AN ABSTRACT OF THE THESIS OF

Misty A. Weitzel for the degree of Masters of Arts in Interdisciplinary Studies in Anthropology, Anthropology, and Geography presented on (June 9, 1998). Title: A New Method for the Analysis of Human Hair: A Morphological Case Study of Five Sample Populations.

Abstract approved: Redacted for Privacy

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Hair is an important piece of evidence in forensic and archaeological investigations. Analysis of the morphological features of hair has been reported since at least the early 1800's. However, many questions still remain unanswered such as, how can human groups (or local populations) be analyzed and possibly distinguished from each other based on the morphology of their hair?

This investigation successfully established a set of procedures for analysis of human hair morphology and explored the possibility of separating populations by examining a case study of 40 hairs from five sample populations (Mongolian, English, Vietnamese, Native American Sioux and Oneida). The methodology leads the investigator from the point of receiving a single hair to acquiring a list of specific, discernible traits characterizing that hair. These methods included a variety laboratory procedures (cleaning, casting, mounting and microtome sectioning of the hair) and examination procedures (microscope and computer imaging and developing a key and database).

Statistical analysis was then utilized in order to determine the variability and/or relationships between the populations. Although the results were not statistically significant, they weakly support a division of three groups: English, Mongolian and Vietnamese, and Sioux and Oneida. The small sample size and overlap between the five populations is a limiting factor in attempting to discriminate between populations and should be taken into consideration in future investigations.

A New Method for the Analysis of Human Hair: A Morphological Case Study of Five Sample Populations

by

Misty A. Weitzel

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Masters of Arts in Interdisciplinary Studies

Presented (June 9, 1998)
Commencement (June 1999)

Masters of Arts in Interdisciplinary Studies thesis of Misty A. Weitzel presented on June 9, 1998

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

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ACKNOWLEDGEMENTS

I would like to thank my committee members, especially Dr. Robson Bonnichsen and Dr. Roberta Hall. Dr. Bonnichsen sold me on the archaeological importance of hair from the beginning and created many opportunities for me to explore the subject. I owe much gratitude to Dr. Hall who provided great insight along the way. She is a professional in every sense of the word.

Thank you also to Belinda Kaye at the American Museum of Natural History for providing the Sioux and Oneida hair samples from the Franz Boas material, Valerie Bishop for the English hair samples, Tim Cahill for the Mongolian hair samples and Jenny Mua for the Vietnamese hair samples.

I wish to thank Kathy Cook for taking the time to teach me how to achieve exceptional cross-sections of hair in addition to trusting me with her equipment and the key to her office.

Forensic scientist, David Schmierbach of the Oregon Department of State Police was very helpful early on, sharing some of his knowledge about human hair morphology, and Alice Hall at the Center for the Study of First Americans has also been very helpful along the way.

Finally, my love and thanks go out to my family and Dustin White for reasons too many to list.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

Page

TABLE OF CONTENTS (Continued)

Page

LIST OF FIGURES

Figure Page

LIST OF FIGURES (Continued)

Figure Page

LIST OF TABLES

A New Method for the Analysis of Human Hair:

A Morphological Case Study of Five Sample Populations

INTRODUCTION

Problem Statement

Human hair is an important piece of evidence in certain mysteries that have plagued both forensic investigators and anthropologists. Observations of the morphological features of hair can reveal a great deal of information about the individual from which it came, such as, what "race" or population the hair (individual) represents. Yet, to date, there is no systematic method used for isolating groups of people based on specific morphological features of their hair. This investigation is an attempt to develop this methodology. Developing the methodology is the primary objective, however, I will also test the variability that exists between population samples by applying some descriptive statistics to a case study of five sample populations, Mongolian, English, Vietnamese, Native American Sioux and Native American Oneida.

The importance of this study is two-fold, with applications in both contemporary forensic studies and archaeological studies. Forensics has utilized hair as a tool for making determinations at crime scenes (Anderson 1969; Clement et al. 1980; Hicks 1977; and Niyogi 1962). Morphology has long been used in identifying species (Moore 1988; Petraco 1987; and Sato et al. 1982), the anatomical region from which a human hair came (Hicks 1977), the probability of the hair coming from a specific individual (Kirk 1941,

McCrone 1977 and Medina et al. 1994), and "race" of an individual (Hicks 1977). Determination of "race", however, has been difficult and very subjective, often limited to a classification determined as either Caucasoid, Mongoloid or Negroid. This investigation improves the attributes and methods previously used in forensic studies and applies them to a more specific set of data.

Archaeologists, too, have become increasingly interested in hair because hair has constantly been released into the environment and deposited through the process of natural shedding. It is, therefore, abundant at many sites in which people and/or animals were abundant. Once recovered, hair can provide a wealth of information aiding in the interpretation of an archaeological site such as, who was present at the site (Bonnichsen and Bolen 1985 and Brothwell and Dobney 1986). Hair can also reveal what their diet/nutrition was (Benfer et al. 1978; and Minagawa 1992) as well as what diseases existed (of the hair and scalp as well as genetic diseases). The period of time they occupied the site can also be learned (Lubec et al. 1994). The various species of nonhuman occupants at the site can be determined (Bonnichsen and Bolen 1985; Bonnichsen et al. 1992; and Meng and Weiss 1997). Finally, DNA studies can provide further information on how people were related to adjacent and distant groups and verify or calibrate biological descent models (Robson Bonnichsen, personal communication 1998; Morell 1994; and Vigilant et al. 1989).

This study will aid in addressing the first point, who was present at the site. Because there are so few archaeological investigations utilizing hair, methods used for analysis of hair morphology are virtually nonexistent in the field. My study provides the foundation for constructing this methodology. If my methods can then distinguish

between groups of modern hair, it should also be possible to isolate groups of hair from the past in future investigations. Hair morphology can compliment other archaeological lines of evidence and this, in turn, will further the knowledge of the rise, spread and demise of human groups through time.

Despite the impact hair can have in both the fields of forensic and archaeological science, too much emphasis has been placed on typological approaches (characterized by the use of a limited number of diagnostic attributes selected for the definition of entire groups or types) that stemmed from the early 1800s, making advances since then extremely difficult. Though the use of types certainly provided a foundation for the advancement of these fields, it was (and still is) problematical. Many of the early hair researchers beginning with the use of the ambiguous attribute "form" or "texture" fail to systematically define the characteristics of the hair attributes and the methods used in analysis (Pruner-Bey 1864; Garn 1950; Steggarda and Seibert 1941; Trotter 1930 and Duggins 1956; and Woodbury and Woodbury 1932, to name only a few). This has resulted in an inconsistent and unclear terminology used for describing hair features. The criteria for comparing one hair with another within or between individuals is not well-defined. Obviously, all of these ambiguities make replication very difficult. As stated above, there is no consensus on the attributes used or indeed the standards used to define a group of people or local population based on hair morphology.

In addition, human hair "types" themselves have often been limited to three common groups: Negroid, Caucasoid and Mongoloid. We now know today (or should know) that these three groups fail to consider climatic, ecological and cultural factors which together produce a wide range of phenotypes (Hall 1997:78), not just three. Yet,

these three racial groups are still being used in many social systems, not to mention in forensics, specifically the Federal Bureau of Investigation (Hicks 1977:7).

That is why I chose to observe samples that more closely represent local populations, the unit in which environment and genetic structure react to form individual phenotypes: or a group of people who live in the same area, interbreed, and share certain cultural features; an operationally defined part of a continent assumed to have ancestors in common (Hall 1997:75). Hall states that, "older studies of human geographic variation that focus on continental races are contrasted with perspectives of contemporary physical anthropologists and human biologists that are based on variation among local populations."

Another limitation of hair studies in the past is simply the lack of technology, which is now available. Both microscope and computer technologies have made great advances in recent years opening up new opportunities for the observation and analysis of hair. Few studies have taken advantage of these recent developments (Bottoms et al. 1972; Lindelof et al. 1988; Medina 1994; and Verhoeven 1972, to name a few).

Consequently, there is a strong need for a new, well articulated set of procedural rules for analyzing the hair of humans. This will advance the study of hair in both archaeological and forensic sciences.

Objective of Study

The purpose of this study is to take advantage of the theoretical and technological advances of today, to develop a new method of analysis and apply this to a new set of

data with the intention of isolating various populations. Specific objectives are the following:

1. Develop a detailed set of laboratory and examination procedures for analysis.
2. Create a thorough list of attributes (or variables) to be tested in a pilot study of samples from two local populations.
3. Develop a final list of useful attributes based on this initial study for use in the final analysis.
4. Conduct the final analysis using a case study of five population samples, Mongolian, English, Native American Sioux, Native American Oneida, and Vietnamese.
5. Analyze variability between the five sample populations using statistical approaches.

Organization of Study

The examination of hair itself begins with an understanding of the properties of hair. Overall hair morphology is well understood in the existing literature; however, morphological variability is not. I begin with a discussion of the surrounding skin and the major elements that make the hair what it is. The growth cycle of the hair is explained in order of its three phases, anagen, catagen and telogen. Overall growth patterns/dynamics are then discussed as well as the stability of hair over time.

Next the background studies involving variability are addressed including variability within a single hair shaft, between hairs of differing anatomical regions, intrapopulation variability and, finally, interpopulation variability.

In chapter three I explain the nature of the hair samples used and how each population of hair was chosen and acquired. The laboratory and examination procedures are explained in detail, as development of these procedures are the main objective of the study and a large part of this project was the long process of trial and error in developing these procedures. It is this methodology that offers the greatest contribution from this study.

In chapter four I present the results and statistical interpretations of the data to the degree that the small sample of data can be interpreted. Each significant attribute will be discussed with regard to each sample population.

Finally, in chapter five, the concluding chapter, I summarize the overall results and contributions of this investigation, the application of this study to forensics and archaeology, and final suggestions for future research.

HAIR AS A BIOLOGICAL ENTITY

Hair Morphology

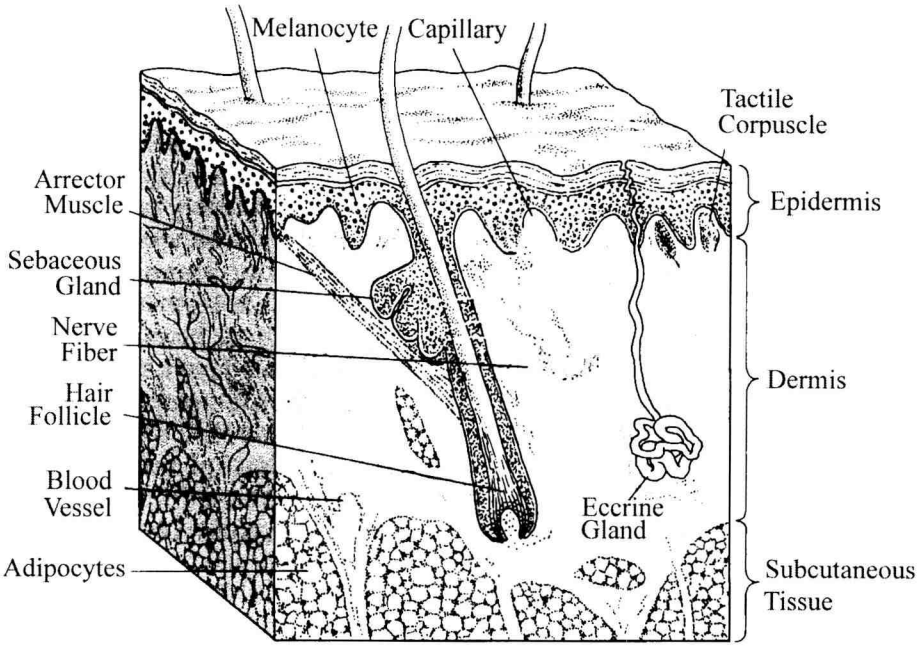
Skin

Hair, itself, is an organ. However, to fully understand the growth and structure of hair it is important to have some knowledge about the body's largest organ: the skin. The skin is a complex system that has been studied in great depth; therefore, only that which is directly related to hair will be discussed.

The body's skin is roughly divided into two regions, the dermis or cutis and the epidermis or cuticle (Figure 1). The dermis is a connective tissue layer consisting of blood vessels (which provide nourishment to the skin cells), nerves, and sensory receptors called the tactile corpuscle. The base of the dermis is attached to a layer of fatty tissue or muscle. The dermis is a tough, flexible layer that protects the underlying organs. Its thickness varies depending on the body region; for example, while the dermis is very thick on the palms of the hands and feet, it is thin on the eyelids. Thickness of the dermis may also vary with age and sex of an individual. Males tend to have a denser dermis layer than females, as do adults when compared to children (Gray 1995:67).

Above the dermis lies the epidermis (Figure 2) which also varies in thickness at differing body regions, often the same way as the dermis, such as being thicker at the palms of the hands and feet. The epidermis is a non-vascular layer composed of both

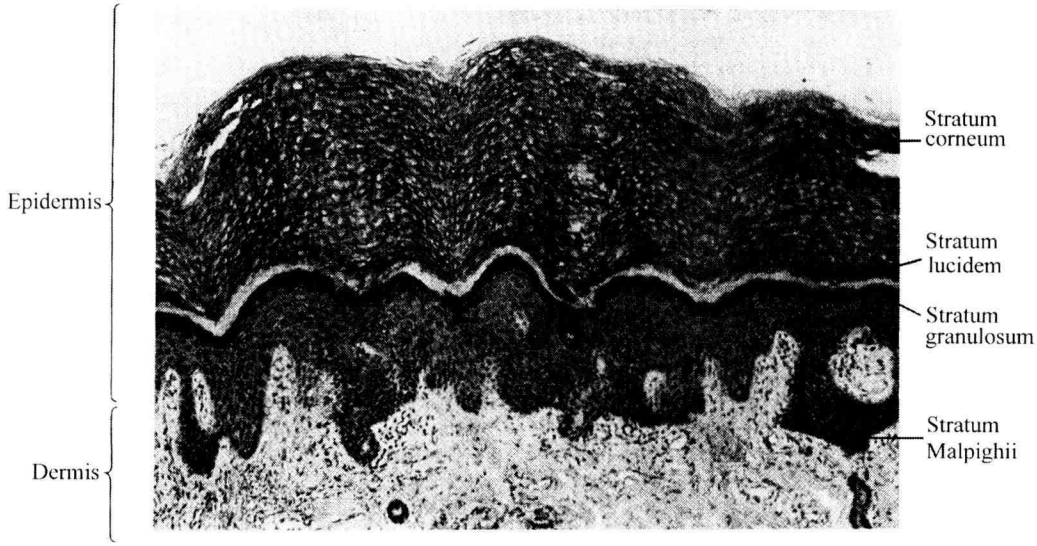
Figure 1. Structure of the skin (modified from Barrett 1986:321).



dead and living skin cells. The dead cells reside in the two outer layers of the epidermis: the stratum lucidem and stratum corneum. The stratum lucidem consists of a clear layer of indistinct cells with traces of nuclei. The stratum corneum is a layer of scale-like cells that have become flattened. These cells lack a discernible nucleus and are composed of 'soft' keratin, as opposed to the 'hard' keratin which makes up most of the hair itself (Ryder 1973:1). These dead cells are continually sloughed away and replaced from the underlying layers so that the developing skin always has a protective function. The living layers of the epidermis lie below the dead and include a transitional layer of flattened, polygonal cells with a central nuclei called the stratum granulosum. This is the layer which produces the protein keratin. Below this is a basal layer (stratum Malpighii) where

cells divide and maintain the epidermis. The cells in this layer forms a bulge or nodule which grows and penetrates down into the dermis. These cells become the hair follicle. All of the preceding layers are products of the innermost germinativum.

Figure 2. Structure of the epidermis (modified from Gray 1995:66).



Follicle and Root

It is the dermis that contains the majority of the hair follicle. The follicle is an epidermal structure with a similar cellular composition to the epidermis but developing primarily in the dermis (Ryder 1973:1). An initial signal from the dermis instructs the epidermis to form a bulge. The cells of the dermis become concentrated around the resulting bulge and form a dermal papilla or a small conical intrusion with vascular characteristics (in response to the second signal from the epidermis). The dermal papilla

provides the stimuli for each growth cycle of a new hair (Hardy 1992:57). As the hair nodule continues to grow, the cells arrange themselves parallel to each other and at right angles to the longitudinal axis of the nodule (Sengel 1976:23), in response to a final dermal message.

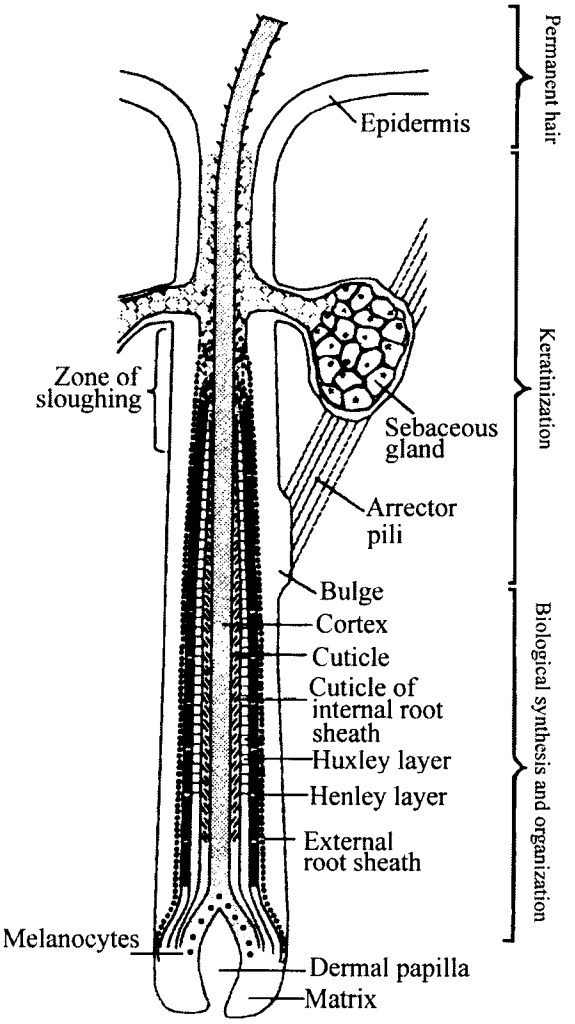
The product, the epidermal hair follicle (Figure 3), has a wide base with a concavity (the dermal papilla). Together they make up the hair bulb. Self-propagating cells of the dermis begin to form an outer connective-tissue sheath at the lower region of the bulb, migrating upwards toward the surface of the skin approximately halfway up the follicle. This external root sheath separates the internal migrating cells from the external dermis. Two swellings often develop out of this sheath; the first is the sebaceous gland in the upper part of the follicle and the second is the arrector muscle (arrectores pili). The sebaceous gland is an organ composed of a single duct with a variable number of sacs inside the duct. Within the sacs are cells and fatty secretions or oils. The arrector muscle is a small bundle of muscle fiber below the sebaceous gland. Both glands exist on the side towards which the hair slopes (Gray 1995:71). When the arrector muscle contracts it causes the hair to 'stand on end' (forming goose bumps on the skin), thus increasing the amount of insulating air trapped by the hair.

As the nodule continues to grow and differentiate, an inner root sheath forms from the base of the bulb at the matrix. The internal root sheath can be divided into the following layers: a delicate cuticle layer with scales pointing downward (corresponding with the upward pointing scales of the hair shaft), the Huxley layer with flat nucleated cells, and the Henley layer with oblong cells and no distinguishable nucleus (Gray 1995:71). The entire inner root sheath grows between the outer root sheath and the (soon

to be developed) cells of the actual hair shaft, and moves distally by sliding against the outer root sheath. When its cells reach the opening of the sebaceous canal, they are destroyed by proteolytic enzymes, thus freeing the hair shaft from the inner sheath (Sengel 1976:24). However, prior to reaching the sebaceous gland, the hair shaft and both root sheaths are still connected. It is this part of the follicle that can sometimes be seen at the root of a plucked hair. Like the inner sheath, the hair shaft is formed from the matrix cells at the bottom of the hair follicle, but only 10% of the cells that leave the matrix form the mature hair, the other 90% building up the root sheaths (Wood et al. 1990:21375).

The entire hair filament can be divided into three regions along its longitudinal axis (Figure 3). The lower region at and around the bulb of the hair is known as the site of biological synthesis and organization. This is a transient region of hair growth where cell differentiation occurs. The middle region is the site of keratinization where the hair shaft undergoes hardening or stability through cystine cross-linking. Finally, the region of the permanent hair is that, which emerges from the surface of the skin. The permanent hair region, as its name implies, does not change positions like the region of biological synthesis. The permanent hair consists of three types of cells: dehydrated cornified cuticle, cortical and medullary cells connected by intercellular cement (Figure 4).

Figure 3. Structure of the hair follicle (modified from Williams and Stenn 1994:472).

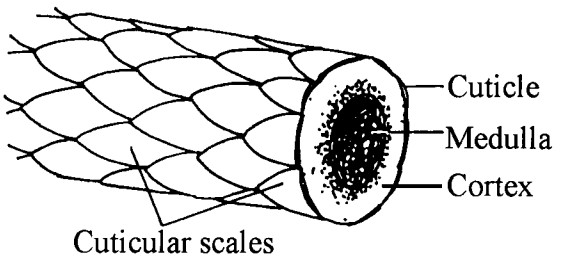


Cuticle

The cuticle layer of the hair shaft is the most exterior stratum of cells that is derived from the matrix cells at the peak of the dermal papilla. The cuticle cells move distally from the matrix in a single row but as the hair grows the cells form approximately five layers at approximately 100 millimeters above the human scalp (Muto et al.

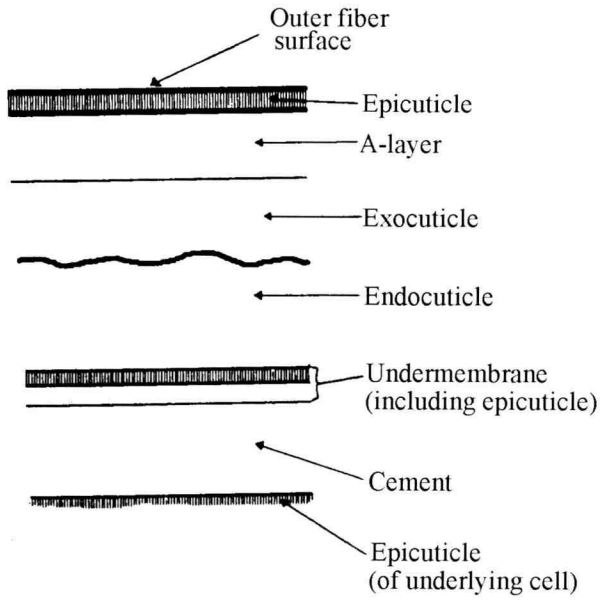
1981:14). Others have reported that cells can be layered up to five to ten cell layers thick, with as few as one to two layers in various wool fiber (Robbins 1994:23). Robbins also concludes that the number of these cell layers varies between species of animals.

Figure 4. Structure of the hair fiber (modified from Teerink 1991:3).



Resulting from this layer formation is a well detailed terminology describing the differing cuticle cells from one layer to the next (Figure 5). At the most outer surface of the fiber is a thin membrane called the epicuticle. Robbins (1994:27) estimates that the most common thickness of the epicuticle is 25Angstrom. Beneath the epicuticle lies the A-layer, a region of resistant cystine (greater than 30%), also present in other layers but to a lesser degree. Below this is the exocuticle layer, sometimes called the B-layer, also relatively rich in cystine (approximately 15%). Beneath the exocuticle, the endocuticle is mechanically the weakest layer of the cuticle (Fraser et al., 1980:6), low in cystine content (approximately 3%). Finally, there is an inner layer of intercellular cement with an underlying epicuticle layer. The cuticle does not exhibit any microfibril/matrix features that are present within the cortex.

Figure 5. Structure of the cuticle layer of the hair fiber (modified from Robbins 1994:26).



All together these squamous cells (or scales) surround and provide a protective layer to the interior part of the hair. They also serve to anchor the hair to the skin. The cells are generally flat and overlapping much like the scales of a fish. The size of a cell can be anywhere from 0.5 μ to one μ thick and 45 μ long (Chatt and Katz 1988:7). Each cell is attached at the proximal end from which it grows and is free at the opposite end that points distally. As a result the hair is less resistant when felt from the proximal to distal end rather than vice versa (a useful property when determining root from tip end). Thus, the hair is oldest at the tip. The scales are usually nonpigmented and appear translucent. However, Robbins (1994:33) reports observations of pigment in the cuticle regions of beard hairs.

Scales vary in individual shape as well as their overall pattern. This pattern is very important as a diagnostic feature of the hair, and many investigations into the identification of hair, particularly in determining species of mammals, have utilized scale patterns. This feature is considered here when examining intra/inter-population variation of human hair.

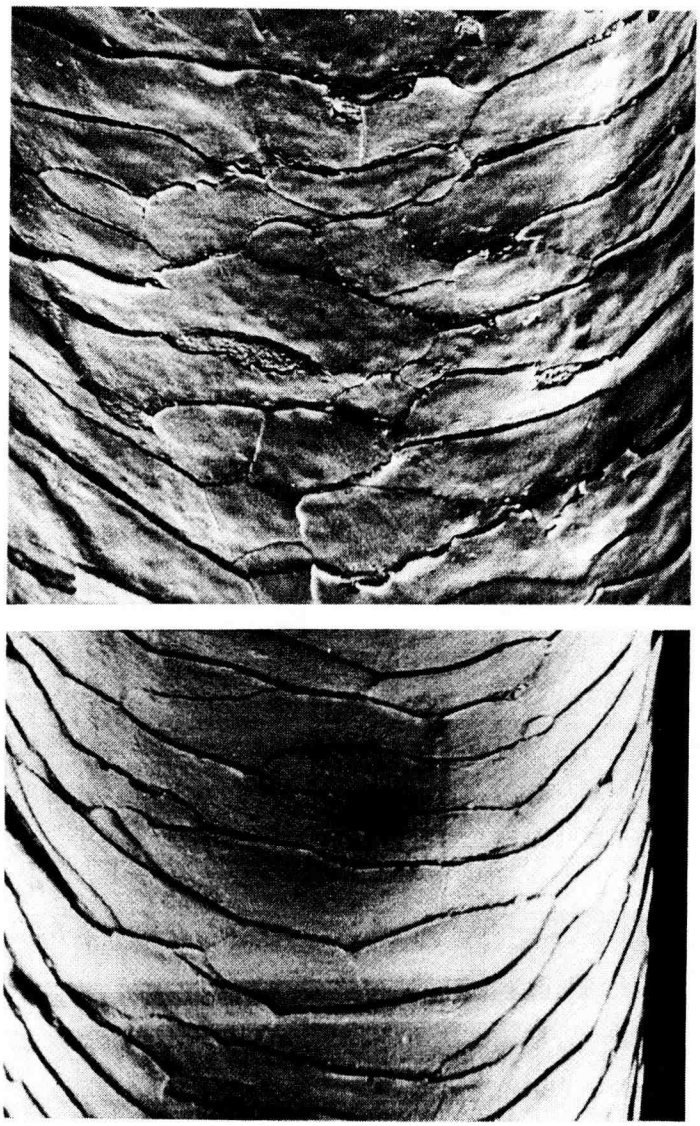
The cuticle is susceptible to change due to factors such as time and activities like washing or brushing. It is common, therefore, for the scale pattern to be smooth and distinct near the root end but broken and damaged closer to the tip (Figure 6).

Cortex

The cortex lies intermediate between the cuticle and the medulla and makes up the majority of the hair shaft (Figure 4). It is made up of cells that may vary considerably in their size and shape yet appear homogeneous under the light microscope. Cells are polygonal or spherical at the proximal end of the hair but become spindle-shaped as the hair moves distally as result of the keratinization process. After a hair is fully formed, cortical cells may be 20 times as long as they are wide (Ryder 1973:12). The cells are arranged with their longitudinal axis parallel to the longitudinal axis of the hair shaft (Sengel 1976:25).

