INTRODUCTION

The detailed study of hair is an example of a scientific project which has resulted from a synthesis of both purely biological and academic interest, as well as highly practical stimuli. The characters of the pelage as a whole have long been used by mammalogists as taxonomic criteria, and the fur and textile industries, as well as sheep and cattle rearing enterprises, have added great impetus into research on the pelage and hair. Publications on hair are available from the end of the nineteenth century when De Meijere (1894) studied hair morphology, to the present when we have papers dealing with such definitive aspects as the ultra-structure of hair, biochemistry of keratinisation and electrophoretic profiles of fibrous and matrix components of hair.

Biologists have become increasingly appreciative of the way in which hair can be used for identification as well as taxonomy. It has the important advantage of remaining relatively undamaged during digestion and with the passage of time, so that, for example, hairs from stomach and faecal contents of predators can be examined and identified. In this respect hairs are unlike bones which are often fragmented during digestion.

In South Africa the identification of hairs is being used both for law enforcement during antipoaching control and for forensic purposes. Although this region has a rich fauna, relatively little research on hair identification has been published. De Boom and Dreyer (1953), Dreyer (1966) and Stutterheim (1975) have all worked on Bovid hair. More South African research however, is available on the study of the pelt and hair in relation to thermoregulation, *vide* Bonsma and Pretorius (1943), Riemerschmid (1943 a and b), Riemerschmid and Elder (1945), Bonsma

(1949) and Bonsma and Louw (1963).

My own interest in this field arose from the epidemiological implications of taxonomic studies of southern African Muridae (Keogh 1974). Thus, for example, in a plague epizootic, rodent remains or pieces of fur found at burrows can be identified, and could indicate which species has been dying in the greatest numbers. The use of hair identification was then extended in epidemiological surveys involving food and water contamination, and various zoonoses. Running parallel with these practical applications were the interests of taxonomy and ecology, and thus the present study was undertaken with a view to relating the structure and morphology of hair to ecology, as well as to provide an atlas which is a pictorial reference system for identification.

As stated later in the text, the atlas of mammalian carnivore hair to some extent fills a gap in knowledge of hair studies from this region and will form part of a more comprehensive hair atlas which will include other southern African mammals.

Hair identification has been extensively studied. The first significant contribution was made by Hausman (1920, 1924 and 1930) in America. The most important subsequent papers are those of Mathiak (1938 a and b), Williams (1938), Dearborn (1939), Mayer (1952), Benedict (1957), Stains (1958), Spence (1963), Adorjan and Kolenosky (1969), all of America; Lodmuller (1924) of France and Toldt (1935) and Lochte (1938) of Germany; Lyne (1959) and Lyne and McMahon (1951) of Australia. In England, Wildman (1954), Stoves (1957) and Appelyard (1960) worked on hair of commercial furbearers, while Day (1966) and Walker (1972) have published work on hair identification of wild species. More recently research has been carried out in this field by Trevor-Deutch (1970) in Canada, and probably the most modern reference work on identification

of mammalian hair comes from Australia (Brunner and Coman 1974).

Although in some cases hair characters lend themselves to the formation of a key (such as that constructed for the scale patterns of the southern African Muridae), the photographic reference system adopted by Brunner and Coman (1974) is possibly the most satisfactory approach which minimizes the various problems encountered in hair identification. Thus in the carnivore hair atlas, micrographs of hair structure, together with coloured plates of typical individual hairs, and distribution maps of the various species studied, are all used in conjunction with each other. Even so, variations in hair structure along the length of individual hairs, as well as different hair types on one individual, constitute problems. Further studies using electron microscopy may solve some of these problems, especially where there is a large degree of interspecies overlap. To some extent however, the construction of all identification systems requires experience and familiarity and this is particularly so with the identification of hair. Thus it is necessary to look at a great number of hairs before it is possible to single out the features most suited to diagnosis of any particular species.

All workers classify hair into two main types, the long thick outer hairs and fine short underfur. However, designation of various hair types seems to vary greatly in publications, Hausman (1920), Danforth (1925), Toldt (1935), Lochte (1938), Noback (1951) and Brunner and Coman (1974), to mention but a few. Ryder (1973) classifies the types in the following most comprehensive way (omitting, however, specific classification of vibrissae):-

Guard hairs (outer coat) - long and coarse.

1. Spines - very large and often defensive, e.g. quills.
2. Bristles - stiff, heavily pigmented typical protective outer hairs.

(also include mane hairs).

3. Awns - hairs with coarse, often flattened tip, but finer base.

Underhair - short, fine and soft (have less pigment).

1. Vellus - shortest and finest hair or 'down'.

2. Fur - thick, fine and relatively short.

3. Wool - longer, soft and usually curly.

Guard hairs and underfur (and mane hairs where present) are described in the atlas of this work.

Hairs are terete structures composed of compactly cemented keratinised cells produced by the sac-like epidermal follicles that grow into the dermis (Montagna 1962). Although much research has been carried out on hair growth the most important references are Lyne and Short (1965), Montagna and Ellis (1958), Montagna and Dobson (1967), who edited books which deal with the biology of hair growth. The structure and the development of the hair follicle have been ably described by Lyne (1966) in a review in which he also describes hair follicle groups. The arrangement of follicle groups is characteristic for a particular species and could be used as a diagnostic feature. However, this aspect of identification has not been dealt with in this study. Hair follicles show intermittent cyclic activity; the stages of activity are described, as anagen, catagen and telogen, being the active, transitional, and resting phase respectively. This aspect of hair growth is not important to this study, but that aspect of growth which is relevant is the sequence in which the hair types appear in the pelage. The guard hairs obviously vary in length as they emerge, and although cuticular scale patterns along the different length hairs also vary, the cross-sectional shape at the widest point is constant. The diagnostic implication of this is evident.

The typical hair consists of the shaft which has a free expelled part and an intrafollicular part, the root, situated below the skin surface. The more superficial part of the root is fully keratinised but the lower part is partially keratinised and merges with the cells of the follicle in the matrix of the hair papilla. The hair consists of the cuticle, the cortex and the medulla, and it is variations of these features which are most commonly used in hair identification.

