Moth or Mollusc? 
A Technical Examination of Byssus Fibers

Denyse Montegut

The molluscs of the Pinnidae family, that produce byssus threads, are bivalves belonging to the order Anisomyaria. They are found in warm seas throughout the world, in sandy or muddy areas at depths ranging from very shallow to about twenty fathoms (Turner and Rosewater 1958). These wedge-shaped bivalves are capable of producing reasonably long anchoring fibers from an appendage that is both the foot and byssus-producing gland. Figure 1 is a sketch of a limited view of the inside of the shell, showing only the location of this external fiber-producing member and some of its supporting muscle system, located near the pointed base of the shell.

The foot guides the organism to a suitable firm foreign body for attachment. Then, from an opening on the side of the foot, a small amount of bubbly, protein-based adhesive is secreted. Within minutes, while the foot is still attached to the site, a fiber is formed along a canal in the ventral surface of the foot, and as the animal pulls away from this point of contact, a gelatinous strand is visible. It is not until they are harvested and dried in the air that the fibers become solid enough to be made into weaving threads.

Although up to twenty species of various molluscs produce byssus, the species most commonly referred to as a source for cloth, both knitted and woven, is that species of the Pinnidae family called Pinna nobilis Linné, that produces an extremely fine thread of a reddish to golden brown color. The length of the fibers varies; the samples used in my investigation were as long as 1.75 inches. For textile production, such a relatively short length requires that the fiber be made into a spun thread of multiple single strands, in contrast to long filaments of silk.

One of the ways byssus fibers were collected was by fishing for the shells off boats, using long tonglike or rakelike iron tools that reached down and disconnected them from their attachment, as pictured in Abbott (1972). According to Simmonds (1878), the foot with fibers attached was cut off and sold to local women who washed it in soap and water and let it air dry in the shade. Eventually, after combing, the fleshy foot was cut off and the remaining fibers were carded. Only three ounces of useful goods were obtained from every pound harvested, making it a costly commercial enterprise. The substantial initial cost of these textiles may be one of the reasons that they are at present so rare.
References to the manufacture of woven or knitted textiles utilizing byssus fibers are found in many sources, for example, in ancient Greek and Roman texts (some modern writers have even suggested that the Golden Fleece sought by Jason was made from byssus). In Arabic records (a gift of 2,285 tiraz textiles, 21 of which were made from "sea wool," was given to Christian princes in Spain in A.D. 997); and in reports from the Crusades (it has been proposed that the term cloth of gold used to describe luxurious medieval textiles was due to their byssus content). Accounts by numerous historians and travelers continue into the early twentieth century.

Many authors discuss the contemporary or historical manufacture of textiles made from byssus (Yates 1843; Simmonds 1878; Beck 1882; Basso-Arnoux 1916; Algoud 1930; Riccio 1932; Allan 1934; Serjeant 1934; Turner and Rosewater 1958; Abbott 1974; Lombard 1978; and Baker 1991, 1995, among many others). The main commercial sites for these products seem to have been located in Palermo, Sicily, Taranto (the byssus cloth woven there was supposedly called Tarantine), and Lucca. Riccio (1932) mentions a large pinna fishing site on Sardinia. Other locations of large populations of pinna, as cited by Basso-Arnoux (1916), were Corsica, the Adriatic coast, the Aegean, the Mediterranean coast of Africa (especially Tunisia), Spain and Majorca, the coast of Egypt, and the "sea near India."

The sheerness of cloth made from byssus seems to have been legendary, although references to specific textiles often repeat the same anecdotes as examples, such as the "sheer dress made for a queen [whose name changes], which could slide through a finger ring." Another account mentions a pair of gloves or a scarf produced for a pope, that could be folded to fit into a snuffbox or walnut shell. Again, the specific details vary. Historical references to the manufacture of these mysterious textiles are thoroughly investigated by McKinley (1998), who debunks many of these canonical anecdotes in his broad overview of several hundred bibliographic references.

