Part VIII
Fibre archaeology and textile conservation

41

INTRODUCTION

The emphasis of this book has naturally been on the relatively short-term durability of textiles: the seconds or minutes of a laboratory test; the minutes or hours of processing; the days or months, or at most a few years, of use. But in the context of archaeological and museum studies it is necessary to examine materials which are hundreds or thousands of years old (the earliest known constructed textiles date from 8000 B.C.).

Natural textile fibres are vulnerable to damage and degradation. As an illustration, only three weeks' burial in moist biologically active soil at 20°C is sufficient to reduce cotton, linen or wool fabrics to such a tender state that they disintegrate under their own weight; similar damage occurs in other cellulose and protein fibres. The more resistant synthetic polymer fibres have a history of no more than 50 years. It is not surprising that in many archaeological contexts textiles do not survive, other than as impressions in clay, on bricks or pottery, as pseudo-morphs following mineral replacement, or when charred or carbonized. Fortunately attack by the majority of biological antagonists is virtually eliminated if one or more of the following conditions persists: (1) absence of water; (2) temperature less than 5°C; (3) absence of air. Most of the significant collections of archaeological textiles have been preserved by such conditions.

The vast majority of textiles have been produced for use. In most ages and civilizations this use was severe and continuous, with items being handed down and modified, as well as patched and repaired until mechanical damage reduced them to a collection of rags. Such textiles suffered considerable fibre damage and disruption prior to being discarded, and were therefore especially vulnerable to rapid biological degradation. As a consequence textiles rarely survive their useful lifetime. Those that do are often found in collections and museums, where despite careful attention they continue to degrade. On display they suffer photo-degradation, and in today's cities they become progressively more acidic, so that cellulosic materials suffer acid-catalysed oxidation. They may even suffer insect damage.

Many of these differing forms of damage produce changes in morphology which are recognizable when examined with the SEM, and work at UMIST is continuing with the aim of generating an atlas of the morphology of long-term fibre degradation. The completion of this work will make it easier in many cases to identify the cause and sequence of the wear and damage, and in particular to distinguish damage occurring during the production and use of the material from damage occurring before or after discovery by the archaeologist.

FIBRE DAMAGE DURING GROWTH AND MANUFACTURE

Characteristic abnormalities occur in both wool and cotton fibres if their growth is interfered with. An illness in the animal or an absence of suitable grazing produces thin or tender places, and many ancient fleece types produce breaks naturally, prior to shedding. An interruption in the growth of the cotton hair, such as drought or premature harvesting, can prevent the secondary cell wall from developing, and produce an immature fibre. In silk, the tensile strength, fibre cross-section and cocoon length are all influenced by the condition and diet of the silk larva, and problems with either of these result in short cocoons and 'thin' filaments.

Cotton and bast fibres are protected from light during their growth, but wool is not, and in sunny countries the tips of the fleece exposed to ultra-violet radiation are often considerably degraded prior to clipping. This damage shows up as increased dye uptake, and the fibre tips may even break off during subsequent processing. Cotton is subject to the attentions of the boll weevil, and the results of such attack are well documented.

While all these forms of damage exist in ancient textiles, it is doubtful whether there is a justification in searching for them in a routine examination. However, it is possible to envisage situations where the identification of breaks, or sun-damaged tips, could provide useful evidence of fleece type or origin.

FIBRE DAMAGE DURING MANUFACTURE

The majority of hand methods of manufacture treat the fibre material gently, and cause little mechanical damage. Exceptions to this general rule include the extraction of bast fibres from the plant stem. With flax the process of retting initiates the bio-breakdown of the cellulose and lignin in the stem. Linen fibres are highly crystalline, and they resist this attack and hence remain intact while the 'wood' is tendered. Excessive retting results in damage to the fibre bundles, with the binder suffering first. Such fibres are likely to split down to the ultimates in subsequent processing and use.

Probably the most extensively damaging form of treatment was the use of certain mordants, such as iron, in order to fix dyes on protein fibres. There is no doubt that iron mordanting speeds up degradation; its use was proscribed by the eighteenth-century Flemish tapestry weavers' guild, because it was known to cause rapid deterioration. The mechanism of such damage is complex, involving the catalysis of protein hydrolysis and the acceleration of photodegradation, as shown and discussed in relation to **43A(2),(3)**, so that it is difficult to relate this process to specific morphological changes. The presence of iron can be proved in many ways, and so far our work involves the 'collection' and recording of the type of damage which results. At this stage there is no clear-cut pattern of morphological change which can be specifically linked to mordant-induced damage.

The use of tin compounds to weight silk causes the rapid photochemical oxidation of the silk protein. Egerton (1948) has shown a reduction in strength of 74% in just 4 weeks' exposure to summer sun in Manchester. Fibre breaks show variable morphology, from simple perpendicular brittle fractures to angular crack propagation, as shown in **43A(5),(6)**.

The processes of felting, fulling, raising and shearing all produce gross changes in the fibre arrangement within a fabric, and these changes usually remain detectable even after burial. However, wool textiles also felt in normal use, and it is often impossible to establish whether felting is deliberate or accidental, unless a relatively large sample survives. In a similar way, polishing or rubbing of linen fabrics smears and smooths the surface ultimates. An example, **41A(1)**, is from the shroud in Tutankhamun's tomb described in the next chapter. This structural change does not survive extensive wear and wet treatment, and is a useful indication of the extent of the use of the object. Again certain types of wear produce a similar effect, and careful examination of a large sample is necessary for positive identification.

FIBRE DAMAGE DURING USE

The useful life of most textiles is characterized by progressive changes. The record of the alteration of fabric structure and appearance, and of fibre damage, due to mechanical wear is the major theme of Parts VI and VII of this book. Work at UMIST reported by Cooke and Lomas (1987) and subsequent publications by Peacock (1988a,b), Mannering (1994), Cork *et al* (1997), and Rast-Eicher (1996), together with investigations by others, have demonstrated that these changes survive extended periods of burial, and can be detected with confidence with the use of the SEM.

Another change associated with wear is creasing. Creases may vary from soft recoverable folds in the fabric, with little associated fibre deformation, to sharp permanent features associated with fibre yield deformation, or mechanical conditioning. With garments, a crease pattern develops which is specific to the relationship between the garment's cut and fit and the anatomy of the wearer. Crease patterns have been shown to survive burial, in reports by Cooke (1988a) and Granger-Taylor (1988), and may contribute to the identification of the function of the object.

Textiles suffer many other types of attack during normal use. They may simply hang in a window, subject to photodegradation. Even in the UK this process is rapid, with a 90% strength loss for an undyed cotton twill after 6 years in a south-facing window in Manchester. In a damp unventilated environment mould growth can develop and there may be damage by the activities of insect pests, as shown in **43C(1)–(5)**. Even in apparently safe places there may be damage by fire and flooding. Many of these forms of damage survive in ancient and archaeological textiles even after burial, and they can often be identified with the aid of a stereo-optical microscope, once the characteristic morphologies have been learnt from the study of high resolution SEM photomicrographs.