The Cuticle consists of keratinised overlapping scales, with their free ends aligned towards the hair tip. The keratinised cells are non-nucleated and are filled with hard or α keratin. The pattern made by these scales around the length of the hair, their shapes and sizes and types of margins, have been recognised and used for identification purposes. Thus a scale-index based on scale size was used by Hausman (1930), and Mayer (1952), but has disadvantages in that they disregard scale-shape and variations along the length of the hair. However, many others have used scale shape and patterns for hair identification of various species ranging from monotremes and marsupials (Lyne and McMahon 1951), bats (Benedict 1957) to animal textile fibres (Wildman 1954), and murids (Keogh 1974), to mention but a few.

The Cortex is composed of non-nucleated cells, filled with hard α keratin, which are seen under electron microscopy (Hashimoto and Shibazaki 1975), but cannot be seen by transmission or reflection light microscopy. The spindle-shaped cells are arranged concentrically, and intercellular spaces are filled by electron-dense substances. The colour of the hair is determined by the number of melanin granules in the cortical cells and these can be seen, in some cases, with light microscopy. In this way Dreyer (1966) has in fact classified pigment distribution in cross-sections of hair. The cortex, as such, is not often a diagnostic

character but its size, relative to the medulla, is used in hair identification.

The Medulla, like both the cuticle and the cortex, is composed of soft or β keratin in the early stages of their development. The cuticle and cortex however grow faster than the medulla and this results in airspaces in the medulla (Rhodin 1974). The dead cells of the cortex are made up of α, or hard keratin, while those of the medulla of soft or β keratin. The keratinisation processes of hard and soft keratin are poorly understood (Rhodin 1974), but hard keratin seems to contain more sulphur than soft keratin. (The dead cells of the medulla may contain pigment, but more often they are unpigmented). The air cavities in the medulla appear black by transmitted light, and this may obscure the actual structure of the medulla. If, however, the air is expelled, the various arrangements of the medulla can sometimes more easily be seen. These arrangements have been classified into types which are described in the text. The significance of the medullary cavities however may well be related to thermoregulation (as postulated later in the text), although the various arrangements have been used as taxonomic criteria by some authors.

In using the findings of the atlas as well as in observations made during this, and previous studies, I have attempted to relate hair structure to ecology. Gilbert White's (1771) description of ecology quoted by Elton (1927) expresses the complexity of this task in a succinct and picturesque manner. "Faunists (in other words taxonomists) as you observe, are too apt to aquiesce to bare descriptions and a few synonyms, the reason for this is plain, because all this may be done at home in a man's study, but investigation of the life and conversation of animals is a concern of much more trouble and difficulty ....."

Ecological data for this work has been largely drawn from the following sources:- Shortridge (1934), Roberts (1951), Dorst and Dandelot (1970), Smithers (1971, 1978 a and b in press), Skinner (1976, 1978 in press) and Cooper and Skinner (1979 in press).

Because of the wide scope of this aspect I have selected for study those cases where ecologically selective pressures have resulted in the more extreme adaptations of the pelage. These are most apparent in aquatic mammals and those mammals on which the environment imposes a particular stress on homeothermy. A great deal of work has been done on the part played by the pelage in thermoregulation but the microstructure of the hair has not been investigated in this connection. Bearing in mind that as much as half of the heat load may be from the far infra-red radiation, the hair was subjected to a search for features which would interact with the wave lengths emitted and received in this region of the spectrum. The size and spacing of the medullary cavities are remarkably constant within this range and have justified a detailed investigation. This has led to an attractive hypothesis that the medullary dislocations act as a selective absorber and wave guide for longwave radiation. Until suitable instruments are available and the relevant measurements can be made, the supposed part played by the medulla in radiation exchange remains speculative.

The size and shape of hairs, especially those of otters and diurnal rodents, have functional adaptations. The latter were investigated as to the manner in which their hairs could nest and the possible function of the deep gutter, which is also found in some species of Bovidae inhabiting drier regions of southern Africa.

Two aspects of mammalian pelage which are common to all

vertebrates are moulting and the power to form melanin, both of which are retained throughout life and obviously must have advantages for survival. The part played by colour is a subject on its own and I have concentrated on colour as a feature of thermoregulation rather than on its cryptic aspect. Pattern in animals seems to be phylogenetically orientated (Portman 1967). Thus in the lower ranking mammalian orders pattern is unrelated to body division, as for example with the stripes of the polecat and in the striped rodents. On the other hand in the higher orders cephalisation becomes apparent, and the head is obviously the leading pole in the pattern arrangement, as for example in the facial colouring of the cats. The neurosensory function of hair has been studied mainly in regard to vibrissae, and Lyne (1959) substantiated the theory that this was its prime function in his findings that more primitive species have larger concentrations of vibrissae, than more advanced mammals. The long guard hairs on mammals, especially burrowing ones, have retained their sensory function (Palmer and Weddell 1964), and a few authors have suggested that guard hairs of various species act as sensory perceptors.

The aim of this present study therefore is two-fold, first to add to our detailed knowledge of hair of mammals from southern Africa, and secondly to point to some of the functions of hair in ecology. Hair has been studied over the years by a great number of workers and from a variety of aspects and its practical applications have been mentioned in regard to taxonomy and various agricultural and industrial facets. It also has applications in the applied science of epidemiology.

Epidemiology may be defined as the study of the distribution and determinants of disease in human populations (Barker 1973). Identification of mammals which may possibly be implicated in the spread of certain diseases, plays an important part in evaluating the cause and

geographical extent of such a disease, and in the implementation of control measures.

As previously mentioned, identification of southern African murids according to the cuticular scale pattern on the hairs, assumed practical application in epidemiological work on plague. Thus rodents can be identified from carcass remains or from hair in stomach contents and scats of carnivores which eat dead rodents in an epizootic (Fourie 1938). This gives a lead as to whether those species which are known to be wild reservoirs of plague, are involved or not.

