INTRODUCTION

Teeth have the great archaeological advantage of being constructed from remarkably tough materials, which can survive a century and more in the harsh environment of the mouth. They also survive in a very wide range of archaeological sites and conditions of burial. Teeth of large animals are part of the carcass which is thrown away early in the butchery process, and so become incorporated quickly into rubbish deposits. They are readily recognised during excavation and routinely recovered in a similar way to artefacts. Often, they are amongst the most numerous finds. At large town sites in Britain, for instance, the number of identifiable bone and tooth fragments frequently exceeds the total of recognisable sherds of pottery.

The importance of recovering such material from excavations has long been recognised. In his *Primeval Antiquities of Denmark* (1849), J. J. A. Worsaae asserted firmly that all objects from archaeological sites, including animal bones, should be preserved. As archaeology developed, finds of the remains of extinct mammals alongside human bones and artefacts came to provide crucial evidence for the antiquity of man. William Pengelly's famous excavations of Brixham Cave in 1858–9 revealed a deposit containing flint tools and extinct animal bones that was sealed by a thick layer of stalagmite, also containing remains of extinct animals (Daniel, 1978).

Most teeth from mammals larger than a cat can be recognised when trowelling on an archaeological site, or quickly recovered by sieving/screening at a coarse mesh (1 cm). Small mammals – traditionally those not tall enough to be seen above long grass – may have very small teeth indeed. A microscope is required to see them properly, and isolated specimens are often missed on site. To recover the small teeth of voles, mice and similar creatures, large samples need to be taken, and sieved at a fine mesh (ideally 0.5 mm, although 1 mm catches many of them). Outside arid lands, dry sieving is difficult, and wet sieving is required. This is time-consuming and samples need to be carefully selected, to maximise return on effort.

Along with such material as shells and insect skeletons, bones and teeth now form a central part of the discipline of archaeozoology (or zooarchaeology). This development has gone hand in hand with the growth of archaeologically based biology in general and, together with work on soils and geomorphology, makes up the wider discipline of environmental archaeology. Specifically anthropological and pathological investigations of human skeletons have been carried out since the early discoveries in European caves and the Egyptian excavations of Flinders Petrie produced large collections of human remains which formed the basis of much work during the 1900s and 1920s. The origins of physical anthropology therefore lie in Europe, but it is in North America that it has expanded most, particularly through the students of Earnest Hooton who spread the subject into American universities during the first half of the twentieth century. Anthropology is a very broad discipline, but specifically dental anthropology has its origins largely in the work of Al Dahlberg in the 1930s and 1940s, with fellow dentists and anatomists. The use of the phrase 'dental anthropology' dates to a meeting in London in 1958 (Brothwell, 1963a). Zooarchaeology, or archaeozoology, developed mainly during the second half of the twentieth century from a number of academic sources, in particular vertebrate palaeontology and zoology, and out of the interests of archaeologists themselves in answering questions about diet, hunting and the origins of farming. The need for reference material for identification purposes has meant that much of its development has gone hand in hand with the building of large collections, not only at major museums, but also in university departments and government organisations.

Teeth themselves are not normally considered a distinct category of finds in archaeological work. They are, however, very different from bones in their biology. Andreas Vesalius first recognised these differences in structure and function as long ago as 1542 and it is now clear that teeth cannot be considered parts of the bony skeleton in a strict sense. Instead, they comprise the dentition, which is connected to the skeleton, but is derived at least partly from tissues akin to the skin and is exposed at the surface of the body. The anatomy, physiology and pathology of teeth are highly specialised subjects with their own long and honourable history. Teeth were included in the general anatomical and medical works of the classical authors. The *Corpus Hippocraticum*, originating in the fifth century BC, mentioned their anatomy and growth, as well as a number of dental diseases and treatments. Teeth were also described by Aristotle and by Galen of Pergamon, physician to four Roman emperors. Galen must have been one of the first to describe human bones from archaeological sites. He was forbidden by law to dissect human bodies and so turned to the study of remains in ancient tombs and monuments (Magner, 1979). Galen's ideas constituted the basis of anatomical science until the great developments of the Renaissance that took place particularly at the University of Padua. Andreas Vesalius gave the first convincing description of dental anatomy in his *De Humani Corporis Fabrica* of 1542 and in 1563 Bartolomeo Eustachi wrote the first known book on teeth, *Libellus de Dentibus*. The first microscopic studies of dental tissues were carried out by Marcello Malphighi and Anthony van Leeuwenhoek during the later seventeenth century, and van Leeuwenhoek was also the first to see micro-organisms in dental plaque (see Chapter 5). Although Pierre Fauchard's great work *Le Chirurgien Dentiste* followed in 1728, the true starting point of modern dental anatomy is usually taken to be John Hunter's *The Natural History of the Human Teeth* first published in 1771. Similarly, a major impetus for comparative dental anatomy came from Sir Richard Owen's *Odontography* of 1840, which included not only mammals, but also reptiles, birds, amphibians and fish. Many of the main features of microscopic dental anatomy were effectively described in the nineteenth century by such workers as Purkinje, Retzius, Preiswerk, Owen, von Ebner and Tomes (father and son). Sir John Tomes in particular is often regarded as the father of modern dentistry.