DAMAGE DURING BURIAL

Burial in soil often provides the ideal environment for the complete destruction of cellulosic and proteinaceous textile fibres. The soil ecosystem operates by breaking down cellulose and protein macromolecules into smaller, more readily accessible units. Fungi and bacteria produce synergistic combinations of enzymes, cellulose and proteolase, which are capable of attacking both the amorphous and crystalline zones of the fibre. *Fusarium oxysporum*, *sporotrichumpruinosum* and *pencilliumfuniculosum* are specific for cellulose and common in soil. Tests involving the soaking of 2-inch strips of untreated cotton fabric in a culture of *fusarium oxysporum* and the subsequent storage with a moisture content of 24% at 30°C ± 2°C produced strength reductions of 45% after 4 days, 92% after 7 days and 100% after 14 days.

Wool seems to be more prone to bacterial attack, for example by *Bacillus mesentericus*, *B. subtilis*, *B. cereus* and *B. putrificus*, but also supports the rapid growth of *penicillium*, *aspergillus* and *actinomyces*. The attack often initiates in contaminants such as soaps, sizes or suint, and then spreads to the wool fibres. The weak point in the undamaged wool fibre is the distal scale edge, and damage at this point in the otherwise resistant exocuticle provides access to the less resistant endocuticle and cortex. The common breakdown mechanism is hydrolysis of the peptide link, caused by trypsin, and an enterokinase activator. When completed such breakdown removes 10% by weight of the fibre, in the form of cell membranes, nuclear remnants, cytoplasmic debris and endocuticle, and results in a 90–95% loss in strength. The keratin of the cortical cells is not attacked, unless the disulphide bonds are broken (Lewis, 1975).

It is fortunate for textile archaeology that fungal and bacterial activity is temperature- and pH-sensitive, and water-dependent. The most rapid attack occurs under the following conditions; 25–40°C, pH 6.5–8.5 and r.h. >95%. Acidic and alkaline conditions inhibit the process, and temperatures less than 5°C prevent active attack.

A number of different archaeological contexts have consistently yielded well-preserved textiles. The most extensive finds have come from desert conditions, such as Egypt and the Sudan, where the virtual absence of water has prevented biological attack. The Northern European acid peat bog has preserved many organic remains, including wood, animal and human cadavers, and textiles. Unfortunately acid conditions lead to acid-catalysed hydrolysis of cellulose, which eventually dissolves; consequently wool and silk survive, while linen, cotton, nettle and jute vanish. A contributing factor to the preservation environment of the peat bog is the development of anaerobic conditions, which also often develop in other waterlogged sites. A number of these have produced extensive textile remains, for example Viking Dublin, Viking York and Vindolanda on Hadrian's Wall (see Chapter 42).

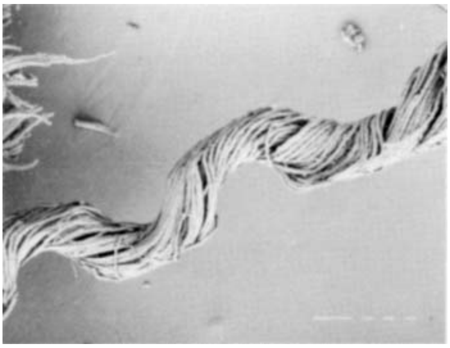
The permafrost layer has the potential to preserve most organic remains, without the selective acid removal of cellulose or alkaline hydrolysis of wool and silk. However, such finds pose considerable problems to conservators, as the return to normal temperatures initiates rapid decomposition. There is evidence that freeze-drying will provide the solution to this problem, Peacock (1988). Certain metal salts, such as the corrosion products of iron, copper and bronze, also inhibit biodegradation, but they catalyse the hydrolysis of both cellulose and protein. In this context the formation of negative casts or positive pseudomorphs may preserve much of the surface and structural detail of the fibre, Janaway (1983), despite the almost total destruction of the textile itself. In one respect the oxidation of cellulose can be advantageous. Under the right conditions cellulose will oxidize in a controlled manner, without total disruption of the fibre structure. This charring is assumed to involve slow combustion, with a limited supply of oxygen. In much the same way that charcoal retains many of the structural features of wood, carbonized textile fibres have recently been shown to retain their structural features, Cooke (1988b), as shown and discussed in relation to **43B(1)–(3)**. The oxidation of cellulose also seems to proceed without combustion, at room temperature, albeit very slowly. Such carbonization can be found in very ancient fabrics such as the Tutankhamun Anubis shroud, as shown in **42D(3)**.

In general the problems of identifying damage associated with the microbial attack of burial are considerable. With modern textiles staining methods are used to reveal fungal (mildew) attack, but these are inappropriate for archaeological objects. Ancient textiles show changes in break morphology, the residues of hyphae **41A(2),(3)**, or colonies of bacteria or fruiting bodies **41A(4),(5)**. When these are not present we can only surmise on the causes of damage such as the extreme erosion seen on a Coptic 'rondelle' in the Whitworth Gallery collection **41A(6)**.

POST-EXCAVATION DAMAGE

Ideally post-excavation damage would not occur. In practice there is rarely adequate funding for immediate conservation, or for appropriate long-term storage facilities. Textiles which have survived for very long periods owing to a happy combination of burial conditions almost inevitably face a more destructive environment as a result of excavation. Who can realistically envisage the safe storage of a Coptic textile for a further 1500 years, or a Pharonic linen object for another 3000 years? Perhaps the greatest risk arises between discovery and conservation. Each burial context leaves the textile open to differing risks and therefore dictates a different treatment method. The actions to avoid can be summarized as: wetting dry textiles; drying wet textiles; neutralizing acid or alkaline textiles; aerating anaerobic textiles; warming frozen textiles; and cleaning metal objects on site. The small-finds manager should be made aware of the rapid destruction of textiles in warm, wet, biologically active environments and the particularly damaging effects of storing wet textiles in polythene bags.

Damage during conservation is increasingly less likely, as the present high standards of training and professional awareness continue to be refined. During long-term storage the risks are easy to identify: fluctuations in temperature and humidity; regular handling by scholars and students; exposure to dirt, insects, spores and bacterial contamination; exposure to light on display; exposure to acidic gases, such as oxides of nitrogen and sulphur; and disasters, such as fire and flood. The studies reported here help to identify and explain the possible forms of damage, but the problem is how to prevent the damage at an acceptable cost.



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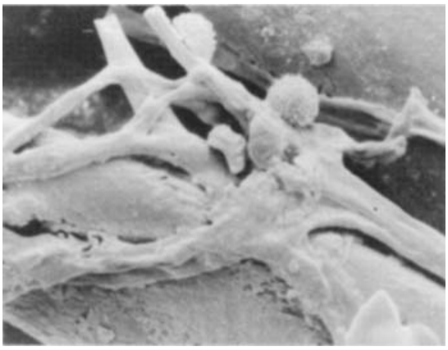

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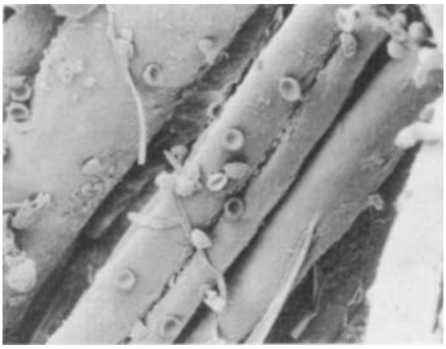

