# A TAPHONOMIC STUDY OF SEAL REMAINS FROM ARCHAEOLOGICAL SITES ON THE WESTERN CAPE COAST

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## Abstract

A method of interpreting the seal body part representation from archaeological sites is presented and applied to three Holocene archaeological assemblages from the west coast of South Africa. The approach that is developed integrates several different methods that have previously been applied to terrestrial species, but that, with few exceptions, have not been employed in the analysis of seal remains. Most of the existing taphonomic indices cannot be applied to seals because of their unique physiology. Appropriate field observations and laboratory measurements are used to construct taphonomic indices that can be widely applied to seal bone assemblages. These include: a *hardness* index that mediates bone destruction through mechanical attrition, a *utility* index that mediates differential transport of body elements, and two indices that mediate the impact of carnivore ravaging - the *carcass consumption sequence*, and the *carnivore destructive template.* A new approach that caters for the simultaneous application of several taphonomic indices to an assemblage, where previously they have been applied individually or in pairs, is developed. In addition to the taphonomic indices, a method of determining ontogenic age is presented, and the potential limits of seal storage are explored.

A review of the ecology of the Cape Fur seal reveals the natural limitations that exist for sealing activities conducted without the use of boats. The availability of seals varies on an annual basis as a result of the breeding cycle, and this variability is manifest in the age and sex structure of the exploitable population. A method of determining the ontogenic age of seals from their mandible dimensions is established by regression analysis of mandible dimensions from modern, known age specimens. This provides a means of assessing the demographic characteristics of the archaeological seal population which addresses both the seasonality of sealing activities and the method of seal procurement.

In order to assess the extent to which the body part representation was determined by transportation logistics, a utility index was developed specifically for the Cape Fur Seal. Six carcasses of animals in various states of nutritional stress were dissected to establish the relative food utility of each anatomical element. The inter- and intra--carcass variability in food utility is negligible, and an index based on the average measurements, the Standardised Modified Bulk Utility Index (SMBUI), is established. To a degree the necessity to abandon elements because of transportation constraints is decreased by the ability to store seal meat. This also has an effect on the mobility of people where the driving force behind their movement is resource availability. Experimentation into storage in beach sand indicates that it is safe to store seal meat for up to two weeks by this method.

Two indices that mediate mechanical attrition are developed. Previously the bias in body part representation that this produces has been attributed to differential bone density or photodensity. Detailed consideration of the structure of bone and the mechanisms of bone destruction indicate that these indices are inappropriate, and an alternative based on hardness is presented. Hardness is measured by forcing an indenter of predefined geometry into the bone surface at a constant rate. The force required to maintain the penetration increases to a maximum and then decreases. The maximum force provides a quantitative measure of the bone's survival potential under uniform conditions of bone attrition such as crushing, while the gradient of the force/penetration curve provides a qualitative measure of the bone's survival potential under uneven conditions of bone attrition such as carnivore gnawing. The hardness indices are applied to assemblages created by jackals and brown hyaenas, and are shown to be adequate mediators of this type of attrition.

Jackals, brown hyaenas and dogs are the most likely carnivores to have modified seal assemblages in the past. Observations of jackals and hyaenas made on the Black Rock, Wolf Bay and Atlas Bay seal colonies in Namibia are used to establish the potential role of these carnivores. Hyaenas are unlikely to have competed with humans for seals directly because they are nocturnal and they eat the seals that they obtain in their entirety. Jackals are more diurnal and are slower consumers of their prey. The carcass consumption sequence represents the order in which jackals consume seals as derived from 17 abandoned carcasses using the statistical technique of Guttman scaling. This index indicates the elements of the seal anatomy that are likely to be underrepresented if people scavenged for seals in competition with the jackals.

Two jackal kitchen middens consisting almost entirely of seal bones were excavated at the Black Rock colony. In conjunction with two hyaenas den assemblages reported in the literature, the idiosyncratic impact of carnivore ravaging on the seal skeleton is identified. Small bones are underrepresented relative to what is expected on the basis of their hardness. This trait is extrapolated to indicated the impact of large and medium sized carnivores on any seal bone assemblage. One of the jackal kitchen midden assemblages is used as a "typical ravaged assemblage" and the body part representation is defined as the carnivore destructive template.

The ageing technique, storage potential and all of the foregoing indices are combined to provide a taphonomic approach to the analysis of seal remains from archaeological sites. The taphonomic approach is applied to the seal bone assemblages from three sites on the Cape west coast in order to establish the extent to which a maritime adaptation existed during the Holocene in southern Africa. The early Holocene assemblage from Elands Bay Cave does not conform to any taphonomic scenario, and it is suggested that during the occupation it was an inland site where seals were obtained through trade. To the extent that this represents an adaptive economic strategy, the late Holocene assemblages from Elands Bay Cave and the nearby Dunefield Midden represent a highly adaptive strategy. Occupation coincides with the season during which abundant dead seals wash up on the beaches. The evidence for dog ravaging on the seal bones at Dunefield Midden that is not found in the upper Elands Bay Cave assemblage may indicate the co-existence of different economic strategies such as hunting and gathering versus pastoralism, but the overriding strategy at this time was to occupy the coast when seal returns were high. The seal assemblage from Kasteelberg B indicates poor utilisation of seals as a resource. Hunting was concentrated in the autumn and spring which is believed to coincide with the arrival and departure of pastoralists in the area. Evidence of carnivore ravaging of the seal bones is consistent with the keeping of dogs and with a pastoral economy. The age (mortality) profiles for the Kasteelberg B seals indicate mass hunting at a breeding colony during the breeding season. Such a practice cannot be sustained, and it is concluded that the inhabitants did not practise a maritime adaptation associated with sealing, but rather a terrestrial adaptation associated with the keeping of domestic stock.

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I met my mates in the morning (and oh, but I am old!)
Where roaring on the ledges the summer ground-swell rolled;
I heard them lift the chorus that drowned the breakers' song -
The Beaches of Lukannon - two million voices strong!

The song of pleasant stations besides the salt lagoons,
The song of blowing squadrons that shuffled down the dunes,
The song of midnight dances that churned the sea to flame -
The Beaches of Lukannon - before the sealers came!

RUDYARD KIPLING '*The White Seal*'

# CHAPTER 1

# INTRODUCTION

## Introduction

Some of the earliest evidence in the world for the exploitation of marine resources is found in the Middle Stone Age middens along the coast of southern Africa (Singer & Wymer 1982, Klein 1977). Absolute dating of these shell middens is difficult but it is believed that some of them were deposited more than 100 000 years ago (Perlman 1980, Avery & Siegfried 1980). Recent shell middens are also found along this coast, and it is possible that they are the end expression of a continuous tradition of marine exploitation from the earliest times. The continuity is difficult to prove because "Ice Ages" occur on this time scale and the resulting sea level changes have drowned and destroyed many Pleistocene coastal sites. The South African evidence contrasts with that in Europe and the New World, where regular utilisation of marine resources did not commence until the Holocene, and in many of these areas it only began in the last 5000 to 7000 years (Perlman 1980). Australia is the only other region in which the relatively early adoption of marine exploitation, perhaps as early as 40 000 years ago, appears to have occurred (Bowdler 1977).

In many regions around the world the utilisation of marine resources remained an ephemeral part of the larger hunting and gathering and (later) agricultural economies, but in others it led to a unique form of coastal adaptation. Semi-sedentary communities that relied almost exclusively on marine resources developed in Scandinavia, northern Canada and the American Pacific North West. The earliest inhabitants of Japan and the South Pacific islands colonised the region by boat which implies a high level of maritime adaptation, and archaeological analyses of sites on these islands show that marine resources were a principal component of their diet. In Peru the maritime economy is believed to have played a major role in the development of complex societies (Moseley 1975, Yesner 1980). These examples contrast with developments in Africa, and in particular southern Africa. Although marine exploitation began here, it did not develop into an advanced coastal adaptation or complex society.

The spread and subsequent development of marine utilisation poses several questions. Why was the incorporation of marine resources into the diet delayed in some areas, while in others it was quickly adopted; and what are the factors that influenced the extent to which a specifically coastal adaptation occurred? The intertidal zone is substantially more productive than most terrestrial environments (Yesner 1980), and the Benguela upwelling region off the Cape west Coast is one of the most productive marine habitats in the world. Why did the historical tradition of marine exploitation not lead to a more explicitly maritime adaptation based on this vast resource?

Part of the problem lies in the definition of a "maritime culture". The emphasis of marine resources in the economy is certainly a feature of a maritime culture, but this does not necessitate the establishment of state hierarchies or monumental architecture. The absence of these traits in the southern African coastal setting does not imply that a successful coastal adaptation did not exist. Agricultural economies are based on a substantial labour investment that results in surplus food production, but pastoral and hunting and gathering (land and marine resources) economies are based on resource management and sustainable utilisation practices. Although there has to be some investment in managing domesticated animals, the same does not apply to most marine resources. They are there to be harvested and as such they have been termed "unearned resources" (Yesner 1980:729). While there was very little that Stone Age people could do to increase the productivity of the marine environment, there was a great deal that they could do that would reduce its productivity. The extent to which a coastal adaptation or maritime culture can be said to have existed depends on the sustainability of the management policies that were practiced. It is possible that the emphasis on human behaviour in archaeological reconstructions has directed attention away from the delicate balance that existed between the resources and the people that used them, and so the notion of a coastal adaptation has either been ignored or assumed to have taken one unspecified form or another. The oversight is not trivial because the ecology of the marine resource base, even in the rich upwelling regions of the world, is not that robust that it can withstand any level of exploitation.

The archaeological recognition of a maritime cultural adaptation based on the above definition requires two lines of evidence. It is necessary to identify characteristics of human behaviour, such as seasonal mobility, duration of exploitation and also the procurement strategy that were employed, and second the impact that the behaviour had on the prey species must be considered. The evidence that has been preserved on archaeological sites, usually shells or the bones of fish or marine mammals, has to be used to address both of these aspects. To reconcile the two arguments without introducing an element of circularity, it is necessary to develop an interpretative model that integrates both of the elements. The research presented in this thesis is aimed at providing precisely such a model. It approaches the impact on the resource from an ecological perspective, and similarly it places the human behaviour into an ecological context. The two are then brought together to form a single predator/prey ecological relation that can be used to assess archaeological remains. The way that the archaeological evidence is assessed is through a number of taphonomic indices that are developed specifically to differentiate between different taphonomic scenarios. Each of these scenarios is a function of the predator/prey relation that existed in the coastal setting.

The model deals specifically with the exploitation of seals. In southern Africa whaling and fishing were constrained by the ignorance of boats prior to the colonial period, and the other main marine resource - shellfish - does not provide a great deal of behavioural diversity that informs about resource utilisation strategies. Instead of analysing diverse lines of evidence from a single location, the emphasis is on a single resource (seals) at a number of localities.

The model for seal exploitation is applied to the faunal remains from three sites on the Cape west coast. The conclusions that are reached are informative from the perspective of constructing past coastal adaptation strategies, but they also make a substantial contribution to the construction of past human ecology.

## The role of seals in maritime cultures

The development of a long term economic adaptive strategy by any community depends on the reliability of the resources that are utilised and the sustainability of the exploitation practices. Marine resources are more reliable and more concentrated than their terrestrial counterparts, especially in environments that are marginal for hunting and gathering based economies. Seals are a particularly important component of the repetoire of marine resources. The species that is found along the coast of southern Africa, the Cape Fur Seal or South African Fur Seal (*Arctocephalus pusillus*), is a very predictable resource in time and space. Every year they aggregate and disperse as a result of their breeding ecology. They are also very successful breeders so they are able to withstand a high cropping rate. In contrast to other marine mammals, such as whales, advanced technology (boats) is not required to obtain them. Many dead seals wash up on the shore, and other individuals that come ashore to rest can be dispatched with little more than a club. They are not of a very aggressive disposition in general and to catch small seals on the land does not even require an implement as simple as a club. They are slow and clumsy and they can be caught by the hind flipper and held at arms' length without a very high risk of being bitten (although the bite that they can inflict is very serious). They provide a large amount of meat, but the most important attribute is the quantity and quality of the fat that occurs in a sub-cutaneous blubber layer. The pelt is also a desirable resource that formed the basis of a large fur industry and almost led to the demise of the species at the hand of European sealers during the 17th and 18th centuries.

The predictability of marine resources makes it possible to schedule their exploitation. This applies from day to day scenarios such as the timing of shell fish collecting to coincide with low tide, to annual scenarios such as the predictable returns from anadromous fish migrations. The returns from sealing in southern Africa (without the use of boats) is also variable throughout the year, but the variability is predictable. The scheduling of marine resource utilisation is a fundamental aspect of a coastal adaptation. It may be the case that certain resources can be used throughout the year, while others cannot, but the fundamental issue in the human adaptation to the coastal biome is that they adjust their behaviour to accommodate the nature of the resource availability.

Another characteristic of any economic adaptation is the maximisation of returns from the available resources. A consequence of this would be increased productivity, and increased population carrying capacity. This in itself would be sufficient driving force for the development of a "maritime culture" from the basis of a coastal adaptation. There are two factors that limit the exploitation. The first is the replacement rate of the resource and the second is the risk involved in the exploitation. This presents a dilemma because the resources can often withstand elevated levels of exploitation, but the risks involved in harvesting them at the maximum sustainable level become significantly greater. This is especially true of sealing in southern Africa. Most of the seal colonies are on offshore islands, but they are within sight of the coast. Space is the limiting factor in their breeding success, and so the exploitation of these island colonies would result in space being available to other animals that would otherwise not have bred. The constraint in the exploitation of this vast resource was the risk factor. Swimming to the islands is possible, but it represents a very high risk. It is surprising that a technological solution to this problem (the use of boats or rafts) apparently did not take place.

The marine resources off the Cape west coast are substantial, but without the use of boats the prehistoric inhabitants of the area were unable to gain direct access to them. The pelagic fisheries were entirely beyond exploitation, as were the whales and dolphins that frequent the region. The stranding of whales and dolphins may have occurred regularly (Smith 1993), but these events were unpredictable. The only marine species to which the people were able to gain predictable and regular access were those at or near the shoreline. There is, nevertheless, still a substantial resource base upon which a coastal "culture" could have developed. Besides seals, it is not difficult to obtain rock lobsters, sea birds, shellfish and even fish with the minimum of technology. The most important of these is probably seals because of their fat yield - a resource that is extremely rare in the adjacent terrestrial resource base. The aim of this research is to test the extent to which seals were exploited as part of a coherent coastal adaptation among the Stone Age people of the west coast of southern Africa.

## Holocene sealing on the western Cape coast

Three archaeological assemblages from sites on the Cape West coast are analysed. The sites are Elands Bay Cave and Dunefield Midden from the Elands Bay area, and Kasteelberg B on the Vredenberg Peninsula (figure 1.1). Each of the sites forms part of ongoing research projects in the Department of Archaeology at the University of Cape Town. I participated in the excavations at both Kasteelberg B and the Dunefield Midden, and although the Elands Bay Cave excavations were complete before the commencement of this research, I was involved in the analysis of some of the stone artefacts from the site. There are several other sites on the west coast that have produced seal remains, but none of these is as important as any of the three sites that are the focus here.

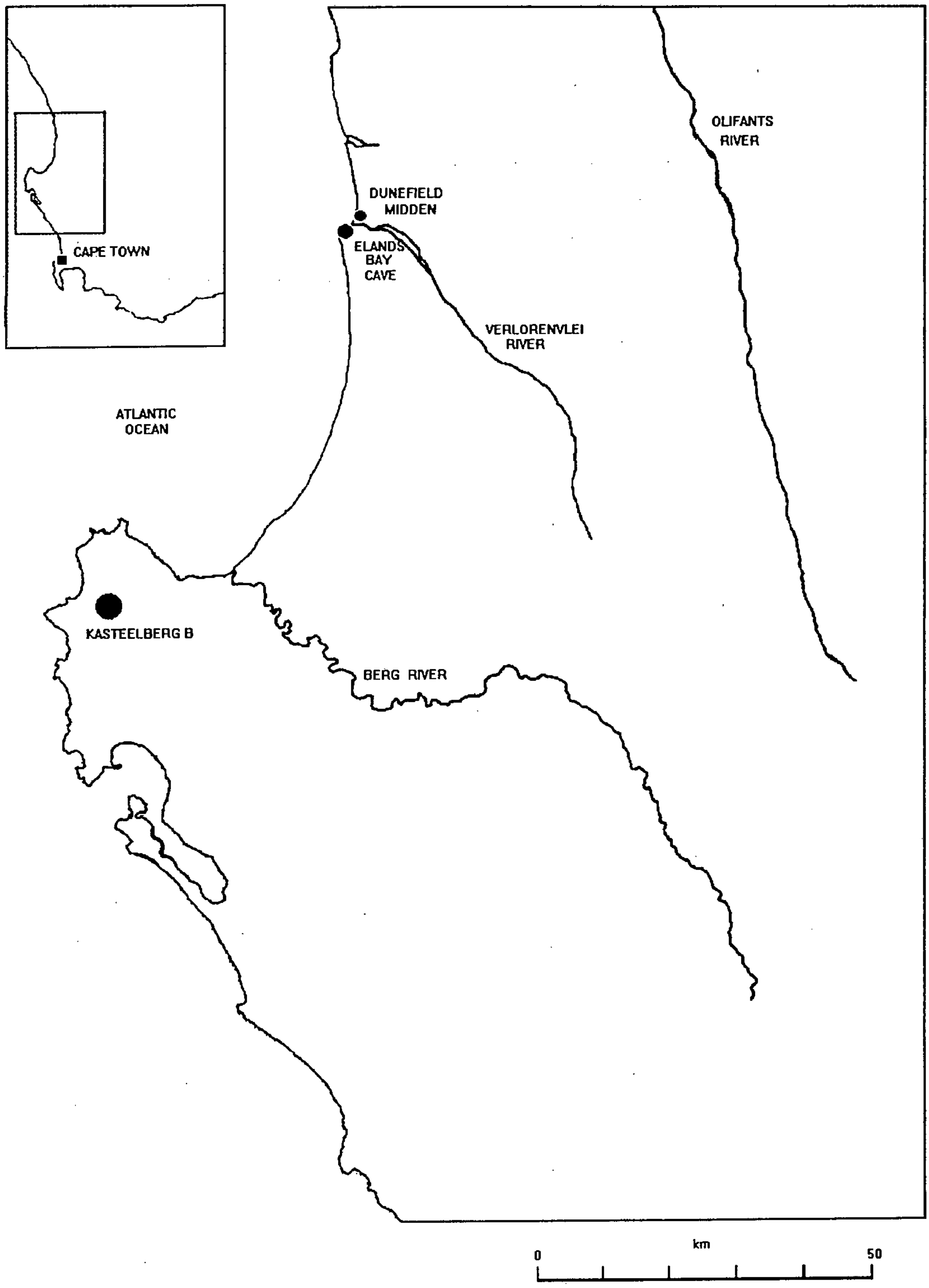

**Figure 1.1** *Map showing the location of sites on the Cape west coast, South Africa.*

### 1. Elands Bay Cave

Elands Bay Cave is located in a cliff overlooking the coastline immediately south of the settlement of Elands Bay. It was excavated by Parkington as part of a wider project aimed at determining past seasonal transhumance and land use patterns in the area (Parkington 1972, 1976, 1981). The earliest deposits contain Middle Stone Age stone artefacts and are older than 40 000 years, but the bulk of the excavated sample was deposited after the last glacial maximum. At this time (approximately 18 000 years ago) the sea level was substantially lower (Miller *et al.* 1995) and the site was probably several tens of kilometres inland. Marine elements, including seals, were first introduced into the deposit about 12 000 years ago, and by 9 000 years ago the deposit is a typical shell dominated coastal midden (Parkington 1986, Klein & Cruz-Uribe 1987).

The cave seems to have been abandoned between 8 000 BP and 4 000 BP, and again between 3 000 BP and 1 800 BP. The latter hiatus is related to a distinctive trajectory in the location and density of sites in the Elands Bay area through time (Parkington 1986, Parkington *et al.* 1988). Caves were the preferred site of occupation until approximately 3 000 BP when the emphasis shifted to the vast mussel dominated "megamiddens". At approximately 1 800 BP occupation shifted to many smaller rock shelters, and shell middens became numerous but ephemeral. At this time there was an increased incidence of ritualistic rock art, and ceramics and the bones of domestic animal species appear in deposits for the first time (Klein 1986*a*, Klein & Cruz-Uribe 1987, Parkington 1986, Parkington *et al.* 1988). The nature of the food parcels represented on the sites also changes. There is a shift towards more intense exploitation of a wider range of small reliable food items. This undoubtedly relates to the appearance of pastoralists on a landscape that previously was the exclusive domain of hunter gatherer societies (*ibid.*) The nature of the interaction between the hunter gatherers and pastoralists is believed to have been exclusive and confrontational by some (Parkington 1977, 1984, Smith 1990*a*, 1990*b*, Smith *et al.* 1991) although others do not agree (Elphick 1977, Schrire 1980, 1984, 1992, Schrire & Deacon 1989). According to Parkington the whole post 1 800 BP package at Elands Bay reflects a society under stress, maintaining a high degree of mobility to ensure its survival.

Elands Bay Cave is one of the key sites in Parkington's seasonal mobility hypothesis (Parkington 1972, 1976, 1977, 1981). On the basis of seasonal indicators recovered from this site, and sites in the adjacent interior, he proposed that the coast was exploited during the winter months. During the summer the occupation shifted to the Cape Folded Mountains. Part of the evidence was the age of the seals that were recovered. This analysis has been revised in this thesis.

### 2. Dunefield Midden

Dunefield Midden is a site located in an active dunefield immediately North of the Elands Bay settlement. The area contains many campsites that were seldom reoccupied, and that were well preserved under the wind blown sand. The result is that the spatial and temporal resolution at this site is very high (Parkington *et al.* 1992). The occupation took place approximately 650 years ago, but there are also remnants of two other campsites, one dated to 950 BP and the other to 500 BP that overlap the Dunefield Midden deposit. The excavations at the site began in 1988, and are expected to end in 1995.

Dunefield Midden does not share the same advantageous proximity to a diversity of marine resources that Elands Bay Cave has. It is approximately 600 m from the shoreline which is a sandy beach at the North end of the bay that gives the area its name. The nearest rocky intertidal zone is approximately 2 km south of the site at the mouth of the Verlorenvlei. The midden itself is still dominated by limpets and mussels that live on a rocky substrate, and crayfish were consumed in exceedingly large quantities. The site also contains the remains of many seals, and in the sample collected prior to 1991 a minimum of 33 individuals had been identified (Cruz-Uribe & Klein 1994). As is the case at Elands Bay Cave, the mammalian fauna from the Dunefield Midden is dominated by seals.

The timing of the Dunefield Midden occupation coincides more or less with the recent occupation levels at Elands Bay Cave. The radiocarbon dates and the presence of ceramics on the site confirm that it was occupied after the arrival of pastoralists. A comparison between the exploitation strategy at the Dunefield Midden and both the pre- and post- ceramic layers at Elands Bay Cave will indicate whether the exploitation strategy that was practiced by the hunter-gatherers was disrupted by the arrival of pastoralists on the landscape.

### 3. Kasteelberg B

The third site that is analysed is Kasteelberg B. It is located on a prominent hill topped with massive outcrops of granite boulders on the Vredenberg Peninsula approximately 60 km south of Elands Bay. It is the largest of 6 sites that have been found on the hill, and one of 4 that have been excavated (Sadr & Smith 1991). The excavations were conducted by Smith as part of a study into the pastoralist economy in the western Cape (Smith 1984*a*, 1984*b*, 1986, 1987*a*, 1987*b*, 1990*b*, 1992). Excavations reached a maximum depth of approximately 1.7 m, and 16 stratigraphic layers were recognised in the sequence. These are divided into three occupation levels on the basis of radiocarbon dates and ceramic seriation (Sadr & Smith 1991). The bottom level, layers 16-12, was occupied between 1 300 BP and 1 100 BP. The most intense occupation of the site was between 1 000 BP and 880 BP which resulted in the deposition of layers 11-2. The top level, layer 1, is dated to approximately 200 years ago and represents an ephemeral occupation during the colonial period. It is not clear if the occupants at this late stage shared the same culture and economy as the people that were responsible for the rest of the deposit.

Although the coastline is 4 km away, the Kasteelberg B deposit is a shell dominated midden and the faunal assemblage is dominated by seals. The bones of cattle are present and domestic sheep are well represented (Klein & Cruz-Uribe 1989). This, together with the high frequency of pot sherds (Sadr & Smith 1991), has led to the conclusion that the site was occupied by pastoralists, and that it functioned as a stockpost and sealing station (Klein & Cruz-Uribe 1989). The season during which the site was occupied has been inferred from the seal and sheep remains (Klein & Cruz-Uribe 1989). The evidence from the sheep is based on the rate of wear on the deciduous $P_4$ tooth, and from the seals it is based on the growth of the humerus. The conclusion is that occupation was during the late winter and early spring.

The faunal remains from Kasteelberg B also document subtle changes that occurred in the pastoralist economy during its relatively short existence at the Cape. The domestic animals in the bottom level are dominated by sheep rather than cattle with a ratio of 10.2:1. This changes in the middle level to a ratio of 4:1 and to 1.4:1 in the top level (Smith 1987*b*) although a decrease in the number of sheep rather than an increase in cattle may be the cause. The shift in emphasis from sheep to cattle is also found at the Die Kelders site on the southern Cape coast (Klein 1986*a*), although the herd and flock management policies that were adopted may be as important in determining this pattern as a shift from a sheep-based to a cattle based economy (Klein & Cruz-Uribe 1989).

The faunal remains from each of the three sites were analysed by Klein and Cruz-Uribe (Klein & Cruz-Uribe 1987, Klein & Cruz-Uribe 1989, Cruz-Uribe & Klein 1994). Because seals are the most important of the mammalian species represented at all of the sites, the patterning in the seal bone representation has been central to many of the conclusions that are made on the basis of the fauna. Unfortunately there are instances where the analysis of seal bones is hamstrung by lack of fundamental taphonomic information. The major component of this project is to provide the taphonomic information that is required to obtain a complete picture of past seal exploitation. Many of the taphonomic indices that are developed are entirely new, or are presented specifically for the Cape Fur Seal for the first time. Although there are some points of disagreement, the research that is presented here is aimed at complementing the results of Klein & Cruz-Uribe. The basic species identification and body part analysis that are used in this project are derived from the results that were generously made available by Klein & Cruz-Uribe.

## Objectives

The aims of this research are: first to provide a means of analysing seal remains. The objective is to make it possible to assess if the exploitation that occurred in the past was part of a coherent coastal adaptation on the Cape west coast. There are a number of fundamental observations about seals that are required to achieve this end, and these are presented first. In attempting to outline the nature of seal exploitation at the sites described above, a number of other issues that are debated by archaeologists are also considered. Among others these include the seasonal transhumance patterns and cultural identity of the western Cape inhabitants over the last 2000 years. A large part of the methodology that is employed in this thesis has previously been used in Pleistocene archaeology where a central issue is the development of the ability of hominids to hunt. Consequently the distinction of hunting versus scavenging of seals can be addressed in the Holocene, although the implications of the mode of procurement are different from the Pleistocene context and will be explored from a different perspective in this thesis.

The second objective in this research is to provide an approach, and the means to implement the approach, for studying seal exploitation at other sites. In this regard the taphonomic indices are not only designed for my application, but for the use of all those with an interest in studying seal exploitation.

The third and final objective is to present an analysis that contributes to the way in which faunal analysis is conducted in general. By focusing on a single species it is possible to achieve a level of detail in the analysis that is often not possible when studying the entire range of species that is present in an assemblage. This presents a framework for future research into the analysis of other species.

## CHAPTER 2

## THEORETICAL BACKGROUND

### Introduction

Bone assemblages are assumed to be invariable entities within the limits set by preservational factors, but patterns within assemblages may be interpreted in many ways. Different analysts often have different explanations for the same evidence because of differences in their knowledge and experience. Differences may also arise when the same evidence is used to address different research problems, or when different theoretical perspectives are adopted to address the same problem. The meaning of an assemblage is not inherent in the bones and it cannot be determined by studying the bones alone. It is necessary to impose some accepted knowledge that relates the observations to the interpretation.

Early analysts used observations made in the fields of zoology, botany, ecology and, more recently, chemistry to explain the patterning that they observed in the assemblages. The resulting reconstructions emphasised past environments, diet breadth and attempts were even made to reconstruct procurement strategies. While the information that was borrowed from other disciplines was often of some relevance, it was seldom an exact parallel for archaeological applications. In the last three decades archaeologists have ventured into the related disciplines in order to make precisely the types of observations that they require. The result is an epistemology that allows the reconstruction of aspects of past behaviour in greater detail than was previously possible.

The epistemology that has emerged is of interest because it defines the limits of what can be achieved. First, it prescribes the types of questions that can successfully be addressed by studying faunal remains, and second it outlines a mechanism or approach for testing the interpretations. To avoid generating and perpetuating falsehoods, research should be conducted according to an explicit philosophy and methodology that is open to scrutiny by others. The epistemology that is used in this thesis is the product of approaches that were tried in the past, scrutinised, criticised, modified and that have eventually attained a level of acceptance. The process does not end here. There are detractors from what is presented here, and even among the adherents to this approach there will be criticism. The future will undoubtedly see further improvements taking place in this field of endeavour.

The epistemology involves the use of innovative and dynamic analogies with the present. Instead of elucidating cause and effect to explain the nature of an assemblage, the relations between different causal mechanisms are used as clues to a broader concept of *process*. A process is a series of interlinked events or occurrences that have some tangible effect that is preserved in the archaeological record. The main thrust of the new approach is in the use of relational as opposed to formal analogies (Gifford Gonzalez 1989, 1991). Whereas formal analogies often rely on uniformitarian cause and effect relations founded on physical, chemical or mechanical principals, processes are dependent on the spatial and temporal interrelations between formal analogies. In other words a set of interconnected phenomena that co-occur in the present are assumed to have occurred in the past.

The interdependence of phenomena in the present is closely linked to ecology, and it is in the reconstruction of human ecology that the new approaches have made a major contribution. Although seals played an important role in the economy, and therefore the ecology, of coastal hunter gatherers in many parts of the world, they have largely been excluded from these developments. The result is that the interpretative framework for this species is deficient in many respects. A large part of this thesis is devoted to the synthesis of a comprehensive set of comparative observations that together redress the balance and provide an interpretative framework for archaeological seal bones. Many observations that are presented here for seals are available for some other species, but in very few instances are all the indices available for a single species.

A brief review of the development of this approach to faunal analysis is presented below. Wherever possible the developments are illustrated with examples from an African or South African archaeological context.

## Review

Most of the developments that have taken place in faunal analysis during this century were the result of controversial claims that offended certain sectors of society. The reaction to scurrilous reports was inevitably an attempt to discredit the findings. Inadvertently this also led to the development of better ways to approach the relevant subject. One of the earliest behaviouralist reconstructions was Dart's analysis of the Makapansgat Cave faunal remains. From 1925 fossilised bones were recovered from the lime works at this site and forwarded to Dart. One of the finds to which Dart attributed much importance was the skull of a hominid that he called *Australopithecus africanus.* He challenged the traditional association of such bone concentrations with the activities of carnivores, in particular - hyaenas (Buckland 1822). Instead he felt that the bones reflected the behaviour of *Austalopithecus,* suggesting that the carnivore notion was based on 19th Century antediluvian psychology and religious dogma (Dart 1956).

Dart published a series of articles in which he outlined the "osteodontokeratic culture", or bone tooth and horn culture, of *Austalopithecus africanus.* He proposed that a "Bone Age", in which skeletal material was used for implements in much the same way that stone was used in the subsequent Stone

Age, was represented at Makapansgat. The behavioural theme was based on three lines of evidence. First a collection of baboon and *Australopithecus* skulls showing damage that was attributed to violent predatory (cannibalistic) habits of *Australopithecus* (Dart 1949). Second the damage to the skulls appeared to have been inflicted with bone clubs. This implemental use of bone he expanded to include the manufacture or utilisation of many bone tools (Dart 1959*a*, 1959*b*, 1961). Dart's third line of evidence was the abundance of particular skeletal elements and the rarity of others that, he argued, was caused by the selection by *Australopithecus* of elements for tool manufacture (Dart 1957*a*, 1957*b*).

Dart's hypothesis was innovative in many ways. The notion of prehistoric bone tool manufacture had been used in other contexts from the turn of the century (see Binford 1981 for a review of this), but Dart based his interpretation on the *use* of bone tools by *Australopithecus.* South African archaeology was dominated by environmental and lithocentric studies, and key aspects of faunal analysis, such as taphonomy, were only being presented for the first time (Efremov 1940). It was not before the 1960's that the significance of taphonomy was to be fully appreciated (Olsen 1980), and many of the shortcomings that emerged in Dart's work can be seen to result from inadequate attention to such details.

The main misgiving with the hypothesis was that Dart had not adequately excluded other factors that may have caused the patterning in the Makapansgat assemblage. Washburn (1957) and Oakley (1957) both suggested that they could be attributed to carnivores. Washburn's reasoning did not follow that originally presented by Buckland, instead he based his objections on observations of carnivores in the Wankie Game Reserve. He proposed that the anatomical body parts represented at Makapansgat were similar to those available to scavenging carnivores in natural circumstances, and that the presence of fossil hyaena coprolites on the site indicated that they were the most likely accumulators of bones. Dart had considered the role of carnivores, and he relied on the observations of Hughes (1954) to substantiate his belief that hyaenas did not accumulate bones in their dens. Based on this he claimed that they were not capable of accumulating the estimated 1 million bone fragments representing approximately 60 000 animals at the site (Dart 1949, 1956, 1958*a*). Dart also dismissed the role of porcupines in the generation of bones that could be mistaken as tools (Singer 1956) by arguing along similar lines (Dart 1958*b*).

These studies represent a milestone in the development of taphonomy in that, for the first time, bone accumulations were considered to be the end product of processes that could be observed and understood in their modern context. This did not invalidate archaeological testing of hypotheses. While the osteodontokeratic controversy was developing, White (1953*a*, 1953*b*, 1954, 1955) suggested that the deviations from anatomical parity of bones from palaeo-Indian sites in the New World were the result of biased introduction of bones to the site and differential destruction of certain elements in the butchery process. Although bone selection for tool use was considered, he emphasised the difference between bones that would be left at a kill site and those that would be transported to a home base. Excavations of complimentary bison kill sites (Kehoe 1967, Wheat 1967) provided a test that did not altogether support White's predictions. In the case of Makapansgat, where most of the contextual information was lost through mining activities, the identity of the primary accumulators was never categorically resolved (Wolberg 1970).

The osteodontokeratic controversy demonstrated that it was not necessary to restrict faunal analysis to the identification of the species and bones present at a site. Answers to questions such as "How did the bones come to be the way they are?" could be attained provided unambiguous characteristics of the assemblages could be identified. The way in which Dart argued his point was innovative in the context of archaeological paradigms at the time, and the critical debate on the subject provided an important catalyst in the development of faunal analysis in southern Africa. The answer to "how did it come to be?" was to see the archaeological fauna as the end product of a process, and the seeds of processual archaeology were sown.

## The development of mechanistic taphonomy 1960-1980

### Processual archaeology

One of the most enlightening advancements in taphonomy that emerged from the osteodontokeratic controversy was presented by Brain. He showed that the alterations in the body part representation of goats after human (Hottentot) culinary practices and carnivore ravaging were dependent on the density of the bone and the age of fusion of long bone epiphyses (Brain 1967, 1969). The resulting body part representation was similar to that of the Swartkrans bone assemblage that was also associated with the remains of *Australopithecus.* Brain proposed that the patterning was not a function of the collector or the selection of certain bones for tool manufacture, but was related to the inherent ability of bone to survive attritional processes. At Makapansgat these processes may have obscured the original behavioural signature, and so it cannot be demonstrated that *Australopithecus* did not use bone tools (Read-Martin & Read 1975), but the challenge to the archaeologist is to decisively prove whether they did or not.

During the 1960s, further middle and lower Pleistocene sites containing protohuman fossils were being discovered in other parts of Africa (Isaac 1971, Leakey 1971). Much of the evidence indicated that the "killer ape" image associated with Dart's behavioural reconstruction was incorrect. Could it be true that early human ancestors obtained meat by scavenging? At the same time a debate was developing over the existence of a pre-Clovis (pre-stone tool) bone technology in the New World (Frison 1970). Observations that could be used to test whether such pre-Clovis bone assemblages were attributable to the activities of people or to "natural agencies" (e.g. carnivores) were required. Altogether the need for a comparative basis to unequivocally establish the significance of these sites provided the impetus for the development of taphonomic theory into the 1970s.

The comparative processual approach that began with Dart and Washburn and that Brain had perfected became entrenched, and aspects of site formation processes and low level behaviour were characterised through a diversity of actualistic studies. These included studies on bone tool manufacture (Sadek-Kooros 1975, Stanford 1979, Johnson 1983, Davis 1985), bone pseudotool generation (Sutcliffe 1973), wear on stone tools after use under different circumstances (Keeley & Toth 1981), differential water transport of bone (Boaz & Behrensmeyer 1976, Hanson 1980), carnivore and other "natural" bone accumulations (Hendy & Singer 1965, Sutcliffe 1970, 1973, Bonnichsen 1983, Behrensmeyer & Dechant-Boaz 1980, Brain 1980, Haynes 1981, Bunn 1983*a*, Hill 1983), bone destruction by carnivores (Binford & Bertram 1977, Hill 1979*b*, Brain 1980, 1981, Haynes 1980, 1983) and through weathering (Tappen 1969, Tappen & Peske 1970, Behrensmeyer & Dechant-Boaz 1980, Behrensmeyer 1978, 1983) and natural processes of carcass disarticulation (Hill 1976, 1979*a*, 1979*b*, Hill & Behrensmeyer 1984, 1985).

Just as Brain had established that bone survival was related to bone density, the physical characteristics of bones were used to establish diagnostic signatures for the occurrence of a variety taphonomic processes. The majority of the studies were based on "mechanistic" processes that provided useful insight into site formation processes. Using these it was possible to test the integrity of an assemblage with respect to certain factors. Where diagnostic criteria for activities were established, the implications for behavioural reconstructions were largely limited to low level behaviour (Blumenschine 1988*a*). Instead of facilitating significant advances in behavioural reconstructions, the early studies of taphonomy limited the scope of interpretations in many instances by identifying overriding non-cultural patterns that obscured the behavioural signatures. Indeed it was possible to show that many interpretations were based on false assumptions regarding the integrity of assemblages, but by emphasising retrospective applications archaeologists were slow to realise the predictive potential that such studies held. The basic taphonomic principles, that were based on the dynamics of analogous processes in the present, were largely inflexible in their application to archaeological problems. From about 1980 a new approach began to be adopted, an approach that has become known as the *actualistic* approach.