It is, however, in investigations of virus diseases, such as Lassa Fever, that identification of the rodent reservoir has become of great importance. *Mastomys natalensis* is the reservoir host of the Lassa type A virus. Recent work in Rhodesia and South Africa (Lyons, Green, Gordon and Walters 1977 a and b; Green, Gordon and Lyons 1978; Hallett 1977), has established that the taxon covers at least two sibling species. The implication of sibling species within the taxon, regarding epidemiological studies, are as yet unknown and of utmost importance to the clarification of the part *M. natalensis* plays in the epidemiology of virus diseases, as well as Bubonic plague. Preliminary investigations using electron microscopy would seem to indicate that differences in the hair of genetically defined sibling species, can be detected. The use of this method of determining the sibling species need not be underlined and further studies and verifications in this direction are of utmost importance.

Hair identification is used at the South African Institute for Medical Research in routine bacteriological and serological surveillance of zoonoses which involve small mammals. The identifications thus made are important in the delimitation of various species in disease

distribution. Identifying mammal specimens in Leishmaniasis surveillance and ectoparasite surveys often involves the use of hair identification.

It has also proved useful in public health investigations when possible breaches in sanitation and hygiene need to be ascertained; for example, suspected contamination of water sources, or processed and non-processed foodstuffs. In many cases the result of the investigation has depended solely on the identification of hairs in the specimens in question.

This technique of identification of hair is also used in medico-legal and insurance investigation. An example of the latter concerned determination of the type of rodent contamination in a large cargo-load of wheat in a foreign ship docked in a South African port.

Most of the above applications of hair identification concern the small mammals but this work is now being extended to include other mammals. Whilst southern African murid species are relatively easily identified using the variations in the cuticular scale patterns, identification of other families calls for the use of more comprehensive criteria before diagnosis can be made. Cross-sectional appearance as well as gross structure and cuticular scale patterns are used. This method has been employed to identify the contents of vulture pellets from some six localities in southern Africa.

As vultures are implicated in the spread of Anthrax, hairs from these pellets were subjected to bacteriological and biological examination. *Bacillus anthracis* has not yet been isolated from this source, although *Bacillus cereus*, a closely related species, has been isolated.

Although rabies in wild carnivores has occurred in epizootics for centuries, more research is needed with information on the epidemiology

of wild-life rabies. In South Africa carnivores implicated in the spread are primarily the mustellids and viverrids, although the felids, canids and *Proteles cristatus* are also involved.

In rabies surveillance the identification of the species involved is vital, and hair samples may be sent from field stations for identification. Hair in spotted hyaena scats from Namibia were found to contain some weasel hairs. Initially this was somewhat puzzling, as the weasel *Poecilogale arbinucha* had not previously featured in the diet. However, shortly after this it was reported that weasels had been found to be dying of rabies in this region.

MATERIALS AND METHODS

Hairs from the following 36 species of southern African carnivores were studied both macroscopically and microscopically:-

PROTELIDAE		
Proteles cristatus	(Sparrman 1783)	Aardwolf
HYAENIDAE		
Hyaena brunnea	Thunberg 1820	Brown hyaena
Crocuta crocuta	(Erxleben 1777)	Spotted hyaena
FELIDAE		
Acinonyx jubatus	(Schreber 1775)	Cheetah
Panthera pardus	(Linnaeus 1758)	Leopard
Panthera leo	(Linnaeus 1758)	Lion
Felis caracal	Schreber 1776	Caracal
Felis silvestris (lybica)	Schreber 1777	Wild cat
Felis nigripes	Burchell 1823	Black footed cat
Felis serval	Schreber 1776	Serval
CANIDAE		
Otocyon megalotis	(Desmarest 1822)	Bat-eared fox
Lycaon pictus	(Temminick 1820)	Hunting dog
Vulpes chama	(A. Smith 1833)	Cape fox
Canis adustus	Sundevall 1846	Side-striped jackal
Canis mesomelas	Schreber 1775	Black-backed jackal
MUSTELLIDAE		
Aonyx capensis	(Schinz 1821)	Cape clawless otter
Lutra maculicollis	Lichtenstein 1835	Spotted-necked otter
Mellivora capensis	(Schreber 1776)	Honey badger
Poecilogale albinucha	(Gray 1864)	Weasel
Ictonyx striatus	(Perry 1810)	Striped polecat
VIVERRIDAE		
Nandinia binotata	(Gray 1830)	Two-spotted palm civet
Viverra civetta	Schreber 1776	African civet
Genetta genetta	(Linnaeus 1758)	Small-spotted genet

VIVERRIDAE (cont.)

Genetta tigrina (senso lato)	(Schreber 1776)	Large-spotted genet
Suricata suricatta	(Schreber 1776)	Suricate
Paracynictis selousi	(de Winton 1896)	Selous' mongoose
Cynictis penicillata	(G. Cuvier 1829)	Yellow mongoose
Galerella sanguinea	(Ruppell 1835)	Slender mongoose
Herpestes ichneumon	(Linnaeus 1758)	Egyptian mongoose
Herpestes pulverulentus	Wagner 1839	Cape grey mongoose
Ichneumia albicauda	(G. Cuvier 1829)	White-tailed mongoose
Atilax paludinosus	(G. Cuvier 1829)	Marsh mongoose
Mungos mungo	(Gmelin 1788)	Banded mongoose
Helogale parvula	(Sundevall 1846)	(Dwarf mongoose)
Bdeogale crassicauda	Peters 1852	Bushy-tailed mongoose
Rhynchogale melleri	(Gray 1865)	Meller's mongoose

I. SAMPLING

Hairs can be taken from live or preserved and dried skins. Most workers in this field have used hairs from museum specimens and these have been found to be indistinguishable from fresh material. Trevor-Deutch (1970) reports that there was no deterioration in the hairs of two vole specimens of over a hundred years old. I have had the opportunity of comparing large numbers of hairs from preserved and fresh material, and have not detected any appreciable differences in their microscopic morphology. In particular mammoth hair samples showed no perceptible deterioration.