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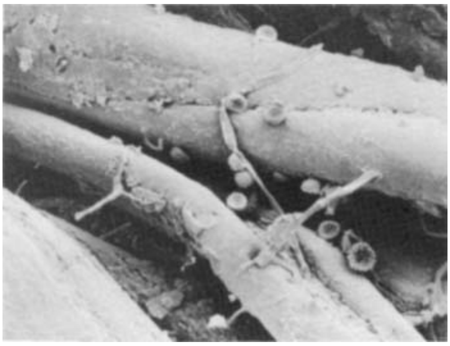

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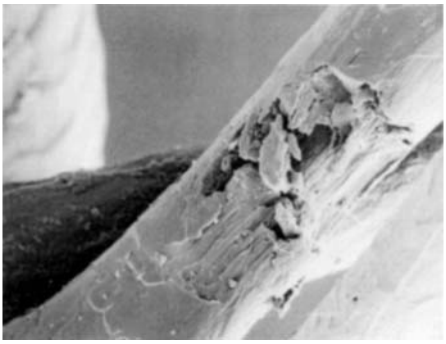

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Plate 41A — Shroud from tomb of Tutankhamun.
(1) Yarn from shroud showing crown flattening.
Damage to 19th century tapestry from Victoria and Albert Museum, London.
(2),(3) Residues of hyphae. (4),(5) Colonies of bacteria or fruiting bodies.
Coptic 'rondelle' from Whitworth Gallery, Manchester.
(6) Unspecified damage.

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MECHANICAL WEAR IN ANCIENT TEXTILES

The combined use of optical and scanning electron microscopy has proved to be a powerful tool in the study of mechanical wear and degradation of ancient textiles. Samples of old fabrics almost invariably shed fibre fragments, and these form the initial target of optical microscopy. Mounted in distilled water, under a coverslip, they are examined for fibrillar breakdown, cracking, splitting, peeling, and for brittle fracture. The fabric surface is then scanned with a stereo-microscope for evidence of macro wear patterns, as well as fractured fibres *in situ*. Once the macro wear pattern is understood, the stereo-microscope is used to identify representative sampling zones for SEM examination. The SEM study provides confirmation of the wear mechanisms, both at the level of structural damage to the yarns as well as in the individual fibres, and produces a permanent photographic or digital record.

Linen fabrics have a reputation for smoothness, coolness and durability. The author had access to a collection of linen sheets and dresses, which had been in regular use for about 40 years, and these were examined using the above methodology. The fabrics were strong and supple, and there was no evidence of fibre shedding. The microscopical examination revealed complex changes in both yarn and fibre structure, and it is probable that these changes, resulting from the effects of washing and wearing, contribute to the feeling of smoothness associated with linen. The changes can be summarized as:

(1) Flattening of yarn crowns, **42A(1)**, which involves the breakdown and fibrillation, often in sheets, of the cellular bundles in the flax fibres, **42A(2),(4)**, and the smearing of surface material, **42A(3)**.
(2) Abrasive action, leading to fibre fatigue and 'brush ends', **42A(5)**.
(3) Extensive wet alkaline treatment producing surface peeling, **42A(6)**, possibly with some separation of cells.
(4) Extended fatigue damage resulting in fibre loss, thin places and broken threads, **42B(1)**.

A similar study of a worn silk dress, ca. 1920, revealed the following pattern of breakdown:

(1) Abrasive action on the yarn crowns produces peeling and fibrillation, **42B(2)–42B(4)**, and ultimately rounded ends in the weave interstices, **42B(5)**, as the fibrils wear off, **42B(6)**.

Excavations at the site of Vindolanda a Roman fort on Hadrian's Wall, have yielded a large number of organic objects dating from the Flavian and Trajanic periods, ca. AD 100. These finds, including writing tablets, leather goods and textiles, were preserved in the anaerobic but not waterlogged conditions of a compacted bracken floor of a wooden military building in the Vicus.

A portion of a leg wrapping was made available for an initial wear study. The loose fibre debris associated with this fabric showed evidence of fibrillation and brittle fracture. The SEM study confirmed the mechanisms of damage as:

(1) Biaxial-type fatigue and fibrillation associated with pilling, similar to that described in Chapter 30, namely multiple fatigue sites along pill anchors, and local clusters of such damage, **42C(1),(2)**. The detailed morphology of this damage is exceptionally well preserved, **42C(3),(4)**, as is the scale structure of the wool, **42C(5)**.
(2) The sample also contained a number of well-defined holes. The fibre breaks associated with this damage were exclusively brittle type, probably resulting from local biodegradation, **42C(6)**.

The extent of the wear damage, together with the very well-preserved longitudinal creases typical of leg wrappings, which were similar to puttees, suggested extensive use.

The success of this initial study led to a three year Leverhulme Trust funded research project at UMIST, completed in the summer of 1995, which has made an extensive examination of the Vindolanda corpus of textile finds made up of more than 750 individual textile fragments. This project has used a range of analytical methods including the use of the SEM and image-analysis to study the fibre, yarn and fabric structures. This examination showed that surprisingly few of the fragments had originated from the same fabric web, and those that did match in terms of weave, twist-angle, fibre diameter, etc, were probably joined prior to excavation. The SEM provided clear low-magnification images of the yarn systems, which facilitated the use of image-analysis to automate twist angle measurement, **42D(1)–(3)**, Cork *et al* (1996), and accelerate the process of fibre diameter measurement.

The majority of the fragments showed the typical signs of very considerable use, and it would appear that clothing was worn until it fell apart, and the remains used for patching other garments, under the rigorous conditions of life for Roman auxiliaries serving on Hadrian's Wall. Even the fabrics found in the officers' quarters, although of higher quality, had the same extensive fibre damage, and the same fragmentary nature. A number of the heavier fabrics showed a definite raised nap, which was visible with a stereo-zoom microscope, as well as with the SEM. The study confirmed the use of diamond twill as the most popular structure on Hadrian's Wall, in common with much of the northern Roman Empire at that time, and recorded 42 different diamond twill constructions.

Museums are another source of historical textiles for examination. For example, **42D(5),(6)** is a silk bodice from the Textile Conservation reference collection at Hampton Court, which is discussed in more detail in the next chapter.

During recent conservation of textiles in the Victoria and Albert Museum, from the tomb of Tutankhamun, a number of small fragments of weave became detached, and these formed the basis of an SEM examination. The fragments came from two textiles, a shawl and a shroud, found draped around the statue of Anubis, which guarded the entrance to the antechamber of the tomb.

The fragment of shawl showed no signs of wear. However, the individual fibres, which appear to be flax, have suffered a concertina-type deformation, **42E(1)**, which seems to be associated with length shrinkage, **42E(2),(3)**. Not all fibres are equally affected, and the cause of this damage is not yet clear.

In contrast, the fabric of the shroud, dated by inscription to the seventh year of the reign of Akhenaten, **42E(4)**, has suffered considerable flattening of yarn crowns, **42E(5)**. The fibres in protected parts of the weave show transverse cracking, often at nodes, but no surface damage, **42E(6)**, whereas fibres in the crowns exhibit fibrillation and smearing, typical of changes associated with wear and wet cleaning, **42F(1),(2)**. The extent of the crown damage suggests considerable mechanical rubbing, together with wet treatment, and may have occurred either through use, or perhaps during a process of wet finishing and smoothing to impart softness prior to use. The shroud is actually a shirt with a neck opening, which would only accommodate the head of a child, and the inscriptional date coincides with the birth of Tutankhamun.

