A Guide to the Analysis of Forensic Household Dust Specimens and Their Statistical Significance

By

Nicholas Petraco, MS, D-ABC
Nicholas D. K. Petraco, PhD

In: Forensic Science Handbook, Volume II; CRC Press, Boca Raton, FL, 2016

FORWARD

The authors' hypothesis: "that the combination of animal, mineral, vegetable, and synthetic materials within any given household dust specimen, in combination with the DNA of its living inhabitants and visiting individuals, offers to the forensic scientist, a formidable cocktail of irrefutable, scientifically sound data which is unique to any single location, and thus can be used to unequivocally identify any site on this planet;" is the underpinning for their work. The authors offer this chapter towards proving their thesis.

INTRODUCTION

The need for the increased utilization of trace evidence in the crime laboratory has been pointed out.[1&2] Mc Crone has estimated that considerably less than 1 percent of all the potential trace evidence in crimes is ever examined.[3] This phenomenon is peculiar indeed, considering the fact that trace evidence has been shown time and again to be a most valuable source of investigative information and proof. These data can be used to: (1) help solve crimes; (2) associate the people, places, and things involved in the crime; (3) deduce the occupation(s) of the principal(s) involved in the crime; and (4) reconstruct the crime scene and/or the event itself.[4-22]

A century ago, Hans Gross speculated that dust is a representation of our environment in miniature. Gross further proposed that by recognizing the constituents composing a particle dust sample one could estimate the surroundings from the con which the dust originated, and that this information could be used to help solve crimes.[4] This fact left the scientific investigator with a difficult challenge: the need to develop analytical methods that could be used to identify minute traces of the many different types of materials that occur in dust as trace evidence. Mc Crone, Delly and Palenik's work with Aroclor®, polarized light microscopy, and *The Particle Atlas* series has certainly established an effective methodology for accomplishing the identification and characterization of all types of dust specimens.[23] Following their lead, some forensic scientists have developed schemes utilizing different mounting media for identifying some of the substances that occur as trace evidence. Graves published an excellent article on the characterization of the minerals in soil, in which he utilized a Cargille® oil having refractive index of 1.54.[24] Fong was first to publish a scheme for the identification of different synthetic fibers in a single mounting medium having a refractive index of l.525.[25] Next, Petraco described a rapid screening method for identifying synthetic fibers in dust and a microscopic method for animal hair identification in Melt Mount® 1.539.[26] Many of the theoretical principles and methods necessary for the collection, identification, examination, comparison, and evaluation of the various types of trace materials that occur in dust have already been presented in Volumes I and II of this Handbook series.[27-34] The primary goal of this chapter is to present a microscopical guide for the identification and characterization of the components of dust specimens mounted in a single refractive index medium, namely Melt Mount® 1.539. It is intended that the resulting chapter will provide the forensic microscopist with a reference that will serve as an introductory guide to the examination of the trace materials commonly encountered in house hold dust specimens:

1. Human Skin Cells
2. Human hair
3. Animal hair
4. Synthetic fibers
5. Mineral and glass fibers and particles, plaster chips, concrete particles, paint chip, glass and mineral fragments and other related materials
6. Miscellaneous substances: white and blue cotton fibers, food stuff particles, plant hairs, pollens, vegetable fibers, paper fibers and plant matter, starch grains, feathers, glitter, construction materials and so on.

Many of the less traditional forms of trace evidential materials found in dust specimens have already been discussed by Palenik in Volume II [32] and thus will not be covered in this chapter. However, serious readers should familiarize themselves with the identification of these substances because they will no doubt be encountered in their casework.

It is the authors' hope that this work will help guide the novice and experienced forensic examiner through the successful analysis of household dust specimens, such as the one depicted in Figure 2-1. It is also the authors' wish that this effort will help foster the utilization of polarized light microscopy and trace evidence in the crime laboratory.

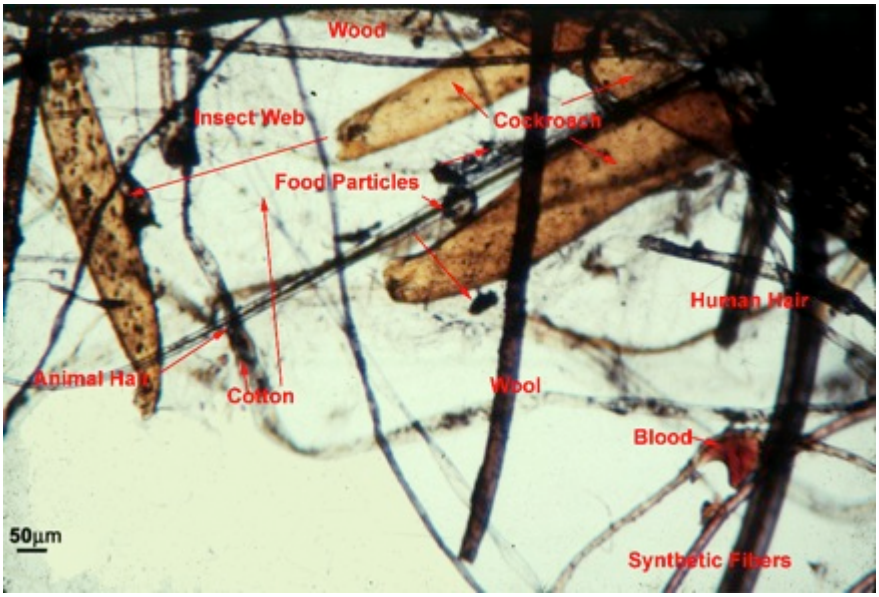


Figure 2-1 A specimen of questioned dust from a double homicide investigation. The specimen is mounted in Melt Mount"' 1.539 and contains the following trace materials: Human hairs; animal hairs; synthetic fibers; vegetable fibers; blood flakes; insect parts, features, food particles, glass fragments, and mineral fragments.

The formation of household dust is a complex phenomenon. The authors' research indicates that a hair, fiber, feather, or pieces of fibrous material initiates the process. Forces such as convection currents, static electricity, breezes, drafts, Brownian motion, all together, overtime, cause additional

lengths of fibrous materials to coalesce into a cage like structure which trap an hold fragments of particulate matter, i.e. skin fragments, plant matter, mineral grains, food particles as demonstrated in Figure 2-2.

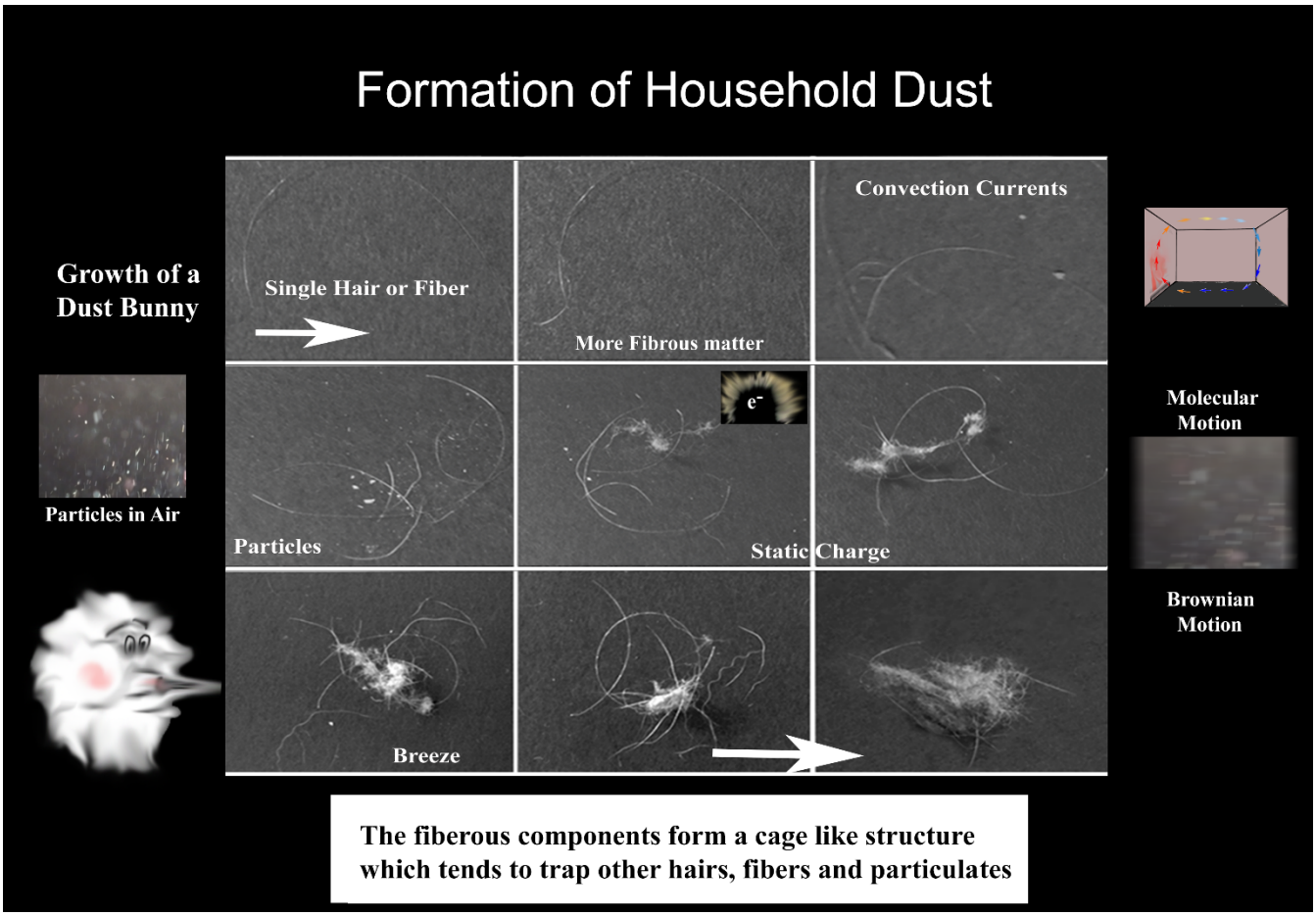


Figure 2-2 The formation of household dust (Dust Bunnies)

Whereas dust traces can encompass an infinite number of different materials, the authors have found that three primary morphological forms compose most specimens of dust:

1. Fibrous materials
2. Particulate matter
3. Structured substances

The three primary morphological forms of materials commonly observed in household dust specimens are listed in Table 2-1.

When searching for dust specimens, one must realize that there is no limit to the places or things specimens of dust can be found in or on. Therefore, one must keep an open mind when searching for dust. Some of the more common places and items to examine for dust traces are: under furniture, under radiators, attached to fans, in room corners, on items of the suspect's clothing such as shoes, outer garments, etc.; the victim's clothing; the suspect's or vehicle; any weapons or objects used

to commit the crime; and so forth. It should be noted that the type of crime can often guide the examiner in collection efforts. Gaudette presents a comprehensive listing for fibers.[34] Many of his suggestions apply to the other elements found in dust, and for aggregate dust specimens as well.

Table 2-1 A selection of the different substances, both fibrous and particulate, that have been encountered in dust specimens during the authors' casework.

Manifested Morphology	***Materials Encountered***
Fibrous	Human hair, animal hair, synthetic fibers, natural fibers, glass fibers, mineral fibers, asbestos fibers, vegetable fibers, lint, dust
Particulate	Mineral grains, glass fragments, saw dust, wood splinters and chips, paper fragments, paint chips and smears, brick fragments, plaster fragments, concrete fragments, chalk fragments, metal shavings, rust fragments, dried blood, tissue fragments, lint balls, welding balls
Structured	Skin Cells, finger and toe nail fragments feathers, pollens, spores, vegetable fragments, starch grains, Spices, tobacco, marijuana, bark, twigs, leaf fragments, seeds, plant hairs, wood fragments, food particles, bone fragments, insects, insect parts, shells and shell fragments, diatoms, glitter, tiny rocks

Of paramount importance to the successful analysis of forensic dust specimens is the procedure employed in the collection and preservation of the **various items of physical evidence to be examined. The associations made possibl**e by dust traces are based primarily on the mutual exchange principle attributed to Dr. Edmond Locard by Nickolls.[35] If one is familiar with Locard's original work, one can see that all the basic elements of this hypothesis are clearly set forth.[36] Simply paraphrased, this principle postulates "that whenever two people, places, and or things interact there is always a mutual cross transfer of trace materials from one to the other."

The trace materials that are transferred during these contacts make the stated associations and deductions possible. Therefore, *accidental contact* between the items of physical evidence that are to be processed for trace evidential materials must be guarded against to prevent contamination. To eliminate this possibility, one must keep each item of physical evidence separate. This is easily accomplished by wrapping each item individually in paper, securing with a druggist fold, or by placing each in a separate paper container. Prior to wrapping the items should not be handled by the same individual or allowed to come into contact with common surfaces. Vacuum sweepings or tape lifts should also be packaged in separate paper containers. It is the authors' opinion that plastic containers should be avoided because they often possess an electrostatic charge that can attract foreign dust traces, causing contamination of the evidence, or repel potentially valuable dust traces. Another factor that is extremely important is whether the item(s) of physical evidence is wet or dry. If wet, the item(s) should be air dried prior to packaging. If dry, the item(s) can be packaged in paper as previously described. Here again, plastic containers should be avoided because they retain moisture, thereby encouraging microbial (bacterial or fungal) growth that may cause biological decomposition. Finally, one must keep in mind that dust traces, due to their nature, are easily lost. To prevent inadvertent loss, the paper packaging should be free of small holes or perforations.

Once received at the laboratory, the dust traces must be collected from each item of physical evidence. A comprehensive discussion of the collection procedures for the recovery of dust has been given in this Handbook series.[37] Therefore, this section covers only the methodology normally used by the authors. It has been the authors' combined experience that a systematic approach is vital when retrieving dust traces, and that each item of physical evidence should be processed separately utilizing the following procedure.

The item to be examined should be removed from its container and laid out on a clean piece of paper that has been placed atop a well-illuminated examination table. The size of the paper is dictated by the size of the article being processed. Ideally, the room in which the examination takes place should be dust free (a clean room). If this is not possible, the room should be kept as clean as possible, and be situated in a low-traffic area of the laboratory. Adequate table top space for laying out the items of physical evidence should be available. Each item of physical evidence is first observed visually, and then with a stereo microscope. As pointed out by Palenik,[37] a boom stand is most useful for this purpose. Various forms and techniques of illumination (oblique lighting, monochromatic laser light, ultraviolet light, xenon or quartz halogen lamps with fiber optics or gel cables, and so forth) can aid in the visual location of dust traces. After location and documentation (sketching, photographing), all visible traces can be removed by hand with forceps or a needle.

Next, the item of physical evidence should be processed with some sort of transparent tape, as first suggested by Frei-Sulzer.[38] When using tape lifts to collect dust traces, the examiner should be aware that the position of the trace evidence on the item of physical evidence can be crucial to any reconstruction efforts. Therefore it is imperative to document the area(s) from which these traces are collected. Several studies and methods employing different approaches and adhesive materials have been published;[13,16,38-45] each has its own merits. The adhesive material and method to be used should be decided on by the individual examiner, depending on his or her own needs and resources. The authors use 1-inch-wide transparent latent fingerprint lifting tape. The item to be processed is taped in segments or quadrants. For example, a pair of men's pants would be taped as follows: 1) the upper or lower (U/L) front right leg, 2) the U/L front left leg, 3) the front top portion, 4) the U/L rear right leg, 5) the U/L rear left leg, 6) the rear top portion; inside areas such as pockets, cuffs, and interior legs are processed when necessary. Each tape lifting is marked for identification as to item and segment taped. The tape lifting is placed adhesive side down onto a clear Mylar® sheet to prevent contamination. After the taping process has been completed, the underlying paper should be checked for any trace material that may have fallen from the item being examined. This material should be collected and preserved for examination. The tape lifting's are observed with a stereomicroscope to locate traces of dust. Contrasting color backgrounds made from pieces of oak tag are useful when screening tapes. All tape lifting's should be stored in paper envelopes.

Finally, when necessary, the item can be vacuumed for dust traces. The vacuum sweepings trap described by Kirk can be used as demonstrated in Figure 2-3.[46] Another effective trace evidence vacuum trap has recently been described.[47] These devices are useful because it aids in the preliminary collects of the trace materials often found in sweepings. It should be pointed out that, although very efficient, vacuuming has many disadvantages; the primary one being that vacuuming often comingles the materials which were recently deposited (often the most important) with substances which were deposited long ago. In any case, vacuum sweepings should

be used only when **absolutely necessary,** only after visual and taping procedures have been previously conducted.[19,46 & 47]

•

Once collected, the household dust specimens are best preserved by storing in paper containers (boxes or paper folds), screw top glass jars, heavy-duty anti-static plastic jars, until examination, or for future reference.

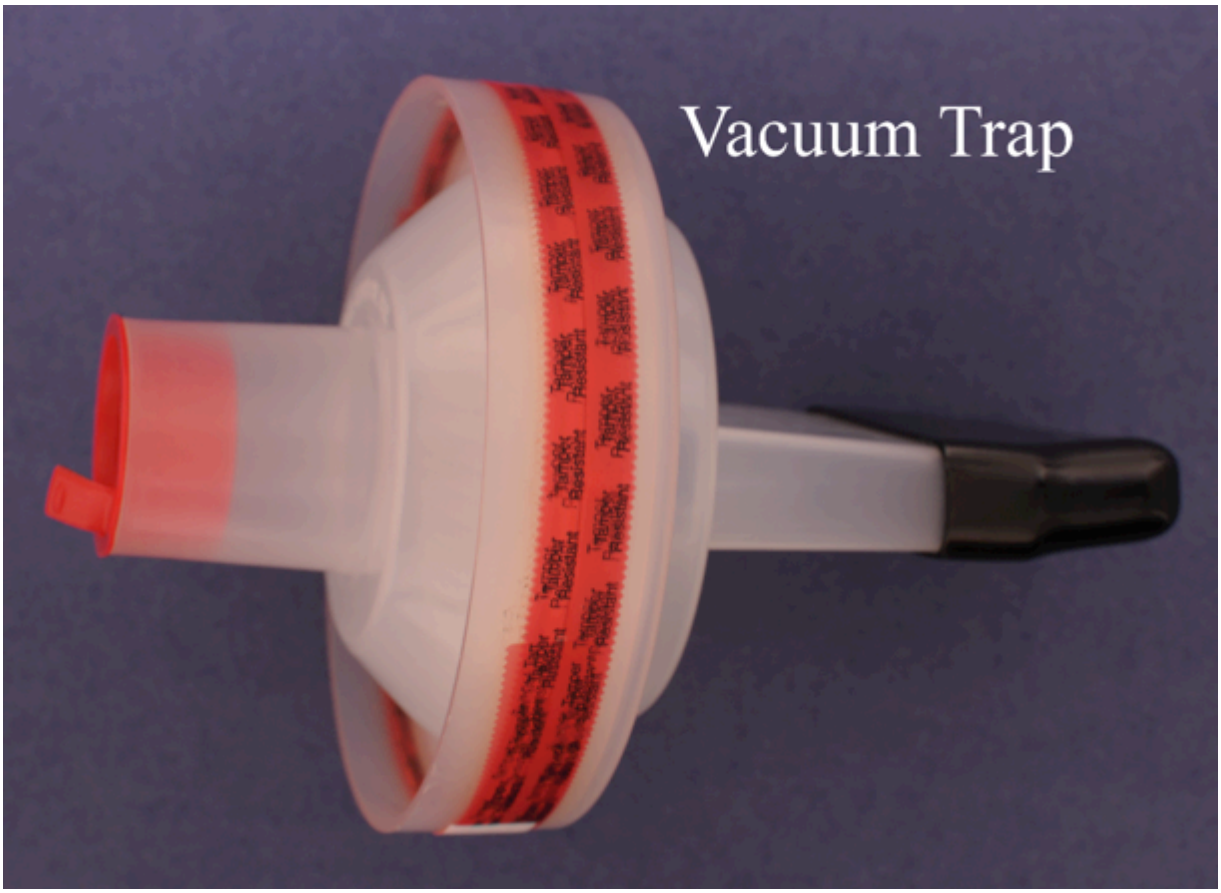


Figure 2-3 Trace evidence vacuum trap as described by Dr. Paul Kirk.

