Hair Reinforcement used in Lime Plaster and Render

Decay Mechanisms and contributing factors

Bill Revie
Construction Materials Consultants

Building Limes Forum
Results of Examination & Analysis
23rd September 2012

Natural Hair

Goat Hair

Yak Hair

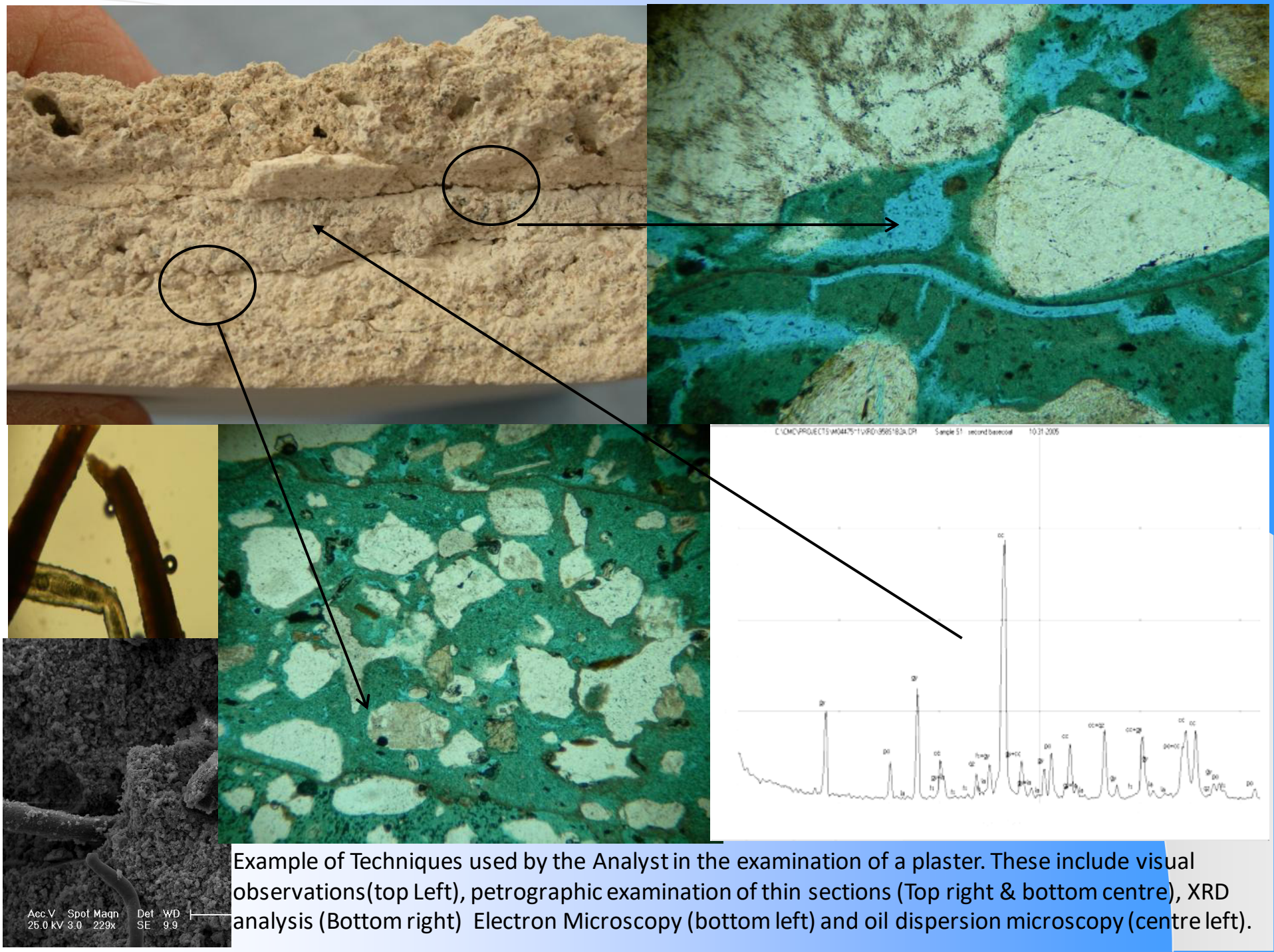
Horse Hair

Cow Hair

All images except that on the lower right were taken in CMC lab, taht on the right (pig Hair was obtained from a suppliers web site

Pig Hair

Examples of Natural Hair used as a fibre reinforcement in Plaster



Example of Techniques used by the Analyst in the examination of a plaster. These include visual observations(top Left), petrographic examination of thin sections (Top right & bottom centre), XRD analysis (Bottom right) Electron Microscopy (bottom left) and oil dispersion microscopy (centre left).

Microscopy

Failure of plaster due to shearing of rivets, in response to shrinkage, hair apparent along rivet roots

Microscopy

Narrow rivet roots either side of a lath imprint, some hair, failure due to "nipping" of the rivet as lath expanded when wetted

Microscopy

Hair concentrated along a disrupted rivet root, confirming hair was added, but here it brittle

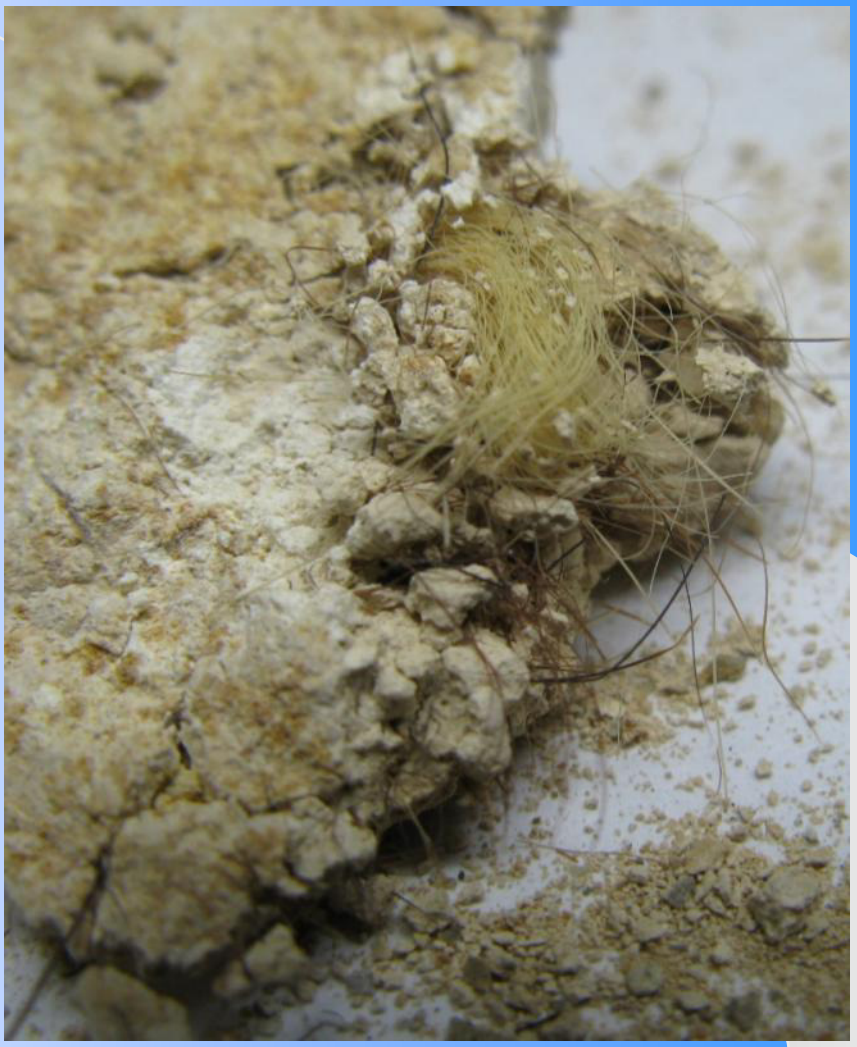
Microscopy

Hair randomly protruding from contact surface of plaster, with entrapment of wood fibre from split lath. This is one of the benefits of using split lath, as the fibres “lift” when the wood is moistened and the fibres become entrapped in the plaster applied.

