

# Forensic Hair and Fiber Examinations in Archaeology: Analysis of Materials from Gravesites at the Home of Samuel Washington

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## ABSTRACT

Forensic trace-evidence examiners can make significant contributions to the analysis of archaeologically recovered materials. Analytical methods routinely used by forensic trace-evidence examiners were applied to fibers recovered during exhumations of remains from a family cemetery on the grounds of Harewood, a 17th-century plantation house near Charles Town, West Virginia. Samuel Washington, a younger brother of George Washington, built the house and was believed to be buried in the cemetery. Human hair from a person of European ancestry was found in one grave. Textile fragments containing cotton and silk fibers were found associated with wooden coffin fragments at two other gravesites. The survival of these natural fibers is attributable to their proximity to sources of copper ions.

## Introduction

Forensic science and archaeology have strong affinities. Both fields deal in the reconstruction of past events; both make use of the careful documentation and collection of artifacts. Forensic science disciplines such as anthropology, molecular biology, and pathology can obviously contribute to the study of human remains exhumed in the course of archaeological excavations. Forensic trace-evidence examiners, who specialize in the examination of minute pieces of evidence, can also make significant contributions to the analysis of archaeologically excavated materials. The nature of their discipline requires that they be able to extract the maximum amount of information from often irreplaceable pieces of evidence. Their examinations focus on first identifying what the evidence is and then on trying to determine from where it came. To accomplish these goals trace-evidence examiners employ a variety of analytical techniques, including polarized light microscopy (PLM), scanning electron microscopy (SEM), Fourier transform infrared spectrometry (FTIR), and pyrolysis-gas liquid chromatography (Pyr-GLC). The list of potential trace

evidence is long: glass, soil, paint, explosive residues, ignitable liquid residues, hair, and fibers. Historical archaeologists, from time to time, encounter items on this list that require identification. The archaeologists may also want to know from where the items may have come. The analytical skills of forensic trace-evidence examiners make them particularly valuable collaborators in these endeavors. Examination of archaeological samples can also benefit forensic trace-evidence examiners: they may encounter similarly deteriorated specimens in the course of a forensic investigation.

This paper focuses on the examination of hairs and fibers recovered in archaeological excavations and will present, by way of illustration, the results of examinations of fibers recovered in the course of the excavation of gravesites in a family cemetery near Charles Town, West Virginia.

## Hairs

Hairs are frequently encountered in forensic investigations, and forensic trace-evidence examiners are familiar with their analysis (Bisbing 2002). Many archaeologists have also developed expertise in the analysis of hairs (Appleyard and Wildman 1970). Sites of human occupation may have hairs from a variety of sources: human inhabitants, domesticated animals (e.g., cattle, sheep, goats, dogs, and cats), vermin (rats or mice), and game animals. Humans have put hairs to a variety of uses: animal hairs have been used in clothing, for decoration, and in cordage.

A typical hair can be thought of as resembling a lead pencil. Its core (corresponding to the lead) is the medulla, a column of specialized cells. These cells frequently shrink after they are created and air or fluid infiltrate the resulting voids. Air-filled medullas appear dark when the hair is viewed with a transmitted-light microscope, while fluid-filled medullas look like bubbles. The widths and

morphologies of visible medullas help identify the species of mammal from which the hair came. For example, cervid hairs (i.e., those of deer, moose, and elk) are characterized by wide lattice medullas.

The cortex of a hair corresponds to the wood in the lead pencil. It consists of elongated keratinized cells held together by matrix proteins. The cortex may contain pigment granules (which may range in size from very fine to very coarse). Occasionally, the cortex may contain other structures such as *cortical fusi* (small fluid-filled vesicles) and ovoid bodies (irregular dark cavities). Hairs also contain a third type of specialized cell: cuticular scales. These flattened cells constitute the outer surface of the hair. Like the morphologies of medullas, cuticular-scale patterns help identify the species of mammal from which the hair came. The presence of scales immediately identifies a fiber as a hair. Mechanical and chemical treatments of human and animal hairs (as well as environmental exposures), however, can strip away the cuticular scales.

Human hairs may also show additional features of interest to archaeologists. Human hair may be infested with lice and ticks, which are vectors for debilitating diseases. Lice eggs may be found attached to the shafts of hairs. Putrefactive fluids from the decaying skin of corpses can break down hair structures, producing what are called putrid roots and dark decomposition bands in the shaft of the hair (Linch and Prahlow 2001; Rowe 2001).