The only exception is that in older dried specimens the root of the hair is sometimes damaged when it is removed from the pelt. During the course of this study as many hair specimens as possible were examined from live samples from various geographical regions. The main source of specimens, however, was the mammal collection housed at the Transvaal Museum. Specimens from different localities were selected from this

collection and hair was sampled from all available individuals of a species. The hair samples of thirty-six species of southern African carnivora were initially taken from the dorsal region; no less than thirty hairs were examined from each individual, and in most cases many more. Subsequently hairs from the belly, chest and rump were examined from most of the thirty-six species. Although this work is primarily based on the study of southern African carnivore hair, whilst engaged on it, opportunities have arisen to examine hair from many other species: in particular Bovids, such as the bontebok, in detail. In order to clarify certain aspects of the possible role of hair in ecology, gutter hairs prevalent in some diurnal rodents were examined, and for this a technique was evolved which will be referred to later in this section. Samples of these rodent hairs were drawn from museum specimens housed in part of the Medical Ecology collection, and from live rodent colonies at the South African Institute for Medical Research, as well as from field-trapped specimens.

II. MICROSCOPIC WORK

(A) Cuticular scale imprints

With ordinary microscopy cuticular scales cannot be seen on the hair itself, however by using imprints, the scale patterns are revealed and easily studied. Terminology varies but in some instances authors refer to impressions, casts or imprints. The term "impression" has been restricted to cases where the entire circumference of the hair is represented by rolling the hair over a suitable medium, and "cast" refers to the imprint made by placing the hair on the medium and later removing it, leaving the imprint of only that part of the hair which came in contact with the medium. I use the term "imprint" throughout; it refers to the latter method.

Various techniques have been described for cleaning, drying and mounting the hair for examination of cuticular imprints. Practice is important in these techniques and the refinements adopted vary from one worker to another. Thus Trevor-Deutch (1970) washed hairs in carbon tetrachloride, which is possibly a suitable method applicable to cleaning hairs from coprolites which he studied. Brunner and Coman (1974) cleaned hairs in an alcohol-ether mixture and dried them between absorbent paper. I have found the most satisfactory method of cleaning hairs to be that of washing them in a mixture of absolute alcohol and sulphuric ether in equal proportions. The hairs were then washed in distilled water for about three minutes and dried on a clean watch glass. The mounting media used also vary: they include polyvinyl acetate (PVA) (recommended by Brunner and Coman 1974), celluloid, gelatin, and various specialised commercial products such as permount and ethofoil (Wildman 1954). I prefer gelatin, which, although perhaps not so satisfactory for photography as PVA, seems to give more sensitive imprints for microscopic study, especially when the hairs are very fine or very coarse.

Finely granulated gelatin was added to cold distilled water until the solution was saturated. Ten per cent by volume of blue dye (Eosin methyl blue) was added, and the container was heated in a water bath at boiling point. Clean slides were thinly coated with this gelatin solution and the hairs were placed in position. They were removed when the gelatin was dry. In the case of concavo-convex hairs the position of the groove along the length of the hair must be taken into account when making imprints. Similarly care must be taken with twisted hairs, by securing the hair at one end before laying it flat. Positive imprints are obtained by making the imprint on a coverslip and inverting this onto a microscope slide. This method was successfully used by Brunner and Coman (1974). Although a positive imprint prepared in this way may

possibly be easier to interpret, and is protected from dust and damage, I have consistently used the technique with which I am familiar, of making negative imprints directly onto the slide.

The nomenclature for scale pattern in this study follows that of Wildman (1954). As the scale pattern varies along the length of the hair, it has been described at the base of the hair, the mid-region of the shaft and the tip region.

Over the years workers in this field have described the scale pattern of hairs: Hausman (1930), Williams (1938), (Lyne and McMahon 1951) Mayer (1952), Khemelevskaya (1965) - to mention but a few.

Patterns (see Fig. 1) are described as:

Coronal: Usually a single scale, occasionally two scales, across the width of the hair; scales often evenly spaced. The margins are transverse and smooth or slightly indented.

Chevron: A waved pattern. In a single chevron either the troughs or the crests are narrow 'V' shaped. In a double chevron both the troughs and the crests are 'V' shaped.

Mosaic: A pattern composed of a number of units; this type is divided into regular, in which the units are approximately the same size, and irregular, in which the mosaic has a random mixture of different scale sizes.

Pectinate: Comb-like pattern. This type is divided into coarse pectinate, in which the "teeth" are wide and large, and lanceolate pectinate in which the teeth are long and narrow.

Petal: Patterns in which the scales have the appearance of overlapping flower petals and which may also be of a diamond or a