### The development of ecological taphonomy 1980-1990

While mechanistic taphonomy was flourishing, ethnographic studies of modern hunter gatherer societies such as the San (Marshall 1965, Yellen 1977), the Hadza (Woodburn 1968), and of other societies with lifestyles that are rooted in the past such as the Dassanetch (Gifford 1980), and also of primate studies (Goodall 1960) came to be used in relating behavioural processes to artifactual remains. Besides providing a corpus of behavioural analogues, the qualitative and quantitative characteristics of residues from intricate multicomponent processes were shown to be too complex to be modelled using the lawlike taphonomic templates. The overprinting and differing contribution of factors such as carnivore ravaging and differential transport had to be holistically considered, and anthropological and primate studies provided the perfect forum to do this.

Several innovative studies in taphonomy have extended the basic premise of processual archaeology to use human ecology, carnivore ecology and prey ecology as *processes* to address higher levels of past behaviour. Although these were not carried out under a particular pennant of research, I have afforded them some distinction under the banner of ecological taphonomy.

### 1. Human ecology

The "laws" of taphonomy that were prolific in mechanistic scenarios, were slow to evolve from the ethnographic literature. There can be little doubt that the most significant exception in this regard was that by Lewis Binford. During the 1970s he undertook ethno-archaeological research among the Eskimos of northern Alaska. He identified the principle factors that determined the destiny of bones from the point at which an animal was killed, to the point at which the remaining bones were finally discarded. Binford's most extraordinary claim was that the differential treatment of various anatomical parts was a function of the different food values represented by each. He measured the fat, meat and bone grease yield of each anatomical unit and combined them into a measure of their "utility". The values, normalised on a scale of 0-100, constituted the "general utility index" (GUI). After further consideration Binford accounted for the fact that certain elements of low utility were treated differently because of their association with adjacent bones of high utility. He derived a new index, called the "modified general utility index" (MGUI), which accounted for the "riders" (Binford 1978).

Binford (1978) compared the Eskimo's behaviour and observable faunal remains with those predicted by the MGUI (and its constituent indices) in circumstances where various combinations of bone attrition processes were known to have occurred. The good correlations that were obtained justified the notion that utility played a large part in butchery and transport decisions, and Binford proposed that the differential treatment of elements on the basis of utility could be extrapolated to explain selection processes among hunting communities world-wide. He thus established a template for decision making that could be demonstrated to be true in the modern context (Binford 1978, O'Connell *et al.* 1988, 1990) and then extrapolated into the archaeological record (Thomas & Mayer 1983, Lyman 1985, 1991, Grayson 1989, Klein 1989*a*). The derivation of the utility indices has subsequently been simplified without compromising the predictive potential of the technique (Metcalf & Jones 1988, Jones & Metcalf 1988).

According to Binford's concept the behavioural differences between assemblages could be related to a normative strategy of carcass processing based on utility. High utility elements were likely to be transported to a "home base", while kill and primary butchery sites would be dominated by low utility elements. By consideration of the relative frequency of high versus low utility elements it was possible to postulate either the function of the activity on the site, or, under certain circumstances, the nature of carcass availability. When the utility indices were applied to archaeological assemblages, the results were not always in agreement with previous interpretations. Two themes in particular came under scrutiny. The first was the *central place foraging theory* and the second was the *schlepp effect.*

*Central place foraging* was a strategy proposed for Pleistocene hominid resource utilisation and social organisation that was based on comparisons between the ethnographic accounts of modern hunter gatherer societies and behavioural observations of the great apes (Isaac 1978, 1981*a*, 1981*b*, Isaac & Crader 1981). Isaac suggested that the distinctions and similarities between the two held clues to the circumstances that led to the evolution of anatomically modern people. Of particular importance was the role of food sharing and the utilisation of a home base. Whereas ethnographic observations were previously used as direct analogies in the recreation of past behaviour, Isaac emphasised the ecology of Pleistocene hominids by extracted *ecological* analogies (Shipman 1983) from the present. Placing the emphasis on ecology had the effect of shifting the objectives of taphonomic studies. Was it possible for the uniquely human behavioural traits identified by Isaac, and the implications these held for human evolution, to be traced in the Pleistocene?

Binford proposed that Isaac's attempt to reconstruct Pleistocene hominid ecology was theoretically flawed. One of the issues was the lack of independent criteria for recognising a well resolved "home base", particularly in the light of the postdepositional time scale and the inherent potential for other taphonomic modifications of the sites (Binford 1981). Binford re-assessed the evidence from Olduvai Gorge and, on the basis of the inverse relationship between the faunal remains and the utility index on many of the sites, he concluded that Pleistocene hominids were not hunters (as assumed by Isaac 1971, Ardrey 1961, Washburn & Lancaster 1968) but scavengers, and that there was no evidence for their occupation of home bases.

Another concept that Binford criticised was the *schlepp effect.* This was conceptualised by White (1954) and popularised by Perkins & Daly (1968) to explain the dominance of cranial and lower limb bones on archaeological sites. They reasoned that the meat from large animals could be stripped from the bone and easily dragged back to a base in the skin - the low yielding skeleton being abandoned at the kill site. The lower limb bones and cranial fragments that remain on the hide would eventually be deposited at the occupation site. An inherent assumption in invoking such an argument is that the mode of procurement is hunting or at least that the carcasses that were obtained were almost complete.

The *schlepp effect* was used by Klein (1976) to explain the disparities in the body part representation from the Middle Stone Age I and II layers at Klasies River Mouth Cave site (Singer & Wymer 1982). A key observation was that the head and foot pattern of representation that characterises the schlepp effect was particularly evident in the larger bovid size categories. Binford argued that such interpretations were "after the fact" and that, since there were no parallel processes in the present, they had little theoretical basis (Binford 1984, 1989). In the case of Klasies River Mouth he suggested that the patterning was not strictly related to size, but to utility as well. He concluded that small bovids were hunted and that large bovid remains at the site had been scavenged, although the proportion of hunting increased through time (Binford 1984).

Klein's response to Binford's criticism illustrated inadequacies in the construction of the utility indices and in the way they were applied, but more importantly it highlighted the fact that ecological principles cannot be used without first considering the role of mechanistic taphonomy. Klein (1989*a*) pointed out that the utility index was tested in a scenario in which the prey species were all medium sized, and that there was therefore no modern example of utility mediated processing of large animals. He used the ethnographic accounts of the Hadza (O'Connell *et al.* 1988) to illustrate, firstly, that there was indeed an independent precedent for the *schlepp effect* among modern hunter gatherers, and secondly, that large bovid kills were handled differently from medium sized bovids because of the greater processing costs. Support for the latter also comes from Gifford (1980), Yellen (1977) and Bunn *et al.* (1988). Klein further argued that the faunal patterning at Klasies River Mouth was similar to that found in many faunal assemblages in southern Africa, including Later Stone Age hunter gatherer and herder sites (Klein 1980, Klein & Cruz-Uribe 1987, 1989) and Iron Age sites (Voigt 1983). Differential introduction of body parts on the basis of utility could not be used to explain the bias in the assemblages where domestic animals were concerned. Klein also rejected inadequate recovery by the excavators (Turner, A. 1989) as an explanation. The only other possibility was differential destruction. Klein compared the body part representation with Lyman's (1984) skeletal density measurements and concluded that the differences in the body part representation between the large and small bovids were determined by the durability and the size of the bones.

Throughout the development of faunal analysis the importance of differentiating between the behavioural modifications and the other taphonomic signatures has been a priority. To a large extent this distinction is the same as that between mechanistic and other ecological processes, and the difference in approach that is required to address them are embodied in the use of formal and relational analogies. Bone density has emerged as one of the main mediators of mechanical attritional processes, and a correlation between the body part representation of an assemblage and density is accepted as an indication that the behavioural component of an assemblage is obscured (Grayson 1989).

Despite the shortcomings of the utility approach in many instances, attempting to use it to identify hunting and scavenging modes of subsistence in the past represented another theoretical milestone in faunal analysis. Binford had extracted an ecological principle from a modern ethnographic context and explored its implications in an archaeological application. Binford called this approach *Middle Range Theory* (Binford 1977, 1981) and, although it had already been used for 15 years in the development of mechanistic taphonomy (see for example Brain 1967, 1969), the novelty lay in the use of ecological principles. The result was the theoretical ability to move beyond "low level" inferences such as diet breadth and site formation processes, to "higher level" inferences about palaeoecology and ultimately to hominid behavioural ecology (Blumenschine 1987, 1988*a*, Bonnichsen 1989).

### 2. Carnivore ecology

Another area of research that was originally used to understand mechanistic processes but has subsequently made a significant contribution to the use of ecological analogies in faunal analysis is ethology. Originally studies were conducted to characterise carnivore ravaged assemblages and to distinguish carnivore bone accumulations from those collected by humans (Sutcliffe 1970, Haynes 1981, Bunn 1981, 1983*a*, Bonnichsen 1983, Hill 1983, 1984, Kehoe 1983, Morlan 1983, Klein & Cruz-Uribe 1984, Brain 1981, Cruz-Uribe 1991) but recently a group of researchers recognised the potential to address one of the fundamental ecological questions being asked - were Pleistocene hominids hunters or scavengers?

One of the first concepts that emerged from ethology was the disarticulation sequence for East African carcasses (Hill 1979*a*, 1979*b*, Hill & Behrensmeyer 1984, 1985). This is related to the strength of articulated joints, and in the case of scavenging carnivores it is a significant factor in determining the relative ease with which different elements of a carcass can be obtained. On the basis of this Potts (1983) claimed that the relative abundance of fore and hind limbs and also the axial and appendicular elements from sites in Olduvai indicated that the hominids had early to intermediate access to carcasses. The apparent contradiction between Binford's (1981) use of human ecology to conclude that the hominids scavenged, and Potts' (1983) conclusion that they were more likely semi-hunters on the basis of carnivore ecology, indicates the importance of defining the boundary conditions when using ecological analogies to interpret faunal remains. Both analyses were based on independent and accurate comparative observations, but Binford implied that the ecology of Pleistocene hominids is comparable with modern human ecology, whereas Potts implied that carnivore ecology was more appropriate. Was the ecology of the hominids more like that of modern hunter-gatherers or of modern carnivores? A clue is that modern hunter gatherer's prey acquisition and consumption is a subset of carnivore ecology in that they occupy a specific niche as primary predators.

In terms of the use of ethology as an ecological analogy, the challenge was to establish appropriate observations of a range of carnivores including those that were not specifically hunters. Blumenschine

(1986*a*, 1986*b*, 1987) conducted research in East Africa aimed at establishing the viability of a scavenging niche for hominids by considering the fate of animal carcasses in a natural setting. An important point that emerged was the extent to which carnivores compete for the available resources. By considering the hominids as carnivores, the principles of carnivore ecology would apply to them, particularly with respect to the access to carcasses. Blumenschine established that over a broad range of carnivores and prey species the elements of the carcasses were consumed in a characteristic order. In a Binfordian sense each element of a carcass could be considered to have a utility, and the carnivores would consume the highest utility element available. Predators (hunters) had access to complete carcasses whereas scavenger's access was limited to low utility elements. The body parts obtained by hominids would, therefore, be determined by their ecological role in the spectrum from hunters to scavengers. The application of the results to Pleistocene archaeofaunas supported the contention that hominids were scavengers (Blumenschine 1986*b*). A similar approach was used by Stiner (1991*a*) in the analysis of middle Palaeolithic sites in Italy.

A criticism that can be levelled at the use of ethology in the ecological approach to faunal analysis is that the role of technology is not incorporated. For example Stiner (1991*a*, 1991*b*) claimed that skulls are among the very last elements to be deleted from a carcass. In her comparative data the behaviour of wolves was used as an example of a hunting carnivore. Wolves are probably incapable of penetrating a skull, but to a hominid fully capable of using stone tools, it would present little obstacle and the brain would become an element high on the consumption agenda. In such an instance a high proportion of skulls on the site would not necessarily indicate scavenging.

### 3. Prey ecology

In relation to the ecological approach to bone taphonomy, the studies described above dealt with relevant aspects of human ecology and carnivore ecology. The ecology of the prey species is equally important, and it has not been ignored. The animals that were introduced into the archaeological sites in the past represent a subset of the contemporary population, and knowledge firstly of the ecology of the prey species, and secondly of the specific subset that was cropped has been an important line of evidence in establishing how the prey was obtained. Klein (1975*a*, 1978) and Klein & Cruz Uribe (1989) established the age profiles for several species of domestic and wild bovids from Klasies River Mouth, Nelson Bay Cave and Kasteelberg. Relating these to the age structure of normal live populations provided an insightful comparison between the normal mortality of the species in question, and the mortality reflected in the archaeological samples. Klein noted that in the southern Cape, small or docile species of wild bovids had mortality profiles that closely resembled the structure of a live population, while large and aggressive species had profiles that resembled those that arise from natural deaths in a normal population. He attributed the differences to selective hunting of large individuals, and the practice of mass hunting strategies for smaller species. Mortality profiles can also be used to address aspects such as seasonality of site occupation (Parkington 1972, 1976, Klein & Cruz-Uribe

1989) and in the case of domestic animals the use of mortality profiles has been used to elaborate on the herd and flock management strategies that were employed in the past (Klein & Cruz-Uribe 1989).

## Summary

The current status of behavioural faunal analysis is a combination of the use of ethnographic analogy as embodied in the concept of economic anatomy or utility to address aspects of site function, and of ecological analogy, as manifest in the use of mortality profiles and in analogies with carnivores to determine the nature of meat procurement. Post deposition changes to assemblages are still modelled in terms of Brain's original work on the mechanical properties of bone, and combining these with ecological principles it is possible to characterise the effects of carnivore ravaging.

## Theoretical background

The approaches to faunal analysis that are outlined above are all based on the study of processes that occur in the present. When studying archaeological bone assemblages the analyst identifies features that are known to be the result of familiar processes in modern assemblages, and by analogous reasoning the process is assumed also to have occurred in the past. There are very few instances in which archaeological reconstructions do not employ analogous reasoning, and even the positivist approach expounded by Binford (1977, 1978), that was seen as the main theme of the *New Archaeology*, relies on the use of analogy. This is because meaning cannot be given to bones without conceiving the meaning in the present. The meaning cannot be inconsistent with the present. An assemblage is a mute collection of bones and the assumption that they can be used to discern the procurement strategy identifies the meaning of the bones with the present. For example meat can be procured by any means from hunting to scavenging, but it cannot take any other form outside of this range. If another procurement strategy that did not fall within the modern conceptual range were possible, then it would be impossible to identify because it could not be described.

Analogies can be made at several levels. At the lowest level the mechanical effects of a bone modifying agency are identified and as far as is possible criteria that distinguish between different agencies are noted. The contribution that this makes is at the level of low range theory (Bonnichsen 1989), and it relies on direct correspondences between the effects of the modern process and the patterning on the archaeological bones. The diagnostic features that are used are often related to the mechanical properties of the bone, and to the force regime to which they are subjected. A danger in this approach is the potential overlap between diagnostic criteria of agencies that have the capacity to produce similar force regimes (Gifford-Gonzalez 1989).

The next level of analogy combines several diagnostic features of an assemblage to demonstrate a functional relationship between cause and effects (Gifford-Gonzalez 1989). A low level analogy may be something like - carnivores gnaw distal ribs, therefore if distal ribs are encountered with gnaw marks it implies the activity of carnivores. At this higher level the basic observation is extended to include observations that certain other bones are also chewed in certain areas, and also that some bones are gnawed more than others. When these are all combined it may emerge for example that the carnivores are chewing soft bones, and ignoring bones with complicated geometries. This is then a process, and when it is used as an analogy it has far reaching consequences. It is possible, for example, that the pattern of an assemblage does not correlate with any modern analogue directly, but that the effects of the process still allow the inference of co-origination to apply. The analogy can also be taken to explore and even predict the impact of carnivores on the bones of species that have not been studied in the present. The use of processes as the basis of analogies is the central theme of middle range theory (Binford 1978, 1981, Bonnichsen 1989).

Processual analogies making use of low and middle range theory allow the reconstruction of past processes and hence past behaviour. This is termed the "behavioural context" (Gifford-Gonzalez 1991). Moving beyond the reconstruction of behaviour requires ecological analogies that integrate diverse aspects of behaviour, but also make use of more sophisticated modern analogues. The Carcass Consumption Sequence (Blumenschine 1986*a*, 1986*b*) and the General Utility Index (Binford 1978) are both examples of modern analogues that are more than low level observations, they extract principles that can be used to understand past events that may not duplicate their modern counterparts (i.e. the past is not being created in the image of the present). The use of relational analogies in this way allows archaeologists to construct past human behaviour at an ecological level (Blumenschine 1988*a*). This is termed the "ecological context" (Gifford-Gonzalez 1991) of the system under scrutiny.

High range theory integrates observations of the global and universal subsystems made in the fields of astronomy, oceanography, geology, anthropology and atmospheric science to address a more cosmological approach to the working of the universe (Bonnichsen 1989). While it has been suggested that archaeology is a fundamental science (Embree 1987) that should employ high range theory to make a contribution in this realm, this remains an aspiration rather than a reality. High range theory does make a contribution in archaeology by outlining the multicomponent nature of the present, but archaeology has only recently begun to contribute high level observations by adding a time dimension to the major processes that are occurring in the present.

The objective of behavioural archaeology is to integrate low level observations with a sound theoretical basis to produce intermediate level observations of prehistoric land use and subsistence patterns. The ecological approach is not the only theoretical standpoint from which these issues can be addressed, but it does hold a great deal of potential for the reconstruction of past behaviour. It provides a link between the resources that were exploited and the way in which people exploited them. This is a fundamental requirement in identifying the extent to which any form of coastal adaptation existed in the past. In attempting to achieve this in the following chapters, the objective is to compliment existing research on seal exploitation (and ultimately to contribute to high range theory). The actualistic approach that is at the centre of behavioural archaeology has not been used to address seal exploitation in southern Africa before, and the way in which it is to be used is outlined in the following model.

## A model for the exploitation of seals in the Later Stone Age

To address the issue of past seal exploitation I have defined a system comprising four major role players that influence archaeological seal assemblages. They are:

1. the seals,
2. the people that exploited the seals,
3. the carnivores that competed with the people in the exploitation, and
4. the changes to the assemblages after deposition (figure 2.1).

I have isolated key aspects within each subsystem and attempted to establish controls for each of the variables. The first three are a closely linked dynamic system that existed in the past. As such they

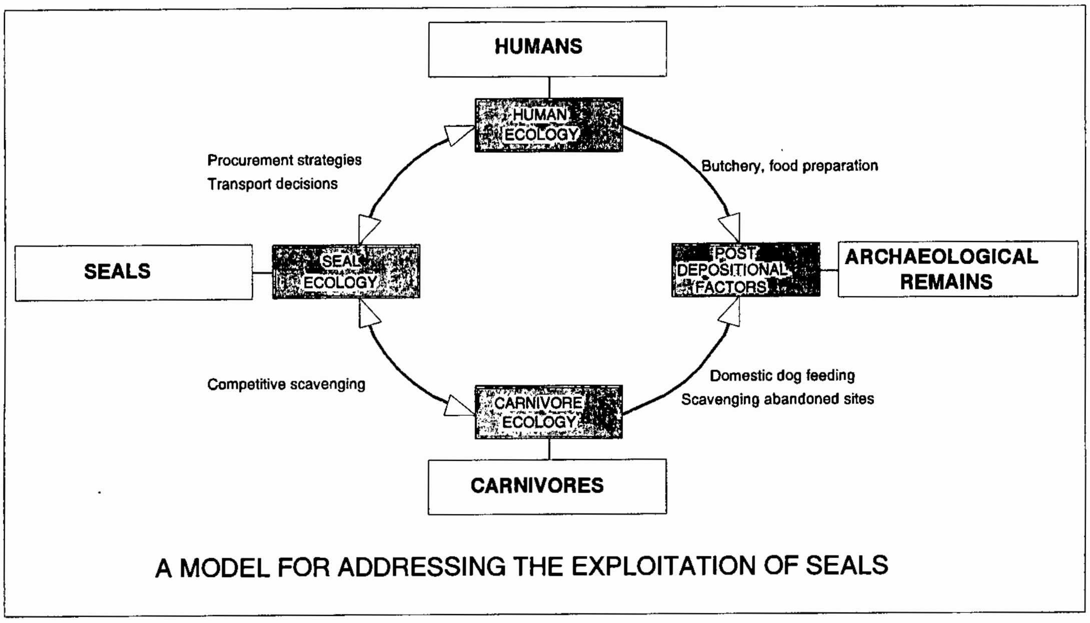

**Figure 2.1.** *The main components in reconstructing past seal exploitation are the seals, the people that exploited them, the carnivores that competed for the resources, and the taphonomic processes that occur after deposition. These have been combined into an ecological model, and appropriate modern ecological analogues have been established.*

represent a well-defined ecological system with the potential to yield behavioural information. The last aspect is a mechanical system that is dealt with in the tradition of mechanistic taphonomy.

### 1. Seal ecology

When considering the role of seals it is important to bear in mind that their behaviour makes them a variable resource in time and space. There is the obvious constraint that seals live most of their lives in the sea, and the early inhabitants of the Cape, without boats, were shore-bound. This left only the coastal margin for exploitation. However the distribution and composition of the seal population along the coast varies throughout the year, placing further constraints on any sealing activities. In order to understand these effects I have included a review of seal ecology and synthesised a model for seal availability based on modern observations (Chapter 3). This is accomplished in terms of sex and age distributions. Resolving the sex and age of archaeological seals is therefore the first issue that is addressed in this research (Chapter 4).

### 2. Carnivore ecology

The ecology of seals provides the basis for understanding when and where seals represent a resource. The exploitation of the seals was, however, not the exclusive domain of the prehistoric inhabitants of the Cape. The carnivores that traditionally scavenged and hunted seals along the beaches competed for the same resource. Observations made of jackals and hyaenas on the seal colonies of Namibia provide a measure of the significance of such competition. These observations can also be directly applied in the behavioural methodology derived for use in Pleistocene archaeology. Through observations and monitoring of kills I have established a consumption sequence for seals, and use arguments that are similar to those used by Blumenschine and Stiner, to address aspects of LSA subsistence strategies and land use patterns (Chapter 6).

A second issue is the effects of carnivore ravaging after bones have been discarded or a site has been abandoned. To address this I have established a measure of jackal destructive capabilities (Chapter 6). The concept is based on what remains of seals after the resource they represent has been totally extracted by the jackals. This will also have a degree of significance in understanding dog ravaging since jackals and dogs are very similar in stature. Unfortunately it is not possible to model the effects of hyaena ravaging.

### 3. Human ecology

Elucidation of past human ecology is the ultimate objective of this research. Through the application of the consumption sequence I focus on the issue of hunting versus scavenging of seals, and the implications this has for land use patterns. I have also established a Utility Index similar to the GUI and its variations (Binford 1978, Metcalf & Jones 1988, Jones & Metcalf 1988) that can be applied to transport decisions taken by hunters (Chapter 7). Existing data on utility are based on animals such as sheep and caribou and cannot be used to understand seal exploitation.

I have also attempted, in conjunction with Assoc. Prof. Smith, to establish a measure of the resource life span of seals (Chapter 8). Based on historical references to the indigenous people of the Cape burying whale meat for preservation, we have experimentally determined how long seal meat can remain buried before becoming fatally toxic (Smith *et al.* 1992).

With the information outlined above it should be possible to establish where, when and how people obtained seals; whether or not they were transported or abandoned because of economic considerations, and accordingly how long it was possible to store them. The resulting signature is however still obscured by the changes that take place in the assemblage once it has been deposited.

### 4. Post deposition factors

Post deposition factors affecting LSA faunal remains can be divided into short term effects operating over days or weeks, and long term effects operating over millennia. Immediately after bones are discarded they may be scavenged by a multitude of carnivores but principally jackals, dogs and hyaenas. The effect of jackals and, by direct analogy, dogs, is modelled in the jackal destructive template explored in the discussion of carnivore ecology (Chapter 6). Modelling the effects of hyaenas is more difficult.

Traditionally the long term effects of trampling and post deposition stresses such as profile compaction have been predicted on the basis of bone density. Experiments carried out in the field of orthopaedic surgery (Weaver & Chalmers 1966, Chalmers & Weaver 1966) indicate that this is only valid for bones with a particular structure. An alternative index for predicting bone survival is developed (Chapter 5). This is the measure of hardness, and it provides a simple, high resolution alternative to the existing techniques.

## Summary

In chapters 4, 5, 7 and 8 of this thesis I establish formal analogies that respectively provide:

1. A means of establishing age profiles for seals,
2. An index of seal bone durability,
3. A utility index for the Cape Fur Seal,
4. The potential resource life span of seal meat.

In chapter 6 a set of actualistic observations of carnivore interaction with seals are presented. These provide relational analogies that provide:

5. A carnivore consumption sequence for seals,
6. A potential means of identifying carnivore ravaging of archaeological assemblages.

In chapter 9 the interdependence of the indices described above is tested. In chapters 10 and 11 the indices and ageing techniques are applied to the seal assemblages from the sites of Kasteelberg B, Dune Field Midden and Elands Bay Cave. The conclusions are presented in chapter 12.

# CHAPTER 3

# SEAL ECOLOGY

## Introduction

Seals are present on many coastal archaeological sites in southern Africa. There is evidence that they were a regular part of people's diet during the Middle Stone Age at Klasies River Mouth (Klein 1976, Binford 1986*a*) and Die Kelders, and were even more heavily exploited during the Later Stone Age (Klein & Cruz-Uribe 1987, 1989, Cruz-Uribe & Klein 1994). Seal remains have even been recovered from colonial sites in South Africa (Cruz-Uribe & Schrire 1991). They are by far the most common mammal species represented at several sites on the Cape west coast. At the site of Kasteelberg B (KBB) they are so numerous that the site has been interpreted as a specialised sealing station (Klein & Cruz-Uribe 1989). In order to gauge the significance of these seal remains it is important to know more than the patterns that emerge from the archaeological analyses, it is necessary to know what could bring them about. Where and at what time of the year can seals be obtained? What level of technology is required to obtain them and what are the dangers that are involved? The people that procured the vast numbers of seals at KBB would almost certainly have known the answers to such questions, because these are details that are acquired through experience and that influence the continued success of the procurement strategy. The boundary conditions of seal exploitation are determined by the behaviour of the seals, and without knowing what these limitations are there is a danger that any attempt to reconstruct the procurement strategy that was followed may be inadequate or entirely wrong (see Marean 1986*a* for a criticism of Binford's 1986*a* interpretation of the Klasies River Mouth seals, and Binford 1986*b* for his acknowledgement of Marean's criticism).

Much of the information that formulated past procurement strategies is encapsulated in the behaviour of seals in the present. Understanding that the ecology of modern seals is a complex package of behavioural traits that existed as deterministic constraints in the past is a classical application of Middle Range Theory (Binford 1978, Bonnichsen 1989). In the latter half of this century a great deal of biological research that is relevant to the understanding of archaeological seal remains has been done on the South African seal population. Unfortunately these studies must be set in the context of commercial sealing ventures that have been under way for the last three centuries. Colonial sealing practices at the Cape had a devastating effect on the seal population, at one point nearly driving it to extinction. The population is still recovering, and in the process there have been some changes in their behaviour that are peculiar to the present situation. These points need to be considered along with the general ecology of the species to gain a complete picture of the boundary conditions of seal exploitation that must have existed in the past. A discussion on seal ecology would therefore, be incomplete if the historical or colonial context of sealing practices was omitted.

Most of the research on the Cape fur seal has been undertaken by the division of Sea Fisheries in order to formulate a management strategy for the population. Since the 1950's, when the large scale commercial fisheries on the Cape west coast began, there has been a perceived conflict between the interests of fishermen and seals (Shaughnessy 1984, 1985, David 1987). In conjunction the overall seal population has been growing rapidly which is seen as a further threat to the fish stocks (Shaughnessy 1985). A debate has emerged in which the seal population is seen to be returning to its pre-exploitation numbers by some, and as an unnatural population explosion by others (see Butterworth *et al.* 1988). Since 1983, when the European and American pelt market collapsed, the culling of seals in South Africa has continued, not because of their commercial value, but on the basis of the impact that seals have on the fisheries. The discussion surrounding whether the population growth is natural or unnatural and the implications that the different scenarios hold for the sustainability of the fisheries is a particularly emotive issue in South Africa, and representations have been made by proponents and opponents to seal culling at the highest political level.

The following historical review is not the result of a comprehensive archival search. Most of the material has been presented in the debate outlined above. Although this is the source of the material it is not my intention to make any contribution to this matter. The review is undertaken with the sole intention of contextualising the ecological studies of seals, and to extract aspects of the research that are relevant to the study of seal remains from archaeological sites.

## Historical review

In 1497 Vasco da Gama, the first European to visit the Cape, saw seals when still five days from land. On anchoring in St. Helena Bay he made the following observation regarding the local inhabitants: "In the land the men are swarthy. They eat only sea-wolves and whales and the flesh of gazelles and the roots of plants ..." a crewman that went ashore further reported: "soon after leaving us they [the Hottentots] caught a sea-wolf, and they went to the foot of a hillock on the moor and roasted it and gave some of it, and some of the roots and plants which they eat to Fernao Veloso ..." (Raven-Hart 1967:3). The sea-wolves that are referred to are seals. Da Gama continued on to Mossel Bay where, for no apparent reason, he fired on a seal colony with his cannon. For the next century this characterised the exploits of the Europeans. French ships as well as those of the Dutch and British East India Companies were involved in killing seals to augment supplies (although accounts suggest that the meat was unpopular because of its oiliness), for the oil that could be rendered, or for sport.

By the beginning of the 17th Century the exploitation of seals for their oil became a more focused, commercial concern. In 1608 Robben Island was visited by Cornelis Metcalf who commented "These dogs [seals] are large and have lovely pelts. Our men amused themselves by clubbing fully a hundred to death." (Raven-Hart 1967:37) and later by John Jourdain "... having brought our boats laden with these seals we cutt the fat from them for oyle, and the rest was thrown a good distance from the tents because of the Noysomeness; on which fish the Saldanians fed very hartilie on." (Raven-Hart 1967:42). The exploitation became significant with large numbers of seals being killed particularly by the Dutch. In 1610 Henry Middleton visited Table Bay where he encountered two Dutch vessels that had already processed 300 pipes (1 pipe = 590 litres) of trane oil that equates to approximately 45 000 seals killed (Hart 1957, Skead 1980). By 1627 the seals were not only being exploited for their oil, but also for their pelts.

Seal colonies were raided indiscriminately to supply ships with meat and trane oil, and the colonies in the vicinity of Cape Town were destroyed even before 1652 when the Dutch East India Company (VOC) established its station at Table Bay (Shaughnessy 1984, David 1987). This refreshment station was an economic experiment and there was obvious pressure exerted on the governor of the Cape by the Herren 17 ('directors' of the VOC) to embark on ventures that would justify its existence. Without any infrastructure available to them, the Cape garrison was forced to exploit the natural resources of the Cape: its forests, wildlife and also the local Khoi and San people with their sheep and cattle stock. In particular seals represented a viable proposition with established markets for oil and skins.

At the time French sealers were very active on the large island colonies in Saldanha Bay, and the British East India Company was operating a parallel venture to that of the VOC (which included sealing at the Cape). The Dutch administration focused its attention on destroying the competition and establishing a monopoly on a resource that promised to be lucrative. VOC invoices and letters bearing testimony to the ensuing Dutch slaughter of seals reveals the development of large markets for seal products in Europe and Japan. In the four months November 1654 - March 1655, 30 000 seals were culled by the Dutch alone. In 1656 13 000 skins were sent to Holland while the demands of the Herren 17 were even greater.

The profits of sealing were not immediately realised by the VOC, probably because of their lack of knowledge on preparing seal products. The raw skins were dried before the lengthy voyages to Batavia and Holland where they were eventually tanned. In 1653 van Riebeeck offered terms of service to the crew of a French vessel that already had 4800 skins, partly with the intention of procuring the skins, but also to gain the knowledge of skin preparation. At that time the Batavian demand for seal skins and trane oil was low owing partly to the low market prices but also because of the complaints over the stink that raw seal products created onboard ship (Wardlaw Thompson 1913).

Unfortunately the colonial sealers had little concept of conservation (contra Grove 1992). Harvesting took place at all times of the year irrespective of the disruptive effect that this had on the seals during the breeding season. There are numerous references to the existence of a substantial seal colony on Robben Island in Table Bay, but between 1648 and 1652 the comments are about the severe depletion of the stock, even before a local European base was established (Skead 1980). The VOC efforts were therefore focused on Dassen Island and the islands of Saldanha Bay. From 1658 the VOC contracted freemen to exploit the Saldanha islands. The oil that they procured was soon being exported to India and to Batavia where it was used for tanning leather. Some of the meat was dried or salted and brought to the Cape to feed the VOC slaves and convicts (Wardlaw Thompson 1913, Skead 1980).

The initial economic success of seal meat, oil and skins was based on the exploitation of viable seal populations at the Cape, but as the seal numbers decreased and the market demands changed, the emphasis of the exploitation shifted. From the end of the 17th Century there are few references to the trade in skins, but the seals were still being exploited for their oil. Permanent oil preparation facilities were established on Robben Island and at the Saldanha Islands in 1710.

There are similarly few references to sealing during the 18th Century which have been interpreted as a lull in the activity of Dutch sealers (Shaughnessy 1984, David 1987). However the colony at Dassen Island was extirpated by about 1750 and the Islands at Saldanha Bay were devoid of seals by about 1773 (Shaughnessy 1984). This suggests that sealing did not decrease but instead continued at a similar intensity to the previous century. From a commercial perspective it appears as if the industry had aligned itself with whaling, emphasising the production of oil. The VOC was always interested in the exploitation of whales but it was not until the end of the 18th Century that a local industry was formally established. The lack of a local market led to the collapse of this venture which is surprising because many American and British whalers active in the Cape waters. In 1790 and 1791 there were 20 and 32 foreign whalers respectively operating out of St. Helena Bay. Ventures that focused entirely on the exploitation of seals had to rely on the seal colonies off the Namibian coast, and in 1793 a sealing base was established on Long Islands - two islands that are situated offshore of the present colonies of Wolf and Atlas Bays where fieldwork for this study was undertaken. By 1796 a base was also established on Possession Island and it is recorded that 30 ships were in attendance at one time here.

By 1820 sealing was being carried out even on the Algoa Bay (Port Elizabeth) colonies. British activities also became more prolific, although a local base was never established.

Whaling reached its maximum in 1822, by which time there had even been Russian vessels involved in the exploitation. A sealing voyage to the islands on the coast of the Namibia and South Africa by Captain Morrell in the ship *Antarctic* in 1828/9 provides an accurate record of the state of the seal population at the time and also an insight into the way in which sealing was practiced. The carcasses of

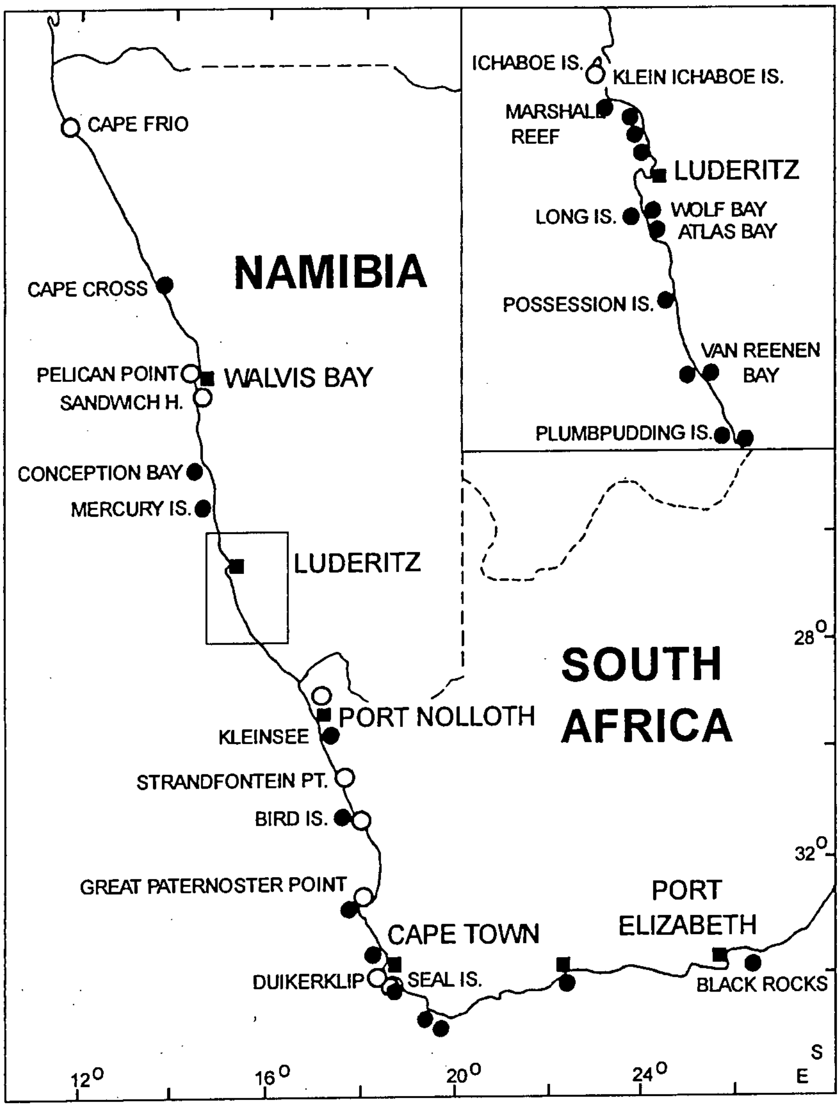

**Figure 3.1** *The current distribution of breeding and non-breeding seal colonies in South Africa and Namibia. Solid symbols represent breeding colonies, circles represent haul outs.*

60 000 seals were found on Possession Island, and a further 50 000 on the Islands at Angra Pequina (Luderitz). It has been suggested that this was the result of a localised pestilence (Wyatt 1980), but further investigation has shown that these seals were probably killed by sealers, and that the carcasses were abandoned after the blubber had been rendered for oil (Best & Shaugnessy 1979). Morrell operated through the breeding season of 1828, and during that time he encountered at least four other ships that were involved in sealing. The low returns of seals from each Island that was visited indicate that the seals had been severely disrupted, and that the population was at an extremely low level even on these remote islands.

Unfortunately the pressure exerted on the seal population became even worse with the "guano rush" that began in 1843. By 1844 the Ichaboe Island and Mercury Island colonies had been extirpated, and by 1885 seal numbers had become perilously low. The crisis was made even worse by the shift in emphasis back to the demand for skins at the end of the 19th Century. Protection was finally afforded to seals by an Act of 1893, a series of proclamations between 1900 and 1910, and by an Act of 1936. This did not prevent sealing, but it stipulated quotas and a season of exploitation.

### The implications of colonial sealing

There are no accounts that describe the pristine seal population that existed at the Cape prior to the commencement of large scale exploitation. The indiscriminate slaughter of seals of all ages, including cows, and at all times of the year, including the breeding season, and the disturbances by guano workers brought about a drastic reduction in the size of the population, but more significantly it disrupted the breeding behaviour of the animals. I shall deal with these two aspects separately.