Microscopy

Hair clumped together found within a void adjacent to a rivet

Microscopy

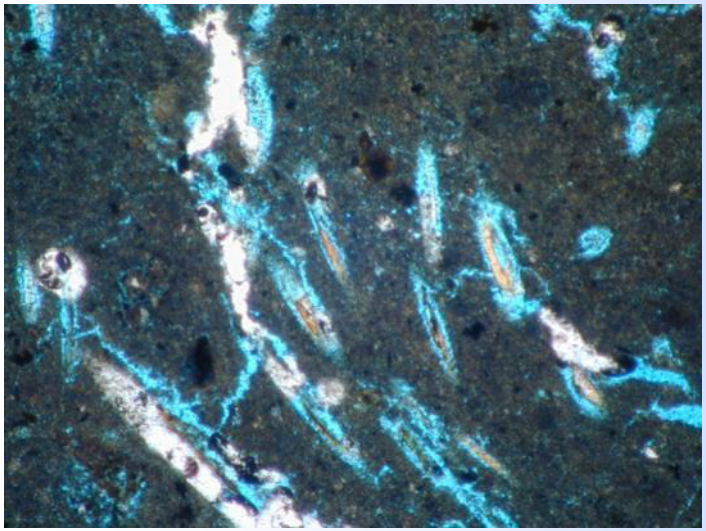


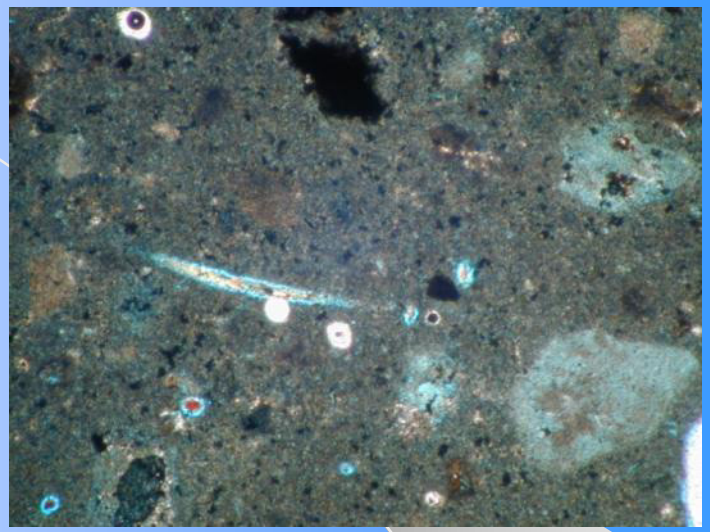
200 year old chalk lime mortar. Hair found to be in as fresh a condition as the day the mortar was mixed

Microscopy

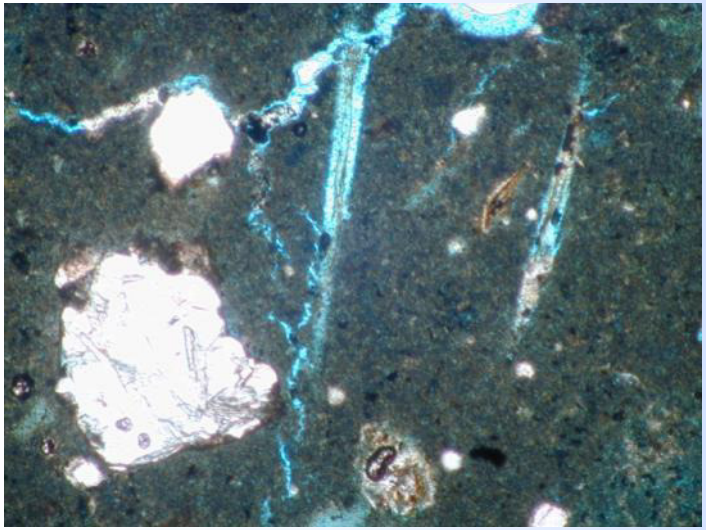
400 year old plaster from Perth with some of the hair in very good condition

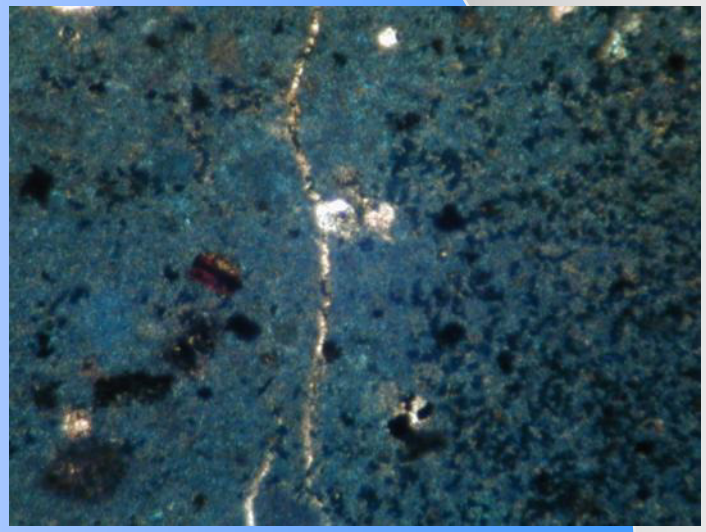
Microscopy





Thin sections of a Fat lime Plaster with Hair





Microscopy

Aligned stiff fibres, in failed plaster, the stiffness perhaps inhibited penetration into the rivet, but hair found to be very brittle.

Hair fibre concentrated along the edge of a rivet, hair found to be brittle and broke when teased out of the plaster.

Hair Structure

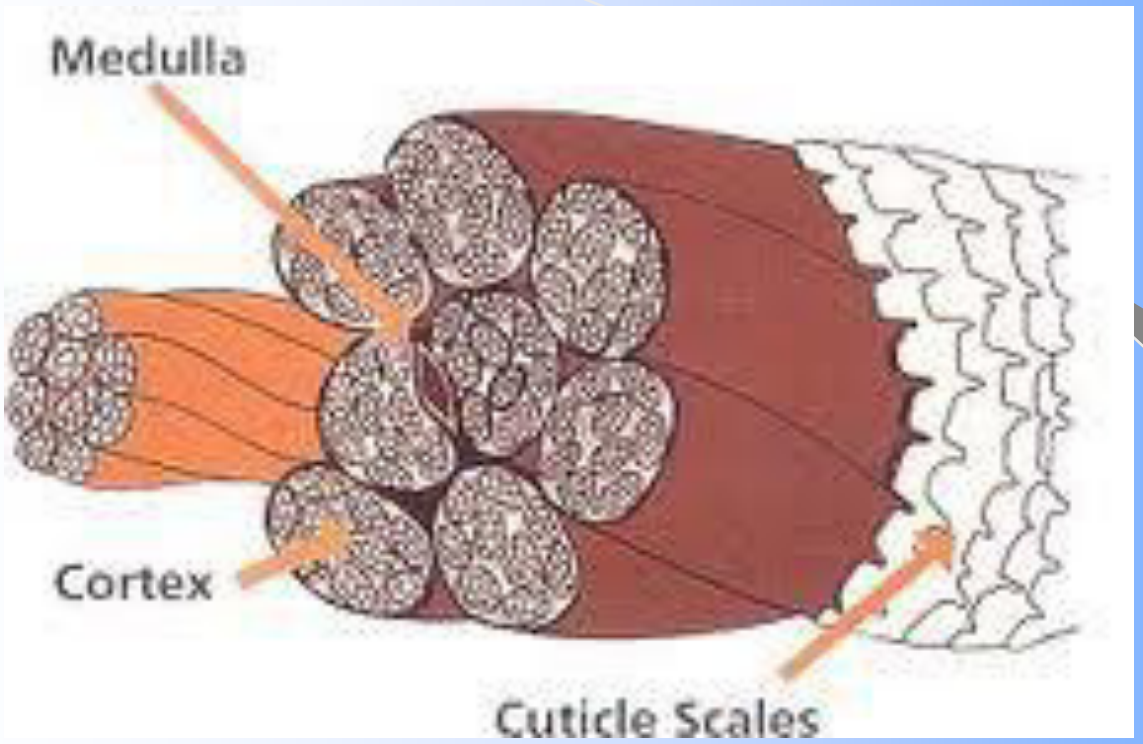
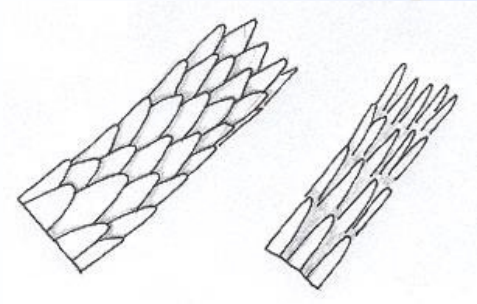


Image obtained off the web

Image from the Web – Google Images - headofhair.net

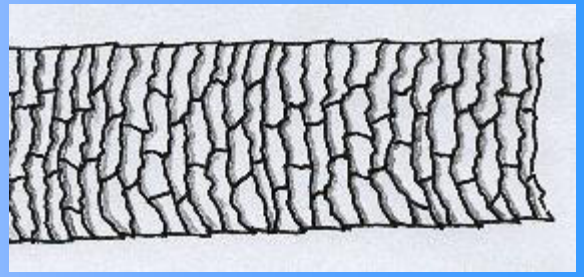
The hair shaft is formed by three layers. The innermost layer of the hair shaft is named the medulla. It is seen only in large and thick hairs. The middle layer of the hair shaft is called the cortex, made of keratin fibres. The strength, colour and texture of a hair fibre are provided by the cortex layer. The outermost layer of the hair shaft is the cuticle. This thin and colourless layer made up of between six to ten overlapping layers of long cell remnants, serves as a protection to the cortex

