HAIR TODAY, GONE TOMORROW: THE DEGRADATION AND CONSERVATION OF ARCHAEOLOGICAL HAIR FIBERS

A Thesis

by

REBECCA M. SAGER

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF ARTS

May 2008

Major Subject: Anthropology

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Approved by:

Chair of Committee, C. Wayne Smith
Committee Members, Donny L. Hamilton
Shawn Ramsey
Head of Department, Donny L. Hamilton

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ABSTRACT

Hair Today, Gone Tomorrow: The Degradation and Conservation of Archaeological Hair Fibers. (May 2008)

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Chair of Advisory Committee: Dr. C. Wayne Smith

The research of this work describes the degradation and conservation of archaeological hair fibers. Chapter I will be a brief overview, with Chapter II following with a literary review and definition of terms. Chapter III focuses on research centered on the structure of hair fibers and their physical and chemical attributes. It will also focus on the archaeological and historical evidence of hair fiber use by humans. This research will help form the backbone of the paper and experiments performed.

The next chapter focuses on the degradation of hair fibers in different environments. Hair fibers left in underwater, open air, burial, and arid environments are monitored for degree of degradation and brittleness. The hair fiber types used are four commonly found hair fibers types: coarse wool, fine wool, mohair, and human hair.

After deposition, conservation using silicone oil treatment is tested on the degraded hair fibers. When silicone oil treatment proves to be a viable conservation method, the technique is then be applied to two artifacts. The two artifacts used are a Victorian era watch fob made from human hair and hair fibers mixed with tar from the excavation of *Kittern* in Bulgaria.

Chapter VII deals with the conclusions of the experiments as a whole. The degradation of the fibers in different environmental conditions show that burial in acidic

sandy clay is the most detrimental to hair fibers, while hair fibers from arid, dry environments are brittle, but well preserved aesthetically. The silicone oil treatments are shown to be viable treatment methods with positive results for all of the fibers tested, including two artifacts, a Victorian watch fob made from human hair fibers and hair fibers mixed with a tar-like substance from the shipwreck *Kittern* in Bulgaria.

To my parents, who always believed I could do anything.

ACKNOWLEDGMENTS

First, I would like to thank the head of my committee, Dr. Smith for his guidance and for allowing me to use his lab for my experiments. Thanks also to my other committee members, Dr. Hamilton, for introducing me to the wonderful world of conservation, and Dr. Ramsey, for giving me unlimited access to wool and mohair for my experiments. Without these individuals, I would never have been able to get this far.

Thanks are also due to my friends and colleagues in the Department of Anthropology. I would like to thank Helen DeWolf, who offered guidance and hope when things seemed the bleakest. Special acknowledgment also goes to Starr Cox and Eloise Eilert for their constant support and unending patience with my obsession with my research.

Finally, I need to thank Chris Crews and my parents. Chris has been my support during the worst times and has always cared about my work and me. My parents have supported me through life. Their support, encouragement, and belief in me have led me to know that I can accomplish anything and that the best job to have is the one you enjoy.

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CHAPTER I

INTRODUCTION: HAIR TODAY, GONE TOMORROW

Hair today, gone tomorrow. Cheesy? Yes. A pun that would make even Shakespeare groan? Definitely. However, it is a tongue-in-cheek way of bringing to light an important issue in conservation and preservation. Conservators have largely neglected the preservation of human and animal hair fibers. These types of artifacts can be found in several forms in the archaeological record, including in raw form, textiles, and on the bodies of the deceased. Although hair fibers can be quite resilient in certain circumstances, they are still susceptible to degradation and require additional attention after excavation. Conservators all over have different ways of dealing with the problem of preservation of hair fibers, but few, if any, protect the hair in a way that easily allows for analysis or display. It is also important for field archaeologists to know what condition hair fibers may be in when excavating. Many times, the fibers found are brittle and difficult to handle. Often, individual fibers break no matter how careful the individual is in handling the artifact. Textiles are easier to handle than individual fibers, since they were, and still are, corded and then woven. Even though it is likely that the individual fibers suffer from damage during excavation and conservation, this is counteracted by the added thickness of the combined strands. However, even textiles face environmental conditions that weaken and destroy the fabric. Due to such problems, it is necessary for field archaeologists to be aware of how different

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This thesis is written in the style of *American Antiquity*.

environments affect hair fibers, and for conservators to look at new solutions in conservation that will allow hair fiber artifacts to be better studied and displayed.

Because of the lack of research done on hair fiber degradation and conservation, it was decided to work on individual hair fibers, as opposed to textiles. By working with the most basic unit, a foundation can be created to build upon. The results discussed in this work can then be applied to more complex hair fiber artifacts.

Before experimentation can begin, it is important to understand the structure of the hair fiber. By finding information in hair fiber industry, a better grasp on how hair fibers act and react can be gained. For the purposes of this work, four common types of hair fibers were used: coarse wool from the Lincoln sheep, fine wool from the Rambouillet sheep, mohair from the Angora goat, and human hair. There are two types of industry that focus on the hair fiber. This includes cosmetology focusing on working with human hair fibers and the textile industry, which is in charge of hair fibers from animals and their practical uses by humans. Not only are aspects of structure addressed, but also common chemicals and their affects on hair fibers are discussed. These works are useful in understanding the chemical reactions that occur during deposition, leading to degradation. They are also useful as insights to chemical conservation and what is necessary for preservation of hair fiber artifacts. Archaeological and historical information on hair fibers was added to the information from hair fiber industry. The combination of information from in the discipline and outside of it allowed of a better overall information base.

Once research was complete, it was decided to deposit the four hair fiber types (coarse wool, fine wool, mohair, and human hair) in different environmental situations. These include an underwater environment, a burial environment, exposure to open air, and exposure to dry, arid conditions. These environmental conditions were chosen due to the commonness in archaeological excavation. The open air exposure would be the least likely environment to find artifacts, but was chosen due to the abundance of Victorian hair art that has mainly remained in family lines and may not have been as well cared for. The open air allowed for the most extreme circumstances to be tested.

After a 7-month depositional period, the hair fiber samples were removed from their environments and the problem of conservation was tackled. The conservation method that was focused on was the use of Passivation Polymers using silicone oil, also known as silicone oil treatment (Smith 2003). This method of treatment is fairly new to the conservation community. It shares commonalities with polyethylene glycol (PEG), which is a polymer. PEG has been used in conjunction with ethyl-hydroethyl cellulose on more brittle textiles in order to increase flexibility (Hamilton 1996). Because both silicone oil and PEG are polymers, it is likely that silicone oil will also address the problem of brittleness common to hair fiber artifacts. A more thorough definition will be provided in Chapter II. There are other issues with hair fiber conservation. These problems include soiling and staining, and destruction from insects, rats, and other pests. However, these dilemmas have been thoroughly addressed in other conservation works, which are discussed in Chapter II.

Once the conservation experiments demonstrated the viability of silicone oil treatment, it was necessary to test the conservation technique on artifacts. Two hair fiber artifacts were chosen for conservation using silicone oil. One object was a Victorian watch fob made from human hair. The brittleness of the fob made it an ideal candidate for silicone oil treatment. The other artifact was a waterlogged composite artifact from the *Kittern* shipwreck excavation. The artifact was found within a block and was comprised of loose hair fibers mixed with a pitch or tar-like substance. This artifact was chosen due to the fact that it was waterlogged and a composite artifact, two conditions that needed to be tested in order to strengthen the argument that silicone oil treatment is a viable treatment method for a variety of different hair fiber artifacts.

The completion of this research gives others who are interested in hair fiber degradation and conservation research a place to start. It also illuminates certain issues connected to the excavation and conservation of hair fiber artifacts. Field archaeologists will be able to use this work in order to better prepare themselves for the state of degradation of hair fiber artifacts and better plan for excavation of the hair fibers. Conservators will be better able to predict the state of hair fiber artifacts based on the sites that the artifacts come from, and learn more about silicone oil treatment and its uses in hair fiber treatment.

CHAPTER II

LITERATURE REVIEW AND DEFINITION OF TERMS

Literature Review

Researching hair fiber conservation can be quit a challenge. There are a limited number of books that specifically discuss the conservation and preservation of hair fibers, and many of these focus on preserving textiles, as opposed to loose fibers. Because of the lack of information, it became important to seek out other sources. For this reason, the literature review will include conservation lab reports from various museums and books that are more commonly used in the hair fiber industry.

Heritage Eaters

Heritage Eaters (Florian 1997) is a wonderful book for studying textile conservation. However, most of the information found within the book deals with pests, such as insects and rodents. Many of the aspects of fiber preservation deal with how to handle the fibers once they have been conserved. Despite its lack of information dealing with the actual conservation of artifacts, *Heritage Eaters* still addresses important information in regards to how hair fibers can disappear with the aid of non-chemical influences and is necessary in understanding the further care, curation, and storage of fiber artifacts after conservation.

Chemical Principles of Textile Conservation

Chemical Principles of Textile Conservation (Tímár-Balázsy and Eastop 1998) acts as an overview of numerous textile fiber conservation methods. The book is divided into sections based on the type of fiber used, including plant fibers, manmade fibers, and

naturally occurring hair fibers. Since the focus of this study is on hair fiber conservation, these were the sections of the book used for research into common conservation practices. These include invaluable information regarding how hair degrades when exposed to ultraviolet radiation. Studies for the book explain how UV (ultra-violet) radiation, heat, and water cause disulfide bonds to break, allowing other elements, such as acids and bases, to enter the interior structure of the hair fiber.

Later sections describe conservation methods that include mechanical and chemical cleaning. One section focuses entirely on the removal of soils and stains that textiles may obtain during deposition. Although this is a very useful section in dealing with a common problem in textile conservation, little information is provided for dealing with protection of the fibers from further degradation.

One chapter of *Chemical Principles of Textile Conservation* (Tímár-Balázsy and Eastop 1998) that deals with conservation and preservation issues has a section on the use of humidification. This method is used on textiles in order to improve the flexibility of textiles and to reduce creases that may be present. There are two main types of humidification processes used in textile conservation called the closed system and the open system. The closed system involves the use of a humidity chamber with control of the amount of water introduced. Open systems can be applied with several different methods. One method involves simply moving the object to an area with higher humidity. However, since these areas are not in a controlled environment, such as the closed system, there is a higher chance that insects will attack the textile. Other open

system methods include using a wet compress and steaming. Both of these use the direct application of water to textiles.

The authors do include a section on possible damage caused by using humidification. Most of the concerns listed deal with dyes and inks that may be present. It is not mentioned until much later that another problem of humidification treatment is that swelling can occur. Not mentioned in the work is the damage that can be caused by mixing humidity with heat, as is done when steaming is used. In certain cases, mixing high humidity and heat can cause the scales present on the outer cuticle layer of hair fibers to meld together, making identification of the fibers difficult, if not impossible.

Another chapter describes solvent cleaning, also known as dry cleaning. The main use of solvents in textile conservation is for the removal of stains. The use of solvents is mainly used in situations where water cleaning is not applicable, specifically for wools. There are several solvents listed that are useful in removing stains. However, almost all solvents are flammable and this should be considered when solvent cleaning is used.

The chapter on wet cleaning mainly provides a list of different water-soluble chemicals that are used to remove stains. These include, but are not limited to ethylene diamine tetraacetic acid (EDTA), polyphosphates, and sodium carbonate. Although both the water cleaning and solvent cleaning methods can be quite useful in removing stains, work still needs to be done. The introduction of water can, in the long run, cause difficulties in maintaining stability of the artifacts. Also, not mentioned is the use of pure lauryl lauryth sulfate. It is a main ingredient in many shampoos and acts as the

primary surfactant cleaning agent (Robbins 2002). This cleaning agent can be found in quantity for a reasonable price. The chemical compound is placed in water and, with mechanical application using a toothbrush, can remove stains easily and gently (Helen DeWolf, personal communication 2007). Soaking can also be done for more stubborn stains. Because of this, quilters commonly use lauryl lauryth sulfate as a safe and effective tool for cleaning new and old textiles. However, beyond the information from Robbins (2002) and personal experience, no mention of using the chemical could be found.

The final chapter that discusses conservation of artifacts once again deals mainly with the problem of removing stains. This chapter discusses the use of acid and alkaline solutions useful in removing particularly stubborn stains. Although the methods described in the chapter can be quite successful in removing stains, every treatment mentioned causes damage to the hair fibers. Both acids and bases are very damaging to hair fibers, although acids are a bit gentler. In many instances, I would only recommend these methods in rare or extreme cases.

Overall, *Chemical Principles of Textile Conservation* (Tímár-Balázsy and Eastop 1998) gave a useful, easy to understand description of different common textile treatment methods. The book is also a prime example of issues of hair fiber conservation being ignored. Almost every method mentioned deals with the removal of stains and not the more detrimental problems of brittleness, waterlogged conditions, and susceptibility to humidity combined with UV radiation. Most approaches to hair fiber

conservation involve the removal of stains and storage by placing the artifact in a dark location with low humidity.

Methods of Conserving Archaeological Material from Underwater Sites

This manual (Hamilton 1996) is a useful tool for conservation methods in general. There is a section on textiles that includes several helpful methodologies. Besides addressing the removal of soils, there is a short section dealing with the reinforcement of fragile textiles. One mechanical method described includes the use of backing to help add strength to the remains of highly degraded textiles. Other methods include the use of consolidants. Most of these are also commonly used on bone, including polyvinyl acetate, polyvinyl alcohol, and acryloid B-72. There is one method described using ethyl-hydroethyl cellulose and polyethylene glycol. This mixture has been used in order to treat dry, brittle fibers and is reported to help add flexibility. However, the use of consolidants for treatment means that retreatment would need to happen fairly often since these chemicals tend to break down within several years and flake off. The use of polyethylene glycol poses other problems if the artifact is composite and includes a metal compound, especially iron.

Another chapter includes the treatment of underwater artifacts. Although this does not necessarily apply to hair fibers, the methods described are useful in treating hair fiber artifacts that come from underwater archaeological sites. This includes the use of dehydration baths to remove all water before submerging the artifact in a chemical bulking agent.

On the whole, Hamilton's conservation manual is useful in understanding other methods of conservation that have little or no mention in other works. Besides adding useful information in the treatment of delicate textiles, it's inclusion of artifact treatment from sites other than terrestrial cause this work to be invaluable.

Archaeological Conservation Using Polymers

This book, *Archaeological Conservation Using Polymers* (Smith 2003), covers various aspects of polymer passivation using both silicone oil and polyethylene glycol (PEG) and its application in artifact conservation. Most of the text deals with conservation of organic artifacts that have an easily recognized cellular structure. Since hair fiber structure is mainly composed of helical shaped fibrils, the information could only be applied to a certain degree. However, one chapter dealt with cordage and textile conservation. Although both examples used were made from plant fiber material, there was still some very useful information. A better understanding of cordage thickness and its affect on silicone oil treatment was useful when later working with cordage created from human hair fibers.

Since the book covered conservation using silicone oil polymers, which are commonly used in Passivation Polymers treatment, the text was extremely useful in understanding the chemistry involved in conservation using this method. Understanding how the silicone polymer chains bond with an artifact allowed for a comprehension of why silicone oil treatment allows fibers to become more flexible after treatment. In addition to this information, numerous catalysts were listed. Some of the catalysts mentioned include UV light and water, specifically in the form of humidity. Both of

these elements would normally be detrimental to preserving hair fibers. By applying silicone oil treatment, these two weakness become strengths.

Overall, this book is a necessity for studying and understanding silicone oil treatment and its place in artifact conservation. Explanations and methodologies are clearly explained and fairly easy to understand. *Archaeological Conservation Using Polymers* (Smith 2003) had some of the most useful information available for this type of study.

Chemical and Physical Behavior of Human Hair, 4th ed.

Although Robbins' (2002) book does not deal with conservation, or even artifacts, the text provided a wealth of information. The book is intended for those that work in the hair care industry, such as shampoo makers and stylists. Several chapters are devoted to understanding the structure of the hair fiber. These chapters helped to develop an understanding of how hair degrades and what is needed for conservation.

Many of the chemicals found in shampoos and salons were also discussed in depth. Understanding how chemicals, both natural and manmade, affect hair fibers, a greater comprehension of how hair degrades after deposition is reached. For the experiments involving hair fiber degradation, many of the questions posed by the hair fiber degradation experiments could be answered.

An added advantage found in the book was a short section on the use of silicone polymers in shampoos and conditioners. Although the silicone polymers used in the hair care products are different in polymer structure in comparison those used in conservation experiments, the similarities between them are close enough to know that silicone oil

would not further harm hair fibers. It was also interesting to note that one of the main reasons silicone oil is used in shampoos and conditioners it to repair highly damaged hair fibers, adding strength and flexibility.

Overall, *Chemical and Physical Behavior of Human Hair* (Robbins 2002) provided more information that one would first believe. Despite the heavy emphasis on chemistry in the book, the diagrams and explanations help those with less experience in chemical jargon to understand the concepts described. It is also a fine example of how another discipline can aid in the understanding of one's own.

Mechanical Properties and Structure of Alpha-Keratin Fibres

Although Robbins' book covers so many aspects of hair fibers, it is designed for working with human hair fibers. Feughelman's (1997) book adds more depth and information to other hair fibers, specifically wool. Since his book is on both human hair fibers and wool fibers, the many differences that exist between them are better highlighted. It also provides information that corresponds with information found in Robbins' book. In some respects, some of the concepts expressed and explained in *Chemical and Physical Behavior of Human Hair* are more clearly explained in *Mechanical Properties and Structure of Alpha-Keratin Fibres* (Feughelman 1997), adding more to my understanding of the hair fiber, specifically the structure.

In general, this book compliments Robbins' work. By finding a work that supported information gained from another source, the likelihood of misinformation is lessened. In some respects, Fueghelman's work was less complete than Robbins', but since the focus was on the mechanical properties only, the largest difference was the

amount of information provided on the chemicals typically applied to hair fibers. However, there was a greater focus on the naturally occurring chemicals that interact with hair fibers.

Museum Lab Reports

Several museums (Liverpool Museum personal communication 2005, Leila's Hair Museum personal communication 2007, Museum of London personal communication 2006) were contacted in order to better understand the most current and common conservation practices in treating hair fiber artifacts. Since many of them use similar treatment methods, the practices will be reviewed as a whole. The only exception will be to mention the practices of a single museum.