Occasionally the evidence of wear in an archaeological object is visible to the naked eye, and can be recorded using macrophotography. A Coptic child's tunic, recently conserved in the Whitworth Gallery, Manchester, has seen considerable use, and has been darned and repaired frequently, **42F(3),(4)**. In the lower back there is a thinning of the fabric, associated with extensive crown damage resulting from lengthy wear, **42F(5)**. Also of considerable interest is the weave distortion or bagging, which has become a permanent feature of the garment, together with the creases at the side seams formed by the stresses developed during sitting, **42F(6)**.

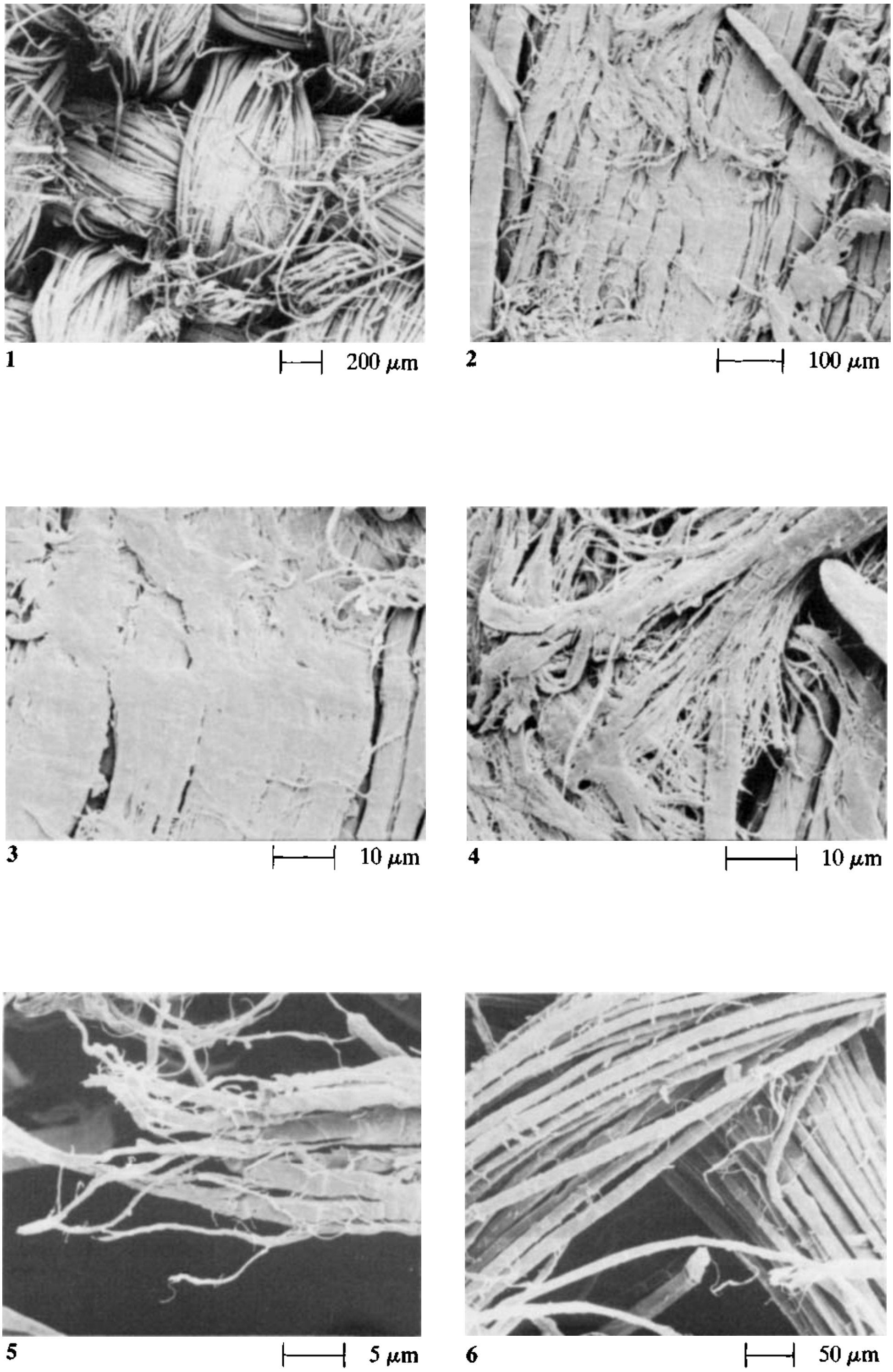
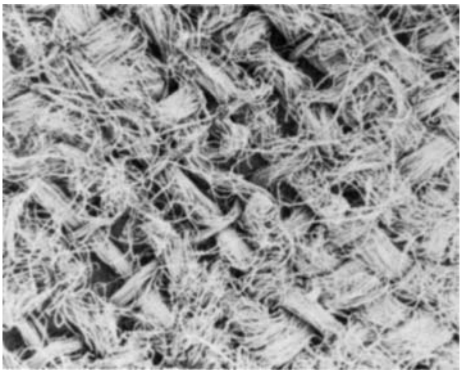


Plate 42A — Wear damage in linen fabrics in use for about 40 years.
(1) Crown damage. (2) Crown damage, fibre flattening and fibrillation. (3) Fibre smearing. (4) Linen fibrillation. (5) Fatigue fracture. (6) Surface peeling.



1 1 mm

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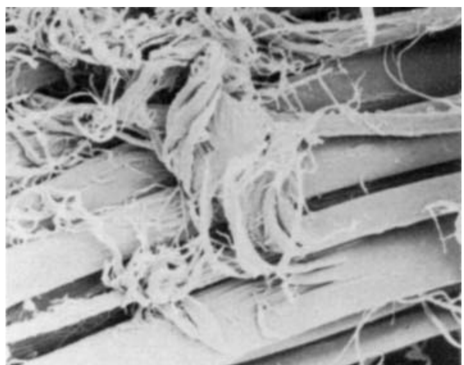

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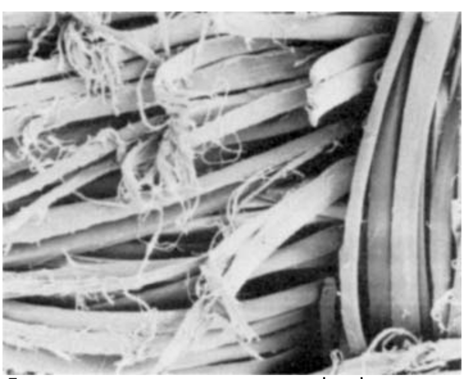

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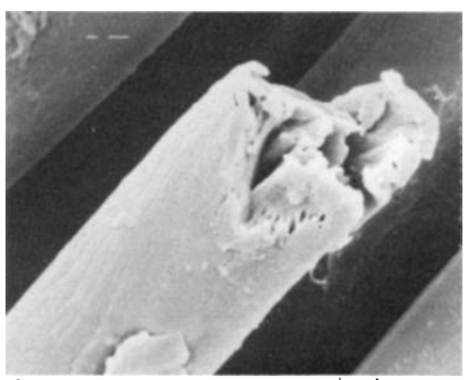


6 2 μm

Plate 42B — Wear damage in linen (continued).

(1) Thread breakdown.

Wear damage in silk dress after 60 years.

(2) Crown breakdown. (3) Fatigue breaks in weave. (4) Peeling and fibrillation. (5) Crown breakdown. (6) Fibre fracture and rounding off.

