institute for Conservation of Historic and Artistic Works includes a statement on sampling works of art in its Code of Ethics and Guidelines for Practice. "Sampling and Testing: Prior consent must be obtained from the owner, custodian, or agent before any material is removed from a cultural property. Only the minimum required should be removed, and a record of removal must be made. When appropriate, the materials should be retained"(AIC 1994). As conservators we carefully consider the need, process, and impact of sampling since it does entail removal of materials from an artifact.

Rationale for Sampling

There are many reasons for sampling. Material identification is probably the most basic and within the field of conservation it is the most common reason for sampling. The information gained from a sample can help decide a treatment protocol. In addition, the information may have historical significance, put an object in context, or help to identify the source of materials. Material analysis can also support research or assist in determining authenticity of an artifact. Ultimately we sample to understand as much as we can about an object.

What Constitutes a Fiber Sample

To the conservator, a sample is a minute specimen of the fibers or filaments that make up a textile. It is as small as possible but large enough for analysis and identification of the material. If more than one fiber or filament type is used to create the textile, they all may be sampled. Within the context of this meeting, the sample is presumed to be analyzed using light microscopy. While many other instruments are used to perform analyses including Fourier transform infrared spectroscopy (FTIR), sample collection for these tests is not addressed by this paper. However, the information derived from other types of instrumental analyses may be included in the Web-accessible reference library.

Sample Site Selection

Specialists dealing with historic textiles thoroughly examine the object before making a determination about sampling. They first establish the information they hope to obtain from the analysis and where to obtain that information. In some cases the information needed may determine the sample site. A historian may be interested in a precise material identification while the conservator may need to merely identify the fiber composition sufficiently to determine a treatment. A sample of fiber in relatively good condition with easily identifiable morphological characteristics better serves the former purpose, while a sample that is easy to remove, possibly from a broken thread would serve the needs of the conservator. For example, Colonial National Historical Park owns sections of the Revolutionary War (1775-1783) campaign tents of George Washington. For the purpose of developing a conservation treatment for the office tent liner, it was sufficient for the conservators to know that the tent was woven from a bast fiber. However, a historian consultant on the project was interested in identifying the fiber as either linen or hemp. The more precise identification would be an important piece of information in his study of 18th-century military tents and the origin of the manufacture of their cloth.

The sampling site is chosen after a thorough examination of the artifact and estimating the information that may be gained from the analysis. Initial observations about fiber content are usually made under magnification to determine if more than one sample should be removed. This is usually done when warp, weft, or other constituent threads seem to be different. Other factors that influence site selection may include fiber finishes, laundering products, colorants, and previous conservation treatment. The site should be as free as possible from soil contaminants or extraneous materials such as adhesives or starch.

Site Documentation

One of the more difficult tasks of sample collection is to adequately identify the sample site. The slides in the NPS microscope slide fiber reference library (Hanson 1999) have such notations as warp, weft, and lace trim. In the corresponding object condition reports, there is no written description, map, or photograph to show the sampling site precisely. Since the original purpose of the sample acquisition was to identify the fiber type, this amount of detail in the label was adequate. Now that we are seeking to use these samples differently, developing a better documentation protocol for description of sample site is required.

Sampling Tools, Equipment, and Procedures

Quality tools minimize the impact of sample acquisition on the artifact. The most useful instruments for textile sample collection are fine stainless steel tweezers, thin probes, a sharp scalpel, and thin-blade scissors. The process is best performed under magnification.

Samples are retained on glass microscope slides with a coverslip. A frosted edged slide makes labeling easy using a permanent marker. A mounting medium can be used such as the commercially available brands of Meltmount or Permount which are synthetic resins that allow for rapid mounting and long term storage of slides. In the HFC fiber reference library, the first samples were compromised by the mounting resin that was used in the 1970s. Today the coverslips are secured to the glass slide by three small dots of Paraloid B-72 placed equidistant around the outer edge of a round coverslip. Water or a stain can be inserted under the coverslip using a hypodermic needle when work takes place on the sample.

Sample Acquisition

Sample removal from a textile may depend on opportunity, material, object condition, adequacy of tools, and the skill of the practitioner. For conservators, an overriding principle of sample acquisition is to avoid damaging the artifact when removing a sample. Conservators will often want to remove a loose or broken thread. Such threads occur most frequently at the edges of a textile, around holes, in seams, and on the reverse. Selection of samples from such sites may affect the sample condition. For example, taking a broken fiber from the edge of a hole will usually yield a quite damaged sample. The artifact may be in good condition, except for the hole, and therefore the sample may not be representative of the condition of the piece. The sample may be perfectly adequate for fiber identification, however.

While conservators are concerned about damage to an artifact caused by the process of sampling, damage can also be done to the sample through mishandling or poor acquisition techniques. In the conservation literature that describes sample acquisition, some practitioners advocate cutting a fiber with a scissors while others recommend gently pulling fibers from the end of a thread when possible. Damage to the sample can even occur from the pressure exerted on the sample from the tweezers used to take the sample. For example, wool scales can break off a very deteriorated sample as a fiber is removed.

Sample Preparation

Sample preparation needs to be considered in the context of future image digitization and potential for image analysis. The basic process of sample preparation involves placing the sample on a microscope slide usually with a drop of water. The fibers are then teased gently apart, and the result should yield a sample in which the fibers are well separated. It is important to obtain continuous areas of fiber that are not impacted by another fiber crossing it for improved image analysis.

Fibers are generally mounted in a mounting medium. A medium is any liquid, resin or melt used to mount microscope specimens before examination. They are selected primarily for their refractive index (RI), the ratio of the velocity of light in a vacuum to its velocity through a transparent or translucent substance. While conservators do not measure refractive index routinely, the RI is often compared to the mounting medium. For example an unknown fiber sample may be said to have a RI greater than, equal to, or less than the known RI of the mounting medium.

Sample Tracking

With any large body of material, each sample needs to be individually identified with a unique accession number so that the specimen can be retrieved when required. The complexity of keeping track of the physical samples pales in comparison to keeping track of all the data that will be generated from the sample. The data may be digital images, graphs, and text. A systematic sampling and data recording protocol is essential to ensure that the data are properly linked to each sample.

Sample Identification and Data Collection

Many techniques are used to identify fibers, but transmitted and polarized light microscopy is fundamental. Computer technologies enable analyses to go beyond identification to precise characterization of morphology. Conservators hope to use these new tools to better characterize fiber condition and levels of deterioration. How these technologies will ultimately impact the field of conservation has yet to be fully determined.

Sample Archives

Within the context of making a Web-accessible reference library of fiber samples, the need for a sample archive is self-evident. However, the issue of redundancy of samples does arise. When a fiber's image is captured and thoroughly analyzed and the information is retained in a digital form, is there a need to maintain the sample and the archive? This is a philosophical question open for consideration, but the practicalities of any sample collection program is that the samples need adequate housing and storage, which takes both money and space.

The samples themselves can be stored in a variety of slide storage boxes and cabinets that are available on the market. Small laboratories tend to use traditional slide boxes that hold glass slides in slots. Box construction materials include paper, wood, polypropylene and other plastics. These boxes are space efficient. When storing slides with coverslips, the position of the slide at rest should be such that the slide is horizontal with the coverslip on top. Storage cabinets and cubes store slides in pull out trays. These take up much more of the laboratory space than the boxes, but are better for the samples. The samples are easier to locate and handle because slides are in pull out trays. In slide boxes, slides can drop from their slots if the box is opened incorrectly.

The sample storage environment should also be controlled. Conservators are trained to think of environments that are known to preserve artifacts. A relative humidity (RH) between 50 and 55 % and a temperature between 68 and 72° F are the target numbers for collections and are also desirable for sample collections. Rapid fluctuations in these numbers should be avoided. While the samples are not artifacts, they should be kept in a good storage environment and not be subjected to environmental extremes. In addition, they should be protected from pests and most particularly dust.

Conclusion

Fiber samples will be an important resource of any Web-accessible reference library of fibers that may develop. As with other aspects of this project, a standard needs to be developed for consistent sample acquisition, handling, identification, and storage among all contributors so that they can have maximum value to textile specialists.

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Exploring Linkages Between Defined Types of Deterioration to Condition of Textile Artifacts

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A database compiling images and information on the features of degraded fibers has been proposed. A powerful database on fiber structure and properties in response to degrading forces can be created by including information on the visual assessment of the textile's condition, evaluation of fabric and yarn structure, and examination of individual fibers. Interpretation of the data compiled therein will be enhanced by knowledge derived from studies of fibers exposed to controlled sources of degradation and of fibers that have naturally degraded over time. Research in fiber and polymer degradation provides information on the chemical and physical consequences of isolated degrading forces. Examination of materials that are naturally aged provides examples of the consequences of the multiple degrading forces experienced by fibers through their active lifetime or in the long term depositional context. Accumulation of the information provided by past research with that provided by new contributions to the fiber database will yield not only a tool for comparison but also may show new patterns linking fiber chemical and physical structure to the condition of the entire artifact.

Examination of the textile object

Given responsibility for a textile artifact, the conservator assesses its condition so that proper treatment and care will be pursued. The first assessment made is a visual appraisal. The conservator gains a sense of the textile by looking at it with a well-trained eye. Holes, tears, discoloration, and worn surfaces or edges may be apparent. Slight variation in color and appearance can be seen, although these may be hard to capture photographically and difficult to explain in words. Further examination by hand-held magnifier or stereomicroscope offers more information. Fraying or flattening of yarn surfaces can be seen as well as whether discoloration is a surface phenomenon or penetrates into the fabric.

Another assessment of the overall condition of a textile object that is made by some individuals is touch. By handling the material, the conservator learns something about the stiffness or flexibility of the textile. This tactile response, however, is representative of an array of possibilities of fiber and yarn structure and condition. It is difficult to capture in words the nuances of sensation that a conservator gathers upon touching a textile although some measures of fabric hand and flexibility are employed in the textile industry.

Microscopic study of fiber samples removed from the textile artifact yields detail concerning fiber identity and consequences of degradation; analytical methods applied to the fibers provide chemical and physical micro-structural data. As the observer focuses more closely and the size of the area observed becomes smaller, some sense of the artifact as a whole can be lost. Information is gained from close scrutiny but translating that information to the entire object requires assumptions to be made. When fiber samples are removed they may represent the worst condition present in the textile, having been taken from an area where wear or a hole or fraying is apparent, or they may represent the best condition present in the textile, having been removed from within a seam or some other protected area. With a textile that contains regions that differ in condition, it may be difficult to accurately represent the overall object without taking samples from each area of apparent difference. This approach may be undesirable however, if the sampling causes too much damage to the appearance of the artifact. It is important, therefore, to have a good concept of the artifact's overall appearance and to precisely identify the location of fiber samples removed from the textile.

While the fiber sample may represent only a portion of the entire artifact's condition, the in-depth examination of single fibers has the advantage of incurring little overall damage to the textile. The information gleaned from the small samples must be translated to the whole artifact, but the chemical and physical structural data derived from analysis of a few fabrics can indicate the types of degradation the entire textile has undergone. These data aid the conservator in determining the appropriate treatment.

Mechanisms of fiber and polymer degradation

Many texts review the modes of polymer degradation and their consequences (e.g. Feller 1994; Grassie and Scott 1988; Hawkins 1972; Mills and White 1994; Tímár-Balázsy 1998) and there is a vast amount of literature on the degradation of particular fibers and polymers. Degradation is sometimes distinguished as chemical or mechanical whereas in others degradation is classified according to the causative agent, whether oxygen, water, electromagnetic radiation, heat, or mechanical stress. Degradation reactions are complex, and the presence of small amounts of impurities can affect the pattern of degradation considerably.

The mechanisms of polymer degradation have been defined for simple systems, such as polymers in solution or thin films, and some of the physical and chemical consequences of those types of degradation are known. The forces of degradation cause changes in the fiber at the submicroscopic level, with alteration in molecular structure, molecular weight, crystallinity, and orientation in the polymer molecules. Main chain bonds may be broken producing free radicals; chain scission and cross-linking may occur. The particular degradation mechanisms incurred by fibers are determined by their chemistry, whether cellulose or protein, polyester or polyamide, etc. The consequences of degradation are also influenced by the packing and order of the polymer molecules, the arrangement of groups of those molecules within the fiber, and the distinctive features of the fiber morphology.

Degradation causes microstructural changes in the fiber. Early in the course of deterioration, the changes may be imperceptible. After some period of time, these structural changes become visible by microscope and by eye. The forces of degradation alter the physical properties of the material, including strength, elasticity, elongation, flexibility, and color. Degradation processes can progress equally throughout the fiber, or they may proceed in localized areas of particular weakness. The degrading force may penetrate the surface of the fiber, proceeding inward, thus consequences may be isolated on fiber surfaces at an early stage of the degradation.

For example, the mechanism of oxidation is a well understood free radical reaction. Initiated by absorption of thermal or photochemical energy, presence of even a small number of carbonyl groups in a polymer is sufficient for a reaction to start. The result is formation of radicals that can then initiate other reactions, i.e. the mechanism is autocatalytic. The initiation, propagation, chain branching, and termination reactions typical of oxidation are well known. The reaction of alkyl radicals with oxygen occurs readily, but degradation is limited by accessibility of the oxygen to the fiber and its rate of permeation into the fiber. When permeation of reactant into the polymer is limited, deterioration becomes diffusion controlled (Hawkins 1972, 9-10). Oxidation reactions can be exacerbated by presence of chromophores or impurities that can absorb photochemical energy, then pass this energy to other molecules in the system. Soils and enzymes from microorganisms make the textile more sensitive to photochemical degradation (Tímár-Balázsy and Eastop 1998, 18-19). Metal oxides and other salts can also promote oxidation through formation of an intermediate oxygen radical ion with the metal ion, which then yields new free radicals able to continue the degradation. Oxidative degradation results in decrease in degree of polymerization; visible consequences include change in color, and decrease in strength.

Photochemical degradation can proceed with or without oxygen. It is initiated by absorption of light or electromagnetic radiation, and results in decreased molecular weight. Visible consequences include decreased tensile strength and elongation. In the absence of oxygen, cross-linking reactions are favored, yielding a material with decreased chemical reactivity and decreased solubility. In the presence of oxygen, photochemical pathways favor chain scission reactions, resulting in increased chemical reactivity and increased solubility. Alterations in solubility and reactivity are important property changes for a conservator to know as treatment plans are made.

Thermal exposure results in depolymerization, or “chain unzipping” of some polymers, while in others side group reactions occur that result in either scission or cyclization involving adjacent repeat units. In some polymers, double bonds are formed that destabilize the next repeat unit so the reaction proceeds along the chain, forming conjugated polyenes. This contributes to the discoloration seen in aged polymers. Byproducts of the degradation reactions can catalyze further degradation reactions, a common feature of cellulose degradation. Chain scission or cross-linking reactions have consequent effects on fiber structure and behavior. For example, degradation of the noncrystalline areas of fibers is related to stress cracking.

Once a polymer is degraded in some way, it is more susceptible to further degradation. Bresee (1986) notes that as the degraded fiber becomes more chemically diverse, it can absorb a broader range of wavelengths of photochemical energy and thus is more likely to deteriorate further. As crystallinity of the fiber decreases, it becomes more susceptible to chemical attack. Thus the conservator is constantly fighting against the ever-increasing and destructive forces of nature.

Methods of Analysis

Many approaches have been taken to determine the paths and consequences of fiber and polymer degradation. Optical microscopy is a long standing method of fiber study (Appleyard 1972; Heyn 1954; McCrone, McCrone and Delly 1997). Using different microscopic techniques in examining a single sample, mounting fibers in media with differing refractive indices, or observing reactivity of single fibers under the microscope as they are exposed to a reagent, can each provide complementary information useful in fiber identification and in characterization of the fiber's chemical and physical structure. New methods of atomic force microscopy and confocal microscopy may be useful in future research as these methods become more readily available. Scanning electron microscopy also provides a platform for multiple types of examination; x-ray microanalysis systems linked to these microscopes provide for elemental analyses. Some additional methods employed in the study of degraded fibers include infrared, Raman, and ultraviolet-visible spectroscopy, x-ray diffraction, thermal analytical methods, and chromatography. Not only do these provide chemical structural information, aspects of physical structure such as indications of relative amounts of crystallinity may be derived from them as well.

These analyses are important since "the micro as well as macro appearance of naturally and artificially-degraded textiles, especially burial-degraded finds, often is a misleading indicator of true state of preservation" (Peacock 1992, 39). As new methods of analysis such as nuclear magnetic resonance and mass spectrometry become adapted to the study of modern textile fibers, the methods will be applicable to the study of historic and archaeological fibers as well.

Research in Fiber Degradation

Two general approaches are taken in the study of fibers and the elucidation of patterns by which they degrade. In the first, fibers or polymers are artificially aged in controlled experiments in which the set of conditions affecting the fiber are known and the degradation consequences related to a specific mode of degradation are isolated. These experiments assume that accelerated ageing is comparable to long-term slow ageing in mechanism and in consequence.

In the second type of study, fibers obtained from historic or archaeological textiles are examined. These studies provide examples of the appearance and chemical structure of naturally degraded fibers. A problem with this approach is that only in a few cases do we know the entire history of the material, so in most cases we don't know the exact modes of degradation that the material has incurred. The degradation incurred is likely to have been complex and not caused by a single force as in the controlled experiments, although in some cases a particular force of degradation may have predominated.

Controlled Degradation Studies of Fibers

Table I summarizes a selection of the studies conducted in the degradation of fibers under controlled conditions. By isolating degrading forces, the particular consequences on fiber chemistry and physical structure for a particular degrading force can be determined. In some cases, but not in all, literature reports include the consequent changes in fiber physical properties. For example, Cardamone (1989) monitored thermal ageing of cellulose by Fourier transform infrared spectroscopy (FTIR), observing the development of carboxylate bands concomitant with increase in friability and brittleness of the fabric. Although she comments on the property changes, she does not indicate the method used for assessment of these properties. In another study, thermal ageing of linen fabric resulted in darkening of the fabric, reduced tensile strength, and reduced abrasion resistance (Needles and Nowak 1989). The microscopic appearance of the fibers change as "long and deep periodic cracks" parallel to the fiber axis are formed (Needles and Nowak 1989, 165). The aged material also displayed limited dyeability but because wide angle x-ray scattering showed that it was less crystalline than the untreated material, the limited dyeability was attributed to cross-linking in amorphous regions. Simulating a case of more extreme thermal degradation, Thompson and Jakes (2002) and Srinivasan and Jakes (1997b) charred materials in a muffle furnace with and without oxygen to simulate the consequences of cremation practices by prehistoric native Americans. The fibers maintained some semblance of their original morphology as well as evidence of the original fiber chemistry.

Some studies have focused on mechanical degradation in particular (Hearle et al. 1989; Zeronian 1986; Bresee and Goodyear 1986). Specific types of mechanical degradation of cotton, wool, nylon, polyester, acrylic, as well as of high performance materials are reported. The fracture tips of the degraded fibers give evidence to the mode of degradation incurred (Table II) although they are influenced by the morphology and chemistry of the fiber as well. Thus, for example, degraded flax may display a spiraling fibrillar tensile fracture. Flax is composed of cellulose polymers aligned into microfibrils that then combine to form fibrils. These fibrils spiral around the central fiber axis, accumulating in tree-like layers. Degradation of the fiber entails splitting of the fibrils as intercellular associations are disrupted. Thus the breakage tip observed is partially determined by the structure of the fiber itself, and not to its chemistry alone. Wool also displays differences in breakage tips as well, due to differing reactivity of the ortho and para cortical cells and of the cuticular cells. While many publications are concerned with the degradation that occurs within the active phase of a textile's life, some controlled degradation experiments that focus on the effects of the burial context have been conducted as well. Peacock (1996a) examined both the effects of soil burial and waterlogging on cotton, wool, and flax noting changes in microscopic appearance and yellowing or darkening of the materials. Needles and coworkers (1986; Needles and Ragazzi 1987) examined the staining of wool and cotton fabrics exposed to soil burial. Jakes and others (Chen, Jakes, Foreman 1998; Jakes and Howard 1986a, 1986b) experimentally mineralized fibers.