As is mentioned in Hamilton's manual, the use of consolidants is common in textile and hair fiber conservation. These can range in viscosity and application, depending on the museum's equipment and the needs of the artifact. There is also mention in several labs reports of museum objects that were more fragile. Many of these were repaired using archival backing and a glue or careful sewing. For artifacts that are soiled, gentle cleaning using deionized water and controlled drying are the most commonly mentioned methods.

The Museum of London uses a packaging technique developed at the museum that was inspiration for a method used in the conservation experiments described later. They use an archival piece of cardboard in conjunction with cleaned cotton textile, mesh, and perforated plastic. Although some modifications had to be made for using a similar structure in conservation, many of the reasons for using the packaging were also

necessary for certain steps in the conservation process. By having a basis from the packing technique to start from, modification became easier. The Museum of London is also unique in the fact that they use no chemicals in the preservation of textiles and hair fiber artifacts.

Another museum with a different approach to conservation of hair fibers is Leila's Hair Museum. Although the curator of the collection, Leila Cohoon, has not been trained in conservation, her efforts in preserving Victorian hairart are worth note. Trained in cosmetology, she uses her knowledge of hair and hair products to help preserve and reconstruct damaged pieces. Even without formal conservation training, her success is notable. All of the pieces within her collection, which are displayed in a museum she began, are in good condition, restored well, and protected from elements that would damage the artifacts. Many of the procedures she uses for restoration are based on her training in the hair care industry, showing possibilities in conservation that may not have been thoroughly explored academically.

Definition of Terms

In order to avoid confusion, it is important that terms used are defined. Most of these terms deal with distinguishing between different hair fibers. Although there has been debate at least since 1977 (Orlove) on what constitutes a wool fiber, it appears that many archaeologists feel that the term wool encompasses any fiber used in spinning and weaving, except for the camel hair (Orlove 1977). However, this definition is too all encompassing to be useful in studying hair fiber types and varieties.

For the purposes of this paper, wool will only refer to the underhair fibers from a sheep. Mohair will refer to the goat hair fibers from the Angora goat. The Angora goat is not the only goat variety whose hair fibers are used by humans, but the definition keeps with the definition from the animal hair fiber industry (Ensminger and Parker 1986). For other animal fibers types mentioned, they will be clarified by referring to the animal that it comes from preceding "hair fiber" or "fiber" (such as a llama hair fiber, or llama fiber). "Hair fiber" will be defined as being a single, unwoven fiber from a mammal.

Another term that will be used in this work that needs to be defined is Victorian hair artwork or hairart. This will refer to the different pieces of artwork created during the Victorian era using human hair as its medium. These works embody several objects, including needlepoint, hair wreaths, and jewelry, just to name a few. Also, when an object is referred to as a textile it will indicate a woven piece of material, comprised of either plant or hair fibers, made by using warps and wefts, along with material that has been corded. Cordage will indicate the specific textile type that involves an object composed of either plant or hair fibers that has been twisted in a specific way was to create a longer, rounded piece of material, such as a rope or a flat braid.

By differentiating between hair fiber varieties, this study will be easier to understand, allowing the reader to know what hair fibers are being discussed. Although the work mainly focuses on wools, mohair, and human hair fibers, other hair fibers types will be mentioned in brief. As more work is done concerning hair fibers, whether as

individual strands or textiles and cordage, hopefully others will see the advantage of clearly defining the hair fiber type.

Finally, Passivation Polymers needs to be defined. This conservation technique uses the application of polymers to treat artifacts in a way that reduces the chemical reactivity of the object with its environment (Smith 2003). One of the main polymers used is the naturally occurring silicone oil polymer. Because there are several different polymers that can be used in Passivation Polymers techniques, the term silicone oil treatment will be used to denote that silicone oil is the polymer being used for treatment during the conservation experiments.

CHAPTER III

WOOL, MOHAIR, AND HUMAN HAIR: THE BASICS

Keratin fibers are common in nature and found in different forms, including the hairs of mammals, nails, horns, claws, and quills (Feughelman 1997). Each type is a biological polymer of polypeptide chains, with each form creating a structure unique to its purpose. In this work, the concern will be on hair fibers only, concentrating on wools, mohair, and human hair. In hair fibers, their structure is made up of three distinct parts, the cuticle, the cortex, and the medulla (Feughelman 1997, Robbins 2002) (Figures 1-2). Each area is unique in its structure and function, creating a complex fiber that begins its formation in the follicles of the animal's skin. The different cells interact through several bond types, creating unique structures, including scaling and helices. It is these bonds that are important in finding a better way to conserve hair fibers. In order to understand how the different bonds and cells interact, it is best to look at each layer in more detail. First, the paper will focus on the most interior layer of the hair fiber structure, the medulla, and move outward to the cuticle.

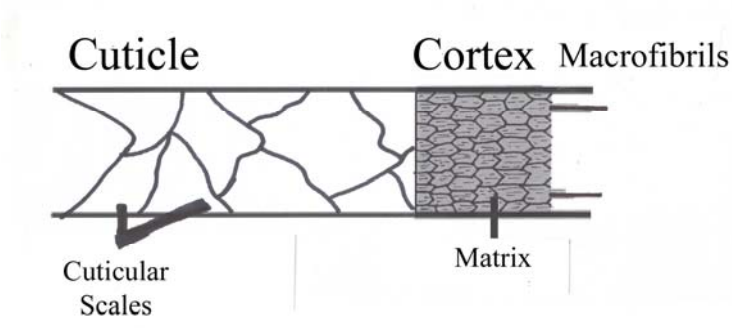


Figure 1. Cuticle and cortex of a hair fiber

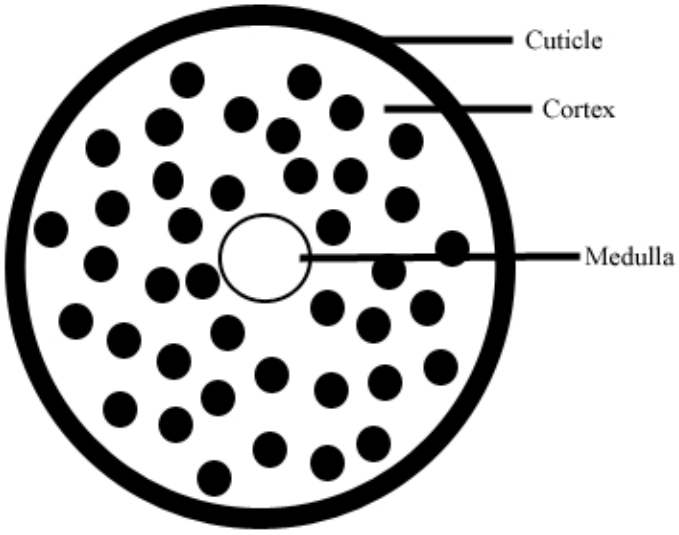


Figure 2. Cross-section of a hair fiber

Also included in this chapter will be a brief look at the archaeological and historical background of the different fibers that will be used during experimentation. This will bring to light the importance of hair fibers in the archaeological record and the need to preserve these artifacts. Within these sections, differences seen on the microscopic level will also be addressed.

The Commonalities of All Hair Fibers

The Medulla

The medulla is located in the center of hair fibers (Feughelman 1997, Robbins 2002). However, little is really known about this region and it appears to be mostly an empty space where the cells within the area are loosely packed (Robbins 2002). Even the cells that are present are hollow inside. The medulla appears to not contribute to the

chemical and mechanical properties of the hair fiber. Because of this, and the difficulty in isolating the medulla, little scientific work has been done.

Another reason that the medulla has been a bit neglected scientifically is its variability in form in different fibers (Feughelman 1997, Robbins 2002). The medulla can be consistent throughout the fiber, fragmented, or absent entirely. Fine hairs, such as merino wool and even some human hairs, often lack a medulla. It appears that as the fiber increases in diameter size, the medulla makes up a larger percentage of the hair fiber structure. Due to the lack of information, there appears to be no scientific explanation of why or how the medulla is formed.

The Cortex

The cortex is a highly complex structure that makes up the majority of the fiber mass and mechanically is the most important component (Feughelman 1997, Robbins 2002). The cells that make up the cortex create helical structures known as fibrils. In this region, wool and human hairs differ considerably. These differences will be examined more closely in the respective section of each.

Within the cortex, there are two main regions, the macrofibril region and the nonfibrillar matter, or matrix (Feughelman 1997, Robbins 2002). The main differences between the two areas are the amount of structure present and the amount of keratin. Macrofibrils are highly organized, or crystalline, in nature, while the matrix, although still high in keratin, is significantly less organized.

The macrofibrils make up the keratinous region of the cortex, and is organized into smaller fibril structures known as microfibrils or intermediate filaments

(Feughelman 1997, Robbins 2002). In between the microfirils is another area of less organized matrix, which is similar to the matrix mentioned above. These microfibrils are arranged in helical proteins that are in coiled coil formation. The base coil of a microfibril is a right-handed α-helix. These are then arranged into a left-handed coiled-coil strand, which are not continuous, ending in nitrogen and carbon termini. Research seems to indicate that these helices are created with hydrogen bonds, with special importance placed on hydrogen bonds between the amide –N-H (nitrogen to hydrogen bond) and oxygen. For a more detailed study of these structures, one should refer to Robbins (2002) and Feughelman (1997).

The Cuticle

The cuticle is the outer layer of hair fibers and looks like scales overlapping one another, much like shingles on a roof (Feughelman 1997, Robbins 2002). Several layers make up the composition of the cuticle and include the epicultice, or A layer, the exocuticle, or B layer, and the endocuticle. In hair fibers, the numbers of scales that are present tend to be related to species, and this is used for analytical work in forensics and archaeological analysis.

The A layer and B layer are rich in cystine and are associated with the keratin rich cortex, although the structure is different in organization. In comparison the macrofibrils, the cortex cells are significantly less organized on the molecular level. These layers are resistant to damage caused by chemical and, to some degree, mechanical means. The endocuticle is low in cystine (about 3% cystine content), and therefore considered a nonkeratinous area.

Research indicates that the nonkeratinous region, specifically the endocuticle, play an important role as a pathway for the entry of harmful elements, such as acids and alkalines, into the hair fiber (Robbins 2002). The endocuticle is the area between the cuticle scales and is what helps hold them together and to the cortical cells. These areas appear to have a lower proportion of sulfur-containing amino acids, such as cystine. The epicuticle, which is on the surface of each cuticle cell, consists mainly of a lipid layer and a highly cross-linked protein layer. Another important area that consists of low cystine content is the delta layer, or intercellular cement. This is found below the cuticle cells and helps bind the cuticle cells to each other and the internal structure of the cortex. Several studies have shown that these areas are susceptible to bases, some acids, hot aqueous solutions, and reducing agents. Experiments demonstrate that in comparison to the cystine rich keratins, these structures are likely to suffer extensive damage. One of the reasons that these areas are more vulnerable is due to the disulfide bonds found in the cystine areas (Figure 3). Many different factors can cause the fission that occurs on the S-S bonds present, including ultraviolet radiation and alkaline substances. This may explain why many hair fibers do not survive well in certain environmental conditions and are, therefore, less likely to be found in the archaeological record at certain sites. However, this could also prove to be an aid in finding a way to conserve the hair fibers that have survived deposition.

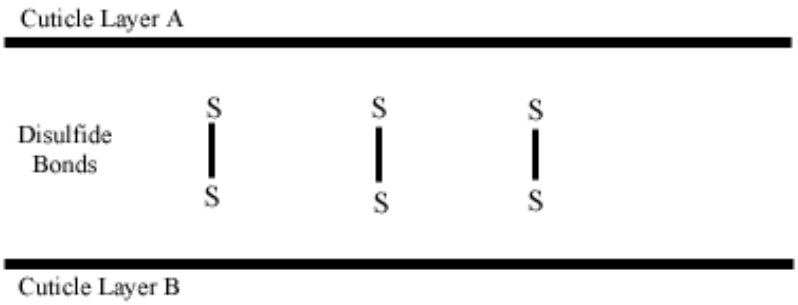


Figure 3. Visual representation of the disulfide bonds. The sulfides are attached to other chemical elements not shown.

Mohair

History

The archaeological and written history of goats, including the Angora goats used for mohair and cashmere production, is significantly less than that of wool. Most information has to be pieced together from sources that concentrate on sheep and wool with brief mentions of goats and mohair. Despite the lack of specific information on mohair and its history as a source for fibers used in textiles, it has shown to be an important fiber in industry today. This importance today hints at its probable importance in history as well. With the information available, a brief outline of the domestication and use of mohair by humans will be provided.

The first evidence of goat domestication comes from Ganj Dareh located in Southern Zargos in the Near East. Goat tracks were found in mud bricks that dated to 7500 BCE (Perkins 1973). Since it is unlikely that wild goats would be found this close to a settlement, it was concluded that the group of people living in the area had

domesticated goats. Besides the tracks found, several juvenile goat bones were found in the vicinity. The high number of juveniles in the area is also indicative of domestication. In the case of this site, little to no remains of sheep were found, it seems that this group of people placed more importance on the domestication of goats rather than sheep. Other sites in the Near East that show domestication of goats include Ali Kosh during the Bus Mordeh Phase (7000 BCE) and the Ali Kosh Phase (6750 BCE) (Perkins 1973). The excavation in the area also shows that these people preferred the domestication of goat to sheep. Within Perkins' (1973) study, there were two sites that definitively showed multiple animals had been domesticated by the people living within those areas. One site dating to 6300 BCE, Ceramic Jarmo, had evidence of domesticated goats and pigs (Perkins 1973). In Preceramic Jarmo, which dates to 6750 BCE, only domesticated goats were found, indicating that they were domesticated first, and possibly easier to domesticate (Perkins 1973). Since there is no comprehensive book on the history of goats available, like there is for sheep, there is little information available on how domesticated goats spread from the Near East to the rest of the world. There is some evidence that goat domestication followed a similar path to sheep domestication (Ryder 1983). If this is the case, then goat husbandry would have moved from the Near East to Asia and into Europe, with areas farther away adopting goat husbandry at the latest date, which would likely have been no earlier than 4000 BCE.

Since breed is hard to tell from zooarchaeological evidence, it is unsure how much goat was used for meat and how much it was used for hair fiber production. The goat breed famous for high quality mohair is the Angora. The breed originated in the

Angora province of Turkey and the mohair was considered valuable enough for the sultan to try and prevent the breed from leaving the country in 1881 in order to try and monopolize the market (Ensminger and Parker 1986). However, by this time the goat breed had already reached South Africa and even the United States. In 1849, Dr. James B. Davis was sent to Turkey by President Polk in order to aid the country in cotton production. When he returned, he brought back nine high quality Angora goats, both bucks and does. There were several other importations of goats into the United States following this, creating what is now a thriving industry of mohair production.

As far as mohair being used as a textile, there is evidence from Sumerian writing that goat hair had become very important as a textile fiber (Ryder 1983). However, it still did not have as high a value as sheep wool, which was sold at four times the amount that goat hair was sold at according to Sumerian records. During analysis of wools from present day Finland, which dated to 1100 BCE, Ryder (1983) found one yarn to be dyed goat hair as opposed to wool, showing that by 1100 BCE, mohair and wool were both being dyed and spun.

Physical and Chemical Properties

Currently, mohair is used to create velour clothing, sweaters, coats, wigs, and other hairpieces (Ensminger and Parker 1986). Mohair's characteristics make it desirable for uses in textiles. Although its uses are similar to wool, its characteristics are distinctive. In some ways, mohair can be closer akin to human hair than wool.

Like sheep, goats have two layers of hair (Ensminger and Parker 1986). The outer layer, or outercoat is created by primary follicles on the skin and produce long,

coarse hairs. The secondary follicles create shorter, finer hair fibers, usually in large numbers to, create the undercoat. In the case of Angora, the undercoat has been selected for in breeding, causing the outercoat to disappear when the Angora kids reach six months of age. Despite selecting for the shorter undercoat, the Angora goat's mohair undercoat grows to considerable length, a quality that can be very useful in creating textiles. In current practices of mohair production, goats are usually sheared either once or twice per year. In one year, the fleece grows an average length of 30 cm (12 in). If the mohair producer gives special attention to the fleece and allows for a longer growing period, the fleece can grow up to 1 m (3 ft). Fleeces allowed to grow to this length are used in creating different types of hairpieces, such as wigs and dolls' hair. The use of mohair for such objects shows how versatile mohair can be as a textile, not to mention its ability to strongly resemble human hair fibers. In other goat breeds that are raised primarily for milk and meat production, the outercoat is still the dominant hair fiber present. Hair fibers from these goats are used in textiles, although, like the angora, only the undercoat fibers are used. These fibers, known as cashmere, are retrieved by brushing the goats during their shedding season. Today, the main source of cashmere comes from the Mongolian People's Republic, Iran, and Afghanistan. Since the emphasis is on milk and meat production throughout most of the world, it is unlikely that breeding selection will start to favor the undercoat of these other goat breeds any time soon.

Another important difference between mohair and wool is the scale pattern (Ensminger and Parker 1986). Mohair scales tend to be fewer in number and less

protruding than wool. When looking at photographs of hair fibers that show scale, mohair appears to have very long scales. In several place, the scales are so flat they seem to almost disappear. Another important characteristic of mohair is the lack of crimp, which is another similarity between human hair fibers and mohair. It is these properties that give mohair its sought after luster and smooth feel.

Mohair is divided into three types of fleece: the tight or spiral lock, the flat lock, and the fluffy fleece (Ensminger and Parker 1986). Of these, the spiral lock is considered the finest, while the fluffy fleece tends to be weak and easily broken. These types of fleeces also correspond to the age of the animal. Once the kid has reached 6 months of age and the coarse outercoat has disappeared, the hair fiber is the finest. As the animal ages, the fiber will become thicker and coarser, eventually becoming the undesirable fluffy fleece. However, even the finest mohair tends to be thicker in fiber diameter than many wool types. In the case of mohair, it is the length and luster that are sought after. The color of mohair is also taken into consideration when being graded. A pure white is the most desirable color since it takes dye well. There are occasionally black Angoras, which are usually culled from the herd. More archaeological and historical research is needed, but it is likely that as mohair became a fiber used by humans, these would be the same qualities that would be sought after.

