ALPACA SKIN HISTOLOGY
IDENTIFICATION AND STRUCTURE
FIBRE GROWTH

SKIN LAYERS:
Sheep's wool and Alpaca fibre vary greatly for fibre diameter (micron), quantity and quality as well for fibre type amongst different breeds or variations of the breed (e.g. Huacaya/Suri).

Variations are also found within a single fleece and within the individual staples which form that fleece.

To better understand why some of these variations occur, we will study the skin of a fibre producing animal and the development of the fibre producing follicles.

FOLLICLE DEVELOPMENT

Wool follicle and fibre growth originates in the skin, which is made up of layers of cells. There are three layers:

| 1. | Epiderm | outerlayer |
| 2. | Basal layer | Layer of cells separating The dermis and epidermis. |
| 3. | Dermis | underlayer |

(G Moore)
Fibre growth begins in the dermis. At certain positions in the skin the basal layer thickens and begins to grow down into the dermis forming a plug of cell tissue, which ultimately becomes the fibre-producing follicle.

At around 60 days (Alpaca 85/90 days – Pedro J 1995) post conception fibroblast cells in the dermis begin to form into equally spaced clusters of committed cells called pre papilla cells. These are the cells, which go to form the follicle. Undifferentiated fibroblast cells maintain their role in producing the collagen, which is the main filler substance in the skin.

Some of the fibroblast pre papilla cells in the dermis forming the first primary follicle at 65 days.

(Maddocks/Jackson)

The pre-papillae are programmed to form aggregates of pre determined numerical sizes.

These aggregates stimulate -

(G Moore)

the epidermal cells which grow into the dermis to form the first primary follicles.

This first plug is seen in the foetus around 70 days post conception (sheep). (alpaca 90 days)

At around 80/90 days (alpaca 187 days) the process is repeated for the first of the secondary follicles and at 100/110 days (alpaca 264 days) the third wave of follicles, the secondary derived are formed. The secondary derived follicles usually share the same opening as the secondary follicle. There is usually 3-4 secondary derived to each secondary follicle, although the number has been seen as high as 5.
The plug becomes bulbous (follicle bulb) and forms a dome like structure over a group of actively dividing cells in the papilla. It appears that the signals emitted by the dermal papilla regulate the cell division in the follicle bulb.

The size of the dermal papilla and the dimensions of the fibre produced are closely correlated (Ibrahim and Wright 1982, Rudall 1956, Van Scott and Ekel 1958).

It is suggested that the signal strength emitted by the papilla determines the fibre growth/length.

Pedro identified that the most productive period of Alpaca fibre growth was between 187 & 214 days. He also states that even at 343 days, secondary derived follicles were still developing.

Moore et al (1998, 1984) proposes that the genetic capacity for fibre growth is mainly determined by the population size of a specific cell line of pre-papilla cells, which are committed to the formation of the papillae of the fibre follicles. He also states that the number and size of the primary follicles are strongly inherited and that if fewer and smaller primary follicles were initiated, a lesser proportion of the pre papilla cells will be used in the formation of primary follicles. Therefore, more cells will be available for the formation of increased numbers of secondary follicles.
Dr Watts in a speech at the International conference in Sydney 2008 stated that “Small prepapilla clutches produce finer diameter fibre”

### MEASURED DERMAL PREPAPILLA CELLS (Watts 2008)

<table>
<thead>
<tr>
<th></th>
<th>PREPAPILLA CELLS PER FOLLICLE</th>
<th>FOLLICLE DENSITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOW MICRON</td>
<td>45.6</td>
<td>74.4</td>
</tr>
<tr>
<td>HIGH MICRON</td>
<td>89.8</td>
<td>37.0</td>
</tr>
</tbody>
</table>

Follicle bulb cells form the fibre and the root sheaths. It is these sheaths that mould the fibre and become harder before the fibre is keratinized (wool fibre). Keratinisation normally takes place a third of the way up the follicle canal. The growing fibre is pushed upwards through the follicle plug by pressure of new cells being formed continuously from the dome of the papilla. It eventually breaks through the skin surface. The sebaceous gland supplies wax to the fibre by means of ducts opening onto the wool follicle near the surface of the skin. This wax lubricates the fibre in its passage through the contracted portion of the skin, as well as adding protection to the fibre in general.