Cortical cells range in thickness from one to six μ, and the length is approximately 100 μ. Throughout the cells are fibrous microfilaments ranging in

Figure 6. Structure of the cuticle layer displaying both smooth at the root end (bottom image) and damaged at the tip (top image) scale patterns (Robbins 1994:25)



diameter from 0.1 to 0.4 μ (Chatt and Katz 1988:7). Also between the cells are variably small air spaces called fusi. In the living portion of the hair root the fusi are filled with water, but as the hair grows and dries out air replaces the water (Montagna and Van Scott 1958:54). Unfortunately size of fusi has not been reported. Human cells of the cortex

generally have an equal amount of fibrillar to nonfibrillar material. Many nonhuman hairs, however, typically have two different types of cells: orthocortical and paracortical.

In fine merino wool, for example, orthocortical and paracortical cells are grouped in two longitudinal strands. The orthocortex often takes up the majority of the cortex in cross-section, while the paracortex is a smaller region. This relationship is an important one as it lends an explanation to the coiling nature of many wool fibers.

The cortex of the hair also contains the majority of pigment granules, which develop in the cells by a phagocytosis mechanism (a process of taking solid materials into the cells) in the zone of differentiation and biological synthesis (Robbins 1994:33).

Medulla

At the center of the hair shaft the cells take on yet another form differing from cells of both the cuticle and the cortex regions (Figure 4). This central region is the medulla and while it may not always be seen, it is present in every hair. Thornton (1977:381) states that, "the medulla does, in fact, exist in hairs which are casually referred to as being of the 'absent medulla' type, but the medulla can not be visualized as easily in the absence of air vacuoles." Air vacuoles appear as a result of the medullary cells shrinking during growth and keratinization, the space between these cells subsequently filling with air bubbles. The medulla exists, then, as a combination of variably and loosely shaped cells connected by a filamentous network and pockets of air. As a result, the medulla's function has been regarded as maintaining hair diameter without increasing the weight of the hair. In fact, the medulla has provided evidence for

the mystery behind why a hair grows back coarser after it has been shaved off, for it is this region of the hair which is stimulated to enlarge (Ryder 1973:14). In addition to this, the medulla plays a very important role in providing thermal insulation (Fraser 1980:9). Finally, the air pockets further influence the reflection of light which in turn influences the color or sheen of the hair (Montagna and Van Scott 1958:54). According to Robbins (1994:45), the medulla provides little to the chemical and mechanical properties of the hair.

Many animal hairs (appear to) lack a medulla within the fine underfur or vellum hairs, as do human hairs at birth. According to Montagna and Van Scott (1958:55), "the percentage of medullated hairs increases rapidly during the first seven months. From the seventh month to the second year, the percentage of medullated hairs decreases; a period of great irregularity follows and then the percentage tends to rise slightly at five years."

Occasionally, the medulla may make up the majority of the entire hair. The medulla, like the cuticular scales, forms a unique pattern differing between species and this pattern too can be used for identification purposes. In humans, the medulla is a relatively small fraction of the hair and the pattern appears altogether absent or fragmented along the shaft. Like the scale pattern, however, the medulla pattern can vary in form along a single shaft of hair.

Keratin

Keratin, from the greek word "keras" meaning horn, is a generic term referring to a group of highly resistant proteins present in structures such as the hair, horn, nail, feather and skin of mammals (Swift 1977:81). Valkovic (1988:47) describes a typical keratin molecule as a two- to three- stranded cable of highly oriented polypeptide chains wound into a helix with secondary folds or distortions combined with a relatively unorganized matrix.

Keratin can be divided into groups of "hard" and "soft" depending on their chemical properties and, more specifically, their cystine content. Hard keratins contain greater than 3% sulfur and are present in the horn and hoof as well as the cortex and cuticle regions of the hair. Soft keratins contain less than 3% sulfur and are present in the skin and inner root sheath and medulla. Keratin provides hair with its durability.

Pigment

Hair color is, in part, a result of pigment granules existing in either one or all three regions of the hair, but mainly in the cortex. These pigment granules are called melanin and occur in two genetically and chemically different forms: eumelanin (also called tyrosine melanin: the brown to black form) and phaemelanin (the yellow to red form). Eumelanin pigment granules are ellipsoidal in shape and range from 0.8 to1.0 μ in length,

0.3 to 0.4 μ in diameter (Swift 1977:128). The darker a hair is, the more eumelanin it is likely to contain. Phaemelanin remains spherical in shape (size of pigment granules has not be determined).

Hair receives pigment only as it is growing. Melanin granules are formed from cells called melanocytes present in the hair bulb (Figure 3). As the cells move distally, melanocytes of the hair matrix donate organelles called melanosomes to the follicular keratinocytes during the growth phase, anagen. The melanosomes are then dispersed within the cells of the cortex, resulting in a melanized hair. Hair color is a function of absorption, reflection and scattering of incident light and these are influenced by the size, number and distribution of melanosomes (Robins 1991:19).

Though hair pigmentation appears to be under genetic control, little is known about how this control works in humans (Ortonne and Prota 1993:855). To complicate the matter further, factors such as hormones, nutrition, and metabolic disorders can also play a role in altering hair pigmentation. A familiar and common occurrence that can often be anticipated is darkening of the hair as a child gets older, and graying of the scalp hair as an adult reaches approximately age 40 to 50, though this is highly variable. Darkening of the hair is brought on by an increase in melanogenic activity, graying by a decrease. Many studies have shown that the amount of pigment present in hair is linked to levels of trace elements present in hair (Chatt and Katz 1988:23).

In many mammals, hair is not of uniform color. Often hair is banded with multiple colors. In such cases the melanocytes present in the hair bulb have the capability to switch from eumelanogenesis. This switch is related to the cysteine content and is

genetically determined (Robins 1991:28). If a human hair is banded (and has not been dyed or colored) it is likely an indication of disease.

Hair Growth

Hair growth occurs in a cycle of three distinct stages. These stages are anagen, catagen and telogen; each one is controlled by androgens, or the hormones that stimulate the activity of male sex glands and male characteristics produced by adrenals and the sex gland (Robbins 1994:8). The dynamics of the hair growth cycle are influenced by differences in species, differing body regions, and follicle types within the same body region (Messenger 1993:5S). Little is known about the molecular nature of the signals regulating the passage from one stage to another, but there is much information on structural changes in follicle activity during each stage.

Anagen

The anagen stage is the period of vigorous growth in which there is an increase in metabolic activity in the hair bulb. Sengel (1976:100) divided the anagen phase into six subphases: four initial subphases (proanagen), a fifth subphase (mesanagen), and a final subphase (metanagen). Many others (Chatt and Katz 1988, Robbins 1994, Ryder, 1973) have grouped the processes involved with the preceding subphases into one stage; anagen. Here, only anagen will be used as the same information is conveyed without the added confusion of boundaries between subphases which are not clearly defined. Because anagen succeeds a resting stage (telogen), cells of the hair bulb must undergo a

restoration at the onset of anagen. The hair bulb begins to grow (deeper) into the dermis, again around the redeveloping dermal papilla. The hair itself then begins to form as the follicle is restructured. The hair reaches the sebaceous gland and then with the matrix starts to experience an increased rate of growth, a phase that can last as long as three years in humans. The entire anagen phase lasts from approximately two to six years in human scalp hair (Robbins 1994:8). In mice, however, it can last approximately 19 days (Sengel 1976:102). The proportion of human hairs in anagen is relatively higher in the months March through September and much lower in the winter months (Randall and Ebling 1991: 146).

Catagen

Catagen is a transition stage between anagen and telogen. During this stage mitotic activity in the matrix of the bulb is severely slowed and finally discontinued. Though new cells are no longer being produced, existing cells are moving distally into the keratinization region. Here (usually at the level of the arrector pili) the cells are contracted, forming a club shape or bulge. Recent researchers (deViragh and Meuli 1995:279, Lavker et al. 1993: 205) have argued that the bulge is the actual site of origin for stem cells (which give rise to amplifying cells) of the follicle and not the matrix as has been the prior consensus. The "bulge hypothesis" implies that cells move downwards through the outer root sheath rather than upwards from the matrix (Messenger 1993:6S). Regardless, when movement of the cells is completed, the telogen stage begins. Catagen lasts one to two weeks (Valkovic 1988:6).

Telogen

Telogen, or the quiescent phase, is a complete cessation of growth. Both cell division and differentiation have stopped. The hair bulb below the sebaceous gland has experienced a harsh reduction in size and there is significant atrophy. The dermal papilla has been diminished to a ball of cells and the dead hair lies in the follicle fastened by its bulge. Eventually the dead hair will get sloughed away or forced out by a new hair during the next anagen stage. According to Robbins (1994:9), telogen lasts only a few weeks. Valkovic (1988:6), however, describes telogen as lasting three to four months. Incidentally, if a hair is plucked during telogen, anagen will almost immediately resume; if plucked during anagen, however, more time is needed for regeneration of the follicle before hair growth can begin again (Sengel 1976:102). Roughly, once a human hair is plucked it can take from 61-147 days to regenerate depending on the anatomical region from which it came (Montagna and Van Scott 1958:62).

Dynamics of Hair Growth

The growth cycle and the overall rate of growth vary with each hair follicle. In humans, each follicle follows its own cycle, a mosaic pattern of growth independent of surrounding follicles (Lavker et al. 1993:16S). In animals such as mice or rabbits hair growth occurs in a wave in which all follicles are relatively synchronized. Each follicle is dependent on the surrounding ones. Generally speaking, human hair is capable of

growing 0.35 mm per day (Montagna and Van Scott 1958:62), approximately one cm per month, 12 cm per year. Scalp hair normally grows to a length of approximately one meter (m) at maturity, yet lengths of three m or more have been reported (Robbins 1994:11). There is no evidence that cutting or shaving hair affects rates of growth.

Robbins (1994:9) provides a detailed summary of human hair growth from birth. The commencement of hair growth in humans starts at the second to fourth month of fetal development. These prenatal hairs, called lanugo, are very fine and short and lightly pigmented, if pigmented at all. Usually these hairs are located on the upper lip, then chin and eyebrows, and are lost prior to birth or shortly thereafter. Prepubertal hair or primary terminal hair replaces prenatal hair and is thicker and longer. As children reach puberty, hair makes a marked change in both size and location on the body. This secondary terminal hair once again becomes thicker and longer and spreads to new regions of the body; to the axillary, pubis and beard regions. Head hair can grow to a maximum length of 100 cm at this time. At age 25 to 30, however, there is a shortening of head hair as well as a decrease in thickness. Terminal hairs often become what is called vellus hair. Vellus hairs will often grow in regions not usually characterized by having hair, for example, the nose, forehead, otherwise bald scalp and eyelids. Table 1 (Robbins 1994:9) shows age, hair length, and diameter for prenatal, primary terminal, secondary terminal and vellus scalp hair.

There are approximately 175 to 300 terminal hairs per cm on the human scalp; 50 to 100 hairs are naturally shed each day (Robbins 1994:11). Factors such as pregnancy or alopecia (hair loss) will decrease the number of hair follicles, thus reducing the number of terminal hairs.

Table 1. Age, length and diameter for each hair type of the scalp (modified from Robbins 1994:9).

Hair Type	Approximate Age (in years)	Approximate Max. Length (in cm)	Approximate Max. Diameter (in μ)
Infant Hair (lanugo)	<1	15	20
Children's (primary terminal)	1 to 12	60	60
Adult (secondary terminal)	>13	100	100
Vellus Hair	>30	0.1	4

In animals, coarse guard hairs give a characteristic appearance and the fine underfur (called lanugo, vellum or down) provides insulation (Moore et al. 1974:19). Overall hair growth of some animals can be dictated by seasonal changes similar to humans. In sheep the number of hairs is 1000 to 10,000 per centimeter (Ryder 1973:29), a marked difference from the human scalp.

While natural processes, such as hormonal activity, in the body of both humans and nonhumans can induce changes in hair growth so too can influences such as an inadequate diet. Carbohydrates, proteins, vitamins, and minerals are a few of the important elements necessary in attaining normal hair growth. Traumatic factors such as disease, injury, and environmental stress can also modify the rhythm of hair growth (Verhoeven 1972:125).

Stability Over Time

There is no doubt that keratin-rich hair is a strong, stable fiber throughout its lifetime. As yet, no definitive statements have been made regarding the long-term post-mortem stability of the hair fiber. In fact, aside from a few archaeological investigations (Benfer et al. 1978; Bonnichsen et al. 1985, 1995, 1996; Brothwell 1986; Hino et al. 1982; Lubec et al. 1987 and 1994; and Massa and Fuhrman 1980), there has been little directed effort to test a shed hair's stability over great lengths of time. Recent recovery of Paleocene fossil excrement has revealed impressions of hair so detailed that the scale cast of four extinct mammalian taxa have been identified in these coprolites (Meng and Wyss 1997:712). While this is perhaps the earliest record of fossil hair, it is not the hair itself that is being preserved. Hair fiber has been proven to exist for several thousands of years, but just how many thousands it may exist cannot be accurately stated.

Variability of Human Hair Morphology

I have discussed how the hair develops, from changes taking place in the skin, to the evolution of the follicle, and finally, transformation into a mature hair. The various features that make up the hair fiber have been mentioned and now the variability that exists within and between these features can be discussed. In fact, much of the difficulty related to analyzing hair for any purpose lies in the profound differences in morphology existing not only between animal species or local populations of people, but within species or populations, between hairs of differing anatomical regions and finally, along

the shaft of a single hair. All hair investigations, then, have the difficult task of understanding and integrating this morphological variability. Indeed, it is impossible to make any general statements about hair without observing the existing variability first.

Variability Along a Single Hair Shaft

Certain research (Vernall 1961, 1963; Verhoeven 1972; and Hrdy 1973) shows that morphological variation along a single shaft of human hair does not outweigh the variation existing between body regions, individuals and local populations. These same investigations also show that the intrapopulation variability does not exceed the interpopulation variability. Many other publications do not even address the potential for hair shaft variability, perhaps because this variation has been regarded as minimal, but some of those that do discuss this are mentioned below. This investigation will proceed on the assumption that the variation existing within a single hair is relatively minimal compared to the larger differences existing between hairs of differing individuals and local populations.

Hausman (1925) was one of the first to recognize that a single hair shows various types of features. He correlates the patterns of the medulla and scales to the overall shaft diameter and concludes that since scales and medullas vary with the diameter of the hair shaft, any hair may show different types of these structures (or variations of these types) in different regions of the shaft (1927:545). Wyncoop (1929:187) further substantiates Hausman's claims with a new set of samples. Seibert and Steggarda (1924:304) demonstrate an increase of shaft diameter in cross-sections progressing from the scalp to

the tip of the hair contrary to Bernstein and Robertson's research (1927:379) claiming "...the hair shaft varies little in area and shape of cross-section from place to place except at the tip where the hair is frayed." Anderson (1969:223) notes that the diameter of the hair is usually smaller towards the outer end but in some cases may also be larger, probably due to the kind and amount of hair dressing used.

The Federal Bureau of Investigation (FBI) (Hicks 1977:11) also points out the potential for single hair shaft variation. Changes in scale pattern along the shaft are demonstrated by Bottoms et al. (1972) using a scanning electron microscope. It was found that the scales near the root are often smooth edged while those near the tip show rippled edges. This is attributed to the physical and chemical trauma experienced by daily brushing, combing, etc.

When head hair was recovered from a body referred to as Lindow man, found in an ancient bog, it was reported to have a medulla that ranged from continuous to fragmentary in shape (Brothwell 1986). In fact, this medulla variation is very common in both humans and animals. This change in medulla may be accompanied by a change in medulla diameter and cross-sectioned medulla shape. My research has shown that variation in both medulla and scale pattern within an individual is much more prevalent in nonhuman than in human hair.

The distribution and density of pigment (and subsequently color) of hair also shows variation from the proximal to distal end of the hair according to Hausman (1928) and Vernall (1963:494). This too occurs more frequently in animal hairs than in humans. Again, recent FBI work supports this. The FBI point out, however, that while the pigment may show variation in the region of hair it is concentrated in, the overall color of

human hair is generally consistent; it is the hair of other animals that show radical color changes (1977:5). These are only a few examples of the variation known to exist within a single hair.

Variability Between Hairs of Differing Anatomical Regions

The task of matching an unknown hair to the particular body region from which it originated can be extremely difficult. FBI studies state, "body area determinations may be made with considerable accuracy; however, variations may occur which make this determination difficult or impossible." Crime laboratory proficiency tests were conducted in 1980-1991 regarding the identification and classification of physical evidence (Peterson et al. 1995:1004). One exercise was to identify the location on the body where various hairs originated, a task few laboratories would attempt in an actual investigation. Labs were correct in 50% of their designations (86% when identifying hair from head and pubic regions, 30% in identifying hair from beard, arm and chest). The following traits have been regarded as useful when identifying body region: length, shaft diameter, medulla diameter, medulla pattern, tip, texture and number of scales.

Scalp hair is considered first. Length of scalp hair can be misleading because hair has almost always been cut. Generally, head hair is still longer than hair from other regions of the body. Hair length greater than eight cm has originated from the head (Niyogi 1962). Shaft diameter is perhaps more useful than length, though it too can show variation within a single hair as stated in the previous section. Hicks (1977:8) describes shaft diameters as fine, moderate or coarse, but fails to provide any indication of what

these terms mean numerically. Nonetheless, he states that scalp hair falls into the moderate category. Verhoeven (1972) gives a range of scalp hair diameter of 45 to 190 μ. Niyogi (1962) states that, as a rule, hairs measuring greater than 100 microns in diameter are not from the head. The medulla ranges from appearing absent to continuous. It is narrow when compared to medulla diameters of hair from other body regions. The tip is usually cut or split. The overall texture (mainly a function of shaft diameter) is "soft" and "pliable" (Hicks 1977: 8). Again Hicks makes no attempt to quantify or define these terms. Riggott and Wyatt (1981:347) use mean scale number (MSN) to separate hairs of differing body regions. MSN is not clearly defined in their paper but they report that the scalp has the lowest MSN of all hairs.

Eyebrow and eyelash hairs are fairly short when compared to other hairs with a maximum length of one cm, according to Niyogi (1962:30). There may be some variation in shaft diameter. Overall, hairs from this region appear "saber-like" and the MSN (Riggott and Wyatt 1981:347) is the highest for all hair.

Beard and mustache hairs range in length from two to four mm (Trotter 1922:280) or less than three cm (Niyogi 1962:30). They have a "coarser" diameter than head hair at .004 to .121 mm (Trotter 1922:280) or 100 to 130 μ (Niyogi 1962:30). In a cross-section the hair is often irregular or triangular in shape. The medulla is larger in diameter than scalp hair and usually continuous. The medulla is also more developed in beard and mustache hair than in hair from the pubic region (Niyogi 1962:30).

Hairs from the arm or leg have a length of less than three cm and a "fine" shaft diameter displaying little variation. Overall these hairs have an arc-like shape. The medulla is broad, like that of the beard and mustache, and discontinuous. The texture of

these hairs is "soft" (Hicks 1977: 8) and cross-sectional shape is round. The diameter range, according to Verhoeven (1972) is 15 μ for soft body hair and 70 μ for coarser body hair. Axillary or underarm and chest hairs have a moderate shaft diameter with some variation. Though the tip may be long and fine, the overall texture is usually "stiff" (Hicks 1977: 9). A layer of greasy and flaky material may be seen on axillary hairs and the color of the hair is often reddish due to sudorific secretion (Niyogi 1962:30).

Hair from the pubis region is distinguished by the wide variation in shaft diameter causing a "buckling" effect. The medulla is relatively broad and usually continuous if present. These hairs are often found with root attached. The tip is rounded or abraded and the overall texture is stiff. Pubic hairs may lack pronounced scales (Verhoeven 1972:127).

Riggott and Wyatt (1981:348) claim that hairs at the androgen dependent sites are wider in diameter than hairs from the rest of the body. Androgen dependent sites include facial, trunk axillary and pubic hair.

This investigation avoids problems produced by variability in anatomical regions by limiting itself to samples of head hair only. Morphological features may also vary in hairs from the same anatomical region within a single individual. Hrdy (1973) finds that the variances within populations are quite comparable to the variances of different hairs from a single individual.

Intrapopulation Variability and Personal Identification

In addition to the variability existing within a single shaft and between hairs of differing anatomical regions, there are morphological differences between hairs from different individuals, even individuals of the same local population. However, a personal identification of hair, analogous to linking fingerprints to a particular person, has yet to be developed (except when DNA has been extracted from the hair, but this is an expensive technique with its own set of problems).

Hausman (1927:554) states when looking at pigmentation "as for identifying individuals from hair samples under the microscope, this, it is believed, is impossible unless the hair is marked by some abnormality in its structure or pigmentation."

In forensics, hair is a form of evidence considered circumstantial and identification of whether it came from a given subject is based on probability theory. "At best, a hair may provide evidence indicating either that it probably came from a given individual or that it could not possibly have come from this individual," according to Duggins (1956:381). Others state similarly that when comparing an unknown hair specimen with one from a known subject side-by-side, the examiner may conclude: 1) that the hairs are consistent or similar and could have come from the same source; 2) that the hairs are dissimilar and did not come from the same source; or 3) that the hairs possess characteristics which are not sufficiently defined to arrive at a meaningful conclusion (Kirk 1941:6). McCrone (1976:15) states that "...the chance of

individualizing hair by light microscopy alone is very difficult and in most cases impossible."

Certainly, there is no standard set of attributes used by examiners in determining intrapopulation variability. However, most investigators have used a combination of the following: color (hue, value and intensity) and color throughout the shaft (looking for radical color changes), length, tip (whether cut, broken, split, abraded or finely pointed), root (plucked prior to maturation or naturally sloughed from the body), diameter of shaft, cuticle thickness and color, scales, pigment (size, distribution and density), medulla pattern and cell structure, medulla diameter in relation to shaft diameter, cortex appearance and artificial treatment. Duggins also observed refractive index and bifringence of hair.

Kirk (1941) suggests the following as valuable characteristics: color, diameter, scale count, (number of scales within a given distance), scale picture (general character of the scale), pigment distribution and medullation. He adds physical factors such as refractive index, bifringence and chemical factors. Kirk states that these factors point to the possibility that human head hair may be positively individualized and used in personal identification.

With a few exceptions, most investigators fail to define the attributes or the methods used for analysis of the attributes in their publications. Without this information, replicability of the procedures has been impossible. This deficiency has held back the progress of understanding intrapopulation variability. A promising new investigation is the development of computer neural networks made to interpret hair images for comparison (Medina 1994:1475). Use of the scanning electron microscope

has also improved the analysis of hair. At this time (1988) a combination of morphological, chemical and molecular analysis appears as the best method for determining intrapopulation variability and personal identification. This will be discussed further in following chapters.

Interpopulation Variability

Hair morphology has been used in classifying people into groups stemming as far back as the time of Herodotus, who used the appearance of one's hair as a basis for dividing Xerses army into groups of straight- and woolly- haired people (Trotter 1938:105). Throughout the 1800s hair was regarded as one of the most useful devices for describing human variation. These early studies were enthusiastic endeavors and certainly made some advances in the field, even if they were fraught with racial biases of the time. One of the ambiguities is that some studies observed differences between continentally-defined populations (traditional geographic races) while others examined and compared local populations and still others used regional types or ethnic or tribal populations. Not all of them described how they chose their subjects. Another problem is they focused mainly on the overall form or texture (a problematic term because the definition varies from one investigation to the next).

Garn (1950:453) states that, "despite the frequent appearance of the term hair texture in the American anthropological literature, it is difficult to find a satisfactory definition of the term, description of the categories that can be distinguished, or attempts to test the reliability of the ratings." Unfortunately the ambiguity and inconsistency in

many of the early investigators descriptive approach made advances come slow in determining the interpopulation variability. Hrdy (1973:7) very astutely described this early work on hair form "... it is surprising how little systematic research has been done to delimit these population differences. For centuries such imprecise expressions as frizzy or curly have been in popular use. Such terms do not connote exact meanings to their users, and their vagueness has increased with continued use."

Later investigators tend to use a more quantitative approach when observing hair morphology with regard to population differences, though many still added to the ambiguity of hair form. For example, Bernstein and Robertson (1927) experiment with weight of hair and find that the average weight of hair was different between Mongoloids, Negroids and Caucasoids. In this same study, hair weight is further divided in the Caucasoid group to Nordics weighing least, followed by Alpines and Mediteraneans. Hausman (1928) conducted a racial study by observing the pigment granules of head hair, summarizing that "the pigmentation characteristics of human head hair are related directly to the color of the hair shaft, and not to the racial origin of the hair".

Trotter's contribution (1922, 1930, 1934, 1938, 1939; and Duggins 1950, 1956, 1959) to studies of hair morphology result partly in her attempt to quantify the early hair form designations. She (with Dawson 1934) also compares hair of French Canadians to American whites using attributes of form, area of cross-section, color and weight. She finds differences between the two groups with each of the attributes.

Woodbury and Woodbury (1932) though not the first to examine the hair of Native Americans, probably provide the most data and description of Native American hair morphology. Their main intention is to distinguish if American Indian head hair is

of one uniform type or a number of different types. Of twelve tribes observed, four distinct types are found. Kneberg (1935, 1936) also attempts to quantify form by observing the hair in cross-section. She then turns to weight as another important feature.

Steggarda and Seibert (1941:318, Seibert and Steggarda 1942) again attempts to help quantify the early descriptive work on hair form. They find that "intraracial variation can exceed interracial differences in their study of six racial groups: Dutch, Hopi, Navajo, Zuni, Negroes and Maya." Hanna (1956) returns to color based on pigment concentrations to observe differences between Caucasians and Negroid.

After the 1960s, studies in hair morphology are few and far between. Those that do exist lend themselves mainly to the more applied task of identification for forensic purposes (Niyogi 1962, Anderson 1969, Verhoeven 1972, Brown and Swift 1974, Rosen 1974, Hicks 1977, Lamb and Tucker 1994). Furthermore, the introduction of new and better technology has allowed those same hair attributes that were used in early studies to be looked at in a closer and more effective way, but only a few studies have taken advantage of these advances (Vernall 1961, 1963, Hrdy 1973, Lindelof et al. 1988, Medina et al. 1994).

From this chapter, it is clear that the morphology and development of hair is now well understood, from the macro to the micro level. It is the variability and the application of this variability to individuals that is still to be discerned, and it is the latter that this study addresses.

MATERIALS AND METHODS

Analyzing human hair requires use of a routine set of detailed procedures to be followed consistently from one sample to the next. This methodology begins with the acquisition of the hair samples followed by a set of laboratory procedures developed for this study to prepare the hair for examination and finally the examination procedures. The following procedures were developed as a collaborative effort at the Center for the Study of the First Americans. Some procedures (cleaning the hair and the examination procedures) were developed by others prior to my thesis work. Other procedures I developed alone or improved upon (casting and mounting the hair, cross-sectioning and development of the key). The entire methodology (excluding the most recent cross-section procedures) was written as a lab manual for use at the Center for the Study of the First Americans (Bonnichsen and Weitzel 1996).

Hair Acquisition

I chose five populations for analysis based on three factors: availability of hair, geographic diversity, and their potential interest regarding the peopling of the Americas. The five groups are Mongolian, Vietnamese, English, Native American Sioux and Native American Oneida. As hair was acquired from each of the five populations, it was placed into a Ziploc bag and labeled with the population name and an accession number assigned to each individual (hairs from each individual were stored in one Ziploc bag). While conducting analysis, I was only aware of the accession number and, therefore, blind to the

sample origin, avoiding any biases that may have resulted by knowing the sample population associated with the hair. As hair was collected from the English and Vietnamese populations, a form was filled out by each subject, which included the following data: place of birth (city and country), place of residence for the majority of their life, sex, age, and whether or not their hair had been chemically altered (through coloring, a permanent, etc.). Similar data for the remaining three populations came with the hair samples.

Mongolian

The Mongolian hair samples were collected from eight living individuals of Ider Soum of the Zavkhan Province. The individuals are Khalka nationality and range in age from 20 to 49 at the time the hair was collected (1996). Seven individuals are male (01, 11, 16, 21, 26, 31 and 36). There is one female (06). The hair was collected by author and "Outside" magazine editor, Tim Cahill, also a member of the Advisory Board at the Center for the Study of the First Americans. Cahill visited the region and brought the hair (two to three samples of hair from eight individuals) to the Center for research purposes soon after his return. The population is somewhat of an isolated group today but play an important role in ideas of early migration into the Americas. A number of theories exist on the relationship between Mongolians (and other northeastern Siberian populations) and native North Americans with regard to biological evidence (Steele and Powell 1993; Szathmary 1993; and Turner 1990, provide only a few).