Currently, the USDA grade standard uses one system for the grading of mohair (Ensminger and Parker 1986). The grading process is for “grease mohair”, mohair that has not been cleaned of impurities, and is performed by highly skilled individuals. The grade numbers represent the number of 560-yard hanks that can be obtained to the

pound. The grades range from coarser than 18s to finer than 40s. It should be noted that only even numbers are used. When compared to fiber diameter, those numbers coincide with the average diameter. Starting at coarser than 18s, the fiber diameter is over 43.01 microns, while finer than 40s has an average diameter that is smaller than 23.01 microns. This shows how much mohair fibers can vary and change as the goat ages.

Wool

History

Wool plays an important part in human life today, and has been playing an important roll for quite some time. Archaeological evidence suggests that sheep were first domesticated around 9000 BCE in what is now Iran and Iraq (Perkins 1973, Ryder 1983). It is likely that the first sheep were domesticated for their meat and dairy, as opposed to their wool (Ryder 1983). Because of this, it has been speculated that there was a significant gap present before a difference between domesticated sheep's and wild sheep's wool would be present. It was only later that the natural colors were bred out of domestic flocks to give sheep their characteristic white wool. This process also would nearly eliminate the long course kemp, known as the outercoat, found in feral sheep in favor of the finer underwool, which is what we associate with sheep wool today. Sheep husbandry spread from Iran into the surrounding areas. Evidence suggests that by 6500 BCE, sheep domestication was present in Asia, specifically Baluchistan and the Indus Valley. By 6000 BCE, sheep had become domesticated enough to be moved overseas. Archaeological dates show that in 6100 BCE, domesticated sheep were present in Greece, and in 6000 BCE, they were present on the Mediterranean islands of Crete and

Cyprus. By 4000 BCE, domesticated sheep could be found throughout Europe, including the British Isles (Ryder 1983).

Textiles created from wool first found in the archaeological record are dated to the Bronze Age, several thousands of years after the domestication of sheep (Ryder 1983). There have been suggestions by certain individuals, such as Ryder, that wool was being used before this time to create textiles, but this is deduced from indirect evidence, and no textiles have been found before this time. However, the evidence is strong that such a conclusion is correct. The indirect evidence includes ancient texts, iconographic studies, and artifacts found that would have been used for textile production, and so it does seem very plausible that people were creating woolen textiles before they appear in the archaeological record since it is likely many textiles did not survive after deposition. Concentrating only on textiles found in archaeological excavations, some of the earliest textiles were found in Greece and date to the 5th century BCE. The remains of two woven pieces of cloth were found in a Scythian tomb (Ryder 1983). Another piece of textile evidence was found in the "Cave of Letters" located near the Dead Sea and included two pieces of woven cloth, one piece of yarn, and some unspun wool. The dates obtained show these pieces of wool to date to the 2nd century BCE. The importance of these pieces is not only their age, but the fact that they are the first evidence of dyed wool. One piece of cloth showed that it had been dyed a green color, the other piece has remnants of yellow dye, and the yarn and unspun wool had been both dyed a maroon color. Although the dye colors showed signs of fading, enough of the dye remains for archaeological study.

Based on the archaeological evidence and information gained on hair fiber structure, it seems likely that textiles from before the 5th century BCE did not survive in the archaeological evidence, and were simply too fragile (Robbins 2002, Ryder 1983). Those pieces we have from the 5th century BCE probably only survived due to the fact that they were deposited in tombs and caves, which gave them better protection from insects and adverse environmental conditions. This evidence exhibits how delicate hair fibers are, and, like other organic materials, it is important to find ways to protect the hair fiber artifacts that are found.

Physical and Chemical Properties

There are several differences between wool fibers and other types of hair fibers. Some of their structural elements differ, giving them their unique characteristics, such as crimp, swelling abilities, and ability to be felted. By understanding what physical and chemical properties are present in wool, it becomes easier to see how wool has become so important to humans.

One major difference between wool fibers and human fibers is the quantity of scales creating the cuticle layer. In wool fibers, the cuticle layer is composed of a thickness of one to two scales, while human hair fibers are around five to ten scales thick (Robbins 2002). Despite the thicker layer of scales present on human fibers, wool usually stands up better to the environment and weathering. Wool fibers are not subjected to some of the same treatments that humans use on their hair to. Humans regularly wash, towel off, and comb their hair, not to mention the harmful chemicals used when dying, bleaching, straitening, and permanent waving hair, which can all cause

a high amount of damage to the scales of the hair fiber. It is possible that as humans became more destructive towards their hair fibers, we evolved to have more scales to protect the cortical region.

Another characteristic of wool that makes it unique is its crimp, which is the naturally occurring wave of the fiber (Feughelman 1997, Robbins 2002). Although the amount of crimp varies between different domestic types of sheep, a certain amount of crimp can always be found. There are some similarities between wool crimp and the crimp present in certain types of human hair, most notably that of Africans and African-Americans, but most human hair lacks this quality. Because of this, the description of what causes crimps will be thoroughly addressed in this section only, and only mentioned in the section on human hair fibers. In hair fibers, the way that the cortex cells are structured determines the crimp or curliness (Feughelman 1997, Robbins 2002). Two different types of cortical cells were first identified in the 1950s and were named the paracortex and orthocortex. More recent studies have shown that there may be a third type of cell structure, known as the mesocortex (Robbins 2002). The ratio of these cells in the fiber determines the amount of crimp in wools. Through dying techniques, it has been shown that in fine wools, where the crimps tend to be more pronounced, the paracortex and orthocortex create a bilateral structure. In this structure, the orthocortex appears on the outside of the wave, while the paracortex can be seen on the inside of the wave (Feughelman 1997). This view may change as more information is found out about the mesocortex. The individual cortical cells are shown to have different microfilament structure. The main difference that has been found by studying the cross-

sections of the different cells is that the microfilaments of the orthocortex contain a whorl pattern, while the paracortex and the mesocortex lack this pattern. Little is known about the differences between the paracortex cells and the mesocortex cells, and more research is needed before mechanical differences can be determined.

Because of wool's crimp, it is ideal for felting. It is probable that humans began felting wool before weaving it, although the only evidence of this is circumstantial (Alexander and Hudson 1954, Ryder 1983). In ancient times, after combining heat and moisture, loose wool was then bound together in rolls and pressure applied by stepping on the rolls and rolling them. The crimps help the fibers to interlock with one another during the felting process (Ensminger and Parker 1986). Only non-human hair fibers can be used to create felt, and due to the natural crimp of wool and the amount of domestication that sheep have undergone, wool still remains the best hair fiber for felting.

A notable property of wool is its ability to absorb water, causing the wool fiber to swell (Alexander and Hudson 1954). How and why this occurs is still a subject of debate among scholars and no one theory can be found to aid in explaining this phenomenon. However, extensive research shows just how much diameter swelling can occur with varying degrees of water content (Alexander and Hudson 1954). Regain percentage is the most common measurement used when discussing water content. It is defined as the weight of the water absorbed divided by the dry weight of the fiber. At a 2% regain, the diameter will swell to an average of 0.64%. When the regain percentage reaches 33%, the fiber diameter will swell to 18%. Even if wool is not directly placed in

water, some diameter swelling can occur from the absorption of water vapors present due to humidity levels. It is probable that this swelling property aids quite a bit in the felting process. Since water is used during the felting process, it is likely that as the fibers shrink in size, they become more tightly interlocked with one another.

Through the domestication process, different types of wool have emerged. Because of this, a grading system has been created (Esminger and Parker 1986). There are several different categories that are judged when deciding the grade according to the U.S. standard. Importance is placed mainly on the diameter, but length and amount of "clean" wool can still play a part. Overall, the main categories, according to diameter are fine wool, medium wool, coarse wool, and braid wool. The two main systems used today to determine wool grade are the count system and the micron system. The count system grades hair on a scale of 28 to 80 in Britain and 36 to 80 in the United States (Esminger and Parker 1986, Ryder and Stephenson 1968). It should be noted that in the grading of wool, only even numbers are used and that the higher the number, the more fine the wool. In the United States count system, between 64s and 80s and higher, the wool is considered to be a fine grade (Esminger and Parker 1968). From 50s to 62s, the wool is graded as fine wool. When the grade is between 44s and 48s, the wool is listed as coarse wool. In the range of 40s to 36s and lower, the wool grade is very coarse or braid. These numbers are theoretically based on the number of hanks of yarn, where each hank is equal to 560 yards or 512 meters. The micron system follows a similar pattern, with the main difference being that the numerical system is done by a professional who has been trained to grade wool based on feel and sight, whereas the

micron system takes the average diameter, in microns, to determine the fineness of the wool. In the micron system, 17.70 and under to 22.04 falls under the fine grade, 22.05 to 30.99 is graded as medium wool, 31.00 to 36.19 is coarse wool, and 36.20 to 40.20 and over is considered very coarse wool or braid. These can be seen in Table. Overall, the coarser the wool, the longer the wool tends to be in length and the lower number of crimp the wool fiber contains.

There is also another factor that is used in deciding the value of wool. This is the class system (Eisminger and Parker 1968). There are four main classes of wool, combing wool or stable wool, French combing, clothing wool, and carpet wool. Combing wools are considered the most valuable wools and both fineness and length important. Clothing wool tends to be the shortest in length, but can be used to make both woven clothing and felts. French combing wool is the class of wool that falls in between combing wool and clothing wool due to its intermediate length. The final class of wool is the carpet wool. This wool tends to be the lowest quality and the coarsest, with a high amount of variability in length. As the name indicates, this is the wool that is used to make carpets or rugs. They are valuable for this type of use due to their resistance to matting and wearing.

Human Hair

History

There are several places that one expects to find human hair remains; tombs, bogs, and arid environments. Although human hair can be found in other contexts, the three mentioned are most common due to more ideal depositions. Many times, the hair

fibers found are still attached to the rest of the human remains, or in close association. However, there are other instances where human hair can be found in other contexts. These examples can be found in many places and in combination with different types of material, including clothing, sculptures, and artwork.

As mentioned above, human hair can found in relation to a burial site. Sites that most commonly have hair remains still intact with the body are arid tombs, like those found in Egypt, and in bog-like areas, similar to many place in Northern Europe. Based on the evidence that hair has remained intact for thousands of years, some individuals believe that hair fiber is fairly resilient. However, often other parts of the body that do not survive, such as the skin, are also present with the hair. Since skin is rarely preserved, the stability of human hair should not be taken for granted. Many times there are degradation problems present that are not visible. Often the hair is brittle and breaks easily, making study of the fibers very difficult.

Another example of artifacts that contain human hair, are pieces of Victorian era artworks (Speight 1872). During this time, people around the world would create objects using human hair. One popular example is hair wreaths. In many cases, these objects would be made by a family member and would include hair from different individuals of the family. These were then mounted in a shadow box for display, creating a unique, visual of the family tree. There are also examples of human hair used to create jewelry and embroidery. One of the best examples of hair embroidery can be found in Kansas City, Missouri at Leila's Hair Museum. Here human hair was used in order to make a beautiful embroidery with very fine detail created by using only single

strands of hair. At this museum, many other hairwork objects can be found illustrating different techniques. While visiting, many objects were connected to other materials, such as metals, other textile materials, wood, glass, and even feathers. Throughout the Victorian era, numerous other examples were created. Because hair is susceptible to UV light, humidity, insects, and bacterial attack, these objects are beginning to degrade. In order to preserve these pieces of our history, it is necessary to look at treatment methods for human hair fibers, as well as animal hair fibers. Fortunately, there are pieces that are still in relatively stable condition. However, this is due more to the fact that they have been sealed behind glass when they were first made, protecting the hair fibers from a few of the conditions that can lead to degradation.

As the Victorian artwork ages and degrades, it is important for conservators to realize that a number of objects are going to need to be preserved for future generations. This is a rare chance to salvage a part of history without having to wait for the artifacts to be excavated. The nature of the hair artwork suggests that these items are likely to be found in individual's homes as heirlooms of their family's history. Not only can these objects aid in genealogy, they also aid current researchers in studying a unique and era-defining art.

Physical and Chemical Properties

Unlike many other hair fiber types, human hair fibers differ in numerous ways. Color is the variable most obvious to the casual eye. However, the cuticle construction and medulla are also affected. When working with human hair fibers, whether it be in

the field or in a conservation lab, it is important to understand that the fibers may act differently based on their individual component properties.

As mentioned earlier, one of the largest differences between wool and mohair fibers and human hair fibers is the number of scale layers present. Both mohair and wool fibers have only a few scales layered to create the cuticle layer. In contrast, human hair fibers' cuticle contains on average six to seven scale layers (Robbins 2002). It is unsure why this distinction exists or even if this modification makes a difference in the cuticle's ability to protect the interior proteins present in the cortex. This also is one of the few properties that unite all human hair fibers.

One variation present between human hair fibers can be observed in how the cortex is structured. It is mostly likely that a human hair fiber will contain a symmetrical cortex that does not have the specialized cortical cells common to wool fibers (Robbins 2002). However, there is always an exception to the rule. In human hair fibers that come from individuals of African decent, the cortical cells will often be divided into the more specialized cells that create the paracortex, orthocortex, and mesocortex. These sections, as mentioned in the earlier wool section, are believed to be responsible for curliness and crimp (Feughelman 1997, Robbins 2002). In these cases, the structure of the cortex is more akin to wool fibers and is more likely to act in a similar manner.

Another variation present in human hair fibers involves the presence or absence of the medulla (Feughelman 1997, Robbins 2002). In wool fibers, the finer the wool, the less likely the medulla is present. However, in human hair fibers, little research has been done on this interior space. Like other fibers, the medulla in the human hair fiber is

highly varied. If it is present, it may be continuous or fragmented. In rare cases, a double medulla can be found (Robbins 2002). Without further research, very little can be stated with certainty when dealing with the medulla structure.

Other Common Hair Fibers

As many are aware, wools, mohair, and human hair are not the only hair fibers used by people. The Angora rabbit, horse, boar, yak, bison, Bactrian camel, and the camel's South American counterparts, the llama, alpaca, and vicuna all contribute their fibers to the archaeological record (Hyde 1988). The Bactrian camel and yak fibers are commonly used in areas of Eastern Europe and China, while the llama, alpaca, and vicuna fibers are common to the Andean mountain range area. In historic times, these fibers have spread to many other places in the world. Alpaca farms are common in the southwest United States and yak ranches are present in the northern Great Plains. However, when researching archaeological fibers, information comes up short. Many archaeological papers use the catch all term "wool" to describe any hair fiber that can be used as a textile. From personal experience, it can be stated that this practice is frustrating, at best, and seriously hinders an understanding of hair fiber variety present in different cultures around the world. Until a more diverse language is used to describe hair fiber types, understanding the archaeological history of these other fibers cannot be accomplished.

CHAPTER IV

HAIR FIBER DEGRADATION

As discussed earlier, hair fibers degrade due to a variety of environmental conditions (Feughelman 1997, Robbins 2002). It has also been noted that certain depositions allow hair fibers to survive for extended periods of time (Ryder 1983). Even the fibers that have survived show signs of brittleness. The goal of the experiments executed for the first part of this study was to better understand how the environments of different depositional situations affect the degradation of hair fibers (Appendix A). Four common environments were chosen: underwater, burial, open air exposure, and arid, dry conditions. Four samples and a control of mohair, coarse Lincoln wool, fine Rambouillet wool, and human hair fibers were weighed before deposition. The wool and mohair fibers used were unprocessed, meaning that the naturally occurring lanolin and vegetable matter had not been cleaned from the fibers.

Once the samples were photographed and weighed, they were placed in the different environmental conditions. The underwater samples were place in a toilet tank. This allowed for a continual supply of fresh water, while also mimicking water current when the toilet was flushed. The burial samples were placed in a terra cotta pot filled with acidic sandy clay found in the topsoil of Bryan, TX and left outside. Because topsoil was used, crab grass seeds were also in the soil, which later sprouted. Although this was not planned for, the presence of root systems added another environmental dimension that would be common at a terrestrial archaeological site. The open air samples were exposed to sunlight, winds, rain, insects, animals, and the other

environmental conditions common to objects left outside, but not buried. In order to ensure that the samples did not become buried, they were suspended on an "L-shaped" rod. The samples used for the arid, dry conditions were placed in an industrial oven set for 120º Fahrenheit (around 49º Celsius). Many of the locations where the first hair fiber textiles were discovered by archaeologists were in caves and tombs located in the Middle East (Ryder 1983). These areas tend to be very hot and dry (Weather Base 2008). In order to test the fibers in the most extreme situations, 120º Fahrenheit was chosen as an ideal temperature to represent the hottest temperature that would be common to the area during the hottest months.

Once the samples were in place, they were left for a seven-month period. The samples were first placed in their environments in February and removed in September. This allowed the sample left in the open air and those buried in the terra cotta pot to be exposed to the weather conditions common in late winter, summer, and early fall. When the samples were removed, they were photographed for comparison to the original photographs taken before deposition and reweighed (Figures 4-11).