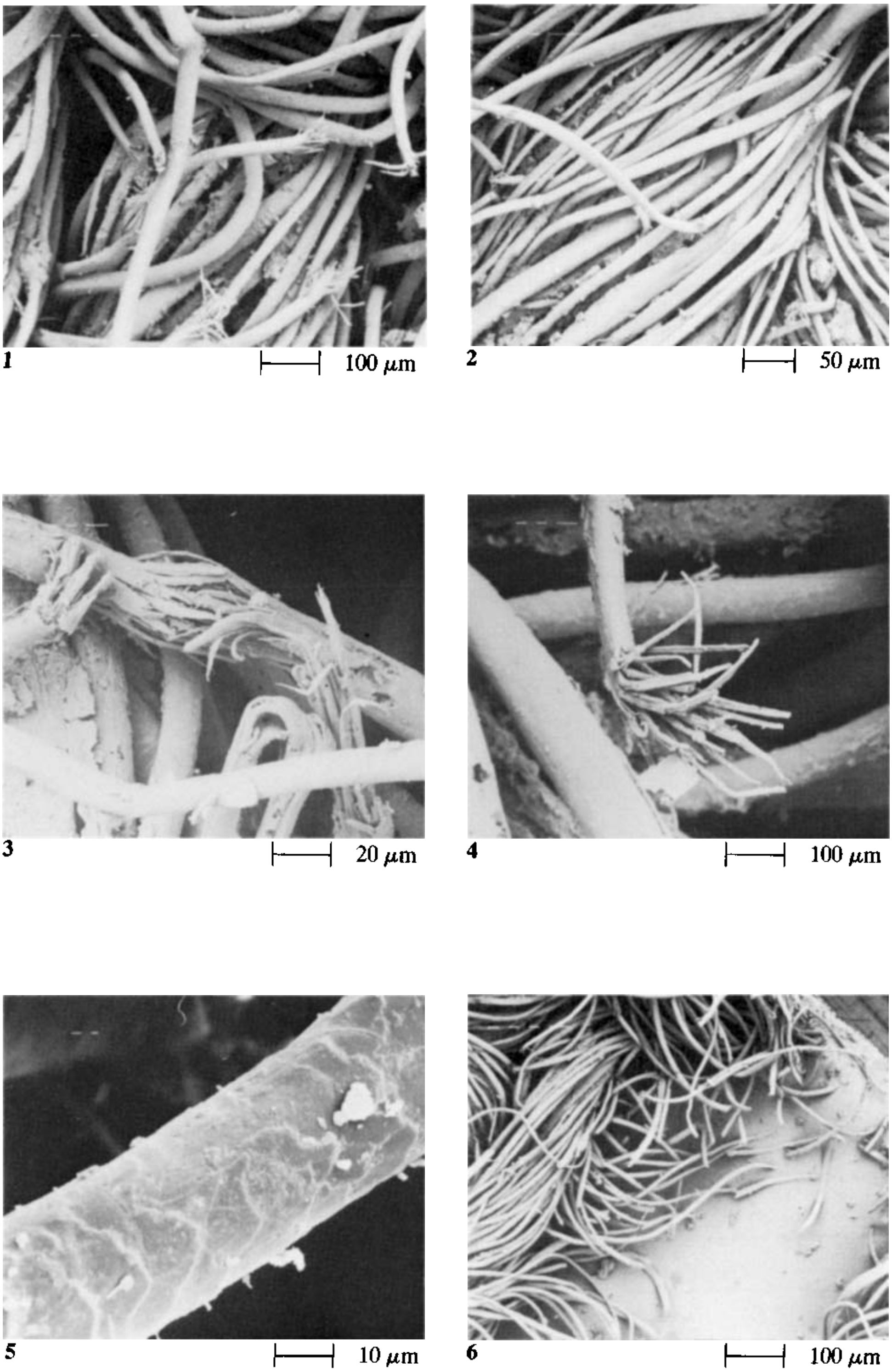
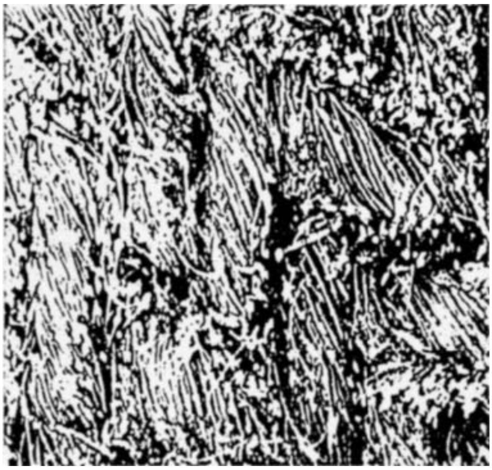


Plate 42C — Fibre damage in Roman leg wrapping from Vindolanda.
(1) Pill site with multiple fatigue breakdown. (2) Pill anchor. (3) Biaxial-type fatigue. (4) Fatigue breakdown. (5) Scale damage. (6) Brittle fracture.



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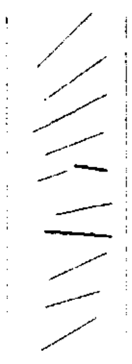

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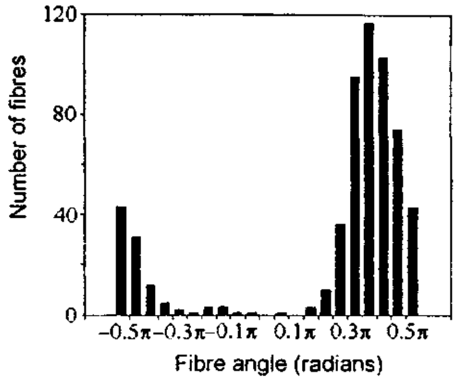

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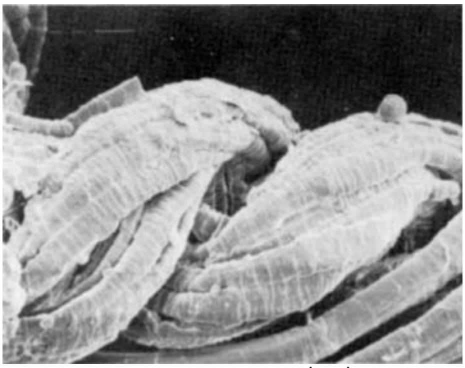
Plate 42D — Roman fabric from Vindolanda.
(1) Frame-grabbed digitally stored SEM image. (2) Final stage of image analysis, showing vector lines for twist-angle measurement. (3) Twist angle distribution histogram generated from image analysis.
Late 19th century silk bodice from Hampton Court
(4) Brittle fractures in warp and weft. (5) Close-up of fractures in warp.