English

I collected the English hair samples (04, 09, 14, 19, 24, 29, 34 and 39) from residents of Corvallis, Oregon in 1997. Their ages range from 38 to 61 and all are female except for sample number 09. Seven of the individuals were born in England as were their parents and grandparents. One individual (24), however, was born in Scotland as were her parents and grandparents. The English population is geographically distant from each of the others and has minor implications to the peopling of the Americas.

Vietnamese

I collected the Vietnamese hair samples (05, 10, 15, 20, 25, 30, 35 and 40) from students at Oregon State University in 1997. The individuals range in age from eight to 23. All are female except for one (05). All individuals were born in Vietnam. Both the parents and the grandparents of six individuals were also born in Vietnam. Sample number 35, however, has a mother and maternal grandparents who were born in China. Sample number 20 also has one set of grandparents from China. Regarding the peopling of the Americas, the Vietnamese are south Asian, a group that is also discussed in debates surrounding North American migrations. For example, they are part of a large group known as Sundadonts to Turner (1990), a group that he states evolved prior to groups in northern Asia and North America.

The Sioux and Oneida hair was graciously donated to this project by Belinda Kaye at the American Museum of Natural History (AMNH) in 1997. The hair included several samples of eight individuals within the Sioux and Oneida population sent in

Ziploc bags. It is part of a collection of material once studied by Franz Boas in the years between 1888 and 1902. Boas' anthropometric studies of American Indians was the culmination of four large projects including the World's Columbian Exposition. Samples from this project were collected and stored at the AMNH along with data sheets which included an identification number, sex, observer, observation place, date of observation, name and age of subject, place of birth, tribe of subject, purity, tribe of mother and father and mode of life (occupation); Richard Jantz (1995) describes the Boas research project.

Sioux

The eight Sioux individuals (02, 07, 12, 17, 22, 27, 32 and 37) are full Sioux and range in age from 13 to 20 at the time the hair was collected. Two are female (32 and 37) and six are male.

Oneida

The Oneida samples (03, 08, 13, 18, 23, 28, 33 and 38) are full Oneida and range in age from eight to 26. Three of the individuals are female (03, 08 and 13), five are male. These two populations have obvious relevance to the peopling of the Americas.

Laboratory Procedures

Cleaning

After a hair is acquired it is essential that it be cleaned in order to insure quality examination, especially when dealing with an archaeological specimen. First the hair is lightly grasped with forceps which have been sterilized by flame, and then the hair is released into a clean glass scintillation vial, one-quarter full of Malinckrodt brand Chloroform. This dissolves the oils attached to the hair and successfully rids the hair of any adhering dust and foreign particles. The vial is capped and agitated slightly for a few seconds. The hair remains in the vial until the next procedure begins.

Length of the hair must be measured first as the hair will soon be cut in order to do cross-sectioning. The hair is retrieved from the vial with clean tweezers. With another set of tweezers, the hair is stretched out beside a ruler and the maximum length is recorded in mm. With a clean razor blade, a 10 mm segment of the hair is cut at 10 to 20 mm from the most proximal end of the hair (which is determined by the presence of a root or the coarseness of the proximal end of the hair versus the finer texture at the tip). The 10 mm segment is placed in a 3 x 5- inch Ziploc bag, labeled with the corresponding sample number, and the hair is stored until it is to be cross-sectioned. The two remaining pieces of hair are placed back in the vial of chloroform.

Scale Casts

A thorough examination of the hair requires a replication of the cuticle layer, or a scale cast, as this cannot adequately be seen by mounting only the hair itself. If a scanning electron microscope (SEM) is accessible, a scale cast is unnecessary as the scales (themselves) can be seen quite well under high magnification. However, for this investigation a cast was obligatory for analysis. Several procedures have been developed (Bowyer and Curry 1983; Koonz and Strandine 1945; and Ogle et al. 1973) and many of them were tested for use in this project.

First, I attempted scale casts using Cover Girl Nailslicks clear nail polish as the casting medium. A thin line of polish was brushed across the length of a Fisherbrand plain, pre-cleaned glass slide (25 x 75 x 1 mm) with the attached applicator. The hair was laid in the wet polish and left to dry. When the polish was completely dry, the hair was carefully removed with clean tweezers, leaving a permanent replication of the cuticle layer. While this method is by far the quickest and easiest, and is also the least expensive, it fails to provide adequate results. Often the hair does not rest entirely in the medium, leaving spaces where the scale cast is missing. The liquid also may leave air bubbles, which obscure the view of the scale pattern. Overall, the replication is of relatively poor quality.

Another method was attempted using sheets of cellulose acetate. A thin layer of acetone, reagent grade, is released onto a slide with a straight medicine dropper. A 22 μ thick (12.7 x 12.7 cm wide) sheet of cellulose acetate film is cut to the same size of the slide or slightly smaller with a clean razor blade. This piece of cellulose is placed over

the acetone. As the plastic absorbs the acetone it becomes a liquid gel. The hair is placed on this solution and lightly tapped down with the tweezers to make sure the entire hair is attached to the gel. When the plastic has dried completely the hair is gently lifted out of the cast. Disadvantages of the cellulose acetate procedure are that when the hair is pulled from the plastic, sometimes the plastic is bonded so tightly to some regions of the hair that it comes off the slide with the hair, in which case the entire scale cast has disappeared in that region. In addition, the sheets of cellulose, because of their high static electricity charge, are prone to collecting dust and floating particles from the air. It is very difficult to keep the plastic clean and this can be seen on the finished slide.

In contrast to the two procedures described previously, the following two procedures both provide acceptable results. The first is a wax casting method developed by John O'Brien, a volunteer at the Center for the Study of First Americans. O'Brien, a retired dentist, is familiar with making wax casts in teeth and applied this knowledge to hair. He developed a procedure in which sticks of Kerr blue inlay casting wax is melted in a crucible over a Cimerac Brand hot plate. The hair is placed on a clean slide. A second slide is heated by laying it on the hot plate for approximately 10 seconds. One end of a third slide is dipped into the wax and quickly brushed along the second slide, leaving a thin, even sheet of liquid wax on the slide. This is immediately placed over the slide with the hair on it wax side down and held tightly until the wax is hardened and the slide is cooled to room temperature. The two slides are then gently pried apart and the hair peeled from the wax. Depending on the thickness and distribution of the wax, the cast is sometimes left on both slides. Both slides should be examined under a microscope

to insure at least one adequate cast was produced. A procedure is being developed in which silicone is sprayed on one slide so that the wax will adhere only to one slide.

The long-term stability of these wax casts has not been tested, but if the slides are stored in a dark, cool place there should be little if any alteration to the cast. This method works especially well with coarser hair (with Alces alces or moose, for example) as it produces shadows between scale margins, giving the replication a three-dimensional effect. When testing this method and the following gelatin method on eight Mongolian hair samples, however, the gelatin method proved more successful.

The gelatin method (modified from Teerink 1991) begins by mixing a 5 percent solution of Difco brand bacto-gelatin, 2.5 milliliters (ml), with distilled water, 50 ml, and a few crystals of ultra pure phenol (which acts as a preservative) in a sterile 125 ml glass flask. The solution was heated over a hot plate, in a water bath, consisting of a 1400 ml beaker filled with approximately 200 ml of water, until all the gelatin is dissolved. There should be little or no air bubbles in the solution. With a slide held at a 45 degree angle the liquid solution is poured over the surface until the slide is covered and the remaining gel has run off the opposite end into a disposable tray. Very quickly the hair is laid into the gel and pressed lightly onto the solution with the tip of the tweezers. After approximately 15 to 30 minutes the gel is dry and has formed a firm, thin sheet. The hair is gently lifted out.

The gelatin cast is very clean, leaving well-defined scale edges and it is equally efficient as the wax method in terms of labor, cost and overall simplicity. Due to the good results of these tests, the hairs used in this investigation were cast using the gelatin method.

Because the hair was initially cut (leaving two segments to be cast), it would be too difficult to orient the hair on the slide consistently with the proximal or root end of the hair on one side of the slide and the distal or tip end of the hair on the other. Therefore, hairs were randomly placed on the slide and proximal and distal ends were determined under the microscope.

After completion of the cast, the hairs are placed back into the vial of chloroform and agitated slightly to release the gelatin from the hair. A coverslip is attached using a small drop of Permount mounting medium at each of the four corners and this is placed over the scale cast, protecting the replicated cuticle of the hair. The slide is labeled with the corresponding number (as described below).

Longitudinal Profile

Finally, the hair itself is mounted. Once again the hair is retrieved from the vial of Chloroform and laid on a new slide, being careful to allow the hair to retain its natural position. It is not pulled straight. A sufficient amount of Permount is dropped over the hair so that the entire hair is covered. A coverslip is placed over the Permount and the slide is left to dry. If the hair is longer than the length of the slide it can be curled back and forth in order for it to fit trying not to cross the hair over itself though sometimes this is unavoidable. If necessary the hair can be cut and mounted on a separate slide if it is too long. The slide is labeled with corresponding number (as described below).

An evaluation of mountants used in forensic hair examinations was consulted (Roe et al. 1991). Roe provides a list of required properties for a mountant. Of the 30

mountants tested, 17 were chosen at least once by the panel of examiners. Permount was included as one of the 17. Disadvantages of Permount were that it had a pale yellow color, it was slow setting, and crystals and bubbles may form in storage. The examiners in the study also found it difficult to use. The authors indicated, however, that Permount has been reformulated in recent years and it certainly worked well in this investigation.

Cross-section

Several important hair attributes cannot be seen from a longitudinal profile of the hair, for example, the shape of the shaft diameter. Cross-sections allow these attributes to be seen. Cross-sections require that the hair is cut and that is why the 10 mm segment of each sample was initially saved. The segment is retrieved from the Ziploc bag, cleaned in a vial of Chloroform, and dried on filter paper. Many researchers have devised techniques for making cross-sections (Douglas 1989; Ford and Simmons 1959; Garn 1947; and Mathiak 1938b).

Here, I initially made cross-sections using sheets of cellulose acetate (modified from Teerink 1991) as described in the previous scale casting procedure. A glass slide is covered with a drop of acetone and a sheet of cellulose cut to fit is placed on the slide. The hair is placed on the liquid plastic much like in the casting procedure but now a drop of acetone is added to the hair and another sheet of cellulose is placed over the hair. After approximately 15 to 30 minutes a single sheet of plastic has formed with the hair embedded in the middle. The plastic is then cut to a working size at

approximately one mm on each side of the hair. The extra plastic is removed from the slide.

Under a stereomicroscope the hair can be cross-sectioned using a new razor blade for every two to three cuts. Several thin sections are cut (approximately 50 to 100 μ wide) and placed on a new slide with the plan view of the cross-section standing up. If necessary, the ends of the cross-section (the cellulose acetate) can be tacked down to the slide with a dab of glue so that they don't tip over when the coverslip is attached to the slide. A drop of Permount is applied to the cross-section after the glue is dry. A coverslip is attached in the same manner as described for scale casts.

This procedure did provide results but not without some critical concerns. First, because the cross-section is cut relatively thick, not all features are seen as well as they should be. Also, it is much more difficult at this thickness to determine if the cross-section is an exact right angle to the longitudinal (or z-axis) of the hair. Often it appears as slanted, thus resulting in a shape and size that is not the true shape or size of the cross-section. In addition, the process can be long and tedious and it may take several cuts before a good cross-section is mounted.

It was therefore necessary to begin a new method for cross-sectioning with the use of a microtome. Initially I avoided this method not only because it seemed unnecessary, but it seemed impossible without the assistance of someone knowledgeable about the use of microtomes with regard to hair. Fortunately, I found consultant Kathy L. Cook and obtained training for cross-sectioning. All samples of hair were cross-sectioned using this method.

The same sections were cleaned as described above. A block of Mathacrylate was made from a square mold and trimmed into two separate blocks approximately 2 x 2 mm with a razor blade. A small drop of Zapagap brand glue was placed over one block (on the smooth rather than rough side). A two mm piece of hair was laid on the glue and the other two mm block was placed over the hair (smooth side down). Some pressure is applied to the blocks for approximately 15 to 20 seconds until the glue is dry. The blocks are then trimmed again so that all edges are straight and the end of the hair is at the edge of the block.

Beam capsules were made prior with an Epoxy kit. The flat end of the capsule was sanded with 100 grit sandpaper so that it was completely flat and another small drop of glue was placed on this surface. The block with the hair is placed on the glue on the capsule so that the hair is perpendicular to the sanded surface of the capsule. Again, some pressure is applied until the glue is dry.

The microtome holds a steel knife with a c-profile. The capsule is screwed into the microtome so that the hair (not the capsule) is oriented straight, perpendicular to the knife. The microtome is set to cut sections at 10 μ. The block is trimmed or faced off until the blade reaches the hair. Cut sections are grasped with a paint brush and forceps and placed on a strip of mounting medium on a glass slide. Three to five sections are cut for one hair and placed on the slide. The sections are then covered with another drop of mounting medium and a coverslip is placed over the sections. Each slide is examined to insure a good cross-section is made. Slides are labeled with corresponding number (as described below).

Labeling and Storage

Slides are labeled by pasting a thin strip of paper with specimen information along the upper longitudinal axis of the slide. The label includes the type of slide (scale cast, hair profile or cross-section) useful for retrieving slides quickly and the accession number assigned to each hair sample. Slides are then placed in a polypropylene slide box for storage.

Examination Procedures

Each hair specimen is examined individually, including its scale cast and cross-section under a Leica microscope. The microscope is connected to a Sony Trinitron color video monitor by a Javelin Smartcam video camera. The monitor allows a full-screen view of the microscope image. In addition, the monitor is connected to a Gateway 2000 P-90 computer. Computer imaging allows a good view of morphological features of hair. As data is gathered from each hair, it is input into a database.

Imaging

Analysis of hair attributes utilizes a combination of both microscope viewing and computer images. However, I depended primarily on computer images for evaluating attributes simply because it allows for more detail to be seen. The image is captured in Optimas 6.0 and saved in a file on an optical hard drive. Optimas 6.0 allows various

calibrated measurements to be applied to hair images at each magnification of the microscope (100X, 250X and 400X).

The stored image is then transported to Adobe Photoshop, which allows enhancement of the image. Each image follows a routine enhancement procedure, which usually includes the initial task of rotating the image in a consistent orientation. This places the hair so that it lies horizontal on the screen. This is followed by the adjustment of the brightness and contrast (auto levels) of the image. The image can also be sharpened entirely or only along the edges if necessary. When the image is of an acceptable quality, the background is erased and converted to white so that it does not interfere with the image of the hair.

It is worth mentioning that there is a fine line between enhancing an image for better viewing and enhancing an image to the extent that the information is manipulated to the point where it is no longer revealing accurate information about the hair. Some amount of subjectivity is unavoidable. In this project, images were enhanced only to bring the already existing attributes into better view as described above and caution was used in order to avoid altering the integrity of the attributes.

After the enhancement is complete, the image is transported back to Optimas 6.0 where it will eventually be stored. At this time measurements are applied to the hair. Specific measurements used are discussed in the Key (Appendix A). The program is calibrated in μ for each of the three objectives. The corresponding measurement is written on the image as an overlay.

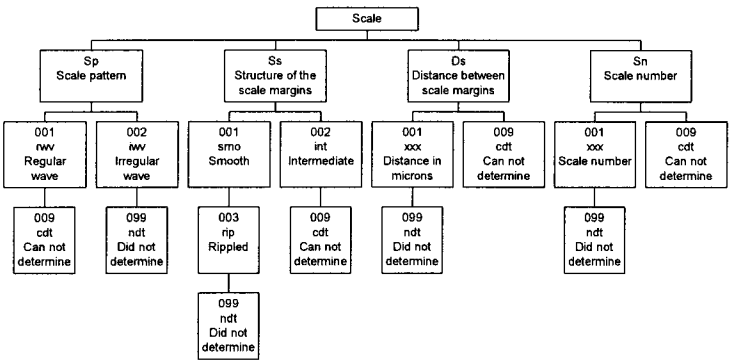
Data Organization

As each hair sample is examined a number of well-defined attributes are observed. In order to systematically account for the overall morphology of a hair, a key has been developed to aid in the analysis of these morphological attributes. The structure of the key borrows from the theory of paradigmatic classification based on the principles of set theory. Groups of data sharing at least one common characteristic are divided into smaller groups based on differences and similarities of at least one additional characteristic. The advantage of paradigmatic classification is that it allows samples to be divided into mutually exclusive categories on the basis of observable, mutually exclusive properties that can be explicitly defined. (Though the key was developed on this assumption, it was not known at the time if samples could be divided on this basis). The key is also based on past research on hair morphology. A few keys used for analyzing hair have been published, most of these having been developed for faunal analysis (Appleyard 1978; Moore 1974; and Teerink 1991). To my knowledge, no key has been published specifically for the analysis of human hair with regard to isolating human populations. The key I developed initially combined attributes from other keys as well as those which I felt might be important based on my own observations.

Before the key was developed, however, organizational charts were initially designed to help organize attributes, subattributes and their corresponding descriptions. These charts illustrate the various possibilities for each subattribute and attribute. (See example of the attribute, scale, in Figure 7). Final attributes and subattributes are then

defined in detail in the key (Appendix A). The following diagram shows the ranked attribute system.

Figure 7. Sample organization chart for attribute, scale.



Each subattribute is assigned a two-letter code with the first letter capitalized (for example, Sp refers to the scale pattern). The corresponding description of this subattribute is assigned a three-letter code (rwv refers to a regular wave pattern). A final code would combine these to read Sprwv, describing the scale pattern as a regular wave. Codes are necessary for condensing information into a string of easily readable descriptions. These codes are entered into a relational database, which links the corresponding attribute data to the images of hair themselves. This database is called Advanced Image Concepts-Image Central.

Advanced Image Central (AIC) allows attribute descriptions (codes) to be entered directly into the database as the hair is being examined. The database is designed in form view with the major attributes listed on the left. Subattribute and description codes are entered to the right of these as the hair is examined. In addition to the above attributes,

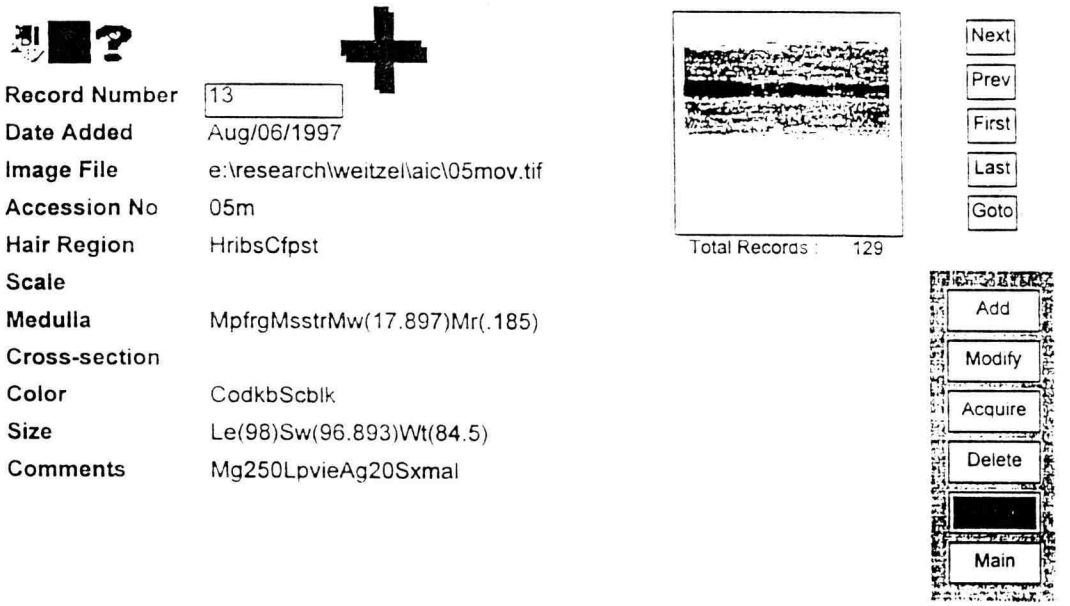
AIC applies three more fields: record number, date added and image file to which the database fills in the corresponding description. The database allows 15 fields to be included in one record.

Each hair has three corresponding records and therefore, three corresponding images. The first record is for the medulla and includes all attribute data except that which relates to the scale and cross-section (including description information on the individual, for example sex, age and local population). The image in this form will be of the medulla pattern, see example Fig. 8. The second record is for the scale features and includes all the attribute information relating to the scales as well as the magnification for the corresponding scale pattern image included in this form. Finally, the third form includes all attribute information regarding the cross-section and the magnification of the corresponding cross-section image in this form. (Cross-section records are not included in samples of the pilot study discussed below; they were not completed on these hairs because an adequate method was still being developed).

Pilot Study

A pilot study was initially conducted to determine which of the chosen attributes proved useful with regard to intra/inter- population variation but it also was a test of the laboratory and examination procedures described above. The study followed the

Figure 8. Database record example (sample 05, medulla).



initially devised key and then tested the attributes in samples from two populations: Oneida (numbers 03A-D and 13A-D) and Mongolian (numbers 06A-D and 26A-D). Two individuals from each of these populations (five hairs per individual) were analyzed, resulting in 20 hairs altogether. Because I analyzed five hairs per individual, I could observe variability between hairs in a single individual, in addition to the variability between individuals and between the two groups. There was a great deal of variability within the five hairs per individual regarding many of the attributes and overlap between individuals and the two groups as well, thus making it difficult to decide which attributes

were useful and which were not. My intention was to utilize attributes that were consistent within the same individual and between individuals but varied between groups; however, the results did not allow for following such simple criteria.

Table 2 is a list of the titles of original attributes and subattributes used in the pilot study. In the following section I discuss my rationale for excluding and adding variables from this list (Note that some of these are merely descriptive attributes).

Table 2. List of pilot study attributes.

Accession Number
Hair Region
- Hair Region
- Root
- Cortex Features
- Tip

Scale
- Scale Pattern
- Structure of the Scale Margins
- Distance Between Scale Margins
- Scale Number

Medulla
- Medulla Pattern
- Structure of the Medulla Margins
- Medulla Width
- Medulla/Shaft Ratio

Color
- Color Number
- Color
- Color Band
- Color of the Color Band

Size
- Length
- Shaft Width
- Weight

Table 2, (Continued)

Structure
- Strictures
- Undulations

Taphonomy
- Taphonomy

Results
- Human or Nonhuman
- Taxonomy
- Race
- Hair Type

Comments
- Analyst
- Magnification

Data Reduction

While conducting the pilot study analysis, it became apparent that certain attributes and subattributes were not useful for this investigation. These attributes were subsequently eliminated from the key and include the following: root, tip, color number, color band, color of the color band, strictures, undulations, taphonomy, human or nonhuman, taxonomy, race, hair type (anatomical region) and analyst.

Analysis of the root was eliminated as very few hair samples contained the root of the hair. The Sioux and Oneida did not have any samples with root attached. The tip of the hair was not useful as nearly all the hair samples were cut, thus showing no variation within or between groups and it does not provide any useful information in terms of evaluating individuals and populations.

Instead of observing the number of various colors present in a single hair sample, I decided to observe the dominate color and add the attribute of second color to record if another color is present and what the color is. Color band, color of the color band, strictures and undulations were attributes borrowed from a key used in faunal identification (Moore 1974) and were nonexistent in the hairs I analyzed (thus, not showing variability).

I decided not to record taphonomic features as this implies that the hair is of fossil origin. While this feature may become useful when analyzing hair from an archaeological context, it serves no purpose in analyzing modern hair samples. The attributes of human or nonhuman, taxonomy and hair type are not necessary as my study only involves modern human hair from the scalp. Race was simply re-worded to local population. All five of my sample populations may not meet the requirement for a local population but they are closer to this definition than any vague characterization such as race. Finally, I was the analyst throughout the investigation, therefore, it was not necessary to document this information in the database.

In addition, some new attributes were added to the key as they were thought to provide further useful information. These include the following: pigment density, pigment distribution, maximum and minimum shaft diameters, shape, maximum and minimum medulla diameters, cuticle thickness, area, second color, age and sex. Most of these attributes were added because a new procedure for cross-sectioning had just been developed. Pigment density and pigment distribution were methods I devised for observing the pigment granules in each sample. Diameters of the entire hair and medulla were added as they seemed to be necessary measurements. The cuticle layer was a

feature that I was surprised to find in the cross-section image and I thought it might be an interesting feature to measure, as was the area of the entire cross-section. Age and sex of each sample was part of the descriptive information included when samples were acquired. This information was not interpreted in this study but could be useful in the future.

In the end, the pilot study confirmed that the laboratory and examination procedures I developed were appropriate for analyzing my set of data. It allowed me to select the most useful attributes based on the examination of the two small sample populations. Table 3 is a list of attributes and subattributes used in the final project, a direct result of the pilot study.

Table 3. Final list of attributes (for complete descriptions refer to the Key, Appendix A).

Accession Number
Hair Region
- Hair Region
- Cortex Features

Scale
- Scale Pattern
- Structure of the Scale Margins
- Distance Between Scale Margins (μ)
- Scale Number (scale no./40μ)

Medulla
- Medulla Pattern
- Structure of the Medulla Margins
- Maximum Medulla Width (μ)
- Medulla/Shaft Maximum Width Ratio

Cross-section
- Pigment Density
- Pigment Distribution
- Maximum Shaft Diameter (μ)
- Minimum Shaft Diameter (μ)
- Shape of the Shaft Diameter

Table 3, (Continued)

	Maximum Medulla Diameter (μ)
	Minimum Medulla Diameter (μ)
	Cuticle Thickness (μ)
	Area (μ)
Color	
	Color
	Second Color
Size	
	Length (mm)
	Maximum Shaft Width (μ)
	Weight (mg)
Comments	
	Magnification
	Local Population
	Age
	Sex

Statistical Methods

As part of my problem statement suggests, I not only aimed at developing the above methods, I also wanted to test the variability existing between the populations using these methods. Therefore, statistical analysis was performed using the program Systat version 7.0 (1997). The following measurements are computed for each attribute: number of cases, minimum and maximum measurements, median, mean, standard deviation, skewness (G1) and Kurtosis (G2). These appeared to be useful, if not now, then maybe in future investigations. The results of these measurements are presented in histograms for the total sample and for each population individually. Nominal variables are represented by tables and bar graphs. Pearsons correlation matrix was computed for the set of metric variables and cluster plots were performed in groups of two, three, four

and five. While much more in the way of statistical analysis (and other types of analysis) could have been applied, I decided it was not beneficial to do so, due to the small sample size I was utilizing. This will be discussed further in the concluding chapter.

ANALYSIS: A CASE STUDY OF HAIR FROM FIVE POPULATIONS

Data Presentation

The data are presented in this chapter, first by population and then by each attribute. As each attribute is presented, histograms and tables illustrate the results and a short discussion describes the variability between each group with relation to that particular attribute. While the data are presented here, a summary of the results is presented in the concluding chapter.

In Appendix B I present the resulting data for each of the 40 samples. (For description of codes see key, Appendix A.) Blank spaces are a result of an inability for this feature to be determined, often because it was absent. Of the 28 attributes listed in Appendix B, only 17 will be discussed in detail, resulting in a second reduction of variables. The remaining 11 attributes are descriptive (such as the accession number, local population, age, sex and hair region) or they contribute little if at all to the variability existing between the five sample populations. For example, some attributes proved not to vary within or between groups (cortex features, scale pattern, medulla pattern and structure of the medulla margins). Others varied so much within individuals as to be simply confusing and ambiguous; in fact, this includes many of my attributes so some of these will still be discussed in detail but length was eliminated on this basis. These attributes were not eliminated prior to the pilot study because it was not conclusive whether or not they were useful. It was only after the final analysis that it was confirmed that they were not useful and detailed rationale for eliminating them is discussed below.

Cortex features were observed in 39 out of 40 samples and, therefore, does not vary within or between groups except in one sample. However, I am convinced that what I've considered as cortical features were in some cases merely pigment granules. Because no clear definition or description of size of cortical fusi or ovoid bodies exists at this time, I believe it is too subjective to determine which features should be considered "cortical features" rather than pigment granules or fragments of the medulla. Until further definition of this term is discovered, it is best to avoid this attribute. From my data, I conclude that cortex features are probably not reliable criteria for separating individuals or groups.