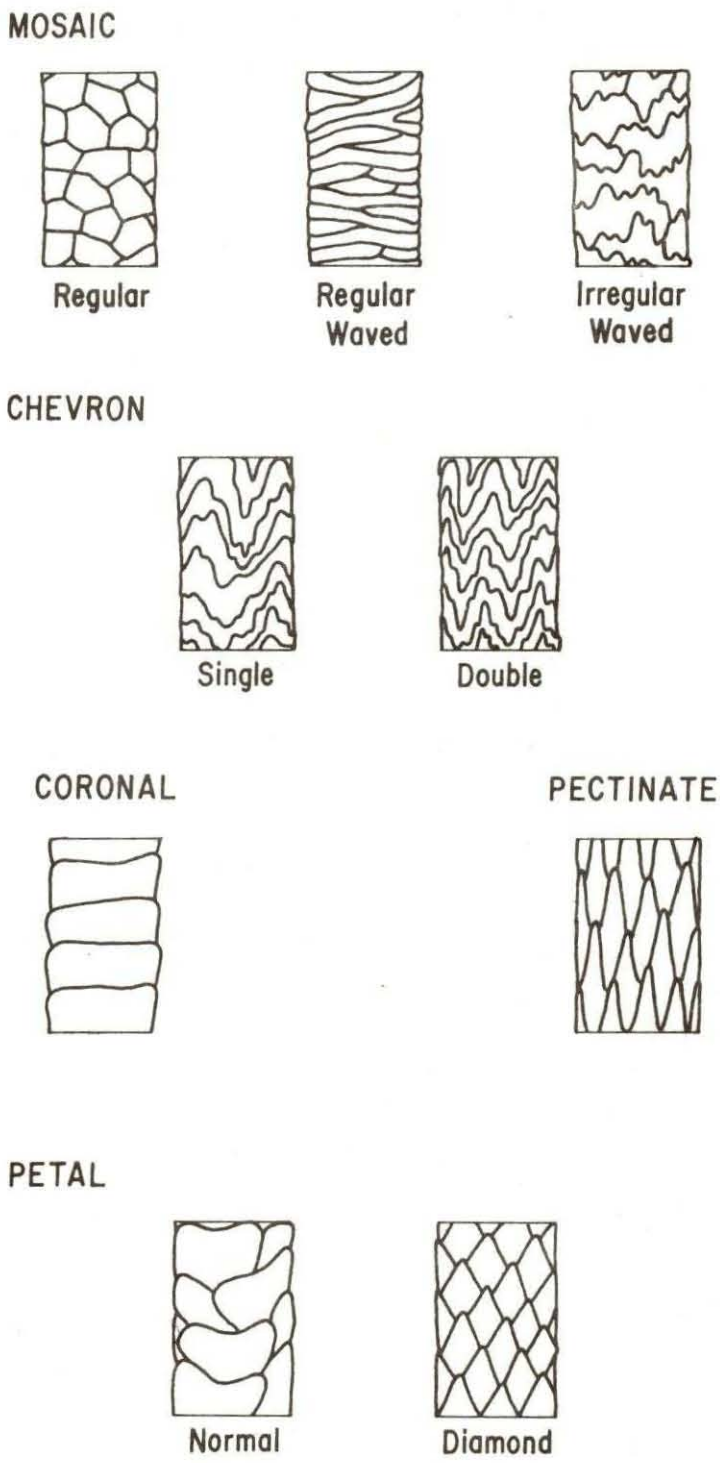


Figure 1. Cuticular scale patterns.

narrow diamond shape.

The distance apart of the scale margins:

This is a distinctive feature of the pattern but cannot easily be quantified. No more than a qualitative measure is justified, and for this purpose the designation used by Wildman (1954) has been followed. Thus distances between margins in the direction of the hair length are described as close, near or distant. See Fig. 2.

The form of scale margin as defined by Brunner and Coman (1974) relates to the free distal edge of an individual scale. This may be smooth, crenate (having shallow but relatively pointed indentations) or rippled (in which the indentations are deeper, but the profile is rounded). (Scalloped and dentate margins have also been described). See Fig. 3.

(B) Cross-sections

(i) Thick sections

(a) Various methods for obtaining cross-sections of hairs have been well described by Brunner and Coman (1974), who used the plate method, with modifications, described by Ford and Simmens (1959). All cross-sections photographed in the Atlas of this work were obtained by the use of this technique, as very thin sections are not necessary for hair identification.

Stainless steel slides approximately 76 x 25 x 0,5 mm with three holes, each 0.8 mm diameter, drilled at equal intervals along the centre line, were used. After drilling, the holes were slightly chamfered to remove sharp cutting edges.

A loop of cotton is threaded through the hole as in Fig. 4. Threads of cellulose acetate yarn are then inserted into the loop,

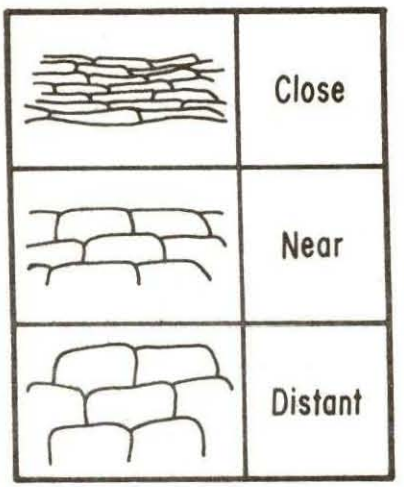


Figure 2. Distance between scale margins.

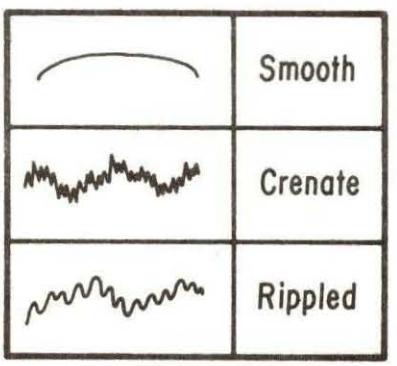


Figure 3. Form of scale margins.

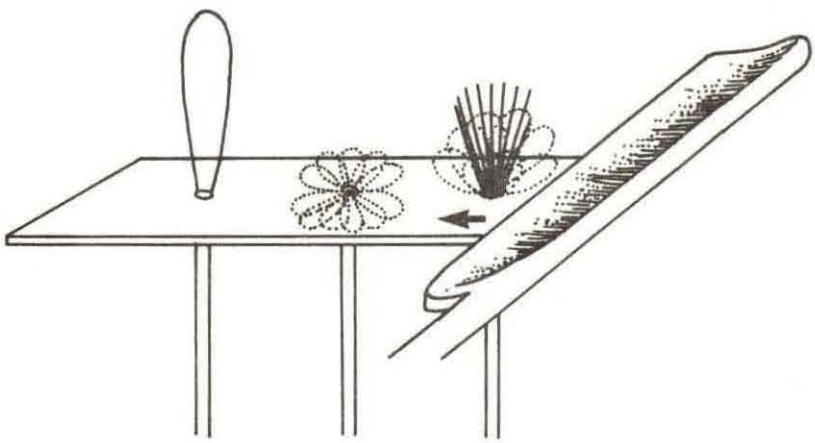


Figure 4. The plate method of cross-sectioning.

and pulled by the cotton thread a short distance down through the hole. The hair tuft is then placed in the centre of the yarn and gently pulled through the hole. I favoured cotton rather than nylon thread as it acted as a better regulator of the amount of hair which could be pulled through the hole. With nylon thread hair can be forced through the hole, resulting in over-packing and hence distortion of the sections. If necessary cellulose acetate solution can be used to dissolve the packing material. The protruding hair bundle is then cut flush with the slide on each side of it. I found a cut-throat razor easier to manipulate than a razor blade, the blade being held at the recommended angle of about 35°. Immersion oil is placed over the sections, which can then be viewed. I found it useful to cover the slide with a coverslip after having cut the sections, as this protected them when stored (see plate 1, page 24).

Cross-sectional shape, and variations in the relative sizes of the cortex and medulla have been used to describe and assist in identifying hairs. Thus in the Atlas of this work the main types of cross-section shape are described. A schematic representation of the cross-sectional shapes at the widest part of the guard hair most commonly encountered is given in Fig. 5.