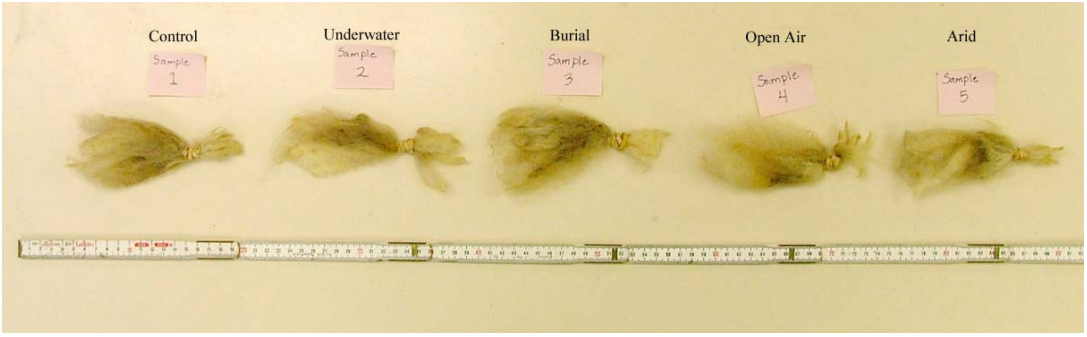
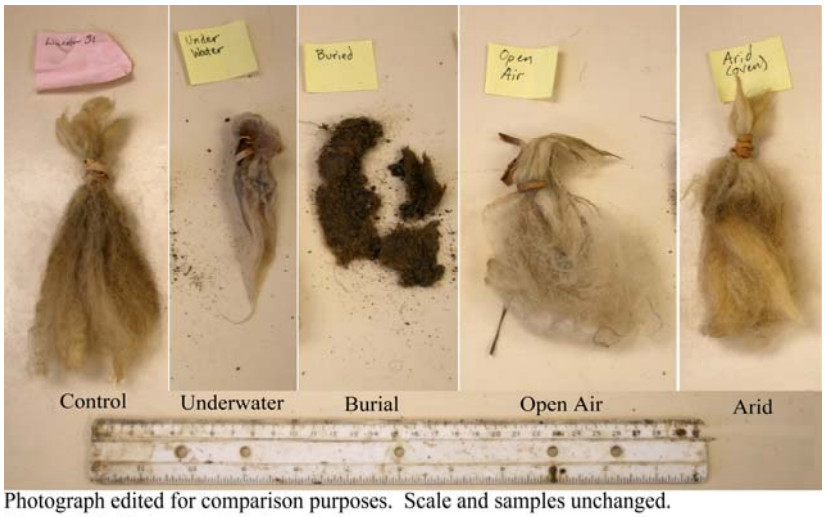


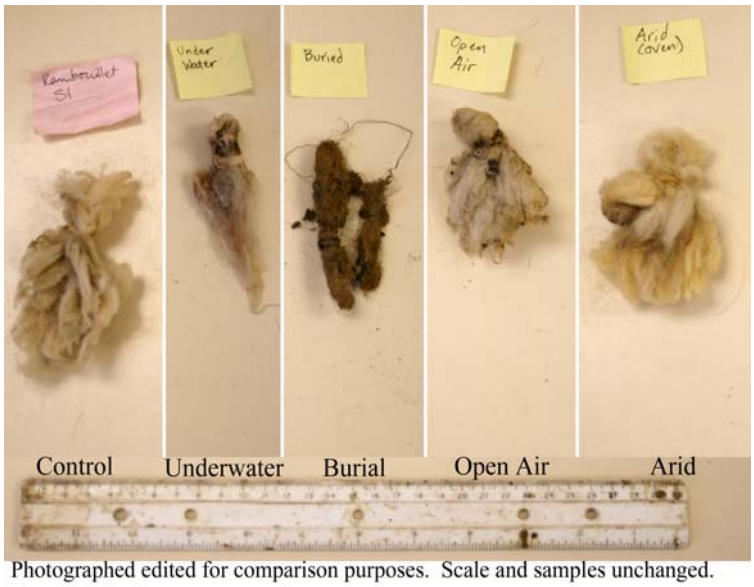
Figure 4. Lincoln samples before deposition



Photograph edited for comparison purposes. Scale and samples unchanged.
For original photo contact author.

Figure 5. Lincoln samples after deposition

Figure 6. Rambouillet samples before deposition



Photographed edited for comparison purposes. Scale and samples unchanged. For original photo contact author.

Figure 7. Rambouillet samples after deposition

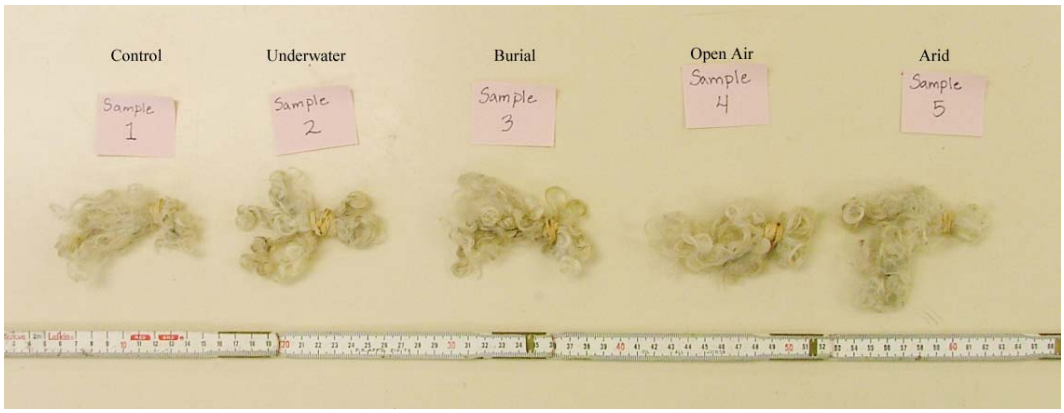


Figure 8. Mohair samples before deposition

Photograph edited for comparison purposes. Scale and samples unchanged.
For original photo contact author.

Figure 9. Mohair samples after deposition

Figure 10. Human hair samples before deposition

Photgraph edited for better comparison. Scale and samples unchanged.
For original photograph, contact author.

Figure 11. Human hair samples after deposition

The results were interesting. After a seven-month depositional period, every sample showed signs of degradation. However, visibly most of the samples did not appear to have significant damage. Once the samples were handled, the damage could be felt. The underwater samples showed a loss of size and were significantly smaller than before deposition. When they were reweighed, there was an increase in mass due to the fact that the fibers were waterlogged. The amount of hair fiber loss could be seen visually, especially when comparing the before deposition and after deposition photographs. However, after treatment, when the water had been removed, the difference in weight was significantly lower than their original weight before deposition,

more accurately reflecting the loss of size. The current created by flushing caused the weaker areas of the fibers to break away from the rest of the sample. This was true of each of the samples, although the mohair lost the most significant amount of mass. The fibers also showed signs of bleaching and were noticeably lighter after being placed underwater. Chemicals commonly used in tap water, namely chlorine, could have caused the bleaching. In order to know for certain, more tests will need to be done using different water types, such as river water, salt water, and deionized water. There is no doubt that hair fibers from underwater archaeological sites will suffer damage from currents and could eventually be washed away as the fibers break. Archaeologists excavating an underwater site would have difficulties in excavating the hair fibers and protecting them from being washed away in the current. For the conservator, the fibers are fairly easy to handle and the largest concern would be creating a way of putting the fibers through dehydration without loosing more hair fiber mass.

The burial samples yielded some of the most dramatic results. All of the fibers were extremely damaged. The human hair remained identifiable, mainly due to its difference in color and structure. However, the coarse wool, fine wool, and mohair were damaged to the point of being almost unrecognizable. The placement of each fiber type had been labeled. This was fortunate since without the labels, identifying which fiber type was which would have been impossible. All of the hair fiber samples were brittle and broke easily with handling. Along with the predicament of the fiber structures being so highly damaged identification became problematic, the presence of roots created another issue. The fine roots were so similar in color and diameter that the roots and

hair fibers looked almost identical. The results demonstrate the difficulties in excavating hair fibers from terrestrial sites. The hair fibers become so damaged when deposited in acidic soils that distinguishing hair fibers from root systems becomes challenging (Figure 12). Since acids tend to be gentler on hair fibers than bases, it is likely that a basic soil would have almost completely obliterated the hair fibers (Feughelman 1997, Robbins 2002). These results indicate that archaeological hair fibers from similar conditions are unlikely to survive, and therefore would not be present in the archaeological record. Even if the fibers survive, it is possible they would not be recognized as an artifact and be mistaken for roots. The fibers that do survive would then present special problems for conservators. The extreme amount of damage present makes handling and cleaning problematic and great care by the conservator would be needed.

Figure 12. Mohair burial sample and root

The open air samples displayed unique problems, especially for a conservator. As expected, the samples were bleached when exposed to the sun. This included the darker human hair fibers. There is no solution for fixing the problem of bleaching. In the case of archaeological hair fibers, there is no way of knowing how much the color has changed over time. Because of this, it should be understood that the hair fibers were likely darker in color before deposition, but no attempt should be made to recreate a darker color. The samples did show signs of brittleness, but less than the fibers from the burial deposition and the arid deposition. More important than the brittleness was the clumping. Each sample became clumped together and had an appearance of being bonded together into a massive unit. Although this made handling of the samples easier, the aesthetic was greatly changed. In the case of archaeological hair fibers, this could be considered an undesirable look. The clumping becomes a blessing for the field archaeologist, but a challenge for the conservator.

Aesthetically, the arid samples showed the least amount of change. The color remained the same and the samples lost little to no mass. However, when the samples were handled, the extent of damage sustained by the hair fibers could be felt. The fibers felt similar to a steel wool and were markedly more brittle. The fibers were easily broken when handled. This indicates that archaeological hair fibers from arid environments would present problems for the excavating archaeologist. Although the hair fibers would appear to be structurally fine, special care would be necessary while excavating to prevent further damage. The conservator would also need to use special care when conserving the artifacts.

Overall, all but the underwater samples showed some signs of brittleness. The brittleness indicates that the disulfide bonds present in the cuticle layer of the hair fiber was repeatedly broken and rebonded (Robbins 2002). Every time the disulfide bonds break and reform, they become more brittle. The bond brittleness is directly connected to the degree of brittleness observed in the hair fiber samples and can act as an indicator for degree of damage hair fibers have suffered on the molecular level. This type of damage was caused by a variety of different environmental conditions. The most problematic samples for excavation and conservation would be the burial samples, since they were the most damaged. Each fiber sample from each depositional environment was damaged to some extent. Because of this, during any excavation the archaeologist should remember that no matter the outward appearance of the hair fiber; there is likely damage that cannot be observed. Also, most samples showed a loss of size. However, in many cases, the addition of other elements from the environment, such as dirt, vegetation matter, and water showed an added mass when reweighed (Table 1). It was not until after conservation a more accurate representation of size loss was reflected in the weight. It was interesting to note that all of the oven samples lost weight, despite the fact that their sizes did not seem to change. This could be due to the loss of the lanolin and natural hair oils from exposure to high heat.

Table 1. Weight change between, before and after deposition

Lincoln	*Control*	*Oven*	*Open air*	*Underwater*	*Burial*
Weight before	2.3 g	2.3 g	2.4 g	2.5 g	2.3 g
Weight after deposition	N/A	2.1 g	2.1 g	8.0 g	3.9 g
% weight change	N/A	-8.70%	-12.50%	220.00%	69.56%
Rambouillet	*Control*	*Oven*	*Open air*	*Underwater*	*Burial*
Weight before	2.3 g	2.4 g	2.5 g	2.4 g	2.3 g
Weight after deposition	N/A	2.2 g	2.6 g	6.1 g	1.9 g
% weight change	N/A	-8.33%	4.00%	154.17%	-17.39%
Mohair	*Control*	*Oven*	*Open air*	*Underwater*	*Burial*
Weight before	2.3 g	2.3 g	2.3 g	2.5 g	2.4 g
Weight after deposition	N/A	2.1 g	2.6 g	3.5 g	1.6 g
% weight change	N/A	-8.70%	13.04%	40.00%	-33.33%
Human Hair	*Control*	*Oven*	*Open air*	*Underwater*	*Burial*
Weight before	2.4 g	2.5 g	2.4 g	2.4 g	2.3 g
Weight after deposition	N/A	2.3 g	2.5 g	4.7 g	2.6 g
% weight change	N/A	-8.00%	4.17%	95.83%	13.04%

CHAPTER V

HAIR FIBER CONSERVATION

Modern, Nonweathered Hair Fiber Experiments (Appendix B)

The Procedure

Before conservation of the weathered hair fibers discussed in Chapter IV, nonweathered hair fiber samples were used in order to determine what percentage of silicone oil to methlytrimethoxysilane (MTMS) that would be the most appropriate. The conservation method tested was silicone oil treatment using Q-1 silicone oil (Smith 2003). There are several different viscosities of silicone oil available. The Q-1 silicone oil was chosen since it has a low viscosity and creates shorter chains (C. Wayne Smith, personal communication 2007). This was ideal for working with hair fibers. The fibers have small diameters and the spaces between the scales of the cuticles are very narrow. Chemically, the thin Q-1 silicone oil has a higher probability of being able to penetrate the hair fibers and is less likely that this silicone oil will create a thick layer on the outside of the hair fiber. The lack of a thick layer of silicone oil means that the conservator would not have to put in as much time and effort in final mechanical cleaning. The MTMS acts as a crosslinker between the silicone polymer chains and between the polymer chains and the hair fibers, allowing the silicone chains that form to strongly bond with the structure of the fibers and the numerous silicone chains created, adding stability and strength. In order to complete the process of silicone oil treatment, a catalyst is used to speed the process of bonding. For these experiments, the chemical TPT titanate was used. The vapor from TPT titanate causes the chemical reaction to

occur, so a direct application is not necessary. Other experiments using polymer passivation have shown that the direct application of the catalyst will likely cause undesirable affects on artifacts; namely creating a hard, plastic appearance on the surface (Smith 2003).

Five different percentages of Q-1 silicone oil and MTMS were used for the experimentation: 100% Q-1, 75% Q-1/25% MTMS, 50% Q-1/50% MTMS, 25% Q-1/75% MTMS, and 100% MTMS. The array of silicone oil percentage used helped to determine the best range of percentages of silicone oil necessary for hair fiber conservation. Five samples and a control of each hair fiber type, Lincoln wool, Rambouillet wool, mohair, and human hair, were used. Before conservation, each sample was weighed and photographed. A spray method was used for application of the mixtures (Figure 13). The spray was placed on a mist setting in order to prevent damage to the hair fibers. The spray application also allowed minimal handling of the fibers during conservation. Once each sample was sprayed with its Q-1 silicone oil/MTMS solution, they were allowed to drain of excess liquid silicone oil for a 24-hour period. After this, the samples were tested for excess liquid silicone oil. Using a paper towel to blot the surface, the amount of silicone oil present on the paper towel was noted. The samples were then put in Ziploc bags with a small amount of TPT titanate placed in a weigh dish. The bags were then sealed and put in an industrial oven set for 55° Celsius. The heat causes the vapor molecules to speed up in their movement, allowing for quicker catalization. Fresh catalyst was put in every 24 hours for a three-day period. Renewal of catalyst was necessary since these chemicals are no longer active after a 24-hour

period (Smith 2000). Once the catalyization process was complete, the samples were removed and blotted with a paper towel.

Figure 13. Spray application of 100% silicone oil to samples

The Results

100% Q-1 Silicone Oil. All of the fibers treated with 100% Q-1 silicone oil were still greasy to the touch. Also, blotting with a paper towel showed a significant amount of liquid excess silicone oil was present. The lack of a crosslinker meant that little to no bonding took place. These results were expected. In order to understand how much time would be involved using this method of treatment, the samples were placed in methlytrimethoxysilane (MTMS) baths. This practice is commonly used at the Conservation Research Lab at Texas A&M University to remove liquid excess silicone oil. The amount of time required for the removal of excess liquid silicone oil is linked to the amount of excess liquid silicone oil present. In order to better judge the length of time the hair fibers would need to be in the MTMS baths, each sample was dipped in

fresh MTMS for two-minute dips. This procedure was continued until all excess silicone oil was removed. The time ranged from two minutes for the mohair to six minutes for the Lincoln wool and the human hair. Overall, the method of using 100% silicone oil for treatment is a waste of time and money.

75% Q-1 Silicone Oil/25% MTMS. These samples still had a high amount of excess liquid silicone oil present before the MTMS baths. However, with the addition of MTMS to the original treatment, there was bonding between the hair fibers and the Q-1 silicone molecules. This could be observed visually on several of the hair fibers where small nodules of excess silicone had hardened on the fibers. These samples also went through MTMS baths. The time was shortened to one-minute baths since the amount of excess liquid silicone was less than the amount present in the 100% Q-1 silicone oil. When the MTMS baths were complete, there were more nodules present. However, these could be removed by careful mechanical cleaning using a soft toothbrush, paintbrush, or a hypodermic needle for the tougher to remove nodules. This is a viable conservation method, but the extra time to clean combined with the use of too much silicone oil makes this method a bit less cost efficient than some of the other methods.

Lincoln: Before MTMS baths, these fibers had a very greasy feel, although less than the Rambouillet wool and human hair samples. Small nodules of hardened silicone oil could be seen on some of the hair fibers. After the MTMS baths, the fibers were flexible, not greasy to the touch and no excess liquid silicone oil was removed when the fibers were blotted. However, the hard silicone nodules remained and had to be removed mechanically.

Rambouillet: Before MTMS baths, this sample had the second most excess liquid silicone of the four samples used, as judged by feel and blotting. There were less nodules of hard silicone present than on the Lincoln, but they were still present. After the MTMS baths, the fibers were flexible, not greasy to the touch and no excess liquid silicone oil was removed when the fibers were blotted. However, the hard silicone nodules remained and had to be removed mechanically.

Mohair: Out of the four samples in this set, the mohair reacted to the treatment the best. There was less excess Q-1 silicone oil present than any of the others, and no hardened silicone nodules could be seen. However, there was still a high amount of excess liquid silicone and the mohair sample also had to go through MTMS baths. After the baths were completed, the fibers were flexible, not greasy to the touch, and no liquid silicone was removed when the fibers were blotted. Because there were no silicone nodules, no mechanical cleaning was necessary.

Human Hair: This sample had the most excess liquid silicone present of the four hair fiber types. When touched, it had a very greasy feel and blotting showed a lot of excess liquid silicone oil. Although there were very few hardened silicone nodules present on the hair fibers, there were problems with clumping. Almost all the hair fibers acted as if they had been glued together. This clumping affect was also observed in the 100% Q-1 silicone oil human hair fiber sample, and the problem only worsened after the MTMS baths. After the MTMS baths for the 75% Q-1 silicone oil/25% MTMS human hair fiber sample, the fibers did feel similar to the control sample, but they stayed clumped together. The fact that it did not worsen could be due to the fact that MTMS

was already added with the original treatment, whereas the 100% silicone oil treatment needed to have the crosslinker added in order for the clumping to occur to the same degree. To some extent, this could be reversed with mechanical cleaning. The mechanical cleaning could be done with a soft toothbrush and either a hypodermic needle or dental pick. However, this only worked to a certain degree. When mechanically cleaned, the excess silicone came out in long, white-colored flakes. These were even more difficult to remove. It is possible that the use of a fine-toothed comb would remove more, but all of these mechanical cleaning methods would be damaging to the hair fibers, possibly causing more harm than good. Overall, for the treatment of human hair, the amount of silicone oil used needs to be considerably less to be a truly viable treatment method.