INITIAL EXAMINATION

All specimens of household dust should be examined visually and with a stereomicroscope for evaluation and sorting. A preliminary data sheet such as the one shown in Table 2-2 should be prepared for each dust specimen. The data collected in Table 2-2 can be used for the initial classification of the material(s) composing the dust specimen, and to guide the examiner to the appropriate identification procedure or scheme.

Table 2-2 Initial data sheet for the characterization and identification of the trace evidential materials commonly found in household dust. This data is obtained visually and with a stereomicroscope.

*Preliminary Data Sheet: Case No._____ Date_____

1. Preliminary Morphology

Fibrous □ Particulate □ Structured □ Mixed □

2. Homogeneous Yes □ No □

Fibrous	**Separate**	**Clustered**	**Both**
Particulate	**Separate**	**Clustered**	**Both**
Structured	**Separate**	**Clustered**	**Both**

3. Heterogeneous Yes □ No □

Aggregates of all primary forms Yes □ No □

No. of possible fiber types_____
No. of possible particle types_____
No. of possible structured types_____

4. Initial Classification(s)

Shape_____ Sketch:

Fibrous: Animal Hair □ Human Hair □ Faux Hair □

Synthetic □ Natural □ Mineral □ Metallic □

Particulate Glass □ Mineral □ Food □ Glitter □ Plant □ Other: _____
_____

Structured Human Skin □ Blood □ Plant □ Wood □ Mineral □ Other:_____
_____

Miscellaneous: _____
_____

*Circle, check or write in response

MICROSCOPIC METHOD

Sample Preparation

Prior to mounting, the dust specimen is held over a glass microscope slide with a flat cover slip forceps, and taped several times as illustrated in Figure 2-4. The particles which fall onto the microscope slide and paper are all collected and secured with a druggist fold, see Figure 2-4. This process has been found to be effective for collecting human skin fragments present in dust.[48]The collected material removed, placed in a druggist fold constructed from glassine weighing paper, packaged securely, marked for identification and forwarded for DNA analysis.

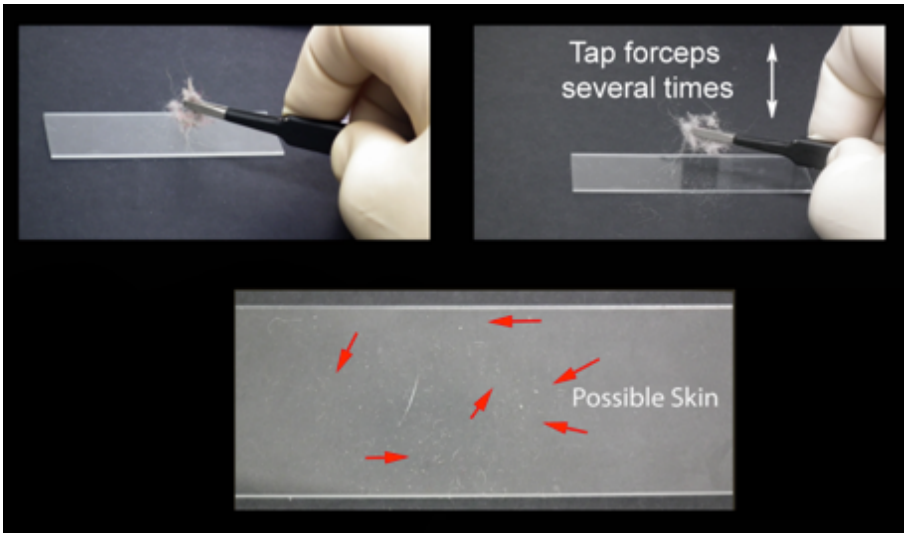


Figure 2-4 Demonstrated is the removal of skin fragments from a ball of dust.

If the specimen appears to be homogeneous, five (5) representative aliquots are mounted on a 75 mm x 75 mm glass microscope slide in either Cargille Melt Mount® with a dispersion (HD) RI oil 1.540 or Cargille Melt Mount® 1.539. The high dispersion oil, can be applied with a glass rod or small polyethylene eye dropper. The stick method for preparing Cargille Melt Mount® preparation has been used by the authors with great sucess.[47] Before mounting, the specimen may be teased with two needles to loosen the fibers and debris composing the dust. A representative sample of a heterogeneous dust specimen can be mounted in the same manner. However, large particles that cannot be mounted should first be sorted out for separate examination. After mounting, the specimen is examined with a polarized light microscope for characterization and identification. The mounting of a typical household dust specimen in high dispersion oil is demonstrated in Figure 2-5. Microscopic methods to characterization and identification the trace materials commonly found in household dust specimens are presented in the following pages. A dust data tabulation sheet shown in Table 2-3 is prepared for each dust specimen. The collected data is transferred to Excel data table and stored for statistical analysis.

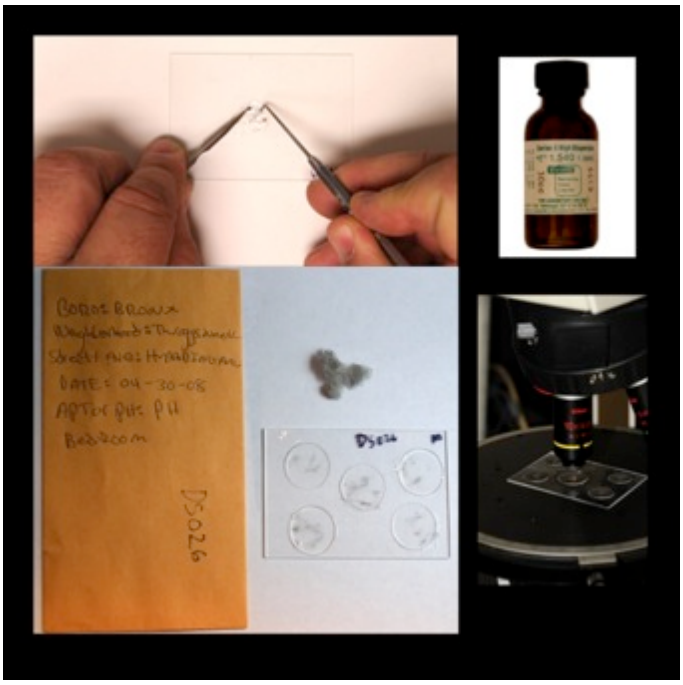


Figure 2-5 Five (5) aliquots of a house hold dust specimen are mounted in on a 75 mm x 75 mm glass microscope slide in Cargille's® high dispersion refractive index (R I) oil with an RI of 1.540 for Na D line at 25°C

The authors have found both Cargille ® High dispersion (HD) RI oil 1.540 and Cargille Melt Mount® 1.539 to be useful mounting media for the identification of many of the materials commonly encountered in household dust.[26,49 & 50] Both Cargille's® HD oil 1.540 and Melt Mount® 1.539 are stable material. Their intermediate refractive indices values enables the microscopist to observe internal morphological details that are necessary for characterization and identification purposes. When a change in relief (contrast) is required, it can be achieved simply by observing the specimen under plane polarized light while rotating the microscope's stage to change the specimen's orientation. The degree of relief (shadowing) change between the specimen and the mounting media depends on several important factors: whether the specimen is anisotropic with respect to its optical properties; the degree of birefringence within the specimen; and the value of the mounting medium's refractive index. If the substance is optically isotropic (possessing only one primary refractive index) there will be no apparent change in relief when the specimen's orientation is changed. If the specimen is optically anisotropic and at least one of its indices is higher or lower than that of the HD 1.540 oil or Melt Mount® 1.539, there will be a change in relief when the specimen is rotated. A review of forensic microscopy can be found in Volume of the Handbook series.[27]

In the event that a fiber or particle must be isolated or recovered from the mounted dust specimen, the Melt Mount® preparation is gently heated on a hot plate, the cover glass is removed, and the item is retrieved with a forceps or fine needle while the preparation is observed with a stereomicroscope. The fiber or particle can be washed with xylene to removed

excess mounting medium if it has been determined that the specimen is not soluble in xylene. The results obtained with these methods can be confirmed with other methods of analysis, such as Micro-FTIR, spindle stage methods, X-ray diffraction, SEM-EDXA, and so on.

Table 2-3 Data sheet for the characterization and identification of the trace evidential materials commonly found in household dust. This data is obtained visually and with a stereomicroscope and with a polarized light microscope.

Dust Data Tabulation Sheet Specimen #_____ Date Aquired_____
Location Acquired _____

Human Hr	C Brn	C Blk	C Gray	C Red	C Blonde	M	N	MX Brn	MX Other	N Gray					
Head															
Pubic															
Other Body Area															
Human Hr	C					M	N	MR							
Head [write in color(s)]															
Pubic "															
Synthetic	Red	Blue	Green	Orange	Brown	Black	Violet	Pink	Yellow	Other	Colorless				
Rug Olefin	Triangular	X-S													
Rug Nylon	"														
Rug Polyester	"														
Olefin	Any	X-S													
Nylon	"														
Polyester	"														
Acrylic	Dogbone	X-S													
Acrylic	Round	X-S													
Acrylic	Other	X-S													
Modacrylic															
Rayon															
Acetate/ Triacetate															
Animal Hr	White	Brown	Beige	Black	Gray	Red	W/Brn	W/Blk	W/Beige	W/Gray	Banded	Dyed Blue	Dyed Gree	Dyed Red	Dyed Aqua
Dog															
Cat															
Rabbit															
Mink															
Rodent															
Other ( )															
Natural F	Red	Blue	Green	Orange	Brown	Black	Violet/pu	Pink	Yellow	Colorless	Gray	Magenta	Aqua	Natural	Wine
Wool															
Silk															
Cotton															
Hemp															
Jute															
Sisal															
Manila															
Flax															
Insect Web															
Other ( )															
Mineral Fibers															
Fiber Glass Fibers (Resin)															
Slag/Mineral Wool															
Foams	Clear	Black	Pink	Yellow	Green	Orange	Burnt	Other							
Glass Chips		Clear	Amber	Brown	Blue	Other	Green	Orange	Yellow	Colorless	Other				
Safety Glass (Dice Pieces)															
Minerals	Red	Blue	Green	Orange	Brown	Black	Violet	Pink	Yellow	Colorless	Gray	Aqua	Transparent	Opaque	Magenta
Quartz															
Calcite															
Feldspar															
Micas															
Talc															
Other ( )															
Feathers		Duck	Pigeon	Parrot	Turkey	Other									
Insects/Insect Parts															
Vegetable Matter															
Pollen/spores															
Plant Hairs Star Shape															
Plant Leaves															
Plant Hairs															
Plant Parts															
Human Skin		Yes	No												
Finger or Toe Nail		Yes	No												
Blood		Yes	No												
Food Stuffs															
Sugar Grains															
Salt Grains															
Starch Paste															
Starch Grains															
Spices															
Artifical Sweetner															
Other															
Construction Debris															
Saw Dust															
Wood Chips/Slinters															
Brick Fragments															
Concrete Fragments															
Plaster Fragments															
Other															

CHARACTERIZATION AND IDENTIFICATION PROCEDURES

Human Tissues

Human blood crusts, skin fragments and hairs are encountered in specimens of household dust on a routine basis. Blood crust are frequently seen attached to fibrous structures as illustrated in Figure 2-1 a questioned dust specimen obtained during a double homicide investigation. Human hairs and skin cell fragments are regularly splayed within the dust matrix. Specimens of skin as they appear when mounted in HD 1.540 oil, and viewed with phase contrast microscopy and PLM in Figure 2-6.

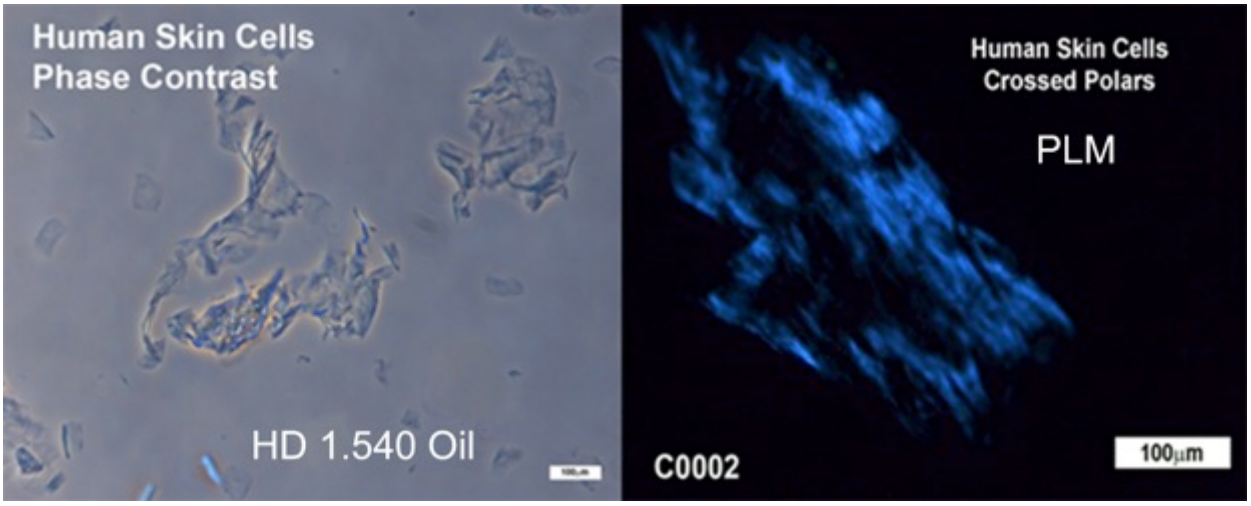


Figure 2-6 Appearance of human skin cell fragments mounted in HD 1.540 oil with phase contrast microscopy (left) and with PLM (right).

Human hair occurs in dust in many forms. First, complete hairs possessing an intact proximal (root) end, medial portion, and distal (tip) end, originating from various parts of the human body, are shed on a daily basis. These hairs can become airborne for short periods and eventually collect in the dust of a given environment or locality. Next, complete human hairs or hair fragments can accumulate in dust by normal grooming practices (such as brushing or combing) and by forcible means (such as pulling or cutting). Finally, hair that has been burned can become airborne, and thus find its way into the dust of a given location. Such hair, if severely burned, is often rendered unsuitable for identification or comparison purposes although it may have investigative value (see Figure 2-7).

If human hair stays in dust for a prolonged period of time, it can become broken or damaged by mechanical action, or decomposed by microbial or insect activity. Figure 2-8 shows a human hair that has been partially eaten. Chille et al. attribute this phenomenon to insect activity.[51] Significance of environmental exposure and its evidential interpretation has also been the subject of recent study.[52] Figures 2-9 and 2-10 illustrate the appearance of twisted and tangled human hairs specimens often encountered in dust specimens.

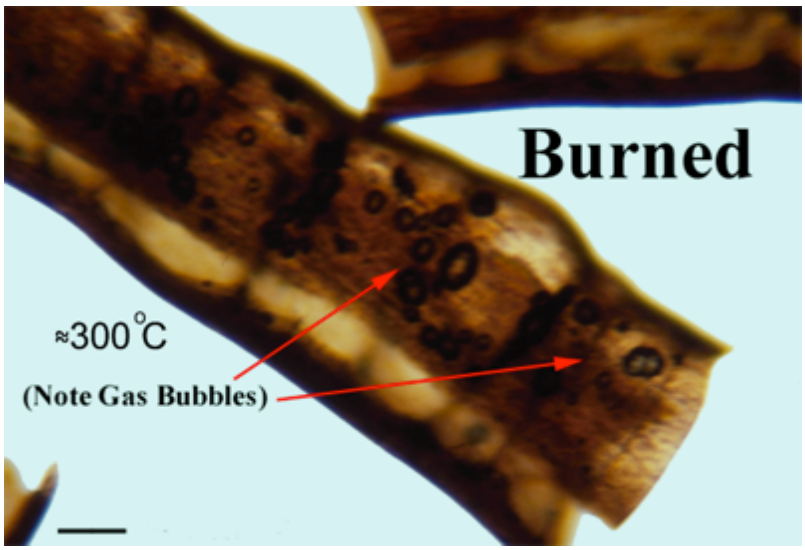


Figure 2-7 Burned human head hair found on the clothing of an arson suspect. Note the expansion of the cortex, and the gaseous bubbles. Human hair typically starts to burn at approximately 300 °C. The specimen is mounted in Melt Mount® 1.539. The black bar is equal to 50μm.

The identification and comparison of human hair is based on its physical morphology. A complete discussion of human hair examination is given in this Handbook series by Bisbing.[28] Identifying characteristics of human hair are readily observed when the hair is mounted in Melt Mount® 1.539.[26,49 & 50]

A brief discussion of the differentiation of human hair from the hair of other mammals is given by Hicks.[53] Figure 2-11 depicts the three primary anatomical regions of hair used in species identification: the cuticle, the outermost layer of hair, which is composed

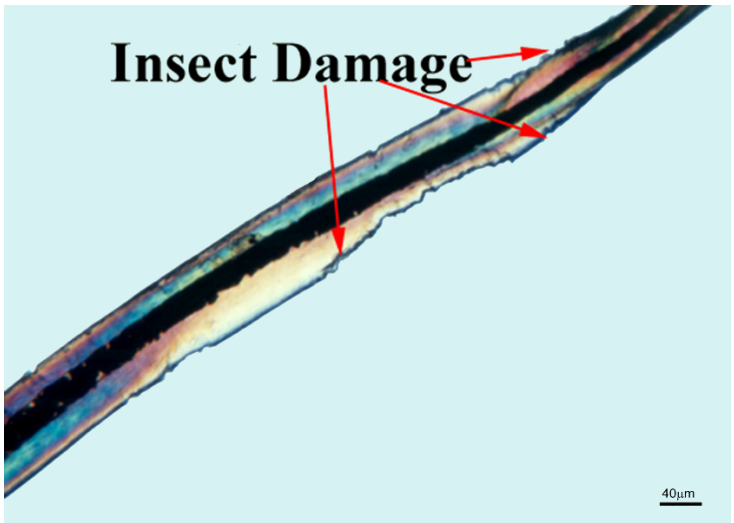


Figure 2-8 Shown is appearance of a partially eaten (insect bites) human pubic hair as it manifests in a household dust specimen. The specimen is mounted in 1.540 HD oil, and is viewed between parallel polars.