(b) A new technique was devised for obtaining cross-sections at known points along the length of the hair. This was used to attempt to evaluate the way in which gutter hairs could nest. The results of this technique are discussed in the Ecology section of the text.

Hair was placed in the middle of a square block of embedding wax, which was cast in two portions. The sides of the blocks were determined by glass sides set in a non-heat-conducting material, and after the first block had set a groove was made, starting at a known distance from the end of the cast. The hair was carefully placed at the end of this groove. The wax was then slightly melted and the second section

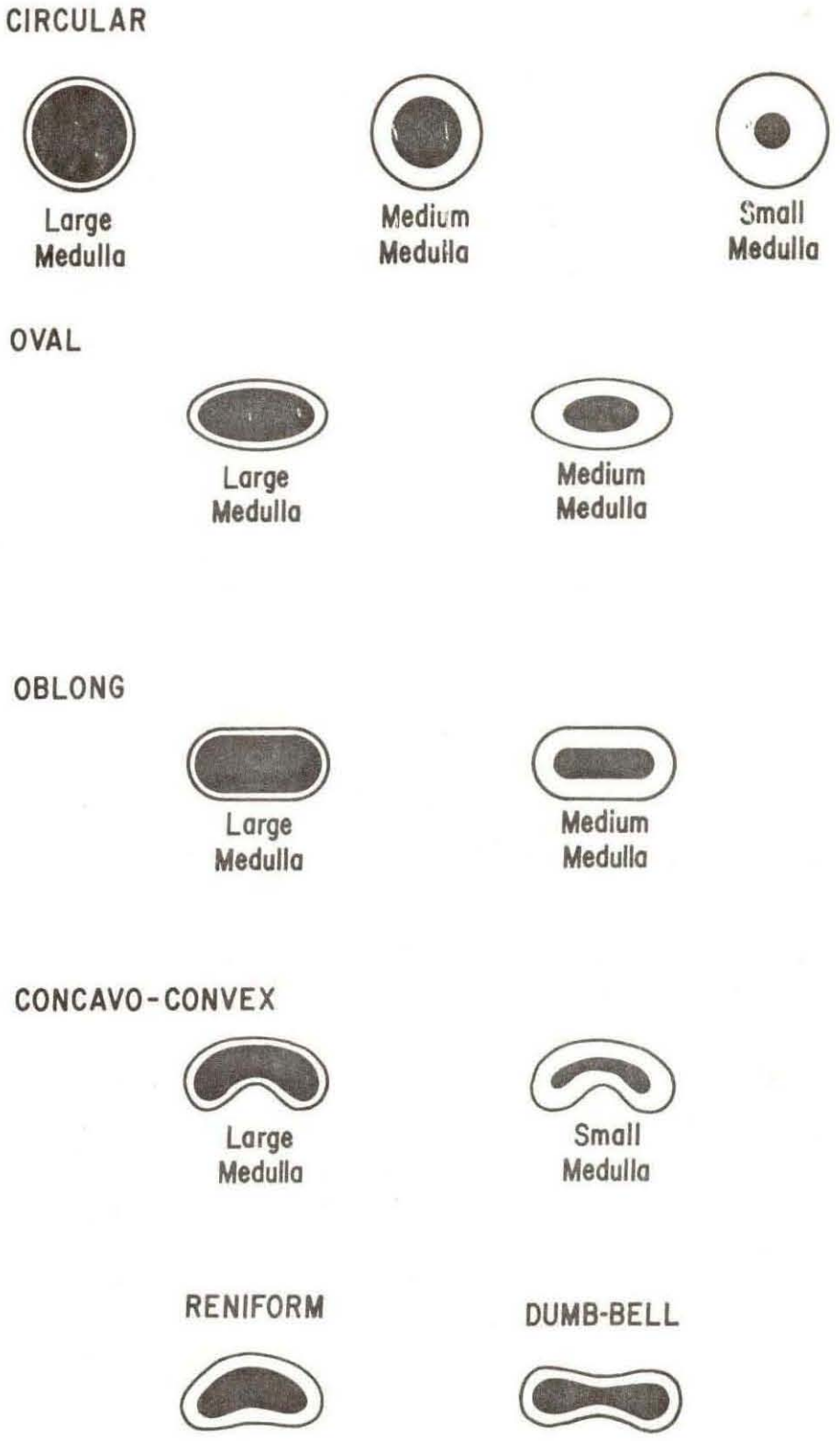


Figure 5. Most commonly found cross-sectional shapes.

of the block poured onto this. Four casts were used for the various stages of this procedure. When set and trimmed the blocks were then placed into a square collet in a lathe and trimmed to the exact size of the microtome - (10 mm in diameter). The hair was lying along the axis and the tip was known to be at an exact distance from the end of the block. Coloured lines drawn down the side of the block determined the orientation of the hair. Thus by cutting at 0,2 mm intervals, sections were obtained in sequence along the length of the hair. A small punch fitted onto the nose-piece of the microscope was then used to punch out these sections which were arranged in sequence on a slide, to ensure accuracy of viewing.

(ii) Thin sections

For making thin sections of hair, the following technique was adopted:-

Hairs were fixed in three per cent glutoraldehyde, dehydrated in grades of ethyl alcohol and briefly cleaned in propylene oxide. They were embedded in Spurr's resin (TAAB Laboratories) for 18 hours under light vacuum before orientation in silicone rubber moulds for curing at 70°C for eight hours. Approximately 1,0 µm sections through the shaft medulla, cut with a diamond knife on an LKB Ultrotome, were collected on microslides and dried on a hot-plate at 60°C. The sections were stained in polychrome methylene blue at the same temperature, then washed and mounted in DPX. For examples, see plate 2, page 24, plates 5,6,7, page 28.

(C) Whole mounts and the examination of the medulla

(a) For temporary mounts, such as used in identification of unknown hairs, the cleaned hairs can be mounted in paraffin oil and examined under a coverslip.

Plate 1. Thick cross-section of white, red and black hairs of *Damaliscus dorcas*. Medullary structure obscured by reflected light of air spaces. X250.

Plate 2

(b) For permanent mounting, a medium such as DPX can be used. The detailed structure of the medulla is obscured under normal light microscopy because the air cavities appear black due to internal reflection of light at the top surface.