50% Q-1 Silicone Oil/50% MTMS. Overall, the 50% Q-1 silicone oil/50% MTMS treatment is better than the two methods using higher amounts of the Q-1 silicone oil. However, a degree of excess liquid silicone is evident. Unlike the 75% silicone oil/25% MTMS treatment, there were little to no hardened nodules of excess silicone present. Instead, the excess hardened silicone was present in the form of thin, white flakes similar to those that appeared when cleaning the 75% silicone oil/25% MTMS treated human hair. With the lower amounts of silicone oil present, this method becomes an even more viable treatment option than the 75% silicone oil/25% MTMS treatment. Although there was excess silicone present in liquid and hardened forms, this could be a good treatment option for hair fibers that are particularly dry and brittle and/or degraded. It would also be a good option for most of the hair fibers if the amount

of silicone oil to be used cannot be easily determined. Although there would be some excess liquid and hardened silicone oil, the amount of excess silicone oil is minimal and is easily removed with MTMS baths and some mechanical cleaning.

Lincoln: The Lincoln sample had the second least amount of excess silicone oil present of the four hair fiber types in this treatment. There was some excess liquid silicone oil present that could be felt and seen when blotted. There was also some excess hardened silicone oil present in the form of thin, white flakes. These flakes could easily be removed with a fine artist paintbrush or hypodermic needle. After the MTMS baths, the Lincoln fibers felt very close to the control sample. The main difference is that the treatment seemed to have removed the naturally occurring lanolin that was present on the Lincoln wool.

Rambouillet: The Rambouillet sample had the second highest amount of silicone. There was a definite greasy feel to the fibers and when blotted with a paper towel, the second highest amount of silicone oil present in this test could be observed visually. Instead of white flakes, there were hardened silicone nodules present. Currently there is no research to suggest what the determining factor is for the formation of nodules versus the formation of white flakes. These nodules could be removed by lightly brushing with an artist paintbrush or hypodermic needle for the harder to remove nodules. After the MTMS baths, the fibers felt very close to the control sample. Like the Lincoln, the naturally occurring lanolin that had been present was stripped away by the MTMS baths. There was still significantly less excess silicone oil present than in the 75% silicone oil/25% MTMS test, making this method more viable.

Mohair: When the mohair sample was felt, the amount of excess liquid silicone oil present seemed to be equal to that on the Lincoln sample. When the mohair was blotted with a paper towel, however, notably less excess liquid silicone was present. Once the MTMS baths were complete, the mohair felt remarkably close to the control sample. Since there was little lanolin present on the original, natural mohair, there was no perceptible difference in the amount of lanolin remaining when using touch.

Human Hair: Once again, the human hair sample had the most excess silicone oil present. Also, like the 75% silicone oil/25% MTMS test, the hair fibers tended to clump together. The clumping affect was less than observed in the other tests mentioned above. The clumping did not worsen after the MTMS baths, but the white flakes of hardened silicone became more noticeable. The amount of white flakes of polymerized silicone oil worsened when mechanical cleaning was attempted in order to reverse the clumping condition. Although the fibers could eventually be cleaned using a soft toothbrush, hypodermic needle, and/or a fine-toothed comb, there would still the problem of more damage than good being done. Unless the hairs fibers are highly brittle and degraded, or are present in the form of cordage or thick textile, 50% Q-1 silicone oil/50% MTMS has too much silicone oil to be a truly viable method of human hair fiber conservation.

25% Q-1 Silicone Oil/75% MTMS. Taking into consideration all of the other treatments and the different hair fibers types, this method was the best overall. Although the hair fibers still had to go into MTMS baths after applying the silicone oil treatment with the spray method, the amount of time it took to remove the excess liquid silicone

was the lowest. Also, there were little to no excess hardened silicone oil present on the fibers. However, it should be kept in mind that a higher proportion of silicone oil may be necessary to treat fibers that are more degraded, drier, or more brittle.

Lincoln: Once again, the Lincoln sample had the least amount of excess silicone oil present, after the mohair. Also similar to the results of the other test, specifically the 50% Q-1 silicone oil/50% MTMS, the greasy feel made it seem that the Lincoln sample had more excess silicone oil present than it really did when the fibers were blotted. MTMS baths were still needed, but considerably less time was needed to remove the excess liquid silicone. There was no excess hardened silicone oil present as either nodules or white flakes at any point during the experiment. After the baths, the only noticeable difference between the control and the sample from this test was the absence of the naturally occurring lanolin.

Rambouillet: In the same pattern as seen in the other tests, the Rambouillet had the second highest amount of excess silicone oil present. There was a greasy feeling caused by the excess liquid silicone and a noticeable amount of the liquid could be seen when the fibers were blotted. Even though there was excess liquid silicone oil present, the amount was considerably less than any of the other tests that used the Q-1 silicone oil. Also, there were no nodules or white flakes present indicative of excess polymerized silicone oil. After the MTMS baths, the Rambouillet was very close in feel to the control. Like the Rambouillet in the other tests, the appreciable difference between the control and the test sample was the lack of lanolin on the test sample.

Mohair: The mohair had the least amount of excess silicone oil present. Although the mohair did not feel like it had an excess of liquid silicone oil, blotting showed that some was present. There was no indication of excess hardened silicone oil. After a short MTMS bath, the mohair fibers felt, and looked, like the control.

Human Hair: As with the other tests using silicone oil, the human hair fibers had the most excess silicone oil, based on both feel and blotting. Unlike the other tests with silicone oil, the amount of clumping that occurred was considerably less. Only a small section of the hair fibers clumped together. After the MTMS baths, the clumping actually lessened in intensity and the fibers felt like the control. With a little bit of mechanical cleaning using a soft toothbrush and hypodermic needle, the fibers also looked like the control. These results indicate that when conserving human hair fibers, less silicone oil is needed than for the wools and mohair.

100% MTMS. Each of the hair fiber type results will not be covered since the results almost identical for each sample tested. All of the hair fiber types were dry to the touch and displayed more brittleness than the controls. The fibers were easier to break than before treatment. The best that can be said for this treatment is that the MTMS did clean the fibers of any dirt present on them (Figure 14). Overall, this is not a viable treatment. The results are as poor as the results for the 100% Q-1 silicone oil test, but for different reasons. Although the treatment is not costly, the results show that the treatment does more harm to the hair fibers than good.

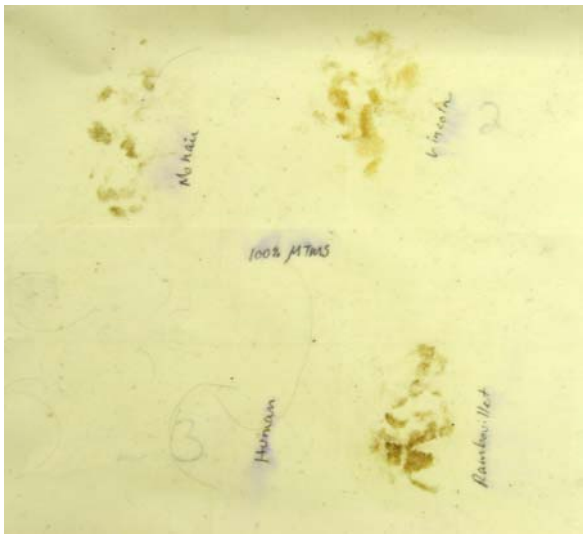


Figure 14. Dirt removed from samples by MTMS treatment

Conclusions

The use of touch and blotting were the main way of determining the presence of excess liquid silicone oil. Visual observation of white flakes and nodules were used to determine the presence of excess polymerized, or hardened, silicone oil. In addition to these qualitative methods, quantitative measurements can also be used. This is accomplished by monitoring weight change (Table 2). By calculating weight gain from the original weight, and then the weight loss after MTMS baths, it can be determined how much silicone oil is present.

Table 2. Weight change after treatment and after MTMS baths

Lincoln	100% si oil	75% si oil/25% MTMS	50% si oil/50% MTMS	25% si oil/75% MTMS	100% MTMS
Before Treatment	2.4 g	2.3 g	2.4 g	2.4g	2.4 g
After Treatment	4.2 g	4.4 g	3.6 g	2.8 g	2.3 g
% Weight change	75%	91.30%	50.00%	16.67%	-4.17%
After MTMS baths	3.2 g	2.6 g	2.6 g	2.4 g	N/A
% Weight change*	33.33%	30.00%	20.00%	0.00%	N/A
Rambouillet	100% si oil	75% si oil/25% MTMS	50% si oil/50% MTMS	25% si oil/75% MTMS	100% MTMS
Before Treatment	2.5 g	2.5 g	2.5 g	2.5 g	2.6 g
After Treatment	5.3 g	5.8 g	3.8 g	3.4 g	2.6 g
% Weight change	112.00%	132.00%	52.00%	36.00%	0.00%
After MTMS baths	3.1 g	2.8 g	2.7 g	2.5 g	N/A
% Weight change*	24.00%	12.00%	8.00%	0.00%	N/A
Mohair	100% si oil	75% si oil/25% MTMS	50% si oil/50% MTMS	25% si oil/75% MTMS	100% MTMS
Before Treatment	2.6 g	2.5 g	2.5 g	2.4 g	2.6 g
After Treatment	3.6 g	3.5 g	3.5 g	3.4 g	2.6 g
% Weight change	38.46%	40.00%	40.00%	41.67%	0.00%
After MTMS baths	2.7 g	2.7g	2.6 g	2.8 g	N/A
% Weight change*	3.85%	8.00%	4.00%	16.67%	N/A
Human Hair	100% si oil	75% si oil/25% MTMS	50% si oil/50% MTMS	25% si oil/75% MTMS	100% MTMS
Before Treatment	2.4 g	2.4 g	2.6 g	2.6 g	2.5 g
After Treatment	3.4 g	2.9 g	3.2 g	3.1 g	2.5 g
% Weight change	41.67%	20.83%	23.08%	19.23%	0.00%
After MTMS baths	2.8 g	2.7 g	2.7 g	2.7 g	N/A
% Weight change*	16.67%	12.50%	3.85%	3.85%	N/A

* change based on before treatment weight

Based on the results of the different experiments, the ideal Q-1 silicone oil/MTMS mixture would be between 25% Q-1 silicone oil/75% MTMS and 50% Q-1 silicone oil/50% MTMS. The precise amounts would need to be determined by the conservator based on the state of degradation, brittleness, and fiber type. If more

silicone oil is used than is needed, the results should still be excellent to good with the use of MTMS baths and possible mechanical cleaning. The exception to this would be human hair fibers. Although results can still be good to excellent if excess silicone oil is present, the fibers do seem to be considerably more sensitive to the excess silicone oil and care should be taken when preparing treatment.

Modern, Weathered Hair Fiber Experiments (Appendix A)

The Procedure

Based on the modern, nonweathered hair fiber experiments, it was determined that the ideal percentage of Q-1 silicone oil necessary for hair fiber conservation is between 25% Q-1 silicone oil/75% MTMS and 50% Q-1 silicone oil/50% MTMS. For this experiment the samples used for the depositional experiments described in Chapter IV were used. This allows for a better representation of how silicone oil treatment would work on archaeological samples. The amount of silicone oil used for each depositional sample was determined based on the amount of brittleness present. Since the open air samples and underwater samples had less brittleness, a 25% silicone oil/75% MTMS mixture was used. For the more degraded arid samples and burial samples a 30% Q-1 silicone oil/70% MTMS mixture was applied.

For the burial, arid, and open air samples, the same spray application described for the modern, nonweathered hair fiber experiments was used. The underwater samples went through a series of dehydration baths. These were necessary for the removal of water from the hair fibers (Hamilton 1997). In order to maintain separateness of the samples and to prevent the hair fibers being lost, a box with separation walls was made

using pantyhose, a plastic mesh, and microfilament line (Figure 15). All of these supplies are easy to find and extremely inexpensive. The first bath was 50% deionized water/50% ethanol. This was followed by a 100% ethanol bath, a 50% ethanol/50% acetone bath, and finally a 100% acetone bath. For each bath, the sample was submerged in the mixture and placed in a vacuum that allowed the alcohols to fully penetrate. Once the baths were complete, the hair fiber samples were submerged in the silicone oil/MTMS mixture.

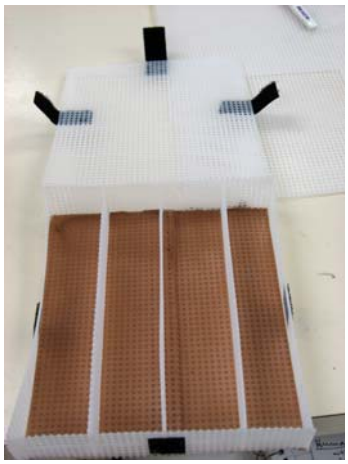


Figure 15. Dehydration box

Once all of the samples had been treated with their respective Q-1 silicone oil/MTMS mixtures, the excess liquid silicone oil was allowed to drain for 24 hours. The samples were tested for excess liquid silicone oil using a paper towel for blotting. All samples were then placed in Ziploc bags with TPT titanate and sealed. These were then placed in an industrial oven with the temperature set at 55° Celsius. The heat allowed for a shorter catalyzation time. Because of the shorter catalyzation time, the

samples were in the oven for three days, with the catalyst being replaced with fresh TPT titanate each 24-hour period. Once the catalyzation process was complete the samples were removed and tested for excess liquid silicone oil and visually inspected for signs of excess hardened silicone oil in the form of white flakes and clear nodules.

The Results

Underwater Samples. The treatment of the underwater fiber samples with 25% silicone oil/75% MTMS was very successful. The fibers felt close to the control samples, with the exception of the lanolin no longer being present. The flexibility was as good as the control and the fibers are soft to the touch. The results were excellent and proved that this method of conservation is viable.

Burial Samples. The treatment of the burial fiber samples with 30% silicone oil/70% MTMS was successful. The fibers became easier to handle and more flexible. However, the initial damage was so severe that the fibers were still quite fragile, even after treatment. It is unlikely that any treatment method would be able to counteract the degradation that occurred from burial of the hair fibers. The results were good, and handling of the fibers did become easier. These results show that polymer passivation is a viable option of treatment, but the fibers may always be fragile.

Open Air. The treatment of the open air fiber samples with 25% silicone oil/75% MTMS proved to be a viable treatment method. The fibers were flexible and no clumping occurred from the treatment. It should be noted that the samples were still clumped from deposition, and this condition could not be reversed using only Passivation Polymers. Because the fibers were not very brittle or dry from exposure to

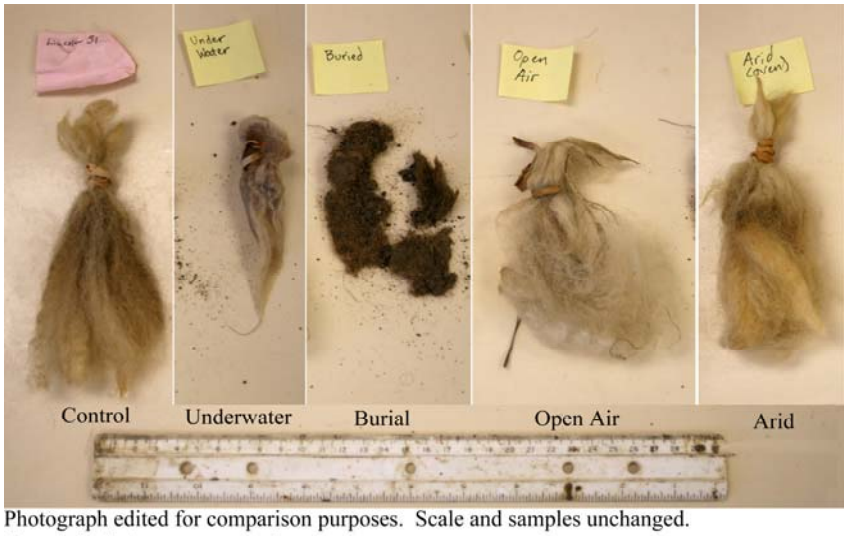
the weather elements, it is difficult to tell if they are more flexible than before treatment. Overall, the results were good.

Arid Samples. The treatment of the oven hair fiber samples with 30% silicone oil/70% MTMS was highly effective. The fibers felt similar to the control and were more flexible and supple than before treatment. The only difference was the lack of lanolin on the oven treated fibers. This treatment method is viable, producing excellent results.

Conclusions

Treatment of archaeological hair fibers using silicone oil treatment is a viable conservation method (Figures 16-23). The best candidates for the procedures used are hair fibers that are brittle. Although not all damage can be reversed, the fibers do become easier to handle, less brittle, and more flexible. If a hair fiber artifact is in decent conditions where flexibility is not an issue, silicone oil treatment may be unnecessary. As with every artifact, the conservator must make a decision based on the individual artifact and the end objectives. It should be mentioned that there are concerns about the reversibility of this method. Silicone oil treatment is not reversible. However, there is no conservation method that is completely reversible (Hamilton 1997, Smith 2003). Every time a new element is added to an artifact, not all of it can effectively be be able to be removed and will remain as a part of the artifact for the rest of time. It is much more important to consider the long term life of the artifact and how best to preserve its aesthetics and value in analysis. Because of this, silicone oil treatment should be considered. Although it is not appropriate for every artifact, it can be useful in

a number of situations. Certain analytical techniques, especially those measuring the elements present, still can be done. When analysis of this type is done, it is a simple matter of the analyst ignoring the silicone spike that will be caused by the use of silicone oil (Smith 2003). Also, there are indications that the silicone oil does not respond adversely to humidity changes and skin oil. This is especially ideal for areas where humidity control is difficult. Finally, the half life of silicone oil is 250 years. For retreatment, it is a matter of recatalyzation, which can be accomplished by using chemical means, or natural ones, like exposure to humidity and ultraviolet (UV) light. This means that retreatment is not a concern for an extended period of time, and when retreatment is necessary, it is a short, simple process.