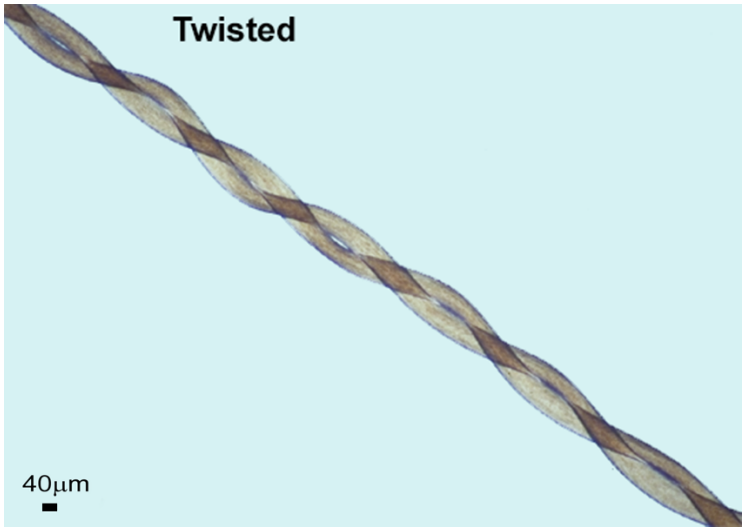


Figure 2-9 Twisted human head hair.

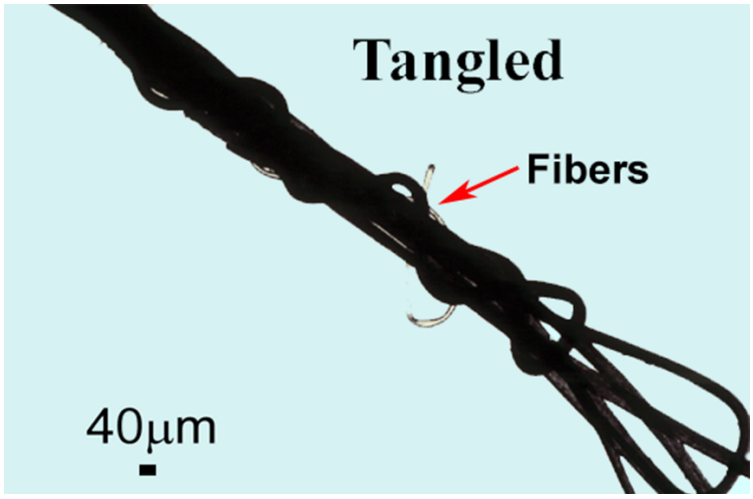


Figure 2-10 Tangled human head hair.

of many layers of overlapping scales; the medulla, the central canal of the hair (can appear present or absent); and the cortex, the primary tissue composing the hair. The cortex contains the pigment granules, cortical fusi, and the other morphological features that make up hair. Figure 2-11 also shows a cast of the dominant scale pattern usually associated with hair of human origin. A procedure for the preparation of a temporary scale cast in Melt Mount® 1.539 has recently been published.[52] When necessary for identification purposes, a hair can be isolated from the dust specimen as previously described, cast in Melt Mount® 1.539, as detailed below, and then remounted in Melt Mount® 1.539 for further study.

The specimen to be cast is placed on a microscope slide which has had a thin layer of Melt Mount® 1.539 spread over most of its top surface. The slide containing the hair specimen is then heated on a hot plate (65-70°C) until the solid layer of Melt Mount® melts. The slide is then removed from the hot plate and allowed to cool until the Melt

Mount® hardens. The hair which is now embedded in the Melt Mount® layer is peeled from the microscope slide. The resulting impression of the hair's scale pattern(s) can now be observed directly with a microscope at 100X.[54]

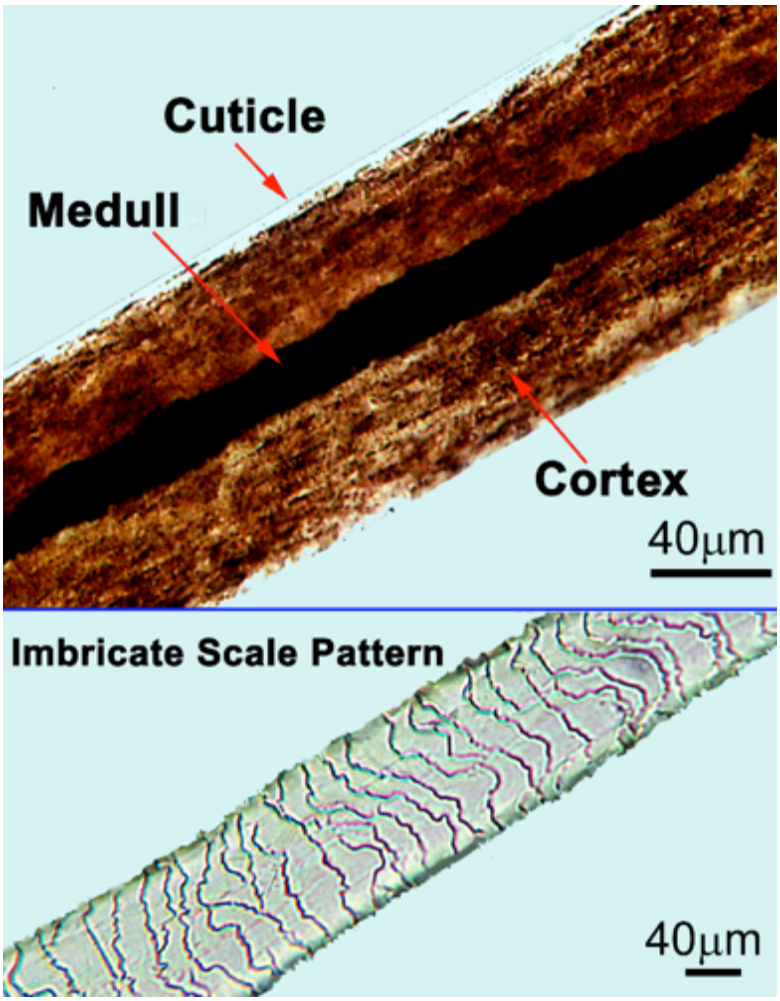


Figure 2-11 A human head hair cast and mounted in Melt Mount® 1.539. On the top, the three primary anatomical regions of a human hair: the cuticle (CT); the medulla (M); and the cortex (C), as they appear in Melt Mount® 1.539. On the bottom is shown a typical imbricated scale pattern (I) common to hair of human origin. The hair cast is shown from the proximal end (P), to the distal end (D).

Human hair seen in household dust specimens usually originate from the head or pubic regions of the body. However, hairs derived from other body areas such as the face, limbs, truck and frequently occur. Therefore, examiners should familiarize themselves with the morphologies of all types of human hairs. Bisbing, Hicks, Petraco and Olgelist the various morphological characteristics used to determine the somatic origin of human hair.[55-57 & 63] Figures 2-12 through 2-14 show the primary physical characteristics used in the identification of human head, pubic and limb hairs. Other configurations can and often do occur; for example, various important root morphologies are shown in Figures 2-17. Several studies of their forensic significance has been published.[58-60] Other anatomical regions of human hair, such as the distal end (tip) and shaft, can vary as well. Many of the characteristics of human hair can be found in the several contemporary published works. [61-63]

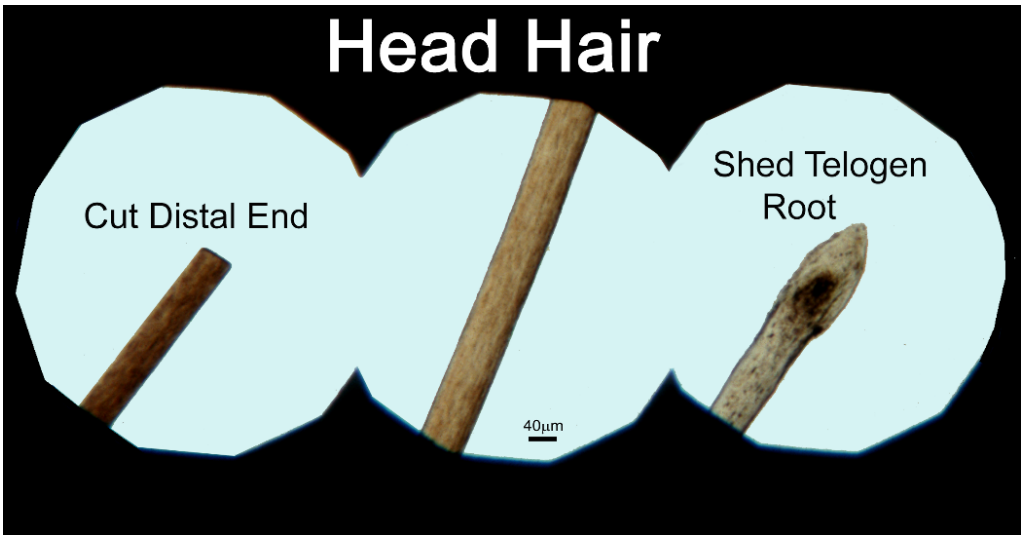


Figure 2-12 The morphological appearance of a shed human head hair showing the cut tip, the telogen stage root, the even shaft.

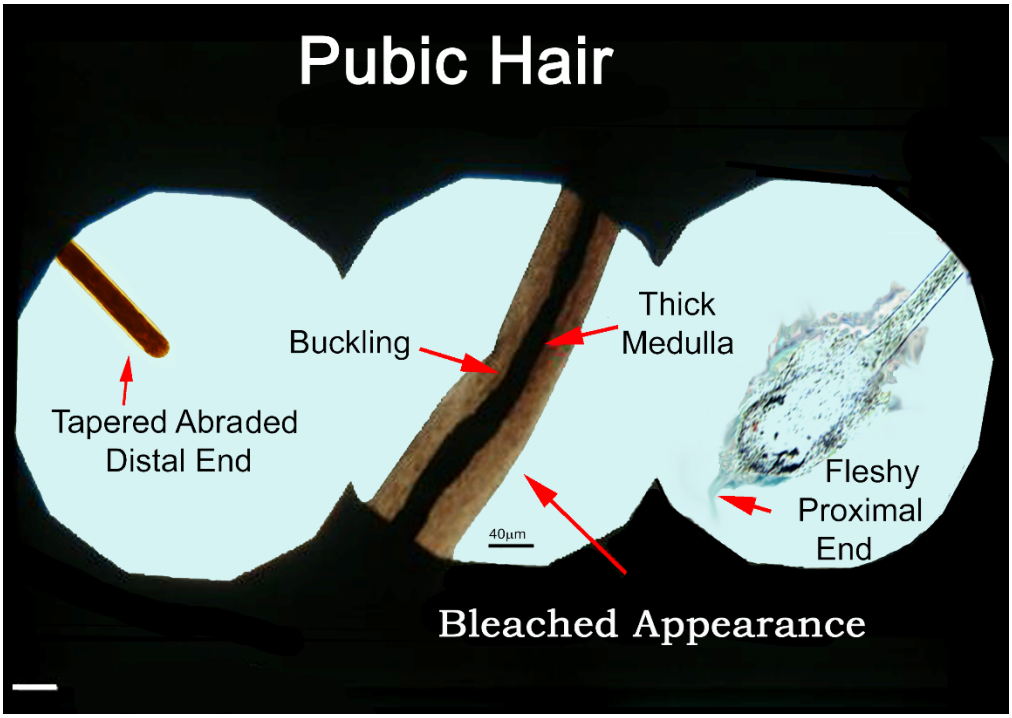


Figure 2-13 The morphological appearance of a shed pubic hair with its abraded tip, fleshy root, broad amorphous medulla and buckling along its shaft.

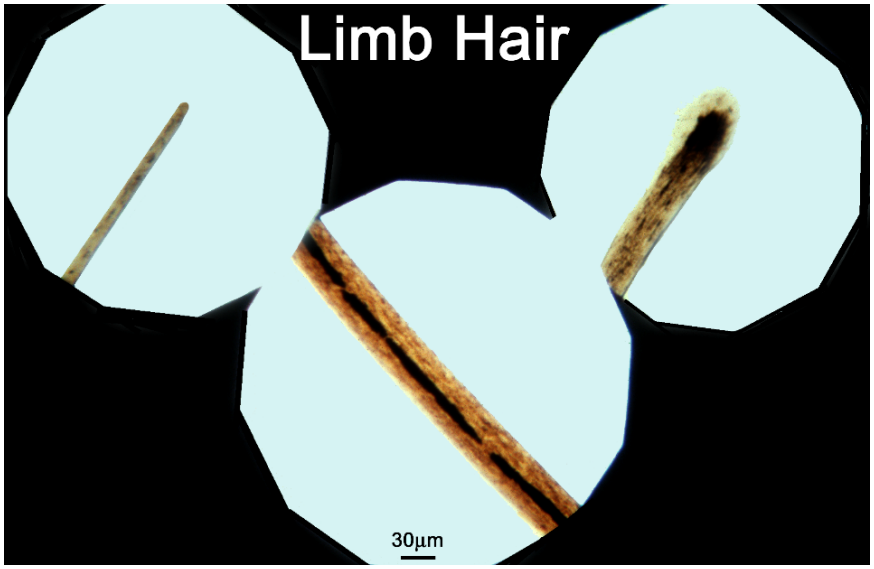


Figure 2-14 The morphological appearance of a shed limb hair with its abraded tip, telogen root, uneven pigment granules and narrow curved shaft.

The somatic origin (body region) and the ancestral background (part of world) of a person who is the potential donor of a questioned hair can often be of vital investigative interest. Both somatic and ancestral origin are made on the basis of morphological features of hair. Olge and Petraco illustrate most of these features with quality photomicrograph.[55, 60-61] Head hairs exhibiting the primary characteristics used to determine somatic and ancestral origin are presented in Figures 2-15 through 2-17.

Figure 2-15 The morphological appearance of a head hair from a person with African ancestry.

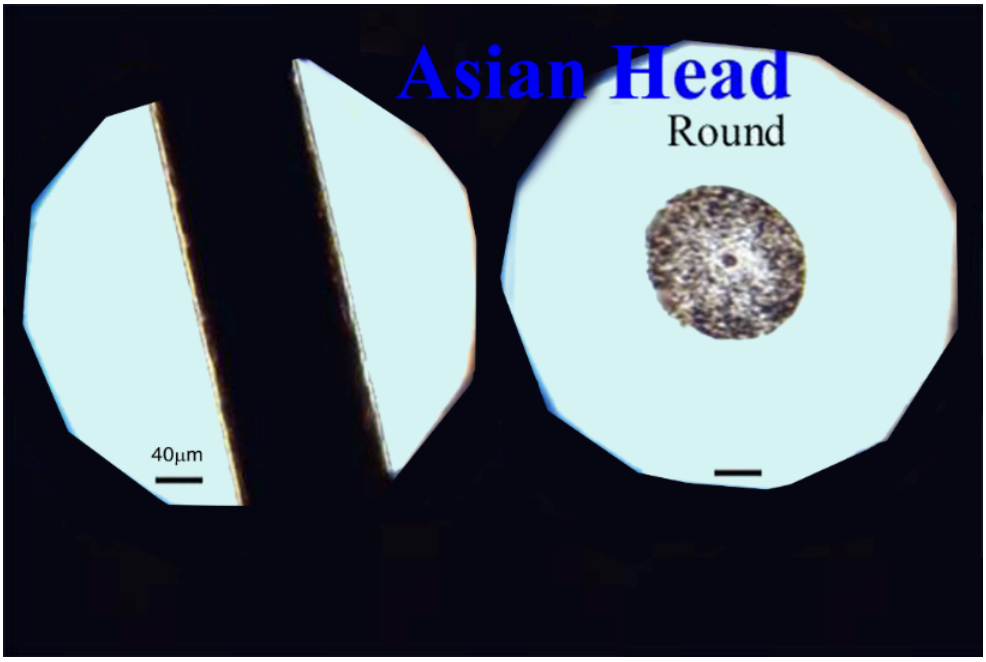


Figure 2-16 The morphological appearance of a head hair from a person with Asian ancestry.

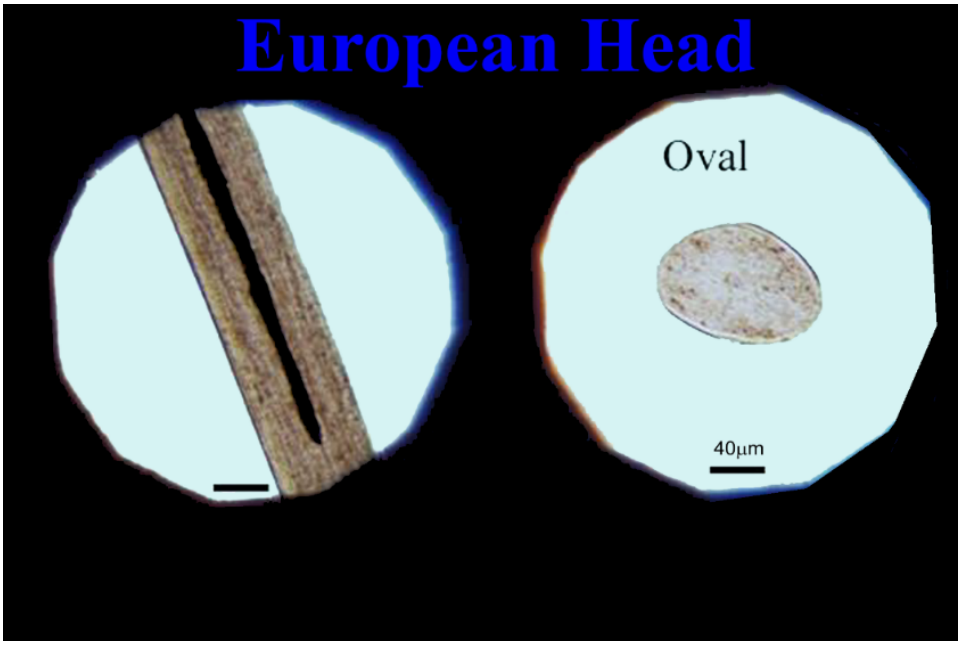


Figure 2-17 The morphological appearance of a head hair from a person with European ancestry.

It is vital to note that the observations necessary for determining the somatic and ancestral origin of questioned human hair can be made while the hair is still mounted in the matrix dust specimen, without the need for isolating, demounting, or otherwise manipulating the dust preparation. The authors have successfully compared questioned and known hair specimens while the questioned hair was still mounted in the original HD oil or Melt Mount® preparation.