Stapleton (1992) suggests that keratinisation is the reaction (which may be enzymatically catalysed) which forms the cystine cross-links in the follicle, and requires the presence of copper. It was found in sheep where copper deficiency was evident the wool would lose its crimp and develop a lustre. This was called steely wool.
The process of follicle formation is established by birth although some follicles take some months to start producing fibre. It should be noted that when an animal suffers from lack of nutrition or ill health, the supply of nutrients to the follicles are reduced and the output of cells from the papilla slow down. This reduces fibre growth, fibre thickness and may cause some follicles to shut down.

As the original primary plug grows, two outgrowths appear.

1. **Wax (Sebaceous) gland** which lubricates and protects the fibre.

2. **Sweat (Sudoriferous) gland.** These glands produce differing degrees of sweat in various animals.

**Alpaca is similar to these structures.**

![Diagram of primary wool follicle](image1)

This figure shows the various structures of the primary wool follicle.

![Diagram of secondary and derived follicles](image2)

This figure shows the various structures of the secondary and derived follicles of a wool follicle.

Alpaca wax glands were found to be smaller than those of sheep. Also there was limited development of the “erector muscle” (Pedro 1995).

Research in Merino sheep (Schinckle & Short 1961) has shown a strong relationship between nutritional levels, pre natal and early post natal with follicle numbers and production.
Depression of pre natal growth of the foetus caused by lack of nutrition of the ewe has shown the effect of:

1. Reducing the number of secondary follicles initiated by up to 10% and thus reducing adult wool production by a similar amount.

2. Reducing the pre natal rate of maturity of secondary follicles to the stage of fibre growth so that the ratio of mature secondary to primary follicles is reduced.

Depression of early postnatal growth of the lamb has the effect of:

1. Reducing the rate of maturing of secondary follicles, but not the proportion of follicles finally reaching maturity.

2. Reducing the size, (diameter and rate of length of growth) of the fibres produced by the follicles.

Therefore a high level of nutrition in the last 70 days of pregnancy (sheep) when secondary follicles are developing and the first 70 days post natal are vital to achieve maximum genetic follicle development. To relate this to Alpaca, there is limited research in this specialised area to date, but in the last 5/4 months of pregnancy, the Alpaca foetus grows at a quicker rate and this may be the equivalent time for follicle development in these animals.

FOLLICLE RELATIONSHIPS
(TRIO GROUPS)

As mentioned, each fibre is produced from an individual follicle and at birth; the two major types are:

- Primary
- Secondary

S/P RATIO 3/1 (C Holt 1995)

The primary follicle has a structure of both wax and sweat glands as well as an arrector muscle, where as the secondary follicle only has a wax gland.

In sheep, follicles start to form in the foetus at approximately 60 days post conception. These are the primary follicles and the secondary follicles start to form at around the 80-day mark. Gestation time for sheep is around 5 months compared to Alpacas at approximately 12 months.
In sheep these follicles tend to develop in-groups of three (trio) primary and associated secondary fibres. However they can vary in number.

Dr Jim Watts (1996) and Dr Norm Evans (2007) have found in Alpacas similar "trio" groups to that of sheep.

**FIBRE STRUCTURE**

A complex protein called Keratin forms the composition of the wool fibre. Keratin is composed of the elements, carbon, oxygen, hydrogen, nitrogen and sulphur.

The fibre itself is a complex assembly made up of an innumerable number of cells. Basic cellular structure **INSIDE (CORTICAL).** The fibre consists entirely of rounded elongated and spindle shaped cells, thick in the middle and tapering away to a point at each end.