A total of 26 seal colonies were extirpated by European sealing (Rand 1972, Best & Shaughnessy 1979, Shaughnessy 1982*a*), five of which were still extant when seals were protected for the first time by the 1893 Act. At least two of these sites were breeding colonies (the significance of this will become apparent in the following section). Three of the sites have been recolonised, but 11 of the remaining 23 abandoned islands have been walled for guano and are unlikely to be repopulated by seals. Furthermore the population of seals on the island colonies is decreasing (Shaughnessy 1984, 1987). This would argue that the pre-colonial seal populations would have been significantly larger than those at present, but this must be considered with the changes in breeding habits.

Breeding colonies were previously restricted to offshore islands where space limitations constrained population growth, but disruption of these sites in the 19th Century probably led to the establishment of the enormous Cape Cross colony, and since 1940 several other colonies have been established on the mainland (David 1987, Shaughnessy 1987). With the reduction in numbers of predators such as jackals and brown hyaenas in recent times, these colonies have been growing rapidly (Shaughnessy 1985, David 1989).

It is not clear whether the modern seal population is unnaturally inflated because of the mainland colonies, or whether their numbers are depressed because of the loss of the island colonies, but the implication for the distribution of seals is clear. There were no mainland breeding colonies that could have been exploited by the indigenous people of the Cape. The availability of seals would have been dependent on the existence of hauling out colonies or on the carcasses that were washed ashore.

## Seal ecology review

Cape Fur Seals are found at 33 permanent colonies between Cape Frio in the North of Namibia to Black Rocks near Port Elizabeth (figure 3.1). The dispersal and aggregation and the changes in the age and sex composition of the seal population at various places along the coast is governed by their breeding cycle (Rand 1956). Breeding takes place at 23 of these while the other 10 colonies function as "haul outs". Only 6 of the breeding colonies are on the mainland. The rest are on offshore islands (Shaughnessy 1985, David 1989).

The breeding cycle is rigidly seasonal. It begins in late September when the bulls arrive to establish individual territories at the breeding colonies. The sexually mature cows come ashore during October and early November and immediately the males attempt to herd them into harems on their territories. Successful bulls have been recorded with 66 cows in a harem although the average number is 28 (Rand 1967). The bulls patrol their territories, physically restraining the cows from leaving, repelling the advances of other males and always seeking an opportunity to herd more cows onto their territory. Fierce competition develops during which small and immature males are excluded to the fringes of the colony.

The mature cows are pregnant from the previous breeding season and they drop their pups in the last two weeks of November or the first week of December. The timing of pupping was recorded over a seven year period at the Van Reenen Bay breeding colony, and this indicates how consistent and concentrated this event is. Of the observed births, 90% occurred between 22 November and 17 December (David 1989). The median date of birth was 4 December. Approximately half of the pups are born by 1 December each year at Seal Island (Shaugnessy & Best 1975), and between 3 and 10 December at the Wolf and Atlas Bay colonies (De Villiers & Roux 1992). At the latter colonies the period during which pupping took place varied between 36 and 40 days.

Mating takes place about a week after parturition. By this time the bulls have spent up to eight weeks on land with vigorous exercise but no access to food. After mating they return to sea and remain dispersed and essentially inaccessible until the next breeding season. Cows make occasional foraging trips to sea after the birth of the pups but they remain bound to the colonies until the pups can hunt for themselves. Foraging trips become more frequent and of longer duration between May and August by which time the pups are more or less independent of their mothers for food. By August the pups begin to spend more time at sea and to disperse widely from the colony. The cows return to sea with a growing foetus and stay there until the next breeding season.

Although some pups still use their natal colony as a base after two years, there is little advantage in competing for space at the breeding colony and very large groups of immature seals migrate to where the pressure is less intense. Here they form "hauling out" colonies (Oosthuizen & David 1988). These colonies are often found on rocks or low lying island that may become awash during large storms. Pups are sometimes born at these colonies, but their chances of survival are poor. It has also been suggested that mainland haul outs are a recent phenomenon that has been brought about by the perceived population explosion (Oosthuizen & David 1988).

### Population structure of Cape Fur seals

Because of the annual breeding cycle, the Cape Fur Seal population does not comprise a continuous distribution of ages. Instead it portrays distinct annual cohorts. At any point in time there is a cohort of animals aged less than 12 months (born during the last breeding season), referred to as the first year cohort, another aged between 12 and 24 months (born the previous season), the second year cohort, and so on. The difference in age between each cohort is always a multiple of 12 months. The physical differences between cohorts become less pronounced after the first two years of life.

The age and sex composition of "hauling out" colonies is distinct from that of "breeding" colonies, and indeed that of breeding colonies varies considerably throughout the year. The animals that are too old to compete at the breeding colonies form another distinctive community. Figure 3.2 represents the structure of an idealised hypothetical seal population through the year. It is not based on detailed census data, and is only meant as a general guide to the dynamic way in which the seal population is constituted. The model makes use of the age structure implied by the annual census calculatations undertaken by the Division of Sea Fisheries. The pups that are born each year represent approximately a quarter of the total population (Shaughnessy 1982*b*, 1987). This implies that breeding females make up another quarter because they normally only have a single pup each year. Immature and post breeding animals must make up the remaining half of the population. The proportion of first cohort animals is assumed to be similar for males and females, and is half the proportion of breeding females in the 4-10 year range. The breakdown of the males and females as it is presented is independent of the number of opposite sex individuals with one exception. This is the relation between the number of breeding females and males that are found at breeding colonies between October and January. A ratio of 5:1 has been used to strucure the adult population during this phase of the breeding cycle. The balance of the males are presumed to be at sea or at hauling out colonies. Having modelled the distribution of individuals along these principles, the age structure is presented so that the sum of the % frequencies of each age group is 100% in any prescribed period. For example the sum of the presented frequencies for females at 'haul outs', 'breeding colonies' and 'at sea' in the October to January period is 100%.

The characteristics of the different population sub-groups are summarised below.

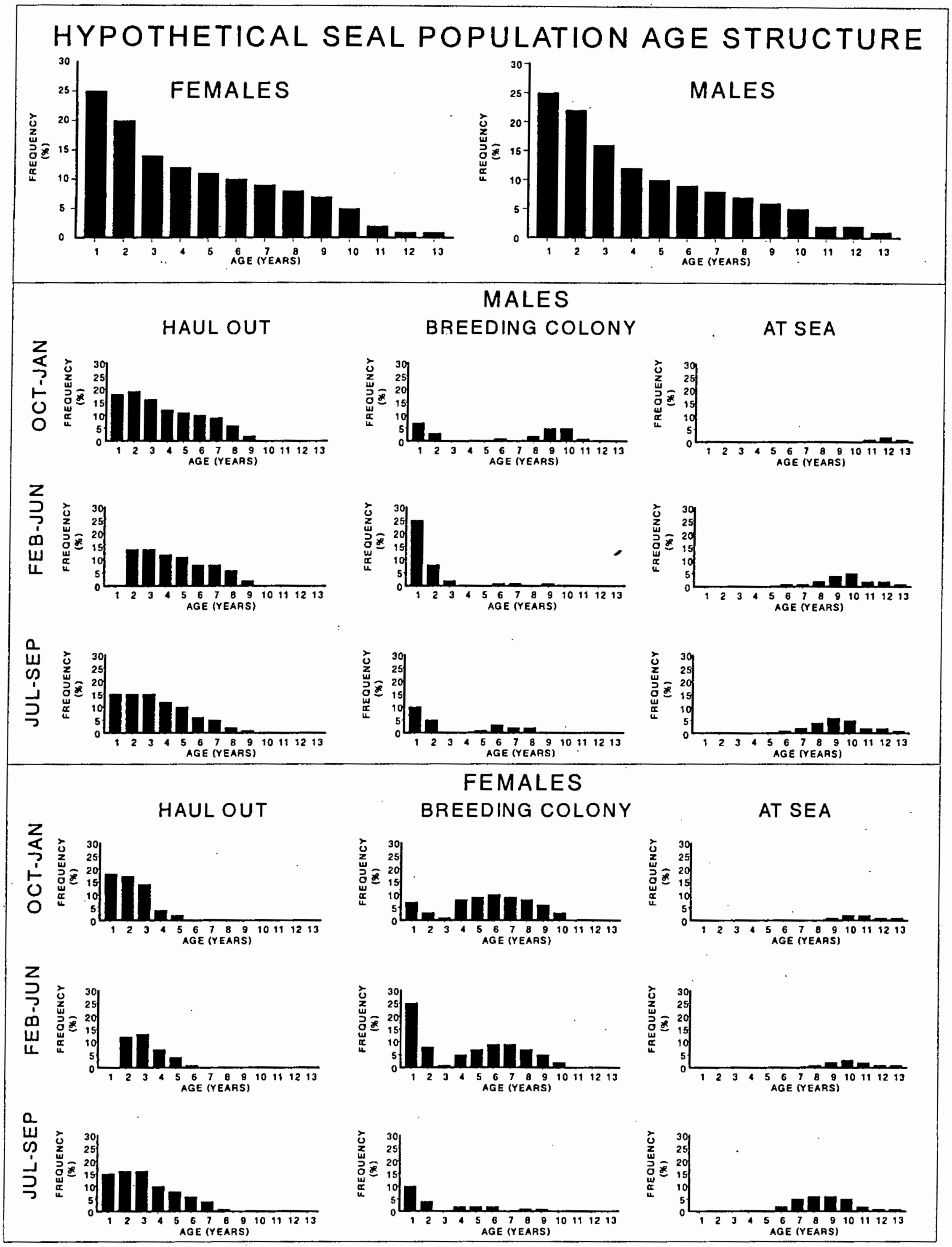

**Figure 3.2** *The seal population can be divided into those that are present at haul outs, those at breeding colonies and those that are at sea. Each part of the population has a characteristic age and sex composition that varies through the year in relation to the breeding ecology of the species. The model is hypothetical, but it accommodates the known parameters of the seal population. These include a ratio of 1:1 for the number of breeding females to pups and for male to female pups. The sum of the pups and breeding females represents half of the population in the breeding season. The age structure of males and females is presented independently so that the sum of frequencies for either is 100 % during any time period.*

### 1. Hauling out colonies

Hauling out colonies comprise the juvenile animals from after they are weaned, when they are aged approximately 8 months, until they are old enough to participate in the activities at breeding colonies. Although it was suggested in early research that females begin to breed at 3 years of age (Rand 1955), the criteria used to age animals was inaccurate (Shaughnessy 1985), and it is not before they are 4 years of age that they leave the hauling out colony (Shaughnessy 1982*a*). It is not clear at what age males are able to compete at the breeding colony, but it is likely that they frequent haul outs until they are about 8 years of age.

The number of animals that frequent haul outs varies through the year. During winter more time is spent foraging at sea and so the numbers decrease. The greatest number of animals is noted during January and February (Oosthuizen & David 1988). In the period February to June the newborn pups at the breeding colonies represent the first cohort, and consequently no first cohort animals are found at haul outs in this period.

### 2. Breeding colonies

At the beginning of the breeding season (November) the males that have successfully established territories, and the breeding females are to be found at the colony. The bulls are probably in the 8-10 year old range while the females are in the 4-10 year old range. Some pups that are approaching 1 year of age may still be hauling out at the colony, and some small bulls that are sexually mature but unable to defend a territory may also be present. By January the pups will have been dropped, mating will have taken place, and the bulls will have returned to sea. Between January and July the colony is made up almost exclusively by cows and their pups, but as the pups are weaned the overall number of animals drops. By late August and September the cows will have returned to sea and the colony takes on the character of a haul out.

### 3. Post breeding animals

The distribution of the animals that are not at hauling out or breeding colonies is a function of age. Younger animals predominate inshore, especially during spring and summer, while adult cows and bulls range further out to sea (individuals have been recorded 220 km offshore) (Rand 1959, Shaugnessy 1982*a*). This group of animals is made up of those that are too old to compete at the breeding colonies and a large portion of the breeding adults when they are not at the breeding colony.

## Seasonality of seal availability

Because all of the precolonial breeding colonies on the Cape west coast were situated on offshore islands (Rand 1972, Shaughnessy 1984), seal availability was restricted to mainland hauling out colonies, occasional seals that came onto the beach, and the carcasses of seals that washed up on the shore.

Seals that randomly come onto the beaches to rest are not a predictable resource in time or space. The chances of encountering them are constant throughout the year. Where they existed, mainland hauling out colonies represent a consistent resource with guaranteed returns throughout the year. In contrast the availability of washed up seal carcasses is seasonal. From July to September, when pups are force weaned by their mothers, many are unable to cope with the stress and die. Where prevailing wind and sea swell conditions are favourable, the carcasses are washed ashore (Parkington 1976, Marean 1986*b*). Pup wash-ups during mid to late winter are an almost predictable source of seals along the coast adjacent to breeding or hauling out colonies. Occasionally the adults become so weakened during the breeding season that they succumb and their carcasses wash ashore between January and March (Marean 1986*b*).

## Seasonal variation of seal condition

Marean has suggested that during winter when terrestrial carbohydrate resources are depleted and when colder average temperatures increase the energy requirements of people, hunter gatherers would have been forced to exploit alternative food sources (Marean 1986*b*). He suggested that animal fat and/or a combination of protein and carbohydrates may have been the alternative, bearing in mind the dangers of a high protein diet (Speth & Spielman 1983, Noli & Avery 1988). In particular the high fat content of seals (c.50% by weight, Shaughnessy 1982*a*, pers. observation) is suggested as being of primary importance in winter, especially since terrestrial ungulates are so lean (e.g. c.2.4% in eland, von la Chevallerie *et al.* 1971).

Marean enhances his argument by suggesting that the blubber content of the Cape Fur Seal varies through the year in response to the breeding cycle (Marean 1986*b*). He proposes that at the end of the breeding season (December-January, summer) the fat content of breeding animals is at its lowest. Hence there is further support for the notion of winter exploitation.

Figure 3.3 presents data on blubber thickness collected by the Department of Sea Fisheries as part of their research into the diet of the Cape Fur Seal. Data are collected over a wide geographic area and over a long time, and spatial and temporal fluctuations in food availability may complicate the results.

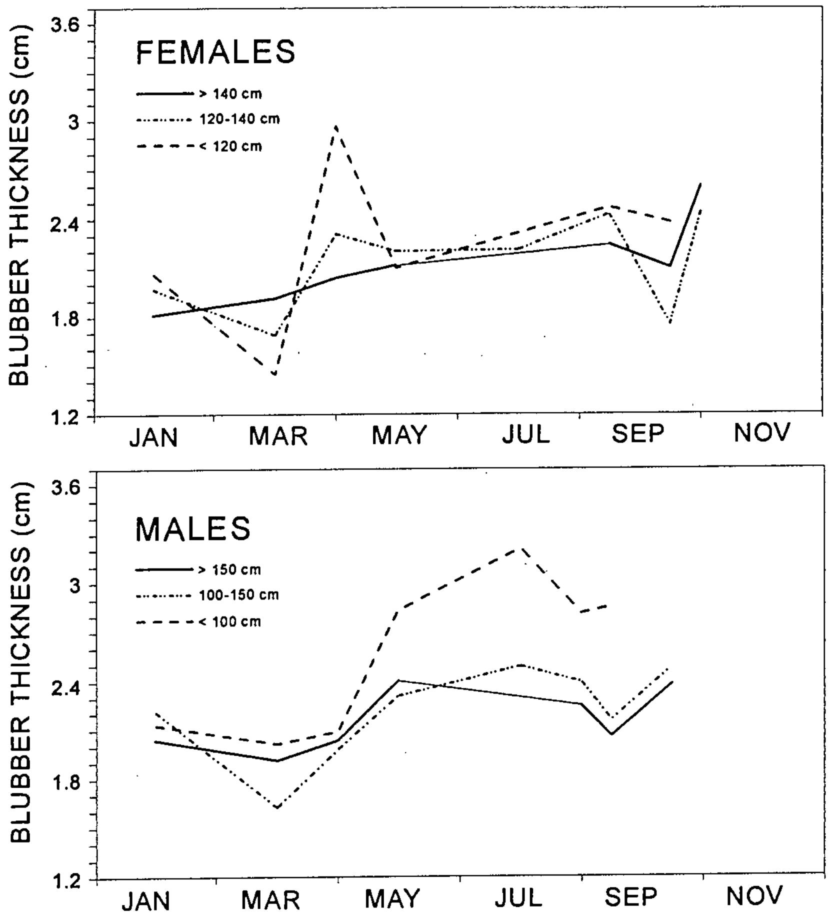

**Figure 3.3** *Seals are annually subject to nutritional stress as a result of their breeding ecology. This is illustrated by the variation in the thickness of the blubber layer through the year. The sample was broken down according to sex and animal length to give a proxy indication of how different age and sex classes are affected by the stress. Measurements were taken by the Division of Sea Fisheries on untagged animals.*

Marean's general expectations are supported, although the fluctuations in blubber thickness are perhaps not as significant as he suggests. There is however a critical exception. Immature animals are not involved in the breeding cycle and are not subject to marked seasonal fluctuations in blubber thickness. These are also the animals most likely to frequent hauling out colonies and are hence the most likely animals to be encountered on the mainland. There is therefore little reason to emphasize seasonal sealing with these animals.

Likewise the high premium that the indigenous inhabitants of the Cape placed on fat as a resource and as a status symbol (see Smith *et al.* 1992) would surely have meant a year round demand for seals. Marean's predictions regarding seasonal demand for seals, and hence differential seasonal processing strategies, are therefore unfounded. The seasonality of sealing is not related to the demand for fat, but rather by the availability of seals for exploitation.

# CHAPTER 4

# DETERMINING ONTOGENIC AGE OF ARCHAEOLOGICAL SEALS

## Introduction

The seal populations that are encountered on the mainland, and that could have been exploited by the prehistoric inhabitants of the south western Cape, are predictably differentiated in time and space. This demographic variability is a function of the breeding ecology and it was considered in chapter 3. Four likely sources of seals emerged. They are the seals that randomly come ashore to rest; the seals that die at sea and are washed ashore; breeding colonies and hauling out colonies. Each of these sources is distinctive in terms of its age and sex composition with the exception of the first class. If the age and sex characteristics of archaeological seal assemblages could be established it would reflect the nature of the seal population that was exploited. Knowing the source of the seals sets the boundary conditions for their exploitation, and will make a substantial contribution to reconstructing the procurement strategies that were employed, and the seasonality of seal exploitation. A prerequisite for such an approach is the ability to determine both the sex and the ontogenic age of archaeological specimens.

Two approaches have been used to age archaeological seals in South Africa. Parkington compared measurements of archaeological mandibles with modern bones to estimate the month of death and by implication the timing of the coastal visits to support his seasonal mobility hypothesis (1972, 1976, 1977, 1981). In a re-examination of his procedure for determining seasonality from seal mandibles it has been established that some of the age estimates for modern specimens upon which he relied are wrong (Woodborne et al. in press). His comparative sample of "known age" animals was the Rand collection of seal skeletons housed at the South African Museum. For each specimen Rand recorded the date of death and an estimate of age based on cranial suture fusion which is very unreliable (Shaughnessy 1985). Where animals were older than a few years the age estimates may be a year, or, in the case of very old specimens, several years in error.

The third approach to ageing seals is that used by Klein & Cruz-Uribe (1989) to construct age (mortality) profiles for the seal from Kasteelberg B (KBB). They used distal humeri mediolateral diameters as a proxy indicator of age. Age was inferred by analogy with distal humerus measurements taken from seals, assumed to be aged 9 months at death, that are housed at the South African Museum. These comparative specimens were not tagged and the ageing criterion that were used are not reported. Many of the measurements taken on archaeological specimens fell within the range of measurements from the 9 month old modern animals. The conclusion was that the bulk of the specimens from

Kasteelberg came from animals aged about nine months, and that the main season of occupation must therefore have been around September (or spring).

Research has also been done on the annuli in seal teeth (Fletemeyer 1977), but this has provided a means of determining season of death rather than the ontogenic age at death. The procedure that was used is time consuming and the results are open to subjective interpretation. The method has not been pursued any further. In order to gauge the merits of the other two techniques for ageing seals, namely that based on the growth of the mandible and that based on the growth of the distal humerus, some of the assumptions that are made in generating age (mortality) profiles need to be considered.

The research presented in this chapter represents an extension of the project that Parkington initiated and that has been continued by Ken Hart. The statistics that will be presented are based on a concept that was proposed by Hart, but the regression analysis and related statistical procedures were explored and refined by the author of this thesis. A joint paper on the results has been submitted for publication (Woodborne *et al.* in press).

## Constructing age (mortality) profiles

Age (mortality) profiles are histograms that usually depict age or a related variable on the x-axis and frequency on the y-axis. Although they have been widely used in archaeology (Frison 1978, Shipman *et al.* 1981, Klein 1982, Levine 1983, Berger 1983, Klein & Cruz-Uribe 1989) there has been little attention paid to the way in which they are generated. Lyman (1987*a*) has presented a critique that highlights three problems. These relate to the scale that is selected for the x-axis.

First, the x-axis scale should ideally be based on ontogenic age. A problem may arise when a proxy measure of age, that is not a linear function of ontogenic age, is used to scale this axis. Typically the growth rate of mammals decreases with increasing age and the size distinctions that are apparent between young animals of differing ages may not be discerned between older animals with the same age disparities. The effect is to collapse some portions of the x-axis relative to others which, in turn, distorts the overall shape of the histogram. Much of the information that can be ascertained from an age (mortality) profile is encoded in the shape of the histogram. This is likely to be a problem with Klein & Cruz-Uribe's (1989) use of humerus width measurements. If a proxy measure of age that is linearly related to ontogenic age is employed, for example in the use of tooth wear (Klein & Cruz-Uribe 1989, Klein 1978), then the shape characteristics of the histogram are more likely to be authentic.

Second, the age scale should be resolved in years or in units that are less than a year. This is not imperative but most mammals have an annual breeding cycle (this is certainly the case with seals) and aspects of this can be manifest in the details of their age profiles. The use of age classes such as percentage of life span (Klein 1978) on the x-axis may bring about a situation in which a unit reflects more than a year if the species is a long lived species, or less than a year if it is a short lived species. Such profiles are more complicated to interpret in terms of the animal's ecology than if an annual cycle was portrayed.

The third problem is mostly a problem of interpretation, but it ought to be considered at the outset. A scale based on animal size must take into account the interspecific size variation in a population. This should include geographic variability as well as sexual dimorphism. The latter is often a problem because of the limited number of skeletal elements that can be used to predict age, and for which the sex can be determined. Klein and Cruz-Uribe's (1989) use of the distal humerus to construct age (mortality) profiles is questionable since sex cannot be determined for isolated humeri. Seals in particular exhibit a substantial degree of size related sexual dimorphism that is manifest soon after birth (Shaughnessy 1985). The average weight of bulls is 247 kg but individuals of 316 kg have been weighed. In contrast adult cows average 57.4 kg with a maximum of 107 kg (David 1987). Clearly it is imperative to make a distinction between males and females in archaeological assemblages.

Throughout this discussion it is assumed that the age determinations that are plotted on the x-axis are accurate and precise. The seasonality of seal exploitation at Kasteelberg B (Klein & Cruz-Uribe 1989) was established by comparison of modern and archaeological humeri widths, but the precision of the modern sample is not established. The possibility exists that a female that was older than 9 months may have had the same humerus size as a 9 month old male, or that the size of a sub-9 month male may have fallen in the range of 9 month old females. Furthermore it is not established whether older or younger animals may have humeri that fall in specified 9 month old size range. Two seal skeletons of individuals that had been tagged as pups at their natal colonies and that were killed during the course of this research provide a test of this. Both were males aged 29 months and 35.5 months respectively. Their distal humerus measurements were 42.7 mm and 45.3 mm placing them in the upper limit of the proposed 9 month age range (Klein & Cruz-Uribe 1989). Whereas the range of distal humerus measurements for 9 month old seals may be real, the growth of this dimension is insufficient to exclude animals that are substantially older than 9 months from falling in this range. For these reasons the distal humerus is considered to lack sensitivity as a proxy indicator of age, and is also limited in its application by the inability to determine the sex of the seals.

If a seal's age at death can be determined to within a few months with reasonable confidence, even after intra-specific variation has been accounted for, then it will be informative about the season of death. This is achieved by reference to the restricted birthing season for this species. This, and other demographic information that can be gleaned from such profiles, will be valid and of considerable interest in the construction of past human ecology. The basic requirement is the ability to predict ontogenic age with the highest possible resolution.

## Establishing age at death

The foundation of Parkington's technique for determining ontogenic age is the predictable relation between age and mandible size, in the absence of usable patterns of tooth eruption or wear (Rand 1950). In order to establish this relation, several mandibular dimensions on modern specimens of known age at death were measured (figure 4.1). The most useful relation is between age and what Parkington defined as *short length* (SL). This is the linear distance between the lateral tip of the mandibular condyle and the posterior edge of the rearmost post-canine tooth socket. The measurement is made on the buccal side of the mandible. This dimension tends to survive on fragmentary archaeological specimens and can be measured irrespective of whether the cheek teeth are preserved in the mandible or not.

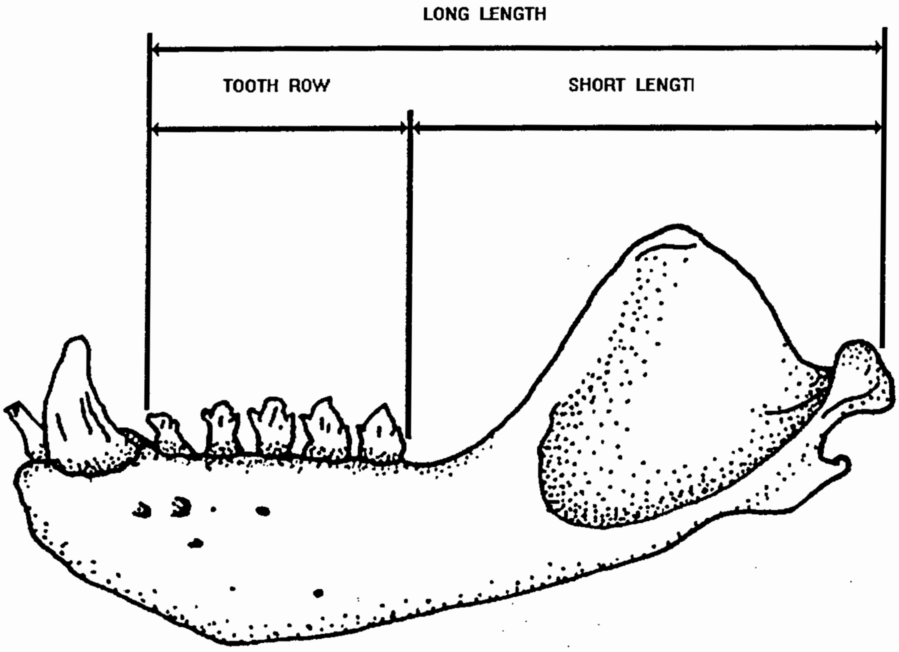

**Figure 4.1** *Dimensions (defined by Parkington 1972) that were measured on modern seal mandibles from known age individuals. The short length (SL) was used to establish a mathematical relation between ontogenic age and size, and it was used to establish the age at death of archaeological seals.*

In this study the South African Museum and Department of Sea Fisheries collections of mandibles from known aged individuals were used. The Department of Sea Fisheries tags seal pups within six weeks of birth at some colonies. The pups carry a distinct black coat until their first moult in March (Rand 1956) so there is no doubt about their year of birth. Mandibles from 170 culled specimens comprising 111 males and 59 females were measured. Whereas Sea Fisheries recorded the sex of the tagged animals, morphological attributes of the mandibles are used to determine the sex of archaeological specimens. Female mandibles have relatively narrow canines and are gracile in comparison with those of males, especially in the vicinity of the canine root.

The Rand collection of seal skeletons housed at the South African Museum was also scrutinised. The cranial fusion criterion that Rand used to estimate age at death is inaccurate as was noted earlier. There can be little doubt that the age of animals presumed to have been in their first year is valid. The length of the canines relative to the post-canines confirms this. During the first year the canine is shorter than the post-canines in both males and females (Meyer pers. comm.). For animals aged less than 4 months Rand definitely made no error since these pups are black. The addition of the first year Rand collection animals makes the total for "known age" males to 122 and to 83 for females.

For each animal in the comparative sample the date of death is known. Assuming a birth date of December 1 for all seals, their "known" age will be in error by perhaps a few days but certainly less than three weeks (see chapter 3). This error will be relevant in any age predictions based on this set of observations, but the statistical procedure employed accommodates it within the confidence limits of the prediction. Nevertheless the error is negligible inasmuch as a two to three month range for the season of death is quite satisfactory. The effect of this error is also partly compensated for by considering the age predictions for several animals rather than relying on isolated specimens. Age is expressed in months and decimals of months.

The nature of the comparative samples significantly influences the procedure for calculating the age at death for archaeological mandibles. Regression analyses are only valid if the data fulfil certain criteria. Consideration of the assumptions and problems associated with regressions and their application in this instance is necessary at this point.

It is assumed that the age\size characteristics of the Cape Fur seal population have remained constant through time, thus making any age prediction based on the modern sample of animals also valid for archaeological seals. Another assumption is that the animals used to establish the age\size relation reflect the allometric variance of the entire population. In this respect the comparative sample has problems that are associated with the restricted birth season of the animals. The restriction of culling to four months each year implies that the modern sample does not include certain age groups. The number of tagged animals at or around the age of nine months far exceeds that of animals at or around 21 or 33 months at death because commercial culling focuses on first year pups. The killing of older animals is incidental and altogether the first year pups represent about half of the total sample population. Clearly the comparative sample does not fully represent the size variance through the entire age continuum of animals found in the modern seal population, nor does it reflect the natural age structure.

Age and size are interdependent variables and a graphic representation is advantageous in establishing the regression relation between them. Since we measure the mandible size in archaeological samples this should be the independent variable whereas we predict age so it should be the dependent variable. A plot of age versus size illustrates the nature of the sampling problem discussed earlier (figure 4.2). A simple regression minimises the accumulated differences between the known age, and the age that the regression equation predicts for the corresponding mandible size. At least for the first cohort, the equation age = 10 months will best satisfy this criterion, but it will grossly misrepresent the post-first year cohorts. Similarly the number of first year animals biases the regression based on all the data points, and the curve substantially underestimates the age of older animals. The problem here is that the variability within the first year cluster of points is contributing more to the regression than the variability between the clusters. The change in size through time, not the variability in size at a single point in time, is what must be modelled. A simple regression based on such a biased population of data points is of little value in predicting the age of seals.

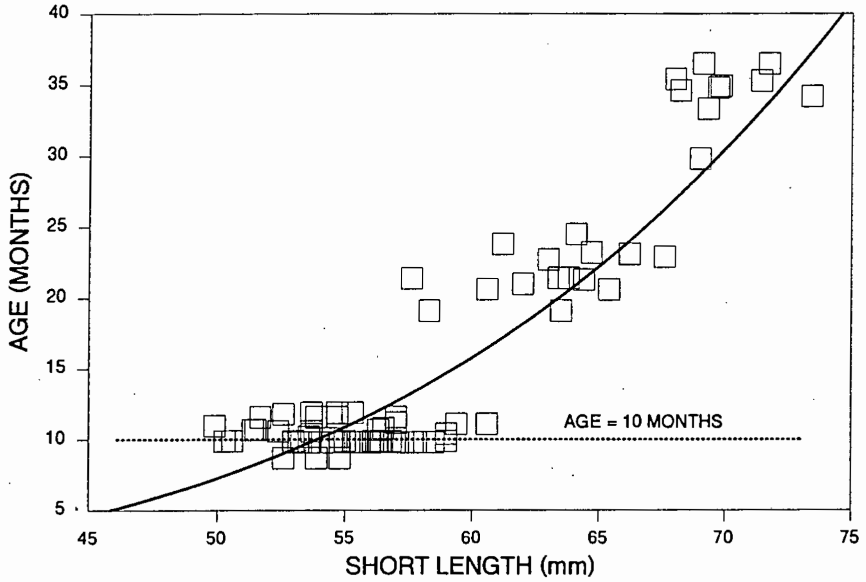

**Figure 4.2** *The "known age" sample of seal mandibles shows distinct cohorts because of the restriction of culling to a particular season each year. The size variability in the first year cohort is best represented by the equation AGE = 10 months. Just as this equation underestimates the age of animals in the second and third cohorts, a regression based on all the sample points is significantly influenced by the first year cohort and similar errors result.*

The remedy to this problem relies on the fact that age and size are interdependent variables. If age is considered to be the independent variable and size the dependent variable, then there are multiple values of the dependent variable for each value of the independent variable. The term group refers to comparative animals with the same age at death. A special form of regression calculates the best fit curve using the mean mandible size in each group. Thus a single point represents each group and the variability within the group does not contribute to the regression. The basis of the regression is then the variability between groups. Only the confidence limits associated with the regression curve reflect the variability within the groups. Sokal and Rohlf (1969: 428-440) provide an excellent explanation and description of this statistical approach. Resolving the comparative data in this way transforms the clusters of points that make up each cohort into several groups. This reduces the bias described earlier.

The method requires that groups have *exactly* the same value for the independent variable. This is not strictly the case in the seal data. It cannot be assumed that animals that were killed on the same day and that were born in the same season are the same age since we do not know that they were born on exactly the same day. This problem technically invalidates the use of the technique to predict age at death, but it must be noted that one of the objectives is to predict season of death. The analysis could be executed in such a way that age does not play a role. If the *age* that we have attributed to the comparative seals is not considered as age in the normal sense of the word, but instead as *the duration of time between 1 December and the death of the animal*, then animals born in the same season and killed on the same day do have the same age. In a strictly statistical sense the predictions that are obtained from a regression phrased in these terms are not ontogenic age, but rather a time period from 1 December. The best representation for this would be as *date of death*, hence the technique provides a direct method for predicting season of death. The difference that emerges in the analysis is entirely semantic and so the use of the term "age" is retained for simplicity. When age (mortality) profiles are generated the true ontogenic age is required, and that there is an error associated with the prediction must be accepted.

**Model selection**

Using the statistical approach described above four alternative regression relations were tested:

$$\begin{aligned} SL &= \alpha + \beta(AGE) && (1)\\ \log(SL) &= \alpha + \beta(AGE) && (2)\\ SL &= \alpha + \beta(\log(AGE+1.5)) && (3)\\ \log(SL) &= \alpha + \beta(\log(AGE+1.5)) && (4)\\ \text{where } \alpha,\beta &= \text{population parameters} \end{aligned}$$

For both the males and the females there were two comparative data sets - (1) the tagged animals, and (2) the latter set supplemented by the Rand animals. The Rand collection includes some newborn individuals, some of which were collected before 1 December. This theoretically attributes a negative age to these "known age" individuals. Since the log transformation is not defined for negative values, a constant factor of 1.5 months was added to the known age of all the specimens when models 3 and 4 were tested. The resulting equations for predicting age includes the term "-1.5" to compensate for this.

We tested the four models on the two "known age" data sets. This produced 8 possible equations for each sex. The regression analysis calculates the best values of α and β for each equation, but it does not establish which model best relates age and mandible size. The variance ratio test F (Sokal & Rohlf

1969, Zar 1984), was used to measure "goodness of fit". Consistently low F values for all model 3 regressions indicate that this is an unsuitable option while model 4 is clearly the best option. Including the Rand collection in the comparative data set improves the regression by producing higher F values. Analysis of variance tables are summarised in appendix A.

To predict age from mandible measurements the inverse form of equation (4) is used (Zar 1984). The equations that best predict ages over a wide range of values are the following:

$$\mathrm{AGE} = 10^{\left(\frac{\mathrm{Log(SL)}-1.492}{0.233}\right)} - 1.5 \quad \text{(males n=122)} \quad \text{(5a)}$$

$$\mathrm{AGE} = 10^{\left(\frac{\mathrm{Log(SL)}-1.571}{0.161}\right)} - 1.5 \quad \text{(females n=83)} \quad \text{(5b)}$$

**Confidence limits**

It is clear from the modern observations that all the animals that achieve a particular size do not necessarily do so at the same age. Thus it is inaccurate to associate a single age with the SL measurement from any archaeological mandible. The age predicted by the equation is the most likely age at death for an animal. The real age could have been older or younger, but the probability of this being the case decreases as one moves away from the prediction. The range that expresses the probable age of death is calculated using the form of the confidence equation for inverse predictions:

$$\bar{x} + \frac{\beta\left(y_i - \bar{y}\right)}{K} \pm \frac{t}{K}\sqrt{s^2_{y\cdot x}\left[\frac{\left(y_i - \bar{y}\right)^2}{\sum x^2} + K\left(1 + \frac{1}{n}\right)^2\right]}$$

where: $K = \beta^2 - t^2 s^2_\beta$

$\bar{x}$ = mean age (modern sample)

$\bar{y}$ = mean SL (modern sample)

$y_i$ = SL of archaeological sample

n = modern sample size (Zar, 1984: 276)

The 95% confidence limits define the range that would accommodate 95% of the spread of ages for animals of a given SL dimension in the seal population.

It is important to note that age predictions do not depend on direct analogy with the absolute values in the sample population. Predictions are valid for mandible measurements even if animals with the corresponding age did not occur in the modern sample. Conversely, the clustering of observations from animals aged nine months in the modern sample does not impose a tendency to predict ages of nine months for unknown animals. Confidence limits can also be calculated for any age prediction.

## Summary

A method of establishing ontogenic age for archaeological seals on the basis of mandible size was presented in this chapter. Regression equations based on the entire set of known age specimens are appropriate for establishing age (mortality) profiles. Regression equations based on the sub-three year old animals have smaller errors associated with age predictions and are therefore used to determine the season of death.

In chapter 10 the equations are used to construct age profiles and to establish season of death using the seal assemblages from Kasteelberg B, Dunefield Midden and Elands Bay Cave. The reason that the results are not presented here is because the indices developed in chapters 5, 6 and 7 need to be applied to the assemblages together with one another. In keeping with this all the results will be presented together in chapters 10 and 11.

# CHAPTER 5

# DENSITY AND HARDNESS OF SEAL BONE

## Introduction

The construction of links between events and activities that occurred in the past and artefacts and features that are preserved in the present is central to archaeology. For these reconstructions to be accurate the links have to be established in accordance with accepted scientific methods. The concern is twofold: first the number of factors involved in creating an assemblage must be identified, and then an unambiguous relation between the observations and the past events must be demonstrated. Does patterning in an archaeological assemblage necessarily reflect human behaviour, and if so, can the behaviour that brought it about be discerned? Could the patterning have been caused by more than one activity or by more than a single accumulating agent? Establishing the integrity and resolution of an assemblage is the realm of mechanistic taphonomy (Binford 1981), and one of the ways in which archaeologists deal with these issues for bone assemblages is the concern in this chapter.