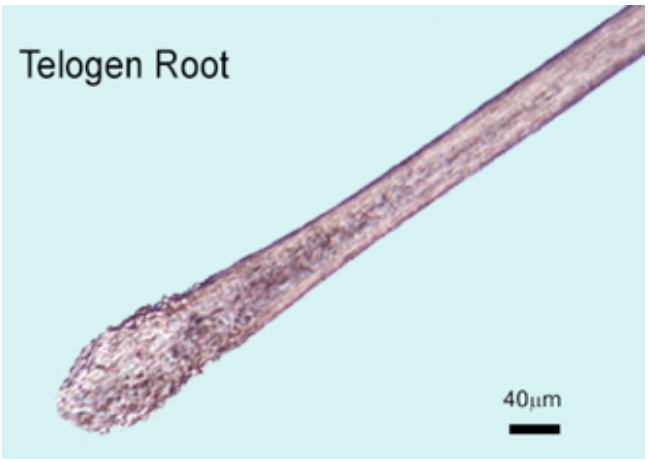


Figure 2-18 Telogen root growth stage typical of shed human head hair.

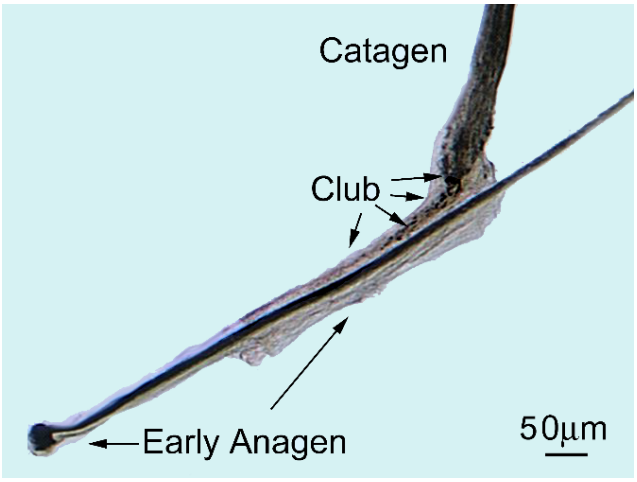


Figure 2-19 Catagen and anagen growth stages of human head hair roots.

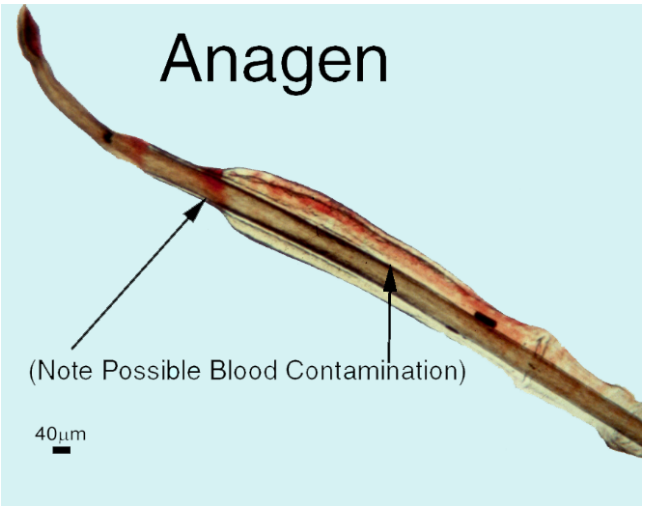


Figure 2-20 Anagen growth stages of human head hair roots with possible blood contamination.

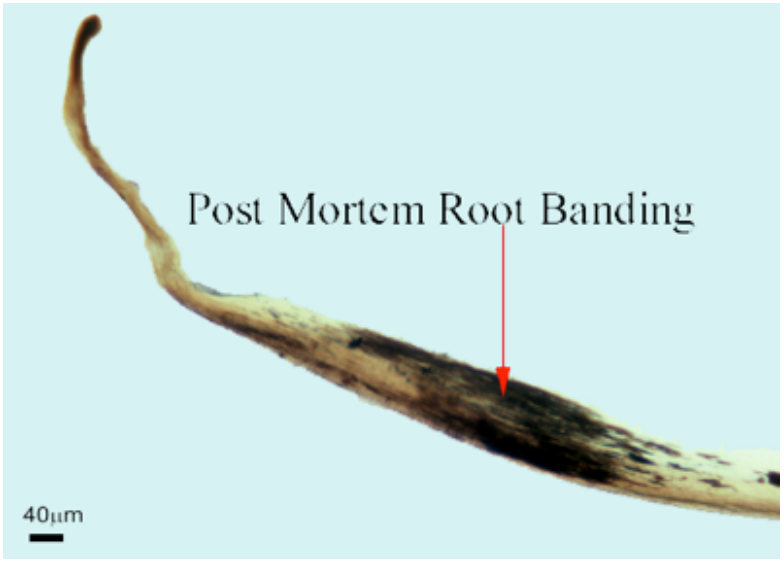


Figure 2-21 Human head hair in anagen root stage exhibiting post mortem root banding (PMRB).

Figure 2-22 Root end of a head hair removed human skeletal remains, black bar equals 100µm.

Many protocols for the examination and comparison of human hair can found in the literature.[64-75] Table 2-4 is a data sheet used to the collection, tabulation, and interpretation of the data somewhat easier. The data recorded in Table 2-4 is used to help establish the somatic and ancestral origin of a questioned hair. The final information is recorded in Table 2-3.

Table 2-4 Question Human Hair Data Sheet – Write in response

Macroscopic Characteristics

Gross Features	
Length	
Color	
Shaft shape	
Texture	

Microscopic Characteristics

Cuticle	
Margin	
Pigment	
Shape	
Thickness	
Color	

Cortex	
Tip shape	
Color	
Color distribution	
Cross-sectional shape	
Pigment granule shape	
Pigment distribution	
Pigment density	
Shaft diameter range	
Shaft thickness variation	
Cortical fusi	
Root structure	
Root shape	
Root end	
Growth stage	
Cortical damage	
Foreign substance	
Oddities	

Medullary Structure	
Medulla	
Amorphous/opaque	
Amorphous/transparent	
Cellular/opaque	
Cellular / transparent	
Distribution	
Thickness	

Animal Hair

Animal hair often occurs in forensic household dust specimens, both as complete hairs and as air fragments. The basic morphology of a mammalian hair (not human) is shown in Figure 2-23. Animal hairs role as evidence in forensic investigations has been established. [2-13, 17, 26, 76-84] Animal hair accumulates in dust in much the same manner as does human hair. Many domestic pets shed hair on a daily basis. Hair from grooming pets finds its way into the dust of a given location. Animal hair originating from articles of clothing and other textile materials made from animal hair or fur can become airborne and thus be incorporated into the dust of a given environment. A scheme to aid in the identification of the various species of animal hair that commonly occur in forensic science casework has been published.[26] This scheme utilizes Cargille's Melt Mount®1.539 as the mounting media.

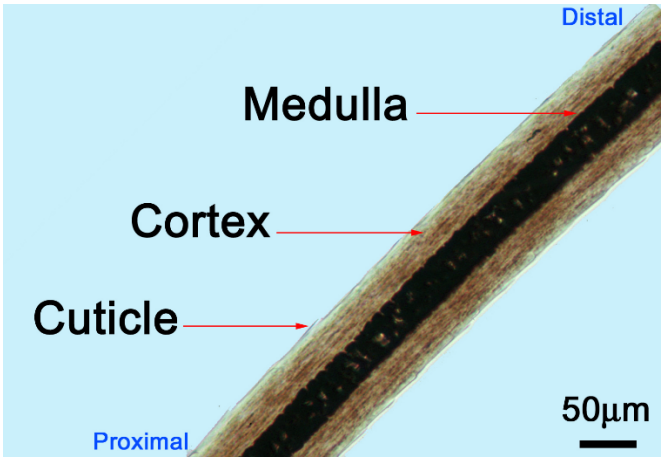
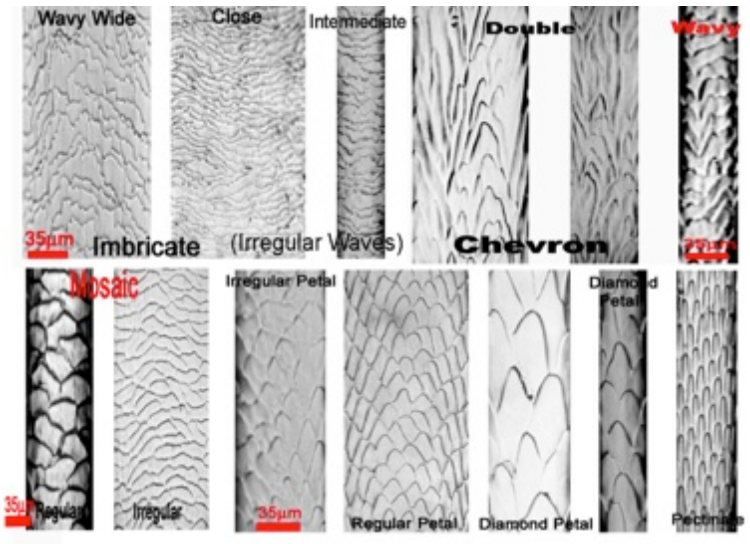


Figure 2-23-The morphology of a mammalian hair (not human).

Complete animal guard hairs present in dust specimens are sorted out during the initial examination. These hairs should be examined visually and with a stereomicroscope. Each hair is sketched and measured, and its' reflected light color(s) and color banding are noted. The data is recorded on a data sheet (see Table 2-5). After preliminary examination, the hair's scale pattern is cast in Melt Mount® 1.539.[54] Next, a wet mount of the guard hair is prepared in Melt Mount® 1.539. Occasionally it becomes necessary to cross section a guard hair for identification purposes. When this is required, and only if there is a large enough sample size, a cross section can be prepared in a few minutes with plastic microscope slides.[85] The specimen is then examined under plane polarized light with a polarized light microscope.

The scale cast is examined first. The dominant scale pattern in the basal region (near the root) of the hair is noted. Next, the scale pattern(s) from root to tip is scanned and noted. Figures 2-24 display examples of the six basic scale patterns. The wet mount is then examined to collect information concerning the specimen's transmitted light color, medullary configuration, and so on (see Table 2-5). Figure 2-25 depicts five primary medullary configurations. All the observations are recorded on the data sheet shown in Table 2-5. A review of mammalian hair morphology and terminology can be found in the literature.[79-84, 86-81] The collected data should be compared with the data in Figure 2-26 for the preliminary identification of the family or species from which the questioned hair originated. In order to confirm the identification, the specimen is then compared with reference standards and data published in various articles, identification keys, manuals and atlases.[84, 86-91]



Figures 2-24 Examples of basic scale pattern.

Table 2-5 A data sheet containing the information necessary for characterizing commonly occurring animal hair.

Animal Hair Data Sheet

Cuticle
Dominant scale pattern basal (base) region (Figures 2-23):_____
_____
Scale pattern(s) along shaft (describe from root to tip):_____
_____
Appearance of cuticle (scale) margin: _____

Cortex
Shape of Shaft: Straight____ Curly_____ Wavy_____ Crimped_____ Other_____
Shaft Length: _____mm Sketch:
Color: Single Color_____ Bicolored_____ Multicolored _____
If more than one color describe root to tip:
_____
Banded reflected color: _____
Banded transmitted color: _____
Pigment density and distribution: _____
Shaft diameter in µm: _____ Range _____ Average _____ Maximum _____
Root shape: _____ Cross-sectional shape: _____
Miscellaneous: _____

Medulla: Absent_____ Present_____
Primary Medullary Configuration): _____
Medullary Index (M.I.) = Medulla diameter/shaft diameter
M.I. = _____

Figure 25 - Examples of primary medullary classes.

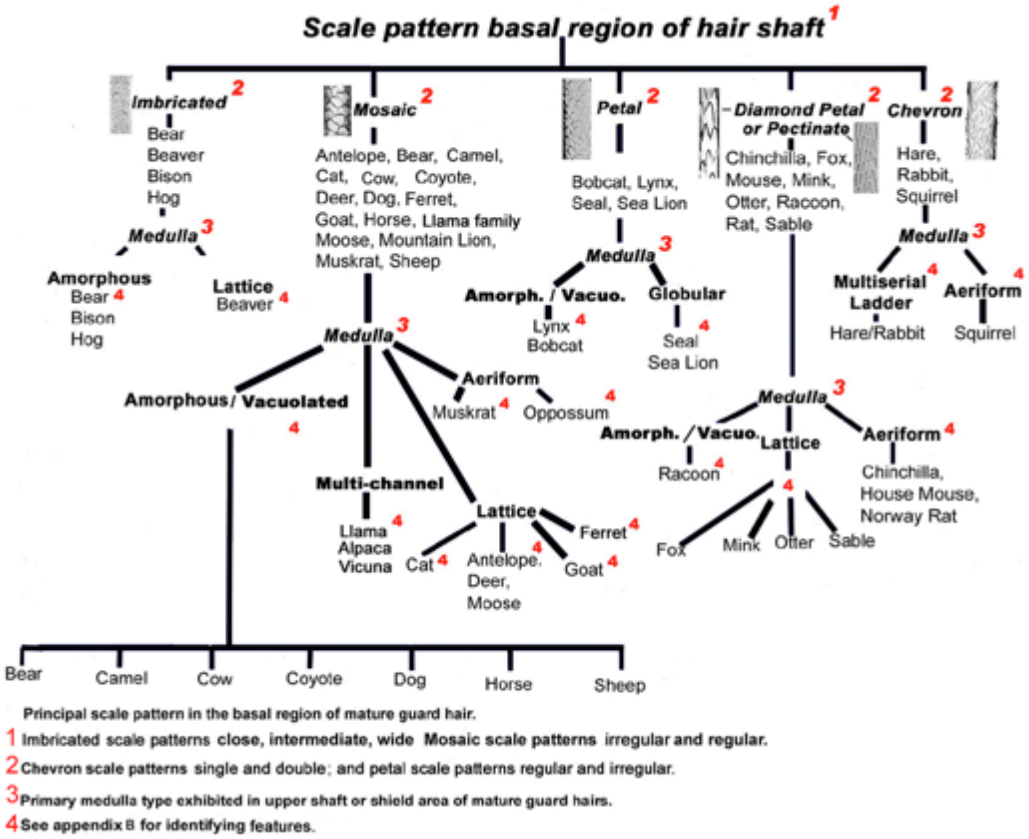


Figure 2-26 - Flow chart for the preliminary identification of the family or species from which the questioned hair originated. In order to confirm the identification, the specimen is then compared with reference standards.

Often, animal guard hairs, under (fur) hairs, and fragments thereof can be tentatively identified as to species or family of origin on the basis of a few morphological characteristics without an elaborate identification scheme. The need and ability to do this is useful when examining forensic dust specimens. Figures 2-27 exhibit several types of animal hairs that frequently occur in forensic household dust specimens that can

be quickly identified. In order to identify these types of specimens accurately, one must have a thorough knowledge of animal hair morphology. This knowledge can be acquired by studying the morphology of hairs from known sources. Study specimens can be obtained commercially and from museum collections. It is advised that one should acquire this background knowledge before attempting to identify hair and hair fragments. Information concerning each animal hair is recorded in Table 2-3.

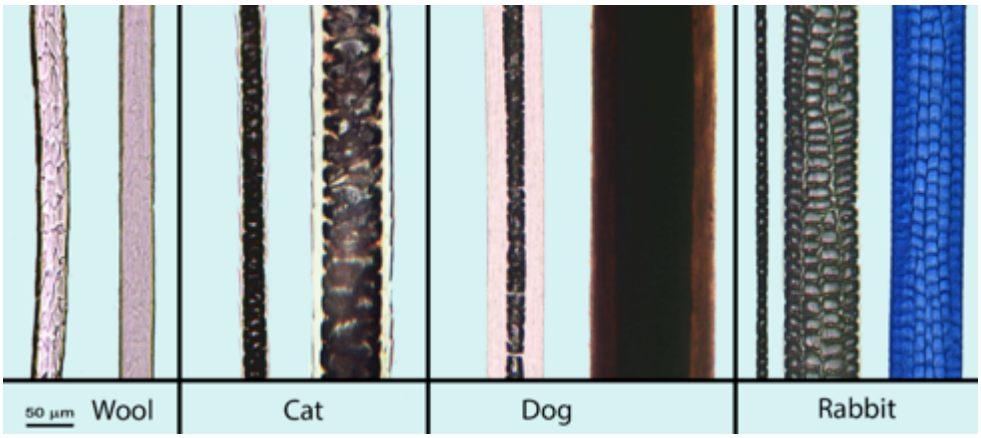


Figure 2-27 – The appearance of several types of animal hairs that frequently occur in forensic household dust specimens

Synthetic Fibers

Today, with the large production of synthetic fibers for all types of textile products, our environment is literally inundated with minute fragments of fibers. Dust specimens composed of synthetic fibers rolled together into balls with other materials to form dust bunnies which are ubiquitous. These dust balls are formed from the erosion or wearing away of textile materials (rugs, mats, clothing, and so forth), as well as the hair from animals and people, natural fibers, and other materials in our environment as demonstrated in Figure 2-2. Dust balls have been compared to soil samples and, like soil samples, often represent the environment(s) in which they are formed.[92] The synthetic fibers entangled in these dust specimens can be identified in the matrix specimen.

The dust specimen is mounted on a microscope slide in Melt Mount® 1.539 or 1.540 HD Oil, as previously described in Figure 2-4. Prior to mounting, the specimen should be teased with two needles to loosen the fibers, hairs, and other debris. After mounting, the preparation is then observed under a polarized light microscope. The microscopist, upon examining the dust preparation, will observe a variety of fibers. At this point, examiners must use their eyes to single out the fiber in question and make a number of observations.

Information concerning the fiber's morphology is collected first. Next, the relative refractive indices (RRI's) of the fiber's $n_{\parallel}$ and $n_{\perp}$ directions — as they compare with the mounting medium's RI — are obtained by the Becké line method using plane polarized light. In the Becké line method the fiber's elongated axis is made parallel to the vibrational (preferred) direction of the polarizer (E—W). The movement of the Becké line is noted when the microscope's focus is raised (the Becké line moves toward the medium of

higher RI under these conditions). The fiber's elongated axis is then made perpendicular to the preferred direction of the polarizer and the movement of the Becké line is noted in this orientation; see Figures 2-28 and 29 for orientation of the fiber and for Becké line movement.

The fiber is then observed between crossed polars. If the fiber is optically anisotropic, the amount of retardation the fiber exhibits is estimated using an interference chart and the appropriate compensator(s). The fiber's sign of elongation (SE) is determined at this stage of

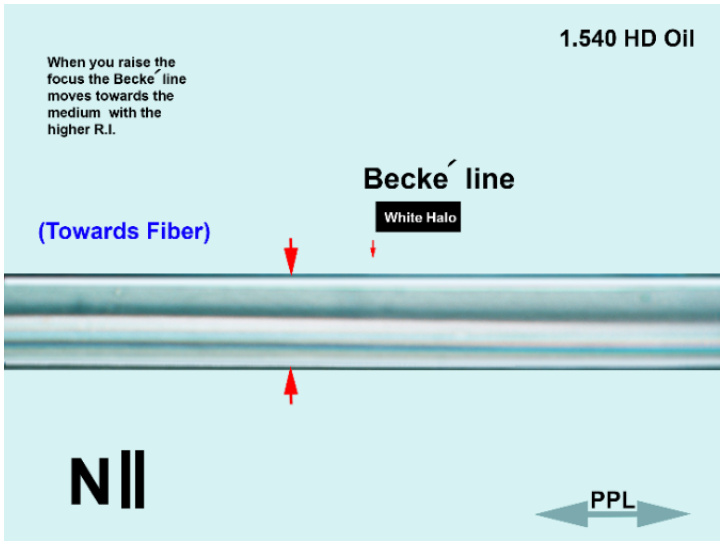


Figure 28 – The orientation of the direction of vibration of the plane polarized light from the condenser (E-W) with the n ‖ direction of the subject fiber. Note the inward movement of the Becké line (white halo) towards the fiber thus indicating that the fibers n ‖ is higher than the mounting medium's (1.540) in this orientation.