The scale pattern too, showed little variability among and between individuals in my 40 samples. In this study, the pattern was a regular wave except in two cases where it was an irregular wave. We know that a regular wave pattern often exists toward the root end of the hair where the hair is the least mature (Robbins 1994). An irregular wave can be a result of brushing, washing, etc. This feature becomes very important at the species level where more patterns are represented but does not appear to be informative among humans.

Each sample exhibited a fragmentary medulla pattern except in the eight cases where the medulla was absent altogether (as one would expect of any human hair). In each population, at least one sample showed an absent medulla. Hausman (1925) suggests that whether or not a medulla is fragmentary or absent is probably not a result of local population variability but dependent on each hair and location on the hair. Although I observed this feature (or absence of this feature) in entire hairs, I did not always have a complete hair (especially the Sioux and Oneida samples). It is possible

that the medulla represented a different pattern in these missing fragments of hair. Again, while the medulla pattern is vital to the determination of species, it reveals little information that can be used to isolate specific human populations.

Similarly, medulla structure lends little information except at the species level. In every sample examined the structure of the medulla was straight if the medulla was present.

Only five of the 40 hair samples had a second color, occurring in three different sample populations. These colors corresponded to the group of dominant colors for each population. Therefore, I see little significance in this attribute, other than as another descriptive feature.

In an ideal world (of hair analysis) individuals would have never cut their hair since the time humans emerged. Length would then play an important role in determining population variability. As this is obviously not the case in the real world, length is yet another descriptive feature not well suited for distinguishing between populations.

While it seems some of these attributes described above could have been eliminated prior to the final investigation, I did not do so. Based on the pilot study results, I did not feel I had enough information to justify elimination of these attributes (also, as stated previously, a few of these attributes were added after the pilot study and were tested for the first time in the final investigation). Perhaps these attributes will again become important after some alteration. Due to time constraints of this project, however, they will not be analyzed further.

The attributes that proved to be useful include the following: structure of the scale margins, distance between scale margins, scale number, medulla width, medulla/shaft width ratio, pigment density, pigment distribution, maximum shaft diameter, minimum shaft diameter, shape, maximum medulla diameter, minimum medulla diameter, cuticle thickness, area, color, shaft width and weight (all are based on measurements except for structure of the scale margins, pigment density, pigment distribution, shape and color). Observations of these attributes are summarized by statistics and are presented in table format for each population sample. For further description of each attribute see Appendix A.

Data Presentation by Population

Eight types of statistical data are given for each of the 12 metric attributes for all five sample populations. These include number of cases, minimum and maximum ranges, median, mean, standard deviation, skewness and kurtosis.

Table 4. Statistical data for the five sample populations combined.

	Distance btwn Scale margins	Scale number	Medulla width	Medulla/shaft width ratio
No. of Cases	39	35	31	31
Minimum	15.120	1.000	8.968	0.122
Maximum	62.750	6.000	39.820	0.309
Median	26.140	4.000	20.840	0.218
Mean	27.857	4.171	21.023	0.217
Standard Deviation	9.959	1.098	7.092	0.049
Skewness (G1)	1.554	-0.643	0.774	0.068
Kurtosis (G2)	3.344	0.907	0.862	-0.909

Table 4, (Continued)

	Maximum shaft diameter	Minimum shaft diameter	Maximum medulla diam.	Minimum medulla diam.
No. of Cases	35	34	20	20
Minimum	74.580	62.340	3.774	3.774
Maximum	168.200	122.700	32.810	25.540
Median	119.600	91.115	19.405	12.655
Mean	117.859	92.092	17.830	13.098
Standard Deviation	20.432	13.772	7.921	5.890
Skewness (G1)	-0.099	-0.132	-0.218	0.254
Kurtosis (G2)	0.215	-0.040	-0.586	-0.384

	Cuticle thickness	Area	Shaft width	Weight
No. of Cases	18	35	39	39
Minimum	1.412	3510.000	38.880	12.500
Maximum	5.208	12238.000	136.900	139.200
Median	2.870	8558.000	94.880	71.400
Mean	2.852	8379.257	91.569	67.908
Standard Deviation	0.915	2214.457	20.780	26.979
Skewness (G1)	0.634	-0.253	-0.160	0.085
Kurtosis (G2)	1.373	-0.334	0.178	0.403

Table 5. Statistical data for Mongolian sample.

	Distance btwn Scale margins	Scale number	Medulla width	Medulla/shaft width ratio
No. of Cases	8	6	6	6
Minimum	19.070	3.000	12.610	0.156
Maximum	62.750	5.000	36.250	0.294
Median	24.365	4.500	19.210	0.216
Mean	32.234	4.333	20.668	0.218
Standard Deviation	16.209	0.816	8.426	0.053
Skewness (G1)	1.346	-0.857	1.517	0.291
Kurtosis (G2)	0.455	-0.300	2.699	-1.198

Table 5, (Continued)

	Maximum shaft diameter	Minimum shaft diameter	Maximum medulla diam.	Minimum medulla diam.
No. of Cases	5	5	1	1
Minimum	85.440	82.990	21.740	21.740
Maximum	168.200	105.000	21.740	21.740
Median	136.600	100.900	21.740	21.740
Mean	129.208	95.778	21.740	21.740
Standard Deviation	30.952	10.422	*	*
Skewness (G1)	-0.358	-0.568	*	*
Kurtosis (G2)	0.233	-2.936	*	*

	Cuticle thickness	Area	Shaft width	Weight
No. of Cases	2	5	8	8
Minimum	1.543	5419.000	66.750	31.300
Maximum	5.208	12084.000	123.200	139.200
Median	3.376	10948.000	84.145	78.100
Mean	3.376	9782.000	88.060	78.550
Standard Deviation	2.592	2626.792	20.530	32.590
Skewness (G1)	*	-1.542	0.681	0.559
Kurtosis (G2)	*	2.379	-0.699	1.052

Table 6. Statistical data for English sample.

	Distance btwn Scale margins	Scale number	Medulla width	Medulla/shaft width ratio
No. of Cases	8	8	5	5
Minimum	17.250	3.000	8.968	0.156
Maximum	34.810	5.000	18.430	0.239
Median	29.150	3.000	17.200	0.175
Mean	27.749	3.500	14.946	0.184
Standard Deviation	5.547	0.756	3.954	0.032
Skewness (G1)	-0.945	1.323	-1.054	1.741
Kurtosis (G2)	0.747	0.875	-0.346	3.394

Table 6, (Continued)

	Maximum shaft diameter	Minimum shaft diameter	Maximum medulla diam.	Minimum medulla diam.
No. of Cases	8	7	3	3
Minimum	74.580	62.340	3.774	3.774
Maximum	135.700	92.500	20.700	8.827
Median	108.930	78.700	8.089	6.682
Mean	108.594	78.097	10.854	6.428
Standard Deviation	20.565	12.578	8.795	2.536
Skewness (G1)	-0.323	-0.221	*	*
Kurtosis (G2)	-0.859	-1.587	*	*

	Cuticle thickness	Area	Shaft width	Weight
No. of Cases	4	8	7	8
Minimum	2.307	3510.000	51.310	12.500
Maximum	3.044	8844.000	103.200	83.000
Median	2.537	6737.000	77.080	41.000
Mean	2.606	6681.125	78.433 7	48.188
Standard Deviation	0.323	2000.387	17.255	23.654
Skewness (G1)	1.031	-0.350	-0.067	0.132
Kurtosis (G2)	0.522	-1.206	-0.126	-0.958

Table 7. Statistical data for Vietnamese sample.

	Distance btwn Scale margins	Scale number	Medulla width	Medulla/shaft width ratio
No. of Cases	8	8	7	7
Minimum	17.200	4.000	15.020	0.148
Maximum	34.530	6.000	39.820	0.291
Median	22.935	5.000	21.640	0.228
Mean	23.952	5.000	23.474	0.226
Standard Deviation	6.498	0.926	8.779	0.049
Skewness (G1)	0.707	0.000	1.238	-0.353
Kurtosis (G2)	-0.830	-2.100	0.997	-0.386

Table 7, (Continued)

	Maximum shaft diameter	Minimum shaft diameter	Maximum medulla diam.	Minimum medulla diam.
No. of Cases	8	8	6	6
Minimum	105.800	88.630	10.490	10.490
Maximum	150.100	110.700	26.090	19.170
Median	121.350	100.950	20.410	12.655
Mean	123.088	100.354	19.182	13.782
Standard Deviation	15.075	7.619	5.526	3.461
Skewness (G1)	0.607	-0.516	-0.580	0.869
Kurtosis (G2)	-0.083	-0.505	-0.031	-0.825

	Cuticle thickness	Area	Shaft width	Weight
No. of Cases	4	8	8	8
Minimum	2.053	7186.000	68.890	36.600
Maximum	3.515	11974.000	136.900	119.000
Median	3.323	9013.000	95.890	78.950
Mean	3.054	9261.000	99.100	76.512
Standard Deviation	0.675	1375.051	21.434	24.849
Skewness (G1)	-1.862	1.106	0.373	0.026
Kurtosis (G2)	3.553	1.095	0.277	0.678

Table 8. Statistical data for Sioux sample.

	Distance btwn Scale margins	Scale number	Medulla width	Medulla/shaft width ratio
No. of Cases	7	7	7	7
Minimum	15.120	1.000	15.120	0.170
Maximum	47.450	5.000	26.490	0.309
Median	23.380	4.000	23.450	0.222
Mean	27.829	3.714	22.883	0.230
Standard Deviation	11.017	1.604	3.917	0.049
Skewness (G1)	1.062	-1.053	-1.516	0.344
Kurtosis (G2)	0.510	-0.380	2.382	-0.568

Table 8, (Continued)

	Maximum shaft diameter	Minimum shaft diameter	Maximum medulla diam.	Minimum medulla diam.
No. of Cases	8	8	6	6
Minimum	78.240	76.580	4.530	3.833
Maximum	134.600	122.700	32.810	25.540
Median	119.350	92.620	20.715	15.200
Mean	113.945	95.104	18.976	14.326
Standard Deviation	20.705	16.130	10.700	8.132
Skewness (G1)	-0.966	0.599	-0.257	-0.045
Kurtosis (G2)	-0.371	-0.533	-1.167	-0.997

	Cuticle thickness	Area	Shaft width	Weight
No. of Cases	4	8	8	8
Minimum	1.713	4622.00	38.880	12.500
Maximum	3.806	12238.000	117.000	99.400
Median	3.194	8482.500	99.895	75.000
Mean	2.977	8409.375	92.643	68.700
Standard Deviation	0.933	2696.875	24.094	28.606
Skewness (G1)	-1.044	-0.043	-1.847	-1.183
Kurtosis (G2)	0.207	-0.851	4.046	1.206

Table 9. Statistical data for Oneida sample.

	Distance btwn Scale margins	Scale number	Medulla width	Medulla/shaft width ratio
No. of Cases	8	6	6	6
Minimum	15.280	4.000	9.662	0.122
Maximum	38.510	5.000	32.970	0.281
Median	28.565	4.000	21.395	0.228
Mean	27.519	4.333	21.412	0.217
Standard Deviation	7.694	0.516	7.538	0.058
Skewness (G1)	-0.560	0.968	-0.052	-0.818
Kurtosis (G2)	-0.185	-1.875	1.767	0.192

Table 9, (Continued)

	Maximum shaft diameter	Minimum shaft diameter	Maximum medulla diam.	Minimum medulla diam.
No. of Cases	6	6	4	4
Minimum	97.720	80.480	11.300	9.734
Maximum	143.100	110.300	27.170	16.610
Median	119.950	87.985	17.445	12.970
Mean	119.003	90.315	18.340	13.071
Standard Deviation	15.029	10.692	6.608	3.449
Skewness (G1)	0.341	1.610	0.770	0.057
Kurtosis (G2)	1.261	2.982	1.443	-5.168

	Cuticle thickness	Area	Shaft width	Weight
No. of Cases	4	6	8	7
Minimum	1.412	6149.000	76.220	49.600
Maximum	3.117	9320.000	130.300	95.100
Median	2.755	8705.500	97.755	62.500
Mean	2.510	8258.667	97.967	67.543
Standard Deviation	0.759	1244.961	18.111	16.537
Skewness (G1)	-1.588	-1.151	0.553	0.543
Kurtosis (G2)	2.629	0.363	-0.092	-0.256

Data Presentation by Attribute

Structure of the Scale Margins

Table 10 gives the percent of each sample population with a smooth, intermediate or rippled structure. These results are further illustrated in the following bar graphs. Note that abbreviations are given for each population, eng is English, mon is Mongolian, one is Oneida, sio is Sioux and vie is Vietnamese. Refer to Appendix A for attribute definitions. A smooth scale margin (1.0 in Fig. 9) was the least dominant among and

between the five sample populations. The English and Oneida samples did not have hair samples exhibiting a smooth pattern. Intermediate patterns (2.0) were the modal pattern in both English (87.5%) and Vietnamese (62.5%) samples. The Oneida (87.5%) were largely rippled (3.0). The Mongolian, Sioux and Vietnamese revealed cases with all three patterns. See Fig. 10 for image examples, Mongolian (11), English (14), Vietnamese (10B), Sioux (02D), and Oneida (03). This feature could be a function of the region of hair present or the daily trauma exerted on the hair.

Table 10. Percent of sample populations with smooth, intermediate and rippled structures of the scale margins.

	Mongolian		English		Vietnamese		Sioux		Oneida	
	#	%	#	%	#	%	#	%	#	%
1. Smooth	1	12.5			1	12.5	2	28.5		
2. Intermediate	3	37.5	7	87.5	5	62.5	2	28.5	1	12.5
3. Rippled	4	50	1	12.5	2	25	3	42.8	7	87.5
Totals	8	100	8	100	8	100	7	99.8	8	100

Distance Between Scale Margins

When all populations were considered the distance between scale margins for the combined samples was skewed to the right (Fig. 11) with the mean at 27.857 and median at 26.140 (Table 4). Each sample population had a mean and median relatively close to the overall mean and median. There was a great deal of overlap between the five populations. However, the Mongolian sample was the only one with cases above 50. See Fig. 10 for image example.

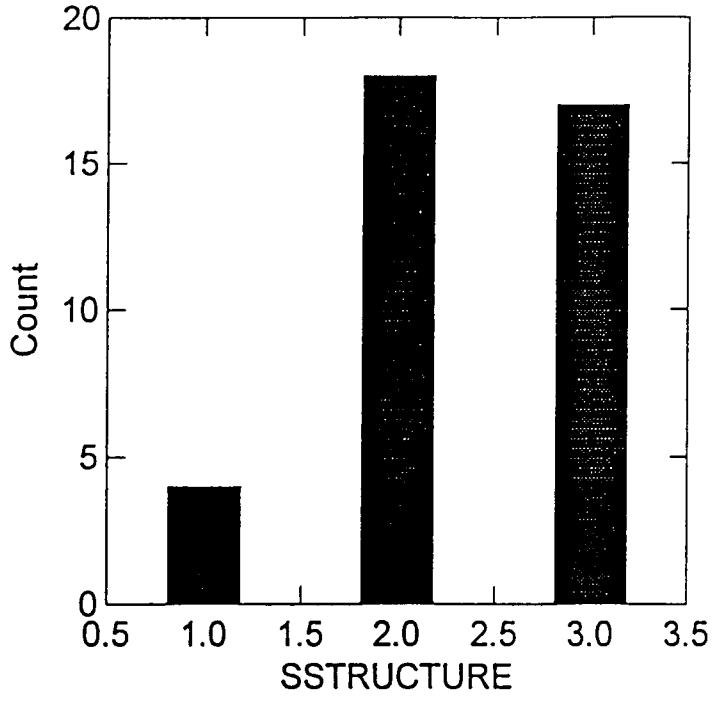
Scale Number

The histogram of the combined populations was skewed slightly to the left (Fig. 12) with a mean of 4.171 and a median of 4.000 (Table 4). The samples that showed the most deviance from the combined were the English with a mean of 3.500 and a median of 3.000 (Table 6), and the Vietnamese with a mean and median of 5.000 (Table 7). Only the Sioux had samples with a scale number less than two, and only the Vietnamese had samples with a scale number greater than five. This variable and the distance between scale margins showed an inverse relationship (as one increases the other decreases) as one would expect.

Medulla Width

The combined sample (Fig.13) showed an approximately normal curve with a slight skew to the right (mean is 21.023 and median is 20.840 as listed in Table 4). The English sample was the only sample with a significantly lower mean and median at 14.946 and 17.200 (Table 6), respectively and the medulla width never exceeded 20. Fig. 14 shows image examples of the variability between medulla widths for four of the populations, Mongolian (31), English (24), Vietnamese (35), and Oneida (33D). Medulla width was highly correlated to the shaft width, the medulla/shaft ratio, weight, maximum shaft diameter and area.

Fig. 9. Bar graphs of structure of the scale margins.



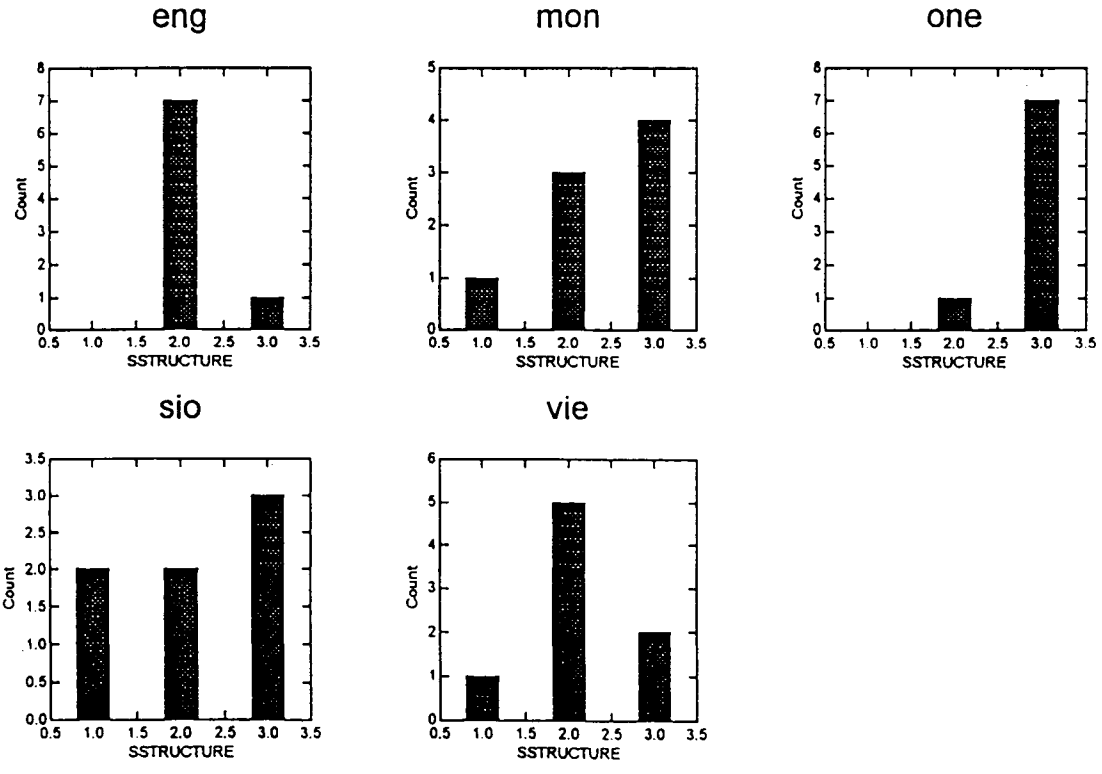
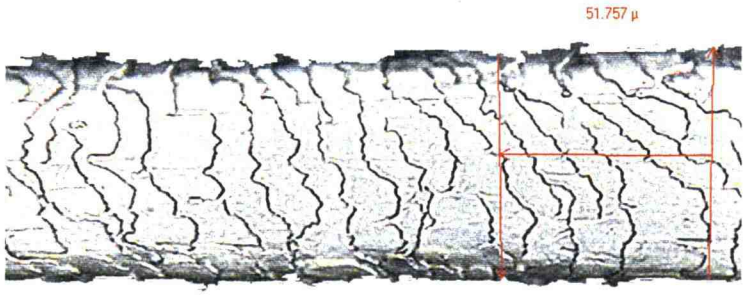
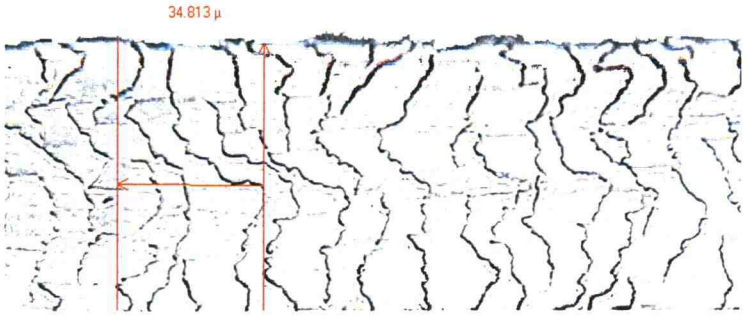


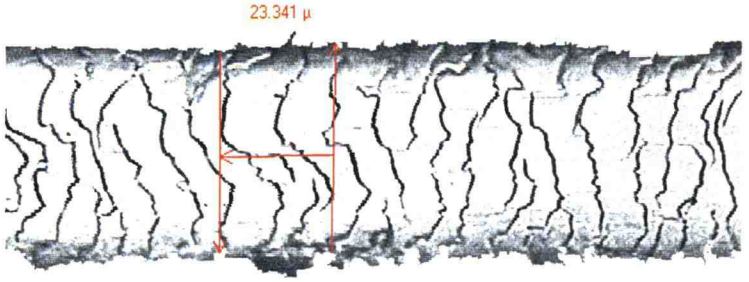
Fig. 10. Example of images showing variability between structures of the scale margins.



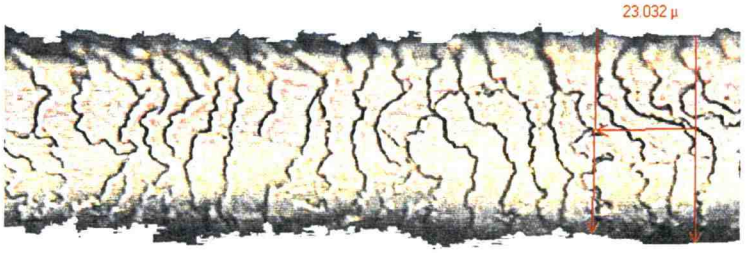
(11)



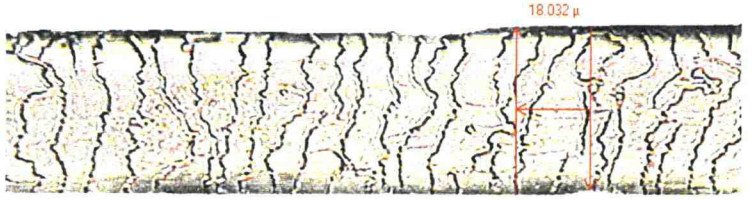
(14)



(10B)

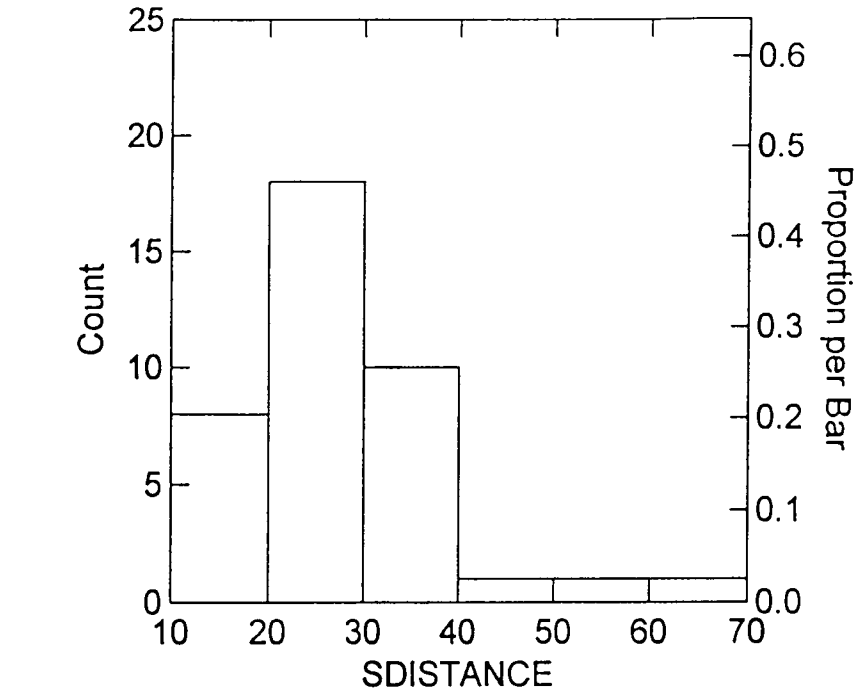


(02D)



(03)

Fig. 11. Histogram of distance between scale margins.