Most authors who have investigated this, describe infiltrating these cavities with the mounting medium, thus facilitating viewing of the internal structure. I obtained the most satisfactory results by heating the hair in a weak acid solution prior to placing it in mounting medium, thus expelling the air by expansion. The cleaned hair was placed in 5,0 per cent acetic acid in a covered petri-dish overnight at 37°C. The hair was then dried and mounted and again incubated for a few hours at 37°C. Once the mounting medium had set the hairs could be examined, and the medulla clearly observed.

Brunner and Coman (1974) have classified the shape and arrangement of the medullary material and its air spaces as: unbroken, broken, ladder and miscellaneous, and have then sub-divided each of these categories, presenting a total of twelve types. On the other hand Ryder (1973) simply classifies medulla types into either latticed or non-latticed. There is considerable variation in the appearance of the medulla, even along the length of a single hair and sometimes between different individuals of the same species, let alone between the species themselves. Moreover, there is often a confusing difference between the structure as seen in the whole mount and that seen in a longitudinal section, and there may be doubt as to whether infiltration has been effective. For these reasons I have felt obliged to discard the use of the medulla as a taxonomic criterion. See plates 3-7, pages 26 and 27.

Nevertheless examination and measurements of medulla have other important uses, particularly in the interpretation of the part played by fur in the thermal exchanges between a mammal and its surroundings, as

Plate 3. White hair of *Damaliscus dorcas*. Whole mount. Medulla not infiltrated. X900.

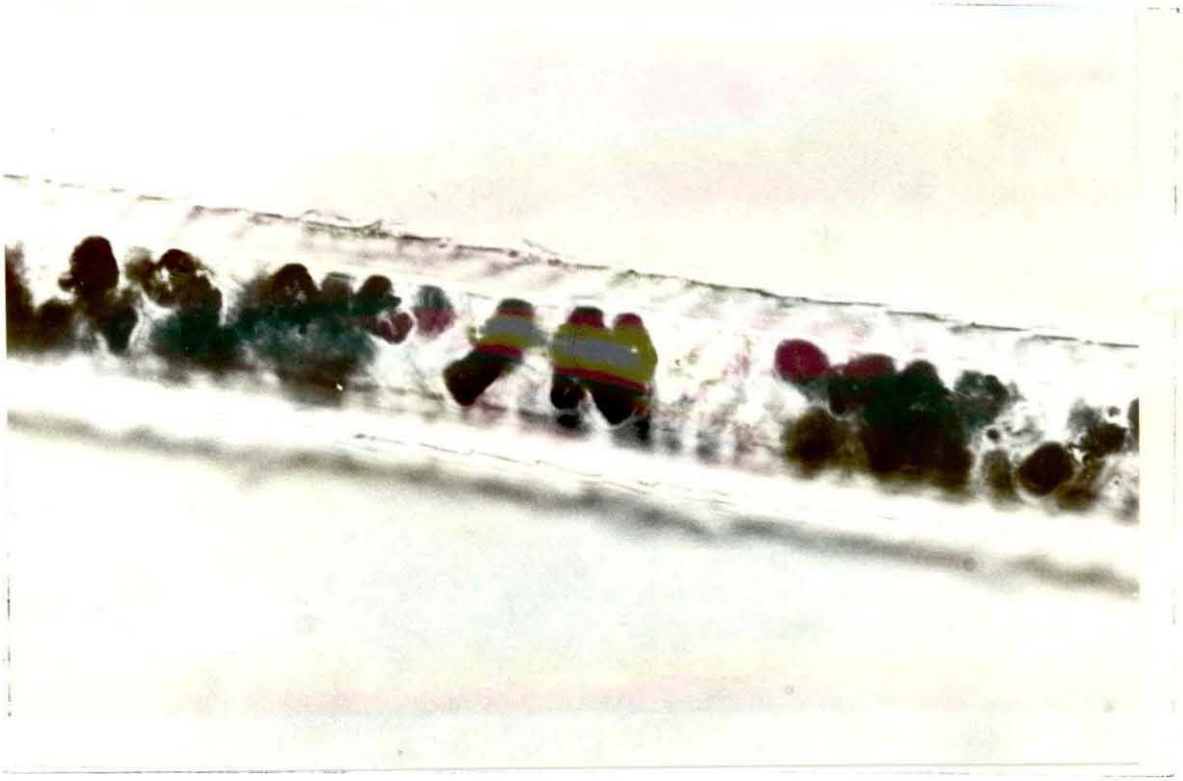


Plate 4. Distal part of white hair of *Damaliscus dorcas*. Whole mount showing partial infiltration of medullary cavities. X900.

Plate 5. Oblique thin section of black hair of *Damaliscus dorcas* showing pigmented cortex and complete infiltration of air spaces in medulla. X900.