As McKinley reminds us, the use of the word "byssus" is historically ambiguous. According to the Oxford English Dictionary (1971), one definition of byssus is

an exceedingly fine and valuable textile fibre and fabric known to the ancients; apparently the word was used, or misused, of various substances. linen, cotton, and silk, but it denoted properly (as shown by recent microscopic examination of mummy-cloths, which according to Herodotus were made of βασσος) a kind of flax and hence is appropriately translated in the English Bible "fine linen."
Van der Feen (1949) discusses the etymology of the word "byssus," and reports on an early source for confusion between the word for "depth" (in relation to the mollusk's environment) and the word for "fine vegetable fibers," a mistranslation of a work by Aristotle in 1476 about the Pinna shell, which led to its "perpetuation and popularization" (Turner and Rosewater 1958). Modern textile references, such as Fairchild's Dictionary of Textiles (1996) discuss byssus in two ways. The primary definition is "the wooly fiber secreted by the marine mollusk Pinna nobilis,...". This is followed by the statement that byssus fibers have been used in Southern Italy and Normandy for small articles and that a cloth was made from it in Taranto. The second definition describes byssus as a yellowish flax used by the ancient Egyptians and Hebrews, followed by the statement that it is "the fabric that was used for mummy wrappings."

Nineteenth-century references, such as the exhibition catalogues for the London (in 1862) and Paris (in 1867) international exhibitions, confirm a few entrants showcasing small goods made of byssus and demonstrating the techniques of gathering and spinning these threads, along with actual products (Saul 1974, McKinley 1998).

It is therefore mysterious that, despite a few late exhibition or tourist pieces, there are no firmly identified extant textiles made from these fibers. Assuming that there are indeed a few existing textiles containing byssus fibers, one obvious reason for their present anonymity may be the fact that we are not properly identifying them using our standard set of fiber references. Except for a few older, out-of-print references like Maurersberger (1947), byssus fibers are not included in fiber identification manuals. Studies of byssus fibers have not been conducted from a textile-usage point of view, but mainly in connection with research in marine biology or in protein studies (Lucas et al. 1955; Neurath 1966; Amato 1991; Waite 1991; Coyne 1997; Engel 1997, etc.). Therefore, these fibers are largely unfamiliar to textile conservators. Their small diameter, translucent properties, and sheen are visually similar to silk. When dealing with pre-nineteenth-century textiles, where no modern fibers are expected, it is perhaps easy to mistake byssus for silk. An added complication, mentioned in a few references concerning the production of "sea-silk" textiles, is the fact that some silk or wool was sometimes spun with byssus (Turner and Rosewater 1958; Saul 1974, etc.). Conservators viewing such fibers under the microscope and seeing the presence of the typical optical properties that characterize silk or wool would have little reason to go further in their confirmation.

Besides the possible reasons already stated for the lack of extant textiles made from byssus - too few were produced, or they exist but we are not properly recognizing them - another important consideration is the chemical and physical composition of byssus fibers, which could be susceptible to a more rapid rate or different path of deterioration than other protein fibers. After all, these fibers were secreted for use as semigelatinous strands in a saltwater environment. As will be seen later, the differences in the amino acid content of silk and byssus lead to a large variation in their respective chemical and physical structures, which presumably have a significant effect on the specific processes
and rates of deterioration. Is it possible that we are not seeing extant textiles made of byssus because of an advanced rate of deterioration that is not yet understood? The byssus sample, collected in the 1880s and used for this study, was extremely brittle. The very act of picking it up with tweezers caused each fiber to break, and any pressure against the glass slide mount reduced the fragments to dust.

It must be remembered also that the archaeological environment of Italy is not favorable in general to textiles; few have been preserved.

GENERAL PHYSICAL CHARACTERISTICS

The following data were compiled using an Olympus BX60, with a Cargille index of refraction liquids. The samples of biological byssus used for this study were generously supplied by the American Museum of Natural History, Department of Invertebrates. They are from the Jay Collection, number 27709, collected in the 1880s. This particular sample of byssus fibers will be useful for our study because it is from the Mediterranean area, is over one hundred years old, and has been aged in a typical museum storage environment.