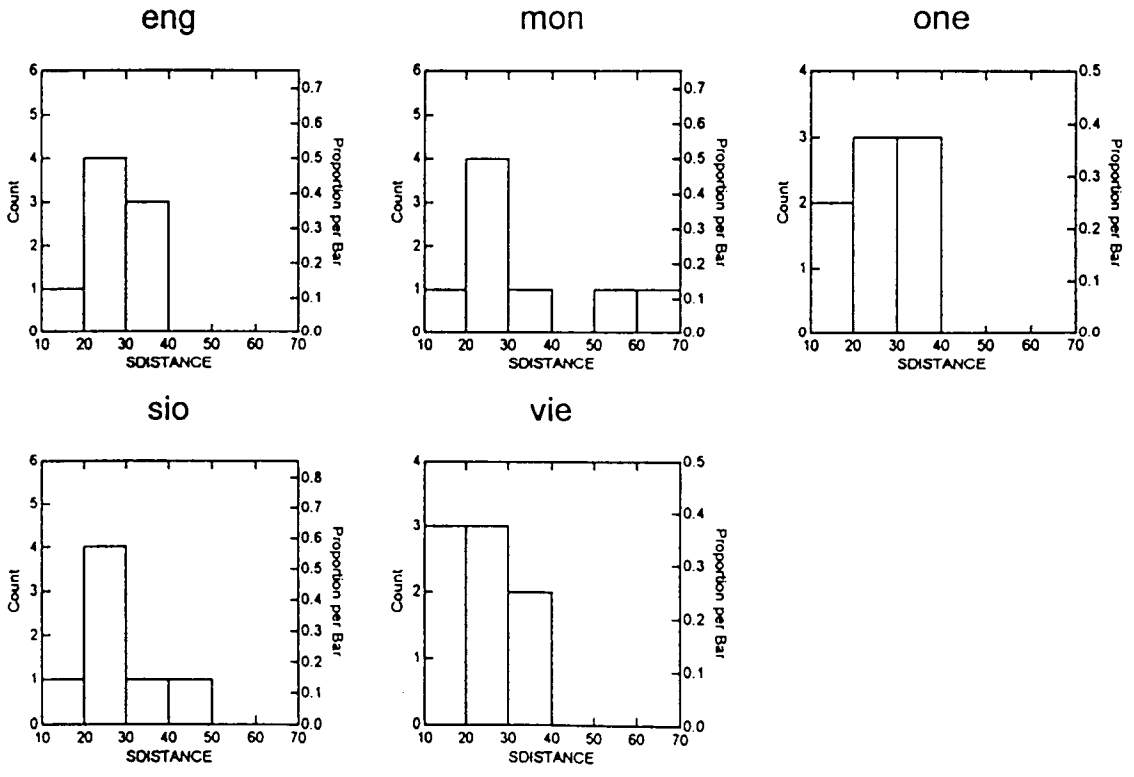
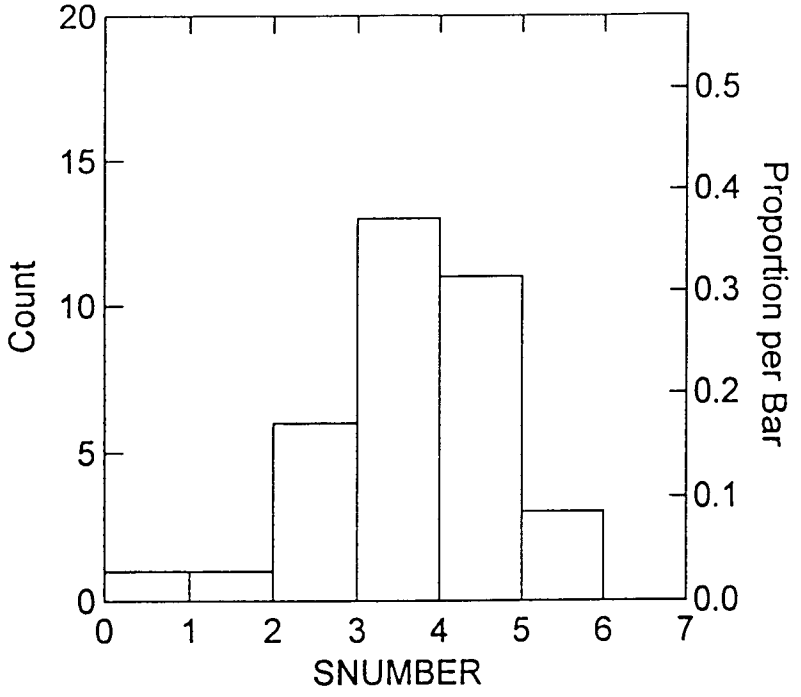
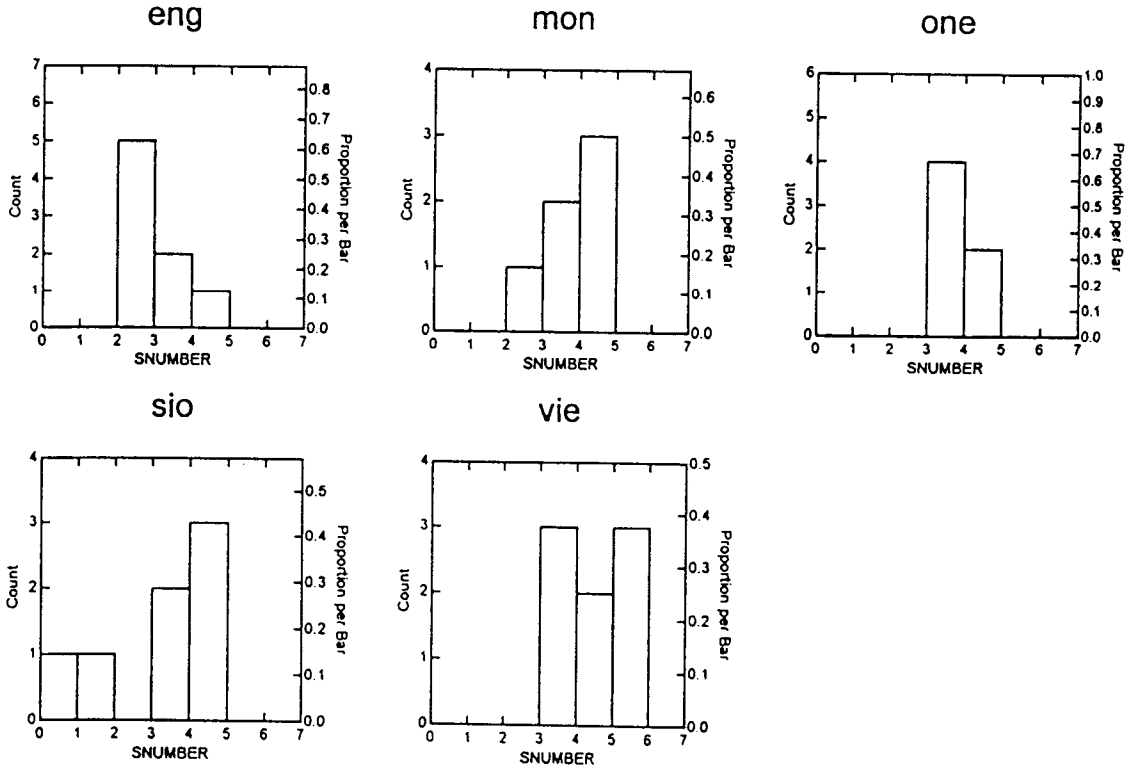


Fig. 12. Histograms of scale number.





Medulla/Shaft Width Ratio

A function of the medulla and shaft widths, the ratio confirmed the overall smaller size of the English samples with a mean of .184 and median of .175 (Table 6). There was a great deal of overlap in ratios between populations (Fig.15).

Pigment Density

Table 11. Percent of sample populations with dense, intermediate and sparse pigment.

	Mongolian		English		Vietnamese		Sioux		Oneida	
	#	%	#	%	#	%	#	%	#	%
1. Dense	2	40			2	25	1	12.5		
2. Intermediate	3	60	3	37.5	6	75	6	75	2	33
3. Sparse			5	62.5			1	12.5	4	67
Totals	5	100	8	100	8	100	8	100	6	100

It can be seen in the bar graph (Fig. 16 and Table 11) that the majority of samples exhibited an intermediate degree of pigment density followed by sparse and then dense (cdt and ndt indicate that there was no data for this trait and can be ignored in this and the following attribute). The Mongolian, Vietnamese and Sioux samples were mainly intermediate and the Mongolian and Vietnamese lacked any samples with sparse pigmentation. Similarly, as might be expected, the English and the Oneida samples lacked hairs with dense pigmentation and were mainly of sparse pigmentation. Fig. 17 showed examples of the variability of pigment densities between the five populations, Mongolian (01D), English (24), Vietnamese (40), Sioux (07D), and Oneida (33D).

Pigment Distribution

Table 12. Percent of sample populations with pigment distributed in units 1, 2 and 3.

	Mongolian		English		Vietnamese		Sioux		Oneida	
	#	%	#	%	#	%	#	%	#	%
1. Unit 1			1	20					1	20
2. Unit 2							1	33.3		
3. Unit 3	3	100	4	80	5	100	2	66.6	4	80
Totals	3	100	5	100	5	100	3	100	5	100

The majority of pigment granules were concentrated in the outer unit of the cross-section (unit 3) for each sample population and the combined sample populations (Fig. 18 and Table 12). The Mongolian and Vietnamese were 100% in unit 3, while the English and Oneida were 80% in unit 3 and 20% in unit 1. The Sioux sample was the only one with a hair revealing a concentration of pigment in unit 2.

Maximum Shaft Diameter

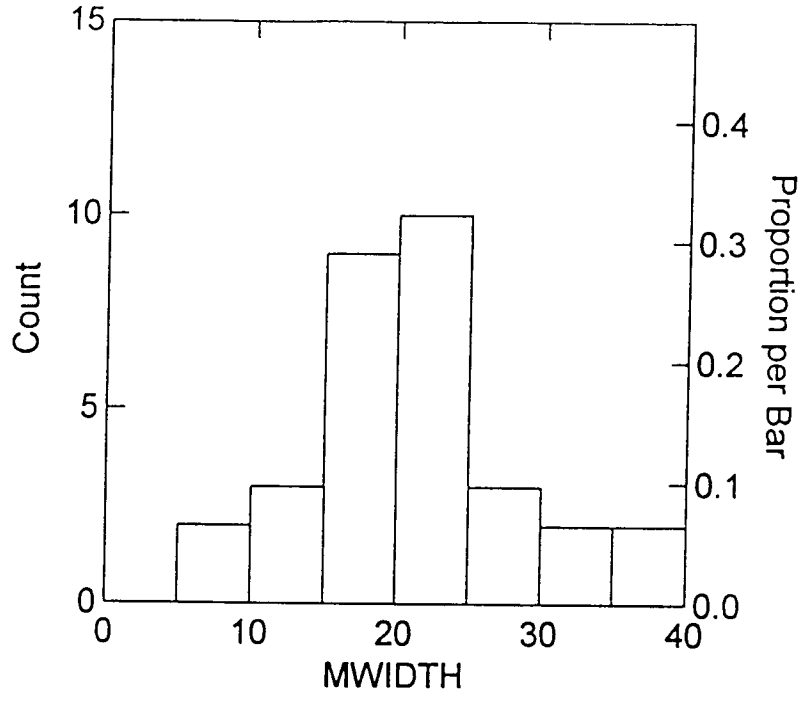
The histogram for the combined samples illustrated an approximately normal curve (Fig. 19). The overall mean was 117.859 and median was 119.600 (Table 4). Again the English showed the largest deviation from the combined with a mean of 108.594 and median of 108.930 (Table 6). The Mongolian sample was at the other end of the continuum with a mean of 129.208, median of 136.600 (Table 5), followed by the Vietnamese. The Vietnamese were the only population exceeding 150. These findings

are in accordance with Hrdy (1973), who found hair of the Ifugao (Philippines), Sioux and Japanese was significantly larger in diameter than the hair of the Bougainville and Malaita (Soloman Islands), east Africans and northwest Europeans. See Fig. 17 for image examples showing variability between maximum shaft diameters.

Minimum Shaft Diameter

The overall shaft diameter (Fig. 20) revealed a bimodal curve with peaks at approximately 85 and 105 (the mean was 92.092 and median was 91.115). As expected, the English strayed the most from the combined with a mean of 78.097, median of 78.700 (Table 6). The English never exceeded 100, as the other four populations did, and they were the only one that had samples below 70. The Mongolian were the highest at 100.900 and 105.000 (Table 5), respectively, followed closely by the Vietnamese. The minimum shaft diameter was highly correlated to the minimum medulla diameter and area. See Fig. 17 for image examples showing variability between minimum shaft diameters.

Fig. 13. Histogram of medulla width.



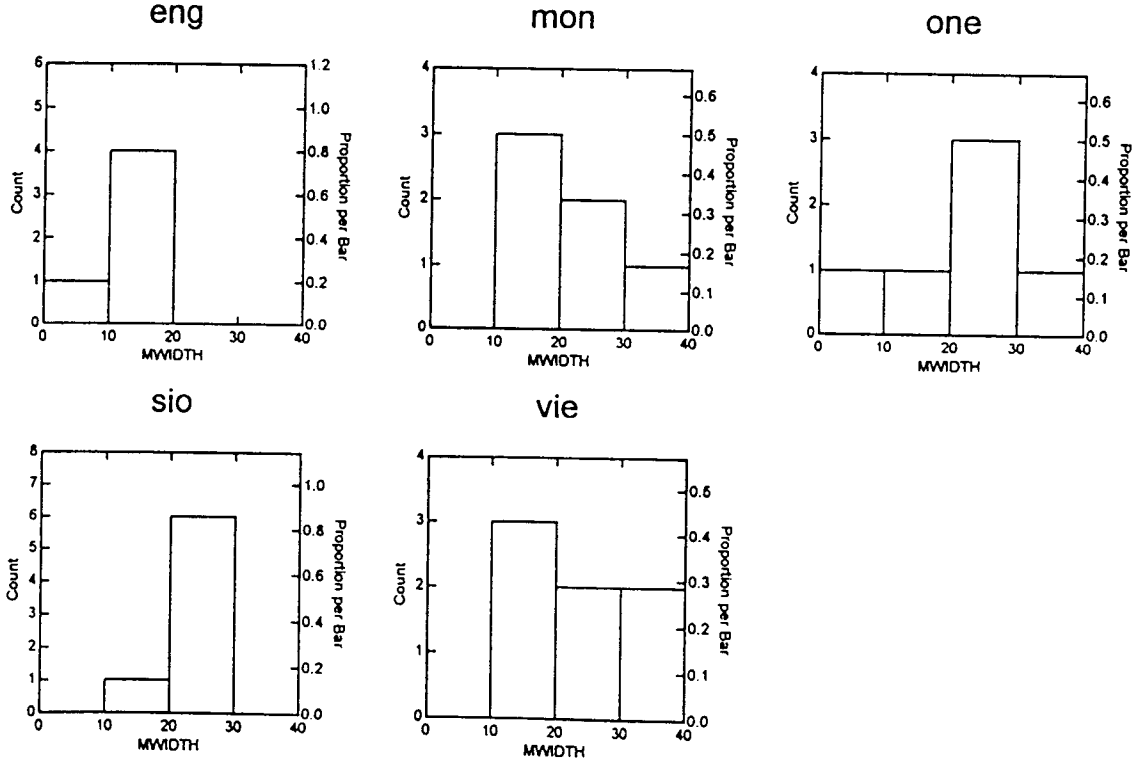
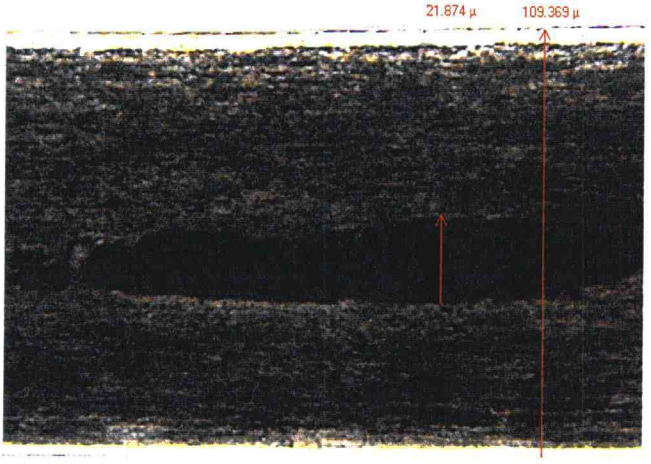
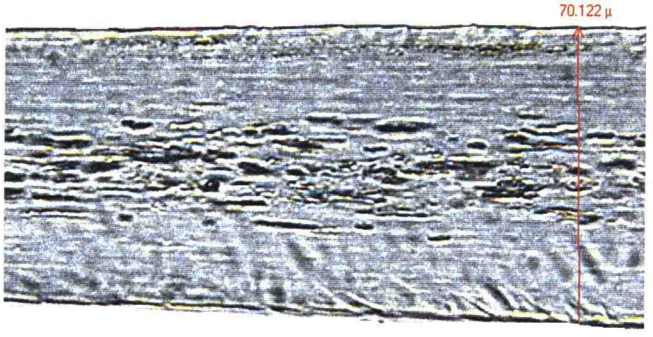


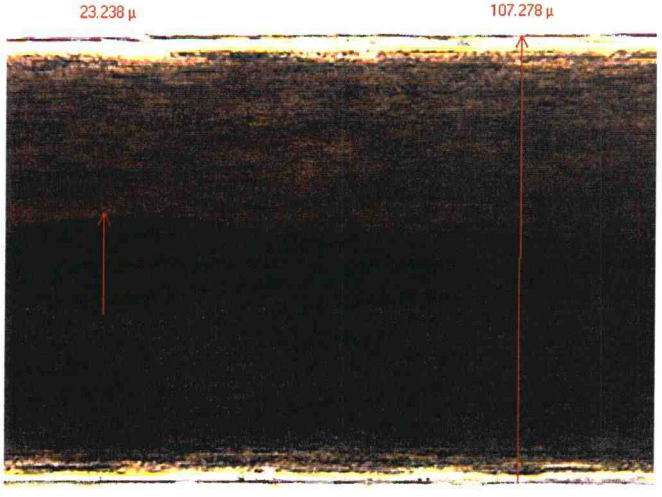
Fig. 14. Example of images showing variability between medulla widths.



(36B)

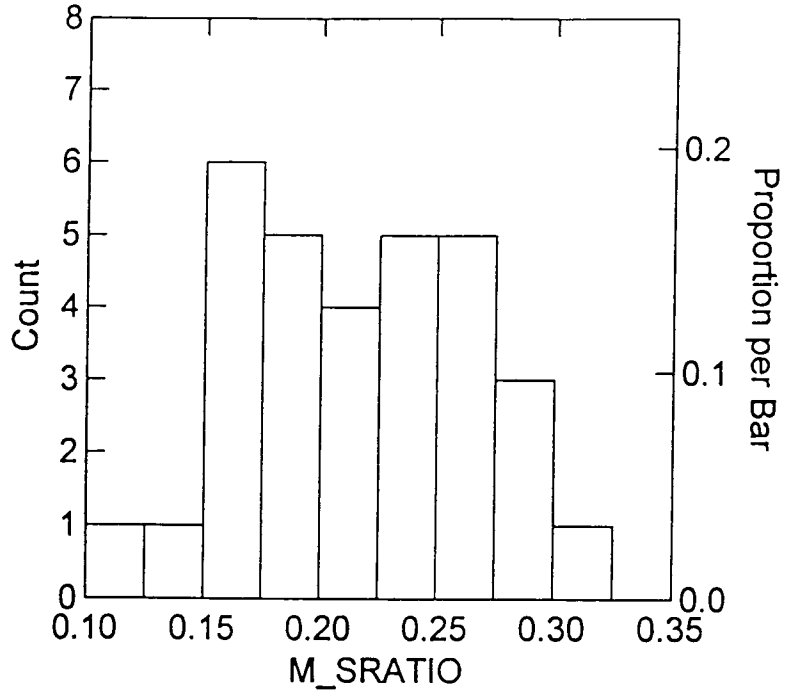


(34C)



(02D)

Fig. 15. Histogram of medulla/shaft width ratio.



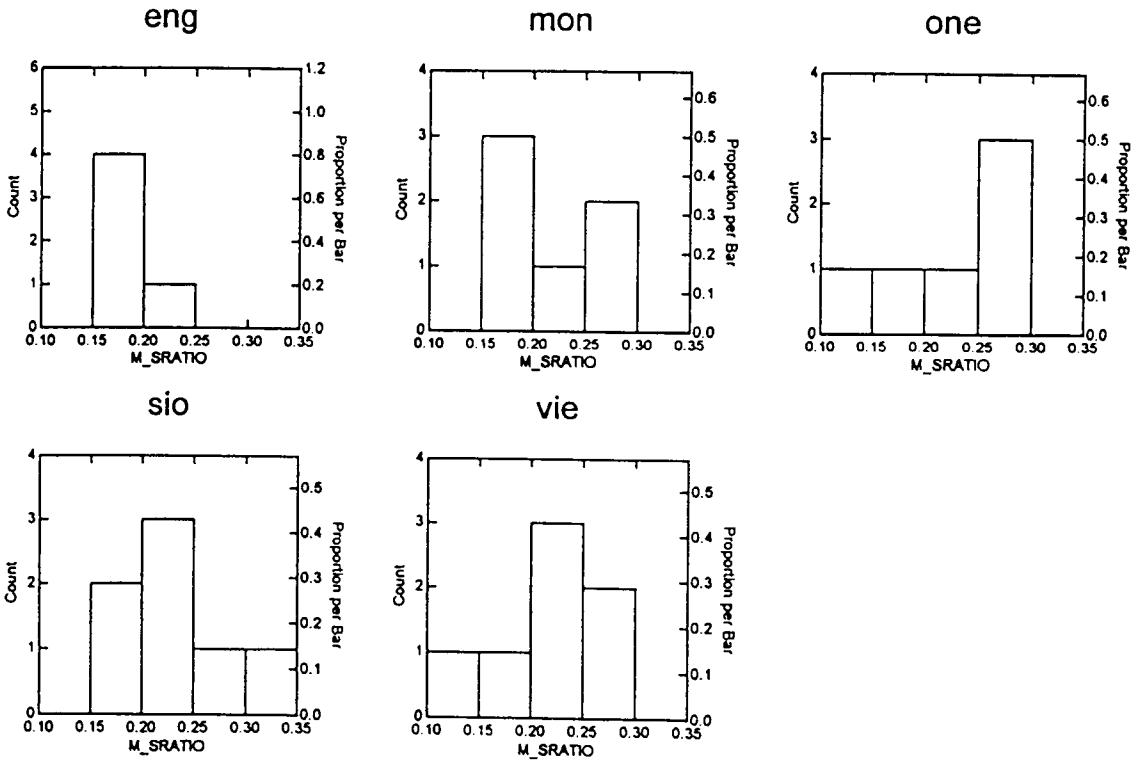


Fig. 16. Bar graphs of pigment density.

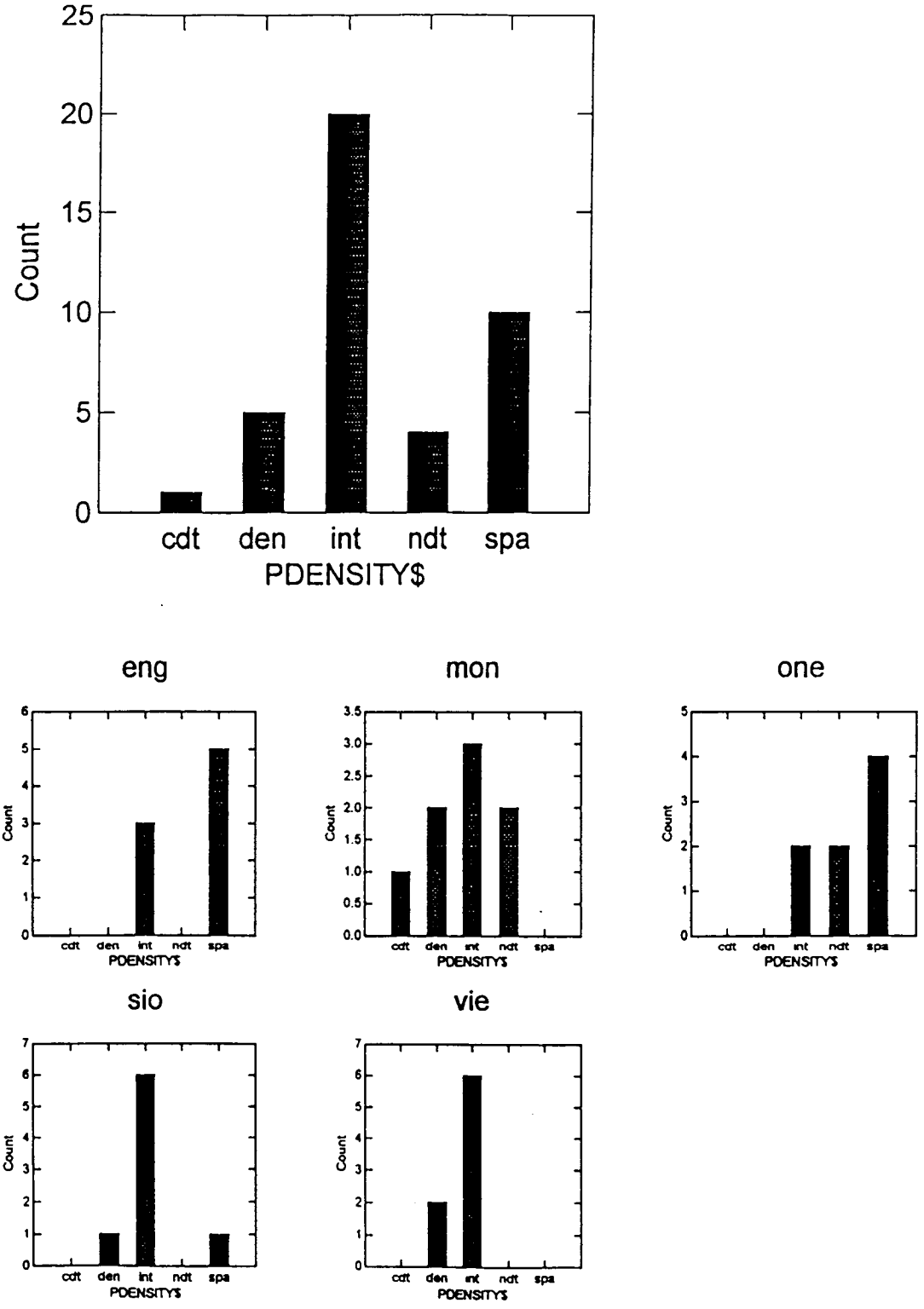
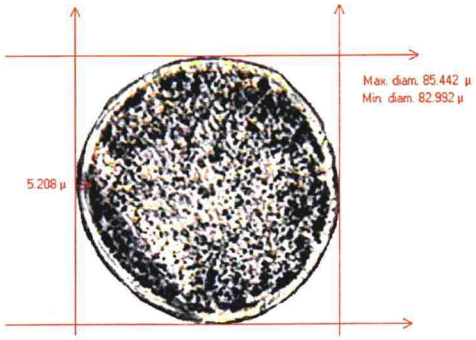
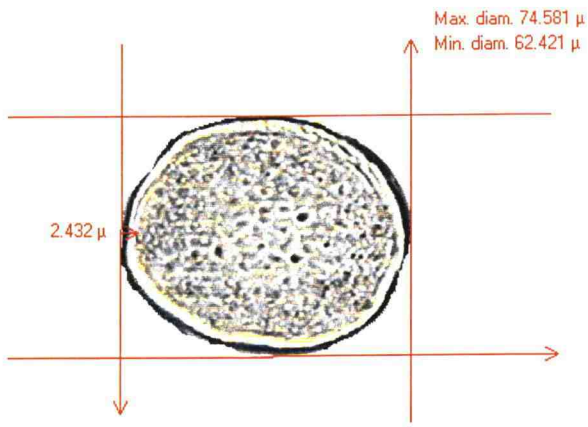


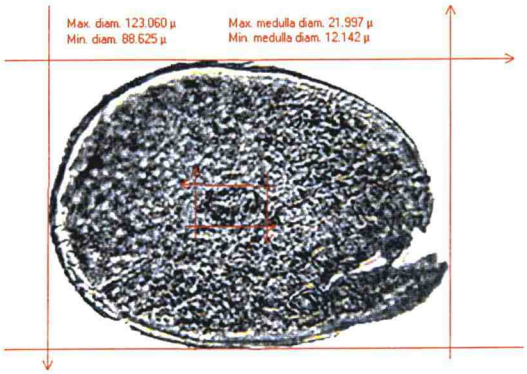
Fig. 17. Example of images showing variability between pigment densities.



(01D)

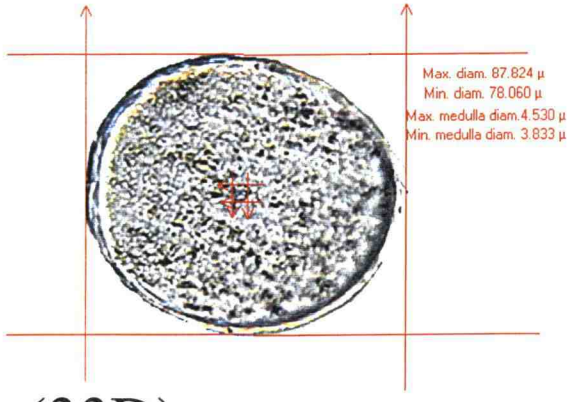
(24)





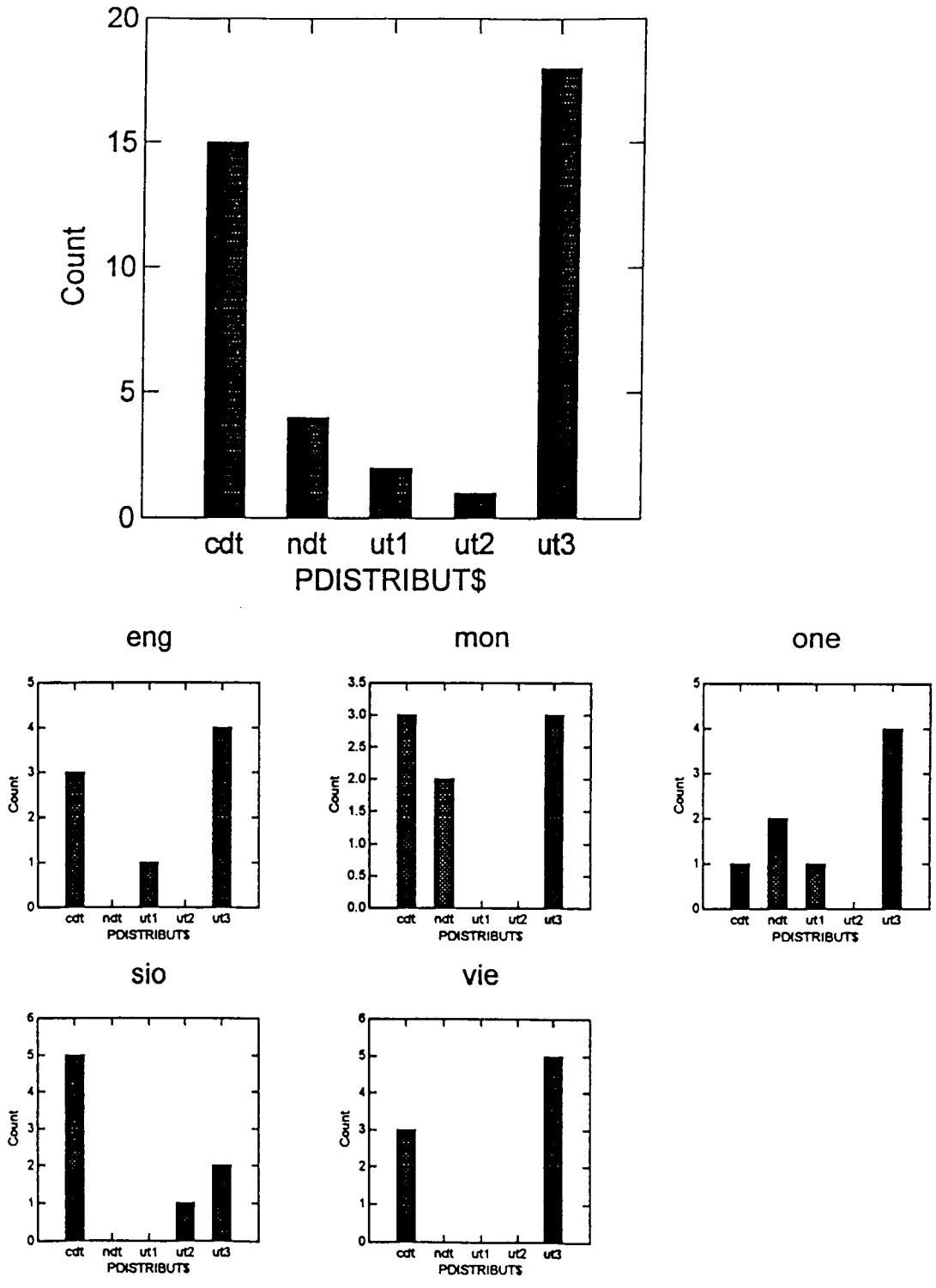
(40)

(07D)



(33D)

Fig. 18. Bar graphs of pigment distribution.