The **OUTER CELLS (CUTICLE)** are hard flattened scale-like cells, which do not fit evenly together. The edges, of these cells protrude from the fibre shaft giving the fibre a serrated edge **(SERRATIONS).** Serrations are an aid during processing as they help the fibre grip together to form a strong yarn.

Research has shown that the cuticle cells on wool fibre protrude approximately .8 micron from the shaft whereas Alpaca and Mohair protrude approximately .4 / .3 microns.
Research average DATA

<table>
<thead>
<tr>
<th>FIBRE</th>
<th>SCALE LENGTH Per 100 um</th>
<th>SCALE HEIGHT</th>
</tr>
</thead>
<tbody>
<tr>
<td>HUACAYA</td>
<td>9 - 11</td>
<td>.3-4</td>
</tr>
<tr>
<td>SURI</td>
<td>5 - 8</td>
<td>.2-3</td>
</tr>
<tr>
<td>GUARD HAIR</td>
<td>14 - 19</td>
<td>.2-3</td>
</tr>
<tr>
<td>MOHAIR</td>
<td>6 - 8</td>
<td>.3-4</td>
</tr>
<tr>
<td>SRS WOOL</td>
<td>8 - 9</td>
<td>.4</td>
</tr>
<tr>
<td>MERINO WOOL</td>
<td>10 - 12</td>
<td>.7-8</td>
</tr>
</tbody>
</table>

The Suri fibre having less cuticle cells than the Huacaya, makes the Suri more slippery to feel and more lustrous than the Huacaya.

Tillman (2006) found that the mean scale frequency of Suri was 6.5 scales per 100 micron. Mohair has a frequency of 6 - 8 similar to Suri. Huacaya has a mean frequency around 9 - 11 (per 100 microns)

In the Huacaya samples, the longest scale length had the greatest amplitude.

Bruce McGregor, (2003) commented on the importance of scale height and length:

“The greater the directional friction effect due to the wool fibre cuticle scales the harsher the handle.”

Photos below show "mean scale frequency, (MSF)", also referred to as "scale length" for Huacaya and Suri.
Cortical Cell Structure

Cut away sketch of a wool fibre showing the major components of the cortical cell.
As you can see the wool fibre has two cortical cells. Para and ortho. In certain coarse fibres as previously mentioned a hollow core may be visible (medulla).

Stapleton – (1992) said, “The cortical cells in Alpaca fibre constitute a variable fraction of the fibre mass, being lowest in coarse and highest in fine fibres where the fraction may be as high as 90%.
Cortical cells are the load-bearing elements of the fibre, whereas the cuticle imparts the inherent aesthetic qualities of the fibre such as softness of handle and lustre. Other functions of the cuticle concern water repellence, felting during washing, and resistance to chemical and physical attack. The entire assembly is held together by a glue called intercellular cement.”

Wool and Alpaca fibre have a bilateral structure. That is the para-cortex and ortho-cortex grow side by side.

The bilateral formation is responsible for the crimp/crinkle in the Huacaya. Research in 1953 by Japanese scientists found that the ortho-cortex was always observed on the outside of the crimp curve (the para-cortex is believed to have a harder keratin than the ortho-cortex).

Because the Suri has a helical coil structure (like mohair) the fibre is relatively straight. Suri has a “non-bilateral” structure.
As mentioned, the Suri fibre has less cuticle cells (5-8) than the Huacaya (9-11) over a given length, of 100 microns.

Hence the Suri is more slippery to feel and more lustrous than the Huacaya.

Villarroel found that Huacaya alpaca (not Suri) like wool has a clearly defined ortho-para differentiation in the crimped fibre (fine). With medium Alpaca (25-35 micron) the cortex was less distinct and the two types of cells were seen to break up into segments. In coarse fibres the ortho segment was seldom seen. In the Suri fine fibre no visible bilateral demarcation was evident.