Table I. Controlled Degradation Experiments and Their Consequences

Fiber type	Author	Causative agent	Physical consequences	Microscopic consequences	Chemical/physical micro structural consequences
Cellulosics	Montegut,Indictor, Koestler	Fungal	Reduced strength, staining		Complex enzymatic attack, hydrolyze cellulose
Cotton	**Needles & Regazzi**	**Soil burial**	**Lighter, more orange coloration**		
Cotton	Cardamone; Cardamone, Keister, Osareh	Thermal	Brittle friable material		Carboxylate bands increase (FTIR)
Flax	**Needles & Nowak**	**Thermal**	**Darker color, reduced strength and abrasion resistance, less dyeable**	**Cracks parallel to fiber axis**	**Reduced crystallinity, more crosslinked**
Silk	Needles, Cassman & Collins	Light exposure	Breaking strength, elongation to break decreased.		
Silk	**Needles, Cassman & Collins**	**Soil burial**	**Breaking strength reduced, increased elongation to break**		
Silk	Becker & Tuross	UV, visible radiation	Solubility changes, yellowing	"Fusing" in appearance at cross-over points	Amino acid compositional changes, solubility changes apparent prior to any visibly detectable change.
Wool	**Peacock**	**Soil burial and prolonged soaking**	**Yellowed**	**Longitudinal splitting and extensive fibrillation, scales intact**	
Cotton	Peacock	Soil burial and prolonged soaking	Darkened	Longitudinal splitting and cracking, loosening of fibrillar bundles and chunks of fiber split away	
Flax	**Peacock**	**Soil burial and prolonged soaking**		**Fibers shrank, forming concertina-like structure**	
Wool, cotton, flax, silk	Hearle, et al	Controlled tensile, torsion, other fractures.		Specific breakage tips observed for specific types of mechanical wear.	
Wool	**Needles, Cassman & Collins; Needles & Regazzi**	**Soil burial**	**Unmordanted: darkened, yellowed. Reduced breaking strength except in alizarin dyed wool.**		**Mordant ions readily exchange with soil elements.**
Wool	Zimmerman & Hocker	Fracture, after artificial sunlight degradation		Split fracture tips ("cut"fracture tips in undegraded wool)	Temperature and RH influence ultimate strength
Flax	**Searle**	**Artificially tendered**		**Applying pressure to swollen and tendered fiber results in fracturing into block-like segments**	
Flax	H. Chen & Jakes	Hydrolytic, mineralization		Fibers encrusted with mineral oxidation products	
Indian hemp	**Srinivasan & Jakes**	**Thermal**	**Charred**	**Fibers shrunk, but maintain some structure**	**Chemical composition is not completely carbonized, IR reflects chemistry of fiber, of dye**
Alpaca hair	Curl & Jakes	Thermal	Yellowing	Little obvious microscopic change	

Table 2. Fiber fracture modes and consequent fracture tips (from Hearle et al. 1989)

Mode of fracture	Fracture tip
Tensile	Brittle
	Ductile
	Variant, light degraded nylon
	High speed
	Axial splits
	Granular
	Independent fibrillar
	Collapsed
	Stake and socket
Fatigue	Tensile
	Flex kinkband
	Flex split
	Biaxial rotation, bend and twist
	Surface wear
	Peeling and splitting (many forms)
	Rounding
Other forms	Transverse pressure
	Mangled
	Localized
	Sharp cut
	Melted
	Natural fiber ends, such as tip of cellulose fiber cell

Table I reviews only a small portion of the literature on degradation of fibrous materials, yet from those summarized it can be seen that the studies each have taken different approaches and collected different types of data. Compilation of the results into a meaningful whole would require some translation into a suitable format for ease of comparison. The linkages between the particular degrading forces imparted on the textile or fiber and the consequences visible in microscopic examination are not always included, and the descriptions of degradation features vary, yet these degradation studies provide valuable information on the chemical and physical response of particular fibers to particular forces. If these features could be included as components of the fiber database, its usefulness would be expanded beyond a comparative tool to one that could provide new understanding of the consequences of degradation.

Examination of Naturally Degraded Fibers

The controlled experiments provide information concerning chemical and physical consequences of specific types of degradation. If the accelerated methods employed are representative of longer term slower ageing, then perhaps it is possible to examine a naturally aged material, observe its chemical and physical structures, relate these to the consequences of accelerated ageing and infer the modes of degradation the naturally aged material has undergone. Over the lifetime of a material, multiple types of degradation occur and the overlapping consequences of these may make the resultant material difficult to "read."

In some sense, all fibers are degraded fibers in the same way that all cars are used cars. From their inception to their final disposal, fibers are affected by the conditions to which they are exposed. While the impact of one event might be small, the

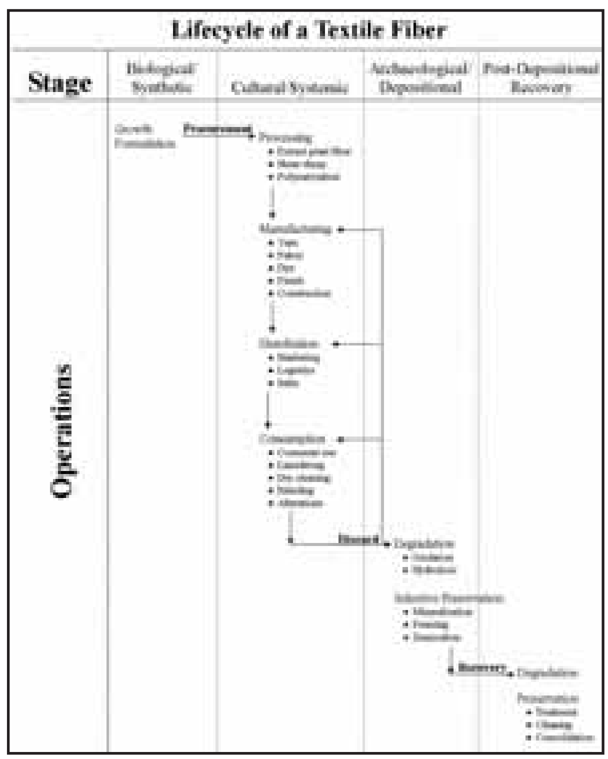

Figure 1. Lifecycle of a Textile Fiber

effects of these forces accumulate (Sibley and Jakes 1986; Ericksen, Jakes, Wimberley 2000). Figure 1 displays a map of the progress of a fiber through its lifecycle. The terms “systemic context” and “archaeological context” are adapted from Schiffer’s (1995) definitions of the stages of life of an object within a cultural system. “Systemic context” labels the condition of an element which is participating in a behavioral system. “Archaeological context” describes materials which have passed through a cultural system, and which are now the “objects of investigation of archaeologists” (Schiffer 1995, 26). The model of the lifecycle of the textile fiber includes additional stages and expands consideration of the life of the fiber from “cradle-to-grave.” These include the Biologic or Synthetic context, and the Post-depositional context.

Corollary to the examination of fibers exposed to controlled conditions of degradation, examining naturally degraded materials provides a wealth of evidence for the consequences of complex degradation patterns incurred through the lifecycle. While all of the contributing factors that caused the observed changes may not be known, some of conditions that caused the degradation might be discernable. Table III summarizes observations of a number of degraded fibers from different archaeological or long-term storage contexts. As with the controlled ageing experiments, the data obtained on the naturally aged materials are diverse. Where conclusions are made concerning the degradation modes incurred by the fibers under study, these determinations are noted in the table.

In the Biologic or Synthetic stage, natural fibers are grown, while man-made fibers are synthesized from a combination of chemicals. In growth or synthesis of the fiber, many factors can influence the final outcome. Temperature, sunlight, and water affect the cell formation in plants; diet affects fiber formation in animals; differing synthetic routes are followed to yield man-made fibers of differing molecular weight and purity. All of these components of manufacture or growth result in fibers with different structures and different performance abilities. Fibrous materials are procured and brought into the Systemic or Cultural context, wherein they are processed into yarn and fabric, then made into garments and other products. Mechanical forces are experienced by fibers as they are spun into yarn and woven or knitted into textiles. Finishing treatments that alter fabric performance also affect the fiber. For example, treatment with durable press resins may weaken fibers or reduce their moisture absorbance even as their wrinkle resistance is improved. Or, as linen fabric is beetled to create a fuller appearance to the fabric, fibers are flattened. The evidence of these treatments may persist throughout the lifetime of the fiber. For example, Hearle et al. (1986) describe an Egyptian shroud that shows evidence of a preparatory finish. Yarn crowns are flattened, and fibers display transverse cracks. Fibers in crowns of the yarns fibrillate and are smeared, typical of changes that occur with considerable mechanical rubbing and wet treatment. The textile was treated by some sort of wet finish and smoothed to impart softness prior to use.

Table 3. Examination of Naturally Degraded Fibers

Fiber type	Author	Environment of long term storage	Physical, visible consequences	Microscopic consequences	Chemical/physical structural consequences
Hair (human)	**Lubec, et al**	**Dry (8-10th century Coptic)**	**Few**		**No differences evident in XRD, no change in conformational hydrogen bonding. Evidence for dehydration is loss of certain IR absorption bands**
Wool	Appleyard	Manufacture and wear		Bent, twisted fiber.Cuticle worn, cortex splits longitudinally	
Wool	**Appleyard**	**Acid**		**Spiral structure broken, fibers break into segments**	
Wool	Appleyard	Heat		Spiral structure not affected at low heats or shorter times, but transverse lines seen. Higher heats and lengths of time, segments	
Wool	**Appleyard**	**Bacterial**		**Localized degradation, but no segmentation as with other chemical treatments**	
Wool	Schweger & Kerr	Frozen		Some without scales: "weathering." Longitudinal cracking, fibrillation. Some with fungal mycelia and spores.	Ca, Al, Si, Mg debris
Wool	**Ryder & Gabra-Sanders**	**Waterlogged**		**Dirt obscured scales**	
Cotton	Schweger & Kerr	Frozen		"Weathering," some with mechanical wear evident	Fe, S, Mg, Al, Si, Ca deposits
Cotton	**R. Chen & Jakes**	**Deep ocean, cold, limited oxygen**	**Black staining, some areas visibly damaged**	**Localized biodegradation, fissures on fiber surfaces of the size of the bacteria**	**Effects in IR, increased crystallinity**
Plant fiber	H. Chen & Jakes	Burial, with copper, water,	Green colored, mineralized appearance	Form of fiber maintained, though encrusted	Increased crystallite size, some organic chemistry remains, impregnation with malachite, others
Silk	**Srinivasan & Jakes**	**Deep ocean, cold, limited oxygen**	**Black staining**	**Deep cracks associated with twisting, surface peeling,**	**Crystallinity ratios smaller than modern silk, but IR not significantly different**
Silk	Goodway	History not defined, weighted, 19th century	Brittle fabric	Splitting, cracks at cross-over indentations	
Flax	**Kleinert**	**Hot, dry**	**Brittle fabric, weak**	**Unaligned crystallites**	**Low DP, overall high crystallinity, but crystallites small**
Flax	Schweger & Kerr	Frozen		Calcite deposits, some unknown paste- like surface	
Flax	**Hackney & Hedley**	**Museum storage**	**Discoloration, strength loss**		**Sulfur dioxide involvement**

Once the material is manufactured, conditions of use and care can also cause considerable alteration of fabrics and fibers. Evidence for mechanical wear in fabrics can be observed in holes, tears, and pills as well as color loss. Well-worn items show patterns of wear. A sandal from the dry caves of Kentucky displayed wear that showed that it had been worn on the right foot (Gremillion, Jakes, Wimberley 2000). Evidence for extensive mechanical wear in archaeological textiles includes flattening of yarn crowns, fiber brush ends, surface peeling, and broken threads (Hearle et al. 1989, 411-412). A Coptic child's garment displays evidence of extensive use, including bagging at the back of the dress due to stresses of sitting.

Multiple forms of chemical degradation also occur in a textile's lifetime. Exposure to sunlight initiates degradation that can continue even in the dark. Laundering, particularly with chlorine bleach or other strong chemical stain removal agents, causes chemical change that accumulates with each washing. Some fibers are sensitive to environmental pollutants. During its lifetime, as a textile is used, it becomes changed by the patterns of that use; subtle marks of the use patterns remain within the fabric, these traces can be detected by instrumental methods of analysis.

At some point in its lifetime, the textile is no longer used, but is discarded. This phase is titled Archaeological/ Depositional to include the possibility of long-term storage in addition to deposit in soil or some other manner that is of "interest to archaeologists" (Schiffer 1995). If the useful wear life of a textile is considered by the owner to be finished, discard may also mean disposal of the textile to a recycler. This textile may be garneted to return it to fiber and then made into another textile product, or reused in part as rags or in its entirety, as with vintage garments. This discard may be intentional but consideration is given in the Archaeological/Depositional stage of unintentional deposition of textiles into environments that later became long-term discard sites. While present-day textiles may end up in a landfill, textiles of the past may have been included in a burial as tribute to the deceased. More recently, materials may have been stored for long periods without use, kept in a basement or attic, with later recognition of their value by a museum. The long-term burial context of ancient Egyptian linen fabrics resulted in a low degree of polymerization, high overall crystallinity, with short crystallites that are disordered along the fiber axis (Kleinert 1972). Using polarized light, the effects of disrupted crystallinity can be seen under the microscope. The fibers are oxidized, and the amorphous components of the cellulose, being more readily accessible, were destroyed first. In contrast, Lubec et al. (1987) found that hair samples from the hot, dry climate of Egypt retained their original appearance.

Interaction with the long-term storage context influences the fabric in many ways. If buried, the surrounding soil and moisture can provide ideal conditions for microorganisms to grow, or for fibers to become filled with water and soil elements. Fabrics in the archaeological context can be waterlogged or frozen or desiccated. Each environment affects the fiber, slowly causing alteration of chemical and physical structure. While initially some degradation might occur in the Archaeological/Depositional context, after a period of time, an equilibrium must be established that supports the preservation of the fiber or some facets of its chemical and physical structure, i.e., selective preservation occurs. Even as materials are degraded, a certain preexisting state of the fabric or a particular condition of the long-term storage context may protect fibers in such a way that some aspects of their chemistry or structure are retained. Without these mechanisms of alteration or preservation, textiles would be completely decomposed or degraded. In environments in which materials are frozen or desiccated, for example, degradation may be slowed enough to allow the textile to persist. Schweger and Kerr (1987) report that textiles from a site in the Arctic display longitudinal cracks, eroded surfaces, and soiling, but that the colors are preserved. Despite these fiber changes the authors suggest that the original structure of the fabrics changed very little. Nineteenth-century textiles from a deep ocean site were well preserved due to the extreme cold and dark conditions. (Jakes and Mitchell 1992; Jakes and Wang 1993; Wang and Jakes 1994; Srinivasan and Jakes 2002). Although some microbial damage was observed in cotton and flax fibers, it was limited in textiles that were dyed and mordanted (R. Chen and Jakes 2001a). Undyed cottons displayed a larger crystallinity index than dyed cotton fibers, indicating that the amorphous areas of the undyed cotton had been degraded (Chen and Jakes 2001b). Silk and wool morphology was preserved (Jakes and Wang 1993; Wang and Jakes 1994; Srinivasan and Jakes 2002) although black staining of sulfides was apparent throughout all of the textiles from the two trunks studied.

In an environment of the appropriate moisture, oxidation potential, and pH, (Chen, Jakes, Foreman 1998, 1996; Chen, Foreman, Jakes 1996; Sibley and Jakes 1986) fibers in the vicinity of corroding copper or iron may become "mineralized," i.e., at least partially infilled with corrosion products of the adjacent or nearby metal. The physical shape is preserved as well as some aspects of the original chemistry. Charred or mineralized textiles are not exactly like their precursors in structure or chemistry, but some components of structure or chemistry are maintained in the altered material (Srinivasan and Jakes 1997). By understanding the mechanism of this selective preservation some inferences can be made concerning fibers used prehistorically. Whether frozen, desiccated, waterlogged, mineralized, or charred, these materials may not be the same as new ones, but with understanding of the mechanisms of alteration, they can provide considerable information on their original composition.

Upon recovery of a textile from an archaeological or depositional context, it is brought back into active life. In effect, the recovery of a textile from an archaeological site, its conservation, and its curation at a museum places the textile in a new phase of life, that of a valued textile remnant of the past. Upon recovery and removal to a location for examination, alterations of chemical and physical structure are initiated. Whether removed from the soil, or from storage, the new environment experienced by the fiber may initiate new forms of degradation. Because the equilibrium that had been established in the long-term storage context is disturbed, the fiber may now incur significant change. A fabric that is fragile or one that is dyed with a sensitive colorant, may be well preserved in a particular set of conditions, but upon exposure to light and oxygen it may change dramatically. The archaeologists who discovered colored textiles at Seip Mound, Ohio (AD 900), comment on the yellow, red, black designs observed, but these colors quickly changed to black after excavation (Shetrone and Greenman 1931, 451-454).

Post-depositional change is also initiated by the conservator in undertaking artifact treatment. Fabrics that are waterlogged may not dry without visible change (Pearson 1987). Experiments in drying waterlogged materials showed that drying methods themselves have some influence on the outcome (Jakes and Mitchell 1992). Wentz (1986) reports that aqueous treatment affects the crystallinity of cotton and alpaca fibers, but nonaqueous cleaning shows little effect. Fiber cleavage was more noticeable in the cotton fibers treated with water compared to those that were dry cleaned.

The Fiber Database

By visual and tactile assessment, the experienced conservator gains knowledge about textile objects. Informed by macroscopic and microscopic study of samples, the conservator makes treatment decisions. Informed in addition by access to a database of examples of degraded fibers, description of their features, and the causes of those features, would enhance the conservator's ability to understand the condition of the textile artifact and to make better treatment decisions built on a body of knowledge and experience incorporated into a supportive reference tool.

The fiber database is an ambitious project. While first conceived of as an accumulation of microscopic images of fibers and text describing the condition of the object from which the fibers were taken, the database could be enhanced by the inclusion of more layers of analytical data, as well as reference to past research in controlled degradation and in examination of naturally aged fibers. While incorporation of past research would be hindered by the lack of consistency in research design and types of data derived, accumulation of the varied results into a single place would bring new opportunities for comparison and synthesis. As new contributions are made to the database, the preparation and mounting of fibers can be well defined and the criteria for images prescribed in order to provide for future ease of comparison but it would be proactive to include space for additional types of analytical data such as infrared spectra or performance properties. Inclusion of past research elucidating the consequences of controlled degradation or the characteristics of naturally aged materials can provide guidelines for future inferences to be made in examination of degraded fibers.

Fields in the database must be given to include as much information as possible about details of controlled ageing studies, or of the known history of naturally aged materials. Given some information about the fiber's lifetime could allow for other inferences about other details to be made. Some translation of past research findings may be necessary. A glossary of terms such as "cracks," "crevices," and "fissures" will create a consistent template of terminology for the features observed in microscopic examination. The features observed in past research of degraded fibers will then need to be converted to the standard terminology.

The database should include the following information:

1. Fiber data contributed to the database
a. Details of the history of the textile object, including whatever is known about provenence

2. Textile artifact's appearance and precise identification of location of fiber samples removed. This should include comments on whether the samples taken are considered rep resentative of the "best" or "worst" condition of the entire object or whether they were taken from areas of particular discoloration.
a. Details about sample preparation
b. Details about means of examination
c. Include fields for additional analytical results

3. Results translated from controlled degradation experiments.
a. Details about ageing procedure to explain isolated degradation mode of interest
b. Microscopic data derived from the examination of the degraded fibers
c. Additional analytical data derived from the examination of the degraded fibers

4. Results from past observations of naturally aged fibers.
a. Details of history, provenience as available
b. Types of examination
c. Inferences about major sources of degradation and their consequence

With multiple methods of information incorporated into a single source, the database could prove to be a new tool for understanding fiber degradation, for learning the best ways to understand a materials' history, or for determination of the best ways to treat the textile to preserve it. Through accumulation of past research results with new entries into the database that are well documented, new understanding of the linkages between the condition of an artifact and the features apparent in the fibers will be possible.