During the twentieth century, there were such strides in understanding of the anatomy, growth, physiology and diseases of the teeth that many avenues can now be followed in research on archaeological material. This book aims to draw together ideas and techniques from many fields, including archaeology itself, palaeontology, physical anthropology, anatomy, histology, mammalogy, dentistry, pathology and forensic science. Some of the methods described are already widely used in zooarchaeology and anthropology, but others are rarely applied. Several techniques have been developed specifically for forensic work on human remains but may well point the way to alternative approaches for other mammals, and zooarchaeological ideas also have application in anthropology. For this reason, humans are deliberately combined with non-humans. More detail on specifically human dentitions is given in Hillson (1996). Many of the methods may also have applications for zoologists, particularly those working on museum collections or in the field.

Teeth are often found on archaeological sites, not just as waste, but as art objects. Dental tissues make attractive materials – finely grained, tough and beautifully patterned – they were used to make artefacts in antiquity, and are still used. Ivory is the chief of these and, from an anatomical point of view, is just a large mass of dentine (Chapter 2). It is found in all teeth, but workable pieces come from the tusks of elephants, walrus, hippopotamus, pig or whales. These different forms can often be distinguished, either by eye or under the microscope. Much ancient ivory came from elephants, although it is not easy to distinguish the ivory of mammoth and Asian and African elephants. Ivory objects, presumably from mammoth tusks, are quite common in Upper Palaeolithic contexts in Europe. These include, for example, the ivory figurines from Dolní Věstonice in the Czech Republic and the burials of two boys at Sungir, near Moscow, in clothes richly covered with ivory beads. Ivory also occurs in later prehistoric contexts in Europe and was quite common in Roman times. The Romans imported much of their ivory through the Red Sea ports (MacGregor, 1985), and probably ultimately from North Africa or even India. After the fall of the Empire, elephant ivory artefacts became rare in Europe, but gradually reappeared in ecclesiastical and royal contexts. Elephant ivory was in good supply again by the ninth century AD, by which time it probably came mostly through Iraq and Egypt. Walrus ivory from local sources became common in northern Europe during the tenth to twelfth centuries AD, and the most celebrated examples are the Lewis chess men at the British Museum. Boar tusks were used in Mycenean Greece as the protective coating for helmets. The lower tusks were split into curved plates, incorporating dentine (in effect pig ivory) and enamel, making a white outside which shone in the sun. Holes were drilled in the corners of the plates, which were fixed, probably, to a leather framework. Famous examples can be seen in the National Archaeological Museum of Athens.

In addition to yielding useful materials, teeth are attractive objects in themselves. They have pleasing, rounded outlines and were indeed quite frequently used as amulets or in necklaces. Cave bear canines, perforated at one end, are common in the Upper Palaeolithic French cave sites, and the burials at Sungir included head-dresses decorated with arctic fox canines. Red deer (elk) canines were often used in the same way, both in Europe and North America. Anglo-Saxon burials in Britain quite often include amulets made from beaver incisors (MacGregor, 1985).

As noted above, teeth form a prominent part of the large collections of mammal remains representing burials, food debris and industrial waste on archaeological sites. The large degree of variation in their shape and form makes them readily identifiable, and teeth and jaws play a major role in the identification of archaeological material. Many fragments of the bony skeleton may yield little precise information, but even a single small tooth can often be assigned to species. This makes comparative dental anatomy an important subject for archaeologists. Relatively few textbooks exist, and few of these provide sufficient detail. Whereas in modern zoology the accent is on physiology, behaviour and ecology, archaeology still badly needs detailed studies of small and obscure anatomical differences if the fragmentary material from excavations is to be identified.