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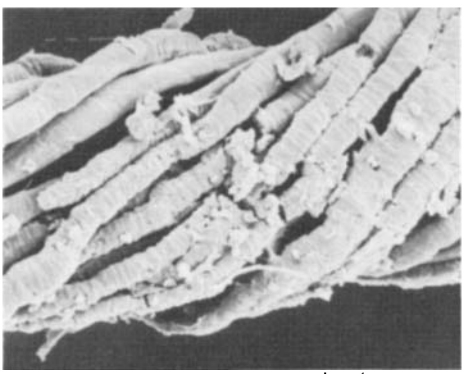

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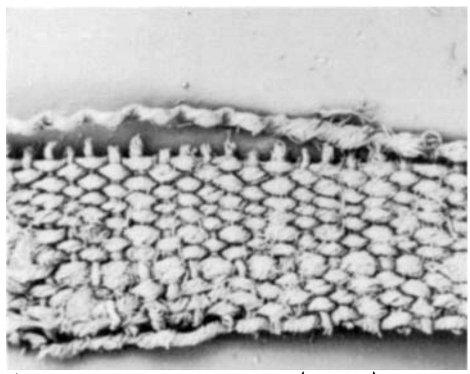

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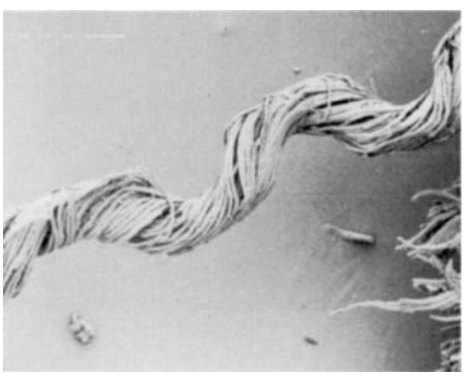

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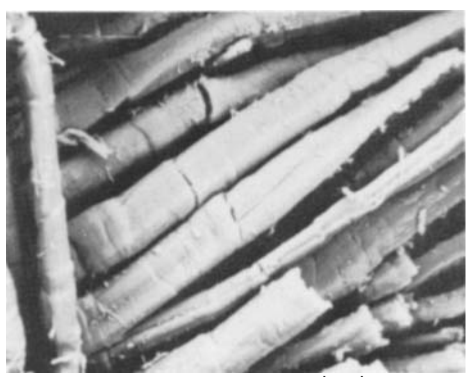

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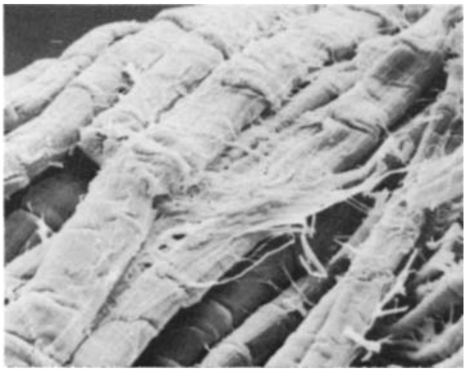
Plate 42E — Textiles from tomb of Tutankhamun.
(1) Flax fibres from shawl. (2) Concertina damage. (3) Concertina damage and shrinkage. (4) Fabric from Anubis shroud. (5) Crown flattening. (6) Transverse cracks.



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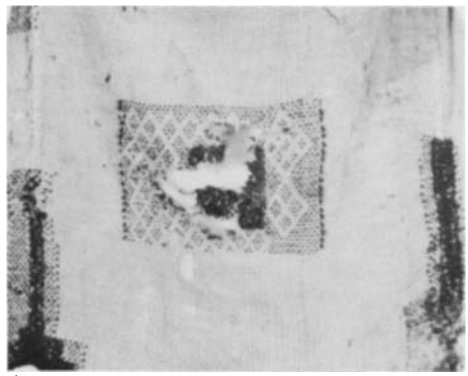

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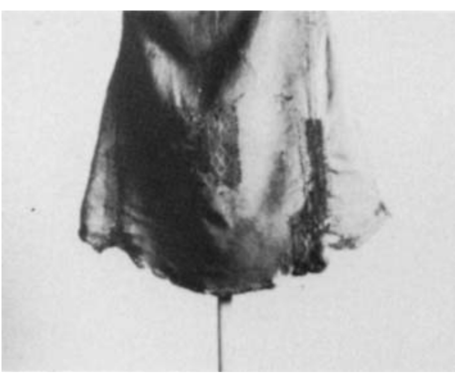

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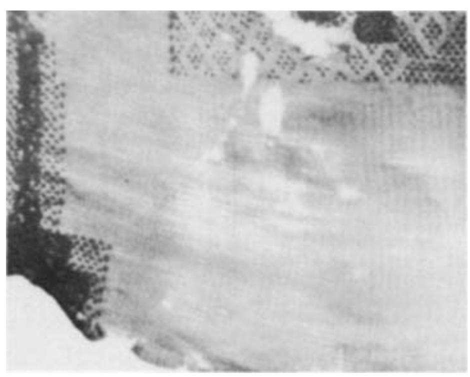

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Plate 42F — Textiles from the tomb of Tutankhamun (continued).
(1) Fibre breakdown. (2) Fibre fibrillation.
Coptic child's tunic.
(3) General front view. (4) Darning. (5) Seating in back. (6) Abrasion damage and thinning.

43

ENVIRONMENTAL DAMAGE

Textiles are liable to suffer environmental damage at any stage in their life time, from fibre growth through to storage in a museum. In contrast with the evidence of wear and use discussed in Chapter 42, environmental damage is difficult to identify with precision, and it is often impossible to decide when it occurred. The latter comment is particularly true for archaeological textiles, as the degradation associated with burial is likely to obliterate prior damage.

Textiles designed for display usually suffer photodegradation throughout their lives, and it is only recently that effective means to reduce this damage have been taken in our museums and collections. At greatest risk are objects with a long natural life, such as drapes, carpets, upholstery and, particularly, tapestries. When new, tapestries are immensely strong objects. The typical products of Flanders and northern France were capable of supporting 2000 times their own weight, Howell *et al* (1997), and they are consequently capable of hanging on display for 300–400 years. The first evidence of damage is provided by changes in dye colour. The initial reduction in tensile strength of the fibres, due to molecular chain scission, has little effect on the tapestry owing to its technical over-construction. Nevertheless, 300 years' exposure does cause damage, including the loss of areas of weft and the consequent disruption of the design.

In order to understand the process of breakdown, a survey was carried out, initially using hand lenses and subsequently an arm-mounted stereo-zoom microscope, of the hanging tapestries in Hampton Court Palace. It was apparent that the protected backs of the tapestries were in a much better condition than the fronts. The colours were much brighter and there was less damage. Further examination showed that certain colours were much more subject to damage, dark brown wools being most seriously affected, together with pink, cream and apricot-coloured silks. The study was then restricted to a tapestry which had been taken down for conservation. This was one of the Alexander series, *Alexander with His Horse Bucephalus* (ca. early eighteenth-century, Brussels workshop). An initial tactile survey indicated that even a tapestry in good general condition had large areas which were dry, abrasive and rough to touch. The problem was restricted to the face side, and was more serious in areas of the design dyed dark brown, which had been close to a window since the time of George I (1714–27). A Nikon stereo-zoom microscope, ×2 to ×40, was used to study the tapestry. The back showed little evidence of fibre damage. The weft crowns were intact and in excellent condition, **43A(1)**. The damaged areas of the face revealed the cause of the roughness, an unusual form of fabric degradation. The weft crowns had suffered very considerable brittle fracture, **43A(4)**, which had converted a proportion of the weft face into a sharp 'pile'. These groups of fractured fibres existed in the interstices of the weave on either side of each weft crown, **43A(2),(3)**. This process of crown breakdown is progressive, and will ultimately lead to total breakdown of the tapestry, Cooke and Howell (1988).