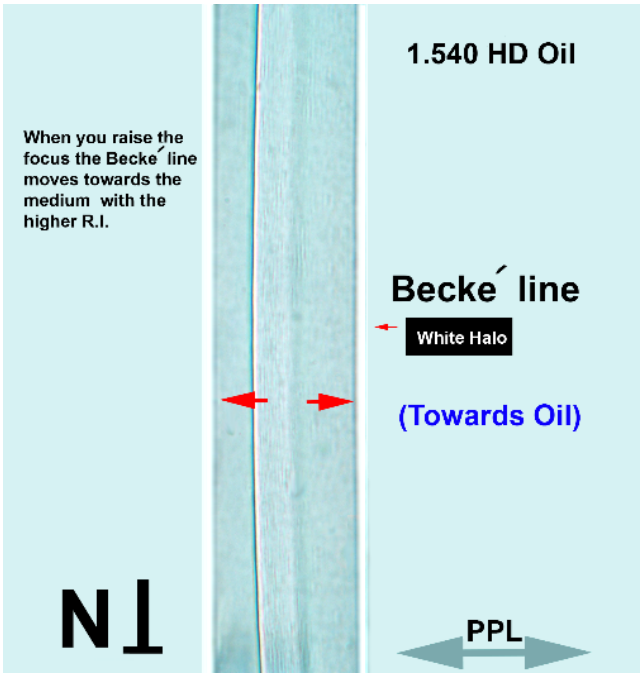


Figure 29 – The orientation of the direction of vibration of the plane polarized light from the condenser (E-W) with the n ⊥ direction of the subject fiber. Note the outward movement of the Becké line (white halo) towards the medium thus indicating that the fibers n ⊥ is lower than the mounting medium's (1.540) in this orientation.

the examination. The fiber's estimated birefringence (EB) is computed using the collected data. Other comparative data concerning the fiber's appearance [delustering agent (Figure 2-30), twist (Figure 2-31), crimp (Figure 2-32), fish eyes (Figure 2-33) and so on] and optical properties [degree of relief (Figure 2-34), and so forth] is collected.

All the data are recorded in the examiner's notes or on a fiber data sheet. A sample data sheet is shown in Table 2-6. The information from this table is used in conjunction with the flow chart shown in Figure 2-35 to identify the generic class of synthetic fibers commonly seen in specimens of household dust. Each type of fiber in the dust specimen is identified in the same manner. If a comparison of a fiber is desired, the questioned fiber (in the matrix dust specimen) and the known fiber specimen(s) can be compared side by side on a comparison microscope composed of two polarized light microscopes that have been optically bridged together. Known fiber standards can be compared in the same manner. The information for each fiber is recorded in Table 2-3.

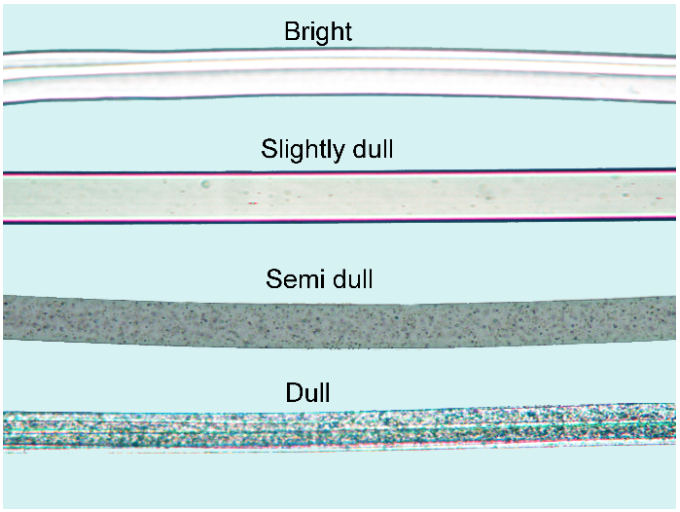


Figure 2-30 – The appearance of synthetic fibers with and without delustering agent.

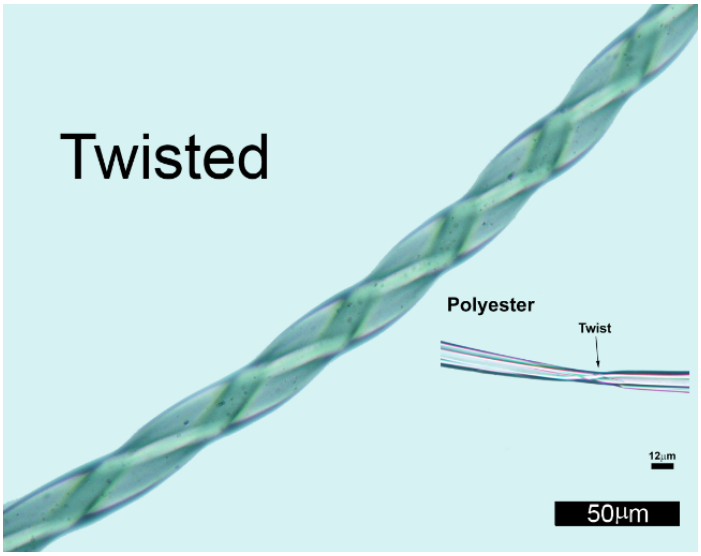


Figure 2-31– The appearance of a synthetic fibers with twist treatments.

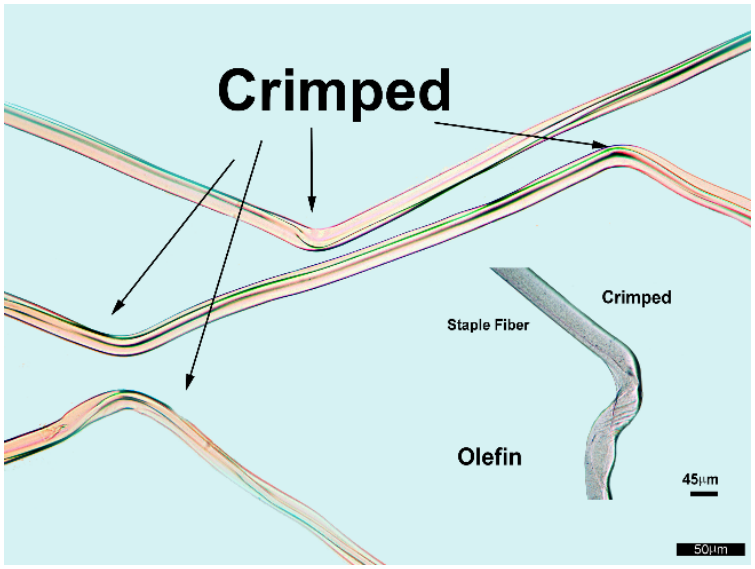


Figure 2-32 – The appearance of a synthetic fibers with crimped treatments.

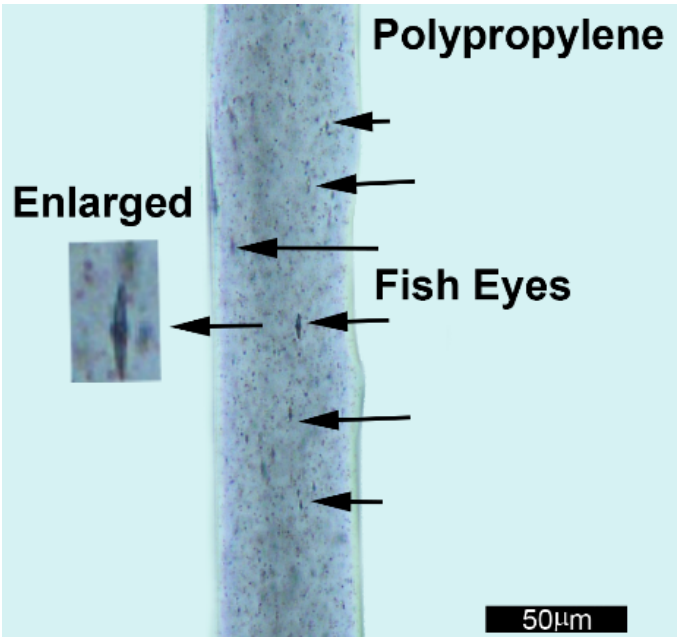


Figure 2-33 – The appearance of a synthetic fibers with "fish eyes."

In Figure 2-36 a questioned fiber is viewed between crossed polars, it is determined to be anisotropic because interference colors are observed. Its thickness, as measured with a calibrated ocular micrometer, is 20µm, while its retardation is estimated to be 450nm, with a full wave fixed compensator. The fiber's sign of elongation is determined to be positive. The fiber's birefringence is estimated to be +0.022 when the thickness and retardation values are plotted on an interference chart as shown. The fiber is identified as viscose rayon.

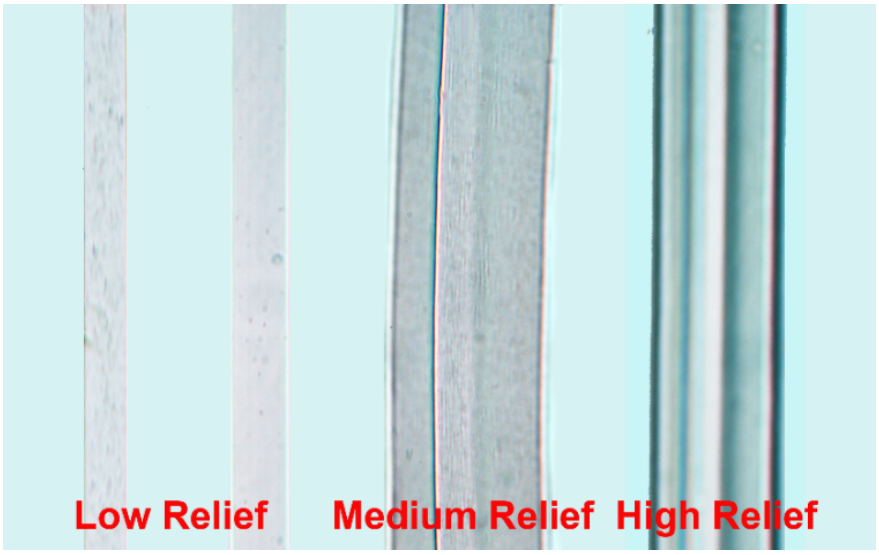


Figure 2-34 Degree of relief.

Table 2-6 A data sheet with the information necessary for the classification of synthetic fibers. Circle and/or write in the appropriate data. Each synthetic fiber is recorded in Table 2-3.

Synthetic Fiber Data Sheet

Fiber Morphology

Longitudinal: Smooth Striated Irregular Other _____
Cross-sectional shape: _____
Diameter or lobe(s) thickness in µm: _____
Continuous length Staple length

Optical Data

Relative refractive indices- relative to medium (1.539 or 1.540)
N parallel (n∥) above_____ below_____ equal_____
N parallel (n⊥) above_____ below_____ equal_____
Crossed polars: Isotropic_____ Anisotropic_____
Estimated retardation in nanometers (nm) _____
(interference colors)
Degree of relief: Low Medium High Very high
Estimated Birefringence (EBi) _____
Sign of elongation: Positive_____ Negative _____

Other Comparative Information

Color: _____ Dyed_____ Undyed_____
Delustering agent: Bright Slightly Dull Semi Dull Dull
Treatment: Crimped Twisted Other _____

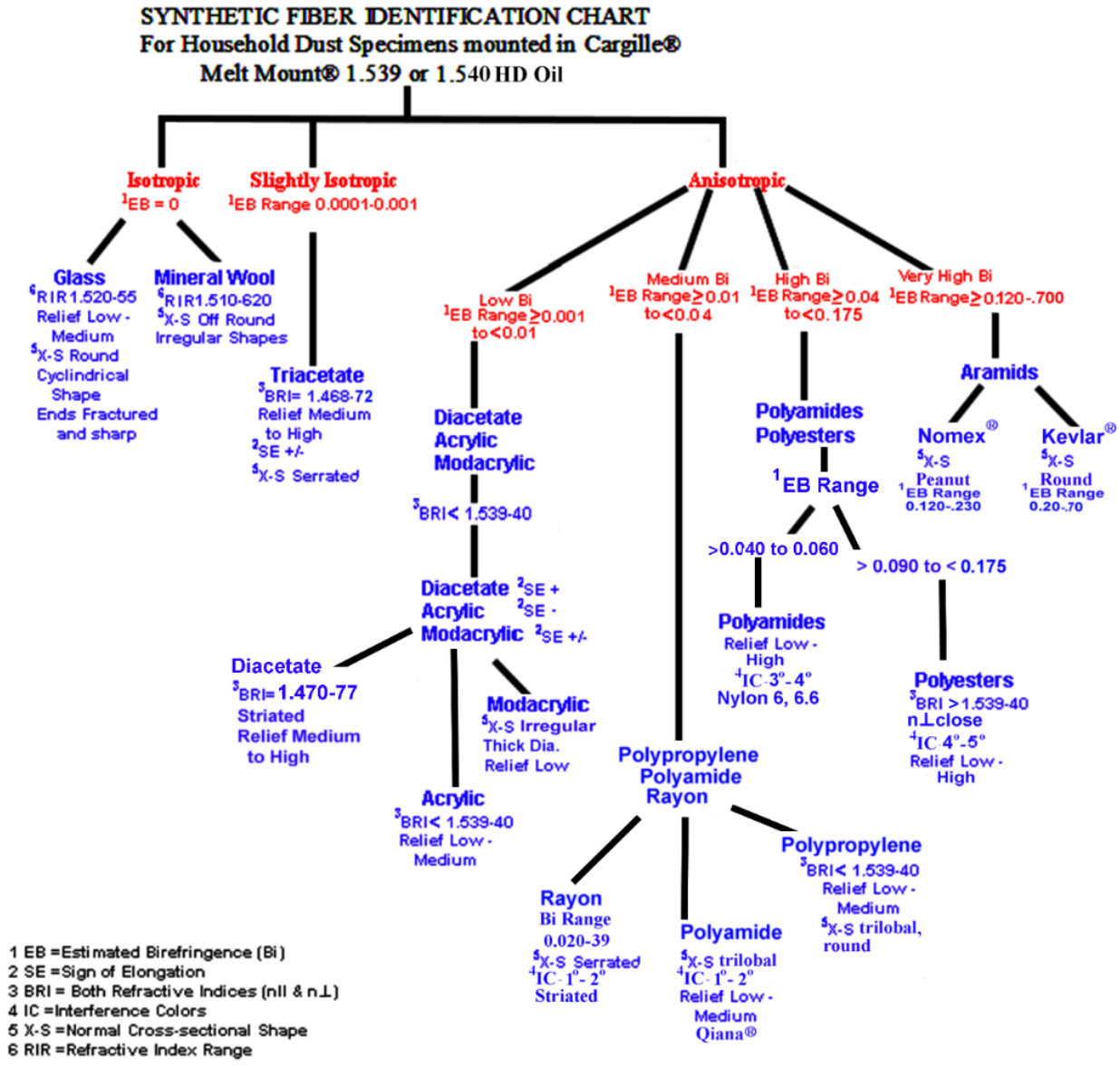


Figure 2-35 - Flow chart for the identification of synthetic fibers commonly encountered in household dust. (Sources of data: references 25, 32-33, 93-96, 99-100).

Minerals, Glass, and Related Materials

Mineral grains form a large proportion of soil specimens. The identification and ratio of each mineral species as it occurs in soil samples has long been a subject of interest in the forensic science community.[1,12,14,24,31,36,101-04] An excellent paper by Graves on soil classification ,which is based on mounting aliquots of sieved soil specimens in Cargille® oil with a refractive index of 1.540 for the sodium D line at 25°C has set the standard for forensic soil mineralogical studies since its publication.[24] McCrone's work on soil comparisons and mineral identification also serves as an extremely valuable and informative source.[104] Together, these two methods provide a sound and rational approach to the identification of mineral grains, glass chips, and the other related

materials often encountered in forensic dust specimens. In this chapter we adapted Graves' approach.

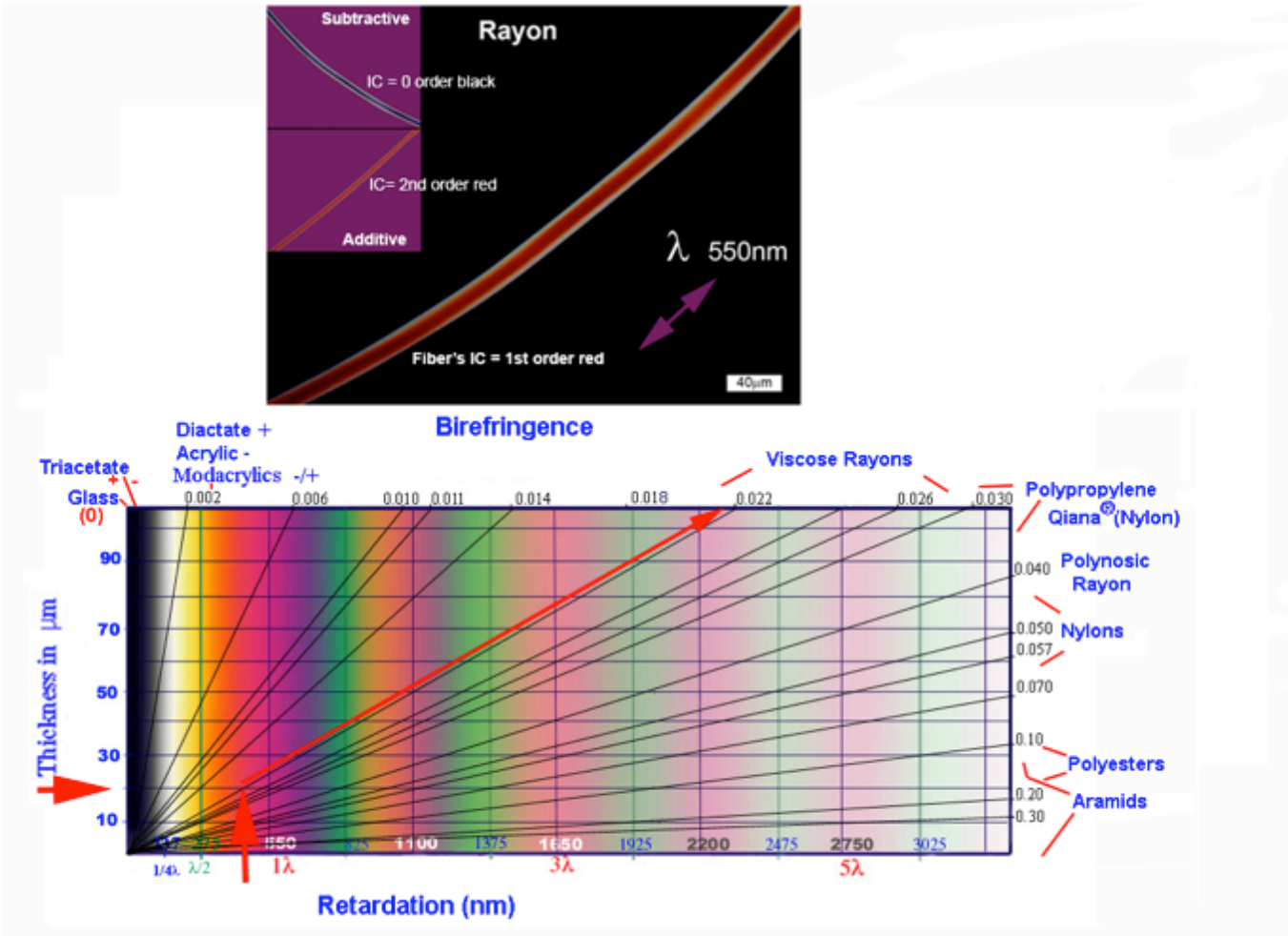


Figure 2-36 – A questioned fiber is viewed between crossed polars. Its thickness, as measured with a calibrated ocular micrometer, is 20µm, while its retardation is estimated to be 450nm, with a full wave fixed compensator. The fiber's sign of elongation is determined to be positive. The fiber's birefringence is estimated to be +0.022 when the thickness and retardation values are plotted on an interference chart as illustrated above. The fiber is identified as viscose rayon.