The main factors that determine the final nature of an archaeological bone assemblage are: the nature of the past environment and the influence this had on the available animal species, the behaviour of the bone collectors, and the changes that took place in the bones after deposition (Driver 1983, Cruz-Uribe 1991). Discerning the role of the former two factors is, in many cases, the final objective of archaeological research, but before their contribution can be isolated the effect of the third must be gauged. Klein and Cruz-Uribe (1984) suggest that comparisons between faunal assemblages from several sites in an area may serve to isolate the contribution of each variable. There are, however, aspects of taphonomy that can be addressed using the bones themselves. Bone surface modification by porcupine and other rodent gnawing is often preserved (Brain 1981) as is the gnawing of larger carnivores (Sutcliffe 1970, Binford 1981, Brain 1980, Haynes 1980, 1983, Bunn 1983*a*, Blumenschine 1991). Where larger carnivores are involved in accumulating the bones, there are characteristic breakage patterns (Sutcliffe 1970, Binford 1981, Kehoe 1983, Wilson 1983, Cruz-Uribe 1991), body part representations (Cruz-Uribe 1991) and also typical age (mortality) profiles (Klein 1982, Driver 1983, Klein & Cruz-Uribe 1984) that can be expected.

An obvious limitation to such characterisations is the inability to deal with processes that remove as opposed to those that deform bones. The emphasis in this chapter is on the latter processes although the potential application to processes that destroy bones will be explored later.

Criteria that can be used to identify non-human bone modifying agents may also provide clues regarding the extent to which human behavioural signatures have been altered. Unfortunately there are so many different agencies that may affect an assemblage that the analyst cannot develop recognition criteria for every possible contingency. An alternative approach is to consider the physical properties of bone and how they effect the way in which bone is altered under different behavioural or destructive regimes. If a causal link between changes in bone and the forces that brought them about can be established, and if that relation can be quantified in terms of the bone's physical properties, then it should be possible to construct the nature of bone modification from the evidence preserved on the bone. The most significant property in the context of this discussion is bone density.

## The role of Bone Density

It has been empirically demonstrated that the relative proportion of trabecular bone to cortical bone determines the likelihood of carnivores destroying a bone (Binford & Bertram 1977, Hill 1980*a*, Haynes 1980, 1983, Binford 1981). Epiphyses, therefore, have different survival potential from diaphyses. Brain (1967, 1969) suggested that bone density is the principle factor in determining the eventual body part representation in assemblages that are subjected to mechanical attrition, and Boaz & Behrensmeyer have shown that it also affectss fluvial transport (Behrensmeyer 1975, Boaz & Behrensmeyer 1976). Indeed, this physical property also determines the chances of survival for bones subjected to trampling, leaching and profile compaction (Klein 1989*a*). Other factors such as size, shape and weight also affect the fate of bones through time, and the contribution of bone density will vary in different depositional and post-depositional circumstances (Lyman 1984), but it remains the most significant attribute in the survival of bone.

Relating bone survival to an index such as bone density enables the archaeologist to predict whether deviations from anatomical parity in a bone assemblage are the outcome of "cultural" modification prior to interment, or of "natural" attrition processes that occur both before and after burial (Grayson 1989).

## Measuring bone density

Three closely related measures of density have been used to approximate bone's ability to survive. These are density, bulk density and porosity. Respectively they are defined as:

$$\rho = M/V$$

$$\rho_b = M_{TOTAL}/V_{TOTAL}$$

$$f_p = (\rho-\rho_b)/\rho = 1-\rho_b/\rho$$ (Lyman 1984: 264-265)

Density is the inherent relation between the mass and volume of a substance. It is constant in homogeneous material and any subsample has the same $\rho$ irrespective of its size. The value of $\rho$ as a subsample becomes infinitely small is defined as the density at a point. The mass and volume can be used to calculate the average density of a sample, but in porous material such as trabecular bone, the mass and volume parameters need to be measured at a point to obtain true density values. This is not directly achievable. Instead measurements must be made by carefully monitored impregnation of the pores with a solution of known density. The sample density is then calculated from the average density by taking into account the contribution of the impregnating solution.

Bulk density is the relation between mass and total volume of a substance irrespective of its homogeneity or not. It is a measure of the average density of all the components of the sample. Measurement of bulk density is much simpler since $V_{TOTAL}$ is the equivalent of displacement.

$f_p$ is the parameter that relates density and bulk density, and it is essentially the proportion of a sample that consists of air. The term $\rho_b/\rho$ is also called the relative density (Gibson & Ashby 1982) and the volume fraction (Turner, C. 1989).

The values that Brain used to pioneer the concept of bone survival are essentially those of bulk density. He determined the volume of the bone by blocking the pores and measuring their displacement. $\rho_b$ was calculated using the dry mass of the bones (Brain 1969). Binford and Bertram derived their values in a similar fashion except that they compensated for the effect that humidity has on volume measurements (Binford & Bertram 1977). Unfortunately they did not account for the volume of the coating wax used to seal the bones (Lyman 1984). Behrensmeyer (1975) and Boaz & Behrensmeyer (1976) derived accurate measurements for density and bulk density respectively, although, again, the effect that temperature has on volume measurements was not controlled (Lyman 1984).

Lyman used a photodensitometer to obtain a measure of bone density (Lyman 1984, 1985, 1987*b*). The technique involves directing a photon beam onto the bone and measuring the degree of absorption. Relating this to the thickness of the bone provides a measure of the density of the bone's mineral phase. The advantage of this method is that a small area can be sampled and so it is possible to obtain several measurements from various positions on a bone. Unfortunately the equipment required to measure photodensity was developed for medical applications and is not commonly available to archaeologists. The results logically approximate density and they provide an accurate account of the relative differences between bones and between different parts of individual bones. This also correlates well with observed bone survival (Lyman 1984, 1985, 1987*b*).

It is important to note that in every application (except that of water transport) the relation between bone survival and density is empirical. There is no detailed explanation for *why* this relation exists. To evaluate how appropriate density measurements are in predicting bone's ability to survive it is necessary to consider two further concepts. The first deals with the force regime that the bone may experience. A branch of mechanical engineering deals specifically with the response of materials when subjected to forces, and a substantial body of theory and method has developed. In particular the mechanical properties of bone have been tested in the interest of medical science for the last century, and a great deal of information that is relevant to the taphonomist exists. The second concept deals with the structure of the bone. This determines the density of the bone and it is here that I intend to trace a causal link between density and survival potential.

In order to explore this corpus of information I shall review the concepts of bone structure and force regimes in a fair amount of detail. This is necessary in order to argue *why* there is a relation between density and bone survival. The argument can then be extended to justify an even better measure for bone survival. This is the measurement of *hardness*.

## Bone structure, force regimes and attrition

### Definitions

In the context of bone attrition, the term *stress* ($\sigma$) refers to the amount of force, or load, acting on a unit area (Hall 1974). When the load is applied at a high rate, for example when marrow is exposed by striking a bone with a hammerstone, it is referred to as *dynamic loading*, while gradually increasing the load is known as *static loading*. It has been suggested that consistent dynamic loading is unique to human behaviour, and the effects of carnivores can be discerned where fracture morphology distinguish between dynamic and static loading (Binford 1981, Johnson 1983, Davis 1985).

There are four types of stress to which a bone can be subjected in various combinations. They are *tension*, *compression*, *shear* and *torsion*. Tension and compression forces act in opposite directions along the same axis, while shear acts in opposite directions along different axes (fig 5.1). Torsion forces act to rotate one part of a bone relative to another around a single axis.

*Strain* ($\varepsilon$) is the resulting deformation expressed as a proportion of the original dimension of the bone subjected to the stress (Hall 1974).

*Toughness* is a material's ability to resist structural failure as measured by the amount of energy imparted during fracturing.

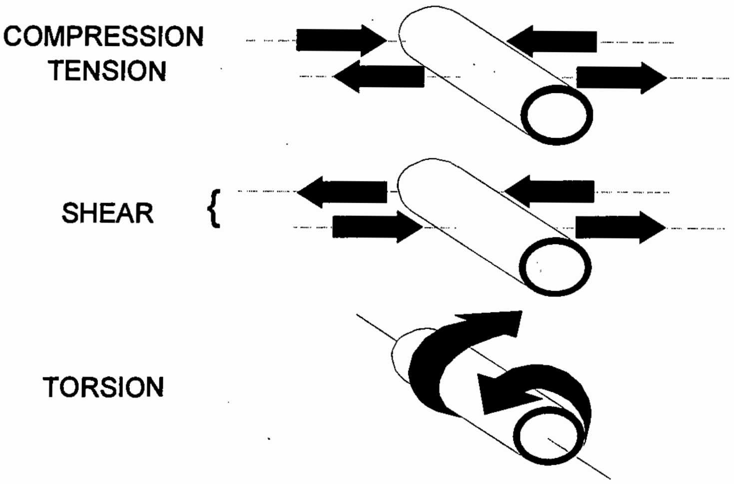

**Figure 5.1** *The force regime to which bones are subjected can be resolved into four categories. Compression and tension forces act against one another along the same axis, shear forces act against one another along different axes and torsion forces act against one another around a single axis.*

Another concept that has potential for application in taphonomy has developed in the discipline of materials science. This is *hardness*.

> "Hardness is a fundamental property which is closely related to strength. Hardness is usually defined in terms of the ability of a material to resist scratching, abrasion, indentation or penetration." (Schlenker 1974: 67)

Hardness is measured by forcing an indenter of a pre-defined geometry into the surface of the material (Cottrell 1975, Schlenker 1974). The relation between the force and the deformation of the material is a function of its hardness.

The manner in which bone hardness testing is carried out is similar to what might be expected when a carnivore gnaws a bone. The measured force is precisely what the carnivore would be required to exert through a tooth if it were to inflict the same damage on the bone. This aspect of hardness testing alone justifies its consideration as an index of bone survival potential, at least in situations in which carnivores are likely to have made a significant impact.

### The structure of bone

The effect that any force has on a bone is dependent on four levels of structure within the bone. They are the molecular structure, the ultrastructure, the microscopic structure and the macroscopic structure (Davis 1985).

### 1. Molecular structure

There are three distinct constituents of bone at a molecular level. The two major structural components are an inorganic, crystalline phase constituting approximately 40%, and an organic phase constituting 30-40% (Piekarski 1970, Davis 1985). The remainder of the bone consists of liquid. Both the inorganic material, made of hydroxyapatite [$Ca_{10}(PO_4)_6(OH)_2$], and the organic phase consisting mainly of collagen, contain a small amount of liquid that is stable except at high temperatures (Bonfield & Li 1966, Lees & Davidson 1977, Lees 1981, Shipman *et al.* 1985). The bulk of the liquid is unstable and it is easily and reversibly removed.

The proportion of organic material is almost constant between bones, and between bones of different animal species, while the proportion of mineral phase to liquid appears to vary in a complimentary fashion (Lees 1981). The balance between liquid and mineral constituents plays a vital role in bone's elastic behaviour, and surface drying for as little as 30-60 seconds can affect the bone's mechanical properties (McElhaney *et al.* 1964, Reilly & Burstein 1974).

Further consideration of the structure of each phase is not relevant except to note that trace element deficiencies operate at a molecular level, and these may also affect the mechanical properties of the bone (Herrmann & Liebowitz 1973).

### 2. Ultrastructure

The ultrastructure of bone refers to the interrelation between the three constituent phases. The collagen molecules are approximately 200 times longer than they are in diameter (3 000 Å x 15 Å). They are bound end to end into microfibrils, and groups of microfibrils are further bound into fibrils. The bonds between the ends of the collagen molecules and between the parallel sides of the microfibrils are dependent on crystals of the mineral phase (Lees & Davidson 1977, Lees 1981). Approximately 80% of the mineral phase is incorporated into the intrafibril structure (Lees 1981). The fibrils are ordered into fibres by a similar mechanism of crystal bridging of the parallel sides of the fibrils (Herrmann & Liebowitz 1973, Lees 1981). The liquid phase is dispersed in the free space between the crystals and the collagen molecules.

The resulting composite of brittle crystal and elastic organic phases is stronger than either phase alone (Shipman *et al.* 1985).

### 3. Microscopic structure

At a microscopic level the fibres form sheetlike structures (called lamellae) within which there exists a preferred collagen fibre orientation (Davis 1985). The geometry of the sheetlike structures is related to the formation of the bone by cells known as osteoblasts and the subsequent dissolution of tunnels through the bone by giant cells known as osteoclasts. These tunnels are integral to the formation of blood vessels and are known as Haversian canals or osteons. Between 4 and 20 concentric layers of lamellar bone surround each osteon. The fibres in each lamellae spiral around the osteon, but the spiral orientation changes in each successive layer (Herrmann & Liebowitz 1973, Davis 1985). Most osteons are oriented along the long axis of long bones, but they are also interconnected by canaliculi and secondary osteons or Volkman's canals (Herrmann & Liebowitz 1973).

Bone containing a high proportion of the specialised lamellar geometry associated with haversian systems is known as haversian bone. The remainder of the bone with its somewhat more nebulous lamellar organisation is called interstitial lamellar or simply lamellar bone (Herrmann & Liebowitz 1973, Evans 1982, Davis 1985).

The bonding between each lamellae is through a ground substance that acts as a cement (Herrmann & Liebowitz 1973). Cement lines are distinct under low magnification, and they have an important role in absorbing the energy associated with stress (Dempster & Coleman 1960, Piekarski 1970, Herrmann & Liebowitz 1973, Robertson *et al.* 1978).

### 4. Macroscopic structure

There are typically two types of bone distinguished by their structure or architecture at a macroscopic scale. In most terrestrial animals the midshaft (diaphysis) of long bones consists of compact haversian and lamellar bone. There is no consistent open volume apart from a large central marrow cavity. In contrast to this the ends (epiphysis) of bones are made from an intricate three dimensional lattice of boney plates or sheets supported by interconnected columnar spicules known as trabeculae (Carter & Hayes 1976, Davis 1985). The precise architecture of the lattice varies in accordance with the weight bearing demands on the bone (Weaver & Chalmers 1966, Pugh *et al.* 1973*a*, Behrens *et al.* 1974, Vahey *et al.* 1987). There is little or no haversian bone in the matrix which is known as trabecular or cancellous bone. The volume of interconnected pores makes up approximately 75% of the volume in human cancellous bone (Dyson *et al.* 1970) and it is filled with marrow. This is protected by a thin, dense surface of cortical bone (metaphysis).

The overall structure of bone is related to its function both as an organ (Currey 1979) and as a structural member (Shipman *et al.* 1985). In the latter regard it appears as if the mechanical properties of bone differ with respect to the biological orientation of stressing. This is illustrated by the somewhat greater strength of long bone diaphyses when tested in the direction of natural load bearing than when tested perpendicular to this axis (Dempster & Liddicoat 1952, Dempster & Coleman 1960, Yamada 1970, Herrmann & Liebowitz 1973). Currey (1979) measured the properties of bones with different functions (long bones, antlers and a non-weight bearing bone found in the ear of whales) and found the variability in their characteristics to be adaptive to their purpose.

## Strain in bone

From an archaeological perspective the ultimate failure of a bone equates to its destruction (or partial destruction if there are areas of greater strength present on the bone). If a bone is destroyed entirely then an understanding of its strength characteristics will explain its low representation on archaeological sites. The main concern, however, is with the bones or bone fragments that are preserved. For this the characteristics of bone deformation prior to failure are likely to be the most informative.

The macroscopic deformation (strain) that results when bone is subjected to stress is the result of several complicated strain responses. Each level of bone structure passes through several strain phases that are best illustrated under conditions of static loading. Initially stress is absorbed by compression in the intermolecular free space within the ultrastructure of the bone (Dempster & Liddicoat 1966, Lees 1981). This allows a degree of microscopic and macroscopic compression, tension, bending and twisting without any permanent distortion occurring. When the stress is released, the molecular structure returns to its original organisation and the higher order structures are also reformed to their original shape. All the energy expended in deforming the bone is recovered.

This type of deformation is known as *linear elastic strain.* It is characterised by a linear relation between stress and strain - increased loading on the bone results in a proportional increase in the strain. The constant of proportionality is known as the *modulus of elasticity* or *Young's modulus* (*E*). Materials that demonstrate this property are said to obey Hooke's Law (Hall 1974).

In linear elastic deformation, strain is equally distributed throughout the column through which the force is directed. Mathematical analysis of strain distribution through materials with cellular macrostructures indicates that elastic response is complicated by the array of possible deformations of cellular members with different orientations relative to the applied load (Gibson & Ashby 1982, Klever *et al.* 1985, Williams & Lewis 1982, Pugh *et al.* 1973*b*). The strain distribution throughout such a column is not even, and elastic collapse occurs in a single layer of cells at a time. The overall response of the material is nevertheless elastic, but the elastic modulus is a function of the dimensions of the tested column (Gibson & Ashby 1982). Such elastic behaviour is known as *nonlinear elastic deformation.*

The intermolecular free space that permits the elastic response is limited, and when the stress levels exceed a threshold value the crystal forming the interfibril and intrafibril bonds impinge on one another to form new bonds in a stable high energy state (Lees & Davidson 1977, Lees 1981). Permanent or *plastic deformation* is the result and the ultrastructure cannot return to its original state. When strain passes from elastic to plastic deformation the material is said to be *yielding* (Hall 1974). Increased stress results in further nonreversable deformation which implies that energy is expended on the bone.

Plastic and elastic deformation are easily identified on a plot of stress versus strain. Elastic strain is represented by a straight line with a gradient equivalent to the elastic modulus. Deviation from linearity with increased stress indicates yielding and the onset of plastic deformation. The area under the stress/strain curve represents the energy required to produce the deformation or *toughness* (Shipman *et al.* 1985). In elastic deformation, energy is conserved and the shape of the stress/strain curve is the same in both loading and unloading (Bonfield & Li 1966). In plastic deformation none of the strain is recovered on unloading. Bone, however, demonstrates a small degree of reformation 5 to 10 minutes after unloading, even when plastic deformation has occurred (Bonfield & Li 1966, Yamada 1970, Linde & Hvid 1987). This response is called *analastic contraction.* In analastic contraction the stress/strain curve differs during loading and unloading indicating a loss in energy.

The extent to which the crystals forming the ultrastructural, and microscopic structural bonds can impinge on one another is limited. When the strain exceeds this limit, the structure can no longer accommodate the force through the mechanism of deformation. At this point the structure is unable to resist the force and it fails. The maximum strain that can be withstood is called the *ultimate strength* of the material.

*Brittle* failure of the material occurs when there is no permanent deformation preceding the failure. If the material passes through phases of elastic and plastic deformation before failing it is *ductile.*

## Variables in strain in bone

Bone structure is a major determinant in bone deformation, but several external factors make a substantial contribution. The most significant of these is moisture. It was stated earlier that elastic deformation in bone is dependent on the liquid filled free space between the collagen molecules and the hydroxyapatite crystals. When the bone dries the matrix shrinks, causing a reduction in the free space. The ultimate tensile strength, ultimate compressive strength, hardness and the modulus of elasticity were empirically determined to increase (Evans & Lebow 1951, Dempster & Liddicoat 1952, Dempster & Coleman 1960, Ascenzi & Bonucci 1964, Yamada 1970). The degree of plastic deformation before failure decreases resulting in brittle fracture (Townsend *et al.* 1975).

The moisture referred to above is that included within the bone ultrastructure. The presence or absence of marrow in the porous macrostructure of cancellous bone has little or no effect on the mechanical properties of the bone (Pugh *et al.* 1973*a*, 1973*b*) except at very high strain rates (Carter & Hayes 1976).

When bone is heated to temperatures in excess of 185°C to 200°C or cooled below -100°C, the moisture contained within the collagen and hydroxyapatite is affected (Lees 1981) resulting in microscopic structural changes (Shipman *et al.* 1985) and concomitant changes in the mechanical properties of these constituents. There is a substantial reduction in the ultimate strength and toughness of the bone, and an increased tendency for brittle fracture to occur (Bonfield & Li 1966, Shipman *et al.* 1985). Yamada (1970) reported results of tensile testing of bone that had been buried for 100 years. While it is not explicit, the moisture content of the collagen and mineral phases must have been significantly altered. The tensile strength was reduced to only 50% of that of unburied bone which contrasts with fresh dried bone which has increased tensile strength.

The temperature at which bone is tested has an effect on the mechanical properties that is independent of the moisture content (Herrmann & Liebowitz 1973, Shipman *et al.* 1985). At higher temperatures the ultimate tensile strength and energy of fracture are reduced, although this is not as significant as that produced by moisture content changes. Heating to 350°C-400°C destroys the organic matrix and further heating to 750°C-800°C causes recrystalisation of the inorganic phase (Shipman *et al.* 1985). The bone is rendered brittle and weak.

In attempting to model bone survival on the basis of density, Binford & Bertram (1977) predicted non-allometric variation in this parameter with growth. This is not the case with respect to the mechanical properties of bone. No significant age related variation in the ultimate tensile strength (Evans & Lebow 1951, Reilly & Burstein 1974), the ultimate compressive strength (Weaver & Chalmers 1966) or ultimate shearing strength (Evans & Lebow 1951) has been found. Likewise there is little change in the hardness of bone after skeletal maturity is reached (Weaver 1966). Yamada (1970) reported results showing a decrease in ultimate tensile strength, ultimate compressive strength and hardness with old age, but the significance of these results is debatable (Herrmann & Liebowitz 1973).

The rate at which strain is applied is significant in determining the response of the bone. The higher the strain rate, the higher the modulus of elasticity, the ultimate tensile strength (Currey 1975, Carter & Hayes 1976, Davis 1985) and the ultimate compressive strength (Carter & Hayes 1976). There is also a reduction in the energy of fracture (Robertson *et al.* 1978). If the mechanical properties of a material are dependent on the strain rate, they are said to be *viscoelastic* (Pugh *et al.* 1973*a*, Reilly & Burstein 1974, Linde & Hvid 1987).

Carter & Hayes (1976) demonstrated a linear log/log relation between strain rate and ultimate strength in the trabecular and cortical bone of the human radius and bovine femur. This study showed that the variation in the strength of trabecular bone when tested at different strain rates was the same as that of cortical bone, but the absolute strength values were significantly less. This was true despite their similarity in density. It was also noted that the presence of marrow in trabecular bone only affected its mechanical properties when tested at extremely high strain rates. It has been suggested that the modulus of elasticity should only be determined at low strain rates (Linde & Hvid 1987).

The basis for the variation in the mechanical properties of bone in response to variation in the strain rate will be discussed under the heading "failure in bone".

## Anisotropy in bone

When the sources of variability described above are held constant, there remains a substantial amount of variability in the physical properties measured at different locations on a bone and also in different orientations at the same location. This is partially related to the variability in the ultrastructure, but is also an intrinsic property of bone. For example, the compressive strength in any orientation within a bone is generally greater than the tensile strength which is greater than the shearing strength (Evans & Lebow 1951, Dempster & Liddicoat 1952, Dempster & Coleman 1960, Simkin & Robin 1973). This suggests that bone subjected to bending should fail on the outside of the curvature where the stress is tensile and not on the inside where the bone is under compression (although Simkin & Robin (1973) have observed examples of compressive failure in bending). The modulus of elasticity, in contrast to the ultimate strength, is greater in tension than in compression (Evans & Lebow 1951).

This characteristic of bone is called *anisotropy.*

### 1. Position related anisotropy

Evans & Lebow (1951) measured the elastic modulus, hardness and the ultimate tensile and shearing strengths of the proximal, midshaft and distal human femur. The elastic modulus and hardness were greatest in the midshaft followed by the distal and then the proximal samples. The tensile strength was greatest in the midshaft and the proximal and distal samples had similar values. The variability in shearing strength was more complicated. In dry bone the shearing strength was greatest in the proximal samples and decreased towards the distal end of the bone. In wet bone the midshaft had the greatest shearing strength and the distal samples the least. In cancellous bone the compressive strength and elastic modulus of the proximal canine femur are greatest near the articular surface (Vahey *et al.* 1987).

The mechanical properties do not only vary from position to position along the length of a bone, but also between the medial, lateral, anterior and posterior sectors. The ultimate tensile strength, measured longitudinally from the lateral human femur was greater than the other sectors while the anterior sector was the weakest (Evans & Lebow 1951).

### 2. Orientation related anisotropy

The ultimate tensile strength, ultimate compressive strength and elastic modulus of cortical bone are greater when measured along the longitudinal axis of the bone than when measured radially (Dempster & Liddicoat 1952, Herrmann & Liebowitz 1973, Davis 1985, Klever *et al.* 1985, Vahey *et al.* 1987). There are no significant differences between the radial measurements of these values and those made in a tangential direction. Hardness values measured radially in the cortical bone of the human femur are also approximately the same (Yoon & Katz 1976) except at the endosteal and periosteal surfaces where a great deal of variability was observed (Weaver 1966).

The shearing strength of cortical bone is dependent on the orientation of the stress relative to the fibre orientation. Fracture along the fibre grain (between the fibres) requires between 50% and 70% of the stress required to fracture across the fibre grain (breaking the fibres) (Davis 1985, Yamada 1970). This is also reflected in the toughness (energy to fracture) associated with shearing failure (Bonfield & Li 1966).

Much of the variability in the characteristics of bone is related to the fibre orientation in cortical bone and the trabecular orientation in cancellous bone (Herrmann & Liebowitz 1951, Davis 1985, Yamada 1970, Bonfield & Li 1966). The precise mechanisms will be discussed under the heading "failure in bone".

### 3. Anisotropy in bone elasticity

The anisotropic variability in the elastic modulus of bone was found to be extremely closely related to $\rho_b$, but regression calculated for tests in any orientation were quite different from tests in any other orientation (Klever *et al.* 1985). When measured radially and tangentially the elasticity values are only half of those obtained in longitudinal measurements from the trabecular bone of the proximal human tibia (Goldstein *et al.* 1983, Klever *et al.* 1985). Similarly, Williams & Lewis (1982) presented two orientation specific regressions relating the cross sectional area fraction (there is a strong interdependence between the area fraction and relative volume or $\rho_b$ (Dyson *et al.* 1970)) of cancellous bone to the elastic modulus. The orientation dependence implies that the elastic modulus cannot strictly be determined from $\rho_b$ which is independent of orientation. The reason is that trabecular bone has slightly different mechanisms of deformation depending on the relative direction of the stress to the trabeculae and sheetlike structures.

In terms of the ultrastructural mechanisms of bone deformation described in an earlier section, Currey's (1975, 1979) determination that increased ash content or mineralisation, results in an increase in the elastic modulus is reasonable. This is related to a decrease in void space within the bone matrix and reduced potential for intermolecular free movement. In cortical bone the preferred crystalline orientation parallels that of the organic phase, and anisotropic variability in the elastic modulus is related to the orientation of the test relative to the bone fibres (Yoon & Katz 1976).

Another possible variable in the elastic behaviour of cortical bone is related to the presence of osteons. Simkin & Robin (1973) predicted the value of the elastic modulus in bending on the basis of the compressive elastic modulus for the inside of the bend, and the tensile elastic modulus for the outside of the bend. The observed elastic modulus was greater than both moduli. This was attributed to the different orientation of the haversian system relative to the stress in tensile/compressive testing and in bending.

The complicated mechanisms of elastic deformation in bone cause the elastic modulus to be dependent on the size of the sample under examination. This is expressed as the length/width ratio of the sample by Dempster & Liddicoat (1952) and as the length/ radius of gyration ratio (slenderness ratio) by Townsend *et al.* (1975), and it may be the cause of the variability in the elastic modulus values measured by different researchers.

## Failure in bone

### 1. Trabecular bone

The bone material that makes up the trabecular matrix has the same elastic modulus as cortical bone (Townsend *et al.* 1975). It accommodates an equal amount of stress (Vahey *et al.* 1987) and strain (Turner, C. 1989) before yielding, irrespective of the orientation of the test relative to the trabecular structure, and its viscoelastic properties are the same as those of cortical bone (Pugh *et al.* 1973*a*). This suggests that the bone material that makes up the lattice is the same throughout the trabecular structure, and that it is also the same as the bone material that makes up the cortical structure (Pugh *et al.* 1973*a*, 1973*b*, Carter & Hayes 1976). The variability in material properties between cortical and cancellous bone, and between different orientations within each structure, is, therefore, related to the macrostructure (Morlan 1980). In cancellous bone it is specifically a function of the trabecular orientation (Pugh *et al.* 1973*b*, Weaver & Chalmers 1966, Williams & Lewis 1982).

The mathematical model derived by Gibson & Ashby (1982) for describing the deformation of synthetic foams provides an excellent analogue for trabecular deformation. It is based on the assumption that the stress is transmitted through the thickest part of the cell wall where three or more cells are joined. The structure then resembles a lattice of beams that compress, bend or shear depending on the orientation of the stress. Such an "open cell" model closely resembles the structure of cancellous bone, and similar approximations have been used in many other models of cancellous bone deformation (Pugh *et al.* 1973*b*, Williams & Lewis 1982, Klever *et al.* 1985).

Gibson and Ashby's (1982) model predicts that the distinction between shearing and bending is dependent on the length of the beamlike structures (analogous to trabeculae). The relative density ($\rho_b/\rho$ ) is used as an index of their average length. Values of less than 0.1 indicate that each beam is long enough to bend, while if the value increases to 0.3 the reduced free length inhibits bending. If the value reaches 0.6 then shear becomes the dominant factor. The slenderness ratio (length/radius of gyration) used by Townsend *et al.* (1975) in measuring compression of individual trabeculae is also an index that relates the mechanism of deformation to the free length.

Plastic deformation through bending, shearing and compressing the macroscopic structure of cancellous bone is known as *buckling*, and it is suggested as the main form of deformation in compression (Pugh *et al.* 1973*b*, Carter & Hayes 1976, Gibson & Ashby 1982). The yield characteristics in buckling are related to the length of the trabeculae and a significant positive correlation exists between $\rho_b$ and $V_v$ (volume fraction = $\rho_b/\rho$= relative density) (Pugh *et al.* 1973*a*, Turner, C. 1989). The ultimate failure of trabecular bone can be seen under magnification to be through shear (Dempster & Liddicoat 1952, Behrens *et al.* 1974). The ultimate strength is, therefore, not related to true density (Vose 1962, Behrens *et al.* 1974), but to the bulk density (Behrens *et al.* 1974, Carter & Hayes 1976) or the cross sectional area fraction (which is partially based on trabecular orientation) (Behrens *et al.* 1974).

The ultimate strength of radially compressed trabecular bone from the proximal human tibia has also been related to the bone mineral content, but the relation is not good (Linde & Hvid 1987). High correlation coefficients were also obtained for the relation between the ash content of cancellous bone from human vertebrae and calcanaea, and the compressive strength (0.827 and 0.811 respectively) (Weaver & Chalmers 1966).

### 2. Cortical bone

Whereas the failure in cancellous bone is governed by the trabecular orientation and the free length of the trabeculae, the failure of cortical bone is dependent on the composite nature and orientation of lamellae (Yoon & Katz 1976, Hayes 1981, Evans 1982), specifically those associated with the haversian system (Dempster & Liddicoat 1952). When the stress is tangentially or radially oriented, the failure takes the form of a crack. At low strain rates the crack propagates along the cement lines between the haversian canals because they represent a path of inherent weakness (Dempster & Coleman 1960, Piekarski 1970, Robertson *et al.* 1978, Davis 1985), particularly in dry bone where shrinkage causes cement line cracking (Reilly & Burstein 1974). The failure mechanism ensures that the blood supply in the osteons remains intact (Piekarski 1970).

If a lacuna, secondary osteon or even a primary osteon is penetrated by the crack, the stress is spread over the circumference of the void, and more energy is required to continue the propagating of the failure (Piekarski 1970, Davis 1985). Consideration of the microscopic stress mechanisms in such a scenario reveals that circular holes and soft inclusions reduce the stress through an antisymmetric rotational stress (couple stress) at the point of crack propagation (Lakes 1982).

At high strain rates the mechanism breaks down, and a catastrophic crack propagates through the bone, irrespective of the presence or orientation or microstructural elements. The energy required to produce the failure is less than in low strain rate failure because the fracture path is shorter (Piekarski 1970, Robertson *et al.* 1978). Piekarski (1970) calculated the difference in the crack length on the basis of the energy absorbed during fracture. At a high strain rate the fracture length was 1.3 mm, while the cement line propagation around the haversian canals in low strain rate failure produced a 76.5 mm crack for a sample of the same size.

Tensile failure in a longitudinal orientation requires the snapping of the osteons and constituent fibres. While the temperature history of the bone plays a role in determining the fracture morphology (Bonfield & Li 1966), the fracture plane of unheated bones was found by Dempster & Liddicoat (1960) to be oriented at approximately 45° to the axis of stress. The fracture surface is also characterised by protruding osteons that "pull out" (Piekarski 1970). These observations indicate that there is a substantial shear component in the longitudinal tensile failure of cortical bone (Dempster & Coleman 1960, Piekarski 1970, Reilly & Burstein 1974), which increases the surface area of fracture and hence the energy of fracture.

Under longitudinal compression the fracture plane is oriented at 60° to the stress (Reilly & Burstein 1974). Shear failure occurs between the bone fibres which allows them to bend. The failure mechanism is, therefore, shearing and buckling (Dempster & Liddicoat 1952).

Evans (1982) suggested that the higher frequency of osteons, and hence cement lines in the human femur relative to the tibia, was responsible for its lower tensile strength. Vose's (1962) analysis of samples of bone taken from the human tibia produced no significant relation between the frequency of osteons and the ultimate tensile strength.

There is, however, a significant relation between the spiral orientation of the fibres in haversian bone and strength. The crystals of steeply spiralling osteons have a preferred orientation that appears dark under polarised light while a low angle of spiral appears light (Yoon & Katz 1976, Evans 1982). The higher the frequency of light osteons, the lower the ultimate tensile strength, ultimate shearing strength and the elastic modulus.

The presence of shearing mechanisms in cortical bone failure implies that the mineral content plays a significant role in determining the energy of failure (Piekarski 1970). Vose & Kabula (1959) and Vose (1962) also obtained a significant relation between the ultimate bending strength of human long bones and the degree of mineralisation or X-ray determined ash content.

**Implications of bone characteristics for modelling bone survival**

If a bone assemblage is subjected to any force regime: compressive, tensile, torsional, shearing, or any combination of these, then bone destruction may occur. Clearly this is a complicated process that is dependent on the orientation of the force relative to the individual bones, their moisture content, the strain rate, the temperature and the temperature history as well as the mineral content of the bone. Any index that accommodates the anisotropy will be so complicated that it will have little practical value to the archaeologist. This is a problem that will be encountered in any index of survival.

To develop a practical index of bone survival it is necessary to assume that some of the variables such as the moisture content, strain rate and temperature are constants within an assemblage, and that aspects of bone anisotropy, such as that related to orientation, are negligible. Making such assumptions is reasonable, but in special circumstances such as selective burning the assumptions will be invalid, and any index based thereon will also be inaccurate.

If it is assumed that the ultimate strength of the bone is a measure of its survival potential, then the tensile strength, compressive strength, shearing strength and torsional strength would suffice as indices under the relevant destructive regimes. Unfortunately these measurements require sophisticated equipment and the required resolution can only be achieved under the rarest of circumstances. The task at hand is to investigate if any other index is an adequate analogue to ultimate strength.

The criteria that must be met by an index of bone survival are that it should be measured with adequate intra-bone resolution in the light of the noted position related anisotropy, and that it provides a consistent measure of bone survival potential at three levels: within any single bone, between several bones of a species, and also between the bones of different species. The last point is important because although complimentary ultimate strength and density measurements do not exist for seal bones, they do for other species. If density, or any other measure, can be shown to be consistently related to strength using existing observations this will reflect on how appropriate an index of bone survival it is. Likewise any inconsistencies will reflect how inappropriate it is. Any index that can be shown to apply in general, should also be applicable to the remains of seals.

## Density, mineral content, hardness and bone strength

The two indices that have been proposed, density and photodensity, can be assessed in the light of the principles and mechanisms of bone deformation established in the preceding discussion. Since this research deals exclusively with seals, and since seal bones contain little or no cortical bone, the discussion will concentrate on trabecular bone. Similarly, taphonomic processes such as carnivore gnawing, profile compaction and trampling are typically compressive stresses, and while torsional and bending forces may affect longer bones such as ribs, the generally short, robust nature of seal bones suggests that compression is the primary mode of deformation. Davis (1985) has dealt with bending and torsional failure of terrestrial mammal long bones.

### Density

Lyman (1984) compared bone assemblages with known attrition histories to three different indices of density. The measure that closest approximated true density was found to be the worst predictor of survival in almost every case, while the index that approximated bulk density was the best. It has also been shown that the ultimate strength of bone in biomechanical testing is very poorly related to true density, if at all, while bulk density is significantly related to compressive strength (Behrens *et al.* 1974, Carter & Hayes 1976, Klever *et al.* 1985). The reason for this distinction is that the buckling mechanism of deformation is dependent on the free length of the bone's structural members, and not on their composition. True density is related to the molecular and ultrastructure and varies very little through the bone structure, while bulk density is more sensitive to the macrostructure, particularly in distinguishing cortical from trabecular bone.

The use of bulk density to index attrition assumes that it governs the intra- as well as inter- bone chances of survival. Its validity in discerning survival between bones is questionable. For example the longitudinal compressive strength of the cancellous bone of the human knee is predicted by

$\sigma_{uc} = 1210\rho_b - 147$ ($p<0.001$) (Behrens *et al.* 1974:203)

and for the proximal tibia by

$\sigma_{uc} = 41 \times 10^2\rho_b^{1.5}$ ($r=0.82$) (Klever *et al.* 1985:169)

Samples of these two bones that have the same density, will have different compressive strengths, and hence different survival potential under compressive stress.

### Photodensity

The primary role played by the mineral phase in bone deformation is the basis for using photodensitometer, X-ray and bone ash determined mineral content to predict bone strength. In each case the mineral content can be related to the volume of the bone to provide a rough measure of the density (bulk density) of the bone (Chalmers & Weaver 1966). While bulk density is sensitive to the free length of structural members, the bone mineral content is also sensitive to the plastic deformation mechanisms involved in buckling.

Bone mineral content has been shown to be closely related to the bending strength of bone (Vose & Kabula 1959, Vose 1962, Borders *et al.* 1977) as well as the compressive strength. Behrens *et al.* (1974:203) obtained the regression

$$\sigma_{uc} = 354U_b - 78 \text{ } (p<0.001) \text{ } (U_b = \text{photon absorption})$$

and Linde & Hvid (1987:84) got

$$\sigma_{uc} = -19.5 + 18.5\text{BMC} \text{ } (r=0.88, p<0.001)$$

for longitudinal compressive failure of trabecular bone from the human knee. As is the case in bulk density, bone mineral content does not predict the differences between longitudinal and radial/tangential strength.

In a study of human cancellous bone, Weaver & Chalmers (1966) also obtained significant regressions relating ash content to compressive strength ($r>0.8$) for both lumbar vertebrae and the calcaneum, however the difference in strength between the two bones was not predicted on the basis of bone mineral content. Samples of vertebral bone with a mineral content of 22-26 g/cc had the same compressive strength as calcaneal samples with only 0.15-0.3 g.cm$^{-3}$. In the Linde & Hvid (1987) study, samples were tested to 50% of their ultimate strength predicted on the basis of bone mineral content - 28% failed, one at less than 25% $\sigma_{uc}$. The implication is that the anisotropic compressive strength of trabecular bone is not dependent on the mineralisation or the structure alone, but on both (Weaver & Chalmers 1966, Carter & Hayes 1976).