In order to understand the selective nature of this light-induced damage, samples of weft from each of the dark colours were subjected to X-ray emission microprobe examination on an SEM. The resulting elemental analysis revealed a significant iron (Fe) peak in the dark brown sample, whereas the other colours were free from traces of iron. It is probable that the damaged wool had been treated with an iron mordant, and the damage had resulted from a combination of iron-induced hydrolysis and photodegradation.

Royal bed hangings are also subject to photodegradation. Queen Charlotte's bed in Hampton Court Palace has been exposed to light since 1715, a similar length of time to the Alexander tapestries, and has suffered considerable fading and photodegradation. Many of the warp fibres are shattered by angular fractures, **43A(5),(6)**, and each movement of the drapes causes more fractures to occur. This damage is not due to tin weighting as this process was only introduced in the late nineteenth-century.

A more recent study of a late c19th century silk bodice from the Textile Conservation Centre reference collection showed catastrophic brittle fracture in both yarn systems, **42D(5),(6)**. EDAX analysis demonstrated the presence of tin (Sn), which had caused the rapid degradation of the fibre, as well as aluminium (Al) and silicon (Si), which probably indicate cleaning with fullers' earth, a process common with silk objects prior to the use of dry cleaning.

Fire is usually the ultimate destructive agency for textile materials, and yet under the right conditions cellulose fibres will oxidize in a controlled manner without total disruption of the fibre structure. In much the same way that charcoal retains many of the structural features of wood, the charring of cellulosic textiles is known to preserve the macrostructure of the fabric. The conversion of cellulose to carbon eliminates most of the risk of biodegradation, and archaeological textiles are often found in a carbonized condition in contexts which would destroy both cellulosic and proteinaceous material. Such objects are difficult to deal with, owing to their fragile state, and their examination has usually been restricted to thread counts and the determination of twist direction. Recent work at UMIST on carbonized textiles from Soba (Sudan ca. AD500) has shown that not only is the yarn structure, twist, etc, preserved in great detail, **43B(1)**, but fibre surface and cross-sectional information is sufficient to allow the positive identification of cotton, and even reveal the maturity of the fibre, **43B(2),(3)**.

A further form of 'oxidation' frequently found in grave goods is the non-specific damage which occurs when textiles are in contact with body fluids, and with certain embalming materials. The examination of an 'oxidized' fragment from a Coptic sprang cap in the Whitworth Gallery collection in Manchester reveals considerable brittle fracture, **43B(4),(5)**, but the surface scale structure of the wool is still intact, and the internal cellular structure is remarkably preserved, **43B(6)**.

The problems of identifying damage associated with the microbial attack of burial are considerable. With modern textiles, staining methods are often used to reveal fungal (mildew) attack, but these are inappropriate for archaeological objects. Ancient textiles show changes in colour and brittleness, and with luck the residues of spores or hyphae, or colonies of bacteria, serve to identify the cause of the damage, as in a Coptic wool textile, **43C(1)**, and a Pharonic linen, 18th Dynasty, **43C(2)**. Extensive fibre damage in a Vindolanda sample would seem to be due to bacterial attack, **43C(3)**, as there are no signs of hyphae or spores.

Many insects are capable of damaging textiles with their mandibles but only relatively few have adapted to using fibre protein as their main source of food. In Europe two orders, Lepidoptera and Coleoptera, pose the most serious threat. The larva of the clothes moth is an avid selective feeder, often choosing particular dyestuffs, for example eating only greens and pinks from a multicoloured embroidery. A study of the debris left after such an attack suggests that the larva eats individual fibres as a child would eat a stick of candy, namely munching down from one end, **43C(4)**. Eaten fibre debris is often found covered with 'moth silk' when the case moth is the cause of the damage, **43C(5)**. This larva extrudes very fine filaments, 0.5–1 μm diameter, to form a protective cocoon during feeding. A further sign of clothes moth activity is the characteristic droppings, **43C(6)**, which often reveal the colour of the wool eaten. The carpet beetle, which feeds on wool both in the larval and adult stages, would seem to bite in a more random manner, often starting half way along a fibre. The droppings are very similar to those of the clothes moth.

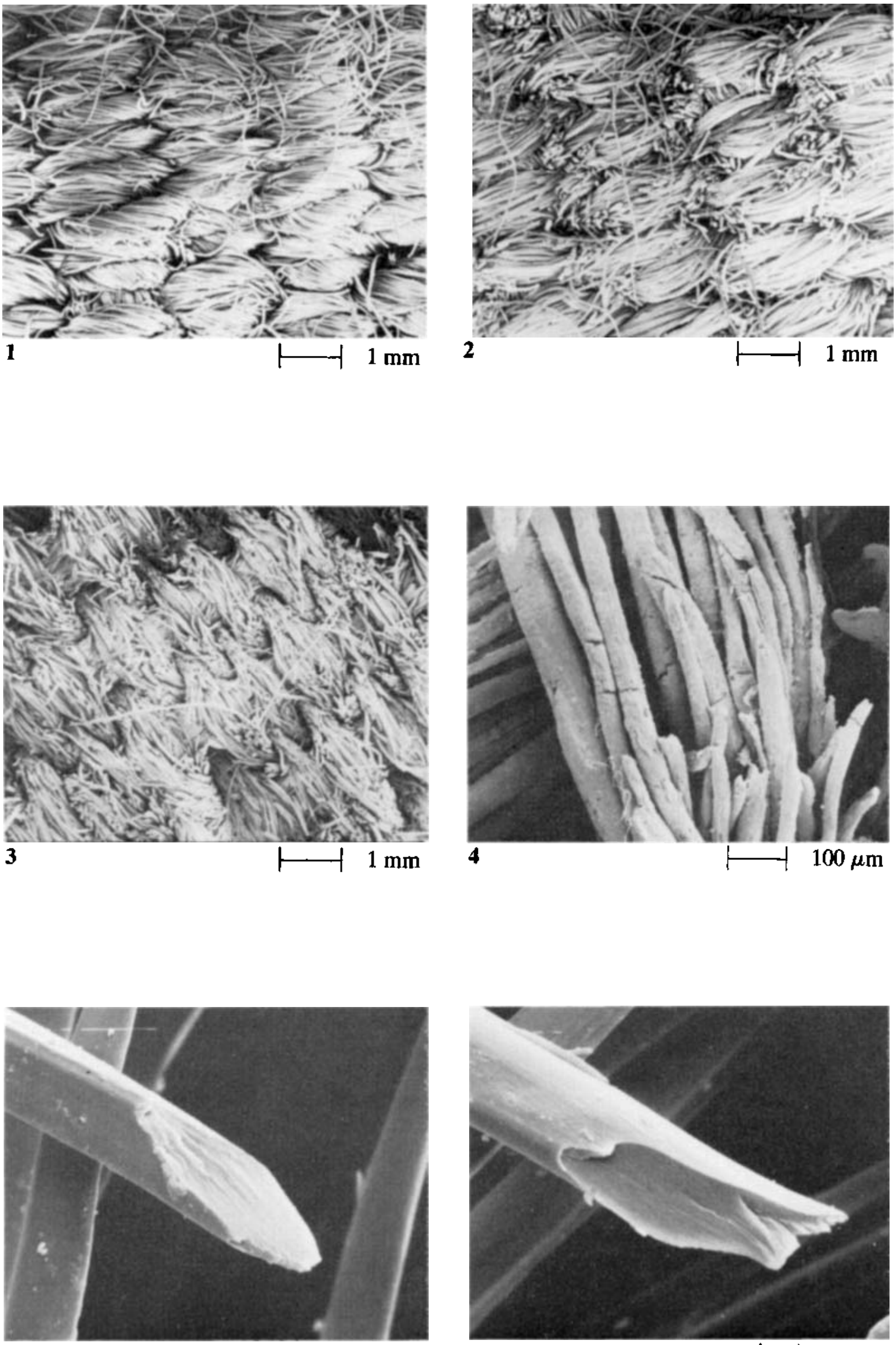
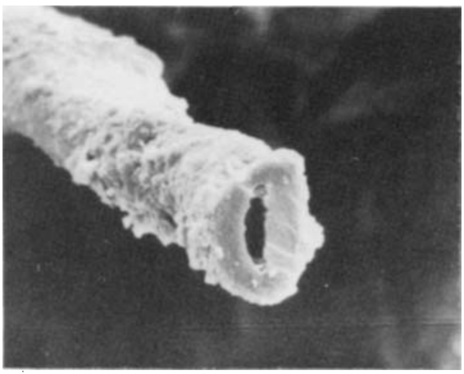