Hair Structure



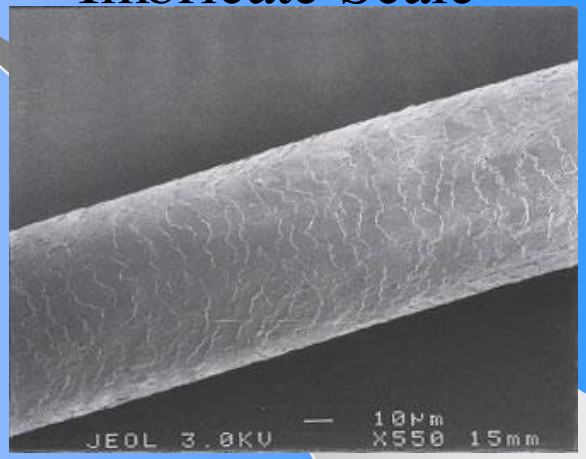
Spinous Scale pattern

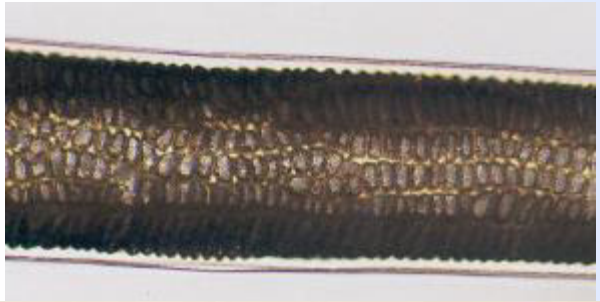
Cuticle types,
there are three types Coronal,
Spinous (mostly in Fur hairs) and Imbricate.
The latter are those most common in animal hair found in plaster.



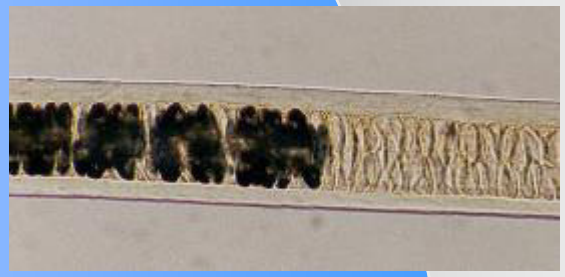
Imbricate Scale

Images and sketches from CHEM 107 – Handout - Federal Bureau of Investigation (FBI) Microscopy of Hair Part 1: A Practical Guide and Manual for Human Hairs, January 2004



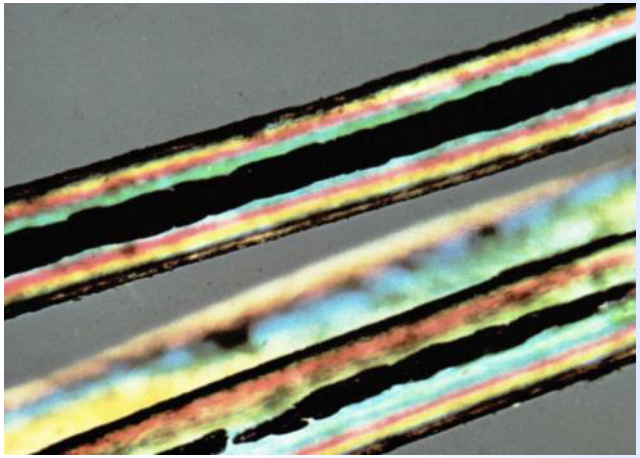


Medulla
Common forms observed in animal hair, multiserial ladder medulla.



The colour of the hair is carried in the Cortex, which is primarily of Keratin

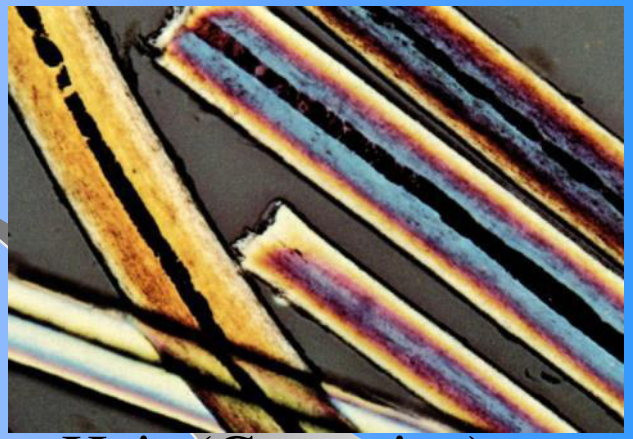
Microscopy



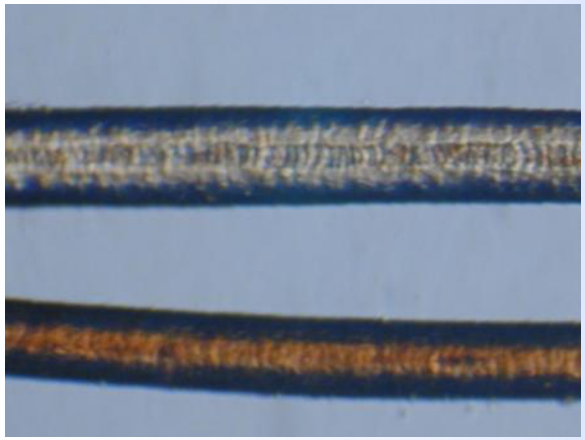
Horse Hair

Top two plates are from the McCrone Delly Particle Atlas Edition two,© Ann Arbor science Publishers 1973

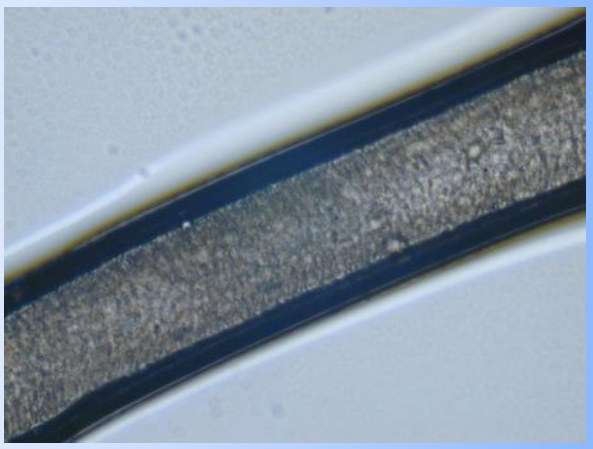
other images CMC



Human Hair (Caucasian)