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A Condition Assesment Rating System for Textiles

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One of the most important factors in treatment, storage, and exhibition decisions for a textile conservator is the condition of the object. In an effort to reduce some of the inherent subjectivity in condition assessment terminology, the author describes a five-level macroscopic condition assessment guide that corresponds to a parallel series of storage and exhibition treatment options. In large part, macroscopic indications of deterioration are reflections of damage within the fibers themselves. The macroscopic condition assessment rating system presented here may serve as a model for a similar approach to developing a standard vocabulary for the description of microscopic fiber deterioration.

One of the most important factors in artifact care decision-making for a textile conservator is the condition of the object. This is usually established through visual examination and further examination under low (up to 70X) magnification. In large part, microscopic indications of deterioration are reflections of damage within the fibers themselves.

Condition descriptions are by their very nature extremely subjective. For example, a colleague who regularly works with highly deteriorated archaeological material might assess a 12th-century textile that I consider to be in fair-to-poor condition as being in very good condition. Our frames of references are based on our own experience and may be very different. This rating system was developed in order to try to standardize the assessment of the macroscopic condition of textiles and to remove some level of the subjectivity.

The condition assessment rating system is divided into five different levels: Good, Good-Fair, Fair, Fair-Poor, and Poor with 10 assessment factors (figure 1, see next page). Good condition is defined by an absence of all of the assessment conditions (no loss of flexibility, no areas of loss or fraying, no dimensional distortions, no surface dirt or stains, no discoloration, no fading, no color bleeding, no mildew, no previous repairs, and no insect infestation). Any change from this "perfect" condition moves the assessment into another level. An additional way of understanding the condition assessment is graphically, where the progressive darkening on the chart translates into worsening conditions (figure 2). This type of condition assessment guides and corresponds to a parallel series of storage and exhibition treatment options that have been developed over the years at the Cooper-Hewitt Museum in response to this institution's collections, resources, and needs.

Figure 2. Graphic representation of Condition Assessment Rating System for Textiles

#1 GOOD CONDITION	#2 GOOD-FAIR CONDITION	#3 FAIR CONDITION
NO LOSS OF FLEXIBILITY	NO LOSS OF FLEXIBILITY	NO LOSS OF FLEXIBILITY
NO AREAS OF LOSS/ FRAYING	SMALL AREAS OF LOSS/ FRAYING	MODERATE AREAS OF LOSS/ FRAYING
NO DIMENSIONAL DISTORTIONS	NO DIMENSIONAL DISTORTIONS	NO MAJOR DIMENSIONAL DISTORTIONS
NO SURFACE DIRT/ STAINS	SLIGHT SURFACE DIRT/ STAINS	MODERATE SURFACE STAINING /DIRT
NO DISCOLORATION (YELLOWING/ BROWNING)	SLIGHT YELLOWING	MODERATE YELLOWING/ BROWNING
NO FADING	SLIGHT FADING	MODERATE FADING
NO COLOR BLEEDING	NO COLOR BLEEDING	NO COLOR BLEEDING
NO MILDEW	NO MILDEW	NO MILDEW
NO PREVIOUS REPAIRS	NO PREVIOUS REPAIRS	WELL-EXECUTED PRECIOUS REPAIRS
NO INSECT INFESTATION	NO INSECT INFESTATION	NO INSECT INFESTATION

Figure 1. Condition Assessment Rating System for Textiles

Level 1, Good Condition:

Storage: Most textiles in good condition can be rolled for storage on archival tubes with a protective over-wrapping (Mylar) and stored in single layers in two stacking trays within an archival box (figure. 3).

Figure 3. A tray of rolled textiles being removed from an archival storage box.

Exhibition: A textile in good condition is usually stable enough to be free hung. In an exhibition of contemporary textiles at the Cooper-Hewitt, physical barriers to the public were the only real protection that was required (figure 4). The pieces are strong enough to bear their own hanging weight. They can be safely manipulated and vacuumed after the exhibition.

Figure 4. *Color, Surface, Light*, installation of contemporary textiles at the Cooper-Hewitt in 1990.

Level 2, Good-Fair Condition:

Storage: Textiles in this category are in good-fair condition, where there maybe some fraying, minor holes or slight staining, but they are still flexible can be interleaved between tissue in an archival box for storage (figure 5). These textiles can be handled on the tissue support without physically touching the piece, which is a significant change from the physical manipulation necessitated during rolling a textile in Level 1 storage.

Figure 5. Embroidered textile samples interleaved between neutral pH tissue in an archival storage box.

#4 FAIR-POOR CONDITION	#5 POOR CONDITION
MODERATE STIFFENING OR INFLEXIBILITY	VERY FRAGILE
AREAS OF LOSS/ FRAYING/ ABRASION	FIBER LOSS WITH ANY MOVEMENT TO TEXTILE
OBVIOUS DISTORTIONS	MAJOR DISTORTIONS
OBVIOUS MARRING STAIN/ DIRT	VERY DIRTY / STAINED
MARRING YELLOWING/ BROWNING	VERY YELLOWED/ BROWNED
LARGE AREAS OF FADING	VERY FADED
COLOR BLEEDING	MAJOR AREAS OF COLOR BLEEDING
PRESENCE OF ACTIVE MILDEW/ MUSTY ODOR	PRESENCE OF ACTIVE MILDEW/ MUSTY ODOR
LARGE NUMBER OF PREVIOUS REPAIRS	LARGE AREAS OF POORLY-EXECUTED PREVIOUS REPAIRS
SIGNS OF INSECT INFESTATION	ACTIVE INSECT INFESTATION

Exhibition: A temporary pressure mount provides physical support for what would otherwise be the vertical hanging weight of the textile and a physical barrier to handling and the exterior environment (figure 6). In a temporary pressure mount the pressure is provided by a sheet of acrylic plastic that is secured directly over the textile. The temporary pressure mounts are removed after the exhibition and the textiles are returned to storage.

For pieces that cannot safely be mounted in a temporary pressure mount another exhibition option for Level 2 condition is on a fabric-covered support board in a vitrine. For example, due to their surface relief, embroidered samplers are not appropriate for pressure mounting, but can be shown on flat or slightly angled support boards within vitrines (figure 7). Exhibited in this way, the textiles do not have to support their vertical weight and are protected from the external environment. After exhibition, the textiles are removed from their press mounts or support boards and returned to storage. Level 2 textiles need to be strong enough for this amount of physical handling.

Figure 6. An exhibition of 18th century damask napkins in temporary press mounts at the Cooper-Hewitt in 1984.

Figure 7. An exhibition of samples in exhibition vitrines at the Cooper-Hewitt in 1985.

Level 3, Fair Condition:

Storage: For textiles in fair condition, the storage mat functions as the exhibition mount. This eliminates the physical stress of moving the textile from storage to exhibition and back again. For example, these 6th-century Coptic fragments are stored in an exhibition/storage mat with a protective layer of translucent tissue over the pieces (figure 8). The mat is stored in a Mylar/Reemay sleeve and stacked in an archival box with other similar pieces.

Figure 8. Two 6th century Coptic fragments in storage/exhibition mats with a protective layer of translucent tissue covering the pieces.

Exhibition: The translucent tissue is removed and the mat can be placed flat in an exhibition vitrine (figure 9). In this type of storage/exhibition mat, the surface traction of the desized, unbleached muslin on which the pieces are resting keeps the textiles in place. There is no additional physical attachment or pressure on the piece.

Figure 9. The Coptic fragments with the translucent tissue removed in an exhibition-ready mount.

Level 4, Fair-Poor Condition:

Storage and exhibition: An example of a Level 4, fair-poor condition textile is a 14th-15th century Hispano-Moresque fragment that is too fragile to be handled from storage to exhibition. A Level 4 condition textile requires protection from physical contact and from air movement. One treatment approach is a Mylar-lined window in the mat (figure 10, note the glint of the Mylar in this photograph). A textile can be exhibited flat in this mat within a vitrine. Note that the accession number in lower right corner is in a removable sleeve for exhibition purposes.

Figure 10. A 14th-15th century Hispano-Moresque fragment in an encapsulated Mylar storage/exhibition mount

Deconstruction of the mat: When the hinged window mat with Mylar is opened, the encapsulated inner structure of the mount is visible and the stitching that holds together the Mylar encapsulation and the inner mat (figure 11). Because this textile is encapsulated, fiber identification must be accomplished and samples should be taken before mounting. The reverse is accessible by flipping over the mat where a Mylar window has been created in the mounting fabric (figure 12). This mount allows the storage, study, and exhibition of textiles in fair-poor condition with full support and protection from any physical handling.

Figure 11. The Hispano-Moresque fragment mount opened to reveal the inner encapsulation held in place with stitching outside the edges of the piece.

Figure 12. The reverse of the encasulated Hispano-Moresque fragment mount showing a viewing window protected with a layer of Mylar.

Level 5, Poor Condition:

Storage and exhibition: For textiles in poor condition, an even more rigid and protective exhibition/storage mount is required due to the extremely fragile condition of the piece.

An example is a 12th-century Hispano-Moresque fragment mounted in a permanent pressure mount framed within a acrylic box and with a thick, rigid support on the back (figure 13). For such a permanently "encased" piece, it is critical to maintain access to the back of the piece and to complete fiber identification and sampling before mounting. This mount was developed with Denyse Montegut during her internship at the Cooper-Hewitt. A series of doors have been cut through the laminated support board, padding, and exhibition fabric to reveal the back of the textile through a protective layer of Mylar (figure 14).

Figure 13. A 12th-century Hispano-Moresque fragment mounted in a permanent presure mount that has been framed in an acrylic box frame.

Conclusion

There is a close connection between the condition of a textile and critical treatment decisions for both storage and exhibition. The use of a standardized assessment system for the macroscopic condition of textiles may be relevant to the development of a similar standardized system and terminology for the assessment of fibers under the microscope. The assessment of microscopic fiber condition may be an additional analytical tool that can inform treatment decisions.

Acknowledgments

The author would like to acknowledge the assistance of Sandra Sardjono, Assistant Textile Conservator at the Cooper-Hewitt, in putting together this paper.

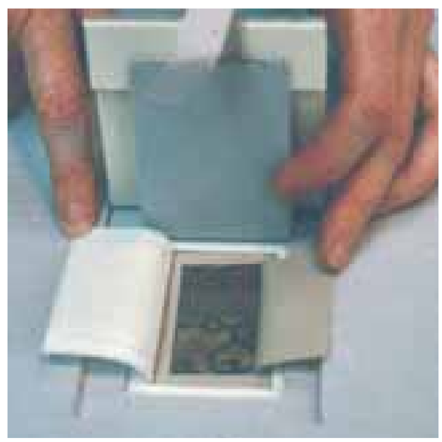

Figure 14. Viewing window on the reverse of the framed permanent pressure mount.

Textile Database Systems Integration

Michael B. Toth
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Any digital library will only be an effective tool as part of a larger information technology system, which will require planning in several steps. First the work processes and textile professional's needs for data and information must be identified. Once these user needs are defined for a fiber database, the appropriate technology can be proposed to address these needs as part of a full system capability. To fully integrate this capability into current and future work processes, as well as other technologies and uses, the key system design factors are then identified. These include the various system inputs, outputs, and controls on the system, as well as the resources available for implementation. The system users must define these important system definition tasks based on their needs. The establishment of virtual or real teams of users to define their business needs, under the leadership of a multi-discipline project management team, will help the clear definition of the various work processes, system capabilities, and technological needs. With collaborative input and leadership from the textile community, an imaging and information storage system will be defined to meet the user's needs, as opposed to having the system defined by the available technology.

Introduction

Technology is not the key factor in managing information and knowledge. Identification of the tasks and goals to which the assimilation of data will contribute is the linchpin of information system planning and development. As Bill Gates (1999) noted in discussing the management of information and knowledge: "Knowledge management doesn't even start with technology. It starts with business objectives and processes and a recognition of the need to share information." Increasingly complex programs for the study, preservation, and display of historic artifacts require the integration of ever growing amounts of data to provide information of value to various users. This is no less true for the large amounts of data available on textiles of all types—heritage or contemporary. The challenge of retrieving data and information about a textile, preserving the data for current use and future generations, and contributing to the creation of knowledge from the retrieved information and digital data requires effective teamwork. Members of the conservation, technical, and scientific disciplines need to define common goals for the collection and study of digital information on a range of textiles. As part of a multi-disciplined team, each of these disciplines offer important contributions which will ensure all appropriate data are available for further analysis and study, thereby increasing the body of knowledge about the textiles.

Textile Database Work Processes

Advances in imaging techniques developed for the study of earth and space provide significant capabilities that can be adapted for the study of historic and cultural treasures (Toth October 2000). The adoption of integrated program management techniques from industry for the development and implementation of a digital database on textile fibers offers the potential to integrate a system that can enhance the full range of skills and disciplines available in the conservation, scientific, and academic communities, as well as other communities in related fields. Conserving textiles with various techniques in a range of conditions, imaging fibers in appropriate spectral bands, storing the digital data and associated information about the data, processing the data to yield useful information, and making the information available for researchers, professionals, and the public requires the integration of diverse work processes and technical skills.

Following accepted program management techniques and tools, a key step in planning an integrated digital library is the definition of the work processes. Prior to developing and integrating the technologies associated with an accessible textile fiber imagery database, the key work processes and workflow required to successfully support the desired activities are defined by the end users. An exemplar list of candidate processes is depicted in figure 1. The current processes should be clearly defined and validated by textile specialists who play a role in these processes as part of their ongoing work. Ultimately these work processes will change with the development of new work processes to capitalize on new information and imagery technology, as well as access to increasing amounts of information.

Textile Database Candidate Work Process

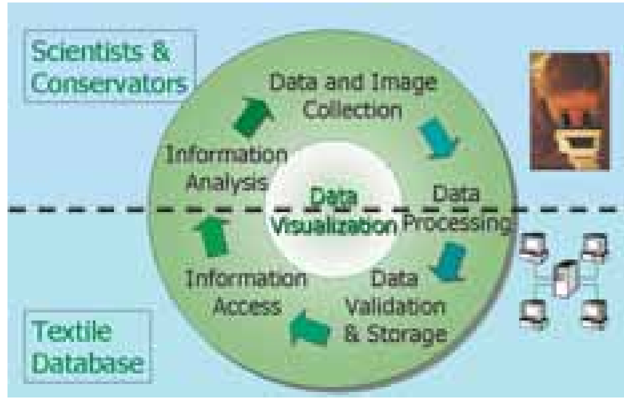

Figure 1. Example of candidate process

Candidate work processes for a textile image database could include the following activities to collect and fully exploit imagery of textile fibers:

- **Data and Image Collection:** Gathering various data elements for an object as digital images from various optical and electronic sources, as well as in textual and/or graphic form (i.e. notes and reports) from a range of non-imaging tests (e.g. chemical, tensile, spectral) and observations.
- **Data Processing:** Digitally manipulating, formatting, and linking additional information about the data to the initial data elements, according to agreed vocabulary, data, and content standards.
- **Data Validation and Storage:** Assessing the data elements and associated metadata to ensure they meet the system standards, and entering or linking the data into the appropriate database according to agreed digital storage and retrieval standards.
- **Information Access:** Retrieving data and information electronically by remote end users through a range of relational search and retrieval techniques by means of electronic public access, while maintaining the integrity of the data.
- **Information Analysis:** Linking data elements and establishing relationships between data elements by knowledgeable users to derive additional information and knowledge.

The integration of conservation and scientific techniques with advanced imaging and processing techniques will require effective systems and information management to ensure the large amounts of digital data can be readily collected, correlated, stored, and accessed. Key to this information management is the storage of associated digital information about each data element, which is referred to as "metadata" (Toth March 2000). A number of metadata standards is used in the museum community (Baca 1998) and earth imaging and geospatial information communities (FGDC 2002). Whatever standards are used for the textile database, they must reflect the needs of the textile user community, and include a process to ensure the standards remain current with the user's needs.

While government and industrial programs have integrated complex technical processes for decades, systems planning and technical integration in the museum and conservation environment requires the application of advanced techniques to a new and unique set of requirements (Toth October 2000). Once the user needs are clearly defined, integrated technical methodologies can be developed to collect all the required imagery, store the digital information, and display the available information for the end users. Ultimately a value chain can be established in which the various elements of the information process are linked together, with the value added through "knowledge acquisition" and "knowledge application" (Powell 2001). Defining the technology in terms of its contribution to the work processes and user needs helps the project management team focus on critical elements of the project so as to implement it efficiently, according to agreed goals and objectives, while mitigating risks. Over time, standardization of work processes, technology, and terminology will provide benefits in terms of improved system efficiency, conservation of resources, and broader availability of and increased confidence in the database products (Toth 1984).

Textile Database Design Factors

Defining those key elements that must be addressed in the development of a database is an essential step in the process of defining the database design factors (Kruchten 1995). These design factors should first be considered in terms of a system architecture (Emery et al. 1996). This is not to imply definition of the technologies, but the organization of the various system elements, as cited in IEEE Standard 1471 (2000): "Architecture: The fundamental organization of a system, embodied in its components, their relationships to each other and the environment, and the principles governing its design and evolution." Before designing a database, a core group of potential system users first clearly identifies the key factors that must be included in designing the system. These usually include system inputs, outputs, controls, and resources. Initially the information flow itself need not be defined, just those key factors that will impact the database design. Nor do these factors define the expected interfaces with other systems. As noted earlier, these factors must be identified by those textile professionals who will actually use the system, in terms of the previously defined work processes. This requires significant effort to better define the key factors that must be addressed in the design of the system. These design factors are not by any means limited to those candidate factors modeled in figure 2, a model developed from that used by Zachman (1987).

Figure 2. Textile datebase design factors

Inputs

System inputs for the textile database are those data and information elements that will become the key components of the database. These could include the following:

- Unprocessed images: Images of all types received directly from the various imaging systems, with associated digital metadata about the textile and collection processes.
- Non imaging data: Data from non imaging tests and scientific studies of textile objects, with associated metadata about the textiles and collection techniques.
- Processed images and data: Digitally altered images and data with accompanying metadata about the image, data, and processing techniques.
- Analyzed images and reports: Images with annotations or digital enhancements that add information based on the experience and knowledge of textile professionals.
- Researcher notes and data: Information and data from studies of textiles that are pertinent to the information available in the database.
- Conservation, scientific and technical notes, images and reports: Information and data from studies of the textiles that are the subject of database entries.

Outputs

System outputs of the textile database comprise the data and information available from the database for the database users to use in enhancing their capabilities and work processes, as well as derived information based on the database content. These could include, and are not limited to the following:

- Database content: All data in the database available for further processing, analysis, and interpretation by users.
- Support information: Derived information that will contribute to textile handling and processing protocols and practices and those of other related fields for similar or identical textiles and objects.

- Deterioration information: Derived information from a range of data elements which contribute to the understanding of textile deterioration.
- Budget support information: Derived information to support the development of conservation, display, and exhibition budgets based on available data for identical or similar textiles.
- New and revised data standards: Standards for storage of digital data elements, metadata, and technical terminology based on user needs and experience in accessing data from this and similar databases.

Controls

System controls for an imaging database are those elements that play a critical role in guiding and defining the scope and content of the database, as well as the utility of the data and information. These include the following:

- User needs: The information users of the database need to glean from the range of data available in the database.
- Metadata standards: Standards for data that describe the parameters of the various data elements to allow for efficient access and retrieval of the data elements as part of a large body of data.
- Nomenclature standards: A standardized controlled vocabulary for the entry of information about the various data elements, as well as a process for making changes to the vocabulary with increased use.
- Organizational agreements: Agreements for the exchange of information and data while addressing data rights and restrictions.
- Software and hardware specifications: Specifications for the hardware and software required for compatibility with other systems or to meet user and/or system requirements.
- Budget and grant conditions: Restrictions and opportunities based on the funding of the database planning, integration, and operations.