## Fibers

Humans have employed various types of fibers for millennia. As is the case with hair, a number of archaeologists have developed expertise in the examination of natural textile fibers (Appleyard and Wildman 1970; Janaway 2002). Fibers are a frequently encountered type of trace evidence (Scientific Working Group on Materials Analysis 1999; Eyring and Gaudette 2005). Plants are sources of cellulosic fibers such as cotton, flax, hemp, and ramie. Animals are sources of wool and silk. Some silicate minerals crystallize in fibrous habits; these are the asbestiform minerals. The 20th century saw the introduction of a number of artificial or synthetic fibers, which are collectively referred to in the textile industry as manmade fibers. Some, like rayon and cellulose acetate, are produced from cellulose; others, such as nylon, acrylics, and polyesters, are produced

from petrochemicals. The presence of artificial fibers in an archaeological deposit may indicate that the deposit (and possibly the entire site) has been disturbed and contaminated. On the other hand, if the site being excavated dates to the 20th century, the presence of a particular type of synthetic fiber in an archaeological stratum can provide a *terminus post quem* for that stratum. For example, the author examined fabric samples recovered during an archaeological salvage excavation from the bottom of a deposit dated to the early 20th century by documentary evidence. One fragment was a piece of knitted nylon hosiery; the other was a piece of woven cellulose triacetate. Neither of these fibers was available until after World War II.

Natural fibers are identified by PLM in conjunction with some simple staining procedures. For example, phloroglucinol:hydrochloric acid can differentiate vegetable fibers based on their degree of lignification (Palenik and Palenik 2005). With the exception of viscose rayon, artificial fibers rarely have morphological features that identify the fiber type. Fibers with a particular polymer composition may be made with a number of different cross sections depending on the intended end use. Forensic trace-evidence examiners use PLM to determine the generic classifications of fibers. The optical properties determined by PLM include the following:

1. *The isotropic index of refraction*: the index of refraction of the fiber determined with unpolarized light. For fibers having two indices of refraction (one for light polarized parallel to the fiber axis and another for light polarized perpendicular to the fiber axis), the isotropic index of refraction is the average of the two.
2. *The sign of elongation*: if the index of refraction of light polarized parallel to the axis of the fiber is higher than that of light polarized perpendicular to the fiber axis, the fiber is said to exhibit positive elongation; a fiber having an index of refraction for light polarized parallel to its axis lower than that for light polarized perpendicular to the axis has negative elongation.
3. *The birefringence*: In the case of fibers, this is the difference between the index of refraction for light polarized parallel to the fiber axis and that

for light polarized perpendicular to the fiber axis. The birefringence of a fiber can be estimated from the colors exhibited by the fiber when it is observed between crossed polarizing filters.

An experienced forensic trace-evidence examiner can identify a fiber as acetate, acrylic, nylon, or polyester in just a few moments. These findings can be confirmed and extended by FTIR and pyr-GLC. An FTIR spectrometer with a microscope accessory can be used to obtain the infrared spectrum of a single fiber. Infrared spectra allow differentiation between the different types of polyester and the different types of nylon. Many forensic science laboratories have both reference collections of fibers and also computerized libraries of infrared spectra of fibers. Pyr-GLC provides the same differentiation but consumes the sample. In pyr-GLC the fiber is thermally decomposed in an inert atmosphere; the resulting molecular fragments of the fiber polymer are separated in a gas chromatograph. Fibers with different chemical compositions will produce pyrolysis chromatograms (often referred to as pyrograms) with distinctive patterns of peaks.

### Comparative Microscopic Examinations of Hairs and Fibers

The final forensic examinations of hairs and fibers are comparative in nature (Scientific Working Group on Materials Analysis 1999; Bisbing 2002; Eyring and Gaudette 2005; Scientific Working Group on Materials Analysis 2005). Reference samples or exemplars from possible sources are compared microscopically with the questioned samples. The main analytical tool here is the comparison microscope, which consists of two transmitted-light microscopes joined by a comparison bridge. The colors of natural and manmade fibers are important points of comparison. The human visual system can often detect subtle differences in color. Because of the phenomenon of metamerism (apparent matching of colors of objects with different reflection or transmission spectra), more stringent color comparisons may be required using scanning ultraviolet-visible microspectrophotometers or thin-layer chromatography (TLC). Color comparisons involving fibers that have been exposed to the environment for extended periods of time should be approached with care. Dyes can be leached from fibers by rain or by groundwater; dyes are also subject to photo-

chemical oxidation. In the case of hair specimens, unknown and known hair samples can be compared microscopically. If they match, mitochondrial DNA may be extracted from the unknown hair samples (unfortunately destroying them in the process) and sequenced. The mitochondrial DNA sequence obtained from a hair can be compared with mitochondrial sequences obtained from other biological samples from the suspected source or with sequences from maternally related family members. Mitochondrial DNA sequencing can be applied to hairs that are not suitable for microscopical examination (unmedullated gray hairs, for example) (Stone et al. 2001).