Photograph edited for comparison purposes. Scale and samples unchanged.
For original photo contact author.

Figure 16. Lincoln samples before treatment

Figure 17. Lincoln samples after treatment

Photographed edited for comparison purposes. Scale and samples unchanged. For original photo contact author.

Figure 18. Rambouillet samples before treatment

Figure 19. Rambouillet samples after treatment

Photograph edited for comparison purposes. Scale and samples unchanged.
For original photo contact author.

Figure 20. Mohair samples before treatment

Figure 21. Mohair samples after treatment

Photgraph edited for better comparison. Scale and samples unchanged.
For original photograph, contact author.

Figure 22. Human hair fiber samples before treatment

Figure 23. Human hair fiber samples after treatment

CHAPTER VI

HAIR FIBER ARTIFACTS: PRACTICAL APPLICATION OF SILICONE OIL TREATMENT

UK Victorian Hair Fob (Appendix C)

The Artifact

During the Victorian Era, hairart became a popular trend (Cahoon personal communication 2006, Speight 1872). Numerous jewelry objects and wreaths were made using human hair. Most people are more familiar with the mourning pieces, but many times other objects were created to act as a way for people to feel closer to those they loved. Hair wreaths were created for weddings to act as a reminder of those that attended. Family members would donate locks of hair for wreaths that represented the family. Many of these objects still survive, often passed down through family lines. One such object is a watch fob. The fob dates to around the turn of the 19th and 20th century and comes from the United Kingdom (Anthony Gray, personal communication 2007). The family history indicated that the watch fob was made from an individual's wife's hair. After being in storage for around 100 years, it was decided that the watch and fob should be restored and conserved. Anthony Gray, a watch restorer, was contacted. Although he had the skills to restore the watch, he was unable to conserve the fob. For this reason, I was contacted. After several emails, it was decided that the fob should sent to the Conservation Research Lab for conservation. Several experiments were performed before conservation of the watch fob (Appendix IV). Unlike the other experiments, the watch fob was not comprised of loose hair fibers, but was corded in a

unique design (Figure 24). This cording required experimentation in order to assure that the silicone oil would fully penetrate throughout the watch fob. After the initial experiments, the silicone oil treatment was applied to the object.

Figure 24. Victorian era watch fob before conservation

The Method

Several conservation procedures were discussed before preservation began. Silicone oil treatment was chosen due to several factors. Since the watch fob belonged to a private individual instead of a museum there were several issues that needed to be considered. There was the possibility that humidity control would be a problem, along with the likelihood that the use of gloves when being handled could be impractical. There was also the problem of reconservation and how often that would need to occur. Also, the fob was quite brittle and extremely fragile in some areas. The two

conservation methods most likely to be successful included silicone oil treatment and the use of polyethelene glycol (PEG) in conjunction with ethyl-hydroethyl cellulose (ethulose) (Hamilton 1997, Smith 2003). Silicone oil treatment was used since PEG is susceptible to humidity changes and gloves would be required to handle the fob. Also, using PEG would require retreatment more often. Objects treated using silicone oil treatment only require retreatment every 250 years if the object was never exposed to a catalyst. Also, humidity is a catalyst for silicone oil treatment and would actually strengthen the bonds between the silicone polymer chains and the hair fibers, protecting the watch fob as opposed to causing undesirable shrinking and swelling (Smith 2003). There are also several indicators that objects treated using silicone oil can be handled with bare hands. Finally, the concern of ultraviolet (UV) light exposure on the watch fob had to be considered. UV light is known to degrade hair fibers and since the fob is not in a museum, control over lighting was less assured (Robbins 2002). By using silicone oil, exposure to UV light became less problematic, since UV light acts as a catalyst and, similar to humidity, would create stronger bonds between the silicone polymer chains and the hair fiber (Smith 2003). Overall, the fact that an individual owned the watch fob was a determining factor in deciding upon the best method of conservation. Lack of control over humidity, UV light, and handling made the silicone oil treatment technique the most ideal choice.

Once the methodology was decided upon, conservation began. Because of the brittleness of the hair fibers in the watch fob, a 40% Q-1 silicone oil/60% methlytrimethoxysilane (MTMS) mixture was used. The mixture was applied using a

spray technique. The spray bottle was placed on a setting between mist and stream. Because of the thickness of the cord, the mist setting would not penetrate throughout the fob. By placing the setting between mist and stream, enough pressure was used to ensure penetration throughout the fob without damaging the hair fibers. Once the silicone oil/MTMS mixture was applied, the fob was allowed to drain of excess liquid silicone oil for 24 hours. Once the 24-hour period was over, a paper towel was used to blot the surface of the fob. No excess silicone oil was lifted from the surface and the fob was then placed in a Ziploc bag with a weigh dish containing a small amount of TPT titanate to act as the catalyst. The bag was then sealed and placed in an industrial oven set at 55° Celsius. The catalyst was replaced every 24 hours for a 48-hour time period. Because there was only one object in the bag, unlike the experiments described in Chapter V, a shorter time period in catalyzation could be used. When the catalyzation was complete, the watch fob was removed from the bag. One area of the watch fob was abraded before conservation. At this area, there were a few white flakes and small, hardened silicone nodules present. This indicated that some excess silicone oil was present in this area of the watch fob. Careful mechanical cleaning using a fine paintbrush and hypodermic needle was performed (Figure 25). After the removal of the white flakes and nodules, the conservation for the watch fob was complete.

Figure 25. Mechanical cleaning of watch fob

The Results

The silicone oil treatment technique was highly successful. Although there was no way to repair the existing abraded damage without compromising the aesthetics and integrity of the object, the fob as a whole is well preserved (Figure 26). A higher degree of flexibility is now evident and the fibers are protected from further degradation. Because of the process used, the object can be handled without gloves and will not be subject to further degradation due to humidity or UV light. The fact that more flexibility is present demonstrates that similar to some PEG/cellulose treatments used in the past, silicone oil treatment can help an object regain some flexibility. Successful treatment of the watch fob using silicone oil treatment demonstrates that this conservation method is a viable treatment for hair fiber artifacts.

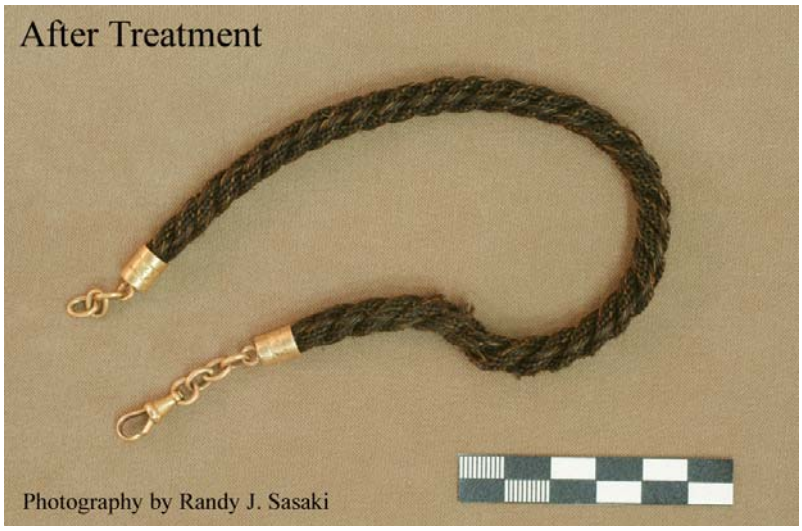


Figure 26. Victorian era watch fob post conservation

Hair Fibers From *Kittern* (Appendix D*)*

The Artifact

The hair fibers used came from the excavation of the shipwreck *Kittern* (Kroum Batchvarov, personal communication 2006). The site is an underwater site located in Bulgaria, and excavated in 2003. The artifact is comprised of a tar or pitch substance mixed with loose hair fibers and was found with artifact number I3LR2, which is a double block. The coloring was a very dark brown to black. Unfortunately, the preconservation pictures were lost due to computer problems. Since the other substance could not be positively identified, it will be referred to as tar for the remainder of the thesis. The fibers are most likely goat, given the region and physical characteristics, but no scaling could be observed microscopically. This can happen, especially at underwater sites. The combination of humidity and heat can cause the scales on the cuticle of the hair fibers to meld together (Robbins 2000).

The Method

Based on results from the experiments performed on the underwater deposition samples from Chapter V, it was determined that a 25% Q-1 silicone oil/75% methyltrimethoxysilane (MTMS) mixture would work best for conservation. Before the artifact could be submerged in silicone oil, the water needed to be removed (Hamilton 1996, Smith 2003). A series of dehydration baths was used to remove all water and allow full silicone oil penetration. The first bath was a 50% deionized water/50% ethanol mixture. This was followed by 100% ethanol, 50% ethanol/50% MTMS, and 100% acetone baths. Once the dehydration baths were complete, the artifact was submerged in the silicone oil/MTMS mixture (Smith 2003). In order to speed up the process, a vacuum chamber was used.

Once the application of the silicone oil/MTMS mixture was complete, the artifact was removed and allowed to drain for 15 hours. A paper towel was used to blot the surface of the artifact to test for excess liquid silicone oil. There was indication of quite a bit of excess liquid silicone oil, so the artifact was submerged in an MTMS bath for two minutes. It was then removed and allowed to drain and dry. The MTMS bath removed the excess liquid silicone oil from the hair fibers, but too much silicone oil was removed from the tar. Because of this, the tar had become flaky and brittle, making handling more difficult (Figure 27). In order to remedy the problem and allow for easier handling, a very small amount of the 25% Q-1 silicone oil/75% MTMS mixture was applied to the drier areas using a cotton-tipped swab. The artifact was then allowed to drain again for a 24-hour period. The artifact was then tested for excess liquid silicone

oil using a paper towel for blotting. There was no excess liquid silicone oil present. The artifact was then placed in a Ziploc bag with an aluminum weigh dish that contained a small amount of TPT titanate. The bag was then sealed and placed in an industrial oven set at 55° Celsius. The artifact was left to catalyze for 48 hours. After 24 hours in the oven, the catalyst was replaced with fresh TPT titanate since the chemical catalyst is exhausted within 24 hours after exposure to the atmosphere. Once the artifact was removed, it was retested for excess liquid silicone oil using a paper towel. It was also visually examined for white flakes and clear nodules, which would indicate excess hardened silicone oil that would need to be removed mechanically. There was no indication of either white flakes or nodules, demonstrating that the artifact conservation was complete.

Figure 27. *Kittern* artifact after MTMS bath

The Results

The silicone oil treatment was successful for the hair fibers. The fibers were flexible and easy to handle. The tar substance did not fair as well. The tar seemed to break and flake off more easily. Reapplication of the 25% Q-1 silicone oil/75% MTMS on the drier areas improved this situation dramatically. It seems that the amount of silicone oil need for the tar was higher than the amount needed for the hair fibers. The problem was remedied and the end results were good (Figure 28). This treatment method is viable. For successful application of this method, the conservator would need to be aware that the different components of a composite artifact may need special attention and that all aspects of the artifact need to be considered individually.

Figure 28. *Kittern* artifact post conservation

Conclusions

Both the UK watch fob and the *Kittern* artifact show that silicone oil treatment is a viable conservation method. The UK fob results were excellent. The hair fibers were originally very brittle and broke easily. Using the silicone oil treatment allowed the fibers to become more flexible and easier to handle. The *Kittern* artifact showed that composite artifacts containing hair fibers could be conserved using silicone oil treatment. However, it also demonstrated that attention to all materials is necessary for successful application. By treating only one part of the whole, an artifact could suffer aesthetically and structurally. More time was needed to address all problems presented, but the end results demonstrate that the extra time was well spent, assuring conservation of both the hair fibers and the tar.

CHAPTER VII

CONCLUSIONS

This work has covered a wide range of hair fiber topics. The structure and history has been covered, along with how hair fibers degrade in certain situations and conservation using silicone oil treatment. As a whole, archaeologists and conservators alike can use this information. Understanding what to expect and why leads to better preparation and a higher likelihood of preserving hair fiber artifacts for future generations. By understanding the basics and building up, many questions and concerns can be addressed.

One important aspect of this research is building a foundation for further hair fiber research. The physical and chemical properties of hair fibers were covered in order to allow for a better understanding of why hair fibers react in the way they do to environmental conditions and conservation treatment. It also allows one to explain why hair fibers are not present in the archaeological record until long after evidence of weaving is present. When hair fiber artifacts do appear in the archaeological record, they are found in dry, arid environments, such as caves and tombs. Because of the lack of exposure to ultraviolet (UV) light, most acids, alkalines, insects, or other pests in caves and tombs, they become ideal depositional environments. The delicate structure of the disulfide bonds found in between the cuticle scales accounts for their degradation in most depositional environments, including arid, dry places. Although the hair fibers are still brittle and delicate, they are present in an archaeological environment. Without

knowing the structure of hair and its chemical bonds, we would never understand why certain environments are more likely to contain hair fiber artifacts and other do not.

In conjunction to researching hair fiber artifacts, depositional experiments were also performed. By place different hair fiber types in different environmental situations, more information could be gathered that is helpful to field archaeologists and conservators. The results showed that four types of hair fibers common to the archaeological record act in similar ways during deposition. The burial samples, which were deposited in acidic sandy clay, demonstrated that finding archaeological samples in traditional terrestrial sites where the soil is exposed to wet and dry weather do not usually yield hair fibers. Underwater sites preserve the hair fibers to an extent, but other environmental factors common to these types of sites present other difficulties that are necessary to address for successful recovery during excavation. Open air samples demonstrated that hair fibers left to outdoor elements survive, but there are greater concerns over the hair fibers' destruction from insects, birds, and other animals. Over time, the hair fibers left in open air situations are likely be destroyed at a quicker rate than those in arid environments. The arid samples demonstrated that hair fibers in dry, arid conditions are more likely to survive. There was still extensive damage to the fibers that can not be observed visually. This teaches field archaeologists and conservators to not take appearance at face value. Although the fibers are less likely to loose mass, handling could be difficult, producing damage created by removal of the artifact.

Once a clearer understanding of hair fiber degradation, the problem of conservation could be tackled. The newer conservation method using silicone oil

treatment was used to demonstrate its viability as a method for conserving hair fibers. The results for the different depositional samples were excellent. However, the burial samples demonstrated that in certain situations, the damage could be so great that the fibers would always remain fragile. The silicone oil treatment using Q-1 silicone oil did allow the fibers to regain some flexibility and reversed some of the brittleness that was present before conservation. By creating a greater amount of suppleness, the hair fibers become easier to handle and could make analytical techniques, like microscopy, easier. The fibers also become easier to display, since a museum curator would not have to worry as much about the environmental conditions and control. Silicone oil treatment allows for more lenient storage conditions and handling (Smith 2002).

After successful treatment of the depositional samples using silicone oil treatment, the methodology was applied to artifacts. A Victorian era watch fob made from human hair fibers and hair fibers mixed with tar from the *Kittern* shipwreck were chosen for conservation using silicone oil treatment. The watch fob treatment was highly successful. Before treatment, the hair fibers were brittle and broken easily. After treatment, the fibers are significantly more flexible and can easily be handled without the fibers breaking. The *Kittern* artifact demonstrated the importance of taking all components into consideration in order for conservation to be successful. More time and effort was necessary, but the added care allowed for excellent end results. Not every hair fiber artifact requires silicone oil treatment, but in case where brittleness is more extreme, this conservation method could be used to combat the degradation present. As

with every artifact, end goals, storage, display, and condition of the artifact must be taken into consideration before conservation begins.

Although many aspects of hair fiber degradation and conservation have been covered in this work, more research could be done. The main focus was on individual hair fibers. With this research as a base, further experiments could be done focusing on corded and woven textiles containing hair fibers. There are other depositional environments that were not covered for this work. More research focusing on basic soils, different water environments, and waterlogged burial sites can now be done, using this work as a base to start from. Also, as silicone oil treatments are applied to more hair fiber artifacts, more information can be gained on which hair fiber artifacts are the best candidates for this treatment method. As with all scientific works, hair fiber research is never complete. The goal is to gain a better understanding of what to expect, understand why, and how to preserve the hair fiber artifacts found. This research helps to provide a base to start from and allow for hair fiber degradation and conservation research to grow as more questions and problems arise.

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APPENDIX A

LAB REPORT: MODERN, WEATHERED HAIR FIBER EXPERIMENT

Object:

In order to understand the degradation process, Lincoln wool fibers, Rambouillet wool fibers, mohair fibers, and human hair fibers were divided into several samples and placed in different environmental conditions. These conditions included exposure to all elements (referred to as open air for the report), arid, dry conditions (referred to as oven for the report), underwater, and burial in local Bryan, TX sandy clay soil. By discovering how hair fibers react to different environmental conditions and knowing what to expect from certain archaeological depositions, the conservator will be better prepared for the degree of degradation.

Once the hair fibers had weathered for 6 months time, they were removed from their environmental conditions and treated using silicone oil treatment(Smith 2002). Based on experiments using modern, nonweathered hair fibers, the percent Q-1 silicone oil and methyltrimethoxysilane (MTMS) to be used for each depositional condition was determined. These experiments give a more precise ratio of silicone oil to MTMS in conjunction with the environmental conditions they were exposed to for the first part of the experiment.

Initial condition:

Lincoln wool: Unprocessed wool with some vegetable matter present, along with naturally occurring lanolin.

Rambouillet wool: Unprocessed wool with some vegetable matter present, along with naturally occurring lanolin.

Mohair: Considered kid mohair, which is a finer, more commonly used clothing fiber than the mohair from older angora goats. It is also unprocessed with vegetable matter present, along with the naturally occurring lanolin. Note of interest: based on the feel of grease on the hair fibers, there appears to be less lanolin present than the wools.

Human hair: Donated from a 50 year old female individual who dyed her hair about once a month. There are sections that are not dyed in the samples, but because it was cut, there are no root sections present.

Treatment Plan: Environmental conditions:

Problem: Test how hair fibers degrade based on environmental conditions. These were then compared to the control.

Method:

Oven: Each of the four hair fiber types had a sample placed in an industrial oven. The temperature was set for 120° Fahrenheit/48.89° Celsius. Although the temperature seems extreme, it is not dissimilar from temperatures at sites where some of the first woven animal fibers were found. The oven also removed humidity, creating an arid, hot environment.