Resources

System resources for an imaging database are those mechanisms and tasks that must be included for the database to function as an informational resource for a broad user community. These could include the following:

- Data and information analysis: Gaining additional information from data through study of the digital record by knowledgeable and skilled users.
- Standards validation: Verification data entered into the database meets the agreed standards for data accuracy, metadata content, and data entry.
- Data integration: Incorporation of data from various sources and objects to facilitate relational links between the data elements, allowing broad searches for specific data elements from various textiles.
- Data storage: The storage of potentially large amounts of data in a single database or multiple linked databases.
- Operation and Maintenance: The operation of the database as a system for assured access, and preservation of the data for access by users well into the future.
- Information Access: Access to the textile data and information by users for additional study through the public access Internet, while preserving the integrity of the data.

Implementation

Good teamwork, documentation of the specific needs with clearly defined deliverables, scheduling key milestones and regular meetings, and timely communications among committed user and management teams are all key factors in the implementation of this type of multifaceted project (Toth March 2000). Establishing a management team with a depth of experience in textile professions ensures the user needs are addressed. The use of virtual teams that cross boundaries between various disciplines, combined with regular interaction, will allow the unstructured and structured communication needed to define the work processes and design factors (Kyte 2002). A multiphased approach can mitigate some of the technical risk inherent in this information technology effort. Starting with a limited data set and then scaling up the system with the incorporation of additional data sets can allow the lessons learned from each phase to drive the final integration and operation of the system. This will also allow the evolution of new work processes, capitalizing on the efficiencies of enhanced textile data and information access with this database.

The use of mature imaging hardware and software currently found in other applications using proven imaging technology minimizes the risk of integrating images and data from a range of imaging systems. Nonetheless, changing information technologies and the lack of technical standards for digitally imaging textiles increase the risk involved in storing and accurately correlating textile data elements. The project scope and costs will grow, schedule delays will build up, and changes in information technology will not be effectively integrated into the system without a clear understanding of the user needs and work processes. While risks cannot be eliminated, they can be minimized through identification of user needs early in the program, and a clear understanding of the work processes and design factors (Toth March 2000).

Conclusion

Planning, integration, and implementation of a digital image textile database is a multiyear effort requiring long-term support from a range of individuals and organizations with other responsibilities. It is not necessary to define technical details early in the project, as the user needs should drive the required technology. Two key steps must be accomplished early in the planning: 1) definition of the key work processes and workflows; and 2) definition of the key design factors to be addressed in the database architecture. Only after these two steps are addressed can technical acquisition begin. Maintaining a team focus throughout the project will be challenging for a far-flung team with varied technical, academic, and operational backgrounds. Regular communication and progress meetings will help identify the user needs and business processes for the development of an effective program plan. Establishing a program plan with interim milestones according to an agreed schedule will help ensure this program achieves agreed goals in a timely fashion for the planning, integration, and operation of the database. Early definition of the project design factors will ensure the users information needs are addressed with the selection and integration of appropriate technical database solutions, to serve as an effective tool for a broad range of textile professionals.

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From Archive to Database to Research Tool: History of The National Park Service's Reference Library of Deteriorated Fibers

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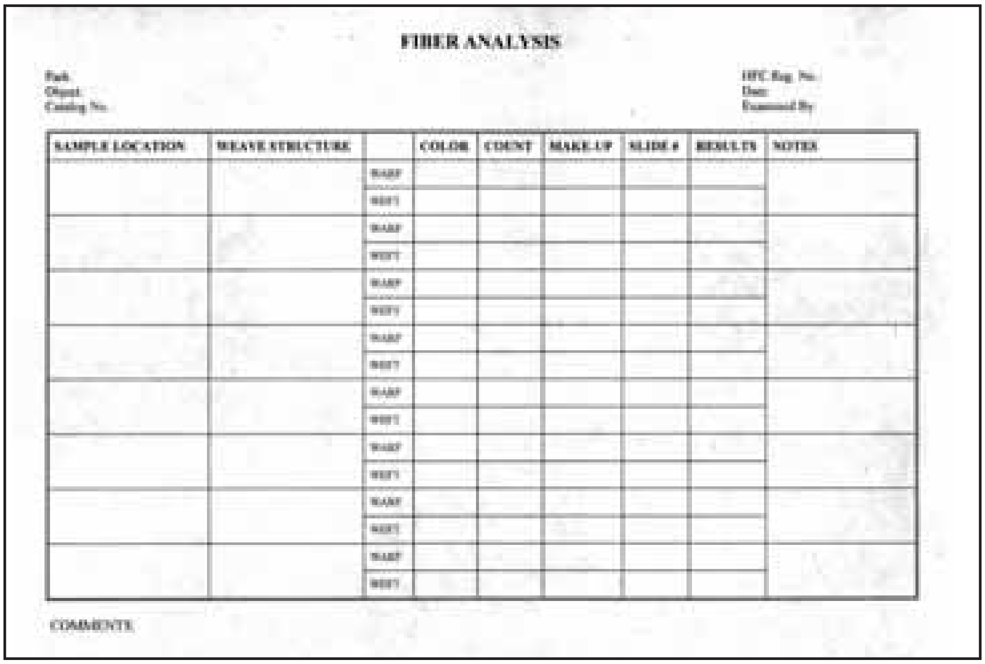
Textile Conservator, Cleveland Museum of Art

This conference convened to discuss the developing of a Web-accessible reference library of fibers represents both an end and a beginning—an end to the historical phase of this project and a beginning of the second phase. To those intimately involved in the historical phase, this meeting marks the culmination of many years work and truly is an exciting milestone. The collective expertise gathered represents textile conservation—where this idea germinated—as well as textile history; textile, conservation, and forensic science; and database and web creation and knowledge management; among others. It is a formidable group; the conference provides an ideal setting in which to update colleagues on work undertaken to date and to determine next steps.

Background and History

For nearly 30 years, objects that have passed through the Textile Conservation Laboratory at the National Park Service, Division of Conservation, at Harpers Ferry Center (HFC) in Harpers Ferry, WV, routinely have been sampled for fiber identification. Today the textile lab's archive of microscope slides with fiber specimens has grown to a compendium of 22 boxes containing nearly 2,200 slides and over 3,000 fiber specimens. While perhaps an unprepossessing physical presence–the entire collection occupies only a portion of one shelf in a cupboard in the textile lab (figure 1 slide of storage cabinet)-the information this resource contains is disproportionately large. Not a standard reference set of idealized, perfect specimens of select fiber types, rather this archive is a collection of fiber samples from historic artifacts in varying states of degradation from National Park collections throughout the country. The specimens are primarily cotton, bast, silk and wool fibers, although some synthetic fibers certainly are represented.

Figure 1. Microscope slide archive housed in the textile conservation laboratory, National Park Service, Division of Conservation, Harpers Ferry Center, Harpers Ferry, West Virginia.



FIBER ANALYSIS

Park:
Object:
Catalog No.

HFC Reg. No.:
Date:
Examined By:

SAMPLE LOCATION	WEAVE STRUCTURE		COLOR	COUNT	MAKE-UP	SLIDE #	RESULTS	NOTES
		WARP						
		WEFT						
		WARP						
		WEFT						
		WARP						
		WEFT						
		WARP						
		WEFT						
		WARP						
		WEFT						
		WARP						
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		WEFT						

COMMENTS:

Figure 2. Fiber analysis form currently in use in the textile conservation laboratory.

In 1997, while the author was a post-graduate fellow in the textile lab, the Division of Conservation (DOC) began the process of creating a database that would compile, in one location, information currently recorded manually on a Fiber Analysis form and dispersed in numerous paper files. The goal was to integrate information from many paper documents and multiple files in an attempt to provide access to information contained in the archive. It was hoped that by so doing, a collection of virtually inaccessible samples would become a true reference library of fiber specimens and a powerful research tool.

Figure 3. Microscope slide format including basic information recorded on the slide itself.

At that time, because the project was still in its formative stages, the many ways in which this information might be used in the future, and by whom, was not yet entirely clear. As a result, the goal of flexibility in database creation necessarily was of utmost importance. In order to design a database with as much flexibility as possible, considerable time was spent on the planning phase. Information was gathered from various sources with comparable databases, including from the field of forensic science. While equipment and space needs for such a resource are minimal, another crucial goal in this project was the retrieval and systematic storage of information extracted from the fibers themselves.

Process and Procedure

The materials and equipment needed to begin an archive such as the one at the Division are few and, with the exception of the microscope itself, not expensive. While the textile lab now has at its disposal an Olympus BX50 polarized light microscope equipped with a PM-30 automatic photomicrographic system, this was not always the case. This project certainly is one that can proceed in phases, with equipment added or upgraded as budgets allow. Even without a microscope, samples can be archived for analysis by an outside concern, or saved for a later date when equipment is available. Other than a microscope, supplies needed include microscope slides and cover slips; water; sampling tools (such as scissors, tweezers, and a probe); Paraloid B-72 (formerly Acryloid B-72 in the U.S.) a methyl methacrylate/ethyl acrylate copolymer or similar resin; permanent marking pens; and slide storage boxes (figure 3 slides of slides).

Figure 4. Tools and supplies needed to archive fiber specimens on microscope slides.

The DOC's microscope slide archive was simple to initiate and has been equally easy to maintain. As with any analytical technique, lab protocols for fiber sampling and archiving have developed over time. By necessity, methodology needed to be simple and straightforward and easily executed by any number of lab staff and interns.

Remarkably, the system for archiving specimens has changed little over the years. One or two fiber samples are preserved on each microscope slide which is labeled with basic information: the four-letter acronym specific to the park owning the object; a slide number—a unique number assigned consecutively; and the number assigned by the registrar to each object that enters the Division for treatment. Inclusion of this number allows fiber specimens to be traced back to specific objects, albeit not easily.

The technique used at the Division to prepare fiber specimens also is quite straightforward. With curatorial permission a minute fiber sample is taken from an object and placed on a microscope slide containing a drop of water. With the aid of needles or probes, and a stereo binocular microscope if necessary, the sample is teased apart to separate it into individual fibers. The sample then is covered with a round glass cover slip, viewed under the polarized light microscope to enable identification, and then set aside to allow the water to evaporate. At this point the slide is made permanent by applying two or three small drops of Paraloid B-72 equidistant around the outside edge of the cover slip. If the specimen needs to be viewed at a later date, water or a stain can be injected under the cover slip with a hypodermic needle, eyedropper, or capillary pipette.

The use of Paraloid B-72 to secure cover slips is the one aspect of this project that has changed materially in the last three decades. Initially, Aroclor, Canada balsam, or cellulose nitrate was used to secure cover slips in a traditional, permanent-mount format. In the intervening years, the first 100-plus microscope slides have turned white and cloudy, and the fiber specimens no longer are visible. Another 80 specimens have yellowed considerably but the specimens remain viewable. An additional 270 slides are "permanently" mounted in the traditional format but remain viewable. Since the mid-1980s, the use of two or three dots of Paraloid B-72 has been the standard.

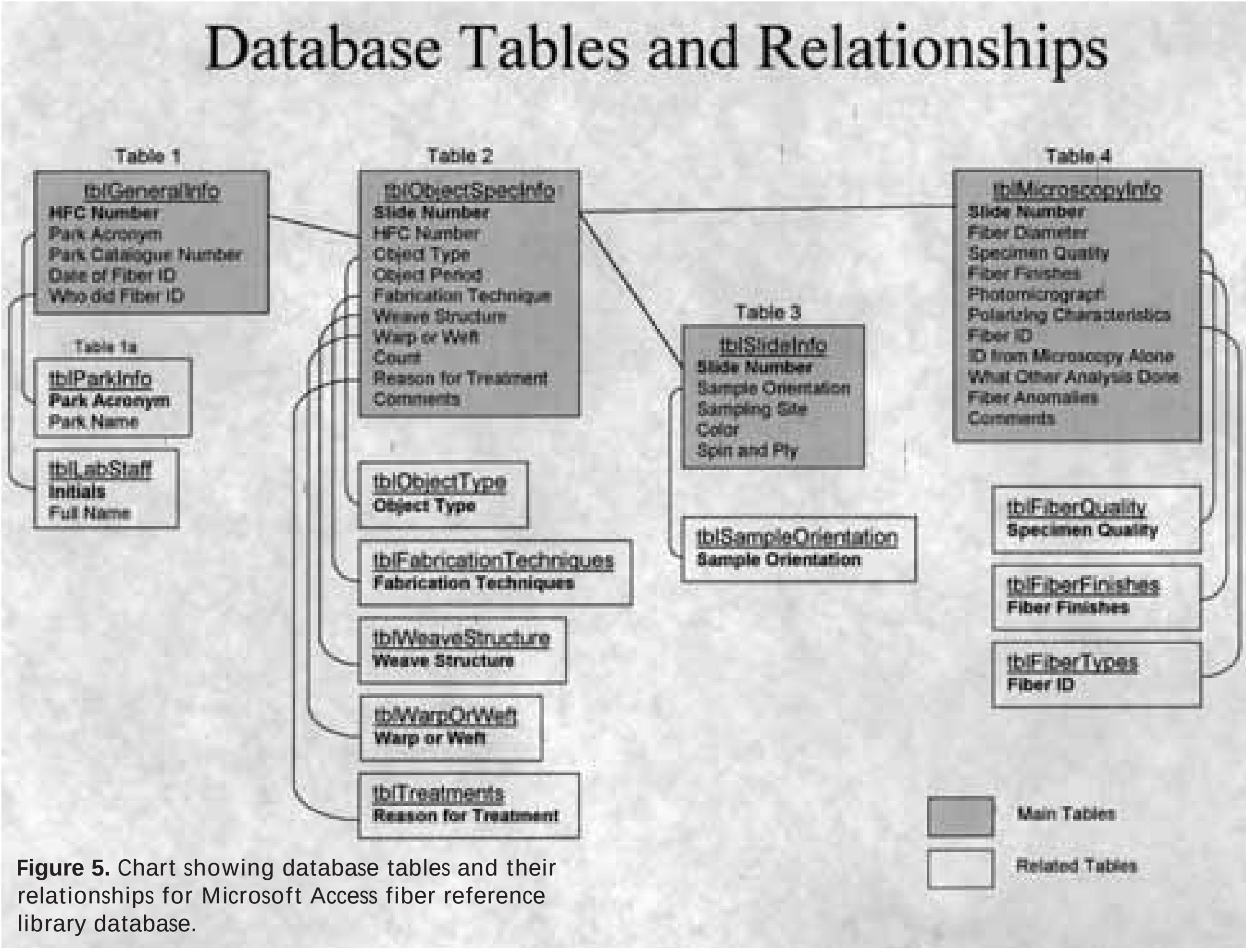

Figure 5. Chart showing database tables and their relationships for Microsoft Access fiber reference library database.

Computerization of Data

The software chosen for this database project was Microsoft Access, a relational database program that belongs to a suite of software programs called Microsoft Office, which is standard for the National Park Service. Access also is an extremely powerful and flexible program, and easily can serve the needs of this database well into the future.

As outlined in figure 5 database relationships, this database was organized into four main tables (Tables 1, 2, 3, and 4, shaded gray) with 11 related tables. This model is certainly neither the only, nor necessarily the best, configuration of the data upon which to improve. The rationale for organizing information in this manner is described below.

The first main table, Table 1 in figure 5, is referred to as the General Information table. It records basic information about an object and includes five fields:

- HFC Number – a unique number assigned by the registrar
- Park Acronym – a unique, four-letter abbreviation assigned to each park site
- Park Catalog Number – a number assigned by a park site to each object in its collection
- Date of Fiber Identification
- Who Performed Fiber Identification – initials of the textile lab staff person undertaking fiber analysis

The second main table, Table 2 in figure 5, is referred to as the Object Specific Information table. It is linked to the first main table (the General Information table) through the HFC Number field. This link is represented by the solid black line connecting the field HFC Number in Table 1 and the field with the same name in Table 2. This table includes 10 fields:

- HFC Number
- Slide Number – a unique consecutively assigned number
- Object Type – standardized nomenclature such as quilt, sampler, civil war uniform, etc. to be determined by lab staff
- Object Period – can be as specific as a year, or as general as “late 18th century”
- Fabrication Technique
- Weave Structure – this field is only completed if the response to the prior field is “woven”
- Warp or Weft – is the sample a warp or a weft fiber, or neither
- Count—the number of warp or weft yarns per cm
- Reason For Treatment – why is the object in the lab, was it wet cleaned, or was something done to it which may alter the fiber
- Comments – a field to incorporate information not included in any of the above fields

The third and fourth main tables, Tables 3 and 4 in figure 5, both are linked to the second main table through the Slide Number field, but are not linked directly to each other. These links again are represented by the solid black lines connecting Tables 3 and 4 to Table 2 through the Slide Number field.

The Slide Information table includes five fields:

- Slide Number
- Sample Orientation – is the sample longitudinal or cross-sectional
- Sampling Site – where on the object was the sample taken
- Color
- Spin and Ply

Finally, the Microscopy Information table (Table 4) includes 11 fields:

- Slide Number
- Fiber Diameter
- Specimen Quality – a subjective classification as to level of deterioration
- Fiber Finishes
- Photomicrograph – a yes/no field indicating whether or not a photomicrograph was taken
- Polarizing Characteristics
- Fiber Identification
- Identification From Microscopy Alone – a yes/no field indicating whether or not other analysis was necessary to identify the fiber
- What Other Analysis Was Done – if microscopy alone was not enough to identify the fiber, what other analysis, i.e. FTIR, was performed
- Fiber Anomalies
- Comments

The 11 related tables, located below the four main tables in figure 5, contain pre-entered menu-accessible information. They serve as look-up tables which allow nomenclature to be standardized throughout, thereby avoiding inconsistent terminology and inefficient searching. They also speed up the data entry process by providing lists of options from which to choose. Table 1a, the

Fiber Analysis Report

HPC Number: 11378.003 **Park Acronym:** WIHO **Date of Fiber ID:** 11/6/97
Object Type: creche figure **Park Catalogue Number:** 967.607.11 **Who did Fiber ID:** RJI
Object Period: 18th century

Sampling Site	Weave Structure	Warp or Weft	Color	Count (per cm)	Spin and Ply	Slide Number	Fiber ID	Comments
cape edge	plain	warp	green	39	Z singles	1905.1	silk	late 19th century replacement
cape edge	plain	weft	green	33	Z singles	1905.2	silk	late 19th century replacement
skirt center back seam	plain	warp	blue		Z singles	1906.1	silk	late 19th century replacement
skirt center back seam	plain	weft	blue		Z singles	1906.2	silk	late 19th century replacement
stomacher	plain w/ supplementary weft	warp	white	71	ST.A	1907.1	silk	18th century original
stomacher	plain w/ supplementary weft	weft	white	16	Z singles	1907.2	silk	18th century original
blouse	plain	warp	white	43	ZZ plied S	1908.1	cotton	18th century original
blouse	plain	weft	white	34	ZZ plied S	1908.2	cotton	18th century original

Figure 2. Fiber analysis report created in Microsoft Access.

Park Info table (figure 5) for example, contains a pull down menu listing the names and acronyms of all 378 parks. When the Park Acronym field in the General Info table is reached during data entry, the related table can be directly accessed and the correct acronym for the park owning the object in question entered.

From these tables, myriad forms, queries, and reports can be created. Several prototype forms have been designed for both retroactive data entry and fiber analysis, and to answer hypothetical questions posed by the textile historian and conservator. In addition, the Fiber Analysis form currently in use in the lab has been redesigned within the Access format report. Access's inherent flexibility allows the creation of additional forms, queries, and reports as specific questions are asked and needs arise.

It was felt that while some of the retroactive data entry is routine and could be done by anyone with basic computer skills, other aspects of data entry are more subjective and require input by someone with extensive experience in microscopy and fiber identification. Information to be entered into the Specimen Quality field, for example, is highly subjective and comparative, and necessitates the individual physical reexamination and evaluation of each specimen in the archive. From this reexamination, quantification of levels of deterioration is possible, with each fiber "graded" on a scale from one to ten, corresponding to a specific level of deterioration. Once information for the entire collection is entered into this field, it alone will become a major component of what makes this archive useful for conservators.