### Taphonomy of Hairs and Fibers

Textile materials composed of natural fibers do not generally survive long-term burial (Janaway 2002). Natural fibers are quickly degraded by the action of soil microorganisms unless the burial conditions inhibit biodegradation. Desiccation, freezing, and the presence of metal ions such as chromium or copper retard microbial action. Absorption of clay particles by biological molecules will also retard microbial attack. Waterlogged soils with low oxygen concentrations will exclude aerobic fungi, although anaerobic bacteria may still flourish.

Soil pH is important in the preservation of textile fibers. In acidic environments, the survival of protein fibers (e.g., wool, animal hair, and silk) is favored, while cellulose-based materials (e.g., cotton and linen) degrade rapidly. Under the more unusual anaerobic alkaline conditions, the survival of cellulose-based material is favored (Janaway 2002).

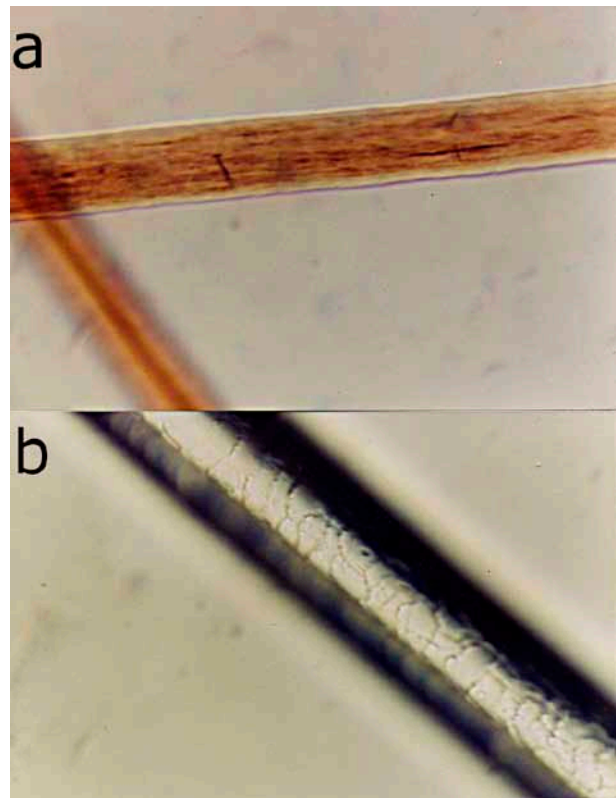
The chemistry of the degradation of cellulose is well understood. In an acid environment, cellulose molecules are susceptible to hydrolysis of the glycoside link between the glucose units. Cellulose chains are shortened and the fiber is structurally weakened. The hydroxide groups in cellulose may also be oxidized to form oxycellulose. The formation of oxycellulose disrupts hydrogen bonding between cellulose chains, reducing fiber strength and causing further degradation of the fiber. Cellulose is readily attacked by cellulolytic enzymes of microorganisms (cellulases). In well-aerated soils, cellulose is degraded by fungi, myxobacteria, and eubacteria. Under anaerobic conditions, it is degraded primarily by *Clostridia* (Janaway 2002).

Artificial fibers vary significantly in their ability to survive environmental exposure (Rowe 1997). Those derived from cellulose (rayon, acetate, and triacetate) break down rapidly in a soil environment. Acetate and triacetate fibers may be hydrolyzed back to cellulose, which is then attacked by soil enzymes, or the soil enzymes may directly attack the cellulose backbone of the fiber polymer. The fibers derived from petrochemicals are far more resistant to decomposition. Soil does not contain microorganisms that produce enzymes capable of breaking down these fibers. They are subject to oxidation, however, particularly if they are exposed to sunlight. Photochemical oxidation can break down the chemical structures of the polymers comprising the fibers. It will also cause the colors of natural and artificial fibers to fade; groundwater can also leach dyes from fibers.