### Hardness

The use of hardness as an index of bone survival is also problematic. Standard tests such as the Rockwell, Brinell and Vickers hardness tests are based on the plastic deformation caused when an indenter of standardised geometry is forced into the surface of the material with a predetermined load (Schlenker 1974). In materials such as metal the mode of deformation is viscous or semiviscous flow, whereas the buckling mechanism of bone involves plastic, elastic, viscoelastic and compressive failure mechanisms (Yoon & Katz 1976). The plastic strain produced in bone hardness testing is related to the bonding between the crystals of the bone. Demineralisation relieves the strain, indicating that a substantial amount of the deformation in the collagen is elastic (Lees 1981). Measurement of the deformation on porous materials such as bone is imprecise, and macroscopic hardness tests are not valid (Cottrell 1975).

To avoid these complications, bone hardness tests have been carried out at a microscopic level using small indenters and low stresses (Evans & Lebow 1951, McElhaney *et al.* 1964, Weaver 1966, Yamada 1970, Yoon & Katz 1976, Lees 1981). While the microhardness is related to the bone mineral content in both trabecular and cortical bone (Weaver 1966), the deformation only occurs in the submicroscopic structure (Lees 1981). The mechanisms that are responsible for the anisotropy in bone, and that determine its overall mechanical properties, are related to the macrostructure, and such measurements would be of little value in predicting bone survival.

**Measuring hardness**

One technique for measuring hardness (of wood) is based on the stress required to obtain a standard deformation (as opposed to the strain caused by a standard stress). It involves forcing an 11.3 mm diameter steel ball into the wood to a depth of half of the ball's diameter. The force required to do this is a direct index of hardness (Schlenker 1974). A similar procedure was used by Behrens *et al.* (1974) on bone. A 0.785 $cm^2$ circular indenter was forced into the bone samples at a constant rate. The force and indenter displacement were monitored. The indenter was advanced until the bone yielded and failed. A stress/displacement plot, similar to a stress/strain curve, was obtained. As in the wood hardness test, the stress required to produce a standard deformation can be determined directly from the stress/displacement curves. The analyst has the flexibility to choose the standard deformation after the testing is completed. However, in this test the load was not transmitted in a linear fashion through the bone, and instead of exclusively compressive strain occurring, the bone was sheared at the edges of the indenter. Furthermore nonlinear elastic/plastic deformation occurs in front of the indenter. Since the mode of deformation differs from conventional tests, this method of determining hardness is not directly comparable with other techniques.

The measure of bone strength obtained in such a test is superior to both density and photodensity, first in that the basis of the test - the production of a localised compressive deformation - is directly analogous to the mode of bone attrition in many taphonomic processes, especially carnivore gnawing and profile compaction; and second because the logical or causal relation between bone strength and its ability to resist deformation is direct. The measurement is of the force required to deform the bone at every level of its structure. The contribution of independent variables such as structural free length and bone mineral content are automatically incorporated into the test.

The only outstanding variable that needs to be addressed is the contribution of the orientation related variability in the compressive strength of bone. The primary distinction is between the longitudinal strength and the radial/tangential strength. If it is assumed that the taphonomic stresses are normally oriented relative to the surface of the bone, then purely on the basis of surface area, the chances are that loading will be in the radial orientation. The hardness tests are measured radially and so it is not a valid index in taphonomic processes in which stress is not compressive or is not oriented perpendicular to the bone surface.

It is important to note that whereas bulk density and photodensity are scalars (they are not measured in any orientation), hardness tested by this technique is a vector, and measurements taken in different orientations relative to the trabecular structure will reflect the strength variations brought about by the structure.

### Stress/displacement analysis

Hardness tests of seal bones were carried out in the Department of Mechanical Engineering at the University of Cape Town. An *ESH Testing* machine with a 10 kN load cell was linked to an automated controller and a PCM 80286 computer to capture the data. A standard Rockwell A, C, and D test indenter, which is a diamond cone with an internal angle of 120° and a diameter of 5 mm, caused the bone to break and crack. The force required to generate enough stress for the bone to yield and fail over the indenter's cross-sectional area of approximately 20 $mm^2$ was too great. Reducing the indenter diameter to 4 mm (tested area of c.12.5 $mm^2$) proved adequate. The indenter was advanced at a constant rate of 0.07 mm/s. When it penetrated the bone surface the force required to maintain the constant rate was measured. Results were automatically graphed with indenter displacement in mm on the X-axis and force measured in kN on the Y-axis (figure 5.2).

The cross-sectional area of the indenter is large enough to assume that the macroscopic structure (in cancellous bone for example) is averaged, but small enough that regional variations in hardness are not averaged. Likewise, the depth to which the indenter penetrated had to satisfy these conditions. A maximum penetration of 5 mm was eventually used. The tests using the described apparatus are, therefore, the closest approximation that can be practically obtained for a bone's ability to resist destruction at a point.

Measuring hardness at a point facilitates high resolution mapping of inter- and intra- bone variability. The precise location of the indents affects the result, and to ensure reproducibility, it is essential to define the exact location of the test. Unfortunately the nomenclature defining positioning on bones does not allow precise enough resolution. I have, nevertheless, described the general location of the

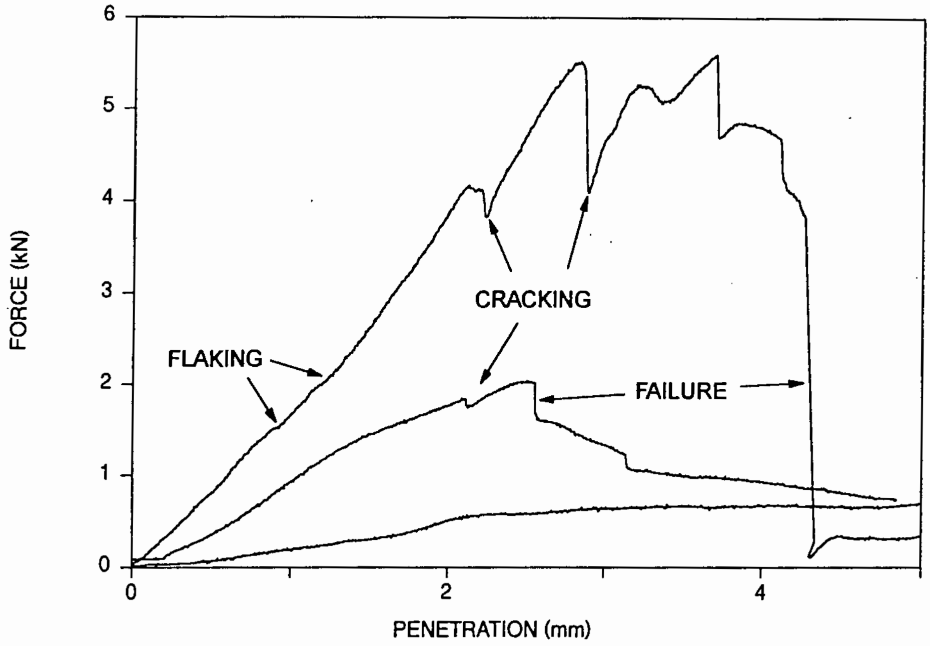

**Figure 5.2** *Hardness measurements were made by forcing an indenter of predefined geometry into the surface of the bone at a constant rate. The penetration (analogous to strain) was automatically logged against the force (analogous to stress) that was required to maintain the constant rate of penetration. The three measurements presented here are from a cow femur because it clearly illustrates the nature of the testing. Similar plots for all the tests done on seal bones are presented in appendix B.2.*

tests (appendix B.1 and tables 5.1 and 5.2). Extrapolating values from a point to an area of a bone is unsound, but, provided multiple testing is carried out on each sample, the chances of obtaining significant errors is reduced. In this regard it was considered beneficial to maximise the testing on a single seal skeleton at the expense of measuring many skeletons. Taking many measurements on each bone also provides a good mapping of position related strength anisotropy.

The seal bones that were tested were from sample AP 3930 which was dissected in developing the utility index. The specimen was a large male of 175 cm length and 117.5 kg mass. The bones were dry when tested. Stress/displacement curves are presented in appendix B.2.

### Theoretical derivation of the hardness indices

### 1. Force index

There are two measures of hardness that can be derived from the force/deformation curves. The first is a direct reading of the ultimate compressive strength of the bone structure.

There were three forms of structural failure observed during the experiment. Each was a means of stress relief indicated by a reduction in the force required on the indenter. The first failure, and the one that invariably required the least force, was flaking. Small flakes of bone were detached from the surface of the harder bones in the vicinity of the indenter. The resultant stress relief was small in comparison to the other forms of structural compromise (Fig. 5.2).

The second mechanism of stress relief was cracking. Cracks varied from micro-cracks, that could not be seen but could be heard and monitored, to macroscopic splitting. The stress relief with this type of failure is considerable and instantaneous (Fig. 5.2).

Both of these mechanisms are the result of point loading, and, while they reflect qualities of the material, they are specific to the circumstances of the hardness test (dry bone). The observations cannot be generalised to predict analogous failure of seal bones during taphonomic processes.

The observed nature of the bone destruction during testing is mostly plastic. This means that the indent that is formed never reforms to the original, pre-indent shape, as is the case in elastic deformation (Hall 1974). When the force on the bone is increased, the amount of plastic deformation (breaking) increases until the ultimate stress is exerted. After this point the force required to further advance the indenter decreases. If a force greater than the threshold value can be exerted on a bone, it will be totally destroyed.

It is proposed that the amount of force that a bone can be subjected to before it is totally destroyed is a direct measure of the likelihood that it will survive mechanical destructive processes. The first index of hardness is, therefore, based on this. Ultimate Strength analogue values are presented in appendix B.1 and summarised in table 5.1. For convenience the results are simplified into proximal, midshaft, distal and epiphyses in table 5.1. These terms apply specifically to long bones, but for non-long bones the measurements are tabulated under "mid-shafts".

### 2. Hardness - Young's Modulus analogue

In many of the tests it is possible to identify a portion of the force/displacement curve in which the relation approximates linearity. This is typical of elastic deformation. Elastic deformation has two relevant properties. As the indenter is removed the material reforms to its original shape and the energy of deformation (the area under the curve) is conserved. There are, however, some fundamental contradictions in the bone's behaviour that are brought about by the boundary conditions of the test.

| | Proximal Epiphysis | Proximal Shaft | Mid-Shaft | Distal Shaft | Distal Epiphysis |
|---|---|---|---|---|---|
| **Jaw** | 1.87 | 1.44 | 2.65 | 4.30 | |
| **Atlas** | | | 2.04 | | |
| **Axis** | | | 1.30 | | |
| **Cervical 3** | | | 0.90 | | |
| **Cervical 4** | | | 0.74 | | |
| **Thoracic 1** | | | 1.05 | | |
| **Thoracic 2** | | | 0.61 | | |
| **Lumbar 1** | | | 1.16 | | |
| **Lumbar 2** | | | 1.10 | | |
| **Sacrum** | | | 0.66 | | |
| **Caudal 1** | | | 0.62 | | |
| **Caudal 2** | | | 0.78 | | |
| **Rib 1** | 0.82 | 2.25 | | 1.96 | 0.70 |
| **Rib 2** | 0.84 | 1.89 | 2.53 | 1.84 | 0.64 |
| **Rib 3** | 0.55 | 1.38 | | 1.80 | 0.43 |
| **Sternum 1** | | | 1.61 | | |
| **Sternum 2** | | | 0.56 | | |
| **Scapula** | | | 3.27 | | |
| **Humerus** | 1.51 | 1.06 | 5.58 | 1.27 | 1.68 |
| **Radius** | 3.14 | 4.81 | 5.47 | 0.83 | 2.20 |
| **Ulna** | | 0.61 | 2.60 | 0.57 | |
| **Metacarpal 1** | | 0.86 | 0.66 | 0.45 | |
| **Metacarpal 2** | | 0.86 | | 0.90 | |
| **Phalange 1** | | | 1.28 | | |
| **Phalange 2** | | | 0.56 | | |
| **Phalange 3** | | | 0.24 | | |
| **Pelvis** | | | 1.92 | | |
| **Femur** | | 1.22 | 5.97 | 1.25 | 0.49 |
| **Tibia** | 2.24 | 1.02 | 2.15 | 0.90 | 0.78 |
| **Fibula** | | 0.40 | 1.85 | 1.56 | |
| **Metatarsal 1** | | 0.36 | 1.65 | 0.88 | |
| **Metatarsal 2** | | 0.36 | 1.76 | 0.82 | |
| **Calcaneum** | | | 1.10 | | |
| **Astragalus** | | | 1.11 | | |
| **Cuboid** | | | 1.15 | | |
| **Carpal 1** | | | 1.89 | | |
| **Carpal 2** | | | 0.88 | | |
| **Carpal 3** | | | 1.18 | | |
| **Carpal 4** | | | 0.56 | | |

**Table 5.1** *Summary of the ultimate strength values obtained for seal bones (kN). The description of the test locations is presented in appendix B1. The terms used here are specifically for long bones. For non-long bones the measurements are tabulated as "mid-shaft" values.*

The scale of distortion used in the test resulted in plastic distortion of the bone, at least at a macroscopic level. In other words the architecture of the bone was permanently destroyed by the indenter. A portion of the energy expended in advancing the indenter was lost on extraction because of this. The linear behaviour of the bone is, therefore, not strictly the result of elastic deformation, but rather a ombination of plastic deformation of the macroscopic bone architecture, and the elastic deformation of the microscopic bone matrix. The linear behaviour of the bone, nevertheless, provides an index that relates stress to macroscopic distortion, and it is the extent of macroscopic distortion that determines the characteristic of a bone assemblage subjected to low level forces. A measure of a bone's ability to resist surface distortion is given by the gradient of the linear portion of the force/displacement curve. The higher the gradient, the greater the force required to obtain a proportional increase in deformation. The linear region of the force/displacement curve can be mathematically described as:

$$\sigma = E\varepsilon$$

where: $\sigma$ = stress exerted perpendicular to the bone surface

$\varepsilon$ = Distortion/Length, or the extent of deformation as a proportion of the overall length of material through which the force is directed.

$E$ = constant equal to the gradient of the line. (Hall 1974: 23)

Because the mode of deformation is essentially nonlinear buckling, it is not accurate to express $\varepsilon$ as the distortion relative to the total length of the material through which the force acts. I have rather chosen to use the absolute displacement values from the surface of the bone. Using displacement instead of epsilon, and acknowledging that the deformation is a complex mixture of elastic and plastic processes, the equation reduces to:

$$\sigma = Ks$$

where: s = displacement from the surface

$K$ = Young's Modulus analogue

The value of $K$, an analogue to Young's Modulus specific to the hardware used in this test, was calculated for each test on each bone to provide a second index of hardness. Young's Modulus analogue values are presented in appendix B.1 and summarised in table 5.2. For convenience the results are simplified into proximal, midshaft, distal and epiphyses in table 5.2. These terms apply specifically to long bones, but for non-long bones the measurements are tabulated under "mid-shafts".

## Results

It is not possible to develop an index that models differential bone destruction in every possible scenario. In this test a uniaxial force was applied perpendicular to the surface of the bone. The results are directly analogous to certain scenarios, and provide a reasonable first approximation to others. Shear, torsion and bending (torque) are entirely different force regimes, and the response of any material to these requires special consideration (Hall 1974, Davis 1985). It is felt that the measurements obtained here are appropriate in fulfilling the role traditionally played by bone density.

| | Proximal Epiphysis | Proximal Shaft | Mid-Shaft | Distal Shaft | Distal Epiphysis |
|---|---|---|---|---|---|
| **Jaw** | 0.80 | 0.73 | 1.69 | 2.43 | |
| **Atlas** | | | 0.93 | | |
| **Axis** | | | 0.51 | | |
| **Cervical 3** | | | 0.46 | | |
| **Cervical 4** | | | 0.55 | | |
| **Thoracic 1** | | | 0.58 | | |
| **Thoracic 2** | | | 0.36 | | |
| **Lumbar 1** | | | 0.68 | | |
| **Lumbar 2** | | | 0.60 | | |
| **Sacrum** | | | 0.46 | | |
| **Caudal 1** | | | 0.43 | | |
| **Caudal 2** | | | 0.38 | | |
| **Rib 1** | 0.61 | 1.79 | | 1.24 | 0.39 |
| **Rib 2** | 0.47 | 1.39 | 2.10 | 1.68 | 0.49 |
| **Rib 3** | 0.33 | 1.16 | | 1.44 | 0.17 |
| **Sternum 1** | | | 0.86 | | |
| **Sternum 2** | | | 0.49 | | |
| **Scapula** | | | 1.41 | | |
| **Humerus** | 0.67 | 0.62 | 3.16 | 0.87 | 0.61 |
| **Radius** | 2.11 | 1.39 | 2.38 | 0.30 | 1.41 |
| **Ulna** | | 0.37 | 0.99 | 0.15 | |
| **Metacarpal 1** | | 0.46 | 0.22 | 0.37 | |
| **Metacarpal 2** | | 0.46 | | 1.02 | |
| **Phalange 1** | | | 0.82 | | |
| **Phalange 2** | | | 0.22 | | |
| **Phalange 3** | | | 0.14 | | |
| **Pelvis** | | | 0.13 | | |
| **Femur** | | 0.82 | 3.56 | 0.46 | 0.20 |
| **Tibia** | 1.63 | 0.48 | 1.77 | 0.59 | 0.48 |
| **Fibula** | | 0.33 | 1.52 | 1.57 | |
| **Metatarsal 1** | | 0.22 | 0.78 | 0.50 | |
| **Metatarsal 2** | | 0.20 | 0.87 | 0.54 | |
| **Calcaneum** | | | 0.80 | | |
| **Astragalus** | | | 1.05 | | |
| **Cuboid** | | | 0.92 | | |
| **Carpal 1** | | | 1.38 | | |
| **Carpal 2** | | | 0.54 | | |
| **Carpal 3** | | | 0.84 | | |
| **Carpal 4** | | | 0.36 | | |

**Table 5.2** *Summary of the Young's Modulus analogue values obtained for seal bones (kN.cm$^{-1}$). The description of the test locations is presented in appendix B1. The terms used here are specifically for long bones. For non-long bones the measurements are tabulated as "mid-shaft" values.*

The results are tabled in appendix B.1 and presented graphically in appendix B.2. Descriptions of the precise location of tests are in appendix B.1.

It has already been acknowledged that there are inherent dangers in measuring values at a point and extrapolating these to represent a region of a bone. On the one hand the variable nature of the hardness of bone means that multiple measurements have to be made to obtain high resolution. On the other hand the hardness values have to be expressed in terms that can be used in faunal analysis. The geographic nomenclature used here is considered to be of more value than multiple hardness values with complicated descriptions of where they were measured.

As is the case in most hardness tests, the values that are obtained are relative (Schlenker 1974). The absolute values are a function of the geometry of the indenter, the strain rate, and the temperature and the moisture content of the bone samples (Hall 1974, Lyman 1984). All of these were constant since all the bones were exposed to exactly the same treatment and tested under the same conditions. The inter- and intra- bone variability that was measured is therefore accurate.

## Discussion

The hardest portion of the longbones is generally the midshaft, while values for the proximal and distal shafts are similar. The radius is an exception. The proximal shaft of this bone is exceptionally hard relative to the distal shaft, and indeed to the rest of the skeleton. The ulna values exhibit a similar trend except that the proximal value is measured on the olecranon which is soft. The values for the bones of the forelimb are considerably greater than those of the hindlimb. In the axial skeleton the jaw, atlas and ribs (midshafts) are the hardest, although on average they are not as hard as the forelimb. The softest bones in the skeleton are the second and third phalanges.

An attractive application of the hardness indices is in the gnawing of bones by carnivores. To achieve a measure of gnawing success a carnivore would have to be capable of exerting forces in excess of the threshold value of the bone. Some bones, or parts of bones, cannot be destroyed by small carnivores. By considering bone destruction by carnivores in terms of the force hardness index, a quantitative measure of the carnivore's destructive potential can be obtained.

In chapter 6 the bones from jackal kitchen middens are analysed from this perspective. If the destructive potential for jackals can be established in terms of the force hardness index, then the extent of their impact can be measured in any assemblage, irrespective of the species represented, provided the hardness values of the bones are known. The determination of the destructive threshold for the Brown Hyaena using seal bones is complicated by their ability to destroy the entire seal skeleton (chapter 6). Possible future application of this technique to large ungulate (Eland) bones should prove revealing. With the proviso that exactly the same test is applied to the ungulate bones, the destructive threshold defined for jackals on seal bones should be directly applicable in predicting the destruction of the ungulate bones by jackals. An interesting comparison can be made between the tests done on a cow femur (figure 5.2) and those done on the seal bones. The ultimate strength of the cow femur is not vastly different from the maximum value obtained for the seal bones.

Another potential application is based on the force/displacement curves and is related to the force index. Where carnivores have scavenged over a site (or when bones are scavenged from carnivores) there is often evidence preserved in the form of gnaw marks on the bone. If an individual gnaw mark is isolated, its depth can be measured and the force required to inflict it can be extrapolated from the relevant force/displacement curve. An assumption is that the tooth that inflicted the gnaw mark had a similar geometry to the indenter used in the hardness test. In many cases this will prove to be a reasonable assumption. Having established the amount of force involved, it should eventually be possible to estimate the size, or possibly the species, of the carnivore that inflicted the mark. This is dependent on the establishment of the potential threshold for a range of carnivores.

The Young's Modulus analogue represents a bone's ability to resist surface deformation. An application of this index is in the modification of bone assemblages by low force regimes. In a situation such as profile compaction the force exerted on the bone gradually increases as the deposit on top of it accumulates. The bones will be progressively destroyed by direct analogy with the test. Provided the maximum force threshold for the assemblage is not exceeded the modification will be mediated by the Young's Modulus analogue.

# CHAPTER 6

# CARNIVORE ECOLOGY

## Introduction

Carnivores have the ability to generate and modify bone assemblages that closely approximate assemblages that humans generate. They generate assemblages by killing animals and they modify them by eating or transporting some of the bones. Some carnivores have the ability to extract nutrition from the bone itself, and in the process they damage or destroy the bones. Each kill produces bone fragments and splinters that, under favourable conditions, could be preserved as part of an assemblage. In the context of archaeological faunal analysis this kind of behaviour poses two problems. First, the natural process of bone distribution and deposition in the environment that takes place largely as a result of carnivore activity, may produce assemblages that are difficult to distinguish from human derived assemblages. Archaeologists have studied the distribution of bone across the landscape, and the relation between this and the biogeographic environment, in order to determine the nature of "natural" bone accumulations (Hill 1975, 1979*b*, 1980*a*, Behrensmeyer 1983, Tappen 1995). In contrast the association of uniquely "human" derived material such as pottery or flaked stone debitage is often an unequivocal indicator of human involvement in recent (Later Stone Age) deposits (Brain 1981), but on sites of Pleistocene age such associations can be the result of processes of accumulation that operate over long time periods.

The second problem that arises from carnivore behaviour relates to their ability to modify bone assemblages that have some association with human behaviour. At this junction the interactions between humans and carnivores takes on an ecological dimension. The scavenging of human campsites is simply part of the carnivore's normal quest for food. Similarly when people scavenge meat from carnivore kills they are acting out a fundamental aspect of carnivore ecology: they are taking a food resource away from competing species to satisfy their own requirements. These situations are complicated to recognise and to quantify in the archaeological record, but some sense of what can be expected can be gained from the study of carnivore feeding ecology.

## Background to carnivore feeding ecology

When prehistoric humans began to eat meat on a consistent basis they became carnivores, and in the carnivore realm there are some ecological consistencies that are important in understanding human behaviour. An important aspect is the lack of clear distinctions between hunting species and scavengers.

In reality there are very few carnivores that will not scavenge. Whenever a prey animal is eaten, the carnivore is in direct competition with every other predator that preys on that species, and given the slightest opportunity the competing carnivores will scavenge as much of the kill as possible. This competition may be minimal, in that, for example, leopards or cheetahs will abandon food to hyaenas with little or no attempt to retain it (Kruuk 1972, Mills 1973, Owens & Owens 1978), but it may also be confrontational, such as occurs between lions and spotted hyaenas (Pienaar 1969, Kruuk 1972). Here it is usually the species with the greater number of individuals present that gets to feed on a carcass, irrespective of which species makes the kill (Eaton 1979, Mills 1985, Cooper 1991). Often such interactions are violent and it is common for individuals to be killed in the process. Some species have adopted alternative means of defending carcasses against competing carnivores, for example when leopards store kills in trees they avoid direct competition from hyaenas, but it is still true that the hyaenas will attempt to scavenge from such carcasses (Kruuk 1972, Mills 1990), even though they seldom achieve any measure of success.

A dominance hierarchy between most carnivore species (and between individuals of the same species) determines the right of access to a carcass. The basis for this is competition for resources between species and assertion of status between individuals. The hierarchy determines the food that is available, and consequently the strategy that is used to procure it. For example lions and spotted hyaenas dominate brown hyaenas (Mills 1973, 1989, Owens & Owens 1978, Mills & Mills 1982), as do wild dogs (Owens & Owens 1978). Of these species the brown hyaena obtains most of its food by scavenging while the others hunt. If the brown hyaenas did hunt, they would lose their prey to the dominant species. Jackals are subordinate to almost all of the large predators (Owens & Owens 1978, 1985, Mills 1990) although several animals have been seen driving individual brown hyaenas from carcasses (Owens & Owens 1978). Jackals are, however, persistent in their attempts to feed at large carnivore kills, and achieve a measure of success because of their agility in avoiding the dominant carnivore's attempts to drive them off. In this way they obtain food from brown and spotted hyaenas as well as lions (Kruuk 1972, Owens & Owens 1978, 1985, Goss 1986, Mills 1990). Leopards and cheetahs are extraordinary in that they are mainly hunters, but they seldom dominate other carnivores. They are even subordinate to brown hyaenas (Owens & Owens 1978, Mills 1973).

The dominance hierarchy between carnivores determines which part of a carcass is available for consumption. In the case of primary feeders, the killing of an animal provides the widest possible range of resources, and so the bones of the prey are of little importance in comparison with the flesh. For animals that cannot compete early on in the consumption of the prey, only small scraps of flesh and hide and some of the bones that the dominant carnivores abandon might remain. On the other hand the greater degree of *socialised* hunting and active scavenging (driving competing carnivores from kills) that is required for successful procurement and defence of high quality prey results in less food being available to each individual at the kill. This demands a greater frequency of kills or the selection of larger prey, both of which result in higher socialisation of food procurement. Indeed the carnivores that actively hunt large (and often dangerous) prey do so in large social groups, while solitary foragers regularly kill small prey but only passively scavenge from large carcasses. The dominance hierarchy also reflects the evolved specialisation of carnivores. Those that are low on the hierarchy are often able to extract resources that dominant carnivores are not able to exploit. Humans (hunter-gatherers) as carnivores would have had to compete in a similar fashion, procuring animal carcasses by hunting or by scavenging, and then having to defend the resource against other carnivores. Even after the bones were discarded there would be carnivores that would scavenge through them on the chance of finding some nutrition.

While it may be reasonable to explore the evolutionary transition to meat eating by modelling hominid behaviour on that of carnivores, it may appear to be a rather dramatic approach to adopt for exploring seal exploitation by Later Stone Age people in the western Cape. Nevertheless the analogy still applies. Later Stone Age people may have scavenged seal carcasses along the beaches; they may have hunted live seals; they may have occasionally come across the partially consumed carcasses that other carnivores had discovered first; and, after transporting them (however procured) back to the campsite for consumption, the bones may have been scavenged over by carnivores after the humans had discarded them. The point here is that carnivores are potential bone modifying agents and, irrespective of the ability of the people to secure the carcasses of seals, there will always have been some competition for the meat (and bone) both before and after human involvement. Rather than focusing on the presence or absence of carnivore activity, it is assumed that carnivores always played a role, and so the primary aim of this part of this study is to establish criteria for determining the timing and the degree of carnivore modification to which an assemblage may have been subjected.

The final appearance of a bone assemblage must be seen as the result of several agents operating to varying degrees at different times. This has been widely recognised in archaeology (Isaac 1983, Avery 1984*a*, 1984*b*, Brain & Turner 1984), but methods of assessing the contribution of each component have only recently been devised. The general approach is to identify the potential agents, and then to characterise their impact on archaeological assemblages (Brain 1980, Maguire *et al.* 1980, Richardson 1980). In the context of this research the most significant contributions are likely to be those of humans and carnivores. The human behaviour that is encoded in the fauna is of interest, but the carnivore contribution to the overall signature must first be understood. This has been approached from several different perspectives, but almost exclusively when analysing terrestrial Pleistocene faunal assemblages. In this chapter I employ these approaches to establish the timing of carnivore access to Later Stone Age archaeological seal assemblages and the impact that this may have had on the bones that are preserved. Although these Later Stone Age sites are relatively recent there is clearly a need for such an interpretative framework. The arrival of pastoralists in the southern and western Cape is associated with a dramatic increase in characteristic carnivore damage on seal bones (Klein & Cruz-Uribe 1989, Cruz-Uribe & Klein 1994). This is true at the Dune Field Midden, Kasteelberg B and Smitswinkelbay Cave (Marean 1985). In contrast the seal bones at Elands Bay Cave, most of which date to the early Holocene, are mostly intact. Besides providing a basis for interpreting each of these sites and for understanding the differences between them, this study will also provide a test of the ecological approach as a whole, and will illustrate some of the constraints that must be considered when looking at the Pleistocene evidence.

## Current approaches in carnivore studies

### 1. Cave taphonomy

In South Africa many Pleistocene fossil assemblages are preserved in caves that were probably never inhabited by hominids. The emphasis in cave taphonomy is therefore on how the bones came to be there; the identity of the accumulators and the processes that concentrated the bones. A great deal of energy has been devoted to establishing criteria that can be used to distinguish between accumulating agents (Dart 1949, 1956, 1958*a*, 1958*b*, Klein 1975*b*, 1986*b*, Richardson 1980, Scott & Klein 1981, Brain 1981, Brain & Turner 1984, Hill 1984, 1989, Grine & Klein 1985, Cruz-Uribe 1991, Klein *et al.* 1991).

The most prominent work in this field is that done by C.K. Brain. He identified the animal species that could potentially accumulate bones and studied each to see if any patterns were idiosyncratic to particular agents. Brain collated existing observations of spotted and brown hyaena denning behaviour and also studied several dens in the field (Brain 1981). He also performed controlled experiments in which baboon carcasses were fed to both species of hyaenas and also to cheetahs. The other species that were studied included striped hyaenas (although they do not occur in southern Africa), leopards, porcupines and predatory birds such as owls and eagles. The most prolific accumulators of bones were found to be brown hyaenas, leopards and porcupines. In every instance Brain studied the feeding ecology of the agent and the influence this has on the selection of prey species and on the elements of a carcass that are introduced into den assemblages. He also studied the damage that was inflicted on the bones. The Swartkrans bone assemblage was originally thought to be accumulated by leopards (Brain 1970), but the criteria established in the above study suggested that a larger predator, perhaps one of the extinct sabre toothed cats found in the assemblage, was the principal accumulating agent (Vrba 1975, Brain 1981). In a similar study of carnivore damage to skeletal elements Richardson (1980) suggested that hominids were the principal collectors of the grey breccia bone assemblage at Makapansgat. This assemblage was also studied by Maguire *et al.* (1980) using almost exactly the approach established by Brain. They concluded that it was a carnivore accumulation. It has to be considered that such large assemblages that accumulated over substantial time periods could be the result of several accumulating mechanisms (Vrba 1976, Brain 1981).

The example of the Makapansgat fauna illustrates the falsifiability of carnivore studies and their use as analogues for prehistoric bone accumulation processes. One of the obvious problems is the existence of extinct species of carnivores that may have played a role in the formation of the assemblage. At Makapansgat there are two extinct species of hyaena, including a giant hyaena (Collings *et al.* 1976). One of the smaller species has been related at subspecies level to the striped hyaena *Hyaena hyaena* on the basis of its dentition, and it is assumed to have behaved in a similar fashion (Maguire *et al.* 1980). Striped hyaenas are prolific bone accumulators (Skinner *et al.* 1980), perhaps more so than brown hyaenas. At Swartkrans the remains of two genera of extinct hyaenas and five species of cats, including three species of sabre toothed cats, have been found. Most of these animals have no modern analogues and their impact on bone accumulations is a matter of conjecture (Brain 1981). There is no means of determining the specific characteristics of bone assemblages associated with such animals. Recently Milo (1994) compared carnivore damage to the Klasies River Mouth, Langebaanweg and Duinefontein assemblages in South Africa. Here the differences between the size of the species represented, and the type of damage inflicted on the bones in the assemblages correlate with the differences in the carnivores represented. In the case of extinct species the damage is consistent with the ecological role that these animals are presumed to have played. This study illustrates an approach that can be used to address the problem posed by extinct species, but it diverges slightly from the approach that is adopted in this research in that it does not identify the taphonomic impact of any particular species of carnivore, but rather the impact of a guild, or category of carnivores (Milo 1994).

The presence of extinct carnivore species obviously prevents the characterisation of every carnivore, but some extant species have been very well studied. Spotted hyaenas collect bones (Sutcliffe 1970, Bearder 1977, Mills & Mills 1977, Henschell *et al.* 1979, Hill 1980*b*, 1983, 1984, 1989, Behrensmeyer & Dechant-Boaz 1980, Brain 1980, Bunn 1983*a*, Lam 1992, Marean *et al.* 1992) but the assemblages are seldom substantial. Brown hyaenas are probably the most prolific accumulators of bones in southern African caves (Mills & Mills 1977, 1978, Skinner 1976, Owens & Owens 1978, 1979*a*, 1979*b*, Brain 1981, Avery *et al.* 1984, n.d., Skinner & van Aarde 1991). The characteristics of their accumulations include the presence of abundant coprolites; the presence of substantial numbers of carnivore remains (especially skulls); bovid representation which indicates the selection of small species, and also small individuals that can be characterised in terms of their age profiles; large quantities of bone with typical cranial to postcranial ratios and also typical body part representations (Avery n.d., Maguire *et al.* 1980, Richardson 1980, Brain 1981, Grine & Klein 1985, Klein *et al.* 1991). Assemblages created by porcupines (Hughes 1958, Hendy & Singer 1965, Brain 1980), leopards (Brain 1970) and striped hyaenas (Skinner *et al.* 1980) have also been studied. Although distinguishing criteria were mostly developed under the ambit of cave taphonomy, and in particular for the caves from which the hominid fossils have been recovered, they have been used most successfully to identify which species of carnivore was the accumulator at other sites (Avery n.d., Klein 1975*b*, 1986*b*, Scott & Klein 1981, Grine & Klein 1985, Klein *et al.* 1991).

## 2. Processual taphonomy

In contrast to the South African situation, East African Pleistocene assemblages are mostly from habitation sites in non-cave settings. These have different taphonomic links to carnivores. Site formation processes are analogous to those of modern east African savannah landscapes, and the associated ecology. Carnivores make kills, they scavenge, they partition carcasses and distribute the bones across the landscape, and they destroy bones as was discussed earlier. Archaeologists dealing with sites in such settings have recognised the role of carnivores and adopted analytical techniques that are appropriate to carnivore ravaged assemblages, and more recently, they have also based their interpretative framework on actualistic experiments of carnivore behaviour.

An example of the necessity of accommodating the effects of carnivore activity in faunal analysis is given by the debate over the FLK Zinjanthropus assemblage from Olduvai Gorge. Bunn and Kroll (1986) noted that this assemblage showed evidence of carnivore ravaging. Previous analyses had calculated the number of anatomical elements that were present, particularly of long bones, on the basis of articular ends (Leakey 1971, Bunn 1982, Potts 1983). These are precisely the parts of the bone that carnivores had been observed to destroy (Bunn *et al.* 1980, Bunn 1983b, Bunn & Kroll 1986) and so the analysis was repeated, but this time basing the calculations on the representation of shaft fragments in the assemblage. The result was that more meaty parts of the carcass were detected and that the evidence of cutting was concentrated in those parts. It was concluded that the Hominids must either have scavenged aggressively or hunted to procure carcasses that would require butchery in these areas. This approach has been criticised by Binford (1988) on the basis of ethnographic observations of Nunamiut marrow cracking in which midshaft fragments of long bones are overrepresented (Binford 1978, 1988). Nevertheless, it has been widely noted that carnivores select and destroy articular ends (Henschell *et al.* 1979, Blumenschine 1988*b*, Marean & Spencer 1991, Bartram 1993). The effects that carnivores have on body part representation can therefore be partially compensated for by changing the basis of the analysis, but there are instances in which knowledge of their impact does not provide a means of rectifying the situation. During the analysis of butchery marks, for example, it must be acknowledged that certain cut marks may never be recognised after carnivore ravaging (e.g. Cruz Uribe & Klein 1994, Milo 1994).

Apart from informing on the manner in which faunal analysis should be conducted, observations of carnivore behaviour have also provided a body of information that can be used in an interpretative manner. Blumenschine studied carnivores in the Serengeti in order to develop an interpretative framework for Pleistocene faunal assemblages (Blumenschine 1986*a*, 1986*b*, Blumenschine & Cavallo 1992). He identified the key predators and scavengers in the modern savannah environment and, by studying their actions and interactions, he modelled the meat availability in each of a range of niches that early hominids may have occupied. In particular he noted the elements of a carcass that were likely to be consumed soon after a kill, and those that remained for an extended period. The dominance hierarchy of carnivore access to kills corresponds roughly to a hierarchy between hunters and scavengers. If Pleistocene hominids were scavengers, then competition with other carnivores would dictate that elements eaten early in the consumption sequence would only occasionally be available, and these would be underrepresented in archaeological sites. Other aspects that he noted might indicate scavenging include a predominance of adults or large animals in an assemblage, and concentrations of cut marks in areas that were defleshed early in the consumption of the carcasses (Blumenschine 1986*b*). Based on these criteria he tentatively suggested that the Pleistocene Hominids were likely to have scavenged.

Blumenschine's observations indicate which anatomical elements might be expected in hunted or scavenged assemblages on the basis of what happens at a kill site. Stiner has approached the problem from a different perspective, but also one that identifies elements that are removed from a carcass early in the sequence of disarticulation and consumption. She studied different carnivore accumulations (the location at which the carnivores abandon bones as opposed to the location at which they obtained the bones) and noted that higher proportions of crania relative to lower limb bones was typical of carnivores that tended to scavenge (Stiner 1991*a*, 1991*b*). Crania persist the longest at kill sites (Kruuk 1972, Blumenschine 1986*b*) while feet are deleted relatively early. Stiner's analysis, however, also takes into account the transportation of the food from the kill site to the site of deposition.