Scanning electron microscopy (SEM) was performed in 1991 at the American Museum of Natural History on a Zeiss DSM 950. Figures 2 and 3 show SEM photographs of a byssus fiber from sample 27709, illustrating the elliptical shape of the cross section and the fine longitudinal lines and rough areas along the length of the fiber. Variations in the elliptical shape are seen in a 200X Joliff cross-sectional mount (fig. 4), and comparison can be made to the rounded-triangular shape of the cross section of silk in a 200X similar mount (fig. 5). When viewing the longitudinal mount of this elliptically shaped fiber, it is usually oriented in its flat position. It is also occasionally seen positioned twisted up on its pointed end, displaying a seemingly narrower diameter measurement. In order to gain a more useful sense of the measure of diameter in a fiber, whose cross section has such a distinct difference between length and width, I took an average of the measurements from point to point and another average of the diameter of the shortest side. The average of the shortest sides was comparable to that of silk (about 10 to 12 microns) but the point-to-point measurements indicating the normal longitudinal position of the fibers on a slide mount averaged about 36 microns.

The interference colors exhibited by byssus fibers under crossed-polars are representative of the low end (first order) of the Michel-Lévy chart, showing only a ghostlike, near-isotropic image that would be expected from its low birefringence of 0.002. This should be a key identification clue. Silk's birefringence is 0.053 (Textile Institute, Manchester, 1985), from the moderate second order of the chart, giving the brightest and most distinct interference colors.

Another very useful clue can be gained by the introduction of the first-order red plate when viewing the fibers at a 45° angle. Byssus fibers, which show a white interference
color under plain crossed-polars without the red plate, show a uniform dull orange when placed parallel to the slow direction of the red plate and uniform dull blue gray when placed perpendicular to it. According to the Michel-Lévy chart, this white interference color, which gives gray blue when you add 550 nm and orange when you subtract 550 nm, is equal to a retardation of about 125 nm. This translates on the chart to a birefringence of between 0.002 and 0.003, confirming the birefringence measurement obtained with the Cargille refractive index liquids. Silk, as was already mentioned, has many rich interference colors, and when the red plate is introduced it gives mixed and varied color patterns unlike the uniform predictable colors for byssus.

The 45° extinction pattern of byssus is also useful in differentiating byssus from silk: byssus has complete extinction, while silk gives an undulating, incomplete pattern. Table 1 (see Illustrations) is a summary of the microscopical examination of byssus fibers using an Olympus BX-60 and a Zeiss DSM 950.

CHEMICAL STRUCTURE

Byssus fibers are predominately made up of a genetically distinct member of the collagen protein family; like all protein fibers they contain repeating sequences of specific amino acid monomers, in which the physical size and the chemical nature of the amino acid functional groups control the behavioral characteristics of the fibers, including their ultimate stability. Collagens perform numerous essential biological functions in all living things, especially in the formation of connective tissue like skin and bones. We can think of byssus fibers as external tendons, attaching the base of the foot to the anchoring site. A key to the versatility of all collagens lies in their genetic ability to develop areas, called “domains,” in which the amino acid sequence is slightly altered to accommodate function. Coyne et al. (1997) published the full amino acid sequence for byssus fibers and analyzed them into domains with "characteristic repeat motifs" for each domain.2 The protein composition along the length of the chain varies and is found to be neither pure collagen throughout nor a homogenous mixture of proteins. For example, there are regions flanking a central collagen area of the chain that are more similar to the protein elastin than to collagen (Engel 1997). Coyne suggests that the elastinlike domains of byssus aid in its unusual extensibility of 160 percent, much greater than that of ordinary mammalian collagen (which is less than 10 percent). She is presently investigating histidine-rich areas of the chain for connections to the formation of metallic-protein complexes that may aid in cross-linking.