Cow Hair - Mixed

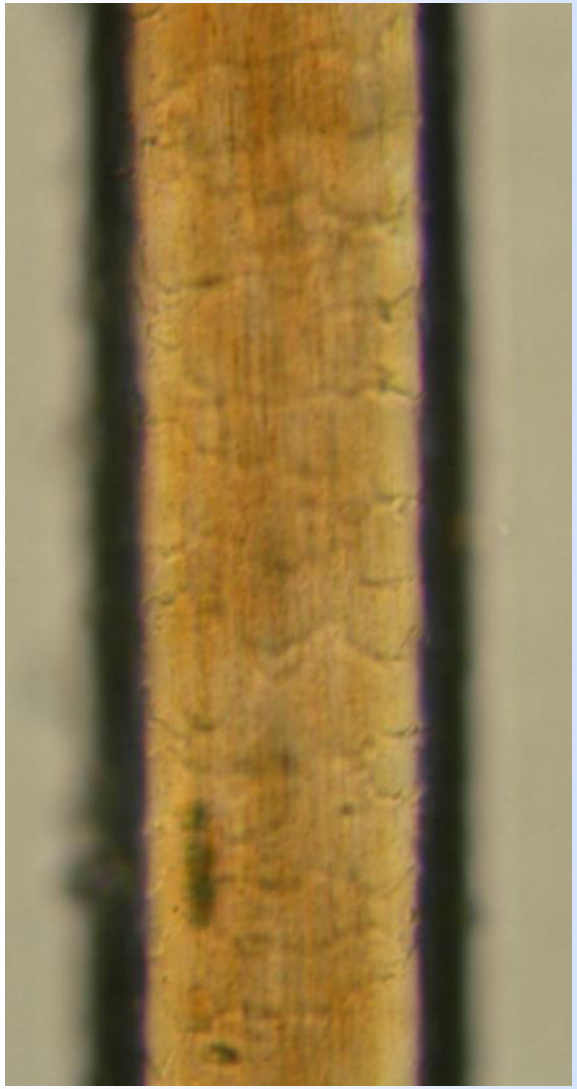


Goat Hair

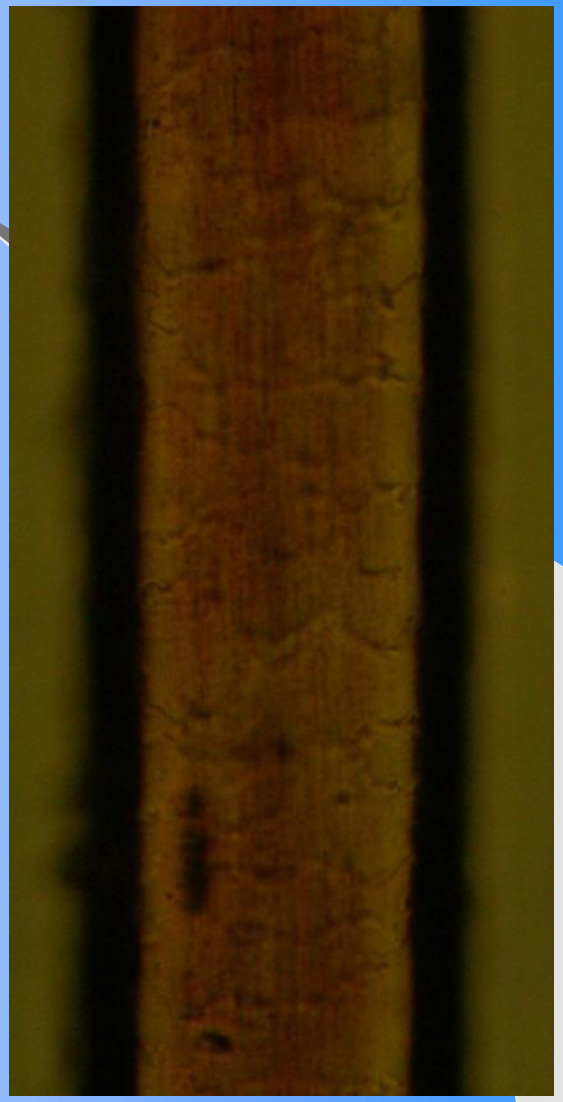
Yak Hair

Microscopic images of hair

Microscopy

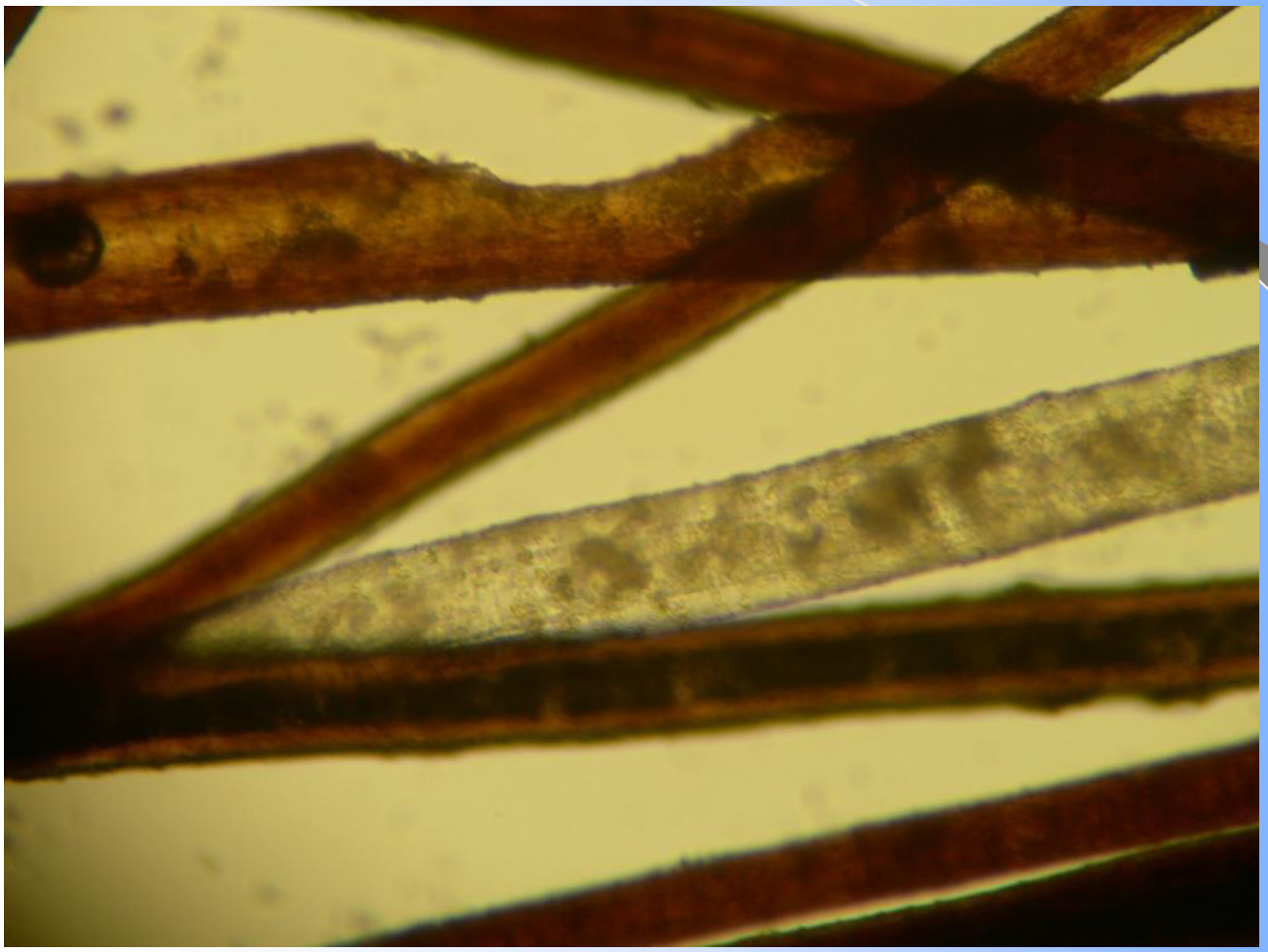


Bovine Hair viewed through a McCrone Oil Dispersion Lens, under two different annular conditions
Hair is in good condition



Microscopic images of hair

Microscopy



Hair recovered from a failed plaster, in which the hair has de-natured, becoming brittle and is slowly being dissolved in the alkaline (non-carbonated) environment within the plaster

Microscopic images of hair

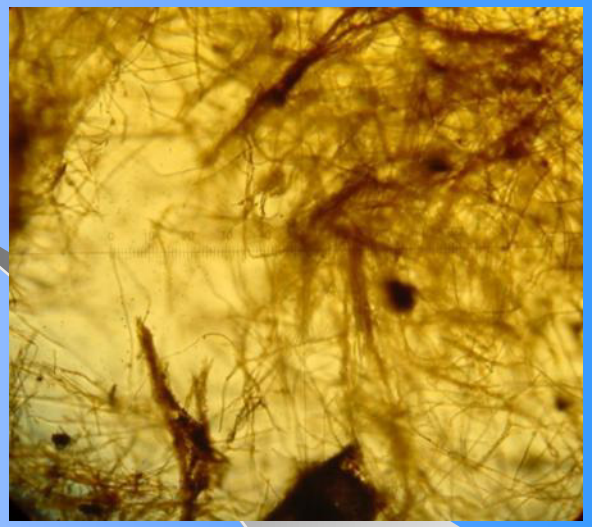
Microscopy

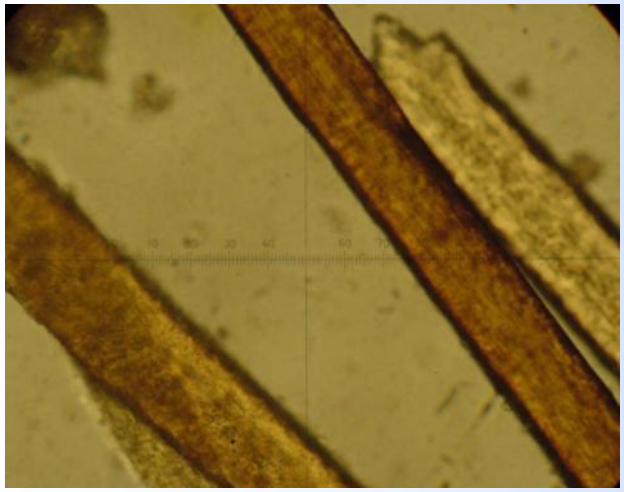
Mechanical damage to hair, possibly induced during mixing, along with evidence of denaturing