**Unpublished research by Holt (1992)** found the following observations.

A fleece from a 1-year-old Australian Bred Huacaya Alpaca (Chilean background) displaying a shallow (low amplitude) good/average characterized crimp (by today’s standards), showed a clear bilateral structure when viewed under the microscope.

It was noted that the ortho cortex was around one third of the fibre unlike wool fibre which shows around 50% ortho-cortex.

Other tests on stronger microned Huacaya fibres were not as well defined. Although these were preliminary tests, it followed previous patterns established in the earlier research of Villarroel 1959.

A "Suri Type" although not “true to Type”, showed a structure that did not show any sign of having a bilateral structure.

Later studies (Holt 1996) on SURI cortical cells, fibre showed that the suri again had no obvious ortho-para differentiation, although a cell differential was seen around the outer perimeter of the fibre.

Maddocks found this also in mohair with a tight ringlet fibre type. The suri tested was also a tight ringlet type.
The Peruvian huacaya (Holt1996) showed ortho-para differences but the “ortho” was not as large as in the sample of sheep’s wool tested but when compared to the “Chili” sample above, the “ortho” was larger. The wool fibres in general were mainly circular compared to the huacaya fibres, which were more elliptical but some circular cortical cells were evident.

MEDULLATED FIBRES
Many animals including Alpacas are found to have a third type of cell known as the medulla. These cells which are hollow and rounded, are found along the main axis of the fibre and may run continuously from end to end of the fibre. Guard hairs (medullated fibres) are true hair fibres, and therefore do not have the same spinning and dyeing properties as “wool like fibres”.

The structure found in medullated fibres is probably an inheritance from previous wild primitive animals that used these fibres for protection.

Medullary cells are formed at the dome of the papilla (see beside) and are confined to the central region of the fibre as it develops up through the follicle.

The Medulla cells may break down before the fibre emerges, and if so the centre of the fibre will be empty.
Some medullated fibres are:-

**Kemp** are short, dead white fibres found about the head and legs of most breeds of sheep and in crossbred goats.

**Gare** are long hairy fibres, which may be found in the britch area of a fleece. As these fibres lack crimp, they are easily detected.

**Guard Hair:**
Guard hair (medullated fibre) grown by goats, and some camelid animals is used as a protective fibre for the fine under down. These may be short like kemp fibres or quite long. They grow from the primary follicle.

(Adapted from Harmsworth & Day)

**Alpaca fibre depending on micron, has some medullation.** Using previous accepted standards, J. Villarroel defined Alpaca medullated types into 5 categories.

(1) Non medullated fibres, 15-20 micron diameter
(2) Fragmented, 20-30 micron diameter
(3) Interrupted, 30-40 micron diameter
(4) Unbroken medium wide, 40-60 micron diameter
(5) Unbroken very wide (near to lattice type), 60 or more micron diameter

Group "5" is undesirable in Alpaca fleece.

(Adapted from J. Villarroel)
If you look at the photo of guard hair

You will notice the numbers of scales along the shaft of the guard hair are completely different to alpaca fibre, huacaya and suri (seen earlier under fibre structure).

(Tillman 2006)

NOTE

Dr Werner Von Bergen (1963) is one of few researchers that have referred to some very coarse fibres as kemp. Kemp is a short guard hair like fibre with similar properties to its longer relation, guard hair.

Cross section of kemps (500 x).
(Von Bergen 1963)

He states that these fibres can occupy up to as much as 90% of the fibre, which is often dumbbell shaped in the cross section (as above). It is suggested that around 80% medulla constitutes a guard-hair type.

Wildman (1954) identifies medulla in various grades of fineness from the finer fibres to the very coarse. These alpaca photos correspond to some that he identified. If you accept Von Bergen’s assessment of kemp then you would have to consider the coarser fibre as guard hair.
In the very coarse 60> micron various expressions of medulla are identified. The shape of the fibre (elliptical/cylindrical) may affect the medulla formation.