Using carnivore ecology to predict the characteristics of hunted versus scavenged Pleistocene assemblages is complicated because scavenging opportunites are dependent on the diversity of scavengers and primary carnivores present in the savannah environment, as well as the size range of prey species. Over such vast time periods both predator and prey diversity have changed as some species became extinct. This must have had some influence on carnivore ecology but it is difficult to determine exactly what this might have been (Brain 1981, Tappen 1995). Another complication is the exploitation of marrow from longbones, a resource that is not consumed by carnivores until very late in the sequence, if ever. It is questionable whether the presence of such bones on a site implies that the hominids scavenged marrow bones, or acquired meat-bearing elements of the carcass. This problem is partially solved by assuming that cut marks are a proxy indicator of the distribution of meat on the carcass (Binford 1981, Blumenschine 1986*b*, Bunn & Kroll 1986, Milo 1994), and partially by considering the order in which the bones of a carcass disarticulate (Hill 1975, 1979*a*, 1979*b*, 1980*a*, Potts 1983, Hill & Behrensmeyer 1984, 1985). The last bones to disarticulate are those that are most likely to be represented in scavenged assemblages. There is usually, however, a temporal disjunction between the natural disarticulation of joints and the consumption of the meat. Natural disarticulation occurs long after the bones cease to be a resource to any carnivore (Blumenschine 1986*a*, 1986*b*). Similarly the disarticulation of an anatomical element does not always equate to the disappearance of the part from the site (Richardson 1980), and disarticulated elements may persist as a resource for the same duration as those that remain articulated.

In the use of carnivore feeding ecology as a model for prehistoric food procurement there is an inherent assumption that what is observed in the relevant system in the present is an indication of how that system operated in the past. The more rigorous the system, the more valid the assumption is likely to be. This is a central theme of actualistic archaeology. In the context of carnivore ecology, the extinction of certain species has already been noted as an uncontrolled boundary condition, but the diversity of behaviour that can be observed within the modern system also needs further consideration. An example of this is the range of behaviour that is exhibited by spotted hyaenas. In the Serengeti and Ngorongoro, groups of spotted hyaenas hunt large prey. When a kill is made there have been observations of up to 52 individuals at a kill, and each individual attempts to maximise its return by eating as much as it can as fast as it can. Twenty one hyaenas consumed a wildebeest carcass of approximately 100kg in 13 minutes; 35 hyaenas took 36 minutes to eat two zebras totalling about 370 kg, and with smaller prey such as gazelle fawns, a single hyaena would consume the entire resource in approximately 2 minutes (Kruuk 1972). They are also capable of eating an enormous amount. Tilson & Henschel (1986) recorded an individual eating 14.4 kg of meat in one night, and Bearder (1977) recorded the consumption of 18 kg of elephant meat in a night. The hyaenas are so competitive that they seldom wait for the prey to die before commencing their feeding, and as soon as a limb or some other element is separated from the carcass they will attempt to carry it off to where there is less competition. Under such intense pressure there is little scavenging opportunity, but this situation is specific to that environment. The Serengeti and Ngorongoro hyaenas live in an open grassland where competition is high between individuals, and between species - partly because of the high visibility, and partly because of the high density of carnivores. The extent to which the physical and social environment affects the behaviour of spotted hyaenas is illustrated by contrasting the behaviour of Namib Desert spotted hyaenas to the plains hyaenas. Namib hyaenas also hunt large and dangerous prey (gemsbok) but they eat in small groups and after about 30 minutes of fast feeding they settle down to a leisurely pace. The same carcass will often be fed on for several consecutive nights (Tilson & Henschel 1986, Tilson & Hamilton 1984). The feeding ecology of spotted hyaenas in the Timbavati Reserve in South Africa is almost exactly the same as that of the Namib animals, although most of their food is obtained by scavenging (Bearder 1977). Spotted hyaena dens in the vicinity of Koobi Fora in Kenya differ from all of those noted above in that they are dominated by the bones of small prey species (Lam 1992).

The diversity of behaviour exhibited by spotted hyaenas makes it difficult to apply aspects of their ecology to archaeological remains unless more is known about the factors that influence their behaviour, and consequently, on our knowledge of those factors in the past. One of the main determinants in the spotted hyaena example is the competitive role of lions, but even this is exceedingly diverse in its manifestation. In the Serengeti spotted hyaenas prefer to hunt in grassland areas (Kruuk 1972) while lions prefer woodland (Schaller 1972). In the Parc National des Virunga in Zaire the preferred habitats are reversed (Tappen 1995). The Timbavati Reserve in South Africa is entirely woodland and so the lions and hyaenas here are forced into close proximity to one another. Instead of a higher degree of confrontational interactions between the species, the hyaenas appear to actively avoid the lions, and they only scavenge from lion kills after they have been abandoned (Bearder 1977). This is similar to the Namib large carnivore ecology where lions and spotted hyaenas seldom interact. Since scavenging opportunites are better at lion kills (Blumenschine 1986*b*) the potential scavenging niche of hominids would be characterised by different carcass encounter rates in the different environments.

The relevance of the scavenging versus hunting distinction, and the likelihood that the modern ecological hierarchy of access to food will apply, does not depend exclusively on the order in which the carcass is consumed, it is also dependent on the biogeographic environment in which the carcass becomes available. Before applying modern observations of carcass consumption to archaeofaual remains, it is imperative that the palaeo-environmental setting be considered. This is often difficult to achieve for Pleistocene assemblages. Consideration will now be given to the application of carnivore ecology to Later Stone Age assemblages.

## The application of Carnivore studies in the Later Stone Age context

The study of carnivore ecology outlined above has been used to address three aspects of bone taphonomy:

1. The identification of accumulating agents
2. The appropriate methods for analysing carnivore ravaged assemblages
3. The distinction between assemblages that were procured through hunting or scavenging.

These issues are as important in the study of the Later Stone Age seal assemblages as they are in the study of Pleistocene hominid sites. Carnivores accumulate seal bones (Avery *et al.* 1984, Skinner & van Aarde 1991), and they may have contributed to archaeological faunas during periods of human abandonment. Although the three archaeological sites that are under consideration in this study were almost certainly accumulated by humans, the observations made in the course of this study provide an opportunity to recognise the characteristics of carnivore generated seal assemblages. Some archaeological assemblages also have clear evidence of ravaging by carnivores (Marean 1985, Cruz-Uribe & Klein 1994), and the veracity of interpretations based on the representation of body parts can be tested by providing a template of carnivore destruction against which the assemblages can be measured.

In terms of the objective of this chapter outlined previously, carnivore ravaged assemblages indicate late timing of carnivore access to the seal remains (i.e. after people had discarded the bones). Early access to seal carcasses by carnivores would be manifest in the archaeological assemblage as scavenging by people. The significance of the distinction between hunting and scavenging of seals must not be overstated. Seals are poorly adapted to their terrestrial niche and even healthy animals are clumsy and slow on land. My experience doing census work on breeding colonies is that they remain oblivious to even the most unskilled stalk and are easy to catch after a short chase (less than 20m). It is also widely accepted that people in the Later Stone Age were capable of hunting (Klein 1989*b*). The recognition of hunting or scavenging in the Later Stone Age, particularly of seals, takes on a different significance in comparison with the evolutionary implications for East African hominids. I place greater emphasis on the behavioural implications. If people chose to scavenge it may have been as a result of the way in which they structured their daily mobility. If they were resident at the coast and foraged daily along the beaches and immediate hinterland, they would detect the presence of a dead or weary seal very soon after it came ashore. In this instance they would be the first to exploit the animal, and the only constraint would be their ability to transport the carcass, whole or dismembered, to the nearby base. If, however, the hunter gatherers lived in the hinterland and scheduled their visits to the beach, perhaps to coincide with low tide when high returns from shell fish gathering are guaranteed, then there is a possibility that carnivores scavenging along the beach would have first access to any seal carcasses that became available. In this instance the carnivores consuming elements of the carcass would effectively be deleting these from the menu available to the hunter gatherers. The less time the hunter gatherers spent on the coast, the more likely it is that the seal menu would have been narrowed by carnivores.

The main problems associated with the approaches that have been developed are mostly as a result of their application to Pleistocene assemblages. These include:

1. The composition of both predator and prey species has changed since the Pleistocene. This brings into question the validity of modern feeding ecology as an analogue to what may have occurred in the past.
2. The feeding ecology of carnivores varies between species, but more importantly it varies within a species depending on the biogeographical environment.
3. The behaviour of carnivore species may have evolved since the Pleistocene and hence they may not have any analogues in the present.

The application of modern carnivore ecology to the interpretation of Later Stone Age seal bone assemblages may have greater potential than in the Pleistocene context. The problems associated with the Pleistocene time depth are reduced or annulled. Environmental reconstructions are based on a wider range of better preserved evidence and on a more comprehensive set of observations. Only one prey species (seals) is under consideration, and the carnivore species are almost exactly those that occurred in historic and modern times. Observable carnivore behaviour can be assumed to be similar to that of their prehistoric ancestors.

The remainder of this chapter deals with the carnivores that eat seals: their ecology, feeding habits, and observations of carcass consumption. The features that characterise accumulations of seal bones that result from their activity are presented. This task is approached from the perspective of bone hardness developed in chapter 5.

## A review of relevant observations of carnivore behaviour

The modern predator/seal relationships in the vicinity of each of the archaeological sites under consideration has been severely affected by the establishment of farms, and by the attitudes towards predators that prevailed during the colonial period. The Dutch East India Company, in an attempt to protect the company flocks, paid bounties to anybody who destroyed wild carnivores (Skead 1980). I do not believe that there are any species that prey on seals in the vicinity of Elands Bay or on the Vredenberg Peninsula. This poses the problem of identifying the species that would have competed with people for seal carcasses, or that may have generated bone assemblages containing substantial numbers of seal bones. Only those that regularly frequent beaches need to be considered. I have identified these using historic records of carnivore occurrences for the Cape Province, and by extrapolating the ecology of the Namibian coast. Here the hostile desert environment mitigates against agriculture, and the occurrence of diamondiferous deposits has led to the total exclusion of people from most of the coastal region by the mining companies. The ecology of carnivores in areas that are remote from mining activities and settlements has not been adversely affected.

In Namibia there are only two carnivore species that regularly prey on seals. They are black backed jackals, *Canis mesomelas*, and the brown hyaena, *Hyaena brunnea* (Shortridge 1934, Stuart 1975, 1976, Skinner & van Aarde 1981, Skinner *et al.* 1984, Stuart & Shaugnessy 1984, pers. obs.). Spotted hyaenas, *Crocuta crocuta*, also occur in Namibia but they are seldom found at the coast (Stuart 1975, Skinner & van Aarde 1981). Historical references to hyaenas in the Cape are rather vague because of the use of the term "wolf" to describe both the brown and the spotted varieties and possibly also jackals. There are, however, records of the occurrences of the brown hyaena (or strandjut or strandwolf as it is also known) and the spotted hyaenas at the Cape peninsula and along the entire west coast (Skead 1980). Some consideration will therefore also be given to the spotted hyaena. All three species have been recorded scavenging over human living sites. Spotted hyaenas become very familiar with people and in the Serengeti, Kruuk (1972) referred to them as the "dustbin brigade". In the Kruger National Park they have also been noted scavenging at dump sites (Pienaar 1969). Although brown hyaenas and jackals are far more timid, they also enter human habitation areas at night (Smithers 1983, Owens & Owens 1985). Ethnographic accounts of carnivore scavenging are numerous (e.g. Gifford 1980, Bartram 1993).

Other carnivores have been seen patrolling beaches for carrion and even eating from seal carcasses, such as the lions of northern (Bartlett & Bartlett 1992) and central (Bridgeford 1985) Namibia. Historically lions were very common at the Cape, and they presented a constant threat to stock and to the lives of people (Skead 1980). Although lions have been noted taking seals on several occasions, seals are considered to be an extraordinary part of the lion diet (Bridgeford 1985) and it is unlikely that they provided as consistent competition to the Later Stone Age hunter gatherers as hyaenas or jackals. Similarly they are unlikely to have had a major impact on the faunal assemblages by scavenging for bones, or by introducing bones after sites had been abandoned by people. The taphonomic role of lions as competitors for seal resources cannot be entirely dismissed, and further actualistic observations of this special circumstance are required before their impact can be adequately addressed.

Only jackals, brown hyaenas and, to a lesser extent, spotted hyaenas are considered in this study. The limited number of species involved simplifies the ecological model associated with seal exploitation in comparison with bovid predation in the savannah. Jackals and brown hyaenas generally occupy a very low position in the hierarchy of carnivores at kills and it may be reasonable to assume that their role as competitors for seal carcasses would be restricted to scavenging. In the absence of any competition, however, brown hyaenas actively kill seals. Jackals also kill small seals, but most of the animals that they eat are already dead when discovered. The competition that these carnivores may have had with people for seals is probably more passive than that envisaged for larger carnivores, but this does not imply that their role is insignificant. The nocturnal limitations of people means that the activities of jackals and hyaenas would be especially significant at night.

There are aspects of the feeding ecology of these carnivore species that have been widely observed, and there are aspects that are unique to animals found at seal colonies. The general characteristics of jackal and brown hyaena ecology have been drawn from several excellent studies of these species at a number of locations in Africa. However the carnivores on the Namibian coast, those that are persistently involved in the exploitation of seals, have not been studied in great detail. The published observations were augmented through personal observations of carnivore predation of seals at three breeding colonies in Namibia. These are the Wolf Bay and Atlas Bay colonies and the Van Reenen Bay colony. A total of three weeks was spent making observations; two weeks at Van Reenen Bay and one week at Wolf Bay and Atlas Bay. Further fieldwork was considered, but in interviews with the Sea Fisheries staff in Cape Town and Luderitz I established that my observations conform to a robust pattern of behaviour that they noted during every visit to the colonies.

Wolf Bay and Atlas Bay are adjacent mainland breeding colonies situated approximately 20 km south of Luderitz (figure 3.1). During the breeding season they support populations of c.118 000 and c.266 000 seals respectively and together they constitute the largest breeding colony of the Cape Fur Seal (census figures from 1983, David 1987). Van Reenen Bay is situated approximately 80 km south of Luderitz and it supports a maximum of 22 000 seals. All three colonies are situated within a diamond concession and access is strictly controlled. Except for visits by harvesting teams or scientists once or twice a year, the colonies are undisturbed by human activity. These breeding colonies are located on the mainland. In chapter 3 I outlined the history of commercial sealing, and it is true that these colonies are a recent phenomenon brought about by disruptive colonial sealing practices. It is also a certainty that the "unnatural" circumstances presented at these colonies did not occur during the time period under consideration in the archaeological study in this thesis. Nevertheless the carnivores that frequent these colonies are precisely those that would have competed with humans for seals in the past. As will become apparent, the behaviour of the carnivores under these conditions is probably little different from that at any of a range of "natural" occurrences of seals including isolated strandings and hauling out sites.

The behaviour of these carnivores and their interactions with seals were observed from sunrise to sunset with occasional breaks. The nocturnal behaviour was therefore not recorded. This turned out to be significant with hyaenas because they are most active at night. They were active on the colonies every night during my observation period, but their behaviour had to be reconstructed from the spoor that remained in the mornings. Although this is not the ideal way to conduct the research, it proved to be less of a problem than might be anticipated. The entire seal colony at Van Reenen Bay is surrounded by a wind blown sand field with the exception of a 30m cliff at the north end of the colony. The tracks that the hyaenas left in the sand were easily distinguished from those of jackals, and furthermore, the wind that blew almost constantly ensured that the only tracks that survived were fresh. I am confident that I could reconstruct the previous night's movements of the hyaenas within a few kilometers of the colony.

At Van Reenen Bay, where most of the observations were made, there were approximately eight hyaenas hunting on the colony every night. At Wolf Bay the hyaenas had bred in a den immediately adjacent to the colony, but rain the previous year had flooded the underground tunnels, and the site had been abandoned.

Jackals were active on the colonies every day and were easily observed and photographed with a 500 mm telephoto lens. They were so numerous (even though they were recovering from an epidemic of sarcoptic mange and the population was smaller than usual) that several feeding incidents could be observed every day. Many of the specimens were in poor condition and every day the same animals could be identified as they scavenged over the colony or waited nearby. The seal population was also at its lowest because the observations were made during September when breeding does not occur and many of the pups are already weaned (see chapter 3).

These extreme conditions were ideal for observing the carnivores. Their activities were largely focused on the acquisition of food (particularly with the jackals), which highlights the extent to which they would have competed with hunter gatherers.

The following section outlines relevant aspects of both jackal and brown hyaena ecology, and in particular their behaviour at the mainland seal colonies of southern Namibia.

## Hyaena ecology

Both the brown hyaena and the spotted hyaena are social animals that live in groups called clans. Spotted hyaena clans may include up to 80 individuals (Kruuk 1972) but in southern Africa they are generally a lot smaller (fewer than 12 individuals) (Bearder 1977, Mills 1990). Brown hyaenas seldom have clans of more than 12 individuals (Mills 1990). Each clan occupies a territory that is closely monitored and defended, although this appears to be related to the degree of competition for resources. In the Namib desert the spotted hyaena clans are not very territorial (Tilson & Hamilton 1984), but in the Serengeti they are territorial in the extreme. Instead of ritualised defence of a territory boundary, the conflict may lead to the death of individuals (Kruuk 1972). Brown hyaenas are also territorial (Owens & Owens 1978, 1979*c*, Mills 1990), but most defensive acts consist of ritualised aggression, and the confrontations that take place are only between animals of the same sex (Mills 1990). The size of the territories, and the number of individuals that occupy them is dependent on the richness of the food patches in an area, and on the distance between food patches (Mills & Mills 1982, Macdonald 1983, Mills 1990). Under similar conditions both species occupy territories that are similar in size, but in the Namib and Kalahari deserts the ranges, although not as strictly defined as a territory, are very much larger than those found in the Transvaal (Skinner 1976, Goss 1986, Mills 1990).

Brown hyaenas are almost exclusively nocturnal foragers (Shortridge 1934, Pienaar 1969, Mills 1973, 1989, 1990, Skinner 1976, Owens & Owens 1978, 1979*c*, 1985, Mills & Mills 1982). Their diet includes small mammals, bones, insects, birds, eggs, reptiles and a large quantity of fruit (Pienaar 1969, Mills

1978, 1989, 1990) which is quite surprising for carnivores. They also eat larger mammals, but the supply depends on the natural mortality and the kills made by larger predators, especially lions (Mills 1990). They are characterised as scavengers (Shortridge 1934), and references to brown hyaenas actively hunting large prey in the Kruger National Park (Pienaar 1969) must be seen in the context of the detailed studies of their behaviour in the Transvaal, central and southern Kalahari, and in Namibia. In every one of these instances the access to large mammals is through scavenging (Smithers 1983, Mills & Mills 1978, Owens & Owens 1978, Mills 1990). They forage alone and the majority of food items that are taken are eaten immediately upon discovery. Of the 205 food items identified by Mills (1990), 80% were eaten in less than one minute.

Spotted hyaenas have a food procurement strategy that is very distinct from that of brown hyaenas. They will scavenge if the opportunity presents itself, but they actively hunt large to medium sized mammals in the range of 12-80 kg and larger (Mills 1989, 1990). The hunting groups consist of 3-5 individuals depending on the size of the prey that they choose to hunt (Pienaar 1969, Kruuk 1972, Mills 1989, 1990). Different clans appear to specialise in hunting different species, and it often appears as if the species that is to be hunted is determined before they set off (Kruuk 1972, Mills 1990). In the southern Kalahari spotted hyaenas obtain 72.6 % of their meat by hunting, in contrast to brown hyaenas that only obtain 5.8 % (Mills 1989). There is, however, a great deal of variability in the behaviour of spotted hyaenas as was noted previously, and it is not valid to assign an exclusively hunting mode to their procurement strategy. Nevertheless, when they do hunt they select predominantly large prey species. For this reason I feel that they are unlikely to have played a major role in seal predation. Skinner & van Aarde (1981) also suggest that the high salt content of seal carcasses is unattractive to spotted hyaenas.

Spotted and brown hyaenas have a well developed sense of smell, and they can detect carrion from distances of several kilometres (Owens & Owens 1978, Mills 1990). When a large carcass is discovered, the brown hyaenas settle down for a long session of feeding. It took two hyaenas 3 hours to consume a 15 kg springbok carcass (Mills 1990) and Owens & Owens (1978) indicated that it would take an individual 200 minutes to eat 4-5 kg of meat or 1.5-3 kg of skin and bones. They may eat up to 8 kg of meat at a feed (Smithers 1983). This is very different from the normal behaviour of spotted hyaenas at a kill which was discussed earlier. If more than one brown hyaena is attracted to a carcass they will eat together under amicable circumstances with no indication of a dominance hierarchy, but on most occasions they feed individually with each animal waiting its turn (Mills 1990). The rare displays of aggression at a carcass are usually assertion of status, and not attempts to secure the resource (Owens & Owens 1978, 1985). When an animal has eaten enough, it usually (on 70% of occasions) tries to detach a leg or some other portion of the carcass which it carries off and caches in a bush or similar hiding place (Mills 1973, 1990, Owens & Owens 1978, 1979). The same kind of behaviour has been observed when brown hyaenas discover undefended ostrich eggs (Mills 1978). Spotted hyaenas rarely cache meat although they have occasionally been seen to place portions of a carcass into waterholes (Kruuk 1972, Mills 1990). Caching appears to be an attempt to save a food resource for later use, and it is interesting to note that spotted hyaenas in the Namib, where there is little competition, have never been observed doing this (Tilson & Hamilton 1984).

In both the spotted and the brown hyaena, the den is the focus of social activity within the clan. This is especially true at breeding dens. Dens usually consist of underground burrows in sandy areas but they will also use holes or rocky grottos. In the case of brown hyaenas, dens will usually be located in areas that are not regularly frequented by lions or spotted hyaenas (Mills 1983). When pups are introduced to the den they usually do a great deal of burrowing of their own, and most of the tunnels are too small to be accessible to adults and thus also to other predators (Kruuk 1972, Skinner 1976, Henschell *et al.* 1979, Owens & Owens 1979*b*, Mills 1983). This does not present a problem for the adults because, although they visit the den regularly, they seldom sleep there unless they have young cubs (Owens & Owens 1979*b*, 1985, Mills 1990). Although the cubs of several different brown hyaena adults may be introduced into the same den (Mills 1983, Owens & Owens 1985), this usually occurs when the adult females are related (Mills 1989,1990). When it does occur, it appears as if the mothers are receptive to suckling cubs that are not their own (Mills 1983, Owens & Owens 1985). Spotted hyaenas always den their cubs communally, but they never suckle one anothers' young (Kruuk 1972). Both species move their dens regularly as a result of flea infestations. Some are totally abandoned, while others are extensively re-used (Kruuk 1972, Mills 1983, Owens & Owens 1985).

Young spotted hyaenas are dependent on their mothers' milk up to the age of 3-6 months at which point they start to attend kills (Kruuk 1972, Tilson & Hamilton 1984). Here they are not given any special consideration in the competition for food, and so they are usually only weaned when they are 12-14 months old (Kruuk 1972). When they are about 18 months old they begin to kill for themselves. While the cubs are bound to the den the adults bring them bones and similar items (Mills & Mills 1977), but these are seldom items that the cubs can eat. Reports of spotted hyaenas provisioning their young (Hill 1980*b*) are treated with caution (Mills 1990). Besides the bones that are accumulated, the den is usually the site of substantial latrines that contain both oral casts (regurgitated hair and bone that is indigestible) and large quantities of scats (Kruuk 1972, Owens & Owens 1979*b*, Mills 1990).

Brown hyaenas definitely provision their young at the den which is why they are such prolific accumulators of bones. When the cubs are about 12 weeks old members of the clan, both male and female, and even itinerant individuals, begin to bring back food items (Mills & Mills 1977, 1982, Owens & Owens 1979*b*, Mills 1989, 1990). These are dropped at the mouth of the den for the cubs. They are dragged into the interior by the cubs, and when they have finished eating , the bones are brought out again (Mills 1983). The result is that bones, hair, feathers, horns and bits of hide accumulate around the den

(Mills 1983, Avery *et al.* 1984, Skinner & van Aarde 1991). Latrines are also found at brown hyaena dens (Skinner 1976, Owens & Owens 1979*b*, Skinner & van Aarde 1981). When the cubs are 12-15 months of age they are weaned, but they remain bound to the den until they are 15 months old (Mills 1989). It is only when cubs are approximately 30 months old that they forage for themselves (Owens & Owens 1985).

The nature of brown hyaena accumulations was discussed earlier. Bones that accumulate here are usually selected from smaller prey species than those found at spotted hyaena dens (Mills & Mills 1977) although this is not invariable (Lam 1992). The bones that accumulate at spotted hyaena dens usually include large numbers of heads and limb bones (Bearder 1977, Mills & Mills 1977, Henschell *et al.* 1979). There is a danger that archaeologists might interpret the disproportional representation of body parts in such assemblages in terms of human behaviour, notably the "schlepp effect", when it is not associated with humans at all.

Modern hyaenas produce bone assemblages at their dens, in their latrines, and wherever they kill large animals. The den assemblages of brown hyaenas are more substantial than those of spotted hyaenas, and it is possible that these may be mistaken for human derived assemblages. The hunting of large prey by spotted hyaenas provides a degree of competition with human hunters. The largely scavenging role of brown hyaenas suggests that they are more likely to modify human habitation sites after they have been abandoned. The role of the spotted hyaena as an early access competitor, and the brown hyaena as a late access modifier of sites has to be considered in terms of the behaviour of these species in regard to seal predation.

### Hyaenas at seal colonies

Brown hyaenas are distributed throughout Namibia (Shortridge 1934) and were also found along the entire west coast of South Africa during the colonial period (Skead 1980). Spotted hyaenas are also found throughout Namibia but they rarely venture to the coast (Stuart 1975, Skinner 1976, Skinner & van Aarde 1981). They were not observed taking seals during field work done in this study and no records of them doing so could be found. There is some danger in assuming that the current Namibian spotted hyaena ecology applied along the entire west coast, especially since spotted hyaenas are reported to have frequented the Cape coast in the past (Skead 1980). The review above indicates that they are very selective hunters. It is possible that they competed with hunter gatherers for seal carcasses, and they would almost certainly have scavenged over human occupation sites. In this respect they will probably have had a similar, or maybe even more pronounced impact that brown hyaenas have, given their superior bone crushing ability. If this premise is accepted, then the devastating nature of brown hyaena interactions with seals that will be presented will indicate the likely impact of spotted hyaenas. As is the case with lions, the role of spotted hyaenas will remain speculative because they were not part of the observed ecology that is the subject of this chapter. Future actualistic experiments may clarify their role as taphonomic agents in the modification of seal bone assemblages.

Analysis of brown hyaena scats collected near seal colonies shows that these animals are not entirely dependent on the seals for food. Between 75 % and 81 % of scats from Wolf Bay and Van Reenen Bay contain seal, but they also contain jackals (7.4%), dassies (2.9%), hares (1.4%), as well as birds, scorpions, fish, plants and insects (Skinner & van Aarde 1981, Stuart & Shaughnessy 1984). The hyaenas are even known to eat shellfish (Shortridge 1934). Although seals are readily available to the hyaenas throughout the year as a vast, concentrated food source, the clans in the vicinity of seal colonies still occupy and patrol enormous ranges (Goss 1986). Brown hyaena scats collected at Bogenfels, 10 km south of the Van Reenen Bay colony, also contained seals and birds, but the plant content was much greater (Siegfried 1984).

The nocturnal habits of the brown hyaena make observation difficult. Most of the observations that I made suggested that, in the majority of kills, they carried the whole carcasses a fair distance away from the colony or beach and then ate the entire prey: skin, bone and flippers included. Observations could only be made at first light when the hyaenas were leaving the seal colony. The following are of relevance:

1. Thursday, 28 September 1989, approximately 6.30 am, weather - clear. At first light I discovered an area in the lee of a large rock standing about 750m away from the colony across a sandy plane, where a hyaena had eaten a seal. All that remained was a very large blood stain, some fragments of maxilla and cranium, and some whiskers.

2. Monday, 2 October 1989, approximately 6.30 am, weather - clear. Approaching the observation point at first light several hyaenas were seen leaving the colony. One was disturbed from a seal carcass it had been eating. After cutting the spoor it was possible to backtrack to the beach and reconstruct the events that preceded my arrival. The hyaena had dragged the seal about 100m from the colony and then killed it (this is where the first signs of blood were seen). It had then dragged the carcass approximately 300 m across the sandy plain to a grassy dune approximately 4m in diameter and 1m high. Much of the grass was flattened and a vast amount of blood, still wet, was sprayed over the grass and ground. There were no other seal remains. Part of the carcass had been carried a further 250 m to another grassy hummock where more consumption took place. The hyaena was disturbed at this point. All that remained of the seal was the snout and mandible with the skin removed (figure 6.1). Based on the remaining dentition the seal was approximately 2 years old and would thus have weighed in the vicinity of 25-30 kg.

3. Tuesday, 3 October 1989, approximately 1.00 p.m., weather - clear. Leaving the colony after the sunrise vigil I crossed the spoor of a hyaena heading North East. The presence of drag marks and blood stains suggested that the hyaena had carried a seal away earlier that day or the previous night (the spoor was not present the previous day). I followed the spoor for approximately 5 km into a set of low, eroded ridges. All that remained in a small cave in one of the ravines was a large blood stain.

In cases 1 and 3 the evidence for the consumption of the entire seal carcass is circumstantial. Both sites may have been further scavenged by jackals. Jackals, however, were not seen eating seal skin and are not capable of destroying all the bones. In case 2 the possibility that jackals affected the observation does not exist. This incident demonstrates that the hyaenas are capable of eating entire seals.

**Figure 6.1** *The remains of a yearling seal after consumption by a brown hyaena.*

Since the hyaenas kill seals and eat the entire carcass they are primary predators, but they provide very little opportunity to people scavenging over beaches during daylight hours. The hyaenas have, however, been observed killing seals and abandoning the carcasses without eating any part of them. This has been noticed at colonies (Roux pers comm.) and at the abandoned hyaena breeding den that I visited near the Wolf and Atlas Bay colonies. Here several putrefied seal carcasses lay strewn around the openings to the underground tunnels that constitute the den. It is assumed that these were brought to the den to provision the cubs, but they remained uneaten. Since these carcasses were complete when they were abandoned, such behaviour would effectively be transparent if the residues were eventually to find their way onto an archaeological site.

The result is that the order of carcass consumption cannot be discerned for hyaena consumption of seals, nor is it of relevance since the hyaenas provide no scavenging opportunity except in the trivial instance in which complete carcasses are abandoned.

## Jackal ecology

Jackals are distributed throughout South Africa and Namibia (Shortridge 1934, Smithers 1983) and were also found along the entire west coast of South Africa during the colonial period (Skead 1980). They are widely perceived to impact negatively on farming, particularly on small stock farming. In South Africa they have been persecuted along with several other medium sized carnivores since the earliest farming enterprises began. In spite of this they still occur in many areas. In order to justify a coherent program of preservation or irradication of this species, several studies of jackal ecology and feeding habits have been undertaken (Grafton 1965, Bothma 1971, Rowe-Rowe 1976, 1982, 1983). These observations are supported by studies done in wildlife reserves where the emphasis is on the role that small carnivores play in the ecology as a whole (Ferguson 1978, Moehlman 1979, 1980, Ferguson et al. 1983). Aspect of jackal diet, social organisation, and denning behaviour that emerge from these studies are relevant in determining the role that they may have played in the formation of archaeological sites.

Dietary analysis and observations on jackals in the Transvaal and Natal Drakensberg in South Africa, the central Kalahari desert in Botswana, the Serengeti in Tanzania and in the interior of Namibia show a remarkable similarity in the range of items that they eat. They are opportunistic feeders that will take any carrion that is available and any small animal that they can overpower (Rowe-Rowe 1976). Items that are eaten include antelope, small mammals including carnivores, snakes and other small reptiles, birds, rodents, scorpions, insects, termites, twigs and grass, stones and grit, and a great deal of vegetation and fruit (Grafton 1965, Bothma 1971, Kruuk 1972, Rowe-Rowe 1976, 1982, 1983, Moehlman 1980, Smithers 1983, Owens & Owens 1985). Over most of southern Africa the principal component of their diet consists of invertebrates and what would be considered as "microfauna" in archaeological terms (Grafton 1965, Smithers 1983). There is some variability in how the meat component of the diet is procured depending on the other carnivores in the vicinity. Small antelope that are assumed to have been hunted represent 22% of the diet in reserves, but only 5 % in farmlands (Rowe-Rowe 1976). The same study indicated 58% of the diet in reserves and 52 % in farmlands is made up of carrion. Carrion is distinguished from fresh meat in the stomach content and scats by the presence of maggots. It was found to be of less importance (28.7% of the volume of the stomach contents) by Grafton (1965) in the Transvaal, and Moehlman (1980) also indicated that the meat from hunted animals is more important than the scavenged component of the diet in the Serengeti.

Foraging is generally done alone, but on occasions pair bonded animals do co-operate to hunt small or young antelope (Kruuk 1972, Ferguson 1978, Moehlman 1979). The majority of the food items that are taken are small and are eaten by the jackals as they forage. The only animals that they are able to kill for themselves are small - the largest prey species is probably the domestic sheep. The large mammal component of their diet is obtained by scavenging from kills made by large predators, or from carrion. The fact that they scavenge large animals in the form of carrion is supported by a greater abundance of larger mammals in scats recovered during seasons in which natural deaths of larger animals are most common (Rowe-Rowe 1983).

The social system of jackals is focused on denning and the raising of young, the maintenance of territories, and most significantly the behaviour of individuals around food. In general, jackals form lifelong breeding pairs and occupy a fixed territory (Ferguson 1978, Moehlman 1979, 1980, Rowe-Rowe 1982, Ferguson *et al.* 1983). The size of the territory is proportional to the availability of food (Rowe-Rowe 1982, Ferguson *et al.* 1983). In areas such as the central Kalahari where food becomes extremely scarce during the dry season, new territories are established annually and the animals that occupy them are seldom the same from year to year (Owens & Owens 1985). Territories are established when individuals reach sexual maturity at the age of approximately two to three years (Ferguson *et al.* 1983). Prior to this the animals range widely, and they are tolerated by the adults when they enter their territories. Jackals are very territorial towards other breeding animals, although it is usually the individual of the same sex as the intruder that will defend the territory (Moehlman 1979). The strict territorial behaviour is only relaxed at large carcasses and at common water sources (Ferguson *et al.* 1983).

Most of the intraspecific aggression among jackals occurs as a result of territorial violations or around food, and it takes the form of agonistic (ritualised) aggression rather than physical violence (Ferguson 1978). There is seldom any aggression displayed between paired individuals. The only competition that has been noted took place over water and fruit (also a water source) in the Kalahari (Owens & Owens 1985). While paired animals may co-operate in the defence of a carcass from other jackals, unpaired animals compete with one another and, when it is possible, they will attempt to secure a share of a carcass by running away from competitors with as much of it as they can carry (Ferguson 1978).

Denning behaviour is of interest because of the potential for the accumulation of bones here. This is especially true for jackals because they provision their young at the den. Pups are born in the late winter and spring months (July, August and September) throughout southern Africa (Grafton 1965, Rowe-Rowe 1982, Ferguson *et al.* 1983). They are suckled for 8-9 weeks (Moehlman 1979), but after about three weeks they begin to eat meat (Owens & Owens 1985). The meat is provided for the pups (and the mother while she is bound to the den) by the adult animals, but also by the sub-adult animals that take on the role of "helpers" (Moehlman 1979, 1980, Ferguson *et al.* 1983). Both the males and the females provision. In contrast to brown hyaenas, however, this behaviour is unlikely to result in substantial bone accumulations. This is because the food is ingested wherever it is encountered, and then regurgitated at the den. In every study of jackal scats and stomach contents mentioned above it was evident that very few bones were ingested. I shall elaborate on this point when I discuss jackal behaviour at seal colonies. After 12-14 weeks the pups begin to forage with the adults.

The diet of the jackal does not include a large component that encroaches significantly on the diet of hunter gatherers. The major role that they are likely to play in the procurement of food by humans is probably that of a subordinate scavenger, and not a competitor. In the course of establishing interpretative criteria on the basis of carnivore behaviour, archaeologists have paid little attention to jackals. This position has to be reconsidered for the predation of seals. Under normal circumstances jackals are also unlikely to accumulate bones, and so there has been no attempt to characterise jackal accumulations. This too has to be reconsidered in the context of seal exploitation by jackals.

## Jackals at seal colonies

Jackals that frequent the seal colonies of Namibia are distinguished from those found in the interior at the subspecies level. The inland subspecies is *Canis mesomelas arenarum*, while those at the coast are *Canis mesomelas achrotes* (Stuart 1975, Smithers 1983). The main behavioural distinction is the particular association of *Canis mesomelas achrotes* with brown hyaenas and seals (Stuart 1975), an observation that has been made by several researchers (Shortridge 1934, Stuart 1976, Owens & Owens 1978, 1985, Skinner & van Aarde 1981). Throughout this discussion on jackals at seal colonies I am referring to *Canis mesomelas achrotes*.

Analysis of jackal scats from the Namibian interior illustrates the importance of plant materials in their diet, while specimens from Sandwich Harbour contain more birds and marine refuse (Stuart 1976). The latter analysis was done prior to the establishment of a seal breeding seal colony at Sandwich Harbour and so they were not well represented. Ninety seven percent of scats from Van Reenen Bay, a well established seal colony, contained traces of seal hair and skin (Stuart & Shaughnessy 1984). The jackals at this site also consumed some birds, and scorpions. An interesting observation was that the scats did not contain recognisable quantities of seal bone. The predominance of seals in the diet of these jackals confirms that the coastal subspecies is closely associated with seal predation.

Jackals are ubiquitous on the Namibian mainland seal colonies and are seen daily wandering among the groups of seals, even jumping over sleeping adults, as they patrol the colony for food. It was not possible to do a detailed census of the jackals that I observed, but figures from 1984 show that there were approximately 60 individuals at the Van Reenen Bay (Black Rocks) colony, and 10 at Wolf Bay (Stuart & Shaughnessy 1984). The impression that I gained during 1989 was that there were fewer animals in attendance at the former colony and more at the latter. The concentration of so many jackals in close proximity suggests that territorial boundaries are relaxed at the colony. Dens were not located in the immediate vicinity of the colonies and none of those that I discovered contained any pups. Some of the co-operative behaviour of the animals when they were at the seal colony was a clear indication that they were mated pairs, and so I expected to find pups. I assume that the breeding dens were located further away from the colony.

During October, when my field observations were made, seal numbers on the breeding colonies are at their lowest and any remaining unweaned pups, approaching 10 months of age, are too big for the jackals to kill. During the breeding season pups are killed at will and the overall mortality through crushing in the overcrowded conditions or through heat exposure is as high as 34% within the first 30 days after pupping (De Villiers & Roux 1992). In September the natural pup mortality and number of pups on the colony are low and jackals have to scavenge for the scarce carcasses. A shortage of food occured during 1989 and the cows were forced to make long hunting forays at sea. The resulting poor condition of the cows was reflected in the pups and weaning was late. It was evident in many instances that cows had abandoned their pups altogether and even foetuses, aborted two months premature, were encountered. Mortality was very high and daily deaths provided many opportunities to observe seal consumption by jackals.

There were clearly two types of behaviour depending on the number of jackals present when a dead seal was found.

### 1. Competitive interactions

When a jackal encounters a dead seal it invariably tries to carry it away from the colony to avoid competition from other jackals. The following competitive interactions illustrate why this happens:

1. Thursday, 28 September 1989, approximately 8.00 am, weather - windy. I watched four jackals tearing at a carcass on the open sandy plain to the east of the colony. Eventually one of the jackals broke away with a portion of the ribcage. In running away from the scene it passed within 10 paces of where I sat. After a short time I decided to get closer to the scene, but I disturbed the remaining animals. All that remained of the carcass was the skin with the blubber still adhering to it, and the skull.