The first aim of this book is therefore to act as a starting point for making identifications. It deals only with mammals, because inclusion of reptiles, amphibians and fish, most of which have teeth too, would make it far too large a book. For similar reasons, it also applies itself particularly to the Holarctic zoogeographical region, which includes mainly Europe, North Africa, Asia and North America. Chapter 1 introduces the dentitions of some 325 genera of mammals which could be found on archaeological sites from approximately the past 100 000 years. These include both common finds and rare specimens, because it is exactly the chance find of the latter that might cause the greatest problem for archaeologists. It introduces mammalian dental anatomy and summarises the distinctive features of the different families of mammals. Much of the necessary information was not available in published works and Chapter 1 is the result of many hours' work with collections in the British Museum (Natural History), the Odontological Museum of the Royal College of Surgeons of England, the Natural History Museum at the Smithsonian Institution in Washington DC and the Field Museum of Natural History in Chicago. These are some of the largest collections of mammal teeth in the world today and, even so, a few mammal genera are today so rare that less than ten specimens were available. Chapter 1 is largely illustrated by axonometric drawings which were specially designed to clarify the three-dimensional arrangement of the diagnostic patterns of cusps, ridges and fissures on tooth crowns. Where specimens are too damaged or, as in isolated rodent incisors, not very diagnostic, it may be possible to use the microscopic structure of dental tissues as a guide. Dental enamel has particular potential for this, and Chapter 2 outlines methods and possibilities. Teeth do not even have to survive on a site to be of interest. Gnawing marks are found on bone, wood and nutshells, and it is often possible to make an identification of the animal responsible (Bang & Dahlstrom, 1972).

Identification is the first task, and it is necessary to identify not only the species present, but also the type of tooth, its position in the dental arcade and whether it is a permanent or milk tooth. The next step is to establish the relative abundance of different species. This is important in the reconstruction of such factors as demography, diet, husbandry and hunting practice. Estimates of abundance are refined by matching up bones and teeth from the same individual, and teeth have a potential advantage for this. Within one species, teeth vary widely in size and shape, and are modified over time by wear and disease. It is frequently possible to match up teeth and jaws by looking for similar patterns, shapes and sizes. If a very reliable match is needed, it may be possible to match the microscopic layered structure of the enamel and dentine (Chapter 2), which is characteristic of that individual.

Once the relative abundance of different species has been established, it is necessary to establish the age at which each individual died, or the season of the year. This is often difficult and teeth are again important because they provide the best methods for age determination. In young individuals, the formation of teeth and their eruption through bone and gums occurs in a regular sequence. Comparison of the state of development between individuals gives an estimate of relative maturity. Comparison with living animals may give some idea of actual age. Chapter 3 therefore outlines the biology of dental development in mammals and shows how it can be used to estimate age. It also deals with the uncertainties and problems involved. In mature individuals, the only guide to age is often the state of wear on the teeth. With continuous use, the teeth gradually wear down and the extent of this yields an estimate of relative age. Chapter 3 outlines various schemes for recording wear and discusses the difficulties in their use. Still other methods are based on the internal microstructure of teeth. These include counting incremental structures formed in enamel during dental development, and the counting of layers formed during adult life in the cement that coats the tooth roots. Such methods are only beginning to be employed in archaeology. The theory, practice and problems are covered in Chapters 2 and 3.

It is also necessary to determine as far as possible the sex of individuals in an archaeological collection of mammal material. A number of bones in the skeleton may show strong enough differences between males and females to be of value for sex determination. Teeth also are often dimorphic, sometimes to the extent of being present in one sex but not the other. In other instances, the size of the teeth can be used in some animals, even in humans, where the difference is small. One particular advantage of teeth is that they are formed full adult size from the start, so they can be measured in young individuals and compared directly with adults. Bones, by contrast, need to reach adult proportions before they can be used to estimate sex. Morphological variation of this kind is included in Chapter 4, which also deals with variation of other kinds within species. Teeth of one species often show a wide range of variations, not just in size, but also in the details of their form. People who see a large collection of teeth for the first time are often surprised by the diversity. Different populations may to some extent be definable by their pattern of dental morphology. This allows, for example, discussion of origins and relationships of ancient mammal populations, evolution of different morphologies, and the effects of domestication.