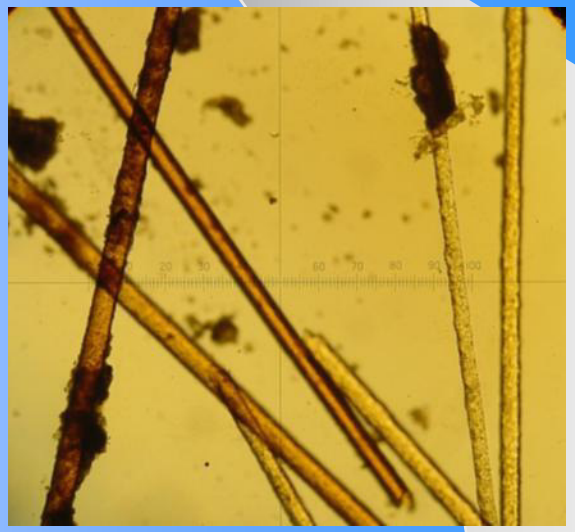
Microscopic images of hair

Microscopy

Mixed hair fibre from a Castle ruin circa1450





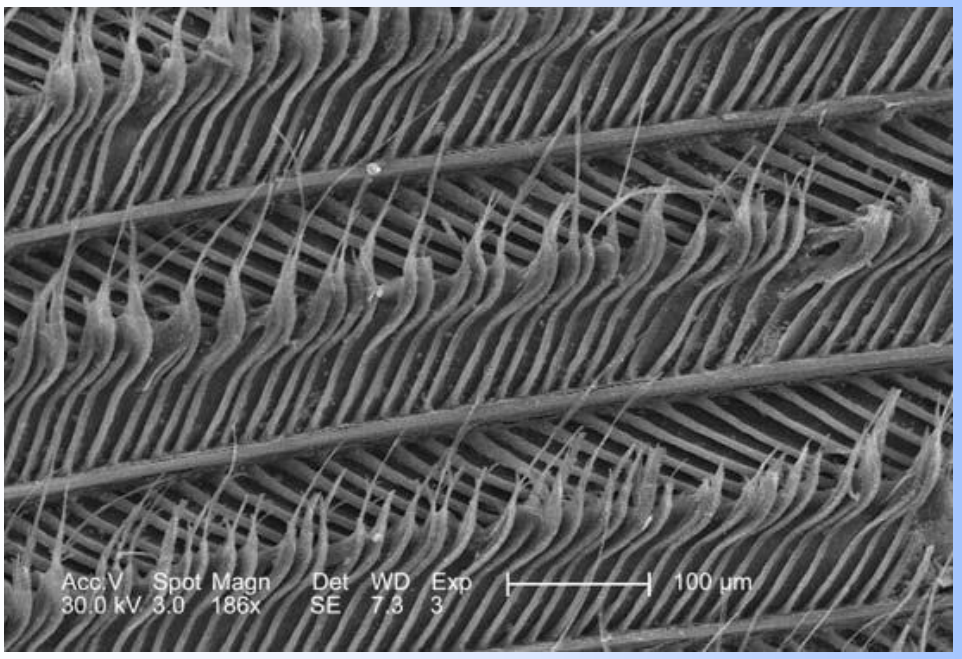


Microscopic images of hair ex Moy Castle

Keratin

Hair is composed primarily of proteins (88%). These proteins are of a hard fibrous type known as keratin. Keratin protein is comprised of "polypeptide chains."

Keratin is the key structural material making up the outer layer of skin. It is also the structural component of hair and nails, where it. forms the strong unmineralised tissues found in hair, feathers, nails, hoofs and Rhinoceros horn.



Scanning electron micrograph showing strands of keratin in a feather,

Image from Web – Google images

Keratin

The "alpha helix" is the descriptive term given to the polypeptide chain that forms the keratin protein found in human hair. Its structure is a coiled coil.

In hair three “Alpha Helices” are twisted together to form a protofibril. Nine “protofibrils” bundle around two others to form a “microfibril”. These are embedded in an amorphous unorganised protein matrix, having a high sulphur content, with hundreds of these bundled together to form “macrofibrils”.

The macrofibrils are grouped together to form the “Cortex”. It is the Sulphur bonds (Cystine Bonds) that gives the hair its strength.

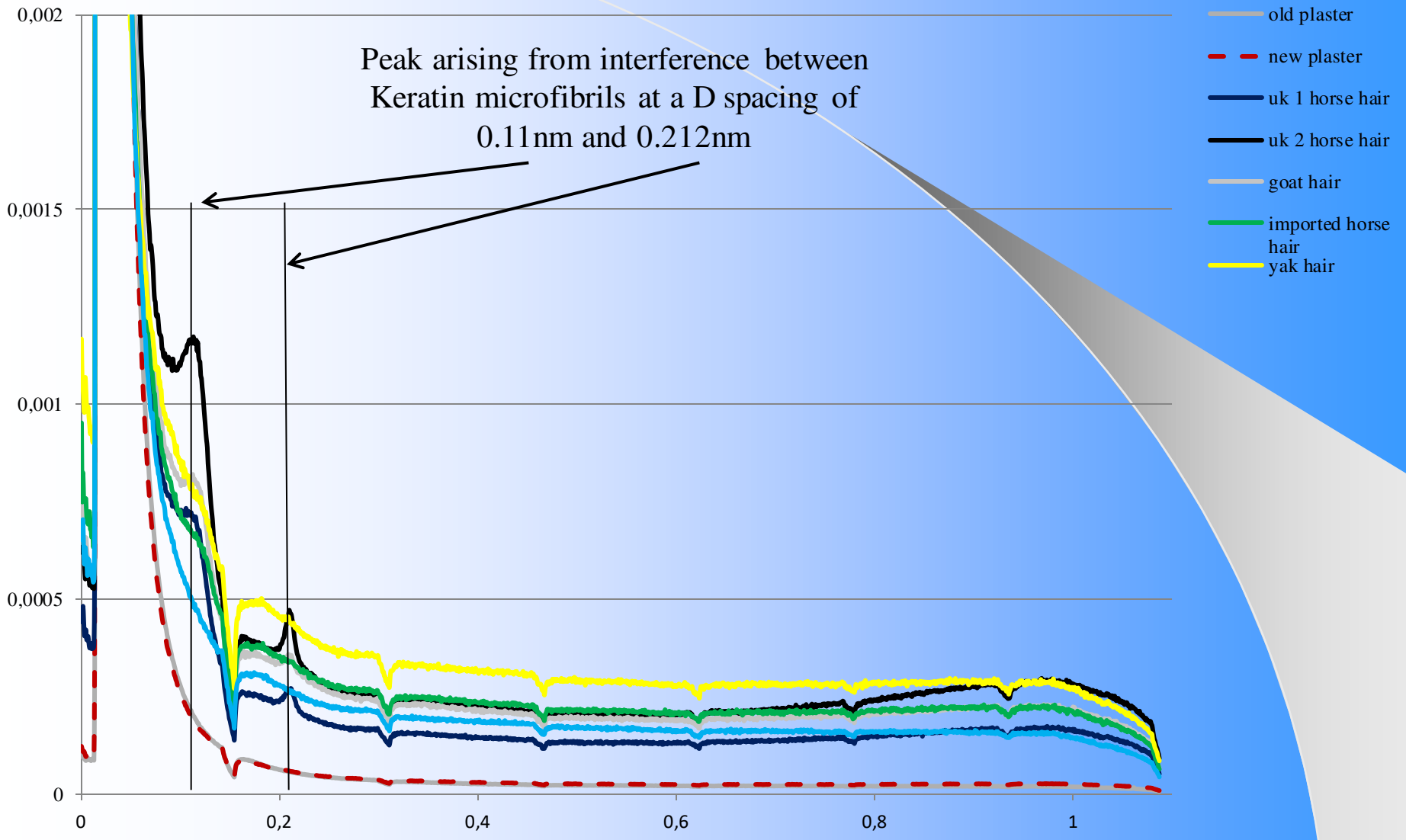
When hair is exposed to high temperature treatment, or if treated with strong acids or solvents, the hair structure is disrupted and these bonds break and the proteins break down.

Hair Analysis

Historic Scotland submitted samples of hair to Tim Wess at Cardiff University. He and his student, Matt Wade, took the samples to the Diamond Light Source in Oxford and analysed the X-ray data at small angles.

The samples submitted were two UK horse hair samples, one from an old plaster and one from a fresh source. An imported horse hair, goat hair, Yak hair and a mixed cow hair were also submitted along with two samples of haired plaster, one containing goat hair and one with a mixed hair.

Hair Analysis



Hair Analysis

The two plaster samples show no indication of hair in the XRD profiles. There is no keratin peak or lipid peak, which are the two main features commonly seen.

UK Horse Hair 1 & 2 are very similar to each other. Both show a broad lipid peak as well as peaks arising from the interference between keratin microfibrils (~9nm in real space, 0.11 nm-1 in D on the graphs and 4.7 nm, 0.212nm-1 on the graphs). These are expected peaks from keratin. The Goat hair also shows these peaks.