The minerals, glass, and related substances encountered in dust specimens usually originate from the soil located in the surrounding region, or from some other sources in the environment such as vegetation, animal activity, glass containers, building materials, vehicles, and safes. When a forensic dust specimen is mounted in Melt Mount® 1.539 or 1.540 HD oil, and studied with PLM as previously described, tiny fragments of these types of materials are often observed. Just as hairs and fibers can be characterized and identified on the basis of their morphological appearance and optical properties, these materials also can be identified in the same manner.

Other commonly occurring minerals and related materials are depicted in Figures 2-37 through -2-42. Most of these substances are easily identified on the basis of their morphological appearances, and by a quick determination of some of their optical properties (degree of relief, birefringence, interference colors, and so forth).

It is important to note that when a mineral is found in a dust specimen its thickness is not known. Nevertheless, it is necessary to know the thickness of a mineral in order

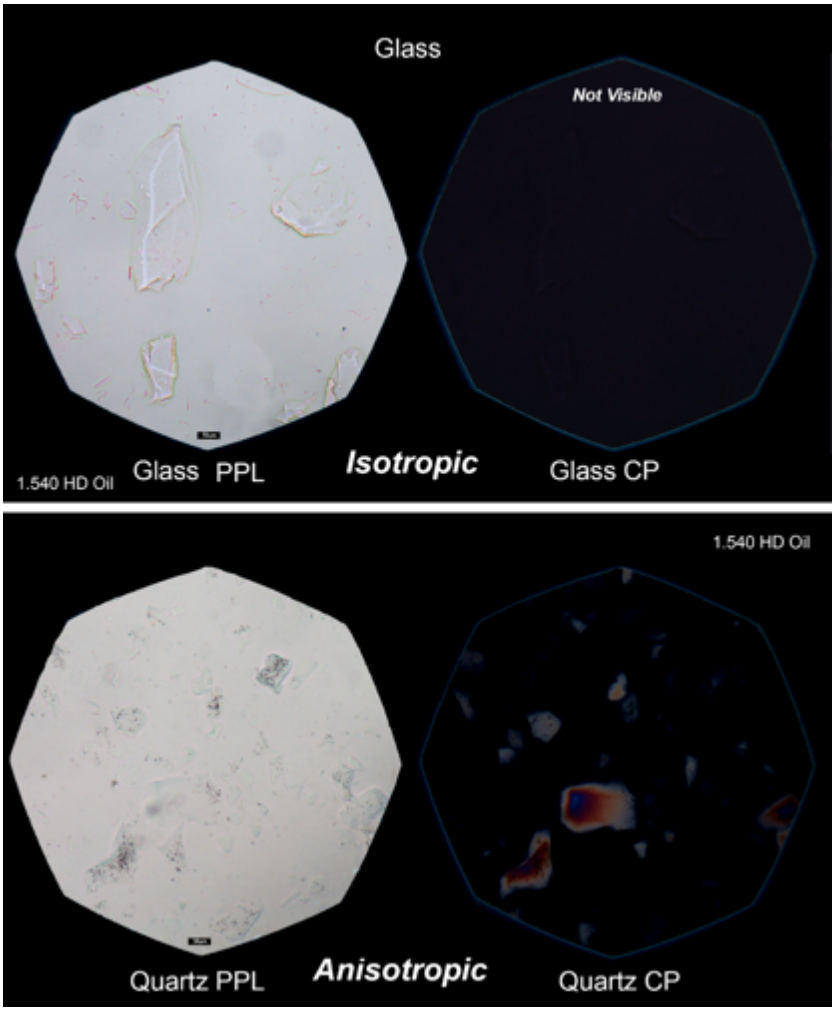


Figure 2-37 Glass with plane polared light (PPL) on top, and quartz on bottom. Note interference colors (IC) on bottom right with quartz under crossed polars (CP).

to obtain accurate birefringence measurements that can be used to help identify the mineral. The thickness of a mineral along the microscope's axis can be measured quite accurately using the micrometer located on the fine adjustment focusing knob found on most high-quality microscopes. Once the mineral's thickness is known, its retardation can be estimated from the interference color(s) exhibited by the mineral grain. These two important pieces of data can be utilized, with the aid of an interference color chart or a simple formula, to estimate the mineral's birefringence. This information can be used to help identify the mineral. An illuminating discussion of the methods of optical crystallography, as well as an interference chart for the identification of common minerals, can be found in Bloss.[105] A short review of the essentials of polarized light microscopy can be found in texts written by Petraco and Kubic.[106]

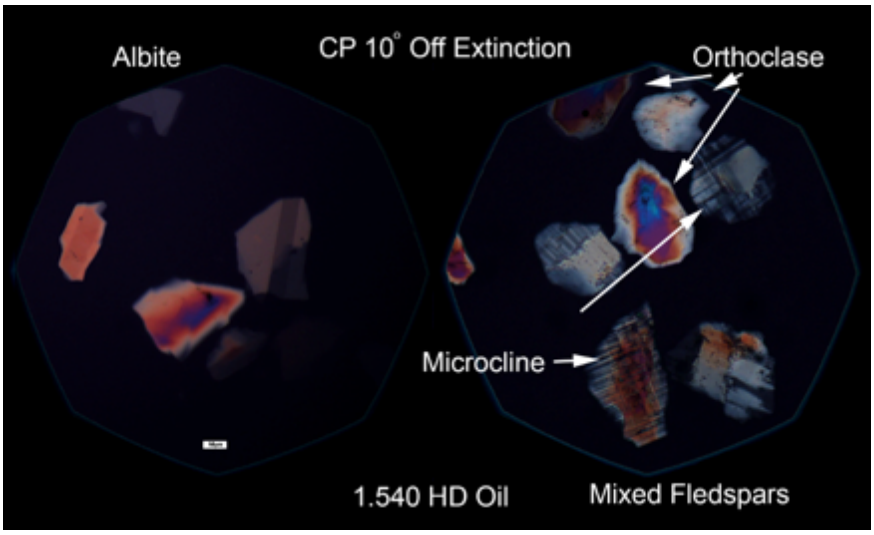


Figure 2-38 – Mixed feldspars as they appear in 1.540 HD oil with CP.

Another advantage of Melt Mount® 1.539 and HD 1.540 oil is that the orientation of a mineral grain can be changed by rolling the crystal a described by McCrone.[101] However, unlike Aroclor® 1260, the Melt Mount® preparation must be slightly heated on a warm hot plate before rolling the crystal. Crystal rolling can be used to obtain vital crystallographic data concerning the specimen, which can be used to identify the questioned mineral. Crystal rolling can also be used to help measure a crystal fragment's thickness. After gently heating, one simply rolls the crystal fragment into the desired orientation, and measures its width with a calibrated ocular micrometer. See Table 2-7 for a list of the various minerals and related materials encountered by the authors in their casework. The physical and optical appearance of each substance in Melt Mount® 1.539 is noted in this table. To determine the identity of an unknown mineral or related substance the data in Table 2-8 are compared with the information in Table 2-7, with a Michel Levy interference color chart, with known published data, and with known standards mounted in Melt Mount® 1.539. If a comparison of questioned and known specimens is desired, it can be carried out in the manner previously described for synthetic fibers. When necessary a mineral grain can be isolated as previously described, and identified by the use of spindle stage methods.[107]

Finally, microscopists who wish to identify the minerals or associated materials that commonly occur in dust specimens should first have a working knowledge of the minerals composing the geographic region served by their laboratories, as well as common building materials, common inorganic salts, and various types of glass. A set of standards containing these materials mounted in Melt Mount® 1.539 should also be available. These materials should be studied thoroughly so that they are easily recognized. This should be done before any attempts at identifications are made in casework.

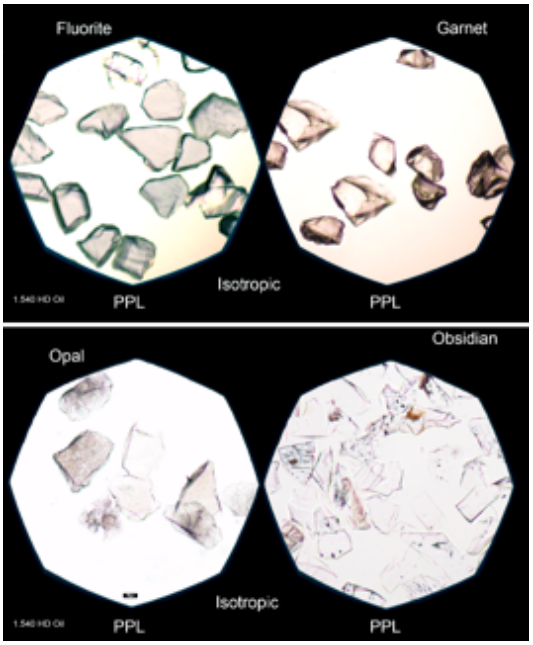


Figure 2-39 – Four common isotropic minerals as they appear in 1.540 HD oil with (PPL): fluorite, garnet, opal and obsidian.

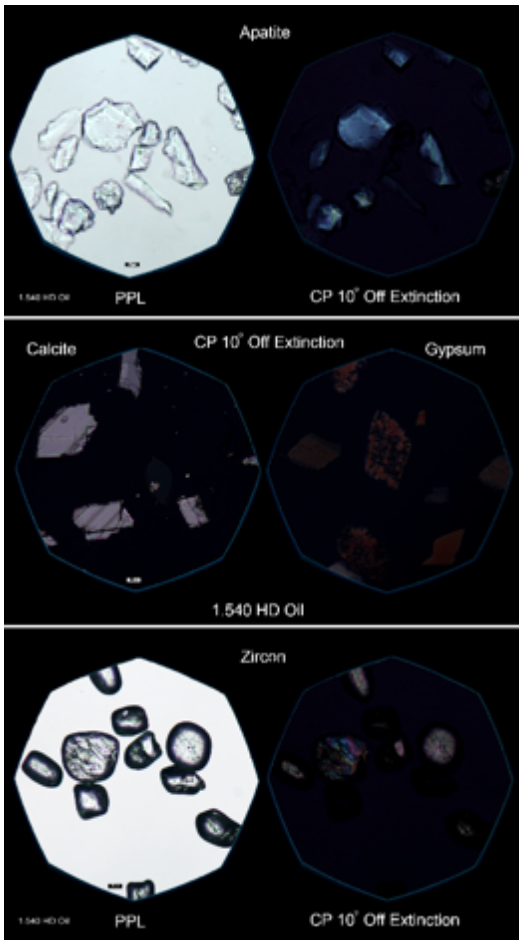


Figure 2-40 Four common anisotropic minerals: apatite and zircon as they appear in 1.540 HD oil with PPL and CP; and calcite and gypsum as they between CP.

Table 2-7 A data sheet for the identification of minerals and related materials. Enter the required data.

Mineral & Related Materials Data Sheet

_____

Morphology

Crystalline form: _____

Cleavage/fracture: Twining type: _____

Cleavage/fracture: Twining type: _____

Cleavage/fracture: Twining type: _____

Diameter Thickness in mm along microscope's optic axis: _____

Optical Data [plane polarized light (PPL)]

Color_____ Opaque_____ Transparent _____

Relief relative to Melt Mount® 1.539 & HD Oil 1.540 with PPL

Very low__ Low _____ Medium _____ High _____ Very High _____

Pleochroic: Yes ____ No ____ Pleochroic formula n‖ _____ n⊥_____

Optical Data [crossed polars(CP)]

Isotropic _____ Anisotropic _____

Estimated retardation in nanometers (nm):_____

Order of Interference Colors: 0____ 1st order ____ 2nd order____ 3rd _____ 4th _____ 5th_____

Estimated birefringence (Bi): _____

Sign of elongation: Positive_____ Negative _____

Extinction: parallel _____ symmetrical _____ oblique _____

Other properties

Magnetic: Yes____ No____

Other

_____

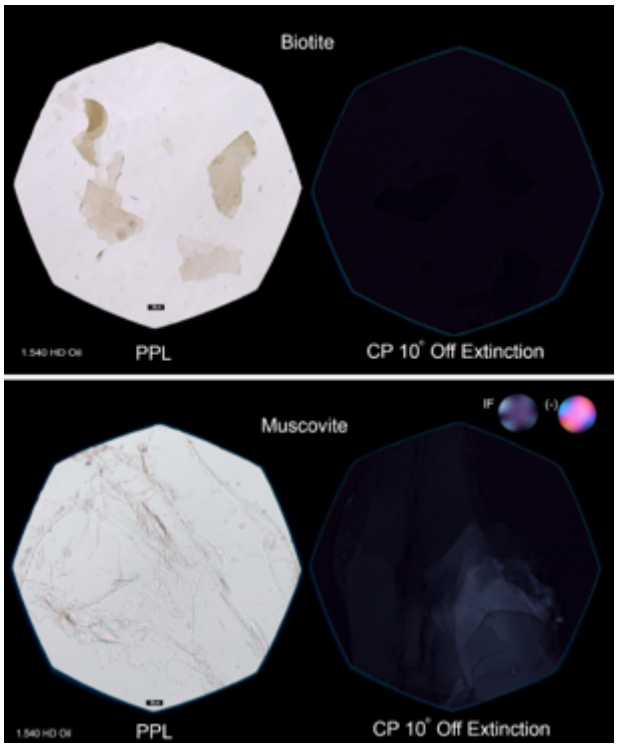


Figure 2-41 Biotite and muscovite mica as they appear in 1.540 HD oil with PPL.

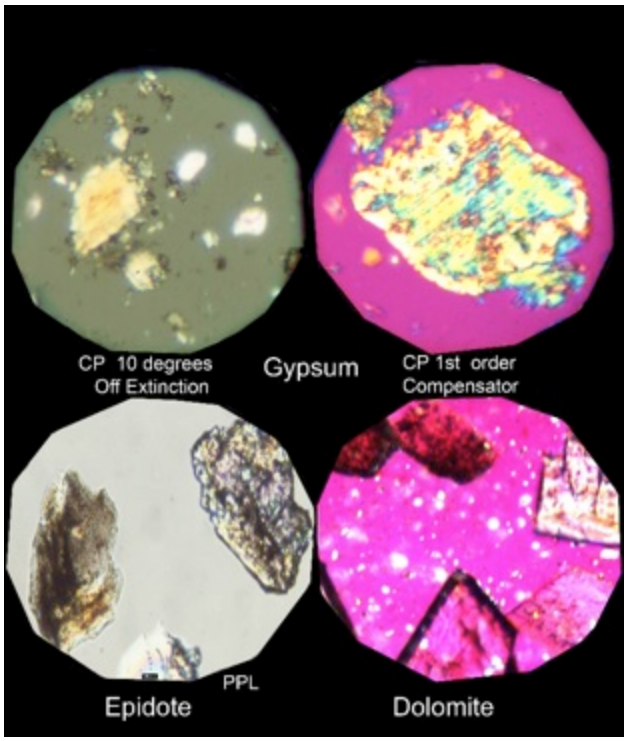


Figure 2-42 Gypsum as it appears in 1.540 HD oil at 10 degrees off extinction, under CP with a 1st order compensator (on top), Epidote as it appears in 1.540 HD oil with PPL and dolomite under CP with a 1st order compensator (on bottom).

Miscellaneous Substances

McCrone and Delly have advocated that a variety of microscopic particles be identified by sight, *in situ,* on the basis of their characteristic morphologies and simple optical properties with the aid of PLM.[105] Vegetable fibers, paper fibers, cordage fibers, paint chips, glitter, salt grains, starch grains, feathers, insect parts, and so forth are just a few of the substances that can be identified in this manner. It has been the authors' combined experience that these materials frequently occur in forensic dust specimens. A few of these substances are shown as they appear in Melt Mount® 1.539 and HD 1.540 Oil in Figures 2-43 through 2-46.

Plant materials such as leaf fragments, bits of wood, and bark, sawdust, pieces of twigs, and grains of pollen as well as insects are ubiquitous in our environment and are consequently found in dust household specimens. These materials can typically be identified on the basis of their microscopic morphology. Atlases such as the ones by Parham & Gray,[108] Cote,[109] Bassett, Compton & Parmelle[110] and the CDC[111] are quite useful when attempting to identify wood fibers and pollens as to their species of origin. Several of these materials are depicted in Figures 2-43 and 2-44.

Other natural fibers that are commonly observed in forensic dust specimens are sisal, manila, flax, feather, plant hair, and cotton.[112] An excellent text by Catling and Grayson concerning the identification of vegetable fibers in the forensic laboratory has been found invaluable when identifying these vegetable fiber.[113] MC Crone's and Delly's text also contains a wealth of information on the identifying features of several other commonly used vegetable fibers. Cotton fibers are easily recognized on the basis of their characteristic morphology and their lack of extinction when viewed between crossed polars.[112] Feathers found in dust specimens usually originate from domesticated birds that are raised for use as food, such as ducks, chickens, and turkeys, or those that are commonly found in our environment, such as pigeons. Feathers removed from birds used as food are frequently used as fillers in items such as jackets, coats, and pillows, to name just a few. Consequently they find their way into the dust found in many places. Feathers can be identified morphologically. One can usually determine the bird family from which a feather originated on the basis of the structure of its down.[114] Figure 2-45 depicts several commonly seen fibrous materials.

Tiny particles originating from food are routinely encountered in household dust. Substances such as starch grains, sweeteners, spices, and other food stuffs can be identified on the basis of their morphology.[115] Figure 2-46 portrays a few of these commonly seen food stuffs as they appear in HD oil 1.540.