Dental diseases, injuries and anomalies (Chapter 5) are amongst the most common pathological conditions seen in archaeological remains. Teeth are used to gather and process food, and touch every particle of it that enters the body. They are strongly influenced, not only by the constituents of the food, but also by the behaviour of the animal. One important factor in dental disease is the wear of the teeth, and related changes in the form of the jaws through life. These are discussed in Chapter 4. Dental conditions are strongly age-related, so it is important to consider this aspect, but they can yield much information on the nature of the diet. Archaeological specimens may provide a pattern of diseases, both for humans and non-humans, for which it is hard to find modern analogues.

Growth and development are potentially of great interest, because the rate and pattern is affected by diet, health and the general environment in which an animal grows up. Generally, it is difficult to study growth in archaeology, because of the lack of an independent technique of age determination – age estimation in juveniles is based on growth-related changes, so it is easy to enter a circular argument. Teeth start at an advantage, because they appear to be less affected than the skeleton by environmental factors and, in any case, growth disruptions can be recognised as defects. Also unlike the bones of the skeleton, they are not continually replaced during life, and the dental tissues preserve a detailed record of growth as a series of layers, some of which record daily growth. This built-in clock can be used to calibrate a detailed record of growth during childhood, and its disturbances. In turn, such a sequence can potentially be used to calibrate bone growth in the skeleton of the same individuals. Chapter 2 describes the complex biology of enamel and dentine growth and the various techniques that can be applied to archaeological material to produce such detailed sequences.

Teeth are complex structures and, although this complexity requires a lot of work to learn, it is also what makes the dentition so information dense. As a class of archaeological finds, they usually repay the amount of effort put into study. At sites where bones are not well preserved and the artefacts are unexceptional, the resilient teeth may yield the most interesting results. Most people would not regard them as beautiful from an aesthetic point of view, but they take on a staggering array of different forms, many of them very stylishly sculptured. Who could resist, for example, the elegant upper molars of a rhinoceros, or the fine lines of microchiropteran bat teeth. Not to mention the astonishing intricacy of the complex-toothed squirrel *Trogopterus*, which probably has the most complicated teeth in the mammal world, and the computer-chip-like detail of *Napaeozapus*, which is difficult to believe when seen for the first time under the microscope.

1

TOOTH FORM IN MAMMALS

What is included

This chapter aims to introduce a wide range of tooth forms, to act as a starting point for identification of archaeological remains, items in museum collections, or zoological specimens. It includes only the teeth of mammals and confines itself to the Holarctic zoogeographical region, and the neighbouring oceans. The idea of dividing the main land masses of the world into broad faunal zones including a range of vertebrates and invertebrates is most strongly associated with Alfred Russel Wallace (1876). The Holarctic region runs in a band around the north of the globe, including Europe, North Africa, and the non-tropical parts of Asia, North and Central America. Various definitions are used and, in this book, the southern boundary follows the line given by Corbet (1978). In Africa, this includes only those countries with a North African coastline. In Asia, it includes the whole of Arabia, Iran and most of Afghanistan, the Himalayas and the high Tibetan plateau, lowland China north of the Hwang Ho river and all the Japanese islands except for the southernmost in the Ryuku archipelago. Together, the European, African and Asian part of the Holarctic comprise the Palaearctic region. The Nearctic part of the Holarctic includes the whole of Canada and the United States of America, together with the northern desert region of Mexico (Hall, 1981). In all, there are 59 families of mammals with members living in the Holarctic land area. Marine mammals are not included in the definitions of zoogeographic zones, but this book also covers nine families of sea mammals whose members approach the Holarctic shores near enough to be included in archaeological sites. In this chapter, geographical range within the Holarctic is denoted by codes:

EU	Europe
AF	North Africa
AS	Asia all areas
ASW	Mainland western Asia
ASC	Central Asia
ASE	Mainland north-eastern Asia
JA	Japan
AM	America all areas
AMN	North America
AMC	Confined to the very south of North America and northern Mexico
ARC	Arctic Ocean and neighbouring seas
ATL	Northern Atlantic and neighbouring seas

PAC	Northern Pacific and neighbouring seas
IND	Northern Indian Ocean and neighbouring seas
MED	Confined mostly to the Mediterranean and Black Seas.