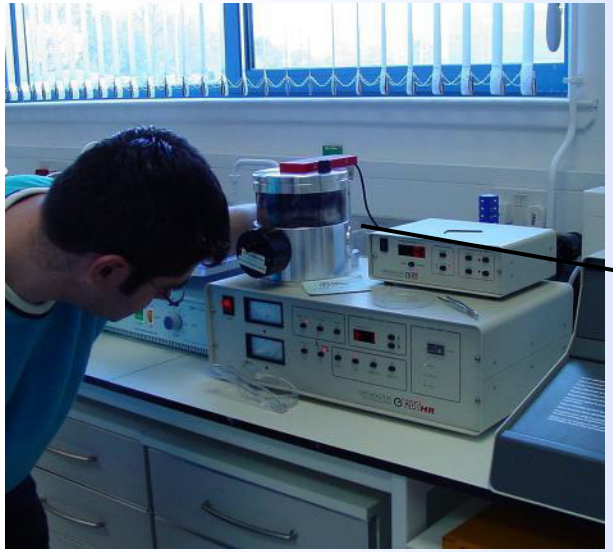
The imported horse hair doesn't show the 4.7 nm peak and only a very weak 9 nm peak, suggesting that the keratin there has somehow been disrupted (steam cleaned or otherwise pre-treated?). Yak hair and the mixed imported hair shows neither of the expected keratin peaks, again suggesting that they have been altered by some form of aggressive treatment.

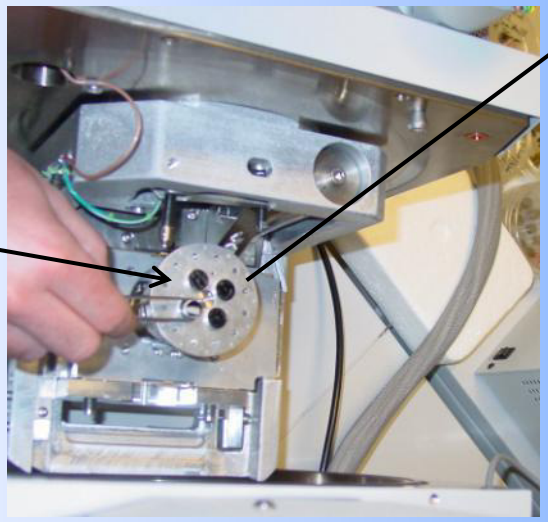
Therefore, the results can be summarised as follows:

Strong keratin signals from UK horse hair 1, UK horse hair 2 and goat hair.

Weak keratin peak(s) from imported horse hair. No keratin peak from yak hair or mixed imported cow hair, or in either of the plaster samples, made with imported hair.

Scanning Electron Microscopy

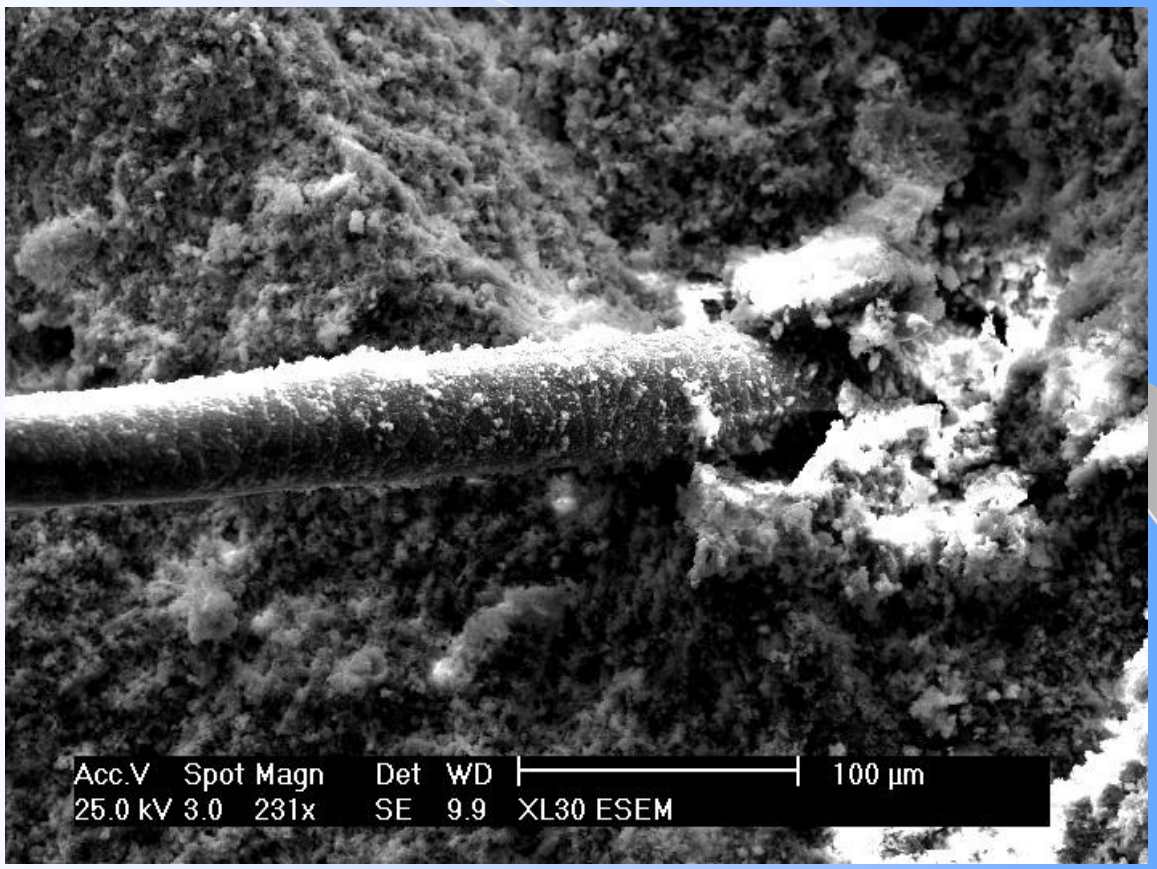




Environmental Scanning Electron Microscope (ESEM) with EDAX Capability, with four samples mounted for examination.

Examination of Plaster samples with Hair

Microscopy

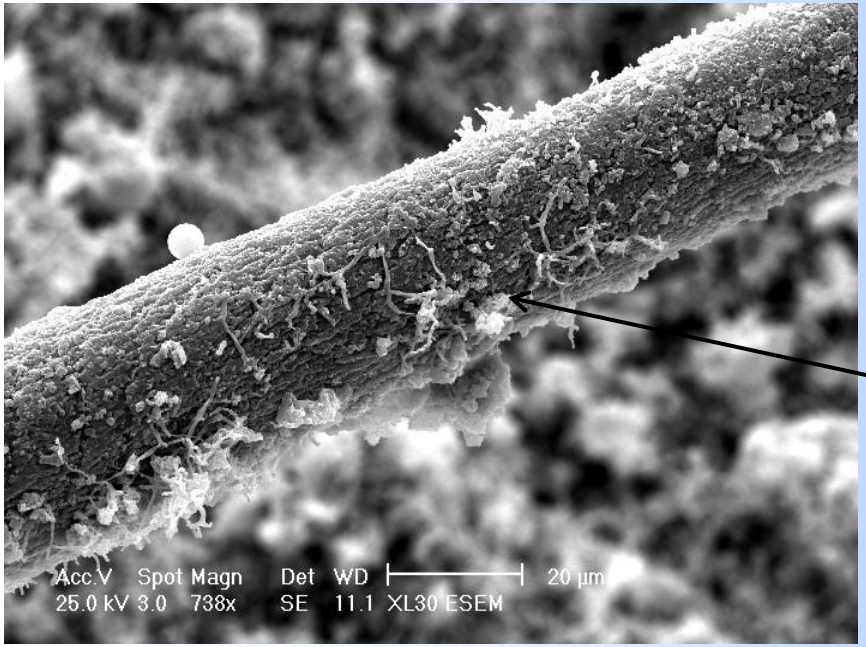


Intact Hair Reinforcement in Plaster
Hair in good condition with well defined imbricate scales forming the cuticle structure clearly observed in the hair fibre