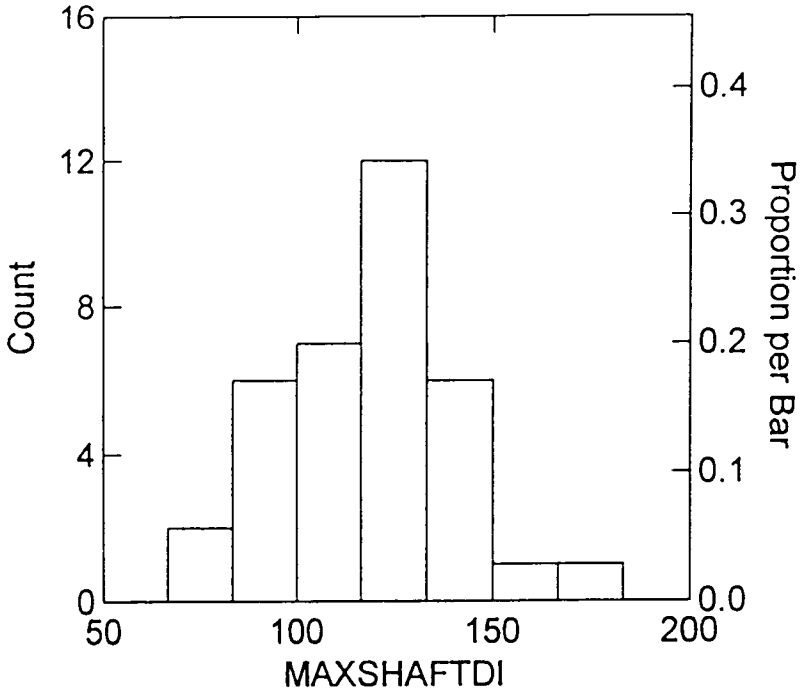
Shape

Table 13. Percent of sample populations with circular, oval, oblong, triconcave, carved and concavo-convex shapes.

	Mongolian		English		Vietnamese		Sioux		Oneida	
	#	%	#	%	#	%	#	%	#	%
1. Circular	2	40	3	37.5	3	37.5	5	62.5	2	33.3
2. Oval	2	40	3	37.5	3	37.5	3	37.5	3	50
3. Oblong	1	20								
4. Triconcave			2	25						
5. Carved					2	25				
6. Concavo-convex									1	16.7
Totals	5	100	8	100	8	100	8	100	6	100

The dominant shapes for all sample populations were circular and oval (Fig. 21 and Table 13). The Mongolian, English and Vietnamese were split evenly between these two shapes. The Sioux were more circular and the Oneida were more oval. According to many early theories, an oval cross-section is more common in whites and circular in Native Americans, though the results here do not necessarily support that theory. Four other shapes appeared in very small degrees but not in any determinable pattern. Again, there was a great deal of overlap between groups.

Fig. 19. Histograms of maximum shaft diameter.



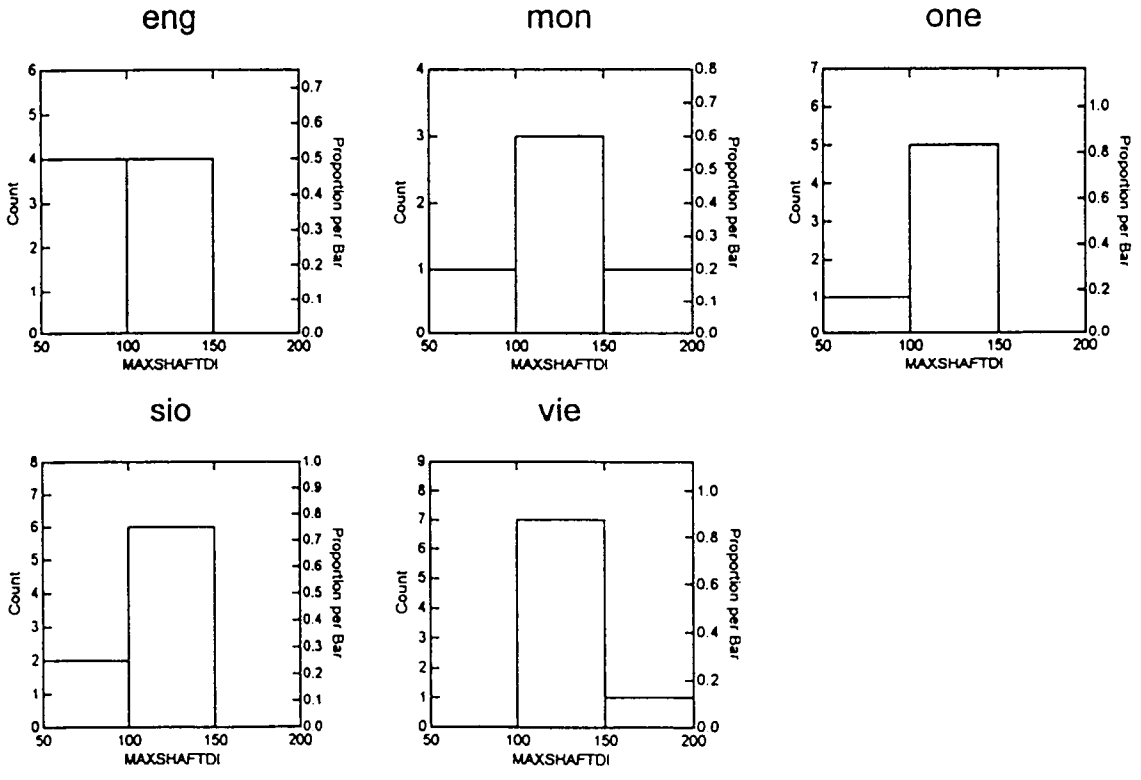


Fig. 20. Histograms of minimum shaft diameter.

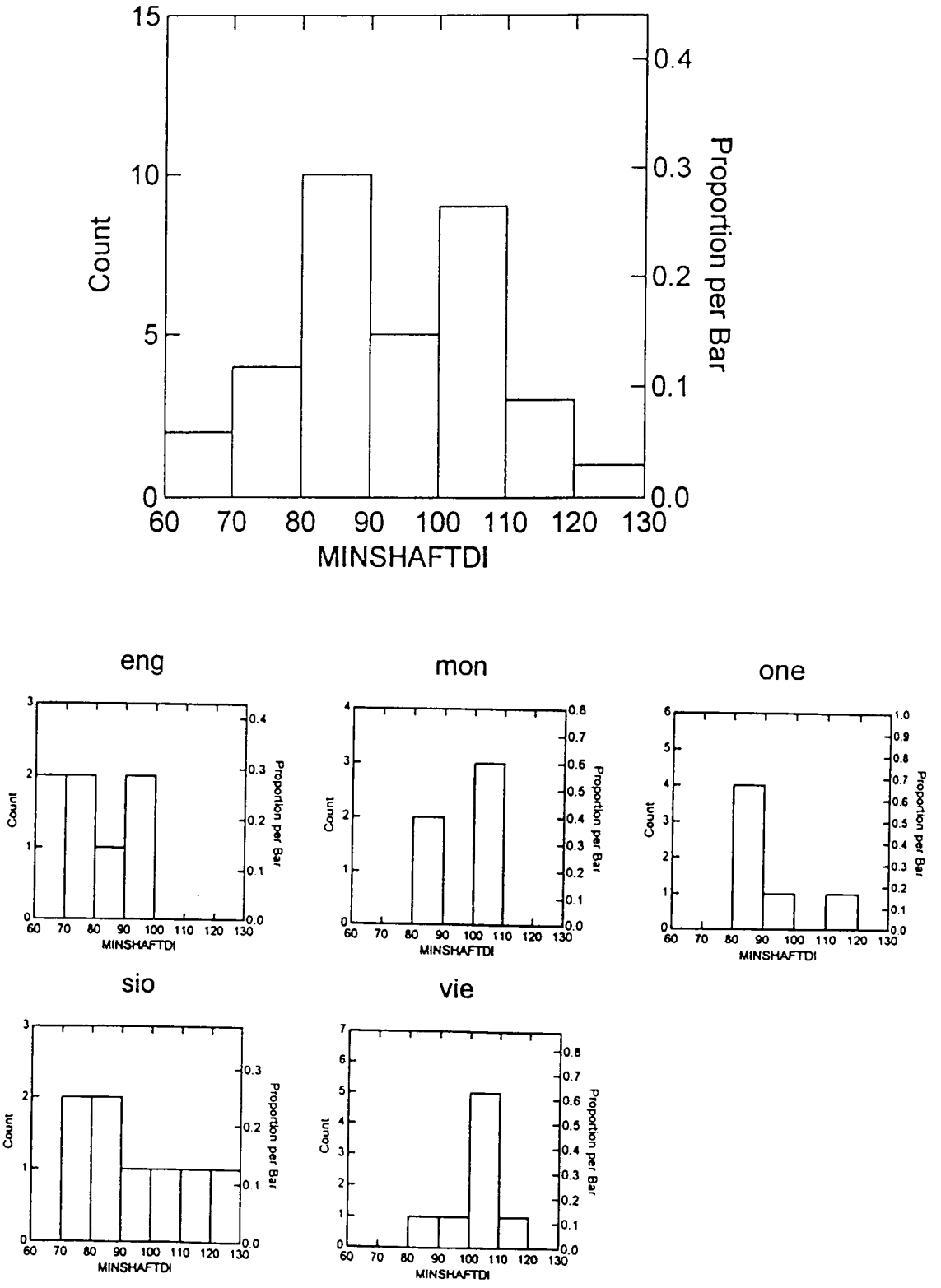
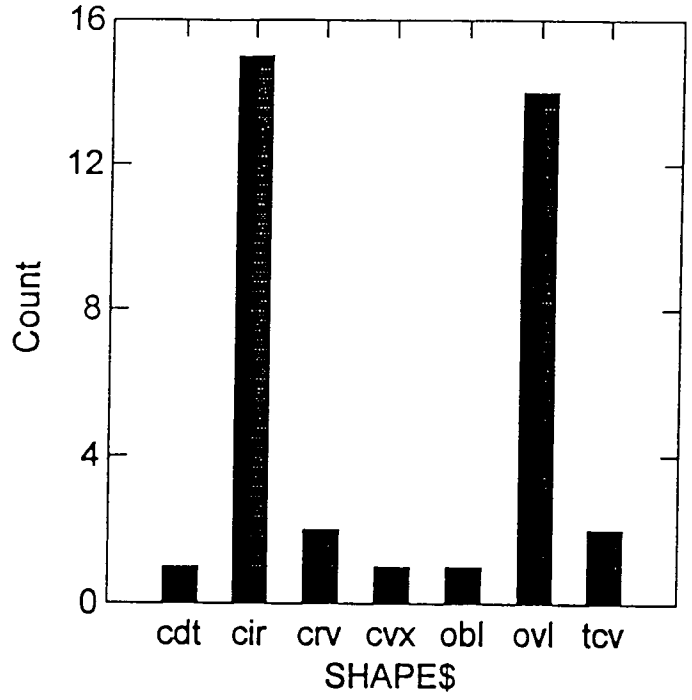
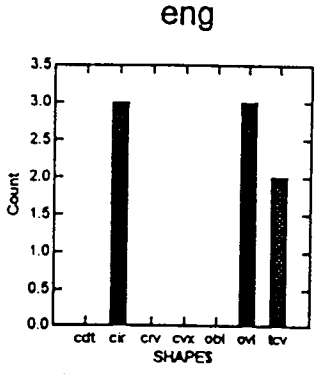
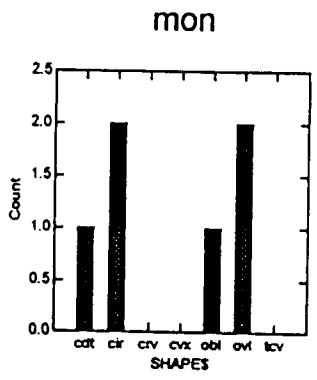
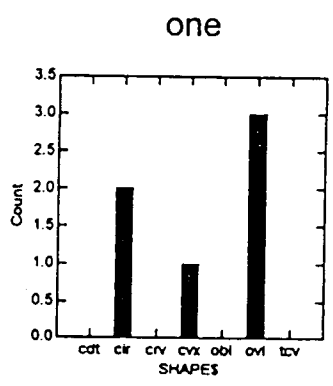


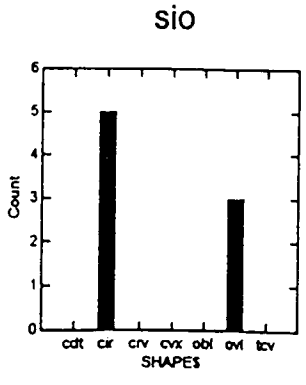
Fig. 21. Bar graphs of shape.

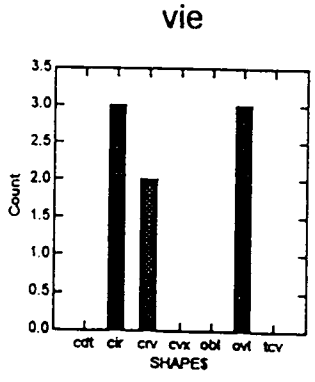












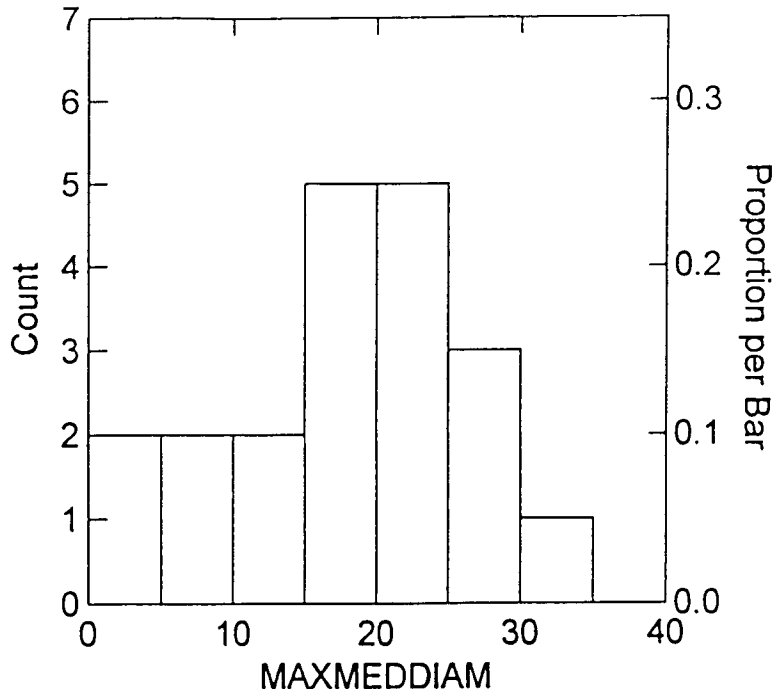
Maximum Medulla Diameter

The combined sample populations had a mean maximum medulla diameter of 17.830 and median of 19.405 (Table 4). Each sample population was relatively close to this except the English with a mean of 10.854 and median of 8.089 (Table 6). Only the Sioux had a sample of a medulla width greater than 30 (Fig. 22). It is important to keep in mind the low case numbers (especially the Mongolian sample) in this and the following variable, as many medullas were absent in cross-section. See Fig. 17 for image examples showing variability between maximum medulla diameters.

Minimum Medulla Diameter

Overall mean of the minimum medulla diameter was 13.098 and median was 12.655 (Table 4). The English was much lower with a mean of 6.428 and median of 6.682 (Table 6). Unlike the other four populations, all of the English had a minimum medulla diameter lower than 10. Only the Mongolian and Sioux exceeded 20 (Fig. 23). See Fig. 17 for image examples showing variability between minimum medulla diameters.

Fig. 22. Histograms of maximum medulla diameter.



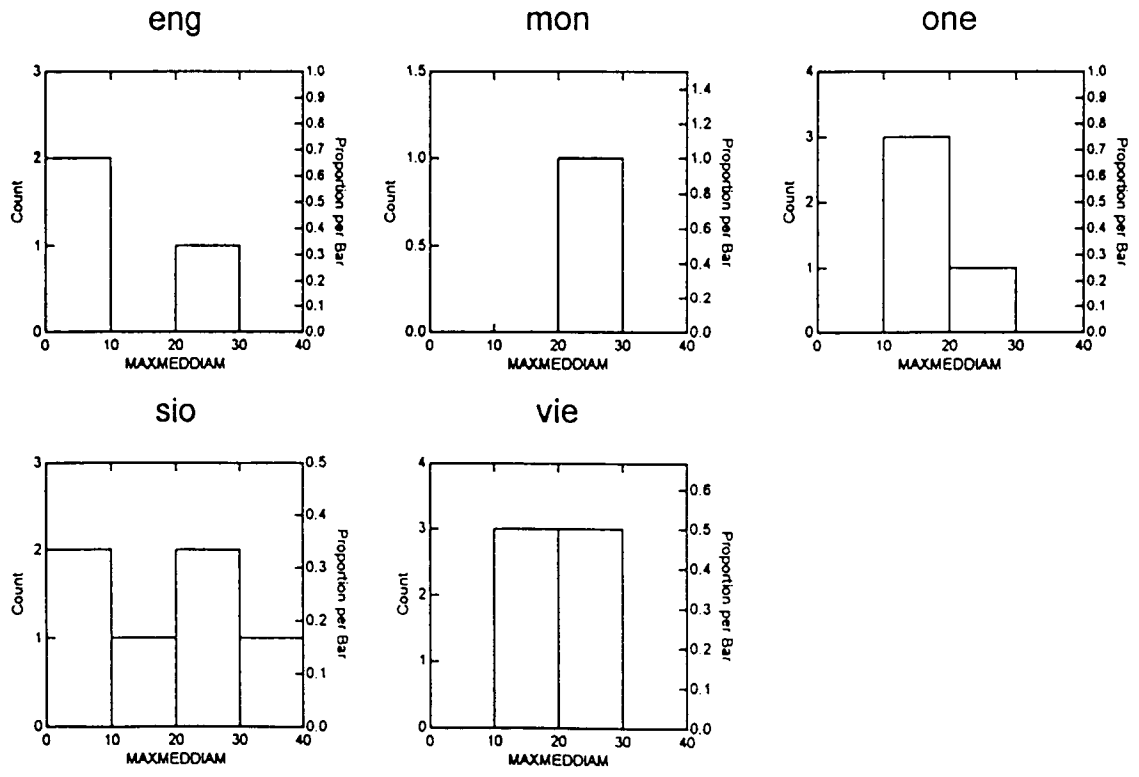
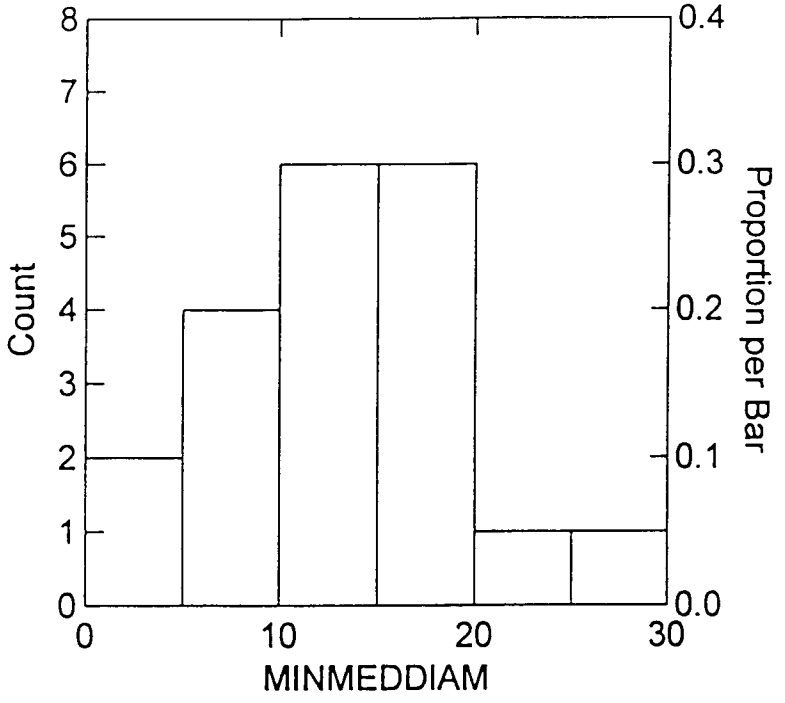


Fig. 23. Histograms of minimum medulla diameter.



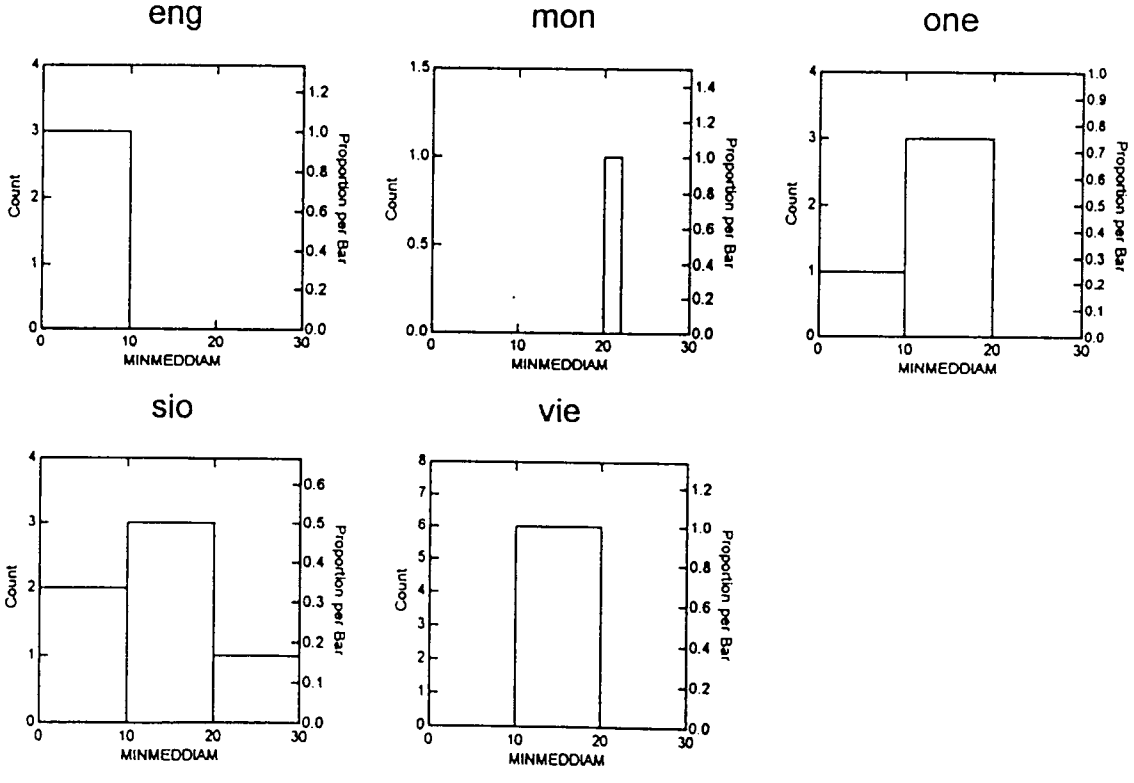
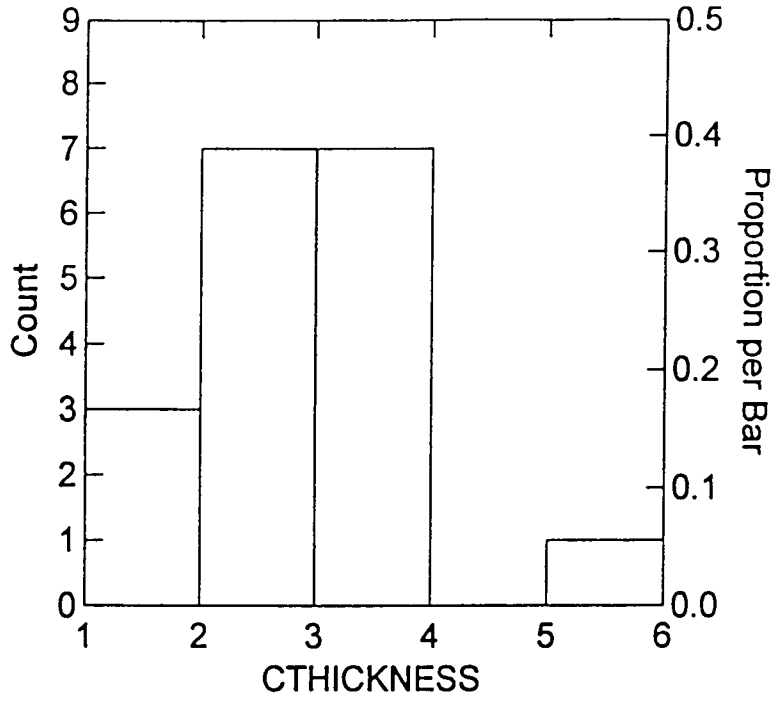
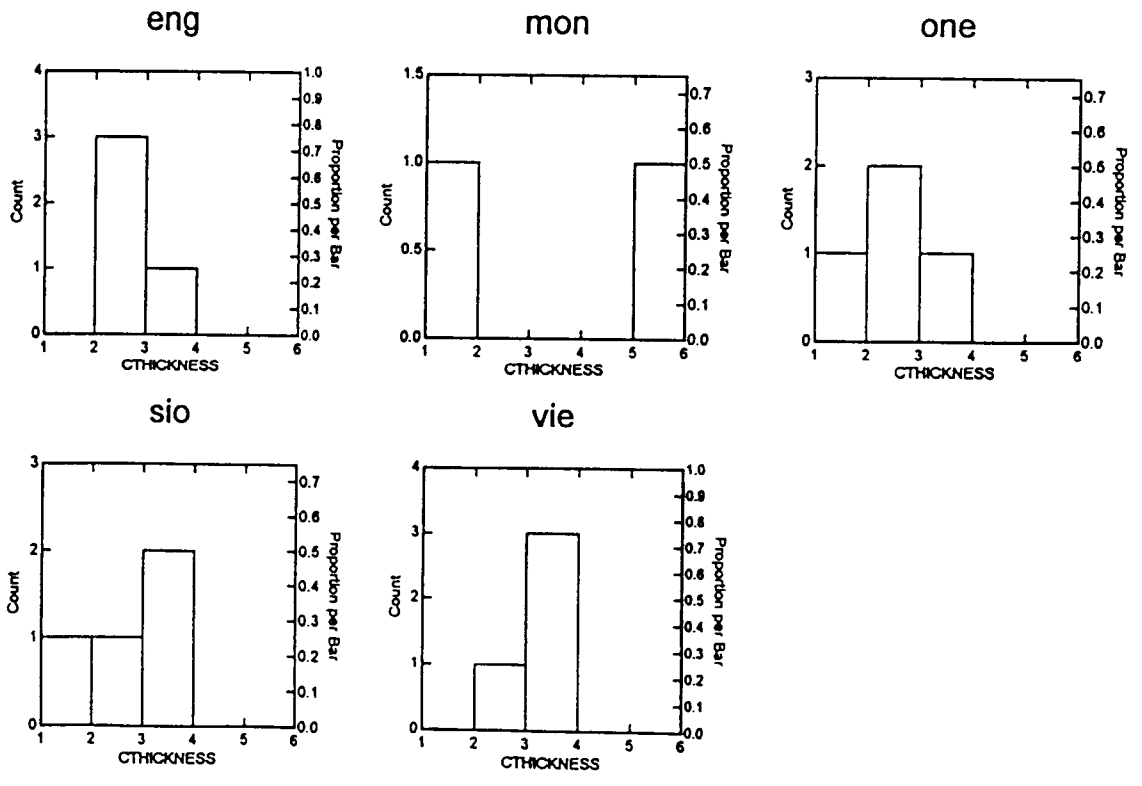


Fig. 24. Histograms of cuticle thickness.