Where the range applies to fossils, and the animal is today extinct in a region, the code is enclosed in parentheses [ ].

Why confine this book to the Holarctic? One of the main roles of teeth in archaeology is identification, particularly in small mammals where the bones are difficult to identify. To be useful, the range of animals included must be comprehensive, but a book this size cannot cover the whole world fully so it must concentrate on one region. Many Holarctic mammal families have wide ranges, with strong general trends in tooth form, and they therefore make it a practical proposition to cover comprehensively. Coverage is also confined to the Late Quaternary period, including the present interglacial and previous cold stage (glaciation), or roughly the last 120 000 years. This includes the majority of archaeological sites.

For comparative dental anatomy, the most useful level of taxonomy is the *genus*. In the majority of mammal families, genera can quite clearly be distinguished from one another by their teeth, but it is harder to define unambiguous identifying features for species, particularly as there is often variation at population or subspecies level. Readers are most likely to find the chapter useful as a starting point, to narrow down the possibilities for identification. Some genera are distinctive enough to be recognised straight away without difficulty, particularly if their geographical range is taken into account. Most, however, require consultation of a reference collection to be certain. The largest general collections at the time of writing are at the Natural History Museum in London, the American Museum of Natural History in Washington DC and the Field Museum in Chicago, but there are other important collections as well.

General structure

Teeth consist of two main elements; a *crown* and a *root* (or roots). The crown generally protrudes into the mouth and the roots are firmly held in the bony sockets of the jaws, but many variations on this theme are possible. Teeth with tall crowns may only show their tips, with more being exposed as it gradually wears away. Other teeth may not have a crown, so the root is the part that protrudes. What really defines the crown is its coating by a layer of hard, shiny *enamel*. The root and, in many animals, the enamel of the crown too, is coated with a layer of bone-like tissue called *cement*. Underlying these surface layers and forming the main structure of the tooth is a very tough and resilient tissue called *dentine*, familiar as the precious material ivory. Deep inside the tooth is the *pulp chamber*. In teeth with roots narrower than the crown, an extension from this runs, like a canal, down the centre of the root to emerge in a tiny hole, the apical foramen, at its tip. Within the pulp chamber in a living tooth is the *pulp* – soft tissue which includes the cells of dentine, the blood and nervous supply. Details of enamel, dentine and cement structure are given in Chapter 2.

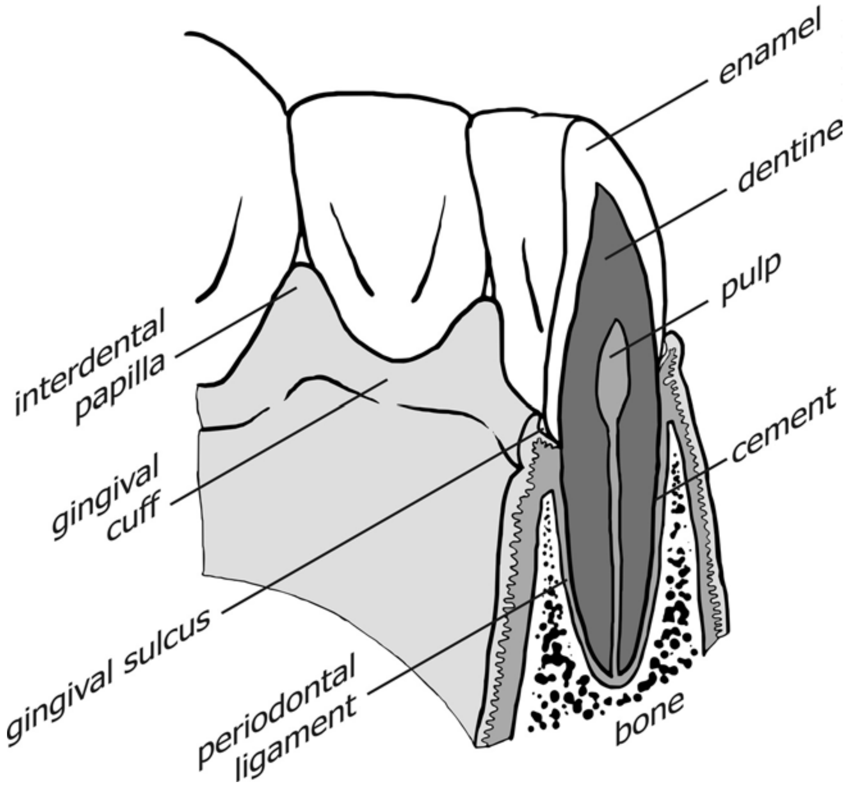

Figure 1.1 Tooth and periodontium.