(C Holt 1996)

Normal primary alpaca fibre with a medulla formation.

Very coarse micron primary guard hair, with a large medulla formation.

In alpaca, guard hair can be seen at levels of fineness (even 20 microns) and it is a mistake to believe that guard hair is only coarse. It would be interesting to see cross sections of these 20 micron guard hairs to see if they have 80% + medulla in them.

This magnified photo is a 20 micron fleece showing guard hair of 27 microns, not as expected in the previous diagram 1.

(C Holt 2000)

Guard hair is a different fibre to alpaca.

The table below (Holt/Stapleton 1993) shows, in the case of four animals, how the proportion of the various categories of medulla in Huacaya, vary across the fleece. The column called "interrupted medulla" is a combination of types 2 & 3 and Continuous is 4 and 5 in the five Categories of Medullation. Type 1 is a solid fibre with no medulla.
### Distribution of Medullation Across a Fleece

<table>
<thead>
<tr>
<th>Animal No.</th>
<th>Age (Year)</th>
<th>Average Fleece Diameter</th>
<th>Site</th>
<th>Medulla (Percentages of Fibres)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>None (1)</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>21.8(_{\text{micro}})</td>
<td>A</td>
<td>39</td>
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<td>P</td>
<td>29</td>
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<td>S</td>
<td>24</td>
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<td>N</td>
<td>74</td>
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<td>B</td>
<td>27</td>
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<td>M</td>
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<td>6</td>
<td>1</td>
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<td></td>
<td></td>
<td>MB</td>
<td>73</td>
</tr>
</tbody>
</table>

* Fibre too badly weathered for examination
**The medulla Cells** on average tend to occur from 20/22 microns onwards, although in some animals some cells change may start at a lower micron. Tumen Wuliji et.al 1993 - Holt/ Stapleton 1993 confirm these observations.

Villarroel’s work on Alpaca fibres showed that Medullation closely followed variation in the fineness (micron) of the fibre. Not only as the fibre gets stronger with age but even along the fibre. He sites a fibre change of 20 micron to 24 micron. The medullation changed from fragmented to broken type.

The micron of fibre changes in size frequently during its year’s growth. *Some of the factors, which cause the changes, are:*  
- Climate  
- Nutritional changes  
- Stress  
- Parasite infection  
- Age

Variation of mean fibre diameter along the length of samples of **Australian grown Huacaya and Suri**. The alpacas were on constant and similar feed for 24 months.
Anecdotal & record keeping evidence tends to support view that as the alpaca ages in it’s first year the fibre fineness (micron) increases (dependent on micron) 1.5/3 microns per year (around 10%) and then tends to increase around 1/2 microns per year until 5/6 years old and then remain static. Its original micron, C of V and the genetic background would have a big influence on the increase. Where normal nutrition and body weight/size is linked to age, these findings tend to follow a pattern. When the Alpaca is subjected to poor nutritional conditions and loss of body weight, the micron will in most cases become finer. Fleece weight tends to decrease at around 4/5 yrs of age onwards.

FIBRE GROWTH is susceptible to nutritional influences. This can be seen by the fluctuations in yearly fleece weights caused by the various seasonal changes, and the variation along the staple as mentioned earlier. Under nutrition of the Alpaca as well as parasitic infection will reduce fibre growth. This is caused by reduced levels of protein available for fibre production in the follicle. This reduced nutritional level therefore will effect:

- staple strength
- fineness
- length
- value
- fleece weight

Dr Walter Bravo (1995) found that alpacas maintained on improved pastures, fibre diameter, fleece weight, length of staple, and yield increased. This trend follows previous research in the sheep industry.