Microscopy

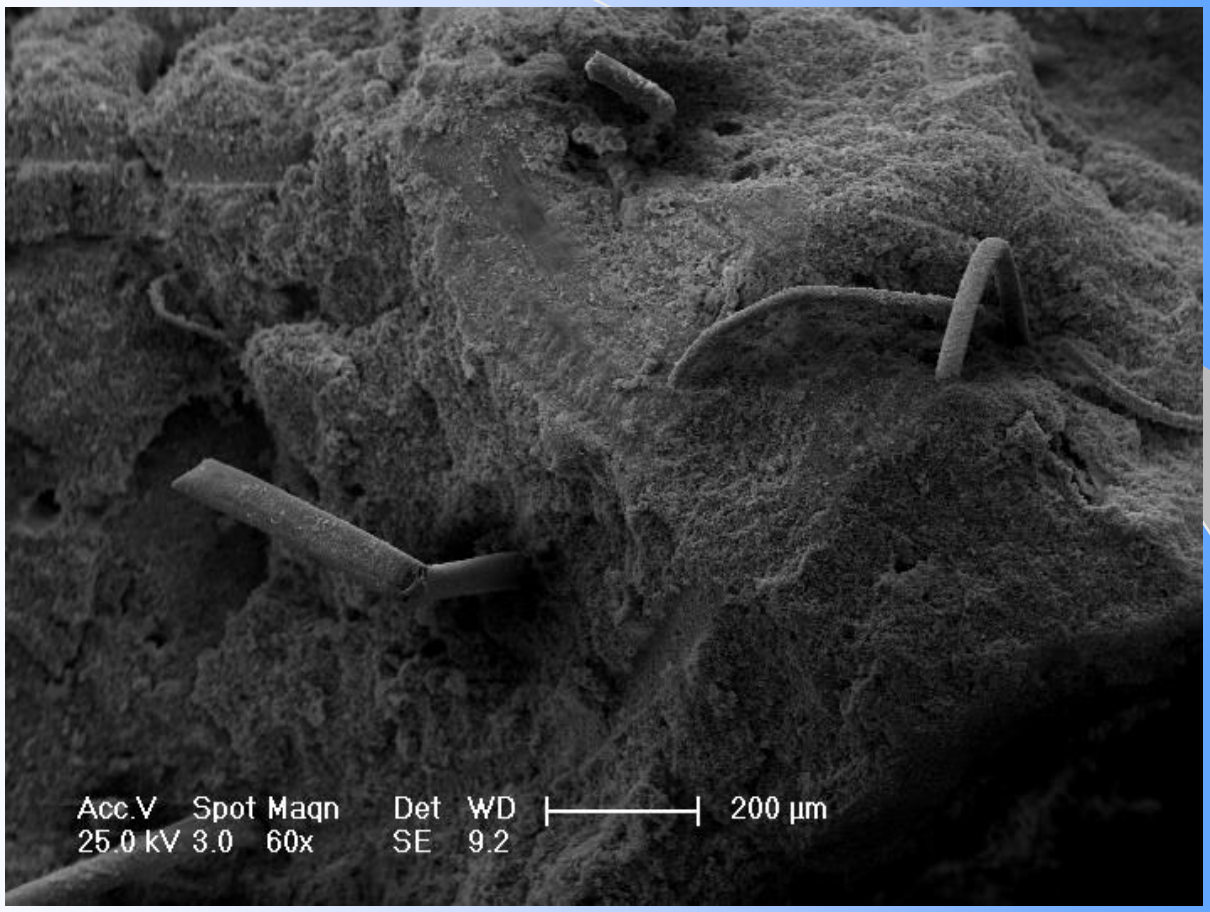
Hair in plaster that had been subjected to long term saturation

Hair partially petrified, and replaced by calcite, now splitting.



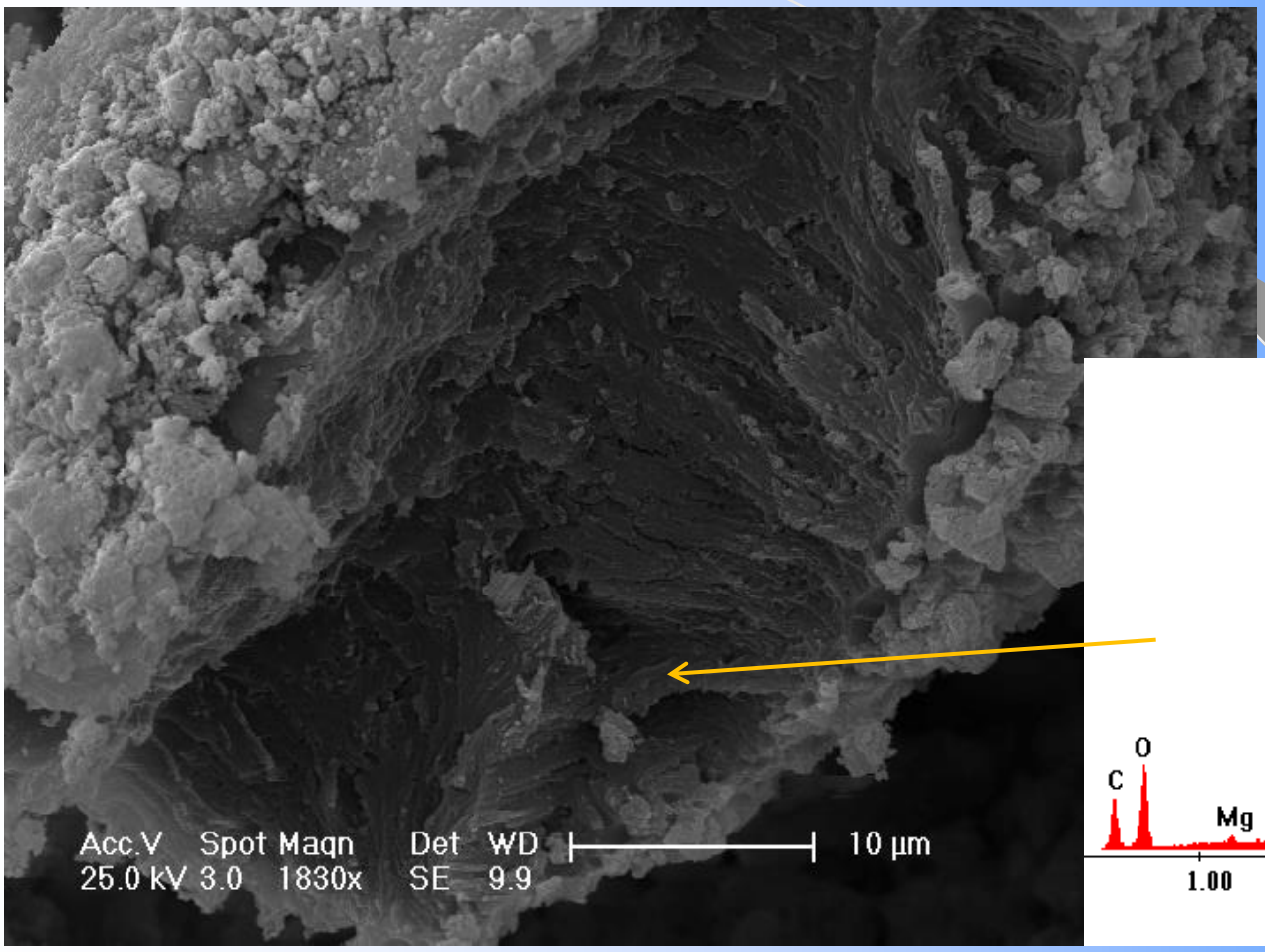
Hair still apparently unaffected, with no structural degradation observed

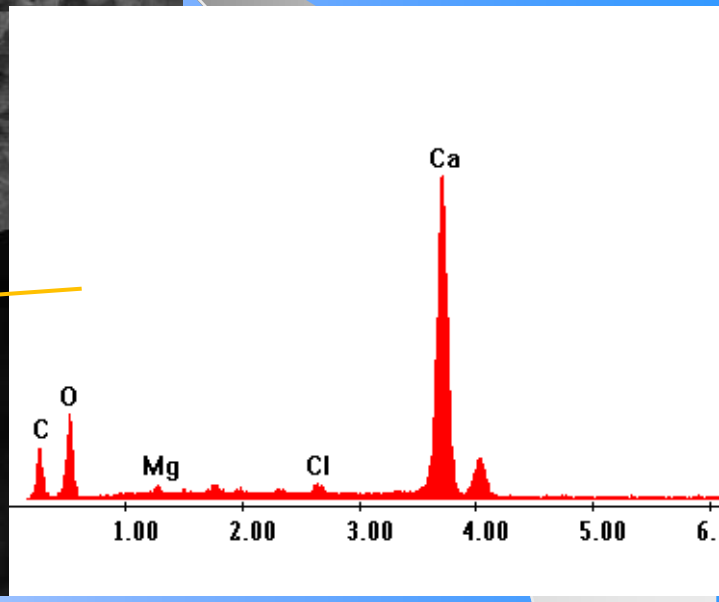
Microscopy



High power magnification of broken and denatured hair fibre in a failed plaster. Residual cuticle scales and absence of a clear medulla suggesting Goat hair.