Conclusion

During the author's internship from 1997 and 1999, testing was undertaken to determine the feasibility of importing digital images of the archived specimens into the database. While at that time equipment did not exist in the lab to realize digital images at high enough resolution, technologies have progressed over the last few years to the point where this aspect of the database is a given. Five years ago little thought was given to image analysis; in the intervening years this has become another tool that has developed to the point that it needs to be considered a viable and necessary component of any resultant database.

As of mid-1999, wholesale data entry had not yet occurred; however, beta testing was begun on several levels. Information on approximately eight artifacts was entered into the Access database for testing purposes. In addition, a Web based database was created and information from a few artifacts entered into that system as well. This allowed some dissemination of information about the project to date. Once computerization is complete, it is expected that this resource will serve a number of functions and be of use to a wide range of people in a number of fields. For textile conservators, where retreatment of an object is anticipated, samples taken during prior treatment will be readily accessible and will obviate the need for resampling. Information extracted from the fibers themselves may assist in the dating of an object. It may assist in setting up a protocol for differentiating between bast fiber types, and in investigating weighted silk, to name but a few.

It is hoped that this historical information will prove useful as a starting point in the discussion of establishing a fiber database at HFC and the ultimate emulation of it at other sites with similar resources. Certainly the technology exists to allow the linkage of multiple databases. Because the NPS microscope fiber slide library is not the only one of its kind in existence, whatever standards result from this process must be adopted globally. Such a database certainly has the potential to become a powerful research and reference tool regarding fiber types and stages of deterioration. In the process an inaccessible archive will have been transformed into a true reference library of deteriorated fiber specimens and a resource that truly is greater than the sum of the parts will have been created.

Notes

An earlier form of this paper appeared in the *TSG Postprints*, Volume 8, ed. Camille Breeze, and was based on a presentation made to the Textile Specialty Group of AIC at its 26th AGM in Arlington, Va., in June 1999.

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Carroll, G. R. 1992. Forensic fibre microscopy. In *Forensic Examination of Fibres*, ed. James Robertson. New York: Ellis Horwood. 99-126.

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Laing, D. K., A.W. Hartshorne, R. Cook, and G. Robinson. 1987. A fiber data collection for forensic scientists-collection and examination methods. *Journal of Forensic Sciences* 32 (2): 364-369.

Luchtel, D. L. and J. C. Boykin. 1997. Tricks of the trade: reclaiming slides mounted in resinous mounting media. In *Microscope* 45 (4): 191-192.

Padama, A. D. 1998. Personal communication. President, Advance Business & Computer Training Center, 9055 Comprint Court, Suite 320, Gaithersburg, Maryland 20877.

Thomsen, F. 1998. Personal communication. Textile Preservation Association, P.O. Box 606, Sharpsburg, Maryland 21782.

Structuring a Web-Accessible Fiber Database

David T. Gilbert
Web Manager, Harpers Ferry Center

Key issues which the fiber application developers must address include:

- Defining a standard nomenclature or controlled vocabulary. For example, spelling of common words like fiber/fibre must be agreed upon.
- Data validation standards and protocols must be established (as described by Toth in this publication).
- Data access restrictions must be established. Who has authorization to upload data to the Web-accessible application? Is peer review required?
- What is the longevity of the data? Do records require an expiration date or some form of update protocol.

Key issues affecting the design and delivery of an online Web application:

- Both fiber application developers and users need to be involved in testing and evaluating the prototype website for usability. Does the website work? Can users access information easily or intelligently? Does the manner in which information is sorted and presented make sense? What image resolution is reasonable and appropriate?
- If the Web application is hosted on a U.S. Government Web server, the website must comply with accessibility standards published in Section 508 of the Rehabilitation Act of 1973, as amended. Other host organizations may be subject to similar accessibility guidelines.
- Special image viewing technologies for the Web, such as LizardTech's "Mr. Sid" proprietary format, which users can zoom into for detailed viewing, need to be considered. The Library of Congress online map library in the American Memory Collection uses "Mr. Sid" to deliver very large map files in a highly compressed but visually detailed format.

Example Websites explored during the presentation:

- Database-driven websites:
  - Conservation Fiber Database (prototype): http://data2.itc.nps.gov/hafe/fiber/fiber-search.cfm
  - Harpers Ferry Center staff directory: http://data2.itc.nps.gov/hafe/hfc/staff.cfm
  - NPS Historic Photograph Collection: http://data2.itc.nps.gov/hafe/hfc/nps-photo.cfm
  - NPS Contracts (IDIQ) Database: http://data2.itc.nps.gov/hafe/hfc/idiq.cfm
- Website that use LizardTech's "Mr. Sid" image technology:
  - American Memory (Library of Congress): http://memory.loc.gov/

Digital Microscopy: Equipment and Costs

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Digital microscopy, that is, the employment of a digital camera to capture images from a microscope, is fast becoming the method of choice for photomicrography in the conservation field. Rapid changes in technology, the wide variation in equipment and its costs, and the lack of standardization has made it a challenge to choose appropriate equipment for doing digital microscopy. This paper discusses some of the issues surrounding digital microscopy, and provides an overview of equipment choices and costs.

Introduction

The advent of the digital age, with the availability of reasonably priced digital cameras, software, and other tools, has afforded the conservation profession increased efficiency in the capture of photomicrographs. These tools allow the conservation professional rapid acquisition of photomicrographs that, until this point, were laborious and costly. This paper provides an overview of some of the equipment and costs associated with digital microscopy, but is not meant to be an exhaustive discussion.

Digital Microscopy Equipment

Digital microscopy requires four pieces of equipment–a microscope, digital camera, computer, and the software to operate the camera.

Microscopes

The quality of a photomicrograph depends on the quality of the microscope and its optics, the camera and the expertise of the user. Microscope choices will not be discussed here, but most laboratories use microscopes from well-known manufacturers such as Leica, Nikon, Olympus or Zeiss, although there are other options. A microscope capable of good quality photomicrographs can be rather costly ($20,000 or more), depending on the type of microscope needed.

Cameras

Classical photomicrography involves attaching a film-based camera to an optical tube on the microscope. Film-based photomicrography is time-consuming, costly and the time delay between taking a photograph and actually being able to see the image can be lengthy. The introduction of reasonably priced digital cameras with good resolution has revolutionized photomicrography.

There are numerous cameras specifically designed for use with microscopes. Examples include the Spot RT and Spot 3CCD, Polaroid DMC2, Nikon DXM 100, Leica DC200, Sony 3CCD DKC-5000, JenOptik ProgRes C14, Optronics MagnaFire, MagnaFire SP, MicroFire and the new MacroFire, Olympus DP12 and DP70, and the ElectroImage

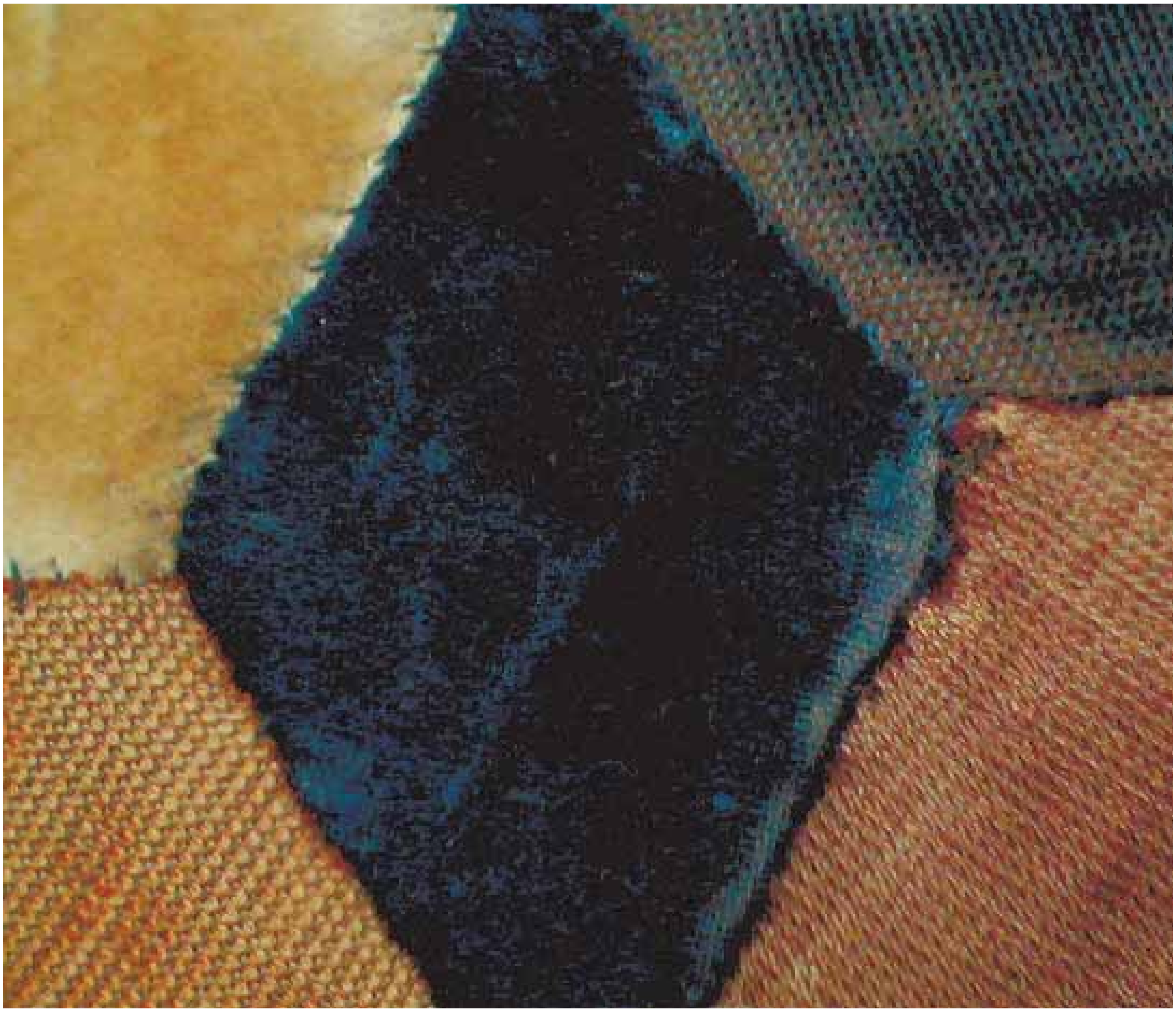

Figure 1. "Photomacrograph" of quilt upholstery of a chair from Lincoln Home National Historical Site. This detailed photograph was obtained with the Intel Video Pro Cam at pixel dimensions of 650 x 480. The image shows good detail of the weave substructure of various pieces of severely abraded velvet or velveteen.

TriPix RGB camera. Prices of these cameras range from about $2500 to $15,000. Other options include the Nikon CoolPix cameras, such as the 4500 ($500-$700, depending on the vendor), which affixes to the microscope eyepiece with a special tube ($150-200).

An excellent option, albeit with much lower resolution, for doing photomacrography without the aid of a microscope is the Intel Video Pro Cam, with 640 x 480 pixel resolution. For a discussion of image quality, resolution, and other camera criteria, see Bischoff *Digital Microscopy and Applications of Digital Image Analysis for the Study of Textile Fibers* in this publication. In figure 1 is an example of the detail of weave structure captured using this Intel webcam. Good focus can be obtained at distances of around 1.25 inches. The Intel Video Pro camera can be purchased for around $60 and has a very user-friendly software and graphical interface. Other webcams are also available for around the same price, but these have not been evaluated for their ability to acquire close-up images with adequate detail. There are also webcams available for around $30, but these have pixel dimensions of only 352 x 288.

Other technologies for "pseudo-photomicrography" include flatbed scanners, which give surprisingly good "photomacrographs" when acquiring images at high resolutions such as 1200 dpi. An example of a higher resolution scanned image is shown in figure 2. Flatbed scanners capable of image acquisition at 1200 dpi can be purchased for as low as $80.

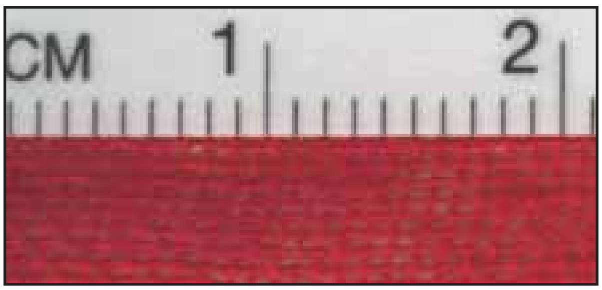

Figure 2. Small section of a Turkish scarf obtained with a flatbed scanner at 1200 DPI. This image, which clearly shows the thread count and weave structure, was obtained without the aid of a microscope.

Software

Software for digital image work can be divided into several types:

- Image capture
- Image manipulation (image editing)
- File management
- Image analysis

Many software packages are multi-functional. For example, Adobe Photoshop can be used for image capture and manipulation, while Image-Pro Plus can be used for capture, manipulation and image analysis. Depending on the needs of the user, one or more software packages are usually required for a full range of digital image work.

Image capture software allows the user to acquire digital images. Basic features in image capture software include selection of digital camera source and acquisition functions, a window for "live view" of the sample, white balance and exposure time. Images are obtained by a simple mouse click or menu choice. Once the image is captured, it usually appears as a separate window and can then be saved. Software prices for image capture software range from $0.00, called "freeware," such as IrFanView, to $700 for the full version of Adobe Photoshop. The cost of proprietary software that comes with many digital cameras is bundled with the cost of the camera. Although some upgrades to proprietary software can be obtained for free from the manufacturer's website, most extensive upgrades (often with significantly changed or enhanced features) are frequently costly ($2000 or more).

Image manipulation software allows the user to edit pictures. There are a wide array of options including sharpening, changing brightness, contrast, hue, and a host of other photoediting features. The "gold standard" for image manipulation is Adobe Photoshop, but it is expensive ($700) and its advanced options are a bit difficult to learn; however, it is available for both PC and Macintosh platforms. Less widely used, and only available for PCs is Ulead Photoimpact, which has many of the features found in Adobe Photoshop. Some advantages of it over Adobe Photoshop is that Photoimpact allows image editing without the complexity of layers, is generally easier to use, and costs around $90. Recently reviewed in PCMagazine were four mid-level image-editing software packages including Adobe Photoshop Elements 2.0 (editors top choice), Jasc Paint Shop Pro 8, Microsoft Digital Image Suite 9, and Ulead Photoimpact 8 (Simone 2003).

A particularly useful small and inexpensive program ($70) for resizing and sharpening images is Shortcut Photozoom (earlier versions were called S-Spline 2). The S-Spline program uses a "spline" algorithm for sharpening photographs and is more effective than sharpening done with the bicubic process, used by Adobe Photoshop. The spline algorithm is especially effective on line or stippled images. An example of the differences in sharpening methods can be found in figures 3a, b, and c.

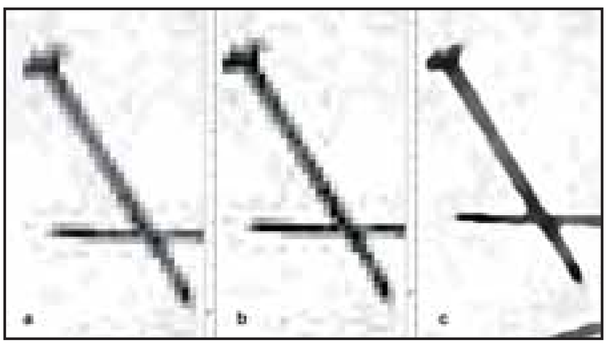

Figure 3. a) Detail of pen and ink drawing of buttons and straight pins by Steven N. Patricia (dimensions: 21 5/6" x 14 3/16"), scanned at 72 dpi, 640 x 451 pixels, 8 bit depth with inset. (Courtesy of National Park Service, Harpers Ferry Center Commissioned Art Collection) zoomed to 1200%. b) the same detail sharpened with Adobe Photoshop and zoomed to 1200% and c) the same detail sharpened with S-Spline 2 and zoomed to 400%.

File management involves digital file organization, which includes archiving and access. Since it is quick and easy to acquire digital files, file management, or the process of archiving, retrieving, storing, file sharing and file interaction, as well as saving of multiple copies of post processed images, can rapidly get out of control. The issues surrounding file management and storage are covered in greater detail in this publication, see Bischoff *Digital Microscopy and Applications of Digital Image Analysis for the Study of Textile Fibers*.

There are numerous software packages that can be used for file management. Inexpensive packages include ThumbsPlus (Standard Version $50, Professional Version $90) and ACDSee ($50), which allow the user to create a catalog of thumbnails. The Professional Version of ThumbsPlus allows file sharing across a network and includes additional file type options for professional cameras and scientific formats, as well as plug-ins for Photoshop.

Another inexpensive option is Cumulus 5 from Canto Corporation ($120 for a single user edition). The advantage of a program such as Cumulus is that it has various modules that can be purchased separately as user needs, such as network file sharing, change and funding permits. Cumulus 5 is also available for a number of platforms including Windows, Macintosh, Linux, and Sun systems. The entire package costs between $2000 and $3000 for network versions.

Some image management programs can be purchased as add-ons to image manipulation packages. For example, Ulead Photo Explorer can be purchased for $30 and works seamlessly with Ulead Photoimpact to easily manage large numbers of images. A more expensive option is IQbase ($2500), that interfaces with the Image-Pro image analysis software. IQbase also can be used to extract knowledge from large collections of images and associated data, a method called "informatics."

Image analysis is a software tool that allows the user to make measurements on digital images. Although this tool has enjoyed wide use in geology, material science, molecular biology and forensics, it is only recently that the conservation profession has begun to explore its use. Bischoff and Reedy discuss some of their research to develop applications for conservation (see Bischoff *Digital Microscopy and Applications of Digital Image Analysis for the Study of Textile Fibers* and *Reedy Comparing Comprehensive Image Analysis Packages: Research with Stone and Ceramic Thin Sections* in this publication).

The industry standard for image analysis software is ImagePro Plus ($3000) but other packages include Clemex ($7300), VisionGauge ($1500), and MCID Analysis ($3500, plus $6000 for a 3-seat server license-additional costs for additional server seats), and ImageJ for the Macintosh (freeware). It is important to point out that even though there are freeware applications available, they come with little or no documentation and essentially no technical support. Thus, they might be "cheap" but not necessarily simple or understandable to use.

Advantages and Disadvantages of Digital Microscopy

Although the resolution of digital images is not as high as film, for most scientific applications, digital imaging can be an efficient way to capture scientific data. The advantages of digital microscopy include lower costs than film (over the long term) and the ability to capture information immediately without having to wait to use a roll of film and/or for film development. Most importantly, image analysis software packages may be used to easily measure features on photomicrographs, a process that used to take several hours for a single sample.

A Final Word

Because digital technologies are changing so rapidly, information on equipment and costs becomes obsolete very quickly. Thus, the equipment and costs described in this paper are to be considered a starting point for anyone considering the purchase of digital imaging equipment. Since this author's presentation at the Fiber Database Conference in April 2003, some new products have been introduced on the market, for example, the "full-field-of-view" digital camera from Optronics called the MacroFire ($8,500).

The adage, "You get what you pay for…" is most definitely true when it comes to digital technologies. Generally the more features in the camera or the software, the greater the expense. Depending on the user's needs and assuming that the user already has a microscope, digital microscopy can be done for as little as $1000. If one wishes to add digital image analysis to his or her toolbox, then the user can expect to spend at least $10,000 for a suitable digital microscopy/image analysis system. The best approach to choosing a digital microscopy system is first to have the best quality microscope that fits your lab budget and second, to define the needs of your lab.

Given the cost, the time and effort needed to do film-based photomicrography, there seem to be few disadvantages to migrating to digital technologies. No doubt, the future holds great promise for increasingly affordable systems and ease of use. Hopefully this paper provides some basic information and guidance to anyone wishing to add digital microscopy to their lab's equipment holdings.