<table>
<thead>
<tr>
<th>GROUP (2YR)</th>
<th>IMPROVED PASTURE</th>
<th>NATIVE PASTURE</th>
<th>DIFFERENCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>MICRON</td>
<td>31.8</td>
<td>25.4</td>
<td>6.4</td>
</tr>
<tr>
<td>FLEECE WT. (LBS)</td>
<td>4.31</td>
<td>3.06</td>
<td>1.25</td>
</tr>
<tr>
<td>LENGTH (INCHES)</td>
<td>5.6</td>
<td>4.9</td>
<td>0.7</td>
</tr>
<tr>
<td>YIELD</td>
<td>94.4</td>
<td>83.9</td>
<td>10.5</td>
</tr>
</tbody>
</table>
FIBRE IDENTIFICATION

Fibre Identification is important in the textile industry, as substitutions can take place to cheapen the final product.

For example:
Superfine wool is sometimes substituted with cashmere. The superfine wool being cheaper than the cashmere and is difficult to detect once the fibre is blended and spun. Microscope examination is the only way to detect this deception.

Microscopic examination of the scale pattern enables us to identify groups of similar fibres. Micron, scale frequency and scale height can be measured using this technique.

A group of Scientists used the above measurements to classify a wide range of animal fibres (PHAN, KH et.al 1987)

<table>
<thead>
<tr>
<th>GROUP</th>
<th>Less than 16 microns:</th>
<th>Greater than 19 microns:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Superfine Wool</td>
<td>Mohair</td>
</tr>
<tr>
<td></td>
<td>Cashmere</td>
<td>Wool</td>
</tr>
<tr>
<td></td>
<td>Vicuna</td>
<td>Alpaca</td>
</tr>
<tr>
<td>2</td>
<td>Iranian type Cashmere</td>
<td></td>
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<tr>
<td></td>
<td>Fine Wool</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Camel</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cashgora</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Mohair</td>
<td>The Mohair and Alpaca had a mean scale height of approximately 0.3-4 of a micron where as the wool had a mean scale height of approximately 0.8 of a micron.</td>
</tr>
<tr>
<td></td>
<td>Wool</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Alpaca</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Llama</td>
<td></td>
</tr>
</tbody>
</table>
Villarroel (1959) also observed a difference in scale heights between wool and Alpaca but suggested the differences became less with the finer fibres.

It would therefore be simple to conclude that the softness of Alpaca, of a given micron over that of wool of the same micron, is due to the scale height (protrusion). Having been able to identify the wool from Alpaca due to this scale height we may need to go to the scale frequency of Alpaca to distinguish it from mohair. Mohair had a frequency of 6 - 8 compared to Alpaca that had a mean frequency greater than 9 (per 100 microns). Villarroel suggests that cuticle cells of the Huacaya protrude slightly more than the Suri.

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The author has made every effort to ensure that the information in this document was correct at time of printing. The information is meant to supplement, the readers own education and experience. The author advises readers to take full responsibility for their decisions related to alpaca fibre / animals contained within.

It is important to understand the large variance still in the alpaca gene pool, as research results quoted in this article with another research group of alpacas, the findings may vary slightly to those results indicated herein.

The author does not assume and hereby disclaim any liability to any party for any loss, damage, or disruption caused by errors or omissions, whether such errors or omissions result from negligence, accident, or any other cause.
Cameron Holt, a leading international alpaca fibre expert has had some 50 years in the fibre industry with 25 of those later years dedicated to alpaca research and education.

In 1990, because of Cameron’s long involvement with wool, mohair and cashmere, he was asked by the founding fathers of the Australian Alpaca Association to develop an educational program and to help in the setting up of standards for both testing and judging of alpaca fleece.

In 2012 Cameron was honoured for his work with the alpaca industries in Britain and Australia.

The production of the book was edited by the publishers of Alpaca Culture (Selle Design Group) of Idaho, USA.

His numerous research programs and publications over these years helped enable this book to be written.