All of these elements are present in even the most complicated tooth. The crown may be wider, taller or flatter. It may include extra mounds, known as *cusps*, or folds called *lophs*. Cement may cover the crown as well as the root, and there may be extra roots. The roots may become much enlarged, so that the whole tooth is composed of dentine and cement, as in the elephant's tusk. But even here, a tiny conical crown is present before the tusk becomes worn. Because of the basic uniformity in design, it is possible to apply the same terms to many types of tooth. The *coronal* end is towards the highest point of the crown. In the same way, the *apex* of the tooth is the extremity of the root and *apical* means towards this end. The *cervix* or *cervical* region is the point where crown and root meet.

Jaws, teeth and dentitions

Although in archaeology teeth are frequently found as isolated specimens, they form, along with the jaws and associated soft tissues, a complex living structure (Figure 1.1). Bone sockets (*alveolae*) are formed around the roots, and are lined with a thin layer of *alveolar bone*. Teeth are held into the sockets by a complex of fibres called the *periodontal ligament*, embedded at one end in the alveolar bone and, at the other, in the cement coating the tooth surface. A small amount of movement is possible at this joint and is important in the function of the teeth. Some animals have exceptionally mobile periodontal ligaments for some of their teeth. One example is the long, protruding canine of some small deer (p. 134), which visibly wobbles from side to side as the animal chews.

Tooth sockets are enclosed in heavily built bony jaw structures. This robustness is useful for archaeologists, because jaws and teeth are often preferentially preserved. The lower jaw in mammals is formed by paired bones called the *mandibles*. Many genera have a joint at the front, the *mandibular symphysis*, so that some flexibility is possible, or the bones may be fused together as one unit. The upper jaw is composed of the *maxillae* and the *premaxillae*. These are the bones that make most of the face, snout, jaws and palate. The extension in which the tooth sockets are contained is called the *alveolar process* in both jaws. Attached to the surface of the bony jaw structures is a complex of muscles. Some control the lips and tongue. Others are attached to the rest of the skull and drive the chewing mechanism. Inside the mouth cavity, these soft tissues are covered by oral epithelium which has a tough, keratinised surface not unlike skin. It is gathered up around the bases of the teeth as they protrude into the mouth as gums, or *gingivae*. At this point, there is a small space, the *gingival sulcus*, running around the tooth. Between closely packed teeth, the gingivae form a small hump, the *interdental papilla*.

Different types of teeth are arranged into rows and the complete set is called a *dentition* (Figure 1.2). In plan, the tooth rows form an arch or loop in each jaw called the dental arcade. Each tooth series is symmetrical on either side of the arcade, so that a tooth from the left side is almost a mirror image of the equivalent tooth on the right. As with the rest of the body, therefore, it is possible to divide the dentition into matching left and right halves, separated by an imaginary surface called the *median sagittal plane*. This gives rise to a useful terminology. For each tooth in the dental arcade, the side which faces along the arcade towards its origin at the median sagittal plane is called *mesial*. The side which faces the opposite way is similarly called *distal*. The side which faces inside the arcade, towards the tongue, is called *lingual* in this book and the side which faces outside, towards the cheeks and lips is called *buccal* here. Other names are frequently used, so that the lingual surface may also be called *palatal* for upper teeth and, properly speaking, buccal describes the side facing the cheeks (Latin *buccae*) so that dentists often use *labial* for the side of teeth facing the lips (Latin *labia*). This is a problem for a book on comparative dental anatomy because the distinction is fairly meaningless for many mammals. One possibility is to use another term, such as *vestibular* (the vestibule is the space between teeth, cheeks and lips), or *facial*. Many people, however, just use the word buccal in a general sense, and that is what is done here. The biting or chewing surface of the teeth, which faces teeth in the other jaw, is called *occlusal*. In sharp teeth, there is not really an occlusal surface as such, so it is usual to talk about its occlusal 'edge' or 'point' instead or, in the case of incisors, its *incisal* edge.