Sources of Equipment

ACDSee by ACDSystems, Inc. (available on-line at: http://www.acdsystems.com)

Adobe Photoshop, Adobe Photoshop LE and Adobe Photoshop Elements 2.0
San Jose Corporate Headquarters
Adobe Systems Incorporated
345 Park Avenue
San Jose, California 95110-2704 USA
Tel: 408-536-6000 or 800-833-6687 (toll free)
Fax: 408-537-6000
Website: http://www.adobe.com

Clemex PE, Clemex Lite or Clemex Captiva
Clemex Corporation
800 Guimond
Longueuil, Quebec
Canada J4G 1T5
Phone: 450-651-6573 or 888-651-6573 (North America)
Fax: 450-651-9304 or 866 651-9304 (North America)
Website: http://www.clemex.com

Cumulus 5
Canto Software, Inc.
290 Division Street, Suite 400
San Francisco, CA 94103
Telephone: 415-703-9800
Fax: 415-703-9823
Website: http://www.canto.com

ElectroImage TriPix RGB Camera
ElectroImage, Inc.
9 Roundhill Road
Great Neck, NY 11020-1212
Phone: 516-773-4305
Fax: 516-773-2955
Email: sales@electroimage.com
Website: http://www.electroimage.com

ImageJ, for Macintosh platform (download from: http://rsb.info.nih.gov/ij)

ImagePro Express, ImagePro Plus and IQbase
Media Cybernetics, Inc.
8484 Georgia Avenue, Suite 200
Silver Spring, MD 20910-5561
Phone: 301-485-3305
Fax: 301-495-5964
Website: http://www.mediacy.com

Intel Video Pro Camera
Intel, Inc.
2200 Mission College Blvd.
Santa Clara, CA 95052 USA
Phone: 800-538-3373
Fax: 408-765-9904
Website: http://www.intel.com/pccamera

IrFanView (download from: http://www.irfanview.com)

Jasc Paint Shop Pro 8
Jasc Software, Inc.
P.O. Box 44997
Eden Prairie, MN 55344 USA
Phone: 800-622-2793 (toll free)
Fax: 952-930-9172
Website: http://www.jasc.com

Leica Cameras
Leica Camera AG
Oskar-Barnack-Straße 11
D-35606 Solms
Germany
Phone: +49(0) 6442-208-0
Fax: +49(0) 6442-208-333
Email: info@leica-camera.com
Website: http://www.leica-camera.com/index_e.html

Leica Microscopes
Leica Microsystems, Inc.
2345 Waukegan Road
Bannockburn, IL 60015
Telephone: 800-248-0123
Fax: 847-405-0164
Website: http://www.leica-microsystems.com

MCID Analysis or MCID Elite
Imaging Research, Inc.
500 Glenridge Avenue
St. Catharines, Ontario
Canada L2S 3A1
Phone: 905-688-2040 or 866-818-1199 (toll-free US and Canada)
Fax: 905-685-5861
Website: http://www.imagingresearch.com

Microsoft Digital Image Suite 9 (can be ordered on-line from http://www.microsoft.com/products/imaging/products/disinfo.asp)

Nikon CoolPix Cameras
Website: http://www.nikon-coolpix.com

Nikon Microscopes
Nikon Instruments, Inc.
1300 Walt Whitman Road
Melville, N.Y. 11747-3064
U.S.A.
Phone: 631-547-8500 or 1-800-52-NIKON (within the US only)
Fax: 631-547-0306
Email: biosales@nikonincmail.com
Website: http://www.nikon.com

Olympus DP12
Olympus Microscopes
Olympus Digital Cameras for Microscopes - DP12 and DP70
Olympus America Inc.
2 Corporate Center Drive
Melville, NY 11747
Main Phone: 800-645-8160
For microscopes: 800-446-5967
For digital cameras: 888-553-4448

Optronics MagnaFire, MagnaFire SP, MicroFire and MacroFire
Imaging Planet – sole marketers of Optronics digital cameras
175 Cremona Drive
Goleta, California 93117
Phone: 866-IP-VIDEO or 866-478-4336
Email: Customerservice@imagingplanet.com
Website: http://www.optronics.com

Polaroid DMC2 Camera
Polaroid Corporation
Polaroid Corporation
Corporate Headquarters
1265 Main Street - Bldg. W3
Waltham, MA 02451
Phone: 781-386-2000
Website: http://www.polaroid.com

ProgRes C14 Digital Camera
Jenoptik
Academic Imaging Associates
P.O. Box 192
172 Carlen Street
Manchester Center, VT 05255
Phone: 802-362-3169
Fax: 802-362-0760
Email: staff@academicimaging.com
Website: http://www.academicimaging.com

Shortcut Photozoom (can be ordered at http://www.shortcut.nl)

Sony 3CCD DKC-5000
Meyer Instruments, Inc.
1304 Langham Creek, Suite 235
Houston, TX 77084
Phone: 281-579-0342
Fax: 281-579-1551
Email: Meyer@MeyerInst.com
Website: http://www.meyerinst.com/html/sony/default.html

Spot RT and Spot 3CCD Cameras
Diagnostic Instruments, Inc.
6540 Burroughs Street
Sterling Heights, MI 48310
Phone: 586-731-6000 or 888-391-1190 (toll-free)
Fax: 586-731-6469
Website: www.diaginc.com/a13

Thumbs Plus (Standard and Professional Versions)
Cerious Software Inc.
1515 Mockingbird Lane, Suite 1000
Charlotte, NC 28209
Phone: 704-529-0200 Ext. 101 or 877-237-4687(toll-free)
Fax: 704-529-0497
Website: http://www.cerious.com

Ulead Photoimpact and Photo Explorer
Ulead
Sales Department
20000 Mariner Avenue, Suite 200
Torrance, CA 90503
Phone: 800-85-ULEAD
Fax: 310-896-6389
Website: http://www.ulead.com/uleadmall

VisionGauge
Visionx, Inc.
15A Cartier
Pointe-Claire, Quebec
Canada H9S 4R6
Phone: 514-694-9290
Fax: 514-694-9488
Website: http://visionxinc.com

Zeiss Microscopes and Imaging Systems
Carl Zeiss MicroImaging, Inc.
One Zeiss Drive
Thornwood, NY 10594
Phone: 800-233-2343
Fax: 914-681-7446
Email: micro@zeiss.com
Website: http://www.zeiss.com/micro

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Reference

Simone, L. 2003. Clean up your image. *PC Magazine* 22(15):111-113, 116-119.

Digital Microscopy and Applications of Digital Image Analysis for the Study of Textile Fibers

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The introduction of reasonably-priced digital cameras has provided the conservation profession with a new documentation tool for instantaneous acquisition of digital photomicrographs and quick interpretation of analytical results. Of recent interest is digital image analysis, a sophisticated computer software tool used to make rapid measurements of morphological features in photomicrographs. This paper will discuss some of the issues surrounding digital microscopy, as well as applications of digital image analysis on textile fibers being explored at the Harpers Ferry Center (HFC).

Introduction

The conservation profession has used digital imaging for documentation, condition and treatment reports, and survey work. While this technology has enhanced the information that can be relayed to both specialist and non-specialist audiences, the potential of digital technologies has not been utilized fully. A review of the literature from the past five years reveals that, though digital imaging is gaining acceptance, few in the profession have used digital image analysis to acquire, synthesize, analyze, and interpret detailed microscopic morphological information from digital photomicrographs.

Image analysis, a sophisticated computer software application, employs specialized software to find and measure features in digital images. Typical image analysis programs include Image Pro Plus (being used at HFC), ImagePro Express, Clemex, ImageJ, VisionGauge, and MCID Elite or MCID Analysis, to name a few.

Although image analysis commonly is used in material science, forensics, and biological sciences, only a few examples can be found in the conservation literature. For example, image analysis has been used to examine the interface between brick and mortar (Elsen 1993), locate and quantify damage on photographs (Lopez 1996), and determined the level of yarn twist in archaeological textiles (Cork 1996).

While easy access of high-quality images of deteriorated fibers would be of great value to textile conservators worldwide, of even greater importance would be the correlation of microscopic features of fiber deterioration with macroscopic behavior. HFC is exploring the application of sophisticated computer image analysis software to analyze fiber characteristics, that when related to artifact condition, may be able to standardize the language of condition, taking it from a subjective assessment to one based on fiber morphology.

Digital Microscopy

Digital microscopy, involving the use of a digital camera to capture images from a microscope, has made it possible for microscopists to quickly and easily acquire photomicrographs without having to deal with film-based systems. There are many choices of digital cameras and software packages to operate cameras and acquire, manipulate, and manage digital image files. Some of this equipment and its costs are discussed in Bischoff *Digital Microscopy: Equipment and Costs* in this publication.

Image Capture Issues

The acquisition of high quality photomicrographs, whether digital or film-based, depends upon the quality of the equipment and the expertise of the user. There are three general categories of concern to obtain images of acceptable quality:

- General photomicrography issues
- Sampling issues
- Issues specific to digital capture

The purpose of the photomicrograph dictates the type and quality of photograph needed. Some important factors to consider include the magnification, type and intensity of illumination, special filters, and bracketing of exposures. The acquisition, processing, storage, and documentation of samples, as well as sample size can also impact the quality of the photograph. Sampling issues are addressed elsewhere in the publication (Merritt *Considerations Regarding Sample Acquisition for a Web-Accessible Reference Library*). Criteria for obtaining high quality photomicrographs are the same ones necessary for capturing digital photomicrographs. Additional factors unique to digital imaging include:

- Digital camera specifications
- Imaging software
- File handling
- Storage issues
- Image archiving and retrieval

Digital Camera Specifications

The image quality required is dictated by the end use of that image. For example, a lower quality image might be sufficient for sample site documentation, but a high-quality image is necessary for observing morphological details. Digital image quality depends on the resolution, pixel dimensions, bit depth and dynamic range, which are functions of the digital camera.

Resolution is the ability to distinguish fine spatial detail. For film-based images, resolution is very high due to the minute particle sizes of silver image grains. Unfortunately, most reasonably-priced digital cameras cannot achieve the resolution of film-based media. The pixel dimensions refer to the horizontal and vertical measurements in pixels. For example, a low-resolution camera might produce an image with dimensions of 650 x 480 pixels. The bit depth is the number of bits used to define a pixel. For example, a bitonal image would have only black and white pixels (2 bits, 0 or 1), but gray scale and color images would have much greater bit depths. Typically, images are either 8 or 10 bit to achieve millions of colors. The dynamic range refers to the range of tonal difference between the light and dark areas of the image. An image of high dynamic range would have a large variation in tone and great spatial resolution.

Another important consideration is the type of camera. A three-pass camera has three filters, red, green and blue and accumulates an image of the specified pixel dimensions for each filter. If the image dimensions are 1280 x 1025 pixels (which is 1.3 million pixels or 1.3 megapixels), then the entire image of a three-pass camera would be about 3 megapixels. A lens array with the same pixel dimensions would give an image of about 1 megapixels.

Another important specification is the refresh rate of the camera. Most digital cameras are only capable of refresh rates of 8-15 frames per second (fps), thus requiring the user to wait after each change of focus. Video cameras have much higher refresh rates.

Imaging Software

Most digital cameras are operated with their own proprietary software; however, many third-party software packages will also operate some digital cameras. All camera software packages allow the user to select the twain-compliant device (digital camera or scanner), perform at least minimal file handling (acquisition, saving, and retrieval) and image manipulation (e.g., changing brightness, contrast, hue). Some image editing limitations can usually be handled using applications such as Adobe Photoshop, Ulead Impact or Paint Shop Pro.

File Handling

The greatest challenge faced by the conservation profession as it enters the digital age is file handling. File handling includes the acquisition, storage, and retrieval of digital image files. Decisions regarding how to name files, format(s) for file saving, the number of images of different formats that should be saved, and where to save files are critical issues. In addition, metadata issues are also important. Metadata is data associated with digital information, or the "data behind the data." It is beyond the scope of this paper to discuss metadata, but is covered by Toth in *Textile Database Systems Integration* in this publication.

Software

Digital photography uses software to operate the camera such as choosing the "shutter speed" and exposure time. This is exceptionally easy with a digital camera, because the user can manipulate these features in "real time" and observe exactly what is happening to the image. The software also allows the user to adjust the white balance, a color correction system for different illumination sources.

Storage Issues

The thorniest issue in digital imaging is the computer storage requirement for digital image files. Most guidelines for digital image capture suggest that images be saved in the TIF format, with no compression. Depending on the camera or other device, images can take from one to several hundred megabytes of storage per image. Large file sizes have implications for server or hard drive storage, as well as image archiving and retrieval and computer system requirements.

Image Archiving and Retrieval

In tandem with the issue of storage of digital files is image archiving and retrieval. For a discussion of image management software packages see Bischoff *Digital Microscopy: Equipment and Costs* in this publication.

Applications of Digital Imaging and Digital Image Analysis

Many conservation laboratories now use digital cameras for photomicrography because of the ease of use, the ability to capture an image in real time, and the long-term savings on time, film costs, and the ability to immediately evaluate and interpret information from a digital photomicrograph. Most conservation professionals are quite familiar with measuring morphological features using a microscope, but no matter the skill level of the analyst, it can take several hours to measure and process data from a single sample. Unless measurement information is critical, it is not worth the time and effort to do the analysis manually.

Although digital image analysis has been used successfully in a number of fields such as forensic science, biology and materials science, only recently has the conservation field begun to explore the use of digital image analysis. The ease of using the software and the speed at which one can obtain measurements on fibers is remarkable. Where manual measurements of the average diameter of a single fiber can take several hours, one can accomplish the same task on 30 samples in the same amount of time using digital image analysis.

Some image analysis applications being explored HFC are:

- Scale length and angle of wool fibers
- Image calibration
- Fiber diameter
- Weave structure and thread count

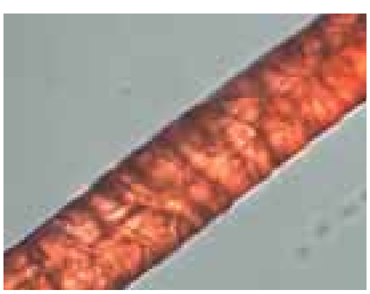

Figure 1 (above) shows the garrison flag from Fort Sumter National Monument, along with a digital photomicrograph of a deteriorated red wool fiber from the flag taken at 40X magnification **(left)**.

SCALE FEATURE MEASURED	LENGTH OF RED FIBER(pixels)	LENGTH OF MCCRONE FIBER (pixels)
L1	87.86353	57.31492
L2	33.10589	62.93648
L3	104.8046	45.34314
L4	101.2126	24.83948
L5	65.05382	43.13931
L6	38.20995	64.35060
L7	82.21922	62.24147
L8	74.02702	56.58622
L9	129.0736	38.20995
L10	103.2279	53.81450
L11	81.63333	43.13931
L12	107.6476	52.32590
L13	106.5082	43.01163
L14	142.0563	54.20332
L15	85.08819	39.05125
L16	65.51336	44.65423
L17	52.83938	57.00877
L18	84.38009	59.90826
L19		56.61272
L20		61.03278
Average Scale Length	86.27957	50.98621

Table 1. Lengths of scale features of a deteriorated red wool fiber sample (40X) from a Flag at Fort Sumter and a wool fiber from the McCrone Reference Collection(40X)

Measurement of Scale Lengths

Many animal fibers (e.g., wool) have scales and deterioration may be linked to scale loss. It may also be possible to identify the animal source and/or species by measuring scale lengths. Because digital capture and measurement of fiber features is quick, it is possible to analyze many samples. An example of scale length measurements follows.

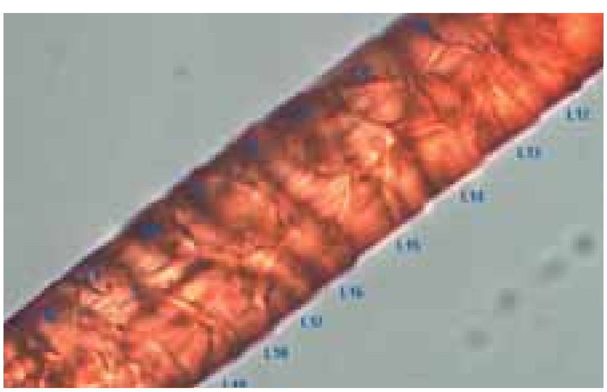

Figure 2. Photomicrograph of deterioriated red wool fiber from the Fort Sumter flag showing line measurements of scale features (taken at 40X magnification).

Using the "line tool" from the Image-Pro Plus image analysis software, 19 separate scales were measured within minutes, as illustrated in figure 2. The data were imported to an Excel spreadsheet, where the average scale lengths were calculated. The results for these fiber measurements can be found in Table 1. The same process was applied to a wool sample from the McCrone reference collection.

Image Calibration

Measurements made using image analysis software are in pixels and not actual measurements. In order to find the number of pixels that corresponds to an actual unit of measurement, the image must be calibrated. Reedy describes the "scale bar method" in a separate paper in this publication and it is also described in the Image Pro Plus users manual (Media Cybernetics, Inc. 2001). Another method is the determination of conversion factors at various microscope magnifications.

Conversion factors are determined by placing a micrometer scale on the stage of the microscope, and capturing digital images at all magnifications of the microscope. Using image analysis software, five line measurements are made on a known length of the scale. In the example shown in figure 3, the five measurements were made of a length corresponding to 0.1 mm at 6.4X magnification.

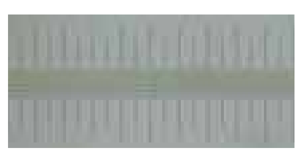

Figure 3. Photomicrograph of micrometer scale (taken at 6.4X magnification) showing five (5) line measurements of 0.1 µm unit.

The length measurements were then imported to an Excel spreadsheet, where the average length was calculated in pixels. These data are shown in Table 2.

Table 2. Length Measurements and Average Length of 0.1 µm Unit on a Micrometer Scale at 6.4X

FEATURE MEASURED	LENGTH (pixels)
L1	942
L2	942
L3	941
L4	942
L5	942
Average	941.8

The calibration factor was then computed by dividing the average number of pixels by the actual distance measured. For this example, the calculation was:

(941.8 pixels/µm) x 1 mm/1000 mm = 0.9418 pixels/µm (calibration factor for 6.4X magnification)

The same steps can be repeated for all magnifications. Calibration factors are used to convert measurement made in pixels to an actual measurement in micrometers. The average scale length for the deteriorated red wool fiber from the Fort Sumter garrison flag was 86.27957 pixels (or 14.61 µm) and for the undeteriorated wool fiber from the McCrone reference collection, 53.86575 pixels (or 9.12 µm), both measured at 40X magnification. The calculation for the average fiber diameter for the McCrone fiber is (using the calibration factor 5.904 pixels/µm determined at 40X magnification):

53.86575 pixels ÷ 5.904 pixels/µm = 9.12 µm

Measurement of Fiber Diameters

Another important property of fibers is fiber diameter. In less than 15 minutes, 20 diameter measurements were made on each of eight fibers and the average fiber diameters calculated. The results of these measurements are given in Table 3.

Table 3. Average Fiber Diameters of Some Samples from the Harpers Ferry Center Fiber Library

OBJECT	SAMPLE DESCRIPTION	FIBER TYPE	AVERAGE FIBER DIAMETER (µm)
Quilt	Quilting Thread	Cotton	17.0
Quilt	Quilt Back	Cotton	17.1
Waistcoat	Weft		16.7
Waistcoat	Thread		15.8
Waistcoat	Warp		17.5
Engraving on Silk	Ground	Silk	10.4
Engraving on Silk	Strip	Silk	13.8
Frockcoat	Interfacing	Linen	26.0

There were several criteria used in choosing which diameters to measure. For fibers with varying diameters, measurements were made across different thicknesses. Measurements were made from edge to edge in focused areas only, since it is difficult to determine an edge of a fiber in unfocused areas and in regions where fibers did not overlap.