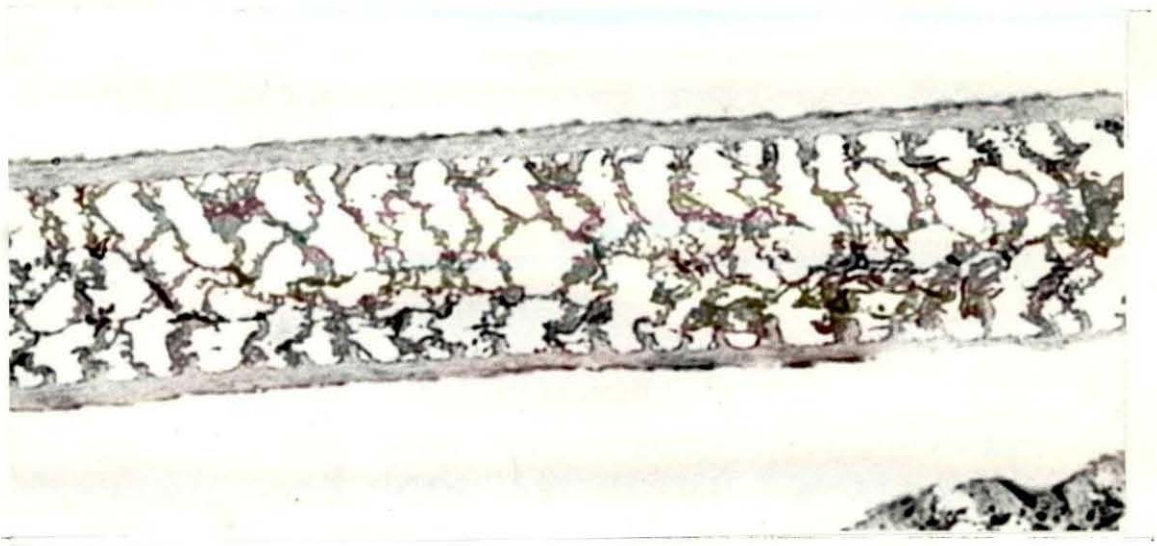
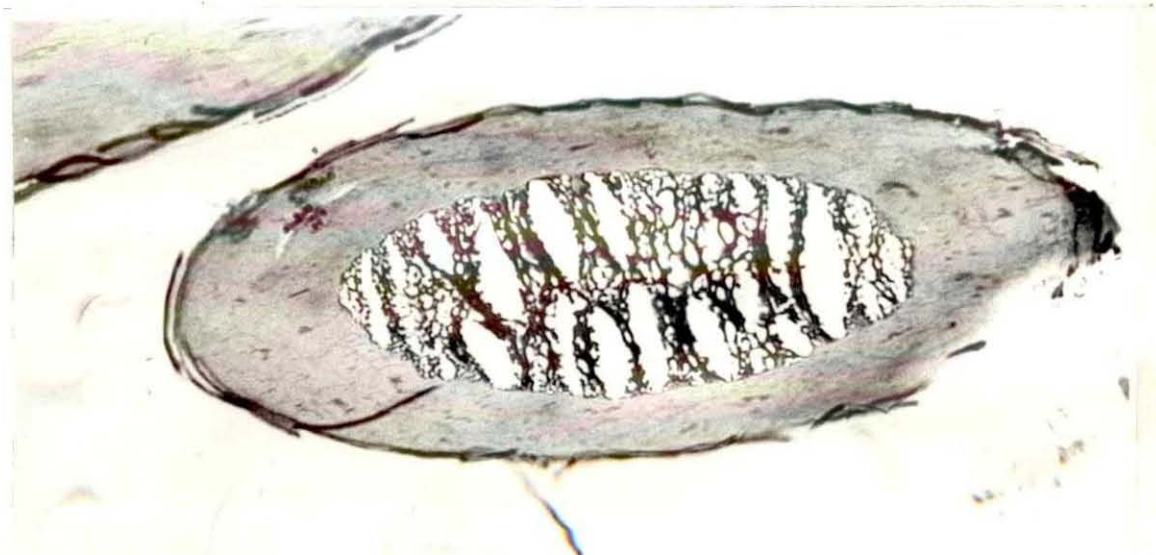


Plate 6. Longitudinal thin section of red hair of *Damaliscus dorcas* showing cortex relatively narrower than above. Medulla air spaces completely impregnated. X900.



described later in the section on ecology. The relevant lattice and ladder types of medulla are shown in Fig. 6.

III. SURFACE TENSION AND TENACITY OF FIBRES

Critical surface tension and fibre breaking strength, tenacity and breaking extension were measured. These tests were carried out at the South African Wool and Textile Research Institute in Port Elizabeth. The critical surface tension was measured by the method described by Mutchler, Menkart and Schwarts (1969). For the fibre strength tests, the average cross-sectional area of the hair (excluding the area of the medulla) was measured and, assuming a fibre density of 1,31 gm/cm^3, the fibre linear density (tex) of the fibres was calculated. The tenacity N/tex was then calculated, this being the unit used in textile technology.

The following species, representative of the nocturnal, diurnal and aquatic carnivora species within the various taxonomic groups, were selected to ascertain possible differences in the surface tension and tenacity:- *Lutra maculicollis, Aonyx capensis, Atilax paludinosus, Crocuta crocuta, Hyaena brunnea, Proteles cristatus, Canis mesomelas, Vulpes chama, Paracynictis selousi, Viverra civetta, Acinonyx jubatus, Felis lybica, Lycaon pictus.*

IV. ENERGY STUDIES

Measurements on conduction, convection and radiation relating to the mammalian pelage have been described by many authors and these will be referred to later in the text. In order to attempt to ascertain if there was any directional influence on the hairs of a pelt on thermal radiation, measurements were made with a thermopile. These measurements were unsuccessful however, as the equipment was not sensitive enough and

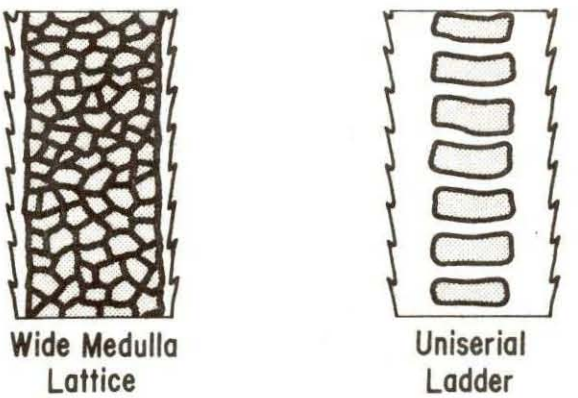


Figure 6. Types of medulla.

the cost of obtaining such instruments to make these measurements with any degree of accuracy proved too great to warrant further pursuit. Thermographic measurements, however, were made on the surface temperatures of the giraffe, the black-backed jackal and the striped polecat. An Agavision System 680 thermal imaging camera was used to measure the surface temperatures of animals in the Johannesburg Zoological Gardens. Filters were incorporated to eliminate errors from solar radiation, thus the longwave radiation was measured. The thermograms presented later in the text (pages 137-139) are in alternate grey tone form. The temperature distribution appears as a gradation of image brightness, the lighter shades representing warmer parts than the darker shades.

V. PHOTOGRAPHY

Photographs were taken with a Univa photomicroscope using Ilford Pan F rated at 50 ASA, developed in Acutol.

All black and white prints in the Atlas are at a magnification of 250X. The coloured prints of hair profiles are at varying magnifications shown by a scale on the print and all other photographs in the text are marked with the magnification.