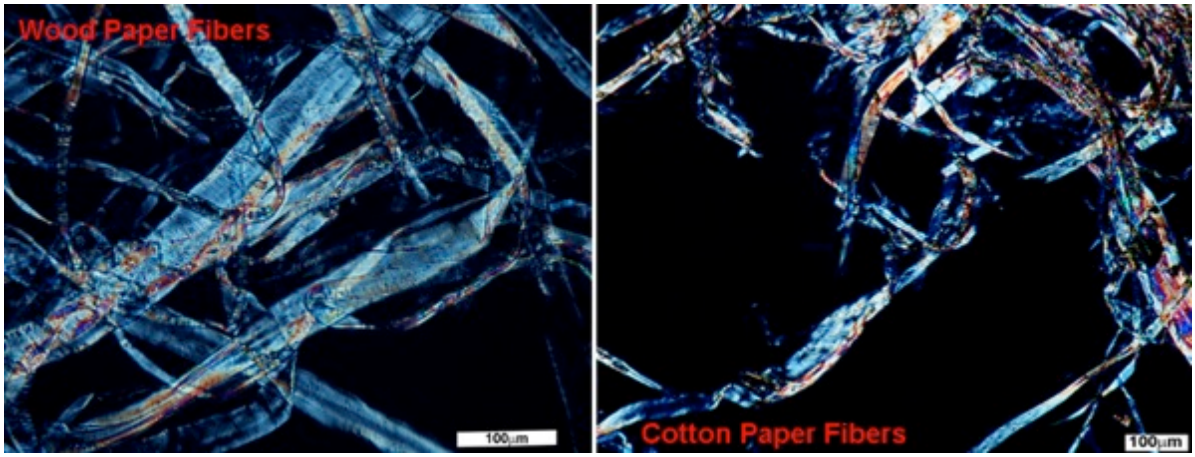


Figure 2-43 Wood and cotton paper fibers often found in household dust samples generated from newspaper, tissue papers and other household paper items. Mounted in HD 1.540 oil.

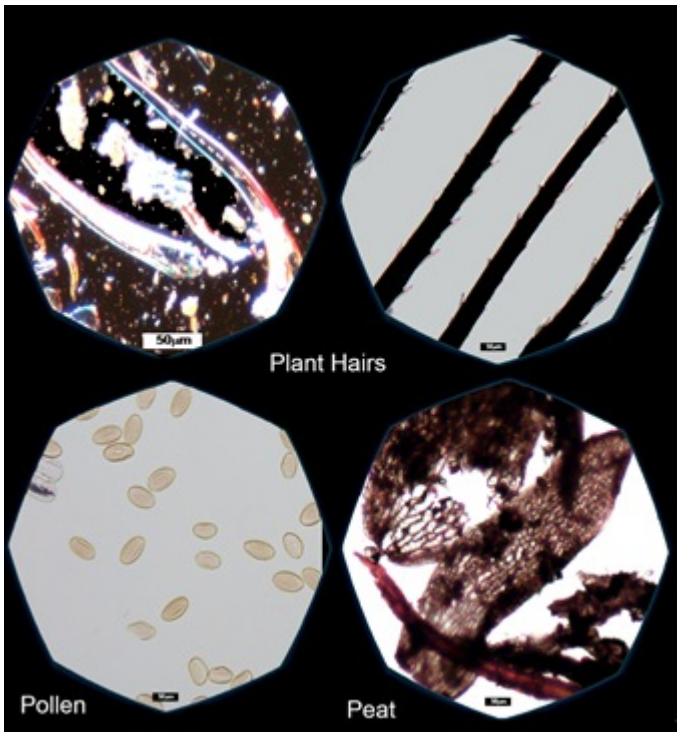


Figure 2-44 Depicted are a few plant materials found in household dust samples as they appear as they appear with PPL or CP mounted in HD oil 1.540.

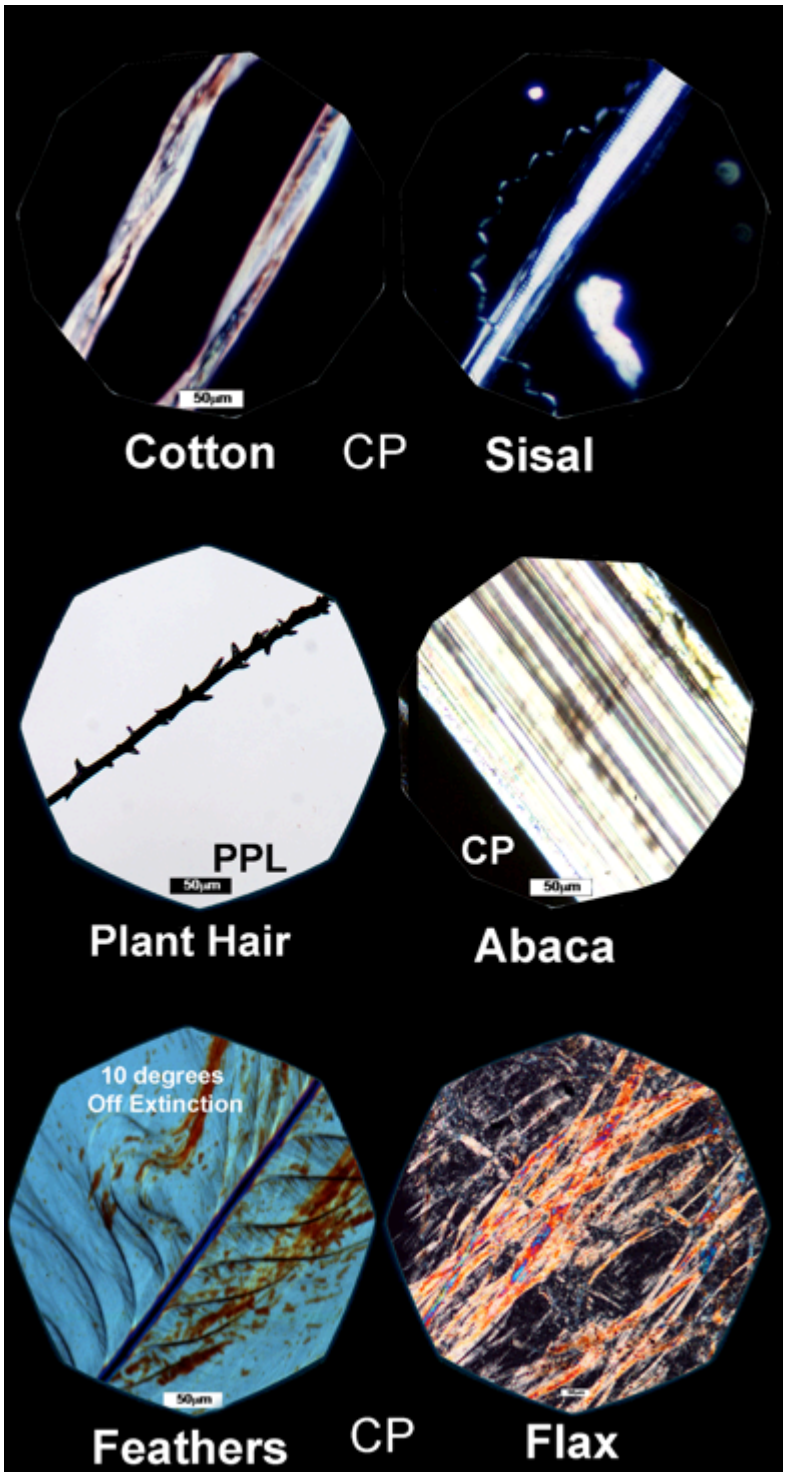


Figure 2-45 Shown are several of the commonly occurring fibrous materials as they appear as they appear with PPL or CP mounted in HD oil 1.540.

Table 2-8 A data sheet for the identification of miscellaneous materials found in dust specimens. Enter the required data.

Miscellaneous Materials Data Sheet

_____

Morphology

Shape: _____

Structure: _____

Texture: _____

Martin's Diameter (Particle in Half) in μm _____

Sketch:

Optical Data [plane polarized light (PPL)]

Color_____ Opaque_____ Translucent_____Transparent_____

Relief relative to Melt Mount® 1.539 & HD Oil 1.540 with PPL

Very low__ Low _____ Medium _____ High _____ Very High _____

Optical Data [crossed polars(CP)]

Isotropic _____ Anisotropic _____

Estimated retardation in nanometers (nm):_____

Order of Interference Colors: 0____ 1st order ____ 2nd order____ 3rd _____ 4th _____ 5th_____

Estimated birefringence (Bi): _____

Sign of elongation: Positive_____ Negative _____

Extinction: parallel _____ symmetrical _____ oblique _____

Other properties

Magnetic: Yes____ No____

Other _____

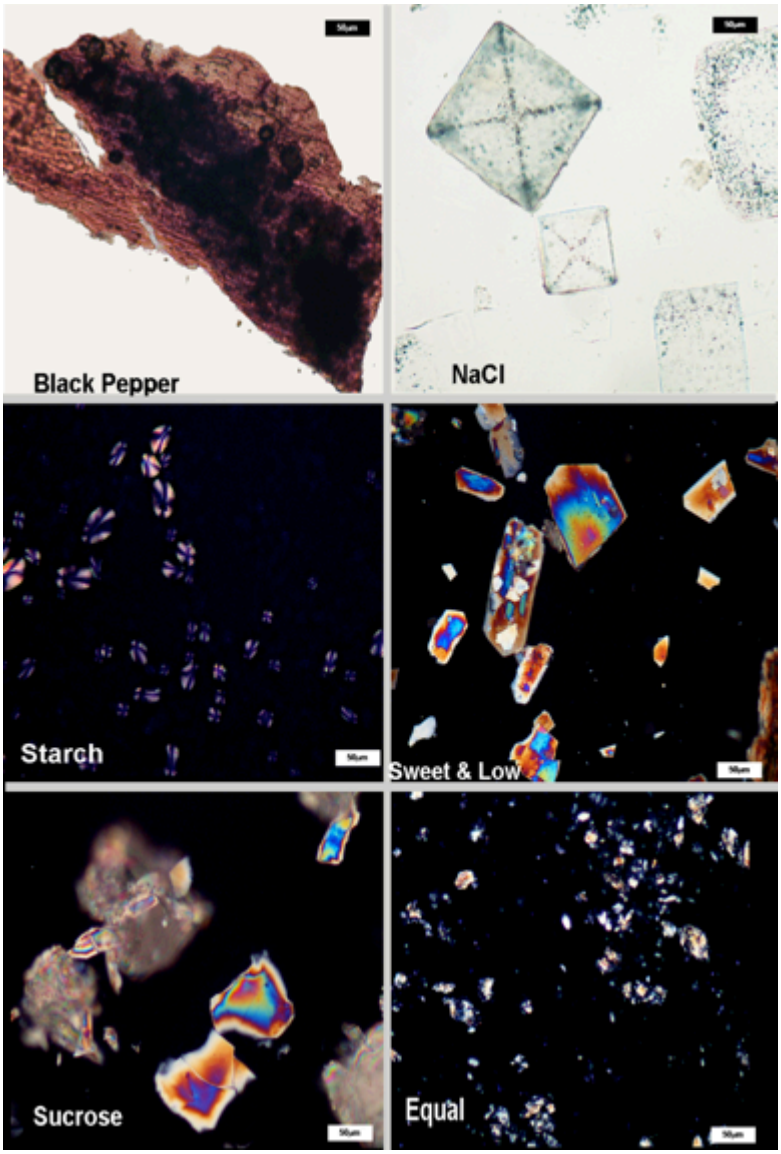


Figure 2-46 Shown are several of the commonly occurring food particles as they appear with PPL or CP mounted in HD oil 1.540.

Dust Comparison

The forensic examination of household dust specimens has been the subject of research for over thirty years.[116-118] Once the trace evidential contents of the questioned and/or known dust specimen has been identified, the information in Tables 2-2, 2-4 through 2-8 is compiled on a Dust Data Tabulation Sheet such as the one shown in Table 2-3. The information recorded on this sheet makes the final comparison and interpretation of the information much easier. The data from Table 2-3 is put into a Microsoft Excel spreadsheet and the data is subjected to statistical analysis. Several recent studies on

household dust specimens have had its data compiled on excel data spread sheets. The data was subjected to principal component analysis with support vector machine. Using this model random match probabilities were estimated using Efron's empirical Bayes two-groups methodology.[119-121]

A plot of the match probability estimates with a 20-D PCA-SVM model appear in Figure 2-47. These result show great promise in establishing a statistical basis for dust comparison. Combining PLM analysis of with DNA profiling shows promises in making this methodology all the more powerful.[122]

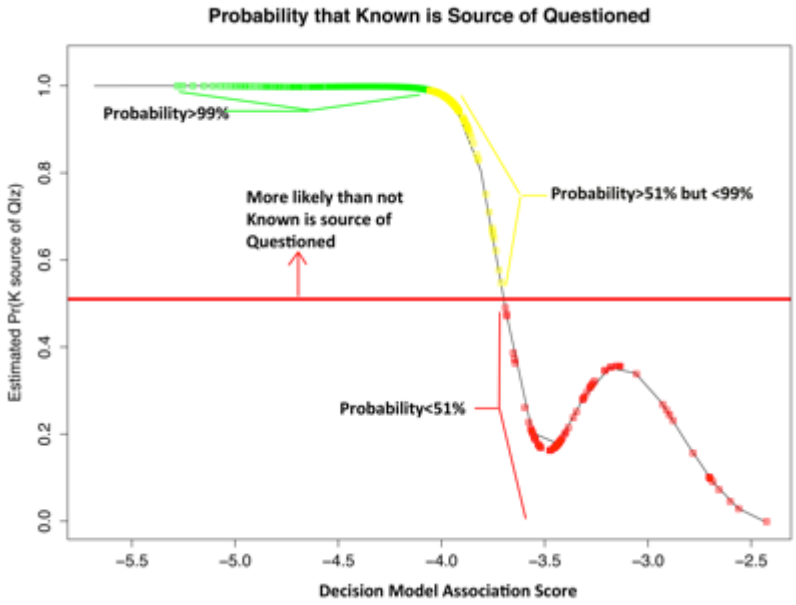


Figure 2-47 20D PCA-SVM Decision Model on Dust Sample Test Set Full decision model was: 20D PCA-SVM, Error Rate: 0.01% [0.0%, 0.04%]@95% level of confidence

Conclusions

This chapter is presented to illustrate how powerful the method of PLM in combination with DNA profiling and statistical analysis is in the identification and characterization of forensic household dust specimens. It is not meant to be a complete discussion of the topic, but rather to serve as an introduction and preliminary guide to the analysis of forensic dust specimens. It is designed to show just how much investigative information and data a forensic microscopist can obtain from a dust specimen, armed only with a polarized light microscope; a knowledge of particle morphology; a set of standards mounted in an appropriate medium; a few good

atlases, whether published or self-prepared; a handbook; and the desire to identify and characterize forensic dust specimens. It is hoped that this chapter will serve to inspire more forensic scientists to utilize PLM in their everyday casework to help reconstruct and solve crimes.

References

[1] W. C. McCrone, "Particle Analysis in the Crime Laboratory," in TheParticle Atlas, vol. 5, W. C. McCrone, J. G. Delly, and S. J. Palenik, eds. (Ann Arbor, Mich.: Ann Arbor Science Publishers, 1979), pp. 1379-1401.

[2] N. Petraco, "The Occurrence of Trace Evidence in One Examiner's Casework," J. Forensic Sci., 30 (1985), pp. 485-93.

[3] W. C.McCrone, "Particle Analysis in the Crime Laboratory," in TheParticle Atlas, vol. 5, W. C. McCrone, J. G. Delly, and S. J. Palenik, eds. (Ann Arbor, Mich.: Ann Arbor Science Publishers, 1979), p. 1379.

[4] H. Gross, Criminal Investigation, adapted from System Der Kriminalistik , by J.C. Adams, (London, England: Sweet and Maxwell Limited, 1924), pp. 144-47.

[5]A. Schneider, "Police Microscopy," J. Criminal Law, Criminology and Police Sci., 11 (1920), pp. 217-21.

[6] E. Locard, "The Analysis of Dust Traces," Am. J. Police Sci., I (1930), Part I 276-98, Part II 401-18, Part III 496-514.

[7] H. T. F. Rhodes, Clues and Crime, (London: John Murray, 1933), pp. 33-35.

[8] H. Söderman, and J. J. O'Connell, Modem Criminal Investigation, (New York and Lon- don: Funk and Wagnalls, 1935), pp. 243-50.

[9] A. Lucas, Forensic Chemistry and Scientific Criminal Investigation, (New York: Long- mans, Green & Co.; London, Edward Arnold & Co. Publishers Limited, 1935), p. 64; pp. 152-60.

[10] C. H. O'Hara, and J. W. Osterburg, An Introduction to Criminalistics, (New York: The MacMillan Co., 1949) pp. 30-36.

[11] P. L. Kirk, Crime Investigation, (New York:Interscience Publishers, 1953), pp. 3-11.

[12] L. C. Nickolls, "The Identification of Stains of Nonbiological Origin," in Methods of Forensic Science, vol. I, F. Lundquist, ed. (New York:Interscience Publishers, 1962), pp. 335- 71.

[13] M. Frei-Sulzer, "Coloured Fibres in Criminal Investigations with Special Reference to Natural Fibers," in Methods of Forensic Science, vol. 4, A. S. Curry ed. (New York, N.Y.: Inter- science, 1965), pp. 141-75.

[14] S. J. Palenik, "The Determination of Geographical Origin of Dust Samples," in The Particle Atlas, vol. 5, W. C. McCrone, J. G. Delly, and S. J. Palenik, eds. (Ann Arbor, Mich.: Ann Arbor Science Publishers, 1979), pp. 1347-61.

[15]N. Petraco, “A Guide to the Rapid Screening, Identification, and Comparison of Synthetic Fibers in Dust Samples,” J. Forensic Sci., 32(3), May 1987, pp. 768-77.

[16] M. C. Grieve, "The Role of Fibers in Forensic Science Examinations, "Journal of Forensic Sciences, JFSCA, Vol. 28, No. 4. Oct. 1983, pp. 877-87.

[17] H.A. Deadman,"Fiber Evidence and The Wayne Williams Trial," FBI Law Enforcement Bulletin, “Fiber Evidence and the Wayne Williams Trial”, FBI Law Enforcement Bulletin, March ·l984, pp. 13-20 & May 1984, pp. 10-19.

[18] R. Saferstein, Criminalistics, 3rd edition, (Englewood Cliffs, N. J.: Prentice-Hall Inc., 1987), pp. 183-220.

[19] P. R. De Forest, R. E. Gaensslen, and H. C. Lee, Forensic Science an Introduction to Criminalistics, (New York: McGraw-Hill, 1983), pp. 146-67.

[20] B. D. Gaudette, "Fibre Evidence," R.C.M.P. Gazette, 47, No. 12, 1985, pp. 18-20.

[21] R. Saferstein, ed. Forensic Science Handbook , vol. I (1982); vol. II (1988), (Englewood Cliffs, N.J.: Prentice-Hall Inc.).

[22] N. Petraco, "Trace Evidence- The Invisible Witness," J. Forensic Sci., 31 (1986), pp. 321-28.

[23] W. C. Mc Crone, and. G. Delly, eds., The Particle Atlas, 2nd ed.,(Ann Arbor, Mich.:Ann Arbor Science Publishers): vol. I 1973, vol. 2 1973, vol. 4 1973, a d W. C. McCrone, J. G. Delly, and S. J. Palenik, eds., vol. 5 1979.