Weave Structure and Thread Count

A unique and inexpensive digital "photomicrography" technique is the use of a flatbed scanner to acquire high-resolution images of flat textiles to determine weave structure and thread count. An example of this technique is presented in a separate paper (Bischoff *Digital Microscopy: Equipment and Costs* in this publication). Although a scanner is not recommended for use with textiles that contain fugitive dyes, or are already in a deteriorated state, it is an interesting exercise in the use of a digital technology to obtain a "microscopic" image, without a microscope.

Other Applications

The examples described here are but a few of the potential applications of digital image analysis in the conservation field. This field has much to learn about applications of digital imaging and image analysis from allied fields such as forensics, biology, biotechnology, and materials science. One such application includes Reedy's preliminary work on the use of digital image analysis for investigation of archaeological ceramics *Comparing Comprehensive Image Analysis Packages: Research with Stone and Ceramic Thin Sections* in this publication.

Future Work

There are still many issues to be resolved, not only in the creation of acceptable standards for digital imaging, but also in the development of applications of digital image analysis in conservation. Digital image analysis is a virtually untapped area of research in the field of conservation. It is clear from this preliminary work that digital image analysis will be an important tool, not only in the analysis of textile fibers and in understanding and defining levels of deterioration, but for many other applications as well. The Scientific Research and Analytical Support Laboratory at HFC will continue its research to develop image analysis applications.

Sources of Materials

Clemex PE, Clemex Lite or Clemex Captiva
Clemex Corporation
800 Guimond
Longueuil, Quebec
Canada J4G 1T5
Phone: 450-651-6573 or 888-651-6573
(North America)
Fax: 450-651-9304 or 866 651-9304
(North America)
http://www.clemex.com

ImageJ, for Macintosh platform
(download from http://rsb.info.nih.gov/ij)

ImagePro Express and ImagePro Plus
Media Cybernetics, Inc.
8484 Georgia Avenue, Suite 200
Silver Spring, MD 20910-5561
Phone: 301-485-3305
Fax: 301-495-5964
http://www.mediacy.com

MCID Analysis
Imaging Research, Inc.
500 Glenridge Avenue
St. Catharines, Ontario
Canada L2S 3A1
Phone: 905-688-2040 or 866-818-1199
(toll-free US and Canada)
Fax: 905-685-5861
http://www.imagingresearch.com

Paint Shop Pro
Jasc Software, Inc.
P.O. Box 44997
Eden Prairie, MN 55344 USA
Phone: toll-free 800-622-2793
Fax: 952-930-9172

Ulead Photoimpact
Ulead
Sales Department
20000 Mariner Avenue, Suite 200
Torrance, CA 90503
Phone: 800-85-ULEAD
Fax: 310-896-6389
http://www.ulead.com/uleadmall

VisionGauge
Visionx, Inc.
15A Cartier
Pointe-Claire, Quebec
Canada H9S 4R6
Phone: 514-694-9290
Fax: 514-694-9488
http://visionxinc.com

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Lopez, J.-G. 1996. Relevés infographiques pour le constat d'état des photographies. *ICOM Committee for Conservation preprints, 11th Triennial Meeting*, Edinburgh, Scotland. Paris:ICOM. 597-600.

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Comparing Comprehensive Image Analysis Packages: Research with Stone and Ceramic Thin Sections

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Museum Studies Program, University of Delaware

Petrographic thin sections of stone and ceramic materials provide an enormous amount of information through polarized light microscopy. Digital image analysis is an important new tool for quantifying and interpreting what is seen under the microscope. Many analysis procedures of interest are also applicable to other subfields of conservation research. Some examples include measuring the thickness of layers, quantifying microcrack patterns, measuring extent of consolidant penetration, and identifying the amount, size, and degree of roundness for certain constituents. We are exploring three comprehensive image analysis packages to assess their ease of use and applicability to the conservation field and to develop protocols summarizing relevant procedures. Two examples are discussed here: calibration of images and measurement of layer thickness.

Introduction

Under funding from the National Center for Preservation Technology and Training (NCPTT), our research group is currently comparing the performance and ease of use of several comprehensive image analysis packages. We are assessing their utility and practicality for conservation research applications with digital images taken under a polarizing microscope. Although our focus is on petrographic thin sections of stone and ceramic materials, many of our findings are applicable to the analysis of fibers.

Petrographic thin sections are made by mounting a sample on a glass slide with an epoxy resin, then grinding the sample down to 30 microns thickness. At that thickness, a wide variety of optical properties under plane polarized and crossed polarized light enable one to identify the minerals present and make many observations and interpretations regarding materials, deterioration, treatment effects, technology of production, and geological or cultural source of the specimen. We first provide a brief overview of the types of research needs presented by petrographic thin sections. We then discuss some of the considerations regarding choice and use of image analysis packages. Finally, we compare three major packages by illustrating how they work with two specific applications (calibration of images and thickness measurements).

Example Research Needs for Stone and Ceramic Materials

For deterioration and preservation studies, examples of research needs include measuring the thickness of layers, studying and quantifying microcrack patterns within single mineral grains, and measuring the extent of consolidant pentration. Weathering layers on stone may provide information on authenticity, as with the schist sculpture specimens seen in figures 1A and 1B.

Figure 1A. Thin section from surface of a Gandhara-style schist sculpture with no weathering layer, probably a modern forgery.

Figure 1B. Thin section from surface of a Gandhara schist sculpture, probably authentic 3rd-century A.D. piece, with thick weathering layer.

Figure 3. Thin section showing multiple microcracks in quartz grain of granite, an indication of deterioration.

Both specimens are from sculptures that are in the style of Gandhara images of the Fasting Buddha, circa third century. However, the sculpture from which the specimen of 1A was taken has been challenged as a possible modern forgery. It is thus of some concern that the thin section shows no weathering layer, whereas the specimen of 1B, with authenticity not disputed, does.

Of course, weathering layers can be cleaned off, so their absence does not condemn a piece; and the degree of weathering can only provide useful dating information if extensive background research has been done for each stone type of interest in the environment of interest. Nonetheless, measuring the thickness of layers can be important in authenticity studies and in identifying extent of ongoing deterioration for preservation studies.

With ceramic materials, the ability to quantify and accurately measure layers can provide information about function, as with layers of increased porosity on the surface indicating use-wear abrasion. Or, measuring the thickness of a slip, glaze, or interaction layer can help characterize a ceramic technology (figure 2).

The presence and patterns of microcracks in quartz grains in granite (figure 3) is one indication of extent of deterioration (Dearman and Irfan 1978; Ordaz et al. 1978; Rainey and Whaley 1994; Fiora et al. 1996; Hernandez 1996; Molina et al. 1996). Multiple thin sections are analyzed (usually at least five), and a standard protocol is applied, such as moving along a linear transverse and checking for cracks in each grain that falls along that area. Some of the variables that can be related to extent of deterioration include the number of cracks within a given area, the average length of cracks, the average width, whether or not cracks extend into adjacent grains, and the fractal character of cracks.

Thin sections can also be used in conservation treatment studies. For example, in many studies of architectural materials thin-section petrography is used to monitor, measure, and interpret the effects of various treatment parameters (O'Brien and Cooper 1994; Esbert et al. 1996; Rodrigues 1996). Figure 4 illustrates the use of thin sections to study and measure the extent to which a consolidant has penetrated the friable surface of a clay-gypsum fresco layer.

Figure 2. Thin section showing lead-cobalt glaze on earthenware ceramic, English, 1820-40.

Figure 4. Thin section of clay/gypsum layer of a deteriorated fresco shows extent of penetration of consoldant: the dark wormy material in many of the intergranular pore spaces.

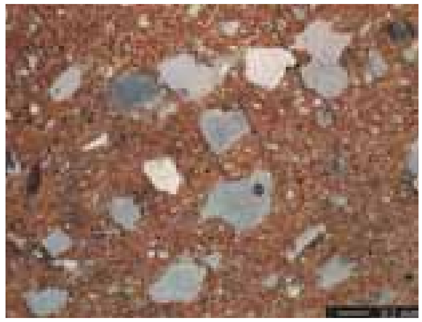

Figure 5. Ceramic thin section showing added sand temper, which appears as the larger grains within a fine-grained clay matrix.

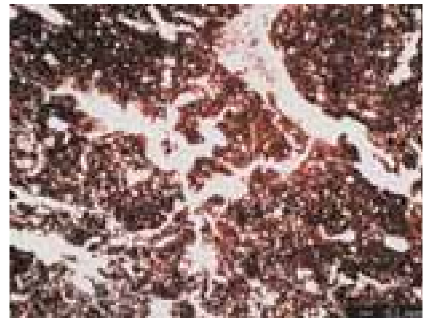

Figure 7. Thin section of an ancient Mesopotamian cuneiform tablet, showing extensive porosity.

Finally, petrographic thin sections are often used in materials characterization and technical studies of sculpture, building materials, and ceramics. Examples of the questions of interest include determining the amount of sand (figure 5), organic matter, or other added temper materials; measuring the minimum, maximum, and average size of quartz grains; measuring the degree of roundness versus angularity for quartz (figures 6A and 6B); characterizing mineral textures, calculating particle size distribution, and measuring porosity and pore structure (figure 7) (Esbert and Montoto 1986; DeHayes and Stark 1994; Fitzner 1994; Reedy 1994; Velde and Druc 1999; Mueller and Hansen 2001). Most of these research questions require good precision and accuracy as well as the analysis of a large number of specimens for statistical reliability, so an image analysis package that allows relatively fast quantitative measurements is advantageous over traditional methods of inaccurate estimation or tedious point-counting (Goins and Reedy 2000).

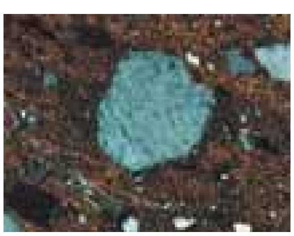

Figure 6A. Ceramic thin section showing a very rounded quartz grain, indicating extensive weathering and transport, information that may be helpful in identifying a geological source. **Figure 6B.** Ceramic thin section showing a very angular quartz grain, indicating a different geological source than the quartz of Figure 6A.

NCPTT-Funded Research on Image Analysis Packages

The existence of comprehensive materials analysis computer packages, eliminating the need for most in-house programming, makes digital image analysis practical and widely available. Existing packages can perform many of the basic functions required for thin-section studies of deterioration, treatment research, and characterization of cultural materials. However, the analysis is by no means automatic, and still requires careful examination of each image and the selection of appropriate choices at each step of analysis. The fact that the most widely-available comprehensive packages were originally designed for non-conservation applications and users (mainly laboratories in the biological sciences or metallurgical analysis in industry) complicates the selection of appropriate choices and development of protocols. Our laboratory is thus conducting research under NCPTT funding aimed at helping conservation scientists who work with petrographic thin sections to more easily and effectively use existing image analysis packages for their particular materials and research applications.

Our research goals include identifying procedures where image analysis packages may be helpful, exploring three comprehensive packages to assess their ease of use and applicability to the conservation field, and developing protocols for each package that summarize some specific procedures of interest. Three packages were selected for study; these were chosen because they are all comprehensive packages (rather than programs limited to one or a few applications), and they are widely available and are not tied to a specific instrument or manufacturer.

The three packages chosen are Image-Pro Plus, produced by Media Cybernetics; Clemex Vision PE (Professional Edition), and Image J, a public domain Java image processing program inspired by NIH Image for the Macintosh, but which can be run on either a Windows system or Macintosh system. Some of the factors we are considering as we explore each package include whether or not it does the specific operations required by conservation research laboratories, cost, ease of use, quality of documentation, amount of time required to learn and gain skill, and quality of output (such as whether or not output is publishable).

Although this research is still in progress, we provide a preliminary discussion of two specific operations, calibration of images and measuring layer thickness, comparing the way in which each of these processes is handled by the three programs.

Calibration of Images

With computer analysis of digital microscope images, the images are represented in the form of picture elements, or pixels, which are small dots that make up the image. In order to perform measurements, the image analysis tools need to know how many pixels there are in one unit length of the image. The unit length may be in millimeters or in micrometers. The process of assigning the number of pixels per unit length to an image is known as calibration. Before undertaking any analysis, each image must be calibrated so that measurements such as length, perimeter, or area can be calculated in a specific unit, such as microns, rather than simply the number of pixels measured.

As the first step, a calibration measure must be obtained. This term refers to the number of pixels per unit length of the image, and depends on the magnification of the objective lens that is used to view the image under the microscope; the resolution under which the image is stored; and the digital camera/microscope combination that is being used to capture the image. Thus the calibration measure only needs to be taken once for each objective lens/camera/resolution combination and this measure will then apply to all images taken with that combination. Usually the documentation accompanying a digital camera will provide information on obtaining calibration measures. Once this is accomplished, each image analysis package will have a protocol for importing the calibration measure to be applied to a specific image under analysis.

Obtaining a calibration measure also allows one to add a scale bar onto the image, either using the software accompanying the digital microscope camera or using one of the image analysis packages. The advantage of using a scale bar is that the relative size of objects is always clear to viewers, no matter how much the size of the image is manipulated before publication. In contrast, listing the magnification in a caption is tricky, because when the image size is manipulated as part of analysis and/or in the publication process, the magnification changes. When the caption lists the original magnification at the microscope, that information is often incorrect as applied to the published photograph. Thus most scientific publications no longer list magnifications, and instead require a scale bar.

We found that the calibration procedure is easy to accomplish with all three of the image analysis

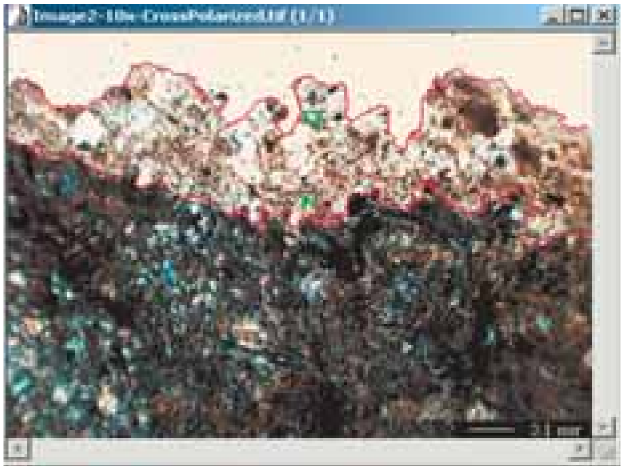

Figure 8 (top). In Image-Pro Plus a drawing tool is used to specify upper and lower boundaries of a layer, then the software can automatically calculate minium, maximum and average thickness of the layer.

packages. However, the process is much more cumbersome with Image J. For both Image-Pro Plus and Clemex Vision PE the calibration measure for each objective lens need be entered only once. The analysis package can then save that information. In future uses the researcher need only click a drop-down menu that gives the objective lenses from which to choose. In contrast, Image J cannot save the calibration information, so the selected unit length (usually microns) and number of pixels per micron as obtained with the camera calibration procedure must be entered each time an analysis is performed.

Measuring Layer Thickness

As previously described, the measurement of the thickness of layers in thin sections is an important element of conservation research, with the thickness or width of a deterioration layer providing one assessment of the amount of weathering present in the specimen. Layer thickness in some cultural materials (such as a glazed ceramic) may also be an important indicator of workshop technology and may be useful in characterizing the technique of an artist, a workshop, or a cultural tradition. But, since a layer often varies considerably in thickness, a single measurement would not give an accurate assessment. Instead, we are usually interested in measuring the layer across the entire field of view, then

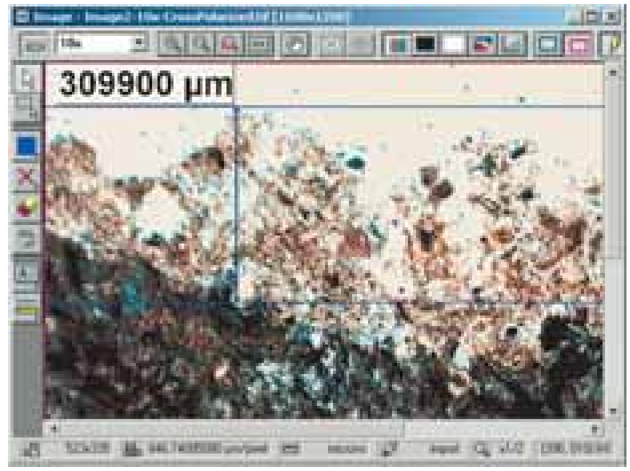

Figure 9 (bottom). In Clemex Vision PE measuring thickness at a single point is easy, simply requiring drawing a straight line across the top and bottom at that point.

obtaining information on the minimum, maximum, and average thickness. The three image analysis packages perform quite differently for measurements of layers.

Image J can take a single measurement of layer thickness. However, it cannot automatically calculate thickness across the layer or calculate minimum, maximum, or average thickness. Therefore, it is not likely to meet most conservation research needs.

With Image-Pro Plus, thickness measurements are simple and intuitive. One can specify the upper and lower boundaries of the layer by simply drawing them using a drawing tool (figure 8). Once the two boundaries of the layer have been defined, the program can then either take single measurements at any point along the layer or take a series of automatic stepped samples across the layer, then calculate the minimum, maximum, and average thickness.

Clemex Vision PE can take single measurements or measurements at regular intervals, and can calculate minimum, maximum, and average thickness of the layer. It is easy to take measurements at a single point; one simply draws a line at the top and bottom of the layer at the point to be measured (figure 9).

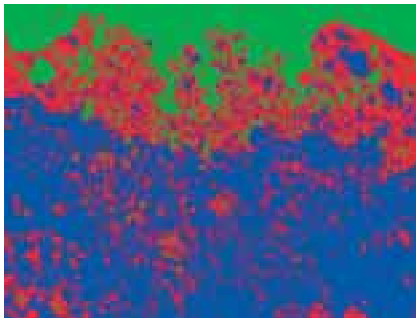

Figure 10. In Clemex Vision PE obtaining minimum, maximum and average thickness along a layer is an involved process including pre-processing to make the layer area more visually distinctive, using a color or gray-scale thresholding tool to separate pixels of the background from those of the layer, and applying a "chord size filter" so that spots of a certain diameter in the background that are similar to the color of the layer of can be ignored.

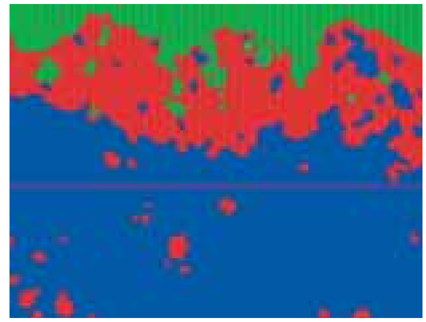

Figure 11. When color areas are filled and well-separated, Clemex Vision PE can perform thickness measurements by creating a set of vertical lines at regular intervals; a frameguard is applied to delineate the area of interest, and a color within that area is specified for measurement.

However, multiple measurements (automatic sampling at regular intervals along the layer) are extremely complex, though highly accurate. Many steps of preprocessing may be required to make the layer area distinctive. Then, "thresholding" (gray or color) separates pixels that belong to the background or non-layer material from those of the layer, based on color or gray scale. Next, it is necessary to apply a "chord size filter," one for the weathering layer and one for the underlying material, to filter out artifacts caused by pores or crystals of similar color as the other material (figure 10). This is done by specifying a diameter, then either removing spots those size or assigning them to the other color.

When color areas are filled and well separated, the analyst can perform measurements by creating a set of vertical lines at regular intervals along the weathering layer and measuring lengths. Once a color area to be measured is specified, a frame guard is applied to eliminate unwanted material from measurements (figure 11). At this point, information on the minimum, maximum, and average thickness can be obtained.

Interim Conclusions

There are clear differences between image analysis packages. Although Image J seems like an attractive choice because it can be downloaded for free, it has limitations that mean it is unlikely to be very useful in a conservation research laboratory. The other two packages cost about the same, but, at least for some applications, Image-Pro Plus appears to be less complex and easier to learn and use than Clemex Vision PE. However, the output of Image-Pro Plus is not the best, and information may need to be transferred to another program (such as Excel or SPSS) to produce publication-quality graphs and statistical tables.