Open air: The four samples of hair fibers were held together by a rubber band. The hair fibers were then suspended on a pole using stainless steel wire that attached to the pole and then to the rubber bands. Because of the set up, the fibers were exposed to UV light from the sun, rain, winds, insects, and other animals, without being

exposed to the soil or plants. It was decided to expose hair fibers to these conditions due to Victorian hair art in the form of jewelry and other wearable objects that would likely be exposed to outside elements.

Underwater: The four hair samples were placed in a toilet tank for the depositional time period. The fibers were bundled using a rubber band and suspended using stainless steel wire. Since it was only the effect of water and water movement, a toilet tank was used in order to prevent having to constantly change out the water and the flushing action to some degree replicated water current.

Burial: The four hair samples were buried in a terra cotta plant potter using a sandy clay soil common to the Bryan, TX area. They were placed on plastic mesh in order to be able to find the fibers after the 6 month depositional time period. Once buried, labels were then placed in the soil in order to prevent any confusion of hair fiber type when the samples were uncovered.

1) Hair fiber samples were weighed. There were a total of five samples for each hair fiber type: one control, one oven sample, one open air sample, one underwater sample, and one burial sample. Photographs were also taken.
2) Hair fibers were placed in different environmental conditions. See above for full descriptions of the environmental conditions.
3) After a six-month time period, the samples were removed. They were reweighed and photographed.

Results:

The results for the different environmental conditions were consistent between the different hair fiber types. Because of this, I will cover each environment condition as a whole, instead of writing a section on each hair fiber type. Any results that differ from the other fiber types will be mentioned.

Oven: The visible appearances of the fibers are all similar to the controls. The color has not changed, and no loss of weight present to indicate loss of hair fibers. However, the fibers are significantly more brittle, and have a dry feel to them. It appears that any natural lanolin present is gone. When the fibers are handled, they break more easily than the controls, indicating that some damage has been caused to the disulfide bonds in the cuticle (Robbins 2002). Although these bonds can reform, they are more brittle and easier to break again.

Open Air: There is definite color change to all the fibers. Exposure to the sun caused the fibers to become bleached. This change is even more striking when the samples are compared to the controls. The fibers also clumped together, possibly caused by rain exposure. The fibers are less brittle and fragile than the oven. There was also a weight increase. This weight change is due to the addition of vegetable matter found on the fibers after the 6-month depositional time.

Underwater: The fibers have definitely suffered damage. Considerable mass was lost from all the hair fibers. It is likely that the current created by flushing caused the fibers to break at points that were already weak. Because the fibers were waterlogged, their weight after deposition increased. The water also had a bleaching affect that was unexpected. Further tests would be needed to determine if the chemicals

added to tap water are responsible, or if this is common to all fibers deposited in waterlogged environments.

Burial: Burial of the hair fiber samples created more damage than any other environment. The fibers were encrusted with dirt and much of the fibers had simply disappeared. During the depositional time, crab grass began to grow in the plant potter. It is probable that the seeds from the grass were present in the soil before deposition. The addition of grass roots made extracting the hair fibers even more difficult. The high amount of degradation and the color change from the soil made distinguishing roots and hair fibers problematic. Visually, the fibers from burial are darker in color than the control samples. This was caused by dirt that could not be completely removed. It is likely that minerals present in the soil were also absorbed into the fibers. However, without further investigation, this cannot be stated with more certainty. Beyond the color change, the fibers themselves were almost too fragile to handle. Too much pressure or wrong movements cause the fibers to break instantly. Without the labels, the wool fibers were completely indistinguishable from each other. The mohair sample was identifiable by its wave, but the fibers were just as fragile as the wool and human hair fibers. The mohair also suffered additional damage from roots. The highest amount of roots was found throughout the mohair sample. The human hair fibers were just as brittle as the others, and had difficulties unique to the fiber. The color of the soil and the color of the fibers had become so close in shade that seeing the human hair fibers was very difficult.

Treatment plan: silicone oil treatment

Problem: Test silicone oil treatment using Q-1 silicone oil and methlytrimethoxysilane (MTMS) on weathered hair fibers. Two percentages were used, based on brittleness and degradation of the fiber samples. 25% silicone oil/75% MTMS was used on the open air and water samples. 30% silicone oil/70% MTMS was used on the oven and dirt samples.

Method:

1) 30% silicone oil/70% MTMS and 25%Q-1/75% MTMS were mixed. These were put in spray bottles for spray application. It was determined that Q-1 silicone oil would be the best silicone oil to use since it has a low viscosity (i.e. smaller molecules) and makes the shortest molecular chains. These qualities make it ideal for working with hair fibers, allowing for more penetration.
2) Once the chemicals were mixed, the mixture was applied to the hair fiber samples using a spray application. Less than 5 mL was used for each sample and each treatment. The exception to this was the method used on the underwater samples. Those were put through a series of dehydration baths designed to remove all water (Hamilton 1996). A vacuum chamber was used in order to decrease the time needed for each bath. The first bath was 50% water/50% ethanol. This was followed by a 100% ethanol bath, a 50% ethanol/50%

acetone bath, and finally a 100% acetone bath. Once the baths were complete, the fibers were then submerged in a 25% silicone oil/75% MTMS bath. The vacuum chamber was also used during this step in order to decrease the time needed for full penetration.

3) After application, the hair fiber samples were allowed to drain of any excess silicone that may have been present.
4) After a full 24-hour period, the samples were checked for excess silicone oil. There was no indication of excess silicone oil, but the burial samples required a second spray application due to the degraded state of the fibers. Because another application of silicone oil was needed, it is likely that a higher percentage of silicone oil could have been used for treatment.
5) After another full 24-hour period, the samples were placed in Ziploc bags with a small container of TPT titanate. The TPT titanate was not applied directly since it is the fumes that cause catalyst to occur. From other experiments done by Smith (2002) it was discovered that direct application could cause polymerization on the surface of the object, producing a hard and discolored area. Added to this, it was also determined that using the vapors would allow for better penetration and more thorough catalyzation. The TPT titanate acts a catalyst between the Q-1 and MTMS, causing the silicone molecules, with the aid of MTMS, to bond to the hair molecules. This creates a

bond that strengthens and protects the hair fibers. Also, it should allow for some flexibility of the fibers.

6) The Ziploc bags were placed in an oven for 72 hours at a temperature of 55˚ Celsius. The catalyst was changed out every day, since the TPT titanate only works as a catalyst for around a 24-hour period. The samples were placed in an oven because heat causes the air molecules containing the TPT titanate fumes to permeate more quickly, which allows for a shorter catalyst time.
7) After 72 hours, the samples were removed from the bags and allowed exposure to the air. The humidity present helps to further catalyze the molecules, ensuring completion. This time also allows for a second check to ensure that any excess silicone has been removed.
8) After another 72 hours, the samples were tested for excess silicone oil and reweighed (Table 3). There was no indication of excess liquid silicone oil when felt and blotted. There were also little to no hard nodules or white flakes present to indicate excess silicone oil that had been hardened during catalyzation.

Table 3. Weight changes after deposition and after treatment

Lincoln	*Control*	*Oven*	*Open air*	*Underwater*	*Burial*
Weight before	2.3 g	2.3 g	2.4 g	2.5 g	2.3 g
Weight after deposition	N/A	2.1 g	2.1 g	8.0 g	3.9 g
% weight change	N/A	-8.70%	-12.50%	220.00%	69.56%
Weight after treatment	N/A	3.2 g	2.2 g	2.1 g	2.0 g
% weight change using before weight	N/A	39.13%	-8.33%	-16.00%	-13.04%
% weight change using weight after deposition	N/A	52.38%	4.76%	-73.75%	-48.72%
Rambouillet	*Control*	*Oven*	*Open air*	*Underwater*	*Burial*
Weight before	2.3 g	2.4 g	2.5 g	2.4 g	2.3 g
Weight after deposition	N/A	2.2 g	2.6 g	6.1 g	1.9 g
% weight change	N/A	-8.33%	4.00%	154.17%	-17.39%
Weight after treatment	N/A	3.6 g	3.0 g	0.8 g	1.1 g
% weight change using before weight	N/A	50.00%	20.00%	-66.67%	-52.17%
% weight change using weight after deposition	N/A	63.64%	15.38%	-86.88%	-42.10%
Mohair	*Control*	*Oven*	*Open air*	*Underwater*	*Burial*
Weight before	2.3 g	2.3 g	2.3 g	2.5 g	2.4 g
Weight after deposition	N/A	2.1 g	2.6 g	3.5 g	1.6 g
% weight change	N/A	-8.70%	13.04%	40.00%	-33.33%
Weight after treatment	N/A	2.6 g	2.4 g	1.1 g	1.1 g
% weight change using before weight	N/A	13.04%	4.35%	-56.00%	-54.17%
% weight change using weight after deposition	N/A	23.81%	-7.69%	-68.57%	-31.25%
Human Hair	*Control*	*Oven*	*Open air*	*Underwater*	*Burial*
Weight before	2.4 g	2.5 g	2.4 g	2.4 g	2.3 g
Weight after deposition	N/A	2.3 g	2.5 g	4.7 g	2.6 g
% weight change	N/A	-8.00%	4.17%	95.83%	13.04%
Weight after treatment	N/A	2.6 g	2.4 g	1.7 g	2.0g
% weight change using before weight	N/A	4.00%	0.00%	-29.17%	-13.04%
% weight change using weight after deposition	N/A	13.04%	4.00%	-63.83%	-23.08%

Results:

Oven: The treatment of the oven hair fiber samples with 30% silicone oil/70% MTMS was highly effective. The fibers felt similar to the control and were more

flexible and supple than before treatment. The only difference was the lack of lanolin on the oven treated fibers. This treatment method is viable, producing excellent results.

Open Air: The treatment of the open air fiber samples with 25% silicone oil/75% MTMS was proven to be a viable treatment method. The fibers were flexible and no clumping occurred from the treatment. Because the fibers were not very brittle or dry from exposure to the weather elements, it is difficult to tell if they are more flexible than before treatment. Overall, the results were good.

Underwater: The treatment of the underwater fiber samples with 25% silicone oil/75% MTMS was very successful. The fibers feel close to the control samples, with the exception of the lanolin no longer present. The flexibility is as good as the control and the fibers are soft to the touch. The results were excellent and proved that this method of conservation is viable.

Burial: The treatment of the burial fiber samples with 30% silicone oil/70% MTMS was successful. The fibers became easier to handle and more flexible. However, the initial damage was so severe that the fibers were still quite fragile. It is unlikely that any treatment method would be able to counteract the degradation that occurred from burial of the hair fibers. The results were good, and handling of the fibers did become easier. These results show that silicone oil treatment is a viable option of treatment, but the fibers will always be fragile.

APPENDIX B

LAB REPORT: MODERN, NONWEATHERED HAIR FIBER

Object:

Originally, only weathered hair fibers were going to be used for experimentation. That project design had to be modified due to the high degree of degradation that occurred to the fiber samples during the weathering process. Therefore, silicone oil treatment (Smith 2003) will be tested on modern, nonweathered hair fibers. In order to determine the appropriate amount of Q-1 silicone oil to methlymethoxysilane (MTMS), nonweathered samples were used. There were four hair fibers samples used: mohair from an Angora goat, Rambouillet wool (graded as a fine wool), Lincoln wool (graded as a coarse wool), and human hair fibers from the head. Each hair fiber type was used in five different Q-1/MTMS ratio experiments: 100% Q-1, 75% Q-1/25% MTMS, 50% Q-1/50% MTMS, 25% Q-1/75% MTMS, and 100% MTMS. Based on these results, I will be able to better calculate the amount of Q-1 silicone oil to MTMS will be needed to treat the weathered hair samples.

Initial condition:

Lincoln wool: Unprocessed wool with some vegetable matter present, along with naturally occurring lanolin.

Rambouillet wool: Unprocessed wool with some vegetable matter present, along with naturally occurring lanolin.

Mohair: Considered kid mohair, which is a finer, more commonly used clothing fiber than the mohair from older angora goats. It is also unprocessed with vegetable

matter present, along with the naturally occurring lanolin. Note of interest: based on the feel of grease on the hair fibers, there appears to be less lanolin present than the wools.

Human hair: Donated from a 50 year old female individual who dyed her hair about once a month. There are sections that are not dyed in the samples, but because it was cut, there are no root sections present.

Treatment Plan:

Problem: Test different percentages of Q-1 silicone oil and methlytrimethoxysilane (MTMS) in order to determine the best silicone oil treatment methods to apply to the weathered hair fibers. Although these amounts will likely need to be modified for the weathered hair fibers, this experiment will help determine the percentage range that will be used on the weathered hair fibers.

Method:

1) The samples were weighed and photographed before treatment.
2) 75% Q-1/25% MTMS, 50% Q-1/50% MTMS, and 25%Q-1/75% MTMS were mixed. These three, along with 100% Q-1 and 100% MTMS were put in spray bottles for spray application. It was determined that Q-1 silicone oil would be the best silicone oil to use since it has a low viscosity (i.e. smaller molecules) and makes the shortest molecular chains. These qualities make it ideal for working with hair fibers, allowing for more penetration.

3) Once the chemicals were mixed, the mixture was applied to the hair fiber samples using a spray application. Less than 5 mL was used for each sample and each treatment.
4) After application, the hair fiber samples were allowed to drain of any excess silicone that may have been present.
5) After one full 24 hour period, the samples were placed in Ziploc bags with a small container of TPT titanate. The TPT titanate was not applied directly since it is the fumes that cause catalyst to occur. From other experiments done by Smith (2002) it was discovered that direct application could cause polymerization on the surface of the object, producing a hard and discolored area. Added to this, it was also determined that using the vapors would allow for better penetration and more thorough catalyzation. The TPT titanate acts a catalyst between the Q-1 and MTMS, causing the silicone molecules, with the aid of MTMS, to bond to the hair molecules. This creates a bond that strengthens and protects the hair fibers. Also, it should allow for some flexibility of the fibers.
6) The Ziploc bags were placed in an oven for 72 hours at a temperature of 55˚ Celsius. The catalyst was changed out every day, since the TPT titanate only works as a catalyst for around a 24 hour period. The samples were placed in an oven because heat causes the air

molecules containing the TPT titanate fumes to permeate more quickly, which allows for a shorter catalyst time.

7) After 72 hours, the samples were removed from the bags and allowed exposure to the air. The humidity present helps to further catalyze the molecules, ensuring completion. This time also allows for a second check to ensure that any excess silicone has been removed.
8) After another 72 hours, the samples were tested for excess silicone oil and reweighed. Since there was still excess liquid silicone present, based on the greasy feeling and blotting with a paper towel, it was then decided to use MTMS baths in order to remove the excess liquid and discover how long it would take to remove the excess liquid silicone oil (Table 4). This is a common practice at the Conservation Research Lab and has shown wonderful results when too much liquid silicone is present. Since the hair fibers had already gone through catalyst, the silicone oil needed for treatment was already bonded, with the exception of the samples treated with 100% silicone oil. This result was expected since without the MTMS to act as a crosslinker, no silicone oil molecules should have bonded.

Table 4. Time in MTMS baths needed to remove excess silicone oil

Hair fiber type	100% si oil	75% si oil/25% MTMS	50% si oil/50% MTMS	25% si oil/75% MTMS
Lincoln	6:00	2:00	1:00	1:00
Rambouillet	4:00	3:00	2:00	2:00
Mohair	2:00	1:00	0:30	0:30
Human hair	6:00	4:00	3:00	3:00
* time in minutes				

9) After the MTMS baths had removed the excess liquid Q-1 silicone oil, the samples were reweighed. They were also photographed again.

Results:

100% Q-1 silicone oil:

All samples were greasy to the touch from excess liquid silicone oil after catalyzation. When the fibers were blotted with paper towels, a very high amount of the excess could be observed. This is what was expected. The MTMS baths were effective in removing large amounts of excess silicone oil, but it is highly unlikely any silicone molecules bonded with the hair fibers for several days after the baths. With the introduction of the crosslinker, the silicone oil would be able to bond with a catalyst. Since the samples were not placed in the Ziploc bag with TPT titanate after the MTMS baths, the catalyst would be the humidity and any UV radiation from the sun that came through the windows. Even after several long baths in MTMS, the samples were still heavier than any others, indicating that excess liquid silicone was likely still present. Overall, this method of treatment is costly, time consuming, and not viable.

75% Q-1 silicone oil/25% MTMS:

These samples still had a high amount of excess silicone oil present before the MTMS baths. However, with the addition of MTMS to the original treatment, there was bonding between the hair fibers and the Q-1 silicone molecules. This could be observed visually on several of the hair fibers where small nodules of excess silicone had hardened on the fibers. When the baths were complete, there were more nodules present. However, these could be removed by careful mechanical cleaning using a soft toothbrush, paintbrush, or a hypodermic needle for the tougher to remove nodules. This is a viable conservation method, but the extra time to clean combined with the use of too much silicone oil makes this method a bit less cost efficient than some of the other methods.

Lincoln: Before MTMS baths, had a very greasy feel, although less than the Rambouillet wool and human hair samples. Small nodules of hardened silicone oil can be seen on some of the hair fibers. After the MTMS baths, the fibers were flexible, not greasy to the touch and no excess liquid silicone oil was removed when the fibers were blotted. However, the hard silicone nodules remained and had to be removed mechanically.

Rambouillet: Before MTMS baths, this sample had the second most excess silicone of the four samples used, as judged by feel and blotting. There were less nodules of hard silicone present than on the Lincoln, but they were still present. After the MTMS baths, the fibers were flexible, not greasy to the touch and no excess liquid

silicone oil was removed when the fibers were blotted. However, the hard silicone nodules remained and had to be removed mechanically.

Mohair: Out of the four samples in this set, the mohair reacted to the treatment the best. There was less excess Q-1 silicone oil present than any of the others, and no hardened silicone nodules could be seen. However, there was still a high amount of excess liquid silicone and the mohair sample also had to go through MTMS baths. After the baths were complete, the fibers were flexible, not greasy to the touch, and no liquid silicone was removed when the fibers were blotted. Because there were no silicone nodules, no mechanically cleaning was necessary.