#### Excavations in Harewood Cemetery: A Case Study in Hair and Fiber Examination

In 1999 excavations were undertaken in a family cemetery at Harewood, a 17th-century plantation house located four miles west of Charles Town, West Virginia. These excavations were under the direction of James E. Starrs, a professor at the George Washington University Law School and a professor of forensic sciences. The object of the excavation was to find the grave of Samuel Washington, a younger brother of George Washington. Samuel Washington built Harewood and lived on the plantation until his death. Over the intervening years the location of his grave had been forgotten. The family cemetery contained both marked and unmarked graves. It was known at the outset of the excavation that the contents of some of the graves had been transferred elsewhere in the late 19th or early 20th centuries. Those graves with headstones were assumed to be correctly marked, and the excavations focused on the unmarked graves. The locations and orientations of the unmarked graves were determined using ground-penetrating radar. The excavations turned up no human remains but did uncover wood fragments, metal coffin components, and a variety of hair and fiber samples.

Loose fibers that appeared to be human hair were found interspersed in the soil of one of graves (designated 2-1). Figure 1 shows photomicrographs of one of the fibers and a cast of the cuticular scale pattern of another fiber. Based on cuticular scale pattern, length, texture, presence of scissor-



**Figure 1.** Photomicrographs of hairs from gravesite 2-1: (a) longitudinal view and (b) scale cast. (Photos by author, 1999.)

cut ends, and general microscopical appearance the fibers were determined to be human head hairs from a person of European ancestry. The fineness of the hair was consistent with that of a child.

Two other graves (designated 3-2 and 3-3) produced large numbers of wood fragments (Figure 2). The context of the material, the thicknesses of the wood fragments, and the rows of decorative brass or copper tacks suggested that these were fragments of coffins. The fragments that bore decorative tacks showed an interesting pattern of preservation: oval regions of intact wood centered on the decorative tacks. This pattern of preservation is likely the result of the antimicrobial activity of copper ions leaching into the soil from the tacks. Textile fragments were found under the heads of many of the tacks. Again, these were presumably preserved by the antimicrobial action of the copper in the tacks. There were two types of textile. The Type I textile (Figure 3) was found on the grave 3-2 fragments and consisted of friable brown and white yarns woven into a narrow strip of fabric (presumably decorative). The Type II