Next Steps

We will continue the comparison of the three image analysis packages for more processes such as measuring crack (line) lengths and fractal characteristics; the relative percentages of certain components such as a sand temper versus clay matrix; porosity amount and distribution; degree of roundness of quartz grains; and average size of specified particles. As part of this work we are preparing protocol sheets to summarize how each procedure is accomplished for each package. Which package a particular laboratory may wish to choose may depend upon the specific procedures to be conducted, as well as upon personal preferences regarding measurement approaches. However, it is clear that comprehensive image analysis packages are extremely important for any laboratory capturing digital images at the microscope and using those images to understand and interpret cultural materials.

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Rodrigues, J. Delgado. 1996. Conservation of granitic rocks with application to the megalithic monuments. In *Degradation and Conservation of Granitic Rocks in Monuments*: 161-242. Brussels: European Commission, Directorate-General XII, Science, Research and Development.

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Sources of Materials and Equipment

Image-Pro Plus, available from Media Cybernetics, http://www.mediacy.com.
Clemex Vision PE (Professional Edition), http://www.clemex.com.
Image J, downloadable from http://rsb.info.nih.gov/ij/

All images in this paper were taken using a Polaroid DMC digital microscope camera (at http://www.polaroid.com/us/productcat/index.jsp) attached to a Nikon Labophot Pol polarizing microscope.

Development of a Web-Accessible Reference Library of Deteriorated Fibers Using Digital Imaging and Image Analysis

Proceedings of a Conference April 3-6, 2003

Closing

Meeting Outcomes

The participants formed work groups to address issues raised during the papers and group discussions. They committed to continue to work together on the key issues they identified among themselves. Developing a purpose statement to which all participants agreed was a key accomplishment.

Purpose and Scope

To establish a fiber reference database that rests in the public domain to be used as a comparative research tool and resource.

This statement serves the needs of all identified users such as conservators, curators, historians, textile scientists, conservation scientists, students, professors, microscopists, forensic scientists, archaeologists, and anthropologists.

Issues ranging from sample collection, to standardization of language and terms and methodoligies, to metadata specifications, to Web-accessibility, to fund raising were discussed. These topics will be addressed by the work teams and other parties who wish to participate. The foundation for a Web-accessible reference library of fibers is now well established.

Participant Biographies

Dr. Judy Bischoff is a Conservation Scientist at Harpers Ferry Center in West Virginia where she has established a scientific research and analytical services laboratory for the National Park Service. Prior to this position, she taught conservation science for four years to the graduate students in the Art Conservation Program at Buffalo State College. As part of her teaching duties, she taught an extensive laboratory and lecture course on optical microscopy, which included a section on fiber microscopy and visible light and fluorescence photomicrography. She has developed extensive computer and digital imaging expertise as they apply to conservation science research.

Her past experience also includes two Visiting Research Scientist positions, one at the Smithsonian Center for Materials Research and Education and the other at the National Gallery of Art. In addition, she was a National Endowment for the Arts Fellow in Conservation Science at the Conservation Services Laboratory at the Detroit Institute of Arts.

Dr. Bischoff has published on a variety of topics including technical studies on the materials and working methods of two famous Americans, the artist Rembrandt Peale and the architect Frank Lloyd Wright, an investigation into the effects of the deacidificant, Bookkeeper on individual objects, a determination of the role of the components in the aqueous-based resin soaps for the cleaning of painted surfaces and an investigation on the chemical image enhancement of faded vintage photographs.

Dr. Bischoff holds a BA in chemistry from Wheaton College in Massachusetts, an MS in inorganic chemistry from the University of Kansas, and a Ph.D. in organic chemistry from the University of Connecticut. As a Professional Associate of the American Institute for Conservation of Historic and Artistic Works (AIC), she is actively involved as one of its associate editors for the Journal of the American Institute for Conservation. She has served as both Vice Chair and Chair of the AIC's Research and Technical Studies Specialty Group.

Her current interests include the role of pore size on the desalination of archaeological ceramics, the investigation of fungicides, algicides, and herbicides for the mitigation of algae and lichen growth on historic tabby and coquina structures in the southeastern United States, retreatment methods for archaeological ceramics, the development of methods for the identification of organic pesticide residues on Native American objects, and the application of image analysis software in conservation for understanding changes in microscopic structure due to deterioration or conservation treatment.

Lucy A. Commoner has been the Senior Textile Conservator at the Cooper-Hewitt, National Design Museum since 1977. Previously, she was an Assistant Restorer for the Textile Conservation and Egyptian Departments at the Metropolitan Museum of Art where she prepared and installed the textiles for the Lila Acheson Wallace Galleries of Egyptian Art. She received a Bachelor of Arts degree in art history and studio art from Brown University. Her areas of expertise include, early Dynastic Egyptian textiles, folding fans (history and conservation), museum storage systems, fiber identification and microscopy, exhibition and mounting techniques for textiles, and the construction and maintenance of a conservation environment.

Michele R. Derrick is a chemist and conservation scientist with over 25 years experience analyzing and characterizing materials. She graduated from Oklahoma State University in 1979 with an MS in Analytical Chemistry then worked at the University of Arizona Analytical Center. In 1983, she joined the Getty Conservation Institute where she worked for 12 years as a conservation scientist. Michele currently has a dual role as a conservation scientist consultant for the Museum of Fine Arts, in Boston and as a chemist at a commercial analytical laboratory. In 1990, she organized infrared spectra exchange from 20 labs to form Art Materials Infrared Spectral Library. More recently, she has developed the Conservation and Art Materials Encyclopedia Online (CAMEO). CAMEO is an Internet database containing technical information on over 10,000 materials used in the production and conservation of historic and artistic objects and sites.

Inge Fiedler is a microscopist in the Conservation Department at The Art Institute of Chicago; she has held this position since 1979. She began her apprenticeship training in painting conservation and microanalytical techniques as applied to conservation in the Conservation Department at The Art Institute of Chicago in 1973. Between 1973 and 1979 she held the position of Technical Assistant in the same department. Her training was supplemented with specialized courses in optical microscopy, chemical microscopy, microanalysis, and chemistry taught at McCrone Research Institute, Illinois Institute of Technology, and Roosevelt University in Chicago. She received her MFA degree in studio art, with a concentration in photography, from the School of The Art Institute of Chicago, and a BFA degree in studio art also from SAIC.

Inge Fiedler has concentrated primarily on research of painting materials, with a particular interest in those used during the 19th century, although her research covers a wide variety of media and time periods reflecting the extensive holdings of The Art Institute's collection. She has also performed fiber analysis for the Department of Textiles and collaborated with the curator on an investigation of ancient Nubian textile fibers (results published in an exhibition catalogue in 1979). Throughout her career at The Art Institute, she has assisted the Department of Textiles with fiber analysis, working very closely with their staff scientist. She has lectured extensively on the application of microscopy to the study of works of art and has co-authored two chapters on artists' pigments in the Artists' Pigment Handbook series published by the National Gallery of Art, Washington, D.C. She has also investigated materials used by numerous 19th century artists such as

Georges Seurat, Claude Monet, and Paul Cézanne as well as modern and contemporary artists such as Grant Wood, Ellsworth Kelly, and Frank Stella.

Most recently Inge Fiedler has worked on two major research projects. One of the projects, done in collaboration with colleagues in Chicago and Amsterdam, studied the materials and techniques of the artists Vincent Van Gogh and Paul Gauguin in preparation of the exhibition held in Chicago and Amsterdam. This study focused mainly on Van Gogh's and Gauguin's collaborative use of materials while working together in Arles. The other recent project is an investigation of the materials of The Art Institute's collection of Northern European Paintings before 1600 in collaboration with the conservation department's special project's conservator and the curator of European Paintings. Recent publications include an appendix incorporating the research on Van Gogh and Gauguin in the catalog of the exhibition and a study of fatty acid migration in two works by Frank Stella, presented at the American Institute for Conservation meeting in St. Louis in 1999 and included in the Paintings Specialty Group Postprints.

Lorna Ann Filippini is Associate Conservator in the Textile Department of The Art Institute of Chicago. She has been fortunate in having the opportunity to care for the AIC textile collection since 1976. Postgraduate work includes studies at Roosevelt University Chicago, Illinois; the Abegg Foundation, Riggisberg, Switzerland; and C.I.E.T.A. Museé de Tissue, Lyon, France. Particular textile interests include structural analysis and study of Pre-Columbian textiles. Personal interests include painting, theater, and travel to archeaological sites and other museums.

Dr Fenella G. France received her Ph.D. degree in Textile Science from Otago University (1995) in Dunedin, New Zealand, and an MBA from Deakin University, Melbourne, Australia (1999). After lecturing at Otago University she was a textile and environmental scientist on the Star-Spangled Banner Project for the National Museum of American History, Smithsonian Institution. At present she is the research scientist at Art Preservation Services, New York, involved in textile and environmental related research, including special projects such as the preservation of the World Trade Center artifacts for the Port Authority of New York.

Joy Gardiner is currently Textile Conservator/ Assistant Director of Conservation at the Winterthur Museum, Garden & Library and a Winterthur Assistant Professor of Art Conservation in the Winterthur/University of Delaware Art Conservation Program. She received a BFA in Textile Arts from Moore College of Art and an MS in Art Conservation with a concentration in textile conservation from the Winterthur/University of Delaware Program. Her third-year internship was spent at the Textile Conservation Center, then in North Andover, MA. She had a NEA Master Apprenticeship in Textile Conservation at the Philadelphia Museum of Art (PMA), then contract work for PMA and other clients until joining Winterthur's staff in 1990.

Jan Gauthier is Deputy Associate Manager, Knowledge Archives and Training, Harpers Ferry Center. Jan began her NPS career at Voyageurs National Park in 1972 as a GS-4 Clerk-Steno. She held several positions at that park including Purchasing Agent, Administrative Technician, Secretary, Museum Aid and Administrative Officer. She transferred to Apostle Islands National Lakeshore in 1985 to the Administrative Officer position. In 1988 she transferred to St. Croix National Scenic Riverway as Administrative Officer. In 1994 she was promoted to Management Assistant and Chief of Operations. In the fall of 1996 she became the Servicewide Training Manager for Administration at the Mather Training Center. She graduated from the Executive Leadership Program in 1995. She recently graduated from the American Society of Training and Development's "Human Performance Improvement" program. She has been a member of the Servicewide Advanced Administrative Instructor Team since 1988.

Dave Gilbert is Web Manager at Harpers Ferry Center, the National Park Service Interpretive Design Center in Harpers Ferry, West Virginia. Dave joined the National Park Service in 1998 after serving as Publications Manager for the Harpers Ferry Historical Association, a National Park Service Cooperating Association which supports the educational and interpretive programs of Harpers Ferry National Historical Park. In addition to managing the Harpers Ferry Center website, Dave has developed database-driven Web applications for the NPS Media Inventory Database System (MIDS), the NPS Graphic Identity Program, and the NPS Historic Photograph Collection.

Christine Giuntini is Associate Conservator at the Metropolitan Museum of Art where she has worked for over 20 years. She cares for the ethnographic and archaeological textiles and composite objects for the Department of the Arts of Africa, Oceania and the Americas. These collections contain diverse fiber artifacts, both plant and animal. Ms. Giuntini lives in New York City with her husband and two children.

Robin Hanson received a BA degree in art history from Mount Holyoke College and an MA in arts administration from New York University. Her graduate training in conservation, with a specialization in textile conservation was undertaken at the Winterthur/University of Delaware Program in Art Conservation. She then completed a two-year advanced internship in textile conservation with the National Park Service where she began in earnest her involvement with the Park Service's fiber library. Since 1999 she has run the textile lab at the Cleveland Museum of Art.

Kathyrn Jakes is a Professor at Ohio State University, where she teaches textile courses and conducts research in fiber science. Studying historic and archaeological materials from many sources, she examines their composition and structure, uncovering clues to their history of use and degradation.

Melanie McMillin is employed by the New York City Police Department Laboratory as a Criminalist, specializing in trace evidence analyses, including, hairs, fibers, and ignitable liquid residue detection in fire debris. She is also an adjunct lecturer in forensic science and natural science at John Jay College of Criminal Justice. She possesses a BS degree in forensic chemistry from Ohio University and is currently pursuing an MS degree in forensic science from John Jay College of Criminal Justice. Membership affiliations include the American Academy of Forensic Sciences and the North Eastern Association of Forensic Scientists. Her academic and professional training have enabled her to participate in numerous courses in hair and fibers analyses, microscopy, and digital imaging. Her practical experience is based on experiments with small sample sizes using standardized methods of analysis.

Jane Merritt has been the Senior Textile Conservator at Harpers Ferry Center, the interpretive media center for the National Park Service for the past 12 years. She has held conservator positions at the Association pour l'Etude et la Documentation des Textiles d'Asie in Paris, France; The Textile Museum in Washington, DC; and the Metropolitan Museum of Art in NY. She has a particular interest in textile materials and fabrication technologies. She holds a BA in Art History, and an MS in Textiles from the University of Maryland.

Ms. Merritt is a Fellow of the American Institute for Conservation and is currently the recipient of their Samuel H. Kress Publications Fellowship to write a book on preventive conservation for historic house museums

Denyse Montgut received an MA in art history and an Advanced Conservation certificate from New York University, Institute of Fine Arts and an ABD University of Delaware (Art Conservation Research). She has done internships and contract work for the Costume Institute of the Metropolitan Museum of Art, the American Museum of Natural History, the Cooper-Hewitt, National Design Museum. Currently she is the contract textile conservator for the Guggenheim Museum, runs a private conservation practice "Archive and Conservation Services," and is chair of the Museum Studies graduate program in Textiles and Costume at the Fashion Institute of Technology, New York. She has taught fiber identification, microscopy, and conservation science for textiles and related materials for the last 10 years.

Kathleen Mulligan-Brown graduated from the Fashion Institute of Technology. She worked in various garment industry companies for several years before settling in with the US Customs Laboratory located in New York City in 1983. She worked in the New York Laboratory for 4 years before moving to the Savannah Laboratory. Over the last twenty years, she has received training in the analysis of wood and paper products as well as attending various courses at the Fashion Institute of Technology and the McCrone Institute. Ms. Mulligan-Brown has been a member of our national methods team since 1995. (These teams were developed in conjunction with the laboratories' push towards accreditation.) She currently is the Methods Team Leader for the methods in the Textile/ Wood/Paper areas as well as the US representative in the NAFTA Laboratory Working Group for textiles and footwear. She is also a member of the ASTM D13 committee.

Cary T. Oien has been an examiner in the Trace Evidence Unit (TEU) of the FBI Laboratory since 1995. During that time, he has worked cases in the areas of hair, fiber, fabric, cordage, fabric impressions, tape, wood, entomology, and feathers. He has testified in both Federal and State/Local courts in a variety of areas of trace evidence examination. He is also the program manager for Quality Assurance/Quality Control (QA/QC) in the Trace Evidence Unit. In addition to assigned casework and managing technicians, the QA/QC Manager is responsible for coordinating and implementing the Laboratory Division's QA/QC program within the Trace Evidence Unit, writing and maintaining protocols, and monitoring safety and security within TEU. Mr. Oien has published papers and a book chapter concerning his research in the field of entomology, and continues to conduct research in the field of trace evidence. He is the primary instructor for the FBI Laboratory's "Introduction to Hairs and Fibers" course. In addition to this course, Mr. Oien has given courses and talks regarding trace evidence examination and evidence collection to a variety of audiences.

Chandra L. Reedy is a Professor in the Museum Studies Program at the University of Delaware. She also holds secondary appointments in the Art History Department and in the Center for Historic Architecture and Design, and serves as director of the Laboratory for Analysis of Cultural Materials. She received her Ph.D. degree from UCLA, then worked as a conservation scientist at the Los Angeles County Museum of Art before moving to Delaware. She served for eight years as Editor-in-Chief of the Journal of the American Institute for Conservation, and for 14 years as director of U.D.'s Ph.D. Program in Art Conservation Research. She is the author or co-author of five books and over 40 articles.

Angharad Rixon is a researcher, lace maker, and artist from Campbelltown (near Sydney), Australia. She completed a Bachelor of Creative Arts, majoring in textiles, at the University of Wollongong in 2000. Moving towards a specialization in lace history, her honors thesis was an investigation of lace fragments, which were retrieved from the wreck of the Dutch East India Company ship *BATAVIA* which was wrecked off the coast of Western Australia in 1629. This project applied an archaeological approach to the study of lace and included a fiber analysis of these fragments comparing them with fibers taken from other laces of the same period. In 2001 she conducted a study of the fiber content of the 16th and

17th century laces in the Powerhouse Museum, Sydney, looking at potential relationships between the fiber content of an object and its origin, particularly the use of cotton in early laces. This research was presented at the North American Textile Conservation Conference in Philadelphia, PA in April 2002. She is currently based in Florence, Italy, where she is conducting research on a private lace collection for her Ph.D., which will be for the Centre for European Studies at Monash University.

Michael B. Toth is an independent consultant with R.B. Toth Associates, which provides a range of strategic services for organizations seeking to structure appropriate and practical responses to complex issues. He provides systems integration and strategic planning for the study, preservation, and display of cultural objects for museums and libraries. In this role Mr. Toth brings extensive US Government experience in program management, strategic planning, and systems integration with his work on information and space systems and subsystems. He has managed the development, integration, and operation of imagery and geospatial information collection, processing, dissemination, and storage systems. He currently manages the integration of a range of US Government information systems and databases.

Experience includes Technical Advisor/Systems Integrator, Archimedes Palimpsest Imaging Program, Walters Art Museum, management, planning and integration of multispectral image collection, processing, data storage, dissemination and study.

National Policy Director, National Reconnaissance Office-development and implementation of globally accessible imagery and geospatial information support systems and databases

Program Manager, Community Open Source Program Office-development of international programs for Internet information sharing

Systems Engineer, National Reconnaissance Office-development and implementation of spacecraft command and control systems

Information Officer, Foreign Broadcast Information Service-Foreign press dissemination, archival and translation services

Education includes a BA in History from Wake Forest University, 1979; graduate Management courses at George Mason University; and Management and National Policy Seminars, Kennedy School of Government, Harvard University and Brookings Institute.

Paul Wyeth joined the Department of Chemistry at Southampton University (UK) in 1978 and now holds a joint appointment as Lecturer in Chemistry and Lecturer in Conservation Science at the Textile Conservation Centre (TCC), and heads the Conservation Science Research Group, which is affiliated to the AHRB Research Centre for Textile Conservation and Textile Studies, at the TCC. He is a Fellow of the Royal Society of Chemistry and a member of the United Kingdom Institute for Conservation and of the Institute for Conservation Science. He has recently helped to establish the Southern Conservation Network, which supports heritage conservators and curators in the South of

England. He teaches the fundamentals of textile science to MA Textile Conservation students, and provides analytical support to Conservation Services at the TCC. His research encompasses the general themes of "Monitoring historic textiles on open display" and "Informing the preventive conservation of textiles," with particular emphasis on the characterization of fiber degradation by non-destructive methodology, especially microstructural and microchemical analysis.

Selected Publications and Reports

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Chang L. and P. Wyeth, 2002. Chemical Finishes on Indigo-dyed Cloth: Characterization of Miao and Miao-related Costume for Guizhou, China. *North American Textile Conservation Conference Preprints, Strengthening the Bond: Science and Textiles*. Philadelphia, PA. 25-34.

Garside, P. and P. Wyeth, 2002. Characterization of silk deterioration. *North American Textile Conservation Conference Preprints, Strengthening the Bond: Science and Textiles*. Philadelphia, PA. 55-60.

Garside, P. and P. Wyeth, 2000. Characterization of plant fibres by infrared spectroscopy. *Polymer Preprints*, 41(2), 1792-1793.

Web Links

Personal Web page
www.soton.ac.uk/~pw

Conservation Science Research Group
www.soton.ac.uk/~csrg

Textile Conservation Centre
www.textileconservationcentre.soton.ac.uk

MA Textile Conservation at the TCC
www.wsa.soton.ac.uk/courses/framepgmatexcon.htm

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