The protein that forms the core of byssus fibers is somewhat similar in substructure to all collagens. It is a relatively long (for invertebrates) left-handed helical polypeptide alpha chain, with a length of 128 nm (Engel 1997). The collagen molecule is formed by the hydrogen bonding of three of these helical chains into a triple right-handed helix, which then connects with other molecules to form long microfibrils by quarter-staggered overlapping of reactive ends on each of the individual single helix chains (Haines 1991).3
According to Waite (1991), after depositing a microcellular adhesive plaque onto the anchoring substrate, a preformed liquid protein material is made into a fiber in minutes by "injection molding" various gradients of the mixture along a groove in the edge of the foot. A protein varnish, consisting of a mixture of polyphenolic protein and catecholoxidase, coats the fiber. Waite describes the coating found on the byssus fibers: "The accessory gland of the foot secretes another latex which coalesces to form the varnish over the entire byssal surface. The function is presumably to protect the load-bearing fibers (collagen and elastic protein) in the core of the thread from microbial and chemical attack." This varnish consists of a mixture of polyphenolic protein and catecholoxidase in which, he suggests, the enzyme "has roles as both a copolymer and catalyst." The varnish coating is not yet fully understood, but it may be similar to the silkworm's sericin protein coating. How much of the coating is washed off during the cleaning and processing of byssus, like the degumming of silk, is not known, but the varnish was not visible on my lab samples at 400X (PLM). Perhaps staining would enhance the coating if it were still present. The rough outer surface visible under the 2000X magnification of the SEM could possibly be related to an abraded coating. Waite (1991) published a photograph of byssus fibers in which this coating was visible, but he did not report the technique or magnification of the image.

Amino acid analysis was performed on our byssus sample at Mt. Sinai Medical Center in 1993. Table 2 (see Illustrations) compares these findings with those for wool and silk (as published by Mills and White 1987) and bovine collagen (as published by Lewis 1991).

It should be noted that our byssus fibers are quite degraded and the distinctive pattern of amino acid breakdown and loss sequence for byssus fibers has not been studied. For byssus, although Coyne (1997) does not calculate the mole percent composition of amino acids, after viewing her published list of amino acid sequences one would expect the presence of hydroxyproline. This expectation is based on the fact that the amino acids in all collagens appear in triplet sequences with the form Gly-X-Y, where x is often proline and y is often hydroxyproline. Coyne (1991) describes the collagen domain in byssus as: "146 Gly-X-Y repeats in which X and Y are frequently Pro. Only the Pro residues at position Y appear to be converted to trans-4-hydroxyproline."

The high percentage (20.8) of glycine coupled with the high percentage of proline (15.6) in our byssus fibers would be enough to differentiate them from silk, and link them to the family of collagens. I cannot comment on why hydroxyproline was not found: either operator error or special decomposition pattern. Further research will involve the amino acid comparison of fresh byssus with an aged sample, run on the same equipment.

Another way of identifying these fibers could be to look at them under FTIR to see if they differ significantly from silk. It is well known that proteins are easily detectable by FTIR but that different protein types show limited spectral differences. The Objects Conservation Department at The Metropolitan Museum of Art ran FTIR tests of our byssus and a comparison sample of pure silk from Testfabrics. The samples were run on
a Bio-rad FTS-40 Spectrometer, mounted in a Spectra-tech diamond cell, placed in a Bio-
rad UMA 500 infrared microscope. Data was collected at four wave number resolution
and fifty scans each. Figure 6 shows the comparative spectra of both fibers. As was
expected, the O-H/N-H stretching band at 3,290 cm⁻¹ is present for both fibers but has a
broader shoulder area in the byssus. The expected protein amide I and amide II bands at
1,640 and 1,545 cm⁻¹, respectively, appear at slightly shifted locations in each fiber, with
the amide II peak appearing considerably smaller in byssus. Also, in the C-O area
(approximately 1,000 to 1,200 cm⁻¹) there are larger, less differentiated peaks in the
byssus. Again, we would be better able to judge the applicability of this method if we
had had a fresh sample of byssus instead of our aged one, in order to see the comparison
of two undegraded fibers. In general, this method would easily detect byssus as a protein
fiber but it would be less accurate as a method to differentiate silk from byssus.