[24] W. J. Graves, "A Mineralogical Soil Classification Technique for the Forensic Scientist," J. Forensic Sci., 24 (1979), pp. 323-38.

[25] W. Fong, "Rapid Microscopic Identification of Synthetic Fibers in a Single Liquid Mount," *J. Forensic Sci.,* 27 (1982), pp. 257-63.

[26] N. Petraco, "A Microscopical Method to Aid in the Identification of Animal Hair," *The Microscope,* 35 (1987), pp. 83-92.

[27] P. R. De Forest, "Foundation of Forensic Microscopy, "in *Forensic Science Handbook ,* R. Saferstein ed. (Englewood Cliffs, N.J.: Prentice-Hall Inc., 1982), pp. 416-528.

[28] R. E. Bisbing, "The Forensic Identification and Association of Human Hair," in *Forensic Science Handbook,* R. Saferstein ed. (Englewood Cliffs, N.J.: Prentice-Hall Inc., 1982), pp. 184- 221.

[29] E. T. Miller, "Forensic Glass Comparisons," in *Forensic Science Handbook,* R. Saferstein ed. (Englewood Cliffs, N.J.: Prentice-Hall Inc., 1982), pp. 139-83.

[30] J. I. Thornton, "Forensic Paint Examination," in *Forensic Science Handbook ,* R. Saferstein ed. (Englewood Cliffs, N.J.: Prentice-Hall Inc., 1982), pp. 529-71.

[31] R. C. Murray, "Forensic Examination of Soil," in *Forensic Science Handbook,* R. Safer- stein ed. (Englewood Cliffs, N.J.: Prentice-Hall , 1982), pp. 653-71.

[32] S. Palenik, "Microscopy and Microchemistry of Physical Evidence," in *Forensic Science Handbook ,* vol. II, R. Saferstein ed. (Englewood Cliffs, N.J.: Prentice-Hall, 1988), pp. 161-208.

[33] B. D. Gaudette, "The Forensic Aspects of Textile Fiber Examination," in *Forensic Science Handbook*, vol. II, R. Saferstein ed. (Englewood Cliffs, N.J.: Prentice-Hall, 1988), pp. 209-72.

[34] Ibid., pp. 214-15.

[35] L.C. Nickolls, "The Identification of Stains of Nonbiological Origin," in *Methods of Forensic Science,* vol. 1, F. Lundquist, ed. (New York: Interscience Publishers, 1962), pp. 335-37.

[36] E. Locard, "L'analyse des poussieres en criminalistique," *Revue Internationale de Cri- minalistique,* 1 Juillet 1929, pp. 176-249.

[37] S. J. Palenik, "Microscopy and Microchemistry of Physical Evidence," in *Forensic Science Handbook,* vol. II, R. Saferstein ed. (Englewood Cliffs, N.J.: Prentice Hall, 1988), pp. 164-68.

[38] M. Frei-Sulzer, "Preserving Micro-Traces Under Adhesive Bands," *Kriminalistik*, No.19/20 (1951), pp. 190-94.

[39] E. Martin, "The Behavior of Textile Fibres in Contact with the Glue of Adhesive Transparent Strips used for Collecting Specimens, "*International Criminal Police Review,* 188 (1965), pp.135-41.

[40]M. C. Grieve, and E. F. Garger, An improved Method for Rapid and Accurate Scanning of Fibers on Tape,"*J. Forensic Sci.,* 26 (1981), pp. 560-63.

[41]M. Y. Choudhry, "A Novel Technique for the Collection and Recovery of Foreign Fibers in Forensic Science Casework," *J. Forensic Sci.,* 33 (1988), pp. 249-53.

[42]T. M. Hopen, Dust Collection Method. Microscope 2000, 48(4), p. 213.

[43]J. R. Millette and P. Few, Sample Collection Procedures for Microscopical Examination of Particulate Surface Contaminants. Microscope 2001, 49(1), pp. 21-27.

[44] N. Petraco, "The Occurrence of Trace Evidence in One Examiner's Casework," *J.Foren- sic Sci.,* 30 (1985), p. 486.

[45] S. Palenik, "Microscopy and Microchemistry of Physical Evidence," in *Forensic Science Handbook,* vol. II, R. Saferstein ed. (Englewood Cliffs, N.J.: Prentice-Hall, 1988), pp. 165-67.

[46]P. L. Kirk, "Microscopic Evidence- Its Use in the Investigation of Crime," *J. Criminal Law, Criminology and Police Sci.,* 40 (1949-1950), pp. 362-69.

[47] N. Petraco, "A Simple Trace Evidence Trap for the Collection of Vacuum Sweepings," *J. Forensic Sci.,* 32 (1987), pp. 1422-25.

[48] N. Petraco, K. Farash, E. Hanson, and J. Ballantyne, Study of the Formation, Collection, Microscopic Trace Material Composition and Genetic Makeup of Household Dust Specimens, AAFS meeting in Orlando, FL, Paper No. B89, Feb. 2015.

[49] P.R. De Forest, S. Ryan, and N. Petraco, "Melt Mount® Stick Mounting Medium," *The Microscope,* 35 (1987), pp. 261-66.

[50] P. R. De Forest, B. Shankles, R. L. Sacher, and N. Petraco, "Melt Mount® 1.539 as a Mounting Medium for Hair," *The Microscope,* 35 (1987), pp. 249-59.

[51] E. A. Chille, R. E. Gorgon, R. A. Adamo, and P. R. DeForest, "Studies of Hair Deterioration - Interior Environments," presented at the 11th Meeting of the International Association of Forensic Sciences, Vancouver, B.C., Canada, August 2-11, 1987.

[52] P. R. DeForest, N. Petraco, and R. A. Adamo, "Significance of Environmental Exposure in the Interpretation of flair Evidence," presented at the 11th meeting of the International Association of Forensic Sciences, Vancouver, B.C., Canada, August 2-11, 1987.

[53] J. W. Hicks, *Microscopy of Hair,* Issue 2, (Washington, D.C.: U.S. Government Printing Office, 1977), p. 6.

[54] N. Petraco, "The Replication of Hair Cuticle Scale Patterns in Melt Mount®," *The Microscope,* 34 (1986), pp. 341-45.

[55] R. E. Bisbing, "The Forensic Identification and Association of Human Hair," in *Forensic Science Handbook,* R. Saferstein ed. (Englewood Cliffs, N.J.: Prentice-Hall Inc., 1982), pp. 201-2.

[56] J. W. Hicks, *Microscopy of Hair,* Issue 2, (Washington, D.C.: U.S. Government Printing Office, 1977), pp. 7-10.

[57] N. Petraco and T. A. Kubic, Color Atlas and Manual of Microscopy for Criminalists, Chemists, and Conservators, New York: CRC Press, 2004, chapter 5, pp. 57-67.

[58] N. Petraco, C. Frass, F. X. Callery, and P. R. DeForest, "The Morphological and Evidential Significance of Human Hair Roots," *J. Forensic Sci.,* 33 (1988), pp. 68-76.

[59] C. A. Linch, S. L. Smith and J. A. Prahlow, Evaluation of the human hair root for DNA typing subsequent to microscopic comparison, J Forensic Sci. 43 (1998), pp. 305–14.

[60] *C. A. Linch and J. A. Prahlow,* Postmortem Microscopic Changes Observed at the Human Head Hair Proximal End, J Forensic Sci., 46 (2001), pp. 15–20.

[61] R. E. Bisbing, "The Forensic Identification and Association of Human Hair," in *Forensic Science Handbook,* R. Saferstein ed. (Englewood Cliffs, N.J.: Prentice-Hall Inc., 1982), p. 201.

[62] N. Petraco and T. A. Kubic, Color Atlas and Manual of Microscopy for Criminalists, Chemists, and Conservators, New York: CRC Press, 2004, pp. 217-37.

[63] R.R. Olge and M. J. Fox, Atlas of Human Hair: Microscopic Characteristics 1st Edition, CRC Press, Boca Raton, FL., 1998.

[64] J. Glaister, *A Study of Hairs and Wools Belonging to the Mammalian Group of Animals, Including a Special Study of Human Hair, Considered from Medico-Legal Aspects,* (Cairo, Egypt: MISR Press, Cairo, 1931), p. 155.

[65] S. Smith, and J. Glaister. *Recent Advances in Forensic Medicine,* 2nd edition (Phil., Penn.: Blakiston's Son & Co. Inc., 1939), pp. 118-24.

[66] B. D. Gaudette, and E. S. Keeping, "An Attempt at Determining Probabilities in Human Scalp Hair Comparison," *J. Forensic Sci.,* 19: (1974), pp. 601-02.

[67] B. D. Gaudette, "Probabilities and Human Pubic Hair Comparison," *J. Forensic Sci.,* 21 (1976), pp. 515-16.

[68] J. W. Hicks, *Microscopy of Hair,* Issue 2, (Washington, D.C.: U.S. Government Printing Office, 1977), pp. 6-27.

[69] R. E. Bisbing, "The Forensic Identification and Association of Human Hair," in *Forensic Science Handbook.* R. Saferstein ed. (Englewood Cliffs, N.J.: Prentice-Hall Inc., 1982), pp. 199- 205.

[70] W. C. Mc Crone, "Particle Analysis in the Crime Laboratory," in *TheParticle Atlas,* vol. *5,* W. C. Mc Crone, J. G. Delly, and S. J. Palenik, eds. Ann Arbor, Mich.: Ann Arbor Science Publishers, 1979), p. 1383.

[71] S. A. Shaffer, "A Protocol for the Examination of Hair Evidence," *The Microsocpe,* 30 (1982), pp. 151-61.

[72] M. A. T. Strauss, "Forensic Characterization of Human Hair I," *The Microscope,* 31 (1983), pp. 15-29.

[73] B. D. Gaudette, "Forensic Hair Comparisons," *Crime Laboratory Digest,* 12(1985), pp.44-59

[74] H. C. Lee, and P.R. De Forest, "Forensic Hair Comparison," in *Forensic Sciences,* vol. 3, C. H. Wecht ed., (New York: N.Y. : Matthew Bender, 1987), pp. 37A-8 & 9.

[75] N. Petraco and T. A. Kubic, Color Atlas and Manual of Microscopy for Criminalists, Chemists, and Conservators, New York: CRC Press, 2004, p. 61.

[76] H. Gross, *Criminal Investigation,* adapted from System Der Kriminalistik, by J. C. Adams, (London, England: Sweet and Maxwell Limited, 1924), pp. 131-38.

[77] E. Locard, "The Analysis of Dust Traces, *Am. J. Police Sci.* I (1930), Part I 276-98.

[78] Söderman, H. and E. Fontell, *Handbok I. Krimina/teknik.* (Stockholm, 1930), pp. 534-52.

[79] J. Glaister, A Study of Hairs and Wools Belonging to the Mammalian Group of Animals, Including a Special Study of Human Hair, Consideredfrom Medico-Legal Aspects, (Cairo, Egypt: MISR Press, Cairo, 1931).

[80] S. Smith, and J.Glaister, Recent Advances in Forensic Medicine, 2nd edition (Phil., Penn.: Blakiston's Son & Co. Inc.,1939), pp. 86-124.

[81] P. L. Kirk, Crime Investigation, (New York, N.Y.: Interscience Publishers, 1953), pp. 152-75.

[82] J. W. Hicks, *Microscopy of Hair,* Issue 2, (Washington, D.C.: U.S. Government Printing Office, 1977), pp. 28-40.

[83] H. Sato, M. Yoshino and S. Seta, "Macroscopical and Microscopical Studies of Mammalian Hairs with Special Reference to the Morphological Differences," *Reports of National Research Institute of Police Science,* 33, no. I (1980), pp. 1-16.

[84] N. Petraco and T. A. Kubic, Color Atlas and Manual of Microscopy for Criminalists Chemists, and Conservators, New York: CRC Press, 2004, pp. 69-76 and 239-55.

[85] N. Petraco, A Modified Technique for the Cross Sectioning of Hairs and Fibers," *J. of Police Science and Administration,* 9 (1981), pp. 448-50.

[86] A. B. Wildman, *Microscopy of Animal Textile Fibres,* (Leeds: WIRA, 1954)

[87] A. S. Adorjan, and G. B. Kolenosky, *A Manual for the Identification of Hairs of Selected Ontario Mammals,* Research Report (Wildlife), No. 90, Dept. of Lands and Forests, Ontario, 1969.

[88] T. D. Moore, L. E. Spence, and C. E. Dugnoue. *Identification of the Dorsal Guard Hairs of Some Mammals of Wyoming,* W. G. Hepworth ed. (Cheyenne, Wyoming, 1974).

[89] H. Brunner, and B. J. Coman, *The Identification of Mammalian Hair,* (Melbourne: Inkata Press, 1974).

[90] H. M. Appleyard, *Guide to the Identification of Animal Fibres,* 2nd Ed. (Leeds: WIRA, 1978).

[91] W. C. McCrone, "Particle Analysis in the Crime Laboratory," in *The Particle Atlas,* vol. 5, W. C. McCrone, J. G. Delly, and S. J. Palenik, eds. (Ann Arbor, Mich.: Ann Arbor Science Publishers, 1979), pp. 1383-84.

[92] William Hanley, NYPD Forensic Investigation Division, 1980, *Personal Communications.*

[93] M. E. O'Neill, "Police Microanalysis- II. Textile Fibers," *J. of the American Institute of Criminal Law and Criminology,* 25 (1934), pp. 835-42.

[94] A. Longhetti, and G. W. Roche, "Microscopic Identification of Man-Made Fibers from the Criminalistics Point of View,"*J. Forensic Sci.,* 3 (1958), 303-29.

[95] R. A. Rouen, and V. C. Reeve, "A Comparison and Evaluation of Techniques for Identification of Synthetic Fibers," *J. Forensic Sci.,* 15 (1970), 410-32.

[96] L. Fortini, and W. C. McCrone, "Dispersion Staining of Fibers," *The Microscope,* 19 (1971), pp. 243-54.

[97] The Textile Institute, *Identification of Textile Materials,* 7th ed. (Manchester, England: The Textile Institute, 1975).

[98] National Bureau of Standards, *Reference Collection of Synthetic Fibers,* (McLean, Va.: U.S. Dept. of Commerce, 1984).

[99] N. Petraco, P. R. DeForest, and H. Harris, "A New Approach to the Microscopical Examination and Comparison of Synthetic Fibers Encountered in Forensic Science Cases," *J. Forensic Sci.,* 25 (1980), 571-82.

[100] N. Petraco, A Guide to the Rapid Screening, Identification and Comparison of Synthetic Fibers in Dust Samples, J. Forensic Sci., 32 (1987), pp. 768-77.

[101] L. J. Goin, and P. L. Kirk, "Application of Microchemical Techniques: Identity of Soil Samples," *J. Criminal Law, Criminology and Police Science,* 38 (1947-48), pp. 267-81.

[102] D. Smale, and N. A. Trueman, "Heavy Mineral Studies as Evidence in a Mulder Case in Outback Australia," *J. Forensic Sci. Soc.,* 9 (1969), pp. 123-28.

[103] F. Fitzpatrick, and J. I. Thornton, "Forensic Science Characterization of Sand,*J. Forensic Sci.,* 20 (1975), pp. 460-75.

[104] W.C. Mc Crone, "Particle Characterization by PLM — Crossed Polars," The Microscope, 31 (1983), pp. 195-96.

[105] F. D. Bloss, Optical Crystallography, MSA's Monograph Series, #5, Washington, DC, Mineralogical Society of America.

[106]N. Petraco and T. Kubic, Color Atlas and Manual of Microscopy for Criminalists, Chemists, and Conservators, CRC Press, Boca Raton, FL, 2004 pp. 135-49.

[107] F. D. Bloss, *The Spindle Stage: Principles and Practice*, Cambridge England: Cambridge University Press, 1981.

[108] R.A. Parham and R.L. Gray, The Practical Identification of Wood Pulp Fibers, (Atlanta, G.A.: Tappi Press, 1982).

[109] W.A. Côté, ed. *Papermaking Fibers: A Photomicrographic Atlas*, (Syracuse N.Y.:Syracuse University Press, 1980).

[110] I. J. Bassett, C. W. Crompton and J. A. Parmelee, An Atlas of Airborne Pollen Grains and Common Fungus Spores of Canada, Biosystematics Research Center, Ottawa, Research Branch, Canada Dept. of Agriculture, Ontario, Monograph, No. 18, 1978.

[111]CDC Pictorial Keys Anthropods, Reptiles, Birds and Mammals of Public Health Significance, U.S. Dept of Health and Human Services, Atlanta, GA., Reprinted 1994.

[112] W. C. McCrone, and J. G. Delly, The Particle Atlas, 2ND ed., (Ann Arbor, Mich.: Ann Arbor Science Publishers, vol. 2 (1973), pp. 352-3.

[113]D. M. Catling and J. E. Grayson, *Identification of Vegetable Fibres*, (London England: Chapman Hall Ltd., 1982).

[114] Metropolitan Police Forensic Laboratory, Biology Manual, (London, England: Commissioner of Police Metropolis, 1978, pp. 6-11.

[115] W. C. McCrone, and J. G. Delly, The Particle Atlas, 2ND ed., (Ann Arbor, Mich.: Ann Arbor Science Publishers, vol. 2 (1973), pp. 457-64.

[116] N. Petraco, L. Kobilinsky, and P. R. De Forest, Chemistry and the Challengers of Crime, Chapter 5 in Chemistry and Crime from Sherlock Holmes to Today's Courtroom, Edited by S. M. Gerber, American Chemical Society, Washington, DC, 1983.

[117]N. Petraco, and P. R. De Forest, A Guide to the Analysis of Forensic Dust Specimens, Chapter 2 in Forensic Science Handbook, Vol. 3, R. Saferstein, Ed., Englewood Cliffs, NJ, Prentice-Hall, 1993.

[118] N. Petraco, Forensic Dust Analysis, Chapter, 4, in *More Chemistry and Crime,* Edited by S. M. Gerber and R. Saferstein, American Chemical Society, Washington, DC, 1997.

[119] N. D. K. Petraco, N. Petraco, C. L. Huemmer, M. Eng, and K. Sekadat, New Statistical Significance of the Household Dust Specimens, AAFS meeting in Chicago, IL, Paper No. A155, Feb. 2011.

[120] M. Eng, N. Petraco, N. D. Petraco, N. D. and A. Duggar, The Microscopic Study of the Statistical Significance of Household Dust Specimens, AAFS meeting in Washington, DC, Paper No. A189, Feb. 2013.

[121] N. Petraco, K. Farash, E. Hanson, and J. Ballantyne, Study of the Formation, Collection, Microscopic Trace Material Composition and Genetic Makeup of Household Dust Specimens, AAFS meeting in Orlando, FL, Paper No. B89, Feb. 2015.

[122] K. Farash, H. O'Brien, E. Hanson, N. Petraco, and J. Ballantyne, Combined Genetic and Micro-Chemical Analysis of Household Dust as a Definitive Trace Identifier of a Room and Its Occupants, AAFS meeting in Orlando, FL, Paper No. B90, Feb. 2015