Plate 43A — Tapestry damage, Hampton Court Palace.
(1) Undamaged crowns on back. (2) Face damage. (3) Structure close to breakdown. (4) Fibre fracture in face crown.
Queen Charlotte's bed drapes.
(5) Silk fracture in face. (6) Silk fracture.

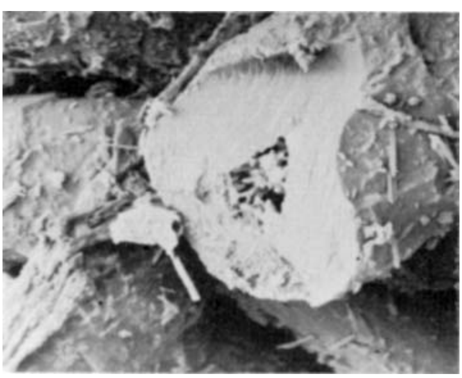
1 1 mm

2 20 μm

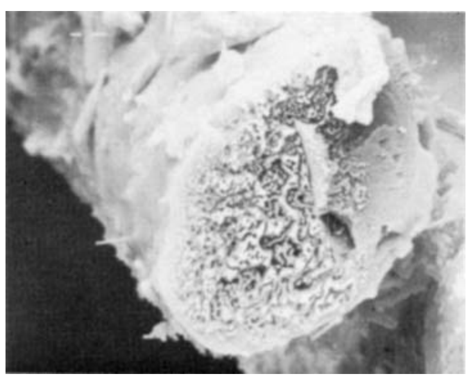


3 5 μm

4 100 μm



5 10 μm



6 2 μm

Plate 43B — Carbonized textiles from Soba, about 1500 years old.
(1) Crossed-loop knitted structure. (2) Cotton fibre convolutions. (3) Cotton cross-section in fracture.
Coptic sprang hat in Whitworth Gallery
(4) Fibre fracture in yarn. (5) Fibre fracture, wool. (6) Cortical cell structure in fracture.

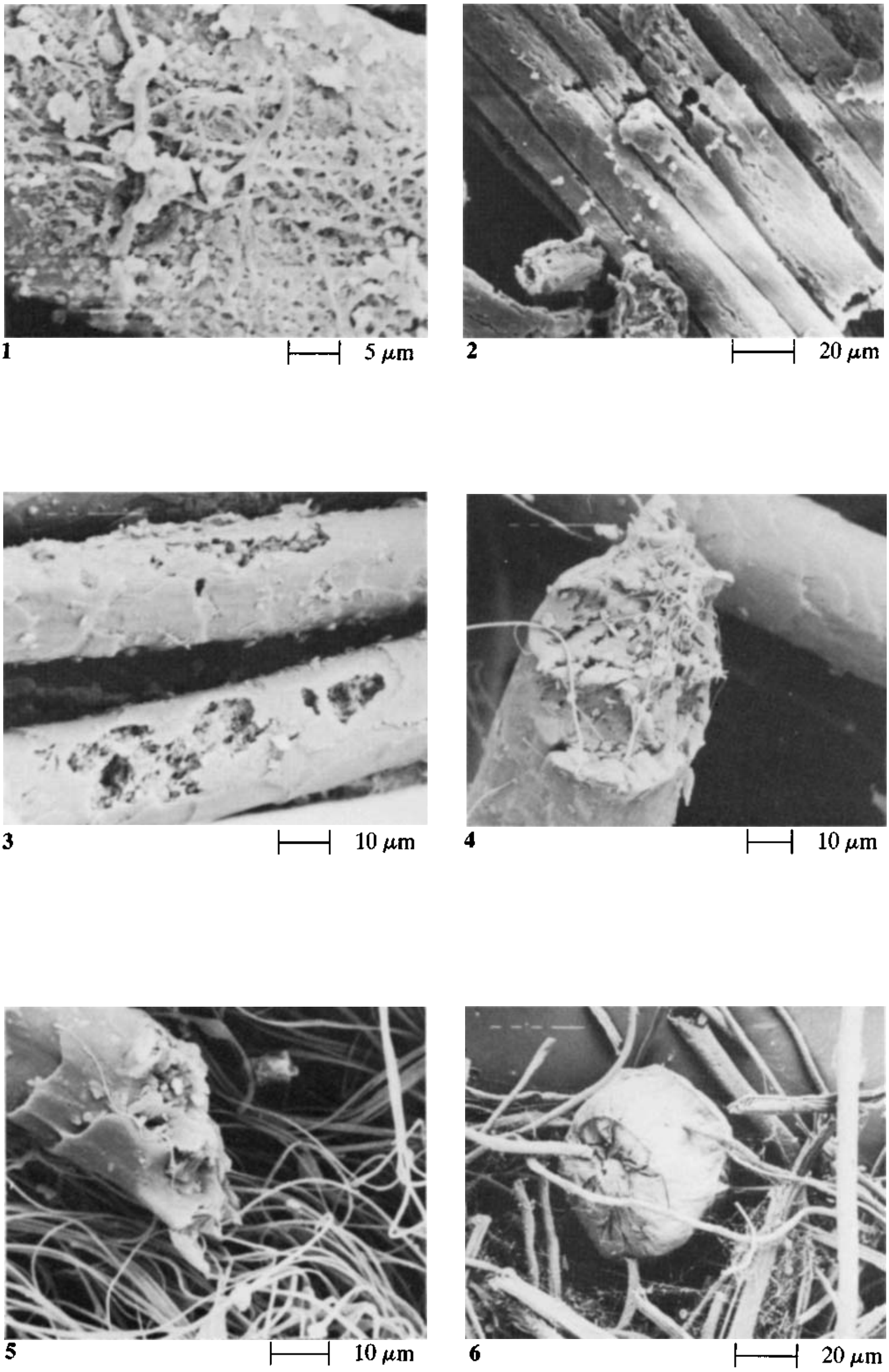


Plate 43C — Biodegradation

(1) Mildew on Coptic wool. (2) Bacterial damage on Middle Kingdom linen. (3) Bacterial damage on Roman wool from Vindolanda.

Case moth damage

(4) Mandible pattern on wool fibre. (5) Wool fragment in moth 'silk'. (6) Moth excreta.