2. Thursday, 5 October 1989, approximately 12.00 noon, strong NW wind. From the cliffs to the east of the colony I observed a jackal eating a pup on a nearby rock platform. In the prevailing wind I was able to stalk unnoticed to within 15 paces of the animals. Several other jackals homed in on the scene and after a brief display of aggression - snarling with bristling hair - the possessive jackal took hold of as much of

its prey as it could and fled. The other jackals immediately jumped onto the rock platform and devoured the scraps that remained.

3. Sunday, 8 October 1989, approximately 6.30 am, fog - clearing. Approaching the colony I observed a commotion among a large group of jackals. They were fighting over a dead pup. Approximately 15 jackals were involved and by all appearances no patterning could be expected in the partitioning of the prey. They were rushing in and tearing at whatever they could - the skin was randomly ripped and a great deal more of the seal was exposed than in non-competitive interactions. A desperate fight ensued after which jackals began leaving the scene carrying parts of the seal - one pair of jackals ran off with the intestines strung between them. As the carcass diminished, so too did the number of jackals in attendance. Their attention had been so focused on the prey that another dead pup lying nearby was left undisturbed.

When competitive interactions occur around a scavenged seal carcass the partitioning is apparently random and it is impossible to develop an order of carcass consumption. The resulting opportunity presented to human scavengers, however, is minimal since the whole carcass is diminished to very little in a very short time. Such interactions are unlikely to occur anywhere other than at a mainland breeding colony, since nowhere else along the coast are jackals to be found in such high concentration. Competitive interactions are therefore unlikely to have any relevance in a non-colony, coastal setting, and the input of this behaviour is considered negligible in developing this methodology for west coast archaeological sites.

**2. Non-competitive interactions**

Non-competitive interactions occur during food gluts or when the jackals can avoid con-specifics after obtaining a seal carcass. They quickly retire with their prey from the colony to elevated areas such as rock outcrops or cliffs. From such a vantage point the jackal is able to eat the seal away from competitors and out of the sand and ever-present wind. Several sites were found in the vicinity of the Van Reenen Bay colony where repeated visits by jackals had led to the accumulation of substantial "kitchen middens". The input into these middens is not exclusively the result of non-competitive interactions since jackals would often retire there with only part of a seal carcass having been successful in a competitive interaction. Likewise what remains after non-competitive interactions is not exclusively found on these middens. Carcasses with typical jackal consumption characteristics were found scattered up to 2.5 km from the colony and a jackal was observed carrying a seal pup 1 km from the colony. As might have been predicted, no seal carcasses or bones were found in or around the jackal dens that were encountered.

Although the jackals were highly competitive around food, those that were observed during my field observations foraged alone. Successful attempts to move the seal carcasses away from the colony immediately upon discovery ensured minimal competition. Even if two jackals competed over a carcass, the scene would attract any others that were in the vicinity and the level of competition would escalate rapidly. Removing the resource from the normal foraging area allowed a jackal to eat at a leisurely pace. They would feed off the same carcass many times in a day, and sometimes over several days, but only eating a small amount at a time.

Non-competitive interactions were too numerous to be recounted in detail here. The behaviour of the jackals appeared very consistent in every case. This can be summarised as follows: firstly the jackal penetrates the neck by biting through the skin at the throat. It then focuses all its attention on removing the flesh and the contents of the chest and stomach cavities while avoiding the blubber, skin and bones. This it achieves by holding down the skin with its fore-paws and biting and pulling at the flesh with its incisors. They achieve a remarkable degree of finesse with their long slender snouts, and I found two bird carcasses (one of which was a penguin) where jackals had eaten the flesh but left the bulk of the bones totally defleshed, intact and still articulated along with the skin. The action of pulling at the flesh of the neck whilst pushing (or pinning down) the skin tends to arch the cervical vertebrae as they are defleshed, and the head bends backwards until the skin inverts at the neck. The process that follows is similar to the removal of a sock. Pinning the skin down and pulling with the snout the jackal attempts to penetrate the chest cavity and remove the bulky flesh from the scapula and shoulder area. The flesh is pulled from inside the inverted skin, and as this proceeds the skeleton of the seal arches backwards and the skin continues to invert. At this stage the sternum, the cartilaginous distal ends of the ribs and the proximal

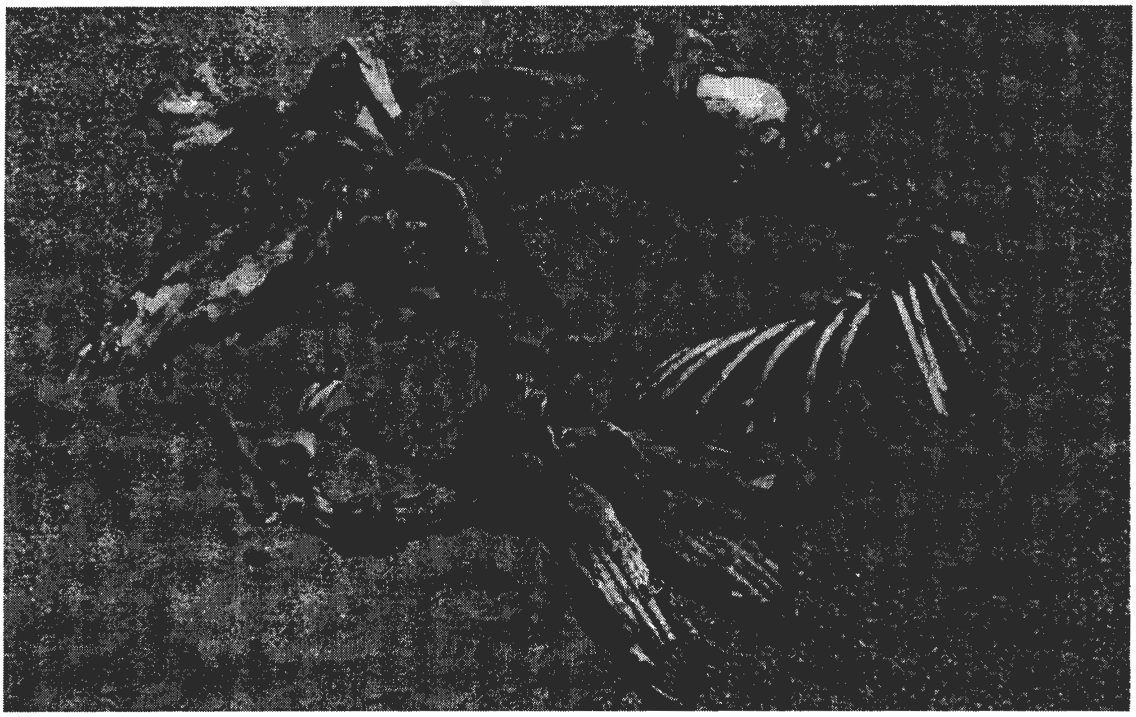

**Figure 6.2** *The way in which skin of this seal was inverted and pulled off of the carcass is typical of non-competitive consumption of seals by jackals.*

margin of the scapula are often destroyed, as is the olecranon. Once the flesh of the chest and upper forelimbs has been consumed the front flippers are no longer attached to the axial skeleton, and they fold inside the inverted skin. Eventually the stomach cavity is eaten out and all that remains is the skeleton arched backwards with the virtually intact skin (except for a hole in the neck), inverted, connecting the head and hind flippers (figure 6.2). Two very important resources remain almost to the last. The brain cannot easily be extracted by the jackals although one kill, monitored for three days, showed that it was eventually consumed. The jackals never seemed to eat the blubber that lines the skin.

The extraordinary persistence of the primary parts of the carcasses from a human perspective (the brain and blubber), and the ease with which jackals can be driven from the scene, creates an opportunity that is very favourable for people to scavenge seals. The characteristics of archaeological assemblage that have accumulated in this way will reflect the order in which the jackals consume the carcasses of seals.

## Deriving the order of carcass consumption - Guttman scaling

Two sets of observations made during the course of the fieldwork in Namibia inform on how jackals consume seal carcasses. The first set comprises the direct observations summarised above. In each instance the jackal activities were recorded and the portion of the carcass which they abandoned, or on occasions from which I had driven them, was noted in detail. The second set of observations comprises desiccated and preserved carcasses that were abandoned in the past. A sample of 17 of these was found in the vicinity of the Van Reenen Bay colony. The state of these carcasses varies from those abandoned because they had reached the end of their resource life to the jackals, to those abandoned in the very early stages of consumption. All of them displayed the characteristic damage inflicted in observed consumption and, in the light of the discussion of hyaena consumption, could only have been the result of jackal activities. Each of the seal carcasses identified a point in the hierarchy of seal consumption by jackals - what remains was of lower rank than what was consumed. I have derived the order of body part consumption in terms of the anatomical elements defined by faunal analysts when analysing archaeological sites. I considered each carcass in the sample as a set of bones which would remain archaeologically visible and thus translated each into an archaeological observation. There is a slight misrepresentation in considering the carcasses as bone assemblages. This is because it is the meat of the seal that is attractive to both jackals and humans. Jackals tend to eat the flesh off of a bone before they delete it, and so there is a slight difference between the flesh that is available, and the bones that are present. The bones that are abandoned represent more anatomical elements than are available as food.

By ranking the seal carcasses from the most complete to the most depleted, and comparing the elements present in each case, the progressive depletion of the carcass should be apparent. The validity of such an hypothesis can be tested using a statistical method known as Guttman Scaling (Torgerson 1958, Kronenfeld 1972, Edwards 1983). Guttman Scaling has three axioms which are integral to the concept of the order of carcass consumption. Firstly, if any anatomical element is eaten from the carcass, it will be the highest ranked element that is present; secondly, if any element of intermediate rank is eaten then all higher ranked elements will already have been eaten or removed; and thirdly, if any element of intermediate rank is abandoned, then all elements ranked lower will also be abandoned (Kronenfeld 1972, O'Connell *et al.* 1988, 1990). These axioms limit the application of this technique to the non-competitive carcass consumption events. Pride or clan associated carnivores that feed socially may consume several anatomical elements of different ranking from a carcass simultaneously. Blumenschine dealt with the problem of social feeding by lions and hyaenas by assessing element completeness as well as the consumption sequence (Blumenschine 1986*b*). In the case of non-competitive jackal consumption of seals, the presence of only a single carnivore means that the linear consumption outlined in the three axioms might reasonably be expected.

| | Carcass Number | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **15** | **4** | **3** | **8** | **13** | **14** | **5** | **16** | **7** | **12** | **2** | **1** | **6** | **9** | **10** | **11** | **17** |
| Maxilla | O | O | O | O | O | O | O | O | O | O | O | O | O | O | O | O | O |
| Mandible | O | O | O | O | O | O | O | O | O | O | O | O | O | O | O | O | O |
| Thoracic vertebrae | O | O | O | O | O | O | O | O | O | O | O | | | O | O | O | O |
| Ribs | * | * | O | * | O | O | * | * | * | * | * | | | * | * | * | * |
| Innominate | O | O | O | O | O | O | O | O | O | O | | | | | | | |
| Lumbar vertebrae | O | O | O | O | O | O | | O | O | O | | | | | | * | |
| Femur | O | O | O | * | O | O | O | O | * | | | | | * | | | |
| Fibula | O | O | O | * | O | O | O | | | | O | | * | * | * | | |
| Tibia | O | O | O | * | O | O | O | | | | O | | * | * | * | | |
| Tarsals | O | O | O | * | O | O | | | | | | | * | * | * | | |
| Phalanges | O | O | * | O | * | * | | | | | | | * | * | * | * | |
| Metapodials | O | O | O | O | * | * | | | | | | | O | * | * | * | |
| Carpals | O | O | O | O | * | * | | | | | | | O | O | | * | |
| Ulna | O | O | O | O | * | * | | * | | | | | * | * | * | * | * |
| Radius | O | O | O | O | * | * | | * | | | | | O | O | O | O | O |
| Humerus | O | O | O | O | * | * | | * | | | | | O | O | O | O | O |
| Scapula | O | O | O | * | * | * | | * | | | | * | * | * | * | * | * |
| Occipital condyles | O | O | | | O | O | | O | | O | O | O | | | O | | O |
| Cervical vertebrae | O | | | | O | O | | | | O | O | O | | O | O | | O |

**Table 6.1** *Guttman matrix of anatomical elements remaining in abandoned seal carcasses. The deletion of the cervical vertebrae and occipital condyles is contingent on the ability of jackals to break the neck. Thereafter the jackals normally remove the elements of the forelimb starting with the proximal elements, the hindlimbs and then elements of the axial skeleton. Carcasses numbered 6, 9, 10, 11, and 17 illustrate the contingency in which jackals initiate consumption through the stomach and remove the hind limbs before the fore limbs.*

The Guttman Scale is constructed by presenting the observations in a matrix in which the columns represent different carcasses and the rows represent various body elements (Table 6.1). Each entry in the matrix lists the element represented by that row as present (O), partially present (*) or absent ( ) in the carcass represented by that column. If a unidimensional scale for the consumption of the carcass exists, the order in which the anatomical elements are listed, and the order in which the observations are listed across the matrix, can be arranged so that the present entries are concentrated at the top and on the left of the matrix. The order in which the anatomical elements are listed then represents, from bottom to top, the order of body part consumption. If the consumption sequence exists on a unidimensional scale then the correct ordering of the matrix can be achieved, but the converse, the existence of an ordered matrix, does not imply that the sequence is unidimensional. The possibility that the order seen in the carcasses is spurious or the result of random behaviour by the jackals (or even another unknown factor) cannot be excluded. The carcass consumption sequence that emerges, however, is verified by the direct observations of jackals eating seals.

A measure of consistency or "goodness of fit" in the sample (similar to an $r^2$ value) is the coefficient of reproducibility (REP) which is defined as:

$$REP = 1 - \frac{NUMBER\ \ OF\ ERRORS}{n \times NUMBER\ \ OF\ VARIABLES} \qquad \text{(Edwards 1983: 184-91)}$$

where errors = inconsistent entries in the matrix after exhaustive manipulation of columns and rows.
n = number of entries in the matrix excluding those from rows with more than 80% of the entries showing the same notation. These skew the results.
variables = number of rows in the matrix excluding those with more than 80% showing the same notation.

Exhaustive attempts to order the seal carcass matrix produced unacceptably low values of REP (values of REP greater than 0.9 are considered acceptable). The conclusion is that the total sample of carcasses does not represent a linear (unidimensional) pattern of consumption. The reason for this is apparent in the sample set and was evident from direct observations. Although the observed consumption of the seal carcasses always began at the neck, the next step is contingent on the ability of the jackal to disarticulate or break the cervical vertebrae. If this was achieved the foramen magnum was quickly exposed and the jackals were able to penetrate the skull and eat the brain. If the neck was not destroyed then the seal cranium, although it is relatively delicate and was often punctured by the jackal canines, usually persisted until the carcass was abandoned. This contingency affects the relative position of the occipital condyles and cervical vertebrae in the order of the consumption - they are either deleted very early in the sequence, or not at all.

A second contingency relates to the jackal's ability to disarticulate or break the lumbar vertebrae. The effect is to expose the proximal elements of the hind limb to the jackals in such a way that they are able to delete these bones. In every instance when this occurred the hindlimb elements were removed before the forelimb. This suggests that these carcasses are not being penetrated at the neck, but rather in the abdomen. This occurred in less than 25 % of the observations and it is suggested that it only happens when the carcass is that of a very young seal, perhaps only new-born pups. During my fieldwork this was not observed to happen regularly. In one observed feeding bout (of a foetus aborted two months premature) the abdomen was consumed before the neck. This confirms that the selection of the stomach before the neck does occur, and that it is associated with the consumption of very young animals.

If the carcasses in which the lumbar vertebrae and hind limb elements were removed prior to the neck and forelimb element are considered separately, then the ordering of the matrix produces a coherent pattern of body part deletion (Table 6.1). If the neck is broken then the occipital condyles and brain are the focus of further attention. Thereafter a linear pattern of element deletion is evident. The forelimb is removed beginning with the proximal elements and continuing to the phalanges. The hindlimb is deleted next, but in this case the phalanges are the first to be eaten, and the proximal elements are deleted last. The axial elements are then deleted beginning with the caudal elements, then lumbar vertebrae and innominate, and then moving on to the thoracic vertebrae and ribs. Eventually all that remains is the snout of the seal attached to the skin and blubber. The mandible was never consumed by jackals.

The values of REP that are obtained when the sample of carcasses is split are 0.89 and 0.9. These values suggest that jackals do consume seals in a predictable and patterned way, but that there are several contingencies that need to be addressed. The first is the age of the seal at death, and the second is the ability of the jackal to break the neck. Age determinations from archaeological seal remains indicate that new-born pups are seldom represented on sites (chapter 10), and so the carcass consumption sequence portrayed in table 6.1 applies.

### Applying the Order of Carcass Consumption

The Guttman scale, and hence of the carcass consumption sequence, is measured on an ordinal scale in terms of favourable versus unfavourable (Torgerson 1958). Such a scale is known as a psychological continuum (Edwards 1983). There are no numbers, and nor should there be. There is no way to determine quite how successfully scavenging humans may have competed against jackals. On occasions the jackals would have eaten most of the seal and left only low order elements, and on other occasions they may have been driven off their prey before much of it was consumed. The number of events and the time scale involved in the accumulation of archaeological deposits would average out the effect of each event in which jackals biased the body part representation. The seal body parts that are ultimately preserved in a predominantly scavenged archaeological assemblage would nevertheless reflect the inverse of the order in which jackals consume seals. Precisely how much an element is underrepresented relative to another is not as relevant as the rank ordering of the elements.

Before applying the data obtained at the Namibian seal colonies to the archaeology of the south western Cape, the differences in the environment also need to be considered. The carnivores observed in Namibia live almost entirely off the seals and occasional bird carcasses they encounter. During the colonial period and probably the Holocene, the south western Cape supported a greater diversity of game including many more primary carnivores (Skead 1980). There was greater diversity in the food base for both predators and scavengers in comparison with the Namib desert. The distribution of food determines the social structure, group size and the size of the territory that carnivores occupy (Macdonald 1983). Among brown hyaenas the richness of food sources determines the number of animals that occupy a territory, while the distribution of the resources (i.e. the distance between food items) determines the size of the territory (Mills & Mills 1982, Mills 1990). In this context seal colonies represent an extremely rich food source that is in fact so vast that carnivores need not venture any further. Namibian brown hyaenas violate this hypothesis by occupying large territories (Goss 1986). This may be a function of the distances that must be covered to obtain some resource diversity, but it is in contrast to the Kalahari and Transvaal clan territories which are much smaller (Skinner 1976, Mills 1990). The jackals and brown hyaenas that lived on the Cape west coast during the time that the three archaeological sites under consideration were deposited probably lived in smaller clans occupying smaller ranges. The overall density of carnivores was probably lower than that encountered at the seal colonies. The social structure of both species would probably also have been more rigid as competition for resources would have been higher.

Seasonal climate shifts would undoubtedly have had an impact on grazing and browse, causing movement in terrestrial prey species and the dependent predators. Larger predators such as lions and spotted hyaenas would probably have migrated with the herds. There is no definite evidence for this, but I would speculate that the carnivores that scavenged over the beaches would have been present year round provided there was a sustained supply of seal, whale and bird carcasses.

Fewer seal carcasses can be expected to wash up in a non-colony setting than are available at a colony. There would therefore be a less focused resource for carnivore activity. The scavenger to carcass ratio is again a matter of speculation, but I would surmise that with lower total numbers of jackals there would be fewer in attendance at each carcass that washed-up in a non-colony setting. The implication is that there would be fewer competitive interactions, improving the carcass persistence and hence providing greater scavenging potential to people.

### Bone destruction by Jackals and Brown Hyaenas

The effect of carnivore ravaging on bone accumulations has been the subject of a great deal of archaeological research over the last 15 years. Ravaging refers to the act of modifying a bone assemblage by partially, or entirely, destroying bones through gnawing or chewing, or by transporting selected bones to other parts of the landscape (Binford 1981, Marean *et al.* 1992, Blumenschine & Marean 1993). In relation to the model of carnivore ecology and its influence on the taphonomy of archaeological sites, ravaging represents late access by carnivores to material that has already been discarded by people. The effects of ravaging range from the destruction of the bone surface, for example when cut marks are obscured by gnawing, to the deletion of entire bones, in which case the interpretation of anatomical part representation is affected. Ravaging has the potential to substantially alter characteristics of an assemblage, and any faunal analysis must accommodate the effects at two levels. First the analytical protocols that are used must be based on units that are not affected by ravaging, and second the interpretation of the results must accommodate the possibility that the observed patterns may be the result of carnivore behaviour and not human behaviour.

In order to establish the impact that carnivores have on bone assemblages from either an analytical perspective or an interpretative perspective it is necessary to establish exactly what carnivores do to bones, and why they do it. The aim is to identify a causal theme that can be used to predict which bones or which parts of each bone are destroyed or removed. This can only be done by studying carnivores in their modern context, and a large amount of work has been done, particularly on hyaenas (Sutcliffe 1970, Klein 1975*b*, Bunn *et al.* 1980, Hill 1983, Bunn 1986, Bunn & Kroll 1986, Brain 1980, 1981, Cruz Uribe 1991, Lyman 1992). The context of these analyses, however, differs from that of archaeological deposits in that the carnivores procured bones that were articulated units, often still bearing large quantities of meat. The bones that remain after humans have abandoned a site are normally disarticulated and fragmented as a result of marrow extraction. Experimental exposure of simulated archaeological sites to hyaena ravaging (Binford *et al.* 1988, Blumenschine 1988*b*, Blumenschine & Marean 1993, Marean & Spencer 1991, Marean *et al.* 1992), and ethnographic examples of ravaging (Brain 1967, Binford 1978) provide a more accurate appraisal of the potential impact of carnivores. A coherent picture of the contingency that the carnivores follow when they discover a bone accumulation is gradually emerging from the feeding experiments and field observations.

The most often implicated carnivore in site ravaging is the spotted hyaena. On the basis of simulated site ravaging experiments it has been suggested that they select less dense bones for consumption because of the higher bone grease content (Marean & Spencer 1991, Marean *et al.* 1992, Blumenschine & Marean 1993). Since Brain (1967, 1969) first suggested that bone density was the principle factor in determining the eventual body part representation in assemblages that were subjected to mechanical attrition, the mediation of carnivore ravaging on the basis of bone density has been demonstrated in a number of studies (Binford & Bertram 1977, Haynes 1980, 1983, Hill 1980*a*, Binford 1981, Lyman 1992, Hudson 1993, Lyman 1993). A recent study that is of particular interest was done by Stynder (1994). He tested whether the size, as well as the mechanical properties of seal bones, played an important role in mediating bone destruction by carnivores at the Dune Field Midden.

The carnivore species that were studied in the course of this research are also potential ravagers of archaeological assemblages, especially seal bone assemblages. In many instances these species are more likely to be the ravaging agent than spotted hyaenas. The aim of this part of this thesis is to test whether jackals and brown hyaenas select and destroy bones on the basis of the physical properties of the bones as has been demonstrated for other carnivore species. Instead of using the density, or photodensity values, the aim is to determine whether the Hardness indices developed in chapter 5 are adequate mediators of biotic destruction of seal bone. The control sample of ravaged bones is from two jackal kitchen middens excavated during my field work at the van Reenen Bay seal colony, and two brown hyaena maternity dens excavated by Skinner & van Aarde (1991). These are the end product of carnivore hunting, scavenging and consuming seals in the vicinity of the colonies, and they represent attrition of complete seal carcasses over the last 40 years.

## Analytical units

Throughout this research I use the Minimum Animal Unit (MAU) term defined by Binford (1978) as the basis for analysis. MAUs are calculated by dividing the number of bones of a particular element that were recovered by the number of times that element occurs in a normal skeleton. This is felt to be a more accurate representation of the number of elements represented in an assemblage than is obtained when Minimum Number of Individuals (MNI) is employed. For example forelimb elements may be introduced into jackal middens through a different mechanism from the rest of the carcass. If the bones of 5 right and 5 left forelimbs were introduced the MNI would be the same as if only 5 right forelimbs had been introduced (MNI=5). The MAU term distinguishes between these situations (MAU=5 in the former instance, and 2.5 in the latter) and better reflects the number of limbs that were introduced. In the instance where a complete skeleton is represented the MAU values for each of the elements will be 1.

The results are normalised onto a scale of 0-1 (or NMAU) by dividing all the MAU values by the maximum MAU value that was obtained. This allows the MAU representation for assemblages of different sizes to be compared on a similar scale.

## Hyaena attrition of seal bones

An important aspect of hyaena feeding ecology is the provisioning of young at a maternity den. I investigated a maternity hyaena den at the Wolf Bay seal colony. It comprised a set of tunnels that were burrowed into a sandy gully immediately adjacent to the seal colony. The burrows had partially collapsed as a result of rain during the previous year and so it was difficult to determine whether the adults would have been able to enter the den. From the vast number of seal bones and complete seal carcasses that were scattered around the entrance to the den it seems likely that the adults dropped the food that they brought back for the cubs around the entrances. This would suggest that it was a typical maternity den that only accommodated the young.

Unfortunately the bone accumulation at this den was not sampled, but two other dens that are also in the vicinity of Wolf Bay were excavated by Skinner & van Aarde (1991). Both were reported to be maternity dens, and while one was located at a seal colony (this is a different den from the one that I visited), the other was located 8.5 km inland. In terms of the distances that brown hyaenas can cover, and the size of the ranges they inhabit, the proximity of the inland den to the source of seals did not present the hyaenas with a problem of access to the food source (see Goss 1986). Both assemblages were dominated by seals. The representation of body parts is presented in table 6.2.

It is important to note that the bones that are introduced to maternity dens are food items that are brought back for the young. Adult hyaenas seldom bring back defleshed food items or any other objects that they would not eat themselves. The damage to the seal bones found at the maternity dens is therefore most likely to have been inflicted by the cubs. The destructive potential of cubs is much less than that of the adults. It has already been shown that the adults are capable of consuming entire seals - including the bones. This affects the use of the den assemblage as a model for the impact of hyaena ravaging on archaeological sites. The defleshed and disarticulated seal bones that are likely to be discarded at an archaeological site still represent food to brown hyaenas, but the parcels are so small that it is unlikely that they would transport them back to a den to feed to the cubs. On encountering the discarded seal bones the adult hyaenas would probably eat them immediately. The impact of hyaena ravaging is therefore characterised in terms of the bones that they select, not on their ability to destroy the bones. The objective in analysing the maternity den assemblage is to test whether brown hyaena cubs selectively consume bones with lower Hardness values. The results of this test are possibly valid only in the case of bone selection by cubs. Nevertheless, if a coherent pattern of bone destruction exists, it may indicate a strategy of bone selection that provides a basis from which to extrapolate the behaviour of the adults.

| Body Part | Coast (NISP) | Coast (NMAU) | Inland (NMAU) |
|---|---|---|---|
| | **Seal bone representation in Brown Hyaena Den Assemblages** | | |
| Ribs | 221 | 0.21 | 0.04 |
| Humerus proximal | 50 | 0.63 | 0.82 |
| shaft | 77 | 0.96 | |
| distal | 57 | 0.71 | |
| Radius proximal | 43 | 0.54 | 1 |
| shaft | 56 | 0.70 | |
| distal | 49 | 0.61 | |
| Ulna proximal | 32 | 0.40 | 0.42 |
| shaft | 38 | 0.48 | |
| distal | 32 | 0.40 | |
| Tibia proximal | 21 | 0.26 | 0.55 |
| shaft | 35 | 0.44 | |
| distal | 21 | 0.26 | |
| Fibula proximal | 4 | 0.05 | 0.16 |
| shaft | 5 | 0.06 | |
| distal | 4 | 0.05 | |
| Scapula | 80 | 1 | 0.53 |
| Femur proximal | 26 | 0.33 | 0.39 |
| shaft | 49 | 0.61 | |
| distal | 31 | 0.39 | |
| Phalanges | 145 | 0.06 | 0.04 |
| Pelvis | 47 | 0.59 | 0.16 |
| Tarsals | 8 | 0.02 | 0.11 |
| Carpals | 16 | 0.04 | 0.03 |
| Vertebrae | 193 | 0.10 | 0.03 |
| Sternum | 1 | 0.01 | 0 |
| Mandible | 54 | 0.68 | 0.74 |
| Metacarpal | 14 | 0.04 | 0 |
| Metatarsals | 8 | 0.02 | 0 |

**Table 6.2** *Seal bone representation at Namibian brown hyaena dens (after Skinner & van Aarde 1991)*

### Inland brown hyaena den

The body part representation of the seal assemblage recovered from the inland den reported by Skinner & van Aarde (1991) is not presented with the same level of anatomical resolution as most faunal analyses in archaeology, nor with the resolution with which the Hardness values were measured. No distinction is made between the proximal and distal ends of long bones, and partially destroyed bones are not reported as such. The assemblage is simply reported as the number of each element that was present. This lack of resolution presents a problem because it is not clear which Hardness values should be used to test the survival potential of bones with both soft and hard areas. I have assumed that the part of the bone with the maximum Hardness value has the best chance of surviving. There is a degree of circularity in this argument because I also want to demonstrate that harder bones have more potential for survival. The null hypothesis is that bones are not destroyed according to their physical properties (Hardness), in which case

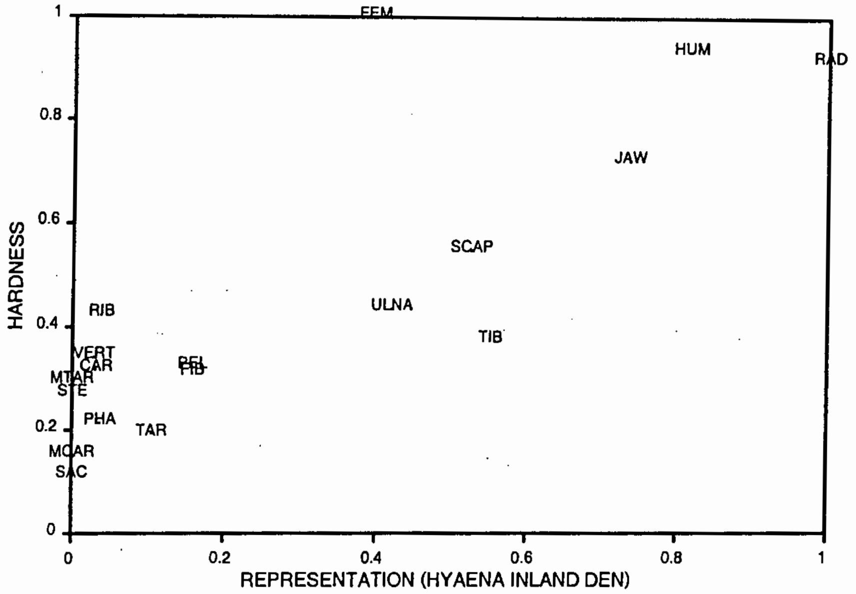

**Figure 6.3** *Normalised representation of seal bones at the inland hyaena den plotted against maximum Hardness values for each bone.*

there will be no relation between Hardness and representation. If this is true then the assumption will not be valid and a random relation between Hardness and representation will still be manifest.

A plot of Hardness versus seal bone representation at the inland hyaena den is presented in figure 6.3. In general the relation appears to be linear with higher MAU values associated with bones with higher Hardness values. A linear regression between the two data sets has a significant $r^2$ value of 0.68. A clear outlier from the trend is the femur. This bone has the highest Hardness value in the entire seal skeleton, but it is clearly underrepresented with respect to the number of bones that are predicted on the basis of the regression. There are two possible reasons for this. Firstly the Hardness index may be an inappropriate mediator of seal bone destruction by hyaenas. This is rejected on the basis of the statistically significant relation that exists between Hardness and MAU for the whole assemblage. A second reason could be that the destruction of the femur is not contingent on the Hardness alone, but on another property as well. Stynder (1994) showed that the seal femur differs from the other long bones in that it is extremely short, and that this plays an important role in determining the destructive impact of jackals. In addition the femur comprises parts that are very soft as well as those that are very hard. It is proposed that the femur is underrepresented because it is easily reduced to a small hard lump of bone that is swallowed whole.

The swallowing of small bones by hyaenas can be tested by considering the fate of other small bones. The metapodials, phalanges and individual elements of the axial skeleton, with the exception of the ribs, are all roughly comparable in size to the femur. Unfortunately all these bones have very low Hardness values and so it is not clear if their low representation in the den assemblage is the result of their size or their

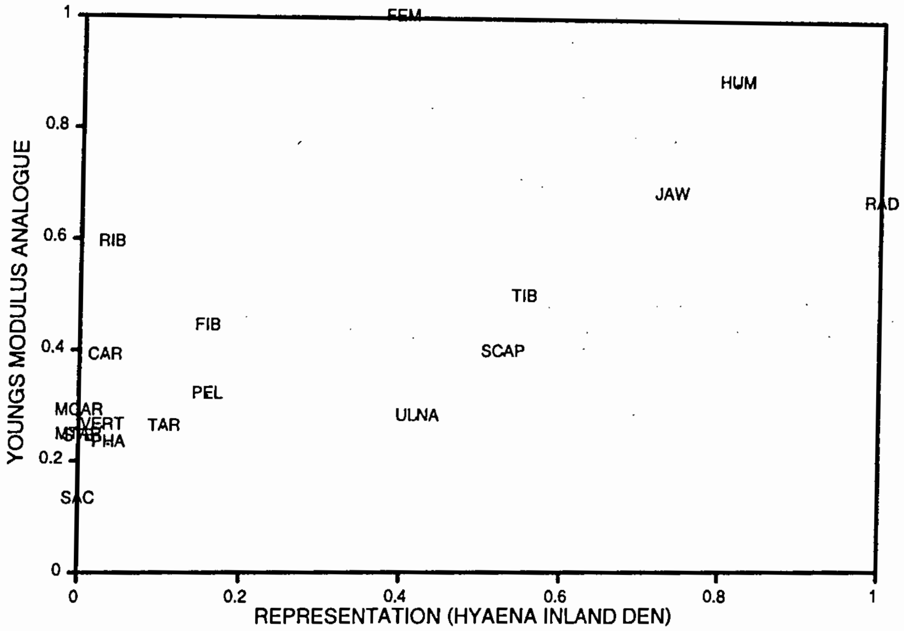

**Figure 6.4** *Normalised representation of seal bones at the inland hyaena den plotted against the maximum Young's Modulus analogue values for each bone.*

Hardness. The unfused epiphyseal ends of the long bones are also small and would be expected to be swallowed whole by the hyaenas. In the case of the inland den the composition of the assemblage is not reported in enough detail to test this hypothesis.

If the low representation of the femur is accepted, for the moment, to be the result of size selective behaviour of the hyaenas then its survival in ravaging scenarios will not be based on its Hardness. The survival of the rest of the skeleton does appear to relate to the Hardness of the bones. Excluding the femur in a linear regression between MAU and the maximum Hardness value of each bone, the relation is highly significant with an $r^2$ value of 0.83. The relation between the MAU values at the inland den and the Young's Modulus Analogue is shown in figure 6.4. Although this index is related to Hardness it does not appear to determine bone survival with the same degree of significance. Regressing MAU and the Young's Modulus Analogue gives an $r^2$ value of 0.47, and rejecting the femur as an outlier the value improves to 0.62.

## Coastal hyaena den

In contrast to the inland den assemblage, the anatomical breakdown of the coastal brown hyaena den assemblage is reported in adequate detail. Instead of assuming that the hardest part of the bone is what was recovered, it is feasible to relate survival to the known Hardness values of bones and bone fragments. This makes it possible to assess whether the principles that determine which elements are represented in the assemblage also apply to the partial destruction of the bones. On the basis of the result obtained for

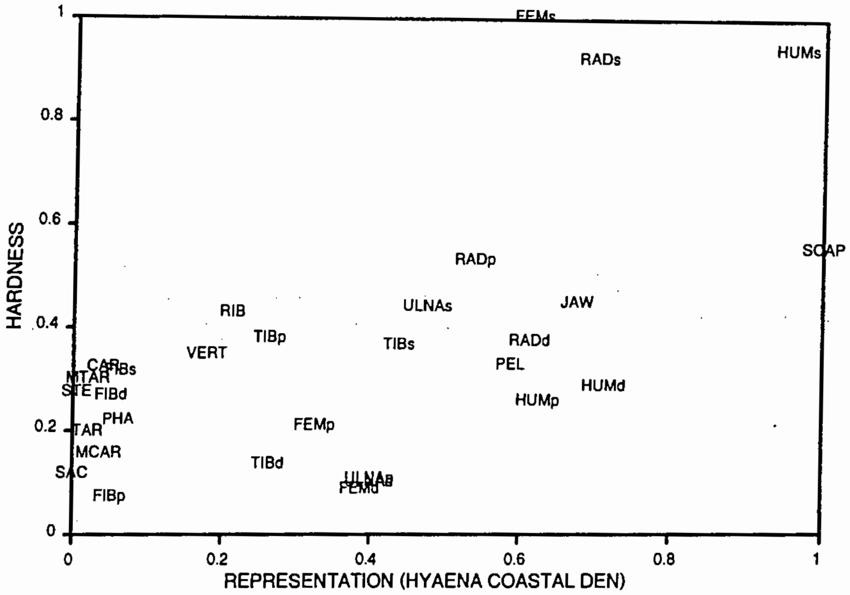

**Figure 6.5** *Normalised representation of seal bones at the coastal hyaena den plotted against Hardness. Subscripts represent proximal (p), distal (d) and shaft (s).*

the inland hyaena den it is suggested that small bones, and those with low Hardness values, are preferentially destroyed. If this applies at the level of each element then the softest part of each bone should also be destroyed preferentially to the harder parts. It is also possible in this ssemblage to test whether the strategy of bone destruction by the hyaenas is coherent across all the bones and all parts of the bones. If it is coherent then the soft parts of every bone should be destroyed before the harder parts of any of the bones. A plot of Hardness versus seal bone representation at the coastal hyaena den is presented in figure 6.5. Although it is not as obvious as in the inland den, there still appears to be a correlation between Hardness and MAU. Harder bones are generally better represented, and a linear regression gives an $r^2$ value of 0.37 ($r^2$=0.42 excluding the femur). The relation between the MAU values at the coastal den and the Young's Modulus Analogue is shown in figure 6.6. As was noted for the inland den, the Young's Modulus Analogue does not appear to determine bone survival with the same degree of significance as Hardness ($r^2$=0.17).