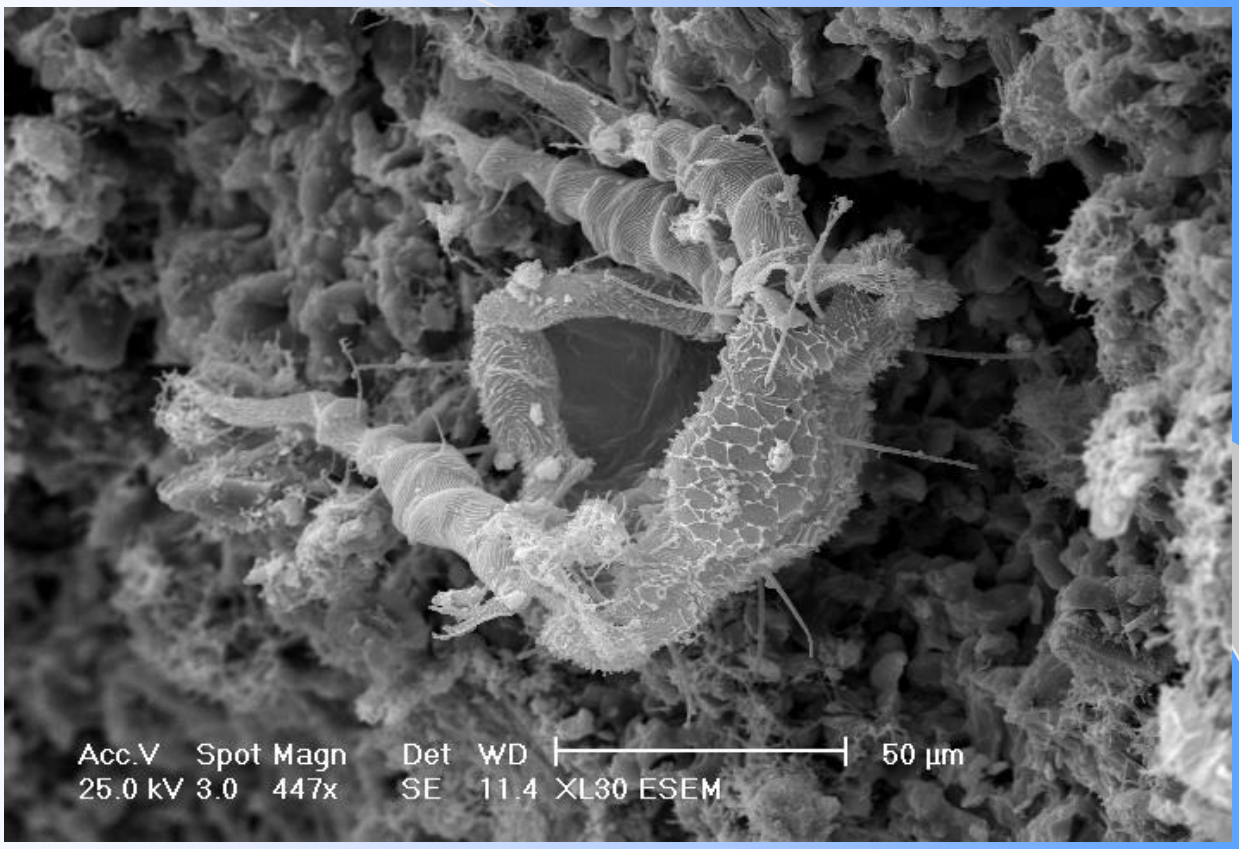
Microscopy





Void left on the dissolution of a hair fibre, with the lining of the void mirroring the pattern of the cuticle scales of a horse hair.
The scales on analysis were found to be pure calcium carbonate.

Microscopy



Occasionally one comes across something unusual or unexpected
Unidentified mite found encapsulated within a 400 year old Lime plaster sample from Elcho Castle, Perth.

Hair in Plaster

Hair is added to plaster to impart a measure of tensile strength the plaster, and in heavily haired nixes, a measure of cohesion, to a material which otherwise would have little resistance to cracking. Although more common in plaster applied to lath, and in mouldings and other enrichments, it is also found in plasters applied directly to masonry, both internally and locally, in some locations, in external renders.

It is not uncommon during the examination of historic and traditional plasters to encounter hair, with the fibres present as individual fibres well distributed throughout the plaster, along with clumps of hair. The hair found, varies in type, length and abundance, but unless the plaster has been subjected to moisture, over an extended period of time, or is exposed to an aggressive environment, such as that which can arise in response to some modern building chemical treatments, it is not uncommon to expose hair that is still pliable, well bound within the plaster matrix, and performing as intended, many tens, or hundreds, of years after its initial encapsulation within the plaster. It is then reasonable to assume that under 'normal' service conditions, hair added to a lime plaster today would be capable of performing its function for many years to come.

Hair in Plaster

Therefore, why does there appear to have been an increase in the apparent degradation of hair added to plaster, in recent times.

One of the main changes is that there is little in the way of indigenous hair available in the UK, with most, if not all, of that now commercially available being imported from the East, with China and India being sources of hair examined by the writer.

Traditionally horsehair and Ox-hair were those the most commonly used, as it was that most easily available before the decline of the horse and the Ox as the means of transport and power in agricultural. Nowadays the hair most commonly found is Ox, Yak and Goat hair, with a low abundance of horse and cow hair occasionally encountered.

Therefore is it the type of hair that is now available or is it the lime, or simply working practices, but something appears to have changed?

Hair in Plaster

The lime, as in lime putty, has not materially changed, and it is still extremely alkaline and will digest organic matter, in time, as it always has. Instances have been encountered where pre-mixed haired lime plasters have been employed in traditional work, where the pre-mixed materials had been stored, for varying periods, prior to use. It was not, therefore, unexpected when investigating the failure of some of these materials to find little or no hair remaining in the plaster, with those observed being short and noticeably brittle.

Examination of the hair confirmed that they were denatured with their structure disrupted. This, however, is not a new phenomenon, with it recorded in several texts on plaster, e.g. in William Miller's "Plastering - Plain & Decorative" in which he states that "hair should never be mixed with hot lime, and with no mortars, until nearly ready for using, because wet or hot lime weakens the hair, more especially if dry (the hair at time of addition)". Similarly he warns of the inadvisability of adding hair too soon to mixes prepared in a mill "When coarse stuff is made in a mill, the hair should not be added until the stuff is ground, as excessive grinding injures it".

Hair in Plaster

Both of these practices will be an anathema to an experienced plaster, and will make perfect sense, however, examples of both have been encountered in recent conservation works, with instances of loss of hair, due to digestion, and shortening and damage of hair fibres due to over mixing. With shortening also encountered due to cutting, with the argument that the hair mixes easier when cut short (<25mm)!

However, there have also been instances, where the hair has been added to the plaster, just prior to use, and the fibre mixed into the coarse stuff either manually or in a paddle mixer for a short duration, and the features commonly observed, in degraded hair due to inappropriate practices, were still evident. It should, however, be noted that the most severe degradation occurred in areas that were maintained in a damp condition for an extended period, due to climatic conditions, but these were not considered to be excessive long. This then would suggest a change in the properties of the hair, which makes it less resistant to the alkalinity of the lime, and possibly more susceptible to mechanical damage.

Hair in Plaster

In the past good hair was stipulated to be long, strong and free of contaminants, grease, etc. This was usually Ox, with some horse and cow hair, which was supplied in a washed and dried condition, normally requiring separation by beating or teasing prior to use, to break down the clumps.

Nowadays, hair comes in sorted bundles, tied neatly, for ease of use, or mixed loose in bags. The other main difference is that the hair, originating, in the most part, from counties where anthrax (*Bacillus anthracis*) is still prevalent, requires that the hair is washed at an elevated temperature, sufficient to kill the bacillus, which results in the hair being boiled or steam treated. The boiling of the hair tends to remove natural oils from the hair, and if the washing is at too high a temperature, i.e. autoclaved, or the period of boiling is inadvertently prolonged, this can also disrupt the cellular structure of some hair types.

In addition to the hair structure (Keratin) it is the presence of the natural oil o and in the hair, which affords a degree of protection to the hair fibres in the aggressive environment of a lime mortar. Therefore, where the oils have been depleted it would be expected that the duration over which the hair will resist degradation will be reduced, in some instances, significantly.

Hair in Plaster

This will, therefore, result in hair being available that will have a reduced serviceability, compared to the hair used historically, and one Chinese source states "Superior twice boiled hair" in its marketing literature.
Therefore, research into the variability and effectiveness of the range of hair available on the market, would be of value to the industry. Particularly if the condition of hair from various sources can be compared, along with its resistance to alkalinity and mechanical impact, can be quantified along with the benefit, if any, of re-oiling of treated fibre.

Tentative discussions with Historic Scotland's Conservation Group have indicated that this is a subject that they would be interested in researching, along with other interested parties. HS may be a good starting point as, historically; again referred to by William Millar "Hair in Scotland is usually obtained direct from the Tanners' yard, fresh, and in a wet condition. This makes the best work, as it is much stronger, and mixes freely". Drying, and washing, at too high a temperature, starts the degeneration process, and perhaps there is a lesson to be learned here.

If research is initiated it may be worth considering the inclusion of other fibres, some of which are less susceptible to lime related decay than hair, i.e. manila, jute, sisal, etc.