SUMMARY

There have been references to extant textiles made from byssus. In Abbott (1972), there
is a picture of a pair of gloves made from byssus, but with no museum accession number
or location given. Patricia Baker (1995) suspects pieces in the Victoria and Albert
Museum could be made out of a blend of byssus and silk. There are other authors who
mention byssus textiles in Monaco. What is needed is a standardized methodology for
identifying byssus fibers, and for this the information in this paper may be useful. A
polarizing light microscope is all that should be needed to identify byssus, or at least
come to the conclusion that the fiber in question is not silk. Perhaps a closer look at
textiles from the Mediterranean, which in the past have been assumed to be silk, will
result in the discovery of a few byssus treasures.

In the search for hypothetical reasons to explain the lack of extant byssus textile
examples, more research clearly needs to be done on characterizing the process of
deterioration of byssus fibers. Waite (1991) states that “byssus represents a robust yet
biodegradable natural fiber with a functional lifetime of two to three years. Curiously,
only the varnish exhibits a resistance to chemical and enzymatic degradation whilst the
load-bearing fibrils in the core (such as collagen) are readily degraded once exposed.”
Throughout its lifetime, the mollusc constantly produces new fibers when needed for use
under water. Once we harvest these fibers and possibly wash off their protective coating,
it seems likely that they would quite rapidly deteriorate.

These fibers have also been described as metallic scavengers (Waite 1991), which
possibly use the metal ions found in seawater to create cross-linking complexes. Could
byssus fibers be a naturally occurring analog of weighted silks, suffering from the same
results of metal complexing as does silk? Their brittleness and tendency to crush to dust
as I prepared them for slide mounts was similar. And if Waite is right about the rapid rate
of deterioration of byssus, we should set our focus on identifying the few nineteenth- and
early twentieth-century examples that are at hand and address their immediate problems.
ACKNOWLEDGMENTS

I would like to thank Norman Indictor for sharing his interest in byssus fiber with me while I was still a student. In the intervening years, several individuals have performed important analytical tests, for which I would like to thank them: William Barnett for SEM work at the American Museum of Natural History; Mary Becker for amino acid analysis at Conservation Analytical Laboratory, Smithsonian Institution, when she was still a doctoral student; Ron Kohanski also for amino acid analysis at Mt. Sinai Medical Center; Margaret Walsh for support and time at the U.S. Customs labs in the New York World Trade Center building; and Dora Henel and George Wheeler for FTIR scans at the Objects Conservation Center, The Metropolitan Museum of Art. Most of all, I would like to thank Larry Majewski for his unfailing devotion to his profession and to his students.

NOTES

1. I am not sure that 1.75 inches necessarily represents the average of only full-length fibers. The sample was given to me as a clump of tangled fibers, which presumably could have contained some broken lengths.

2. Although Coyne and the other marine biologists mentioned in this article have only studied one species of byssus-producing molluscs, the M. edulis, we will accept these studies as also being representative of the Pinna nobilis, whose function and method of production are identical to the former. The reader should be aware that there may be slight variations in some measurements.

3. Care should be taken when reading data concerning "collagen" that although the basic triple helix structure is similar, species sources and function cause variation in amino acid content and chain lengths in microfibril formation. For example, the 300 nm chain lengths that are normally published for unspecified collagen (usually for mammalian connective tissue such as animal skins) are substantially longer than the 128 nm lengths for byssus collagen. Also, the published shrinkage temperature of 65° C for raw collagen (Sykes 1991) is different from the shrinkage temperature of over 90° C found specifically for byssus collagen (Coyne et al. 1997).

4. Becker and James (1994) have done such studies on silk, and Hansen and Sobel (1992) have published a large bibliography on silk degradation.
REFERENCES


Simmonds, P. L. 1879. The commercial products of the sea; or marine contributions to food, industry, and art. New York: D. Appleton & Co.