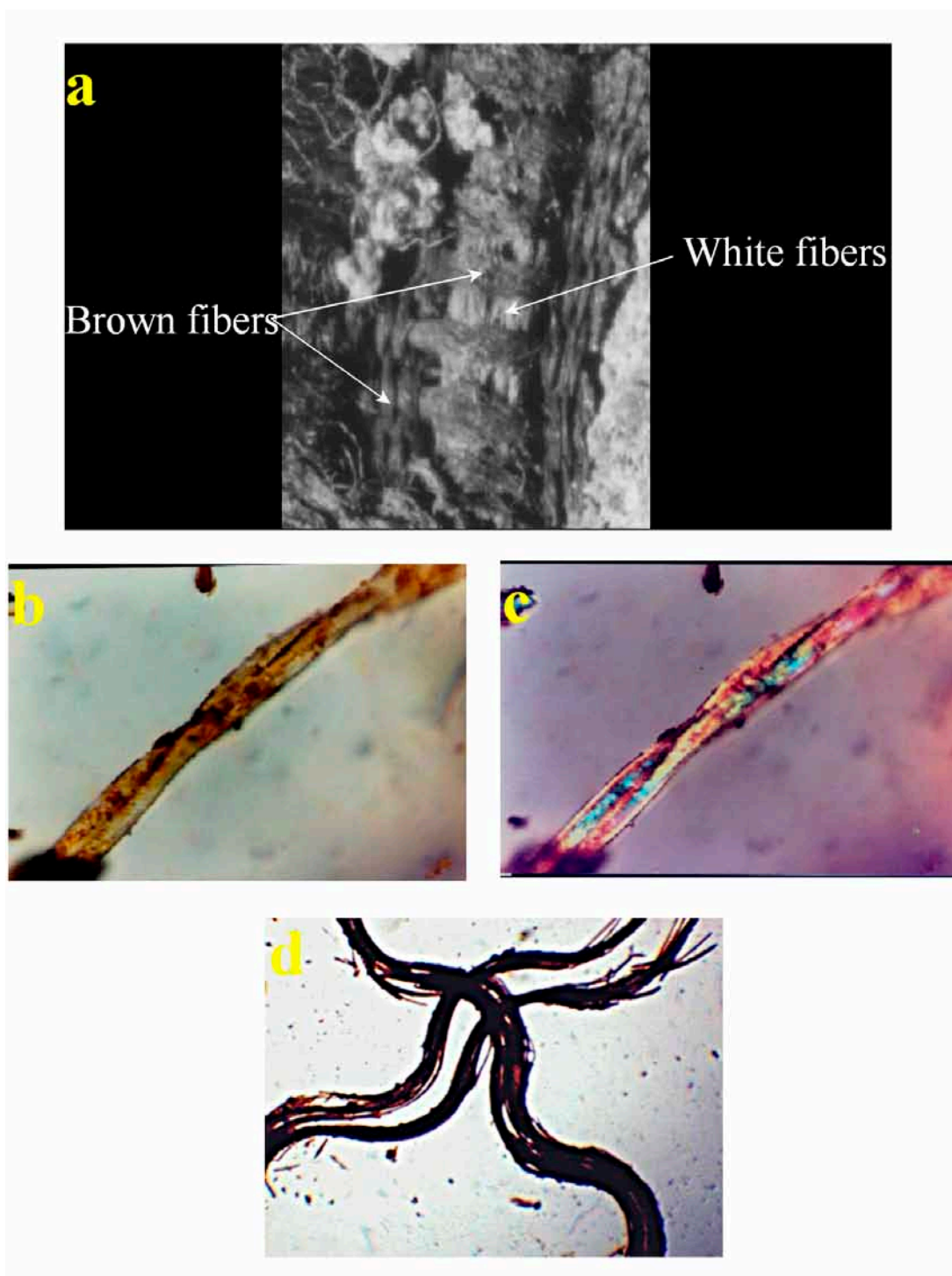


**Figure 2.** Wood fragments and other artifacts from gravesite 3-3. (Photo by author, 1999.)

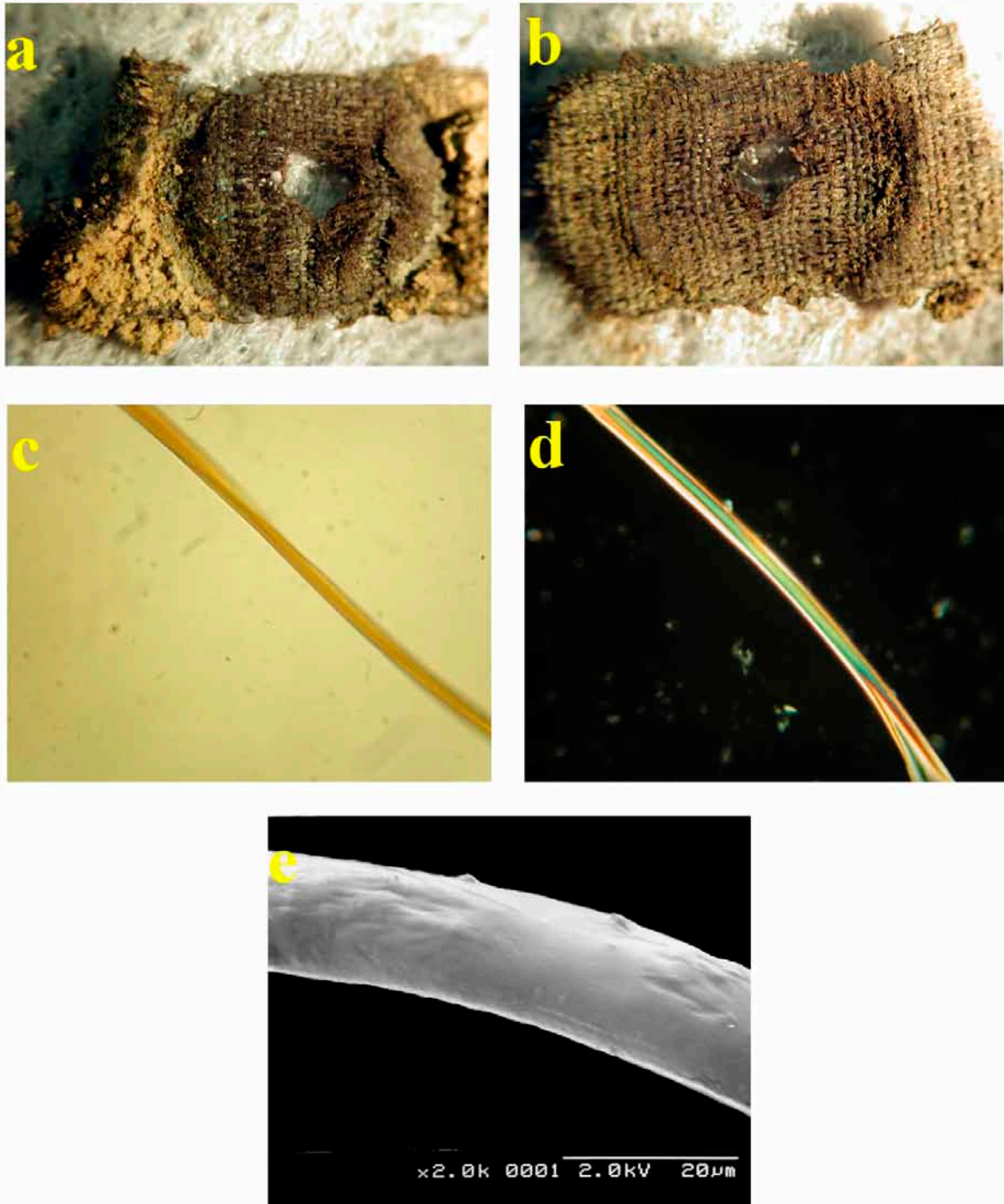
textile (Figure 4) was found on the grave 3-3 fragments and was composed only of friable brown yarns in an open plain weave. Microscopical examinations (Figure 3*b* and *c*) of the fibers in the white yarns of the Type I textile revealed them to be unmercerized cotton. Microchemical tests (reactions with concentrated nitric acid and 5% sodium hypochlorite solution) showed that the brown fibers in both textiles were probably composed of protein. Microscopical examinations of the brown fibers (Figure 4*c–e*) revealed them to be consistent with silk. The original colors of these fibers could not be determined. Buried silk fibers are known to turn honey brown (Janaway 2002).