Cuticle Thickness

Cuticle thickness tended to be 2.852, mean and 2.870, median (Table 4). Again, case numbers are low, but still the measurement was highest in the Mongolian sample (mean and median is 3.376, Table 5), with a cuticle thickness above four (Fig. 24).

Area

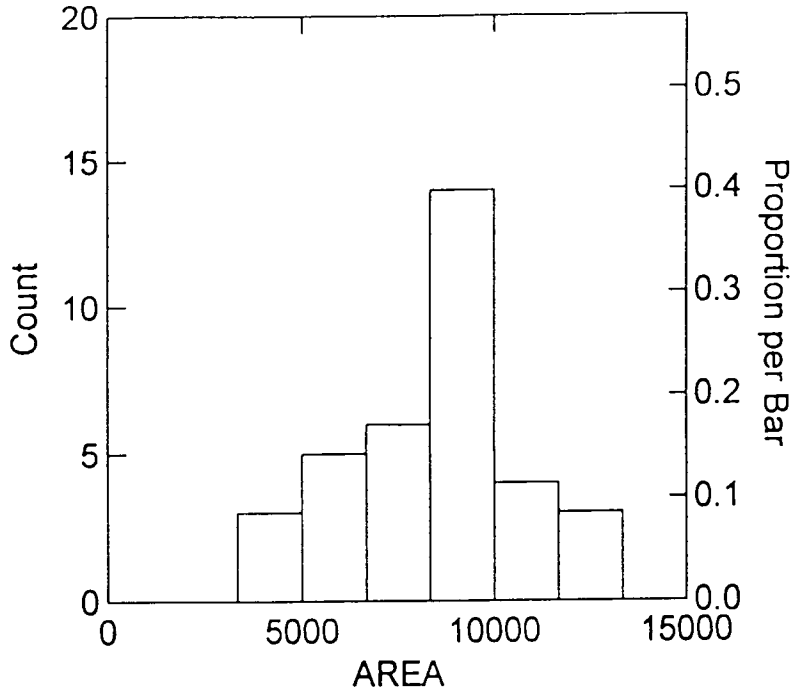
The area for the combined sample populations showed a central tendency at approximately 8,500 (Fig. 25), with much overlap between populations. The Sioux and Oneida samples fell fairly close to this. The English sample was much lower (mean was 6,681.125 and median was 6,737, Table 6). The Mongolian had the highest averages (9,782.000 and 10,948.000, respectively, Table 5) followed by the Vietnamese (9,261.000 and 9,103.000, respectively, Table 7).

Color

Table 14. Percent of sample populations with black, dark brown, light brown, red and clear colored hair.

	Mongolian		English		Vietnamese		Sioux		Oneida	
	#	%	#	%	#	%	#	%	#	%
1. Black	6	75	1	12.5	4	50	1	12.5		
2. Dark Brown	2	25	4	50	4	50	6	75	8	100
3. Lt. Brown			1	12.5						
4. Red			1	12.5			1	12.5		
5. Clear			1	12.5						
Totals	8	100	8	100	8	100	8	100	8	100

Fig. 25. Histograms of area.



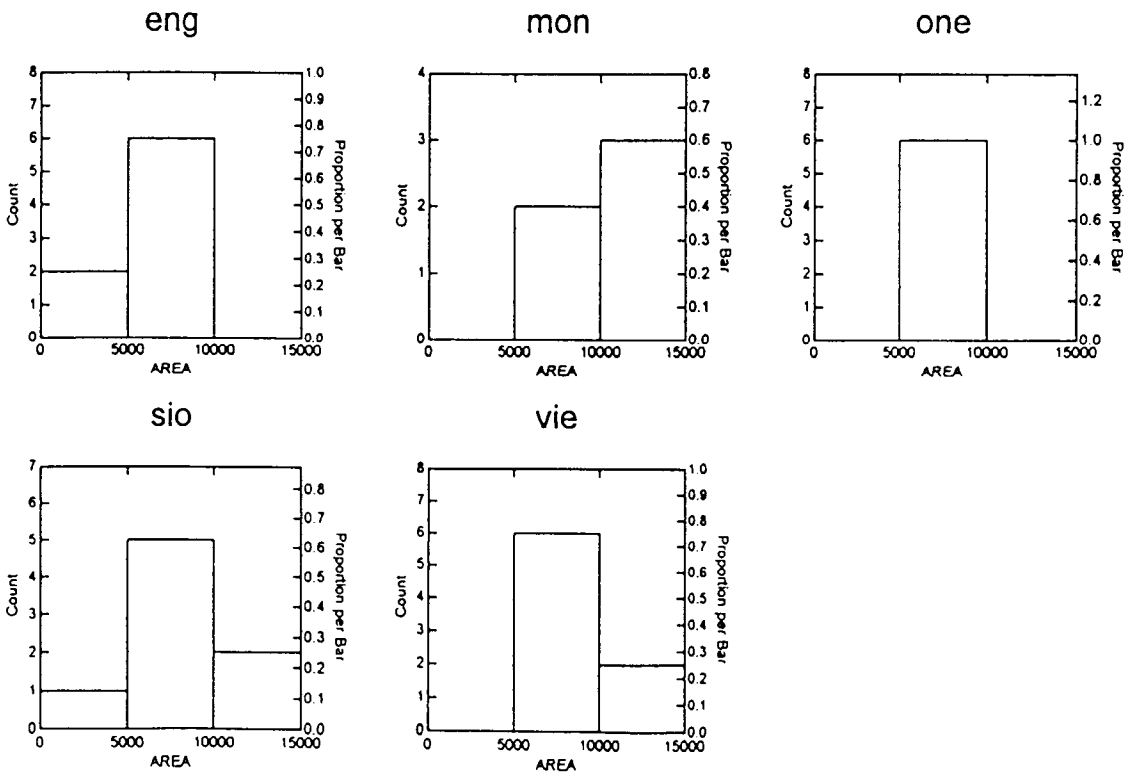
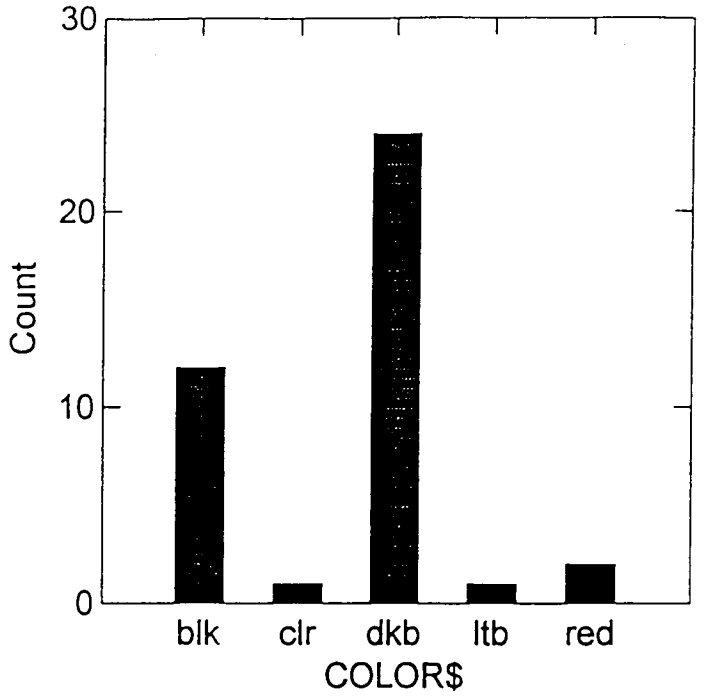
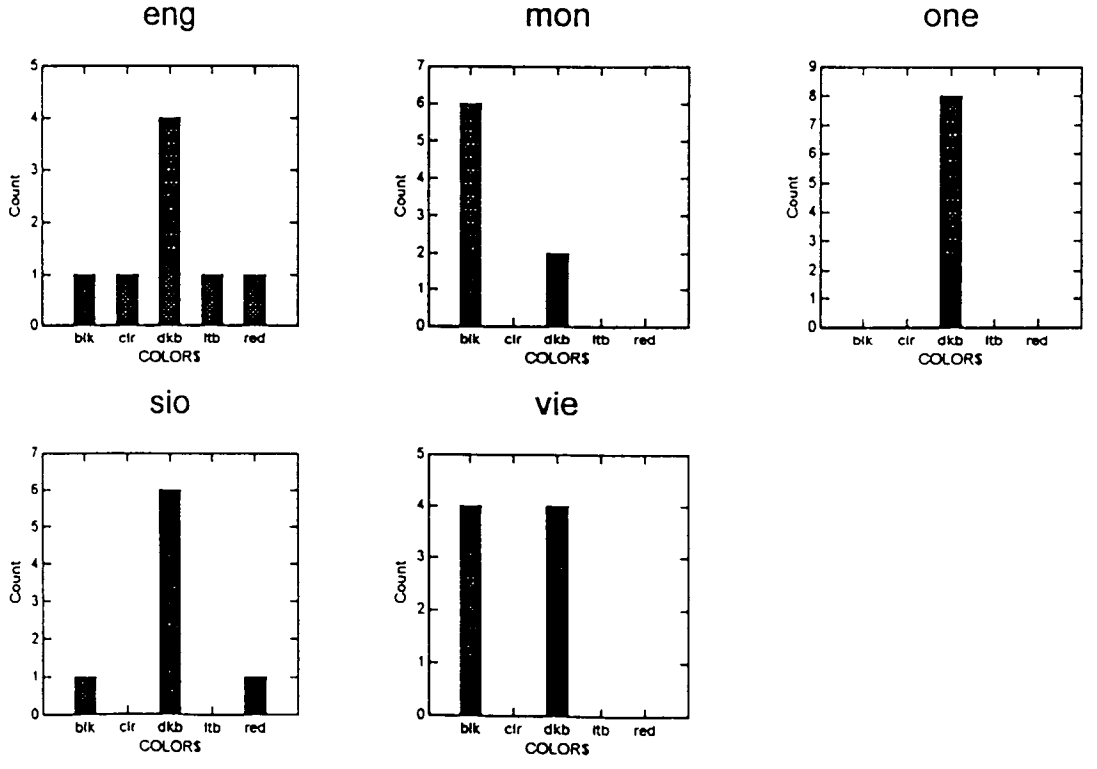


Fig. 26. Bar graphs of color.





Each sample population included hair that was mostly dark brown in color (the Oneida and Sioux were all dark brown), except for the Mongolian sample, which had more black colored hair (75%) than dark brown (25%) and the Vietnamese, which was 50% black and 50% dark brown (Fig. 26 and Table 14). The greatest variability was seen in the English sample with hair varying between all five different colors.

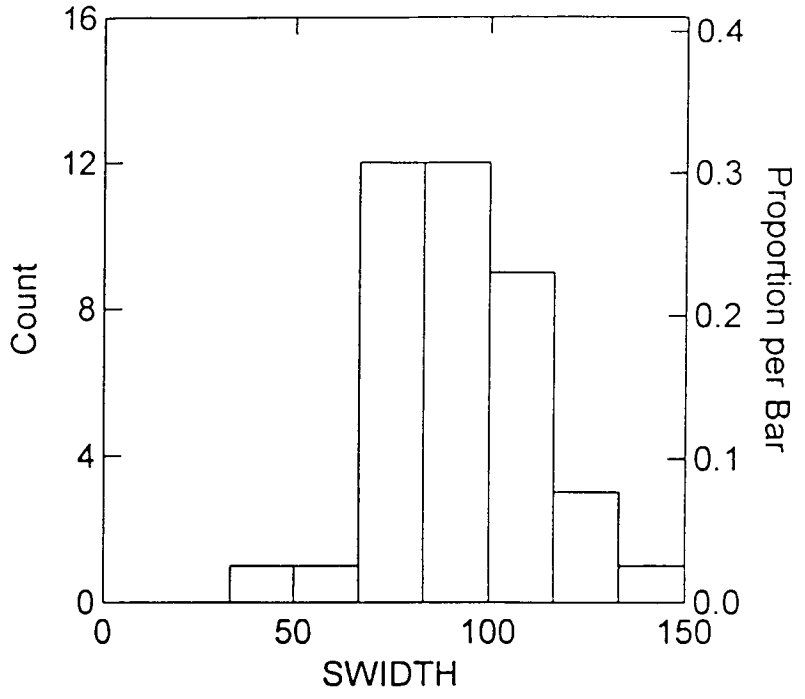
Shaft Width

Shaft widths of the combined sample populations were approximately 91.569, mean and 94.880, median (Table 4). The only significant deviation from this was the low width of the English (78.433 and 77.080, respectively). Table 6 and Figure 27 illustrated the overlap between populations. Fig. 28 showed examples of shaft width variability between three populations, Mongolian (36B), English (34C), and Sioux (02D).

Weight

Overall weight showed a great deal of variability within and between sample populations (Fig. 29). However, in accordance with most variables, the weight was lowest in the English sample (mean is 48.188 and median is 41.000, Table 6), followed by the Oneida, Sioux, Vietnamese and Mongolian (mean is 78.550 and median 78.100, Table 5). Only the Mongolian and Vietnamese weight exceeded 100. This finding supports the early work of Bernstein and Robertson (1927) in that average weight can be differentiated between samples considered "Mongoloid" and "Caucasoid".

Fig. 27. Histograms of shaft width.



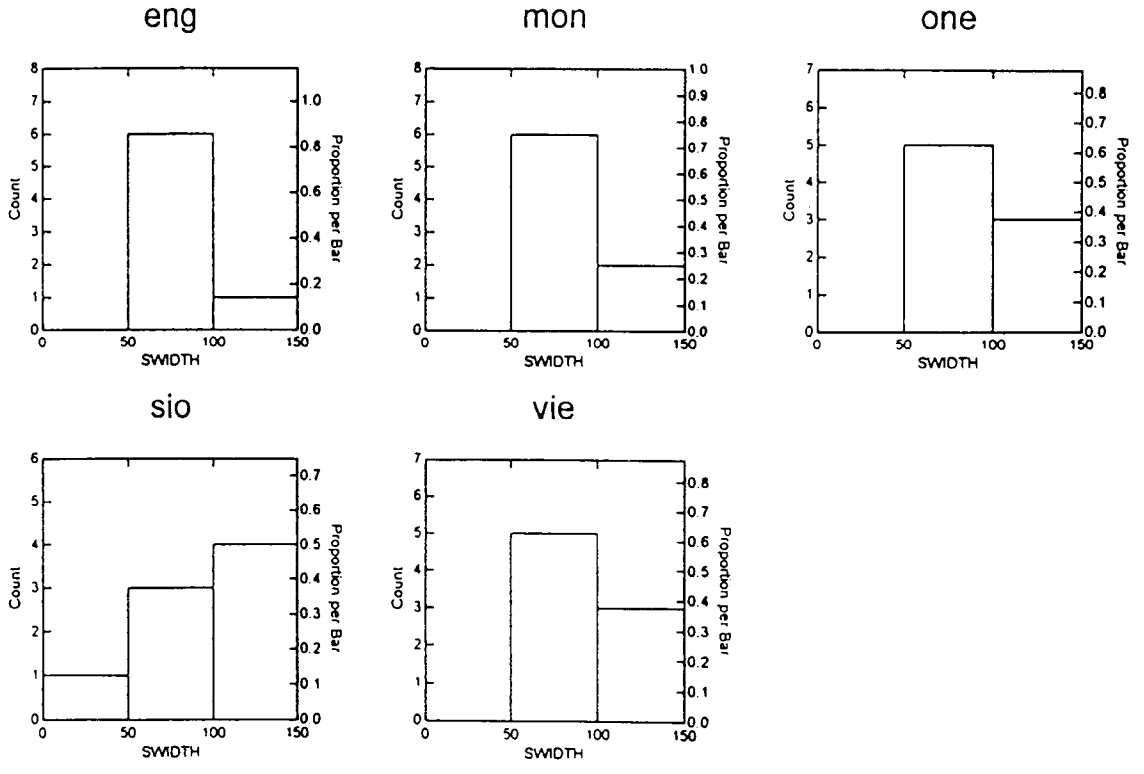
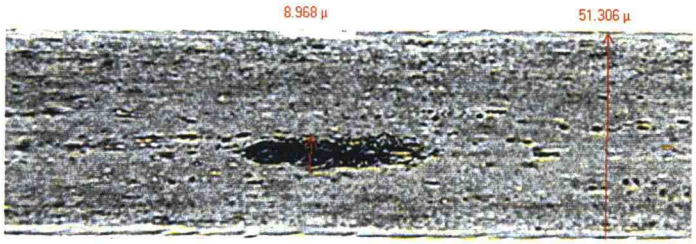
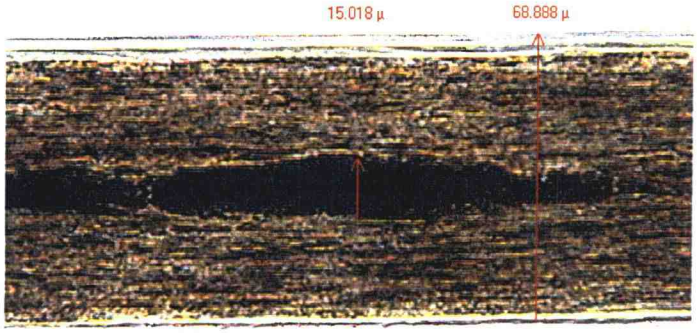


Fig. 28. Example of images showing variability between shaft widths.

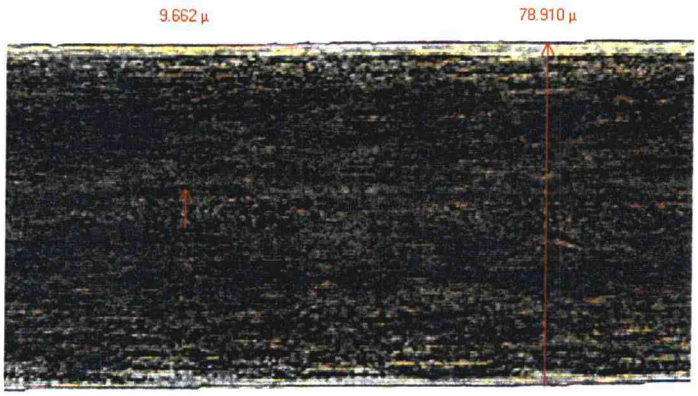
(31)



(24)

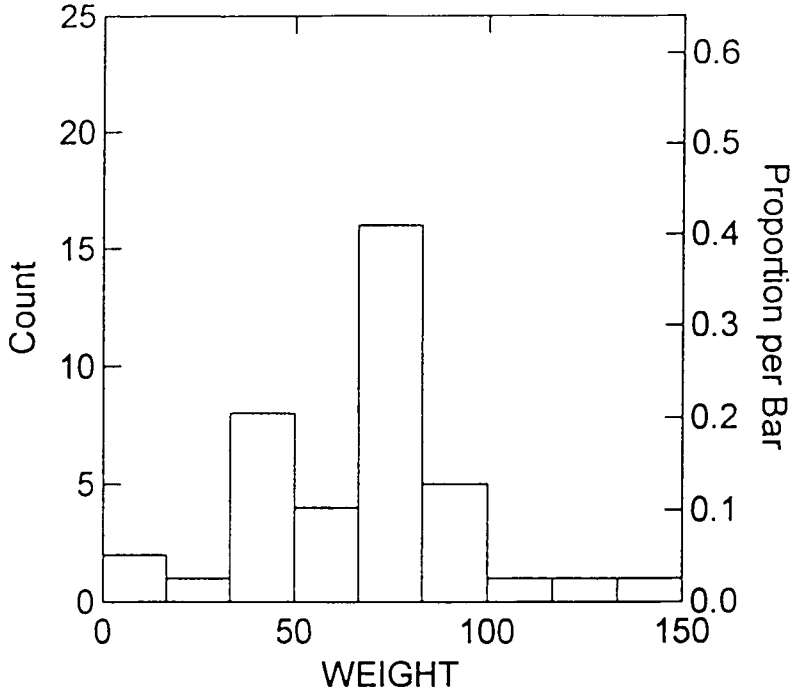


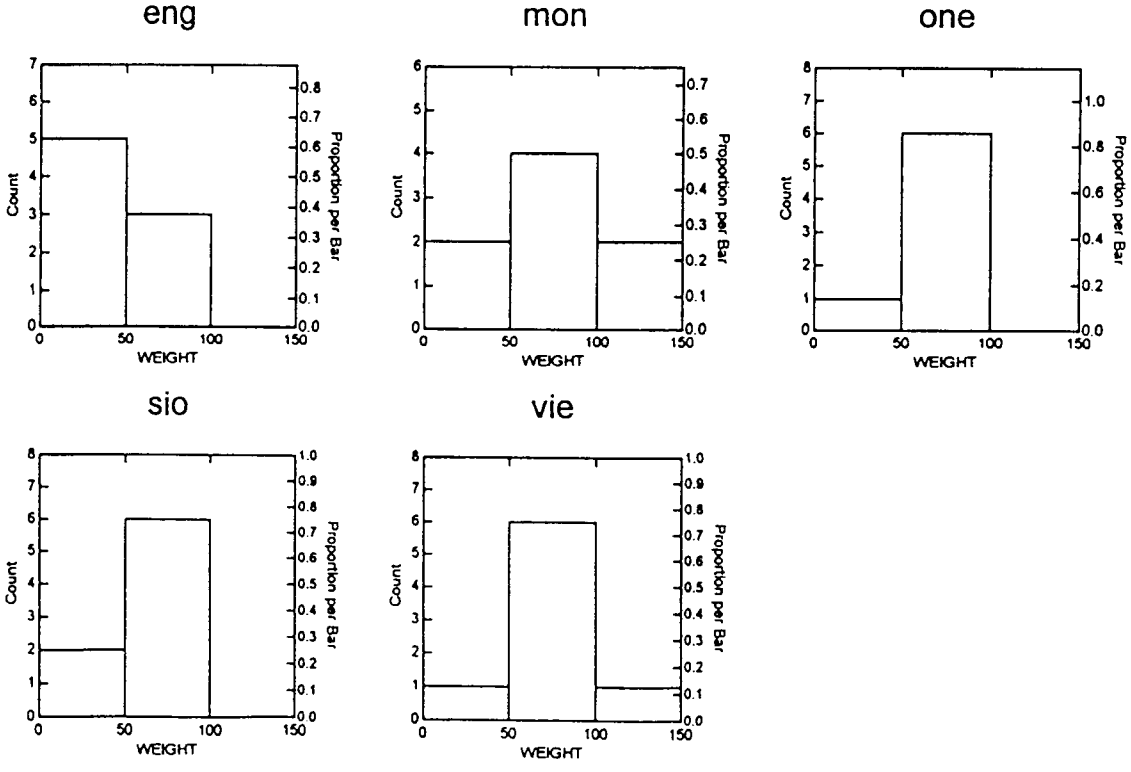
(35)



(33D)

Fig. 29. Histograms of weight.





SUMMARY AND CONCLUSIONS

In the beginning chapter, I put forth my intent for this investigation, to develop a new method for the analysis of human hair morphology, which can be used for describing and possibly isolating human populations. In addition, I wanted to test the methodology's effectiveness in determining variability using a small case study of 40 samples (total) from five populations, and this was accomplished. In this chapter, I discuss the results and return to each specific objective listed in the introduction. I also address the problems with this investigation and previous investigations and the potential this study has for helping to resolve certain forensic and archaeological questions. Finally, I provide some suggestions for future research in studies related to hair.

With respect to each of the more specific objectives for this investigation, each of these were accomplished. I have developed a new, well-described methodology for hair analysis consisting of both laboratory and examination procedures. This, in fact, is the largest contribution to this study. I created a list of attributes that seemed useful for analysis. In order to test the usefulness of these attributes, I conducted a pilot study. This allowed me to eliminate those attributes that were of no use and keep or add those that showed promise in analyzing variability. These attributes are made explicit in the key (Appendix A) and I have no doubt that the procedures are replicable. I then analyzed 40 hairs from five sample populations using this new methodology and created a database of hair sample descriptions with their associated images. Finally, I used simple statistical approaches to analyze the variability that exists among the five groups.

Unfortunately this method does not allow samples of the five local populations to be divided into five mutually exclusive categories on the basis of observable, mutually exclusive attributes (for example, by creating branch diagrams using pattern analysis), as there is a great deal of variability within each sample population and too much overlap between sample populations, as illustrated in the histograms presented in chapter four. I can only uphold a statement made early on in this investigation by a professional working directly with morphological analysis of hair and that is, "when you're dealing with morphology and issues of race, you're dealing with ranges" (Schmierbach, personal communication 1996). In this investigation, I am indeed working with many overlapping ranges. However, ranges (and other statistical measurements) can still be informative among the five sample populations, as illustrated in the previous chapter, even if isolation or classification of the five groups is impossible.

What does the statistical analysis reveal? 1) that populations do show variability and, 2) that this variability is fairly ambiguous in terms of separating populations. I conducted a multivariate analysis of variance using six metric variables (weight, maximum shaft width, maximum shaft diameter, minimum shaft diameter, area and distance between scale margins) to see if there were differences between the five population samples. Only 31 cases were used (instead of all 40) as Systat only uses a case if every variable is known for that case. The analysis developed a discriminate function with an approximate F equal to 1.2835 and an associated probability level of .2064 (using Wilks' lambda). I repeated this analysis of variance using seven variables (adding scale number to the original six variables) to see if there were differences between three groups. These groups were English, Mongolian and Vietnamese, and the

two Native American groups. This test produced an approximate F equal to 1.6308 and a much stronger probability level of .1084. Classification matrices were also produced for the five populations and the three groups. Forty-five percent of the five populations were correctly classified, while 65% of the three groups were correctly classified. While this is more than half, it is still a long way from a 100% classification.

In another test, I chose eight variables to be used for cluster analysis (area, maximum shaft diameter, minimum shaft diameter, weight, maximum shaft width, medulla width, scale number and distance between scale margins) in groups of two, three, four, and five. Observations of the histograms showed these attributes to be of most use, varying the most between populations. When I used Systat to cluster the metric variables into two groups, all the Vietnamese samples were placed into cluster one with the majority of the Mongolian, Sioux and Oneida samples. The majority of the English samples were placed in a second cluster. There was a large amount of overlap in groups of three and four. In groups of five, the majority of Vietnamese were placed in group one, the majority of Sioux and Oneida in group two, the majority of Mongolian in group three and majority of English in group four (group five included only five cases).