Human Hair: This sample had the most excess liquid silicone present of the four samples. When touched, it had a very greasy feel and blotting showed a lot of excess liquid silicone oil. Although there were very few hardened silicone nodules present on the hair fibers, there were problems with clumping. Almost all the hair fibers acted as if they had been glued together. This affect was also observed in the 100% Q-1 silicone oil, and only worsened after the MTMS baths. After the MTMS baths, the fibers felt similar to the control sample, but they stayed clumped together, although the clumping did not worsen. The fact that it did not worsen could be due to the fact that MTMS was already added with the original treatment, whereas the 100% silicone oil treatment needed to have the crosslinker added in order for the clumping to occur to the same degree. To some extent, this could be reversed with mechanical cleaning. The mechanical cleaning could be done with a soft toothbrush and either a hypodermic needle or dental pick. However, this only worked to a certain degree. When

mechanically cleaned, the excess silicone came out in long, white-colored pieces. These were even more difficult to remove. It is possible that the use of a fine-toothed comb would remove more, but all of these mechanical cleaning methods would be damaging to the hair fibers, possibly causing more harm than good. Overall, for the treatment of human hair, the amount of silicone oil used needs to be considerably less to be a truly viable treatment method.

50% Q-1 silicone oil/50% MTMS:

Overall, the 50% Q-1 silicone oil/50% MTMS treatment is better than the two methods using higher amounts of the Q-1 silicone oil. However, there were still some amounts of excess liquid silicone present. Unlike the 75% silicone oil/25% MTMS treatment, there were little to no hardened nodules of excess silicone present. Instead, the excess hardened silicone was present in the form of thin, white flakes similar to those that appeared when cleaning the 75% silicone oil/25% MTMS treated human hair. With the lower amounts of silicone oil present, this method becomes an even more viable treatment option than the 75% silicone oil/25% MTMS treatment. Although there was excess silicone present in liquid and hardened forms, this could be a good treatment option for hair fibers that are particularly dry and brittle and/or degraded. It would also be a good option for most of the hair fibers if the amount of silicone oil to be used cannot be easily determined. Although there would be some excess liquid and hardened silicone oil, there is little enough that it would be easy to remedy through MTMS baths and some mechanical cleaning.

Lincoln: The Lincoln sample had the second least amount of excess silicone oil present of the four hair fiber types in this treatment. There was some excess liquid silicone oil present that could be felt and seen when blotted. There was also some excess hardened silicone oil present in the form of thin, white flakes. These flakes could easily be removed with a fine artist paintbrush or hypodermic needle. After the MTMS baths, the Lincoln fibers felt very close to the control sample. The main difference is that the treatment seemed to have removed the naturally occurring lanolin that was present on the Lincoln wool.

Rambouillet: The Rambouillet sample had the second highest amount of silicone. There was a definite greasy feel to the fibers and when blotted with a paper towel, the second highest amount of silicone oil present in this test could be observed visually. Instead of white flakes, there were hardened silicone nodules present. Currently there is no research to suggest what the determining factor is for the formation of nodules versus the formation of white flakes. These nodules could be removed by lightly brushing with an artist paintbrush or hypodermic needle for the harder to remove nodules. After the MTMS baths, the fibers felt very close to the control sample. Like the Lincoln, the naturally occurring lanolin that had been present was stripped away. There was still significantly less excess silicone oil present than in the 75% silicone oil/25% MTMS test, making this method more viable.

Mohair: When the mohair sample was felt, the amount of excess liquid silicone oil present seemed to be equal to that on the Lincoln sample. When the mohair was blotted with a paper towel, however, notably less excess liquid silicone was present.

Once the MTMS baths were complete, the mohair felt remarkably close to the control sample. Since there was little lanolin present on the original, natural mohair, there was no perceptible difference in lanolin amount using touch.

Human Hair: Once again, the human hair sample had the most excess silicone oil present. Also, like the 75% silicone oil/25% MTMS test, the hair fibers tended to clump together. The clumping affect was less than observed in the other tests mentioned above. The clumping did not worsen after the MTMS baths, but the white flakes of hardened silicone become more noticeable. This condition worsened when mechanical cleaning was attempted in order to reverse the clumping condition. Although the fibers could eventually be cleaned using a soft toothbrush, hypodermic needle, and/or a fine-toothed comb, there is still the problem of more damage than good being done. Unless the hairs fibers are highly brittle and degraded, or are present in the form of cordage or thick textile, 50% Q-1 silicone oil/50% MTMS has too much silicone oil to be a truly viable method of human hair fiber conservation.

25% Q-1 silicone oil/75% MTMS:

Taking into consideration all of the other treatments and the different hair fibers types, this method was the best overall. Although the hair fibers still had to go into MTMS baths, the amount of time it took to remove the excess liquid silicone was the lowest. Also, there were little to no excess hardened silicone oil present on the fibers. However, it should be kept in mind that more silicone oil may be necessary to treat fibers that are more degraded, drier, or more brittle.

Lincoln: Once again, the Lincoln sample had the least amount of excess silicone oil present, after the mohair. Also similar to the results of the other test, specifically the 50% Q-1 silicone oil/50% MTMS, the greasy feel made it seem that the Lincoln sample had more excess silicone oil present than it really did when the fibers were blotted. MTMS baths were still needed, but considerably less time was needed for the excess liquid silicone to be removed. There was no excess hardened silicone oil present as either nodules or white flakes at any point during the experiment. After the baths, the only noticeable difference between the control and the sample from this test was the absence of the naturally occurring lanolin.

Rambouillet: In the same pattern as seen in the other tests, the Rambouillet had the second highest amount of excess silicone oil present. There was a greasy feeling caused by the excess liquid silicone and a noticeable amount of the liquid could be seen when the fibers were blotted. Even though there was excess liquid silicone oil present, the amount was considerably less than any of the other tests that used the Q-1 silicone oil. Also, there were no nodules or white flakes present to indicated excess hardened silicone oil. After the MTMS baths, the Rambouillet was very close in feel to the control. Like the Rambouillet and other tests, the appreciable difference between the control and the test sample is the lack of lanolin on the test sample.

Mohair: The mohair had the least amount of excess silicone oil present. Although the mohair did not feel like it had an excess of liquid silicone oil, blotting

showed that some was present. There was no indication of excess hardened silicone oil. After a short MTMS bath, the mohair fibers felt, and looked, like the control.

Human Hair: As with the other tests using silicone oil, the human hair fibers had the most excess silicone oil, based on both feel and blotting. Unlike the other tests with silicone oil, the amount of clumping that occurred was considerably less. Only a small section of the hair fibers clumped together. After the MTMS baths, the clumping actually lessened in intensity and the fibers felt like the control. With a little bit of mechanical cleaning using a soft toothbrush and hypodermic needle, the fibers also looked like the control. These results indicate that when conserving human hair fibers, less silicone oil is needed than for the wools and mohair.

100% MTMS:

Each hair fiber type results will not be covered since the results were similar to each other. All of the hair fiber types were dry to the touch and displayed more brittleness than the controls. The fibers were easier to break than before treatment. The best that can be said for this treatment is that the MTMS did clean the fibers of dirt present on them. Overall, this is not a viable treatment. The results are as poor as the results for the 100% Q-1 silicone oil test, but for different reasons. Although the treatment is not costly, the results show that the treatment does more harm to the hair fibers than good.

Overview of the treatment methods:

The use of touch and blotting were the main way of determining the presence of excess silicone oil. In addition to these qualitative methods, quantitative

measurements can also be used. This is accomplished by monitoring weight change. By calculating weight gain from the original weight, and then the weight loss after MTMS baths, it can be determined how much silicone oil is present.

Based on the results of the different experiments, the ideal Q-1 silicone oil/MTMS mixture would be between 25% Q-1 silicone oil/75% MTMS and 50% Q-1 silicone oil/50% MTMS. The precise amounts would need to be determined by the conservator based on the state of degradation, brittleness, and fiber type. If more silicone oil is used than is needed, the results should still be excellent to good with the use of MTMS baths and possible mechanical cleaning. The exception to this would be human hair fibers. Although results can still be good to excellent if excess silicone oil is present, the fibers do seem to be considerably more sensitive to the excess silicone oil and care should be taken when preparing treatment.

APPENDIX C

LAB REPORT: HAIR WATCH FOB

Artifact number: N/A

Object:

Watch Fob made from human hair. Dates to the Victorian Era and is approximately 100 years old. The fob was made using a double cording method. It appears several long hair fibers were twisted together to create strands. One strand was plaited to look like chain link. These pieces were then twisted together to create the fob cord. However, without taking the object apart, the exact method for creating this cording cannot be completely known.

Project: N/A

Evaluation:

Visually, there appears to be very little damage, except for one area that is very abraded. However, upon closer examination, the hair fibers throughout the fob were found to be very brittle, which could lead to more abraded areas and eventual destruction of the object. Because of this brittleness, the owner decided to have the fob treated in order to help protect the object from further damage.

Treatment Plan:

Problem: The fob is brittle with some damage already present. It does not bend well without breakage of individual fibers and needs to retain the flexibility that remains. Also, treatment is needed in order to help prevent further damage from occurring. Because of these problems, it was decided to use the silicone oil treatment (Smith 2003).

Method:

1) From previous experiments, it was established that a 40% Q-1 silicone oil and 60% MTMS (methyltrimethoxysilane) would be the best mixture to use in order to preserve the hair fob.
2) A spray bottle was used to mix the Q-1 and MTMS. The spray was placed on a setting between stream and mist, allowing for deeper penetration.
3) Once the chemicals were mixed, the mixture was applied to the fob. Less than 5 mL was used for treatment. The treatment was applied on the hair area only.
4) After application, the fob was allowed to drain of any excess silicone that may have been present.
5) Once it was established that excess silicone was no longer draining, the fob was placed in a Ziploc bag with a small container of TPT titanate. The TPT titanate was not applied directly since it is the fumes that cause catalyst to occur. From other experiments done by Smith (2002) it was discovered that direct application could cause polymerization on the surface of the object, producing a hard and discolored area. Add to this, it was also determined that using the vapors would allow for better penetration and more thorough catalyzation. The TPT titanate acts a catalyst between the Q-1 and

MTMS, causing the silicone molecules, with the aid of MTMS, to bond to the hair molecules. This creates a bond that strengthens and protects the hair fibers. Also, it should allow for some flexibility of the fibers.

6) The Ziploc bag was placed in an oven for 48 hours at a temperature of 55˚ Celsius. The heat causes the air molecules containing the TPT titanate fumes to permeate more quickly, which allows for a shorter catalyst time.
7) After 48 hours, the fob was removed from the bag and allowed exposure to the air. The humidity present helps to further catalyze the molecules, ensuring completion. This time also allows for a second check to ensure that any excess silicone has been removed.
8) After eight days, the fob was finished with the chemical treatment. There was no indication of liquid silicone. There were a few small nodules of catalyzed silicone oil found, demonstrating a completion of the catalyzation process.
9) The small silicone nodules were removed with a fine paintbrush or a fine point hypodermic needle. However, very little mechanical cleaning was necessary.

Results:

The silicone oil treatment technique was highly successful. Although there was no way to repair the minimally existing damage without compromising the aesthetics

and integrity of the object, the fob as a whole is well preserved. A higher degree of flexibility is now evident and the fibers are protected from further degradation. Because of the process used, the object can be handled without gloves and will not be subject to further degradation due to humidity or UV light. The fact that more flexibility is present demonstrates that similar to some PEG/cellulose treatments used in the past, silicone oil treatment can help an object regain some flexibility.

Alternatives:

There were several alternatives available, including polyvinyl acetate (PVA) and polyethylene glycol (Hamilton 1996). Both have been used as conservation treatment methods, with varying success. For each one, the reasons that the method was not used will be examined.

Although PVA can be a good consolidant, there were several concerns with using this method. One concern was the tendency for PVA to create sheen on the surface of an object once dried. Also, over a fairly short time period, the bonds would deteriorate, creating even more problems with brittleness. This issue alone is why PVA application was not used on the fob. Along with PVA, Paraloid B-72 can also be used. However, since it is also used as a consolidant, the same problems with PVA are also present when using Paraloid B-72.

The second alternative, as mentioned above, is the use of PEG. For the treatment of textiles, PEG has been used in combination with ethyl-hydroethyl cellulose to allow a textile piece to become more flexible. There are several reasons that this method was not used. There can be a greasy feeling left on the object that can occur if too much

PEG was used. Also, there are many instances of PEG causing objects to darken in color. Since the fob is made from a dark hair, there was concern that any color differentiation would be eliminated, destroying one of the interesting features of the object. Anther problem would be that PEG is sensitive to humidity changes. Often, an increase in humidity will cause treated objects to swell and the PEG to migrate or seep out of the material, while a decrease in humidity will cause the opposite affect. Finally, treatment with PEG would mean that the fob would not be able to be handled, unless with gloves since PEG can react negatively with skin oils. Since the object is a family heirloom, belonging to an individual as opposed to a museum, this would create problems.

Silicone oil treatment was chosen for many reasons. It allows the object to be handled without gloves, does not react to humidity, and has now shown the treatment can help hair fibers become more flexible. It has the big advantage of PEG/cellulose treatment without the undesirable qualities, making the choice of treatment that much easier.

APPENDIX D

LAB REPORT: *KITTERN* SHIPWRECK HAIR FIBERS

Artifact number: I3LR2

Object:

Mass of loose hair fibers mixed with a tar or pitch-like substance. Was found on a double block from the shipwreck *Kittern*. The shipwreck was excavated in Bulgaria. Currently an excavation report is being prepared.

Project: *Kittern* shipwreck

Evaluation:

Visually, there appears to be little damage to the hair fibers. The biggest challenge will be the inability to predict how the tar will react to treatment and whether the mass will stay together as a whole.

Treatment Plan:

Problem: The hair fiber and pitch mass are heavily waterlogged. In order to better understand how well silicone oil treatment works on composite waterlogged hair fibers, that method will be used to treat the artifact (Smith 2003).

Method:

1) From previous experiments, it was established that a 25% Q-1 silicone oil/75% MTMS (methyltrimethoxysilane) would be the best mixture to use in order to preserve the waterlogged hair fibers.
2) Before the application of the silicone oil/MTMS mixture, the artifact was put through a series of dehydration baths. After testing for

salination levels, it was determined that the amount of chlorides was sufficiently low enough to begin dehydration. The first dehydration bath was a 50% deionized water/50% ethanol solution. The artifact was placed in a container made from plastic mesh, pantyhose, and microfilament line in order to ensure that the artifact would not loose any size. Once submerged, the container was placed in a vacuum chamber. A vacuum was pulled to 22 psi in order to force the 1st dehydration bath to replace the water. The vacuum was left in place for a 24-hour period. Once the first bath was complete, the artifact was placed in a bath of 100% ethanol, 50% ethanol/50% acetone, and then 100% acetone. For each of the baths, a vacuum was pulled and allowed to remain in place for 24 hours.

3) After the series of dehydration baths, the artifact was submerged in the Q-1 silicone/MTMS mixture. Once submerged, the container was placed in the vacuum chamber. Like the dehydration baths, a 22-psi vacuum was pulled. The vacuum was used for steps 2 and 3 in order to shorten the time needed for each submergence. Without the use of a vacuum, the time needed for dehydration and polymer passivation would have equaled a month or more.
4) After the 24 hours, the artifact was removed and allowed to drain for 15 hours. The artifact was tested for excess liquid silicone oil using a

paper towel to blot the surface. This test indicated that there was excess liquid silicone oil present.

5) Since there was excess liquid silicone oil, the artifact was placed in an MTMS bath for two minutes. After the artifact was removed, it was allowed to drain and dry. In less than an hour, a paper towel used for blotting the surface showed no sign of excess liquid silicone oil. There was also a lack of white flakes and nodules, which would indicate the presence of hardened, or polymerized, silicone oil.
6) The tar seemed to have suffered from the removal of the excess liquid silicone. The surface was flaking and brittle. A small piece broke away from the original. Also, the darker color that is more common for tar-like substances was much lighter and seemed to reflect the loss of wetness necessary for tar to not flake and crumble. In order to ensure that the flaking and breakage that was occurring to the tar did not continue, a very small amount of 25% Q-1 silicone oil/75% MTMS was applied to the drier areas with a cotton-tipped swab. This was then allowed to drain of any excess liquid silicone that may have been reapplied. After 24 hours, the artifact was retested for excess liquid silicone oil using a paper towel. There was no indication of any excess.
7) Once it was established that excess silicone was no longer present, the artifact was placed in a Ziploc bag with a small container of TPT

titanate. The TPT titanate was not applied directly since it is the fumes that cause catalyst to occur. From other experiments done by Smith (2003) it was discovered that direct application could cause polymerization on the surface of the object, producing a hard and discolored area. Added to this, it was also determined that using the vapors would allow for better penetration and more thorough catalyzation. The TPT titanate acts a catalyst between the Q-1 and MTMS, causing the silicone molecules, with the aid of MTMS, to bond to the hair molecules. This creates a bond that strengthens and protects the hair fibers. Also, it should allow for some flexibility of the fibers.

8) The Ziploc bag was placed in an oven for 48 hours at a temperature of 55˚ Celsius. The heat causes the air molecules containing the TPT titanate fumes to permeate more quickly, which allows for a shorter catalyst time. After 24 hours, the catalyst was replaced with fresh TPT titanate since the chemical catalyst will not work after one day.
9) After 48 hours, the artifact was removed from the bag and allowed exposure to the air. The humidity present helps to further catalyze the molecules, ensuring completion. This time also allows for a second check to ensure that any excess silicone has been removed.

Results:

The silicone oil treatment technique was successful for the hair fibers. The fibers were flexible and easy to handle. The tar substance did not fair as well. The tar seemed to become easier to break and flake off. Reapplication of the 25% Q-1 silicone oil/75% MTMS on the drier areas improved the situation dramatically. It seems that the amount of silicone oil need for the tar was higher than the amount needed for the hair fibers. The problem was remedied and the end results were good. The tar substance was still fragile, but could be handled with much more ease. Also the light color was removed and the more natural darker color was regained. This treatment method is viable. For successful application of this method, the conservator would need to be aware that the different components of a composite artifact may need special attention and that all aspects of the artifact need to be considered individually.

VITA

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