**FURTHER READING**


196


TABLE 1. SUMMARY OF MICROSCOPICAL EXAMINATION of BYSSUS FIBERS *(PLM and SEM)*

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Color (normal reflected light)</td>
<td>light gold to reddish brown</td>
</tr>
<tr>
<td>Color (transmitted light)</td>
<td>translucent, usually golden yellow</td>
</tr>
<tr>
<td>Crossed-polars</td>
<td>faint, very pale yellow at 45°</td>
</tr>
<tr>
<td>Extinction</td>
<td>complete extinction every 90°</td>
</tr>
<tr>
<td>Surface</td>
<td>smooth in fine fibers, rougher and more corroded in coarser ones; fine. longitudinal striations visible</td>
</tr>
<tr>
<td>Internal structures</td>
<td>none</td>
</tr>
<tr>
<td>Cross section</td>
<td>elliptical, with slightly rounded pointed ends</td>
</tr>
<tr>
<td>Diameter range</td>
<td>10 to 60 μm; average 36 μm</td>
</tr>
<tr>
<td>Index of refraction</td>
<td>$n_\parallel = 1.564$</td>
</tr>
<tr>
<td></td>
<td>$n_\perp = 1.562$</td>
</tr>
<tr>
<td></td>
<td>(the set of Cargille refractive index liquids used had increments of .004 per bottle. $n_\parallel$ was found to be exactly 1.564 and $n_\perp$ was found to be between 1.560 and 1.564 (i.e., 1.562 ± .001)</td>
</tr>
<tr>
<td>Estimated birefringence</td>
<td>0.002 (±.001)</td>
</tr>
<tr>
<td>Amino acid</td>
<td>Aged byssus</td>
</tr>
<tr>
<td>---------------</td>
<td>-------------</td>
</tr>
<tr>
<td>Glycine</td>
<td>20.8</td>
</tr>
<tr>
<td>Alanine</td>
<td>5.6</td>
</tr>
<tr>
<td>Serine</td>
<td>9.4</td>
</tr>
<tr>
<td>Threonine</td>
<td>3.1</td>
</tr>
<tr>
<td>Glutamic acid</td>
<td>7.1</td>
</tr>
<tr>
<td>Aspartic acid</td>
<td>10.7</td>
</tr>
<tr>
<td>Tyrosine</td>
<td>4.0</td>
</tr>
<tr>
<td>Phenylalanine</td>
<td>2.4</td>
</tr>
<tr>
<td>Leucine</td>
<td>5.5</td>
</tr>
<tr>
<td>Isoleucine</td>
<td>2.0</td>
</tr>
<tr>
<td>Valine</td>
<td>5.5</td>
</tr>
<tr>
<td>Arginine</td>
<td>4.2</td>
</tr>
<tr>
<td>Tryptophan</td>
<td>---</td>
</tr>
<tr>
<td>Cysteine</td>
<td>---</td>
</tr>
<tr>
<td>Cystine</td>
<td>---</td>
</tr>
<tr>
<td>Methionine</td>
<td>2.4</td>
</tr>
<tr>
<td>Histidine</td>
<td>1.0</td>
</tr>
<tr>
<td>Lysine</td>
<td>0.8</td>
</tr>
<tr>
<td>Proline</td>
<td>15.6</td>
</tr>
<tr>
<td>Hydroxyproline</td>
<td>---</td>
</tr>
</tbody>
</table>
Fig. 1. Sketch of the inside of a Pinna half-shell showing the location of the foot, byssus, and some of the immediate supporting muscle system.
Figs. 2 and 3. 2000X scanning electron micrographs of a byssus fiber from sample 27709 illustrating the elliptical shape of the cross section (top) and the fine longitudinal lines and rough areas along the length of the fiber (bottom). Photo by William Barnett at the American Museum of Natural History.
Figs. 2 and 3. 2000X scanning electron micrographs of a byssus fiber from sample 27709 illustrating the elliptical shape of the cross section (top) and the fine longitudinal lines and rough areas along the length of the fiber (bottom). Photo by William Barnett at the American Museum of Natural History.
Figs. 4 and 5. Variations in the elliptical shape of byssus are seen in a 200X Joliff cross-sectional mount (right). Comparison can be made with the rounded-triangular shape of the cross section of silk in a 200X similar mount (left).
Figs. 4 and 5. Variations in the elliptical shape of byssus are seen in a 200X Joliff cross-sectional mount (right). Comparison can be made with the rounded-triangular shape of the cross section of silk in a 200X similar mount (left).
**Fig. 6.** Comparative FTIR spectra of byssus fiber (top) and silk (bottom).