The results of the data in chapter four and the conclusions I presented above were obtained from a sample size that is small, 40 samples (eight from each population). Because of this and because there is overlap between them, the results are not statistically significant. The probability value (p) for the three groups (English, Mongolian and Vietnamese, and Native American Sioux and Oneida) is approximately .10, weaker than .05, which is the commonly accepted statistically significant level but stronger than that achieved in five-group analysis, which is approximately .20. This means that there are 10

chances out of 100 that differences between the three groups are not real. Therefore, it may be that the some metric differences between the groups really do exist but with a p of .10 one cannot make that conclusion.

Other studies have had much larger sample sizes and produced statistically significant results. In particular, Hrdy (1973) analyzed hair from seven populations (Bougainville and Malaita from the Soloman Islands, East Africa, Northwest Europe, Sioux, Ifugao from the Philippines and Japanese), using eight variables. Only three of these variables were similar to those that I used. Univariate and multivariate techniques were applied to at least 30 hairs from each population and each individual. In all variables the between group variance was higher than the within group variance with a significance below the p=.001 level, except for one variable at the .05 level. The populations also broke into separate groups in most cases. Those traditionally grouped as Mongoloids formed a cluster (Sioux and Japanese and Ifugao less so), the Melanesians grouped together, and the Europeans and Africans were isolated.

Hrdy's study parallels mine closer than any investigation I've seen thus far. His population samples, like mine, are separated by great distances, yet his variables are quite different. I believe it would be worthwhile to obtain a larger sample of my populations with samples from other populations to further understand variability between populations, as Hrdy did with his samples.

Incidentally, I analyzed three additional hairs using the same methodology. These were not part of my case study of samples (thus, they are not mentioned in preceding chapters). These included two specimens from Nepal (one from the Kathmandu valley and the other from the Kathmandu valley but whose parents are from Kathmandu and

Bhaktapur) and another specimen from Norway. Overall, the Norwegian specimen most closely matched the English sample in weight (37.6 μg), maximum shaft diameter (99.53 μ), cuticle thickness (2.42 μ) and area (7,054 μ^2), pigment density was sparse and color was clear or transluscent). The weight (37.6 mg) is lower than any of the five averages. Bernstein and Robertson (1927) report that, "…'Nordics' weigh least of Europeans behind 'Alpines' and 'Mediterraneans'."

The Nepalese cases are quite different though they appear very similar on the surface. The individual with an entirely Kathmandu origin is ethnically Brahmin, an Indo-European speaker, and her hair attributes most closely resemble the English sample (except that the pigment is dense). The maximum shaft diameter (99.9 μ) and area (6,357 μ^2) are even lower than the English averages. The sample that is from Kathmandu and Bhaktapur is Newari, ethnically a Tibeto-Burmese language and the oldest population known in the valley, purportedly from the east (Tibet, China or beyond). This hair sample has very large measurements overall and is closest, therefore, to the Mongolian sample. The weight (95.4 μg) and maximum shaft diameter (141.6 μ) are higher than all five averages. Obviously, these are isolated specimens but all three relate to my samples as would be expected; thus, more analysis using a greater number of samples of these populations would be interesting.

I now return to the forensic and archaeological aspect of this study and the implications of my results. Regarding the contribution to forensics, my study does not provide a method for determining the exact local population associated with an unknown hair, for example, from a crime scene. My study does provide a database of samples that have been analyzed by routine statistical procedures, something which I have yet to come

across in forensic literature. My results show that groups can be described based on morphological features and there is variability between populations. This variability is more specific than the typical forensic divisions of Negroid, Caucasoid and Mongoloid. I believe forensics has a need, too, for making more specific determinations. For example, it is much more useful to know that a hair is characterized as English than as Caucasoid. With continued improvement my methods could serve as the foundation for a standard morphological analysis of hair. It certainly avoids the kind of typological classification and subjectivity that exists in forensic tests to date.

Similarly, this analysis is useful when applied to ancient hair or hair from an archaeological context. I cannot determine the population of an unknown hair from an archaeological site (often archaeologists are dealing with only fragments of a hair, which makes this even more difficult). However, because it is possible to show variability exists between groups of modern hair, it can be assumed that it should also be feasible for ancient hair (if a sufficient amount of hair is recovered). Alone, this will confirm the presence of humans at a site and could tell us if one or more human groups occupied the site (if there is a wide range of variability in morphology between them). It can also be determined how adjacent and distant groups of people are related by comparing hair samples between sites. Analyzing hair found in context with other types of data, such as artifacts, can help to resolve numerous issues . For example, it could determine if Clovis is associated with more than one group of people.

Regarding population relationships and the peopling of the Americas, the five populations I used do represent quite dispersed geographic areas, which may explain to a large extent the phenotypic variability and/or relationships between them. The English

are geographically located the farthest from each of the four other populations, and they are very different morphologically. The Mongolian and Vietnamese are geographically close and in some ways so is their morphology. The Native Americans (Sioux from the plains and Oneida from the northeast) are morphologically similar, as would be expected, yet they show some variability between them, which is also interesting.

In terms of timing of the North American migration and the number of waves of migration, this can only be answered by radiocarbon dating the hair and comparing hair samples from several Native American tribes. DNA from hair would help to support conclusions made from morphological analysis. There is no doubt that new data are needed to resolve the impasse that exists in debates surrounding the peopling of the Americas. Hair morphology (and hair research of other kinds) is providing one new line of evidence.

In conclusion, I have made the following suggestions for future research:

1.) A similar study using a much larger size of samples would be very useful to determine whether the lack of statistical significance is due to this study's small sample size or the lack of differences in populations.
2.) Utilizing a broader geographic scope would also help to further test variability between populations, as well as theories regarding the movement of peoples. Simply adding samples from a wider variety of geographic areas to the database would provide a foundation in which unknown forensic and or archaeological samples could be compared and possibly matched.

3.) A thorough analysis of hair morphology (in conjunction with DNA and other types of analysis of hair) of several Native American tribes and perhaps north Asian populations would be useful for answering or at least providing new evidence for questions important to the peopling of the Americas.

In conclusion, hair morphology alone may never provide enough information for answering large-scale forensic and archaeological questions. However, it is one line of evidence that, when considered with others (such as DNA, fingerprints, artifacts, etc.) can be useful for answering these questions.

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APPENDICES

APPENDIX A KEY

Accession Number

(An) Accession Number. An accession number is assigned to each hair sample. The number represents the individual sample, a letter designation corresponds to each hair from that individual. Letter designations may be used for the following: s for scale features, m for medulla features and x for cross-section features.

1. (xxx) The accession number for the specimen.
99. (ndt) An accession number was not recorded for this specimen.

Hair Region

(Hr) Hair Region. The region of the hair sample allows the analyst to determine what part of the hair is present and indicates whether the hair is complete (in its natural state) or incomplete (lacking a particular section). If the hair is incomplete, regions that are present are recorded (Moore et al. 1974:8).

1. (com) Complete. Hair includes the basal (root), shaft and tip.
2. (ibo) Incomplete. (Basal) Hair includes the most proximal, root and slightly beyond.
3. (iso) Incomplete. (Shaft) Hair includes the mid-section or shaft (or a section of the shaft) only.
4. (ito) Incomplete. (Tip) Hair includes most distal, tip portion only.
5. (ibs) Incomplete. (Basal and shaft) Hair does not include a most distal, tip region.
6. (ist) Incomplete. (Shaft and tip) Hair does not include a most proximal, root region.
9. (cdt) The portion of the hair being examined can not be determined.
99. (ndt) The hair region was not determined.

(Cf) Cortex Features. Diagnostic features may or may not occur in the cortex region of the shaft. These features include ovoid bodies or large circular and oval shapes within the cortex and cuticle fusi or irregular shaped air spaces that are smaller than ovoid bodies

but larger than pigment granules within the cortex (usually occurring near the root) (Hicks 1978:4).

0. (abs) Absent. The hair does not display ovoid bodies or cortical fusi.
1. (pst) Both ovoid bodies and cortical fusi are present within the cortex.
9. (cdt) The presence of cortex features can not be determined.
99. (ndt) The presence of cortex features was not determined.

Scale

(Sp) Scale Pattern. The dominant scale pattern is recorded (Moore, et. al. 1974:15; Teerink 1991:7; and Appleyard 1978:viii).

1. (rwv) Regular wave. Scales form a transverse pattern with a shallow wave.
2. (iwv) Irregular wave. Scales form a transverse and sometimes longitudinal pattern. The waves have deeper troughs and are less regular.
9. (cdt) The scale pattern can not be determined.
99. (ndt) The scale pattern was not determined.

(Ss) Structure of the Scale Margins. The scale margin is observed at the edges of the scale crests and troughs and the dominant form of the margin is recorded (Moore, et al. 1974:13).

1. (smo) Smooth. The margins of the scales show no indentations and appear as a smooth line.
2. (int) Intermediate. The scales have indentations intermediate between smooth and rippled.
3. (rip) Rippled. The scales have small indentations along the margins, usually close together.
9. (cdt) The structure of the scale margins can not be determined.
99. (ndt) The structure of the scale margins was not determined.

(Ds) Distance Between Scale Margins. The maximum distance between scale margins is found by locating the most proximal and the most distal point on an individual scale.

Line segments are projected through these points perpendicular to the longitudinal axis of the hair. The distance between the two lines is measured in microns and recorded as the maximum distance between scale margins (Moore, et al. 1974:12; and Teerink 1991:7).

1. (xxx) Distance between scale margins (μ).
9. (cdt) The distance between scale margins can not be determined.
99. (ndt) The distance between scale margins was not determined.

(Sn) Scale Number . Scale number is found by counting the number of each complete scale within a 40 microns. The scale number is recorded.

1. (xxx) Scale number.
9. (cdt) The number of scales can not be determined.
99. (ndt) The number of scales was not determined.

Medulla

(Mp) Medulla Pattern. The dominant medulla pattern is recorded for each hair specimen (Teerink 1991:10; Moore, et al. 1974:10; and Appleyard 1978:vii).

0. (abs) Absent. Medulla is absent (can not be seen).
1. (frg) Fragmented. The medulla is sporadically interrupted by cortical material (the medulla is absent at one or more sites).
9. (cdt) The medulla pattern can not be determined.
99. (ndt) The medulla pattern was not determined.

(Ms) Structure of the Medulla Margins. The medulla margin forms are observed along the most lateral edges of the medulla and the dominant form is recorded (Teerink 1991: 10).

0. (abs) Absent. The medulla is absent (can not be seen).
1. (str) Straight. The margins form a smooth, straight line.
2. (sca) Scalloped. A series of convex, rounded projections form the margin of the medulla.

9. (cdt) The structure of the medulla margins could not be determined.
99. (ndt) The structure of the medulla margins was not determined.

(Mw) Maximum Medulla Width. The maximum medulla width is found by locating the maximum distance between each of the medulla margins. A straight line is measured in microns perpendicular to the hair.

0. (abs) The medulla is absent (can not be seen).
1. (xxx) Maximum medulla width (μ).
9. (cdt) The maximum medulla width can not be determined.
99. (ndt) The maximum medulla width was not determined.

(Mr) Medulla/Shaft Maximum Width Ratio. The medulla/shaft maximum width ratio indicates the difference between the maximum medulla and maximum shaft widths and is found by dividing the maximum medulla width by the maximum shaft width.

1. (xxx) Medulla/shaft maximum width ratio.
9. (cdt) The maximum medulla/shaft ratio can not be determined.
99. (ndt) The maximum medulla/shaft ratio was not determined.

Cross-section

(Pd) Pigment Density. Pigment density is found by observing how densely packed the pigment granules are within the cross-section. Three options are possible, dense, intermediate and sparse.

0. (abs) Absent. The hair is absent of pigment. It is translucent.
1. (den) Dense. The pigment granules are densely packed together with little space between them.
2. (int) Intermediate. The pigment granules are nether densely packed or sparse but in between.
3. (spa) Sparse. The pigment granules are sparsely packed.
9. (cdt) The density of pigment granules can not be determined.
99. (ndt) A cross-section has not been prepared.

(Pn) Pigment Distribution. The pigment distribution is found by dividing the cross section into three equal units: Unit 1 is located at the center one-third of the cross-section, Unit 2 is located at the middle one-third and Unit 3 is located at the exterior one-third. The pigment distribution is recorded as existing predominantly in the first, second or third unit of the cross-section.

0. (abs) Absent. The hair is absent of pigment. It is translucent.
1. (ut1) Unit 1. The pigment is distributed mainly within unit one (inner third).
2. (ut2) Unit 2. The pigment is distributed mainly within unit two (middle third).
3. (ut3) Unit 3. The pigment is distributed mainly within unit three (outer third).
9. (cdt) The distribution of pigment granules can not be determined.
99. (ndt) A cross-section has not been prepared.

(Sd) Shaft Diameter. Computer images of cross-sections are oriented so that the greater width of the cross-section lies horizontally on the monitor. The maximum shaft diameter is found by locating the two most lateral points along the margin of the shaft in cross-section. Line segments are projected through these points perpendicular to the z-axis of the shaft. The distance between these line segments is recorded in microns. The minimum shaft diameter is found by using the same method as above except that the two least lateral points are located. Maximum and minimum diameters are recorded in microns.

1. (xxx) Maximum and minimum diameter.
9. (cdt) The shaft diameter can not be determined.
99. (ndt) A cross-section has not been prepared.

(Ss) Shape of Shaft Diameter. The shape of the shaft diameter outlines the form of the shaft in cross-section. (Teerink 1991:11).

1. (cir) Circular. The cross-section forms a circle.
2. (ovl) Oval. The cross-section is oval, between the circle and oblong shape.
3. (obl) Oblong. The cross-section is oblong, a stretched out (narrower) oval shape.

4. (bcx) Biconvex. The cross-section is and oblong shape with pointed ends.
5. (cvx) Concavo-convex. The cross-section is similar to an oblong shape with one side concave and the opposite side convex.
6. (bcv) Biconcave. The cross-section is oblong with both sides indented (concave).
7. (tcv) Triconcave. The cross-section is triangular with all three sides indented (concave). This shape may also display a very long rounded side.
8. (qcv) Quadraconcave. The cross-section is rectangular with all four sides indented (concave).
9. (cdt) The shape of shaft diameter can not be determined.
10. (dmb) Dumb-bell. The cross-section is oblong with both sides indented (concave) similar to biconcave except that the indentation is exaggerated more on one side and the medulla is larger within the shaft taken up 75% of the cross-section.
11. (crv) Carved. The cross-section is circular with a small piece carved out of the circle.
12. (hsh) H-shaped. The cross-section is square/rectangular with small pieces carved out of two of the opposing ends.
99. (ndt) A cross-section has not been prepared.

(Md) Medulla Diameter. The maximum medulla diameter is found by locating the two most lateral points along the margin of the medulla in cross-section. Line segments are projected through these points perpendicular to the z-axis of the medulla. The distance between these line segments is recorded in microns. The minimum medulla diameter is found by using the same method as above except that the two least lateral points are located.

0. (abs) Absent. The medulla is absent (can not be seen).
1. (xxx) The maximum and minimum medulla diameters (μ).
9. (cdt) The medulla diameter can not be determined.
99. (ndt) A cross-section has not been prepared.

(Ct) Cuticle Thickness. The thickness of the cuticle is found by measuring the distance from the exterior margin of the cortex to the exterior margin of the cuticle. The measurement is taken at the left side, center with the cross-section in proper orientation.

0. (abs) The cuticle layer is absent.
1. (xxx) Cuticle thickness (μ).
9. (cdt) The thickness of the cuticle can not be determined.
99. (ndt) The thickness of the cuticle was not determined.

(Ar) Area. Area is found by tracing a line around the entire cross-section. Area is automatically computed in square microns by the Optimas program.

1. (xxx) Area (μ).
9. (cdt) The area of the cross-section could not be determined.
99. (ndt) The area of the cross-section could not be determined.

Color

(Co) Color. The dominant macro (eye view) color or hue is recorded comparing the sample to Munsell (1976) descriptions of hair color.

1. (clr) The hair is clear or transluscent.
2. (whi) The hair is white (10YR 8/1).
3. (gry) The hair is grey (2.5 YR 6/0).
4. (bld) The hair is blonde or very pale brown (10 YR 8/2).
5. (brn) The hair is brown (10YR 5/3).
6. (ltb) The hair is light brown (10 YR 6/3).
7. (dkb) The hair is dark brown (10 YR 3/3).
8. (red) The hair is red (2.5 YR 4/6).
9. (cdt) The color of the hair can not be determined.
10. (blk) The hair is black (2.5 YR 2.5/0).
99. (ndt) The color of the hair was not determined.

(Sc) Second Color . Hairs are scanned for the number of colors present along the shaft. If more than one color is present the second color (least dominant) is indicated using the same method described above.

1. (clr) The hair is clear or transluscent.
2. (whi) The hair is white (10YR 8/1).

3. (gry) The hair is grey (2.5 YR 6/0).
4. (bld) The hair is blonde or very pale brown (10 YR 8/2).
5. (brn) The hair is brown (10YR 5/3).
6. (ltb) The hair is light brown (10 YR 6/3).
7. (dkb) The hair is dark brown (10 YR 3/3).
8. (red) The hair is red (2.5 YR 4/6).
9. (cdt) The color of the hair can not be determined.
10. (blk) The hair is black (2.5 YR 2.5/0).
99. (ndt) The color of the hair was not determined.

Size

(Le) Length. The length of the entire hair sample is determined from the most proximal end to the most distal end (scales point toward distal end) in millimeters, keeping in mind that hairs may be cut or broken. The hair is gently pulled straight between two sets of tweezers and placed next to a millimeter scale. Length is recorded.

1. (xxx) Length (mm).
9. (cdt) The length of the hair can not be determined.
99. (ndt) The length of the hair was not measured.

(Sw) Maximum Shaft Width. The maximum shaft width is found by locating the most lateral points along the right and left margin of the hair shaft (avoiding any unusual nodes or bulbs on the hair). A straight line is projected between the two points perpendicular to the longitudinal axis of the hair. The width is recorded.

1. (xxx) Maximum shaft width (μ).
9. (cdt) The maximum shaft width can not be determined.
99. (ndt) The maximum shaft width was not measured.

(Wt) Weight. A one centimeter fragment from the specimen is weighed on a balance sensitive to micrograms.

1. (xxx) Weight in micrograms.
9. (cdt) The weight could not be determined.
99. (ndt) The weight was not determined.

Comments

(Mg) Magnification. The magnification used while examining the hair on a Leica microscope is recorded by multiplying the eyepiece magnification by the objective magnification. For example, if the magnification of the ocular lens is 10x and the magnification of the objective is 25x, the total magnification is 250x.

1. (100) Magnification is 100x.
2. (250) Magnification is 250x.
3. (400) Magnification is 400x.
99. (ndt) The magnification was not recorded.

(Lp) Local Population. The local population is defined as a group of people who live in the same area, interbreed and share certain cultural features (Hall 1997:75).

1. (xxx) Local population.
9. (cdt) The local population could not be determined.
99. (ndt) The local population was not determined.

(Ag) Age. The age of the individual from which the hair sample is taken is recorded if known.

1. (xxx) Age.
9. (cdt) The age could not be determined.
99. (ndt) The was not determined.

(Sx) Sex. The sex of the individual from which the sample was taken is recorded if known.

1. (xxx) Sex.
9. (cdt) The sex of the individual could not be determined.
99. (ndt) The sex of the individual was not determined.

APPENDIX B DATA PRESENTATION

	Accession Number	Population	Age	Sex	Hair Region	Cortex Features	Medulla Pattern	Structure of the Medulla Margins	Medulla Width
4	04A	eng	55	female	iso	pst	abs	abs	
9	09D	eng	61	male	iso	pst	abs	abs	
14	14	eng	45	female	iso	pst	frg	str	18.43
19	19	eng	40	female	ibs	pst	frg	str	17.25
24	24	eng	49	female	iso	pst	frg	str	8.968
29	29A	eng	38	female	iso	pst	frg	str	17.2
34	34C	eng	60	female	iso	pst	abs	abs	
39	39	eng	38	female	iso	pst	frg	str	12.88
1	01D	mon	41	male	iso	cdt	frg	cdt	
6	06A	mon	44	female	com	pst	frg	str	17.23
11	11	mon	49	male	ibs	cdt	frg	str	21.19
16	16C	mon	26	male	ibs	pst	abs	abs	
21	21D	mon	27	male	iso	pst	frg	str	14.86
26	26C	mon	40	male	iso	cdt	frg	str	12.61
31	31	mon	43	male	iso	pst	frg	str	36.25
36	36B	mon	20	male	isb	pst	frg	str	21.87
3	3	one	12	female	iso	pst	abs	abs	
8	08D	one	8	female	iso	pst	frg	str	19.13
13	13B	one	11	female	iso	pst	abs	abs	
18	18	one	23	male	iso	pst	frg	str	20.71
23	23A	one	24	male	iso	pst	frg	str	22.08
28	28B	one	14	male	iso	pst	frg	str	23.92
33	33D	one	21	male	iso	pst	frg	str	9.662
38	38D	one	26	male	iso	pst	frg	str	32.97
2	02D	sio	13	male	iso	abs	frg	str	23.24
7	07D	sio	16	male	iso	pst	frg	str	15.12
12	12	sio	17	male	iso	pst	frg	str	25.88
17	17A	sio	15	male	iso	pst	abs	abs	
22	22B	sio	17	male	iso	pst	frg	str	23.45
27	27	sio	14	male	iso	pst	frg	str	20.84
32	32D	sio	20	female	iso	pst	frg	str	25.16
37	37	sio	14	female	iso	pst	frg	str	26.49
5	5	vie	20	male	abs	pst	frg	str	17.89
10	10B	vie	18	female	iso	pst	frg	str	16.83
15	15A	vie	23	female	iso	pst	frg	str	21.64
20	20	vie	20	female	ibs	pst	abs	abs	
25	25	vie	20	female	ibs	pst	frg	str	30.17
30	30	vie	19	female	iso	pst	frg	str	39.82
35	35	vie	18	female	iso	pst	frg	str	15.02
40	40	vie	18	female	iso	pst	frg	str	22.95

APPENDIX B, (Continued)

Medulla/Shaft Width Ratio	Color	Second color	Length	Shaft Width	Weight	Scale Pattern	Structure of the Scale Margins	Distance between Scale Margins	Scale Number
	dkb	abs	106	69.66	35.8	iwv	2	17.25	5
	dkb	abs	67		34.8	iwv	3	31.07	3
0.239	dkb	brn	194	77.08	46.2	iwv	2	34.81	3
0.182	dkb	abs	117	94.88	70.9	iwv	2	28.65	3
0.175	ltb	abs	152	51.31	12.5	iwv	2	26.56	4
0.167	red	abs	111	103.2	67.9	iwv	2	29.65	3
	clr	abs	145	70.12	34.4	iwv	2	22.68	4
0.156	blk	red	312	82.78	83	iwv	2	31.32	3
	blk	abs	106	77.08	48.6	iwv	2	32.35	5
0.256	dkb	dkb	425	67.36	31.3	iwv	3	19.07	
0.232	blk	abs	65	91.21	82	iwv	3	51.76	3
	blk	abs	72	66.75	139.2	iwv	3	22.84	5
0.156	blk	abs	58	95.35	74.2	iwv	2	24.85	4
0.17	blk	abs	114	74.13	69.9	iwv	3	62.75	
0.294	blk	abs	75	123.2	101.1	iwv	2	20.37	4
0.2	dkb	abs	36	109.4	82.1	rwv	1	23.88	5
	dkb	abs	119	96.16	53.9	iwv	3	15.28	
0.251	dkb	abs	155	76.22	46.6	iwv	3	38.51	5
	dkb	abs	48	99.35	60.6	iwv	3	28.43	
0.187	dkb	abs	26	110.7	76	iwv	3	32.62	4
0.206	dkb	abs	22	107	78.1	iwv	3	28.7	4
0.281	dkb	abs	13	85.1		iwv	3	31.26	4
0.122	dkb	abs	30	78.91	62.5	iwv	3	27.9	4
0.253	dkb	abs	25	130.3	95.1	iwv	2	17.45	5
0.217	blk	abs	37	107.3	96	iwv	3	23.03	5
0.17	dkb	abs	21	88.87	42.2	iwv	1	23.38	5
0.309	dkb	abs	21	83.8	73.5	iwv	1	21.84	4
	dkb	abs	20	38.88	12.5	iwv	2	15.12	4
0.222	dkb	abs	25	105.5	71.4	iwv	2	37.84	2
0.178	dkb	abs	38	117	76.5	iwv	3	47.45	1
0.249	dkb	abs	74	100.9	99.4				
0.268	red	abs	116	98.89	78.1	iwv	3	26.14	5
0.185	dkb	blk	98	96.89	84.5	iwv	2	32.05	6
0.148	dkb	abs	520	113.4	91.2	iwv	2	23.34	4
0.228	dkb	abs	330	94.89	77.5	iwv	2	22.53	5
	dkb	abs	104	76.65	52.1	iwv	2	25.66	6
0.273	blk	abs	385	110.3	70.8	iwv	3	34.53	4
0.291	blk	abs	270	136.9	119	iwv	3	17.2	6
0.218	blk	red	275	68.89	36.6	iwv	2	18.1	5
0.242	blk	abs	129	94.88	80.4	rwv	1	18.21	4

APPENDIX B, (Continued)

Pigment Density	Pigment Distribution	Maximum Shaft Diameter	Minimum Shaft Diameter	Shape	Maximum Medull Diameter	Minimum Medulla Diameter	Cuticle Thickness	Area
int	cdt	119.5	78.7	ovl			3.044	6,923.00
int	ut3	98.36	62.34	ovl			2.307	4,707.00
int	ut3	94.72	74.34	cir	3.774	3.774	2.641	5,552.00
spa	ut3	121.7	92.5	tcv	8.089	6.682		8,804.00
spa	cdt	74.58	62.42	cir			2.432	3,510.00
spa	ut1	135.7	84.35	ovl	20.7	8.827		8,558.00
spa	cdt	96.99		cir				6,551.00
spa	ut3	127.2	92.03	tcv				8,844.00
den	ut3	85.44	82.99	cir			5.208	5,419.00
ndt	ndt							
int	ut3	114.9	103.9	cir	21.74	21.74		9,362.00
int	cdt	168.2	86.1	obl			1.543	12,084.00
cdt	cdt			cdt				
ndt	ndt							
int	cdt	140.9	100.9	ovl				11,097.00
den	ut3	136.6	105	ovl				10,948.00
ndt	ndt							
spa	cdt	97.72	82.74	cir	16.48	9.734	2.621	6,149.00
ndt	ndt							
int	ut3	122.4	89.18	ovl	18.41	16.61	2.888	8,405.00
int	ut3	122.6	92.4	ovl				9,006.00
spa	ut3	110.7	110.3	cir	11.3	10.52	3.117	9,225.00
spa	ut3	117.5	80.48	ovl			1.412	7,447.00
spa	ut1	143.1	86.79	cvx	27.17	15.42		9,320.00
int	ut3	124.2	100.7	ovl	19.98	15.52	2.851	9,373.00
int	cdt	87.82	78.06	cir	4.53	3.833		5,139.00
int	ut3	112.8	96.9	cir	26.52	19.8	3.536	8,432.00
den	ut2	78.24	76.58	cir	8.566	6.385	1.713	4,622.00
int	cdt	114.5	86.15	ovl	21.45	14.88	3.806	7,466.00
int	cdt	127.1	88.34	ovl				8,533.00
spa	cdt	132.3	122.7	cir	32.81	25.54		12,238.00
int	cdt	134.6	111.4	cir				11,472.00
int	ut3	132.2	100.4	ovl	10.49	10.49	3.515	10,200.00
int	cdt	133.4	90.2	ovl	26.09	10.95		9,109.00
int	ut3	105.8	100.9	cir	18.83	16.77	2.053	7,816.00
int	ut3	114.2	110.7	crv				8,917.00
den	cdt	119.6	107.1	cir	15.59	13.17		9,782.00
int	ut3	150.1	101	ovl	22.1	19.17	3.264	11,974.00
int	ut3	106.3	103.9	cir			3.382	8,118.00
den	cdt	123.1	88.63	crv	21.99	12.14		8,172.00