Infrared spectra of the brown fibers were obtained using the potassium bromide (KBr) disk technique: a tuft of the fibers was ground with KBr, the mixture was pressed into a thin disk, and the infrared spectrum of the mixture was then scanned from  $400\text{ cm}^{-1}$  to  $4400\text{ cm}^{-1}$ . Because of their friability the brown fibers were easily ground to a fine pow-

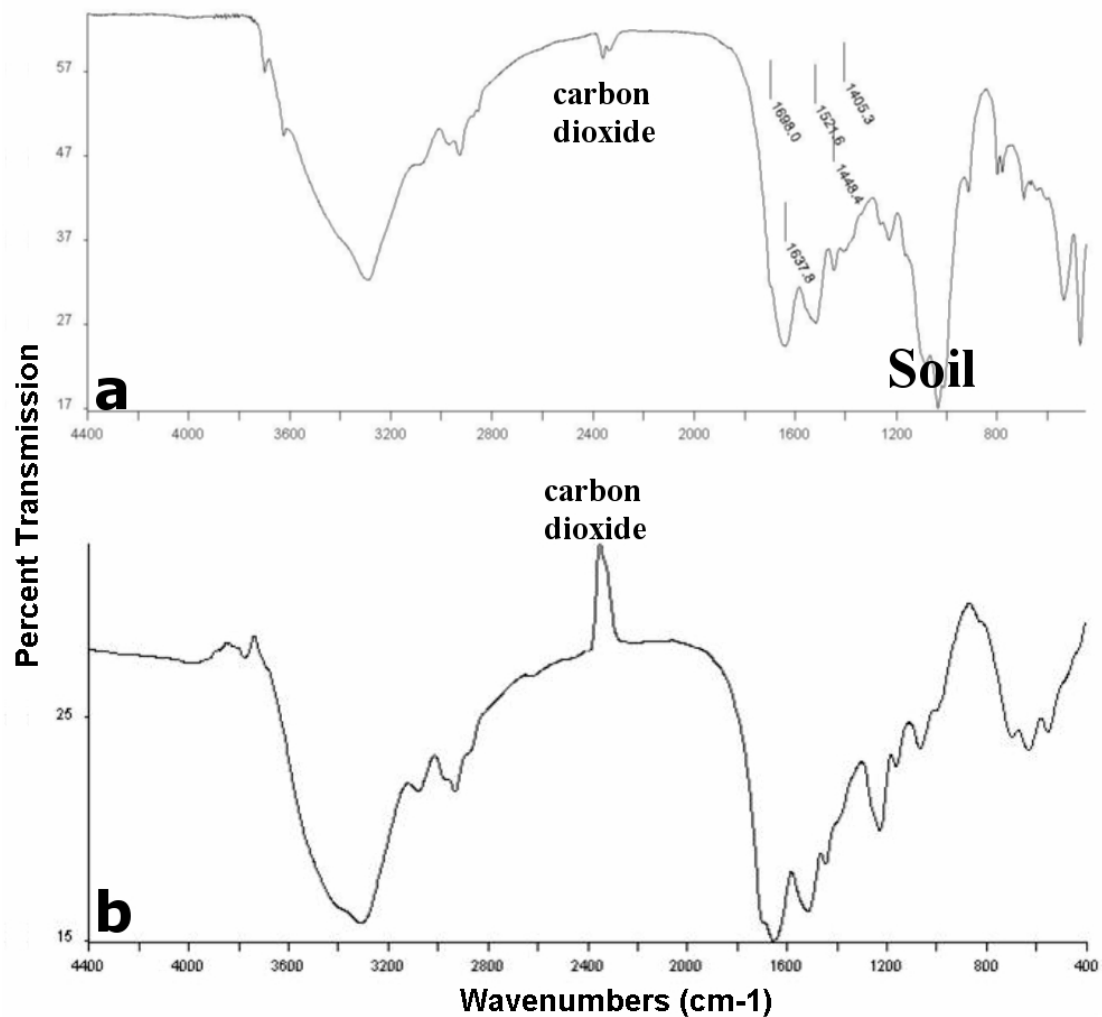
der and dispersed in the KBr. Although efforts were made to remove adhering soil particles from the fibers, some of these remained and contributed to the infrared spectra. Silicate minerals have infrared absorption bands in the mid-infrared region (Salisbury et al. 1991). An infrared spectrum of the soil was obtained and subtracted from the infrared spectra of the brown fibers. As may be seen in Figure 5, the contribution of the soil particles to the infrared spectrum of the fibers could not be completely removed. The infrared spectral region from  $1200\text{ cm}^{-1}$  to  $1800\text{ cm}^{-1}$  was available for study and for comparison with the infrared spectrum of known silk fibers, however. The infrared absorptions of the peptide linkages in the fibroin protein that comprise silk fall within this spectral region (Krimm and Bandekar 1986). The agreement between the major absorptions of the brown fibers and those of known silk in this spectral region is remarkably close and indicates that much of the conformational structure of the fibroin has survived burial intact.



**Figure 3.** Type I textile from gravesite 3-2: (a) textile in situ on back of tack; (b) white (cotton) fiber; (c) white (cotton) fiber, partially uncrossed polars; and (d) brown (silk) fibers. (Photos by author, 1999.)



**Figure 4.** Type II textile from gravesite 3-3: (a) upper surface of textile, showing impression of tack head; (b) lower surface of textile; (c) brown (silk) fiber; (d) brown (silk) fiber, crossed polars; and (e) scanning electron micrograph of brown (silk) fiber. (Photos by author, 1999.)



**Figure 5.** Infrared spectra: (a) brown (silk) fiber from gravesite 3-3, with the absorption peak at approximately 1,050  $\text{cm}^{-1}$  from soil and (b) known silk. (Photos by author, 1999.)

### Conclusions

Forensic trace-evidence examiners possess skills that can aid archaeologists in the identification of fibers that may be recovered in the course of excavations. Their laboratories have a wide array of analytical instrumentation that can be used to analyze these fibers. In the case of the samples from the Harewood family cemetery, the use of routine forensic fiber examinations allowed the identification of human hair and two types of natural fibers (cotton and silk). Finally, examination of archaeological specimens can give forensic trace-evidence examiners a better understanding of the taphonomy of various forms of trace evidence. The cotton and silk fibers in graves 3-2

and 3-3 survived because of their close association with sources of copper ions, which are known to have antimicrobial activity. The fragmentary condition of the material recovered from the graves along with the lack of human skeletal remains led the leader of the excavation team to the conclusion that the contents of graves 3-2 and 3-3 had been moved to another location. Neither of the graves was that of Samuel Washington.

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