On the basis of the hypothesised fate of the femora in the inland den it was predicted that small bones such as the epiphyses would be underrepresented at the coastal den. Inspection of figure 6.3 (table 6.2) shows that the elements that deviate most significantly from the expected pattern are the epiphyses, but contrary to expectation some are overrepresented (proximal and distal epiphyses of the humerus and ulna, and the distal femur), while others are underrepresented (proximal epiphyses of the radius and tibia, and the distal epiphysis of the fibula) with respect to their Hardness values. The distal and proximal epiphyses of the long bones are represented by fewer MAU's than the shafts - as might be expected on the basis of their Hardness values - but the degree to which they have been deleted by the hyaenas is not consistent

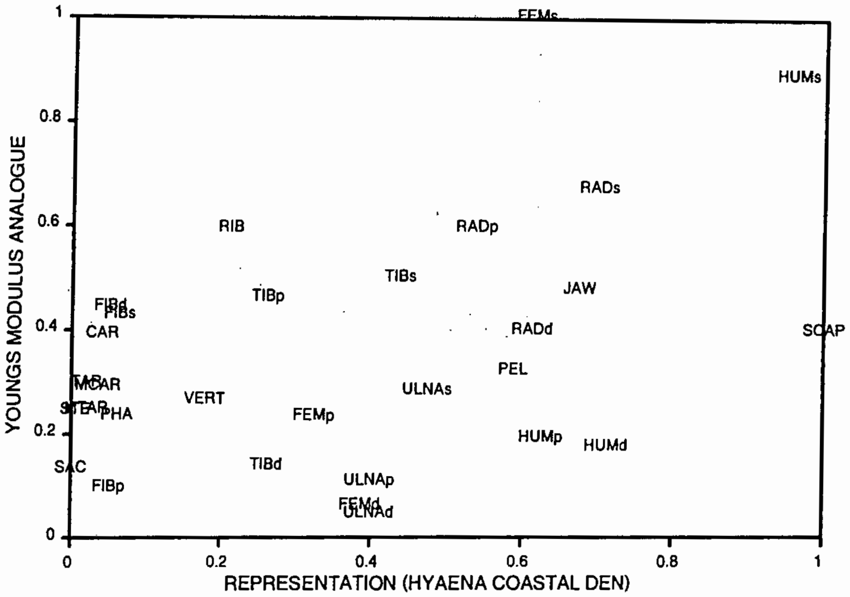

**Figure 6.6** *Normalised representation of seal bones at the coastal hyaena den plotted against the Young's Modulus analogue values. Subscripts represent proximal (p), distal (d) and shaft (s).*

with the overall trend. In other words the strategy of bone destruction did not result in the coherent deletion of the soft parts of all the bones. Hard parts of some bones were destroyed before the soft parts of others, and conversely the soft parts of some bones were ignored while hard parts of others were destroyed.

When hyaenas ravage assemblages made up of terrestrial bovids they tend to destroy the cancellous ends of long bones (Bunn & Kroll 1986, Binford *et al.* 1988, Blumenschine 1988*b*, Marean & Spencer 1991). Seal bones present a different set of options to carnivores because, with the exception of the skull and perhaps the scapula, they are made up entirely of cancellous bone. The number of long bone epiphyses that are preserved in the coastal den is not significantly less than the number of corresponding shafts. This implies that the hyaenas are selecting the bones that they destroy on the basis of Hardness, but the bones that they do not select are mostly left intact. The relatively low proportion of bone fragments in the assemblage indicates that the selection of a bone more often than not results in its complete destruction. The overall body part representation of the assemblage (inter-bone representation) therefore results from a process of selection by the hyaenas. The part bone representation of seals (intra-bone representation) in the assemblage is probably related to the destructive potential of the cubs, but only the part of the assemblage that they select is subject to this attritional process. Within the population of bones that are subjected to attrition by hyaena cubs there may be a relation between Hardness and survival, but this is a different system from that of bone selection.

The distinction between the selection of a bone as one process, and its destruction as another, has important implications. It is not clear how the hyaenas determine which bones they will try to extract

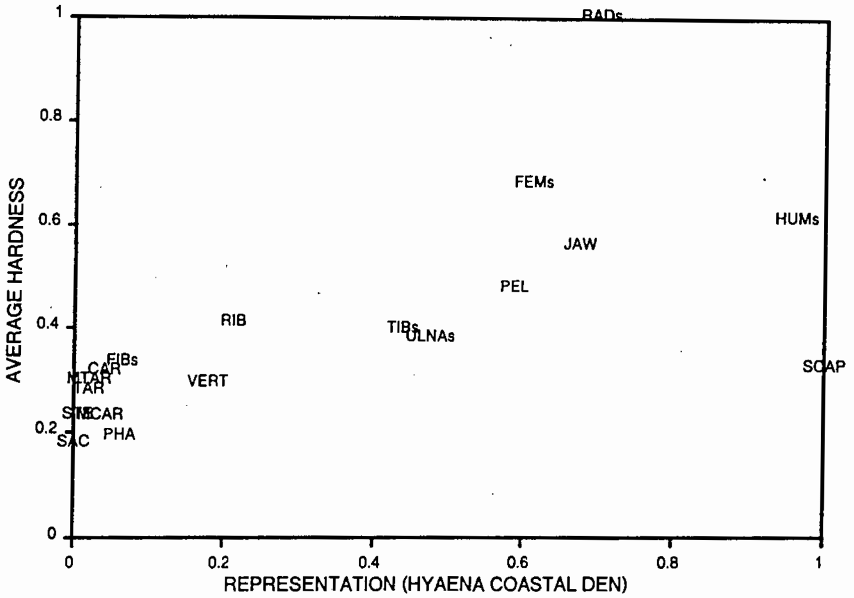

**Figure 6.7** *Normalised representation of seal bones at the coastal hyaena den plotted against average Hardness. Subscripts represent proximal (p), distal (d) and shaft (s).*

resources from, but it is done before the bone is substantially damaged. In other words the criteria that the hyaenas are using are based on each bone as a complete unit. If this is true then the part bone analyses presented in figures 6.3 to 6.6 are misleading. Any relation between MAU and Hardness should be calculated on the basis of whole bones. Marean & Spencer (1991) and Marean *et al.* (1992) obtained a strong relation between the average photodensity (based on Lyman 1984) of bone ends and their selection for consumption by spotted hyaenas. Figure 6.7 is a plot of MAU versus the average Hardness (obtained by averaging all the Hardness values obtained on a bone). A linear regression through these points gives a $r^2$ value of 0.46 relative to that obtained in the bone part analysis, but the radius and scapula are obvious outliers and when these are excluded an $r^2$ value of 0.80 is obtained. The scapula and radius fall as outliers in this plot because of the variable nature of the cancellous bone, bearing in mind that the hyaenas destroy the bones to obtain the nutrition contained within. The scapula contains very little marrow bearing cancellous bone and so, even though on average it is a relatively soft bone, it does not represent much food to the hyaenas. The radius is attractive to hyaenas because it has a high marrow content, but it is similar in structure to the femur in that it contains extremely hard and soft parts. The average hardness of the bone is deceptively high because part of the bone is extremely hard, but the remainder is extremely soft.

The significant relation that was established between the maximum Hardness values and representation at the inland den is not improved when the average Hardness values are used. The difference between the two dens may be related to the distance from the food source. For the hyaenas that reside near the coast, a regular supply of seals is guaranteed, and carcasses may be brought back to the den on a regular basis. This means that less effort need be invested in extracting the resource by hyaenas living at the coast than those living inland. In a sense the coastal cubs are employing a "gourmet" strategy in their bone selection. Only the very softest bones will be impacted before the hyaena cub will invest its effort in another food item brought to the den by the adults. The result is that the coastal hyaena assemblage is characterised by the process of bone *selection* by the cubs. The inland hyaenas that had to complete a minimum 17 km round trip to obtain seals for their cubs may do this less often. The cubs invest more effort in destroying the bones to access the marrow, and the result is that the survival of bones is closely aligned with the destructive potential of the hyaenas. The coastal situation is similar to that described by Lyman (1993) in which the destructive impact of the carnivore does not progress far enough to reach a point at which the relation between survival and photodensity, in his case, is manifest. This may take up to three weeks of gnawing (Garvin 1987 cited in Lyman 1993), and is more likely to be seen at the inland den.

### Summary of hyaena den results

The bone assemblages that accumulate at brown hyaena maternity dens are subject to attritional processes inflicted by the cubs. The attrition appears to take place in two discrete steps. The first is the selection of bones to chew. This appears to be affected by the average Hardness of each bone, although in some instances the relative size of the bone plays an important role. The second step is the actual process of chewing, which is presumably done in order to derive nutritional benefit from the bone grease. In most instances the selection of the bone results in its total deletion from the assemblage, but some partially destroyed bones do remain. The seal body parts that were recovered from the inland den are assumed to have been subject to more intensive ravaging than the coastal den, and as a result a greater proportion of the assemblage has been partially gnawed. Here the highest Hardness value obtained for each bone is a better mediator of survival.

The qualitative index of Hardness *viz.* the Young's Modulus Analogue, does not appear to play a significant role in mediating bone survival at the hyaena dens.

The selection of bones on the basis of photodensity by adult spotted hyaenas supports the hypothesis that the Hardness mediated destruction of bones by brown hyaena cubs noted in this study is a universal aspect of hyaena behaviour. If this is true then bone selection by adult brown hyaenas when they ravage human sites may also be determined by the average Hardness of the bones.

### Jackal attrition of seal bones

An important aspect of jackal feeding ecology is the way in which these carnivores focus on obtaining the meat from a carcass without impinging on the bone. The grease in seal bones does not appear to be an important part of the jackal diet, which is not very surprising considering the amount of blubber that can be obtained from a seal carcass, but which the jackals also ignore. In the course of my fieldwork there were numerous occasions when fresh seal bones could be obtained from any of a number of carcasses around the colony, but rather than gnaw on the bones the jackals seemed to prefer the often fruitless vigil for fresh carcasses. Jackals were never seen gnawing on bones the way domestic dogs often do.

Two jackal middens in the vicinity of Van Reenen Bay were excavated and analysed. As was discussed earlier the bone deposition at these middens is the result of intraspecific dynamics designed to avoid competition for resources. Inevitably there is a degree of competition between the jackals and hyaenas because they are both competing for the same resource. The hyaenas are normally the dominant species, but jackals sometimes scavenge seal carcasses from them. On occasions the jackals even drive the hyaenas away by "mobbing" them (Goss 1986). The damage to the seal bones that are deposited in the jackal middens is mostly the result of jackal behaviour, but there is a small component that is affected by the primary feeding of hyaenas.

The first jackal kitchen midden is located on the top of a 30m cliff at the northern end of the Van Reenen Bay seal colony. At this site it is possible for the jackals to eat the seal carcasses on a rocky substrate, in a position that is well protected from the wind and wind blown sand, and most importantly that is suitably obscured from detection by other jackals on the colony. The second midden was excavated from a prominent rock outcrop located in the sandy plain to the east of the colony. This site has the same advantages as the northern midden, except that it is in clear view of the colony. Observed consumption of seals here led to competition from other jackals within a very short time. The middens are called North Cliff Midden and East Rock Midden respectively, and are referred to as middens J1 and J2 by Stynder (1994). The body part representation for each of the middens is presented in table 6.3.

While there is evidence for gnawing on many of the bones in the jackal middens, the ability of the jackals to impact on seal bone assemblages is much less than that of hyaenas. The objective in this part of the thesis is to determine whether jackals systematically destroy bones, or parts of bones, on the basis of their Hardness, and to establish whether there are characteristic features that could be used to identify their impact on archaeological seal bone assemblages. Jackals are also very similar in stature to the domestic dogs that were kept by the indigenous inhabitants of the Cape when the Colony was first settled by Europeans. The damage that is inflicted by jackals may be a reasonable analogue to the damage that domestic dogs might inflict on an assemblage.

| | North Rock Midden | | East Rock Midden | |
|---|---|---|---|---|
| **Body part** | **NMAU** | **NISP** | **NMAU** | **NISP** |
| Humerus proximal | 0.06 | 5 | 0.15 | 7 |
| proximal shaft | 0.53 | 48 | 0.35 | 16 |
| shaft | 0.74 | 67 | 0.5 | 21 |
| distal shaft | 0.63 | 57 | 0.37 | 17 |
| distal | 0.11 | 10 | 0.17 | 8 |
| Radius proximal | 0.08 | 7 | 0.26 | 12 |
| proximal shaft | 0.57 | 51 | 0.39 | 18 |
| shaft | 0.69 | 62 | 0.43 | 20 |
| distal shaft | 0.38 | 34 | 0.22 | 10 |
| distal | 0.01 | 1 | 0.09 | 4 |
| Ulna proximal | 0.04 | 4 | 0.07 | 3 |
| shaft | 0.58 | 52 | 0.57 | 26 |
| distal shaft | 0.29 | 26 | 0.28 | 13 |
| Scapula | 0.34 | 31 | 0.26 | 12 |
| Carpals | 0.01 | 16 | 0.002 | 2 |
| Metacarpals | 0 | 0 | 0 | 0 |
| Tibia proximal | 0.02 | 2 | 0.07 | 3 |
| proximal shaft | 0.23 | 21 | 0.17 | 8 |
| shaft | 0.34 | 31 | 0.28 | 13 |
| distal shaft | 0.14 | 13 | 0.07 | 3 |
| distal | 0 | 0 | 0.02 | 1 |
| Fibula proximal | 0.23 | 21 | 0.07 | 3 |
| shaft | 0.34 | 31 | 0.13 | 6 |
| distal shaft | 0.14 | 13 | 0.04 | 2 |
| Femur proximal shaft | 0.17 | 15 | 0.07 | 3 |
| shaft | 0.24 | 22 | 0.15 | 7 |
| distal shaft | 0.19 | 17 | 0.13 | 6 |
| distal | 0.02 | 2 | 0.04 | 2 |
| Phalanges | 0.01 | 19 | 0.000 | 1 |
| Pelvis | 0.2 | 16 | 0.07 | 2 |
| Ribs | 0.17 | 202 | 0.16 | 95 |
| Vertebrae Thoracic | 0.03 | 17 | 0 | 0 |
| Lumbar | 0.03 | 11 | 0 | 0 |
| Atlas | 0.18 | 8 | 0.09 | 2 |
| Axis | 0.09 | 4 | 0 | 0 |
| Sacrum | 0.04 | 2 | 0.04 | 1 |
| Caudal | 0 | 0 | 0 | 0 |
| Sternum | 0 | 0 | 0.04 | 5 |
| Mandible proximal | 0.56 | 50 | 0.52 | 24 |
| shaft | 1 | 90 | 1 | 46 |
| Metatarsals | 0 | 0 | 0 | 0 |
| Tarsals | 0 | 0 | 0 | 0 |

**Table 6.3** *Seal bone representation at Namibian jackal kitchen middens.*

In this analysis of the jackal midden material I have attempted to relate Hardness and representation at the highest possible level of resolution. Each long bone has been divided into five zones: the proximal and distal epiphyses, the proximal and distal shafts, and the mid shaft. The highest Hardness or Young's Modulus Analogue value that was obtained within each of these regions of the bone is assumed to be the characteristic to which the jackals responded. The response of hyaenas to the softest part of some bones (the femur and radius) may be an indication that this is not a valid assumption. However the five part breakdown of the long bones results in fairly high resolution mapping of the variability in the Hardness, and averaging the values would make very little difference to the value attributed to each zone. Similarly the maximum index values were associated with the axial and limb elements, and they would not have changed significantly if I had averaged the results.

### Midden J1 (North Cliff Midden)

The foregoing analysis indicates that the damage to seal bones in hyaena den assemblages involved two discrete steps. The first step was the choice of which bone from the seal skeleton to chew, and the second was which part of the bone to chew. The damage that jackals inflict on seal bones is not likely to include the first step. In most instances of observed seal consumption, jackals were unable to disarticulate the skeleton to a significant degree, and so they were not in a position to choose between the bones. This is supported by the sample of seal carcasses used to determine the order of carcass consumption. If the jackals were able to disarticulate the cervical or lumbar vertebrae then they would eat the seal in a different manner from when they could not break the spine. The number of instances in which the lumbar and cervical vertebrae remained intact in the sample of abandoned carcasses indicates that the jackals were not able to disarticulate the bones in many instances. In other words the entire seal skeleton, except for the forelimbs which are not articulated with the axial skeleton, represents a single unit to the jackals. The choice of which part of the skeleton to chew is based on the same criteria as the choice of which part of a bone to chew.

Figure 6.8 is a plot of Hardness versus representation in MAU units using the level of resolution for the seal skeleton that was described above. The plot appears to be random suggesting that the jackals do not inflict damage on the seal skeleton on the basis of bone Hardness. When the elements of the forelimb are removed from the plot, however, a coherent relation between Hardness and representation emerges (figure 6.9). The axial and hind limb elements are linearly correlated with Hardness with the exception of the femur which is significantly underrepresented. This is the same pattern that was observed for the hyaena and the reason for it may be that the jackals also gnaw the soft parts of this bone, and the remaining hard part is small enough to swallow. Other bone parts that are underrepresented include the proximal tibia epiphysis, the sternum, ribs and phalanges - all of which, with the exception of the ribs, are small bones.

The seal bone representation at North Cliff Midden is plotted against the Young's Modulus Analogue in figure 6.10. Again the plot appears to be random, but splitting the forelimb elements from the rest of the

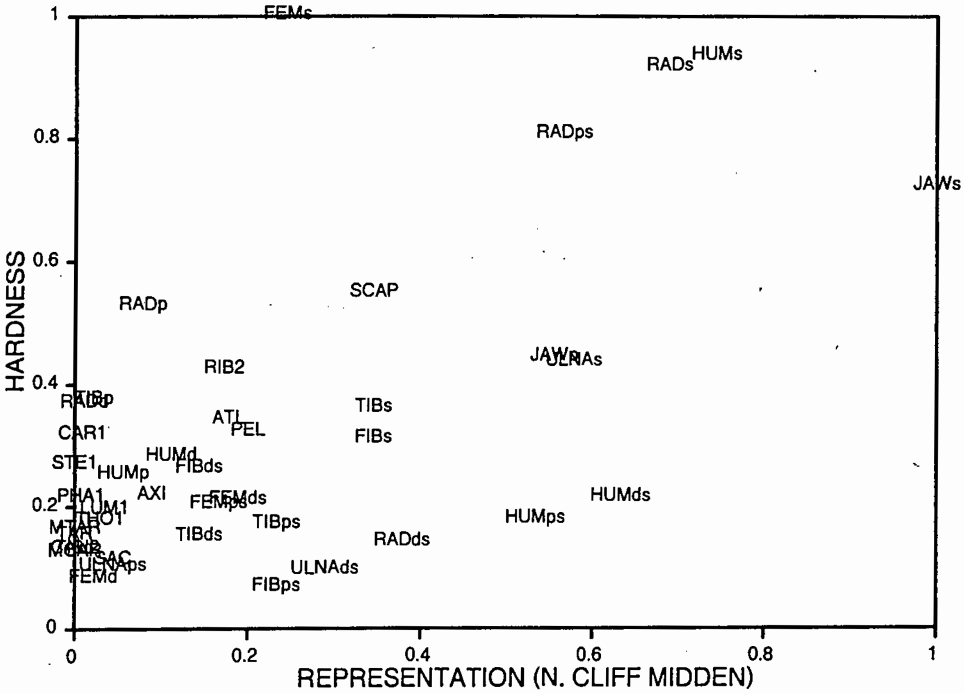

**Figure 6.8** *Normalised representation of seal bones at jackal kitchen midden North Cliff Midden plotted against Hardness. Subscripts represent proximal (p), proximal shaft (ps), shaft (s), distal shaft (ds) and distal (d).*

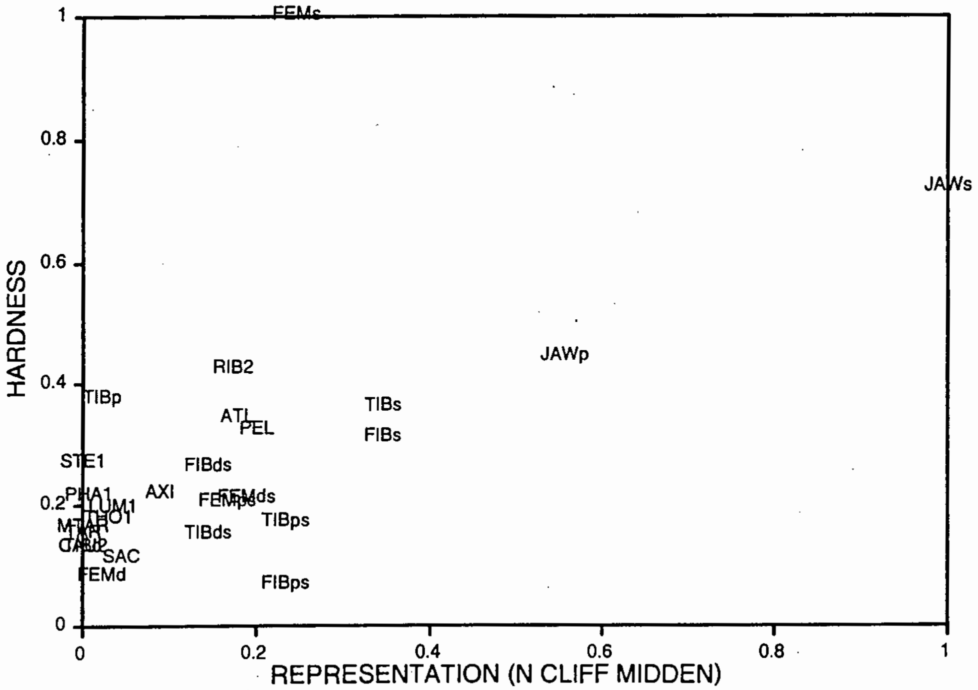

**Figure 6.9** *Normalised representation of seal bones at jackal kitchen midden North Cliff Midden (excluding elements of the forelimb) plotted against Hardness. Subscripts represent proximal (p), proximal shaft (ps), shaft (s), distal shaft (ds) and distal (d).*

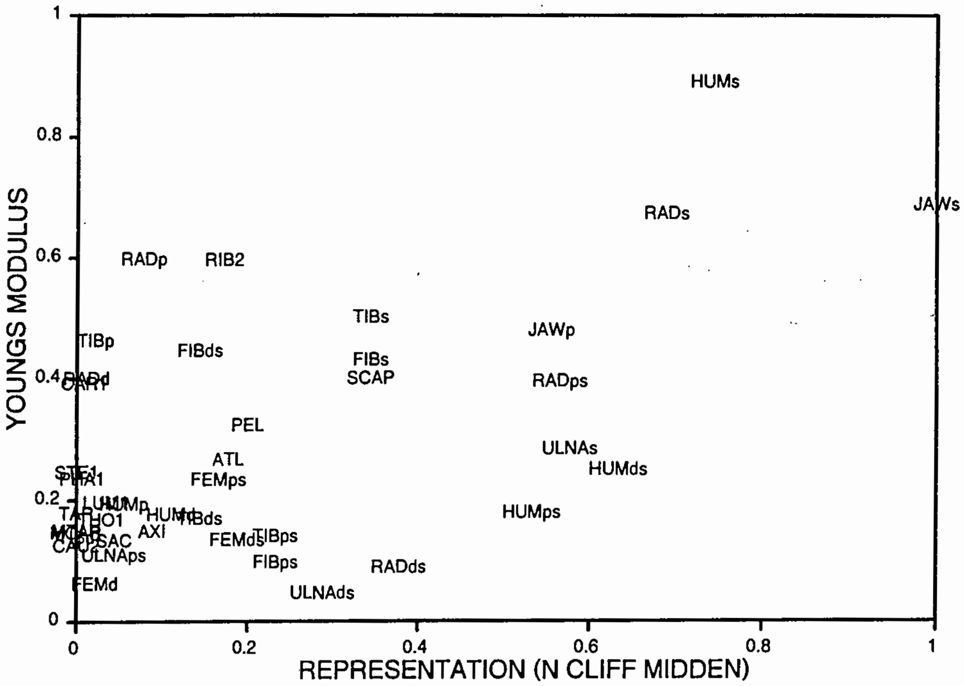

**Figure 6.10** *Normalised representation of seal bones at jackal kitchen midden North Cliff Midden plotted against Young's Modulus analogue values. Subscripts represent proximal (p), proximal shaft (ps), shaft (s), distal shaft (ds) and distal (d).*

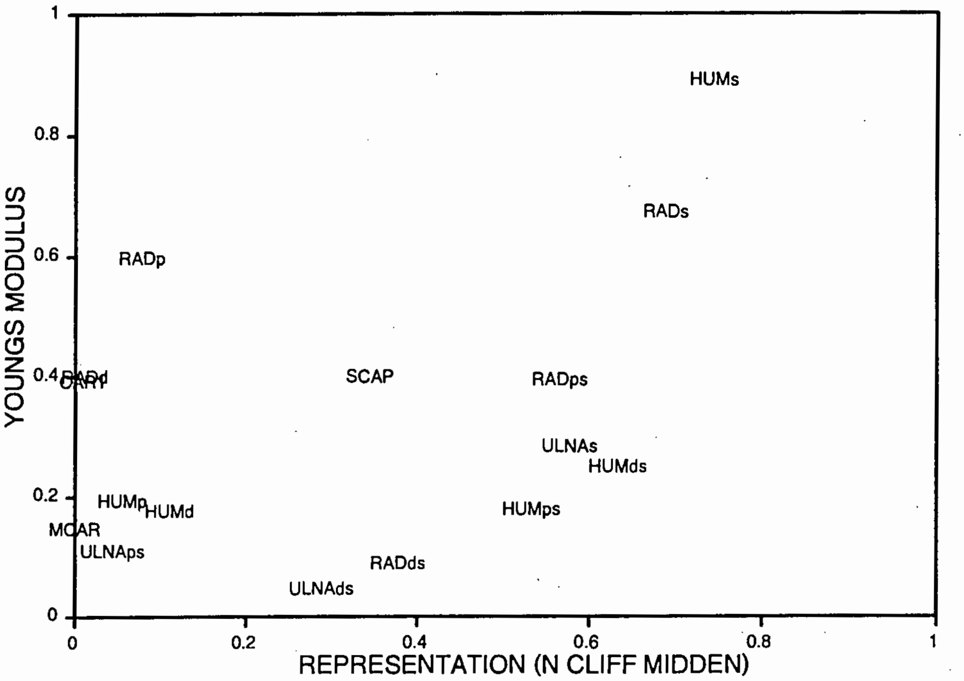

**Figure 6.11** *Normalised representation of seal bones at jackal kitchen midden North Cliff Midden (elements of the forelimb) plotted against Young's Modulus analogue values. Subscripts represent proximal (p), proximal shaft (ps), shaft (s), distal shaft (ds) and distal (d).*

skeleton clarifies the relation. In this case it is the axial skeleton and hind limbs that are randomly patterned while the forelimb elements are coherent (figure 6.11). The scapula, forelimb longbone epiphyses and the carpals are poorly represented, but the rest of the long bone elements have a curvilinear correlation with the Young's Modulus Analogue. The deviation of the epiphyses and carpals may be the result of the same mechanism that caused the underrepresentation of the femur, namely the destruction of small bones by completely ingesting them. The underrepresentation of the scapula in the jackal midden is related to the mechanism that differentiates the forelimb from the rest of the skeleton, and will be elaborated upon later.

The impression that is gained from the analysis of the North Cliff Midden is that the forelimb is dealt with in a different manner from the rest of the skeleton by the jackals. The destruction of the axial skeleton appears to be the mediated by the Hardness index, while the forelimb is mediated by the Young's Modulus Analogue. The jackals also seem to preferentially destroy small bones which results in the underrepresentation of the femur and long bone epiphyses. The robusticity of this pattern can be tested at the second midden that was excavated.

### Midden J2 (East Rock Midden)

The representation of seal bones at the East Rock Midden is plotted against Hardness in figure 6.12 and against the Young's Modulus Analogue in figure 6.13. As was noted in the analysis of the North Cliff Midden there appears to be very little patterning in the plots except when the forelimb elements are separated from the rest of the skeleton. The correlation between the representation of the axial and hind limb elements and Hardness is again linear with the femur shaft severely underrepresented (figure 6.14). The representation of the forelimb is best related to the Young's Modulus Analogue by a curvilinear relation with underrepresentation of the epiphyses and scapula (figure 6.15). This is exactly the same pattern that was noted at the North Cliff Midden.

The distinction between the pattern of destruction of the forelimb and that of the rest of the skeleton is related to the way in which the seal skeleton disarticulates in the process of consumption by jackals. The forelimb is not articulated to the axial skeleton and is the first part to be removed. Once it has been separated, the carcass is essentially reduced to two independent parts. Each jackal is only capable of eating a small portion of a seal and they will abandon the carcass when they have eaten sufficient. The early removal of the forelimb noted in the carcass consumption sequence is probably a strategy to guarantee a small part of the resource rather than defending the whole carcass against competitors. The fact that the forelimb is the first part to be deleted implies that more of them are eaten by the jackals than any other part, and furthermore the abandonment of the rest of the carcass in many instances indicates

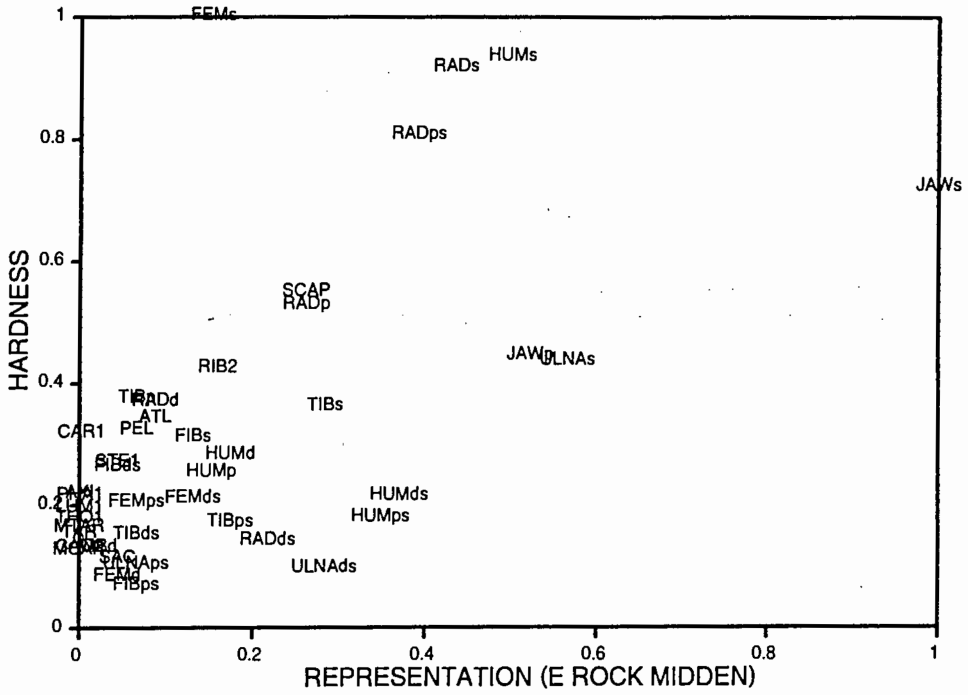

**Figure 6.12** *Normalised representation of seal bones at jackal kitchen midden East Rock Midden plotted against hardness values. Subscripts represent proximal (p), proximal shaft (ps), shaft (s), distal shaft (ds) and distal (d).*

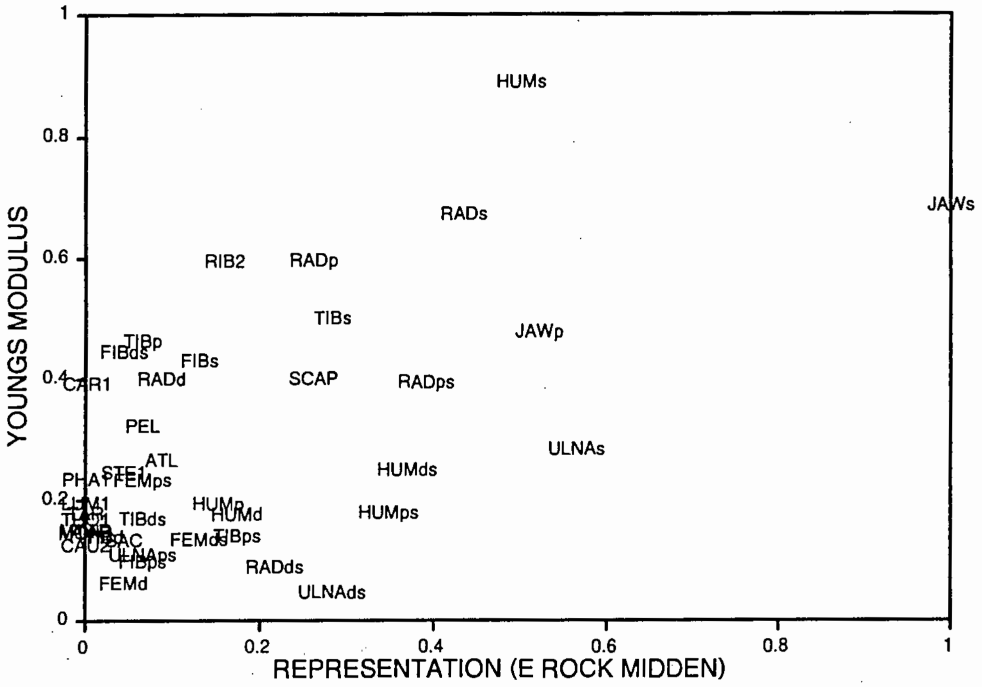

**Figure 6.13** *Normalised representation of seal bones at jackal kitchen midden East Rock Midden plotted against Young's Modulus analogue values. Subscripts represent proximal (p), proximal shaft (ps), shaft (s), distal shaft (ds) and distal (d).*

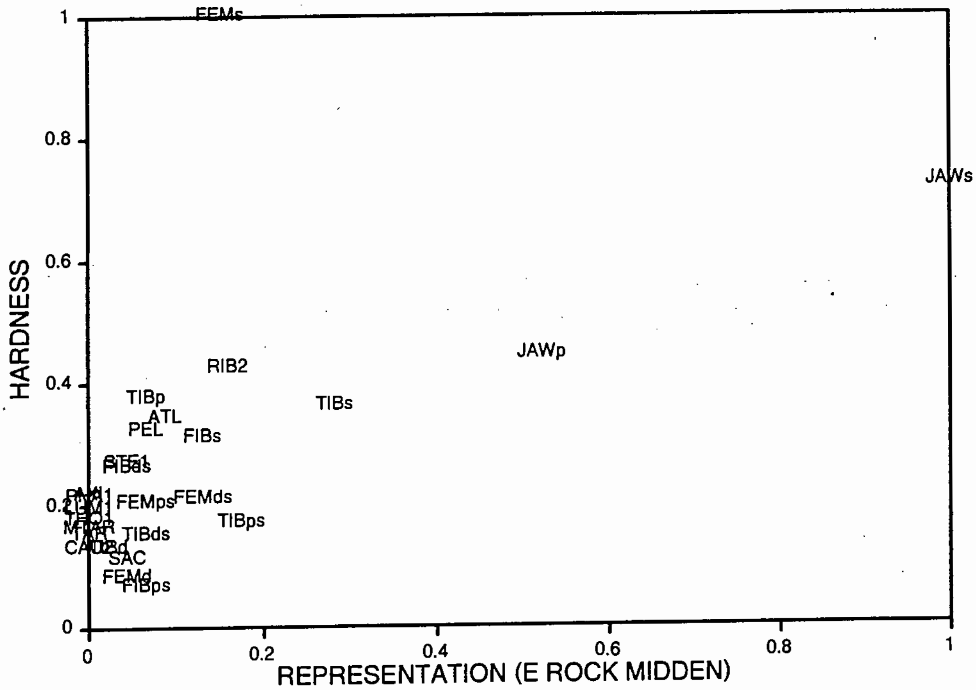

**Figure 6.14** *Normalised representation of seal bones at jackal kitchen midden East Rock Midden (except forelimb elements) plotted against Hardness. Subscripts represent proximal (p), proximal shaft (ps), shaft (s), distal shaft (ds) and distal (d).*

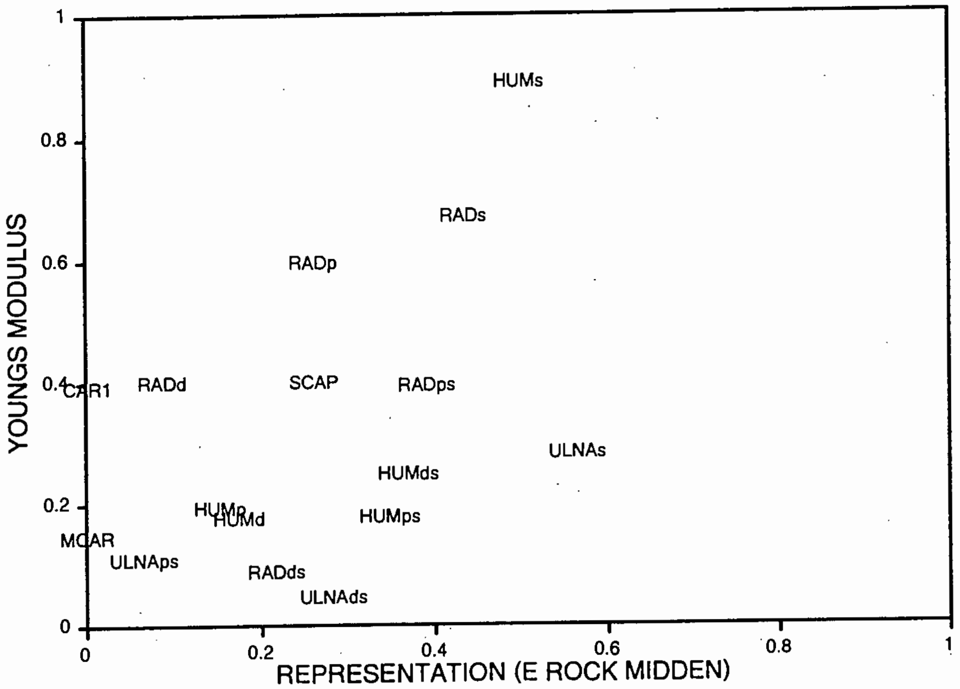

**Figure 6.15** *Normalised representation of seal bones at jackal kitchen midden East Rock Midden (elements of the forelimb) plotted against Young's Modulus analogue values. Subscripts represent proximal (p), distal (d) and shaft (s).*

that the jackals are not under a great deal of nutritional stress. When these forelimb elements are introduced into the midden they are not subjected to intensive gnawing and the strategy that would be employed in the destruction of the bone would be determined by the Young's Modulus Analogue as was argued in the development of this index. The curvilinear relation between the Young's Modulus Analogue and representation is an indication that the jackals are destroying parts of the forelimb on the basis of the qualitative Hardness - the parts of the bone that feel too hard are not eaten.

The underrepresentation of the scapulae with respect to the frequency expected on the basis of the Young's Modulus Analogue occurs in both jackal midden assemblages. This bone is most often the first bone to be deleted, and it usually disarticulates from the forelimb before the forelimb has been removed from the carcass. In such instances the scapulae are abandoned wherever the initial consumption took place, which need not be at the midden.

The axial and hind limb bones are low order elements in the carcass consumption sequence, and the energy invested in their consumption indicates that the jackals are under nutritional stress when the bones are deposited in the midden. Under such conditions the destruction of the bone is determined by the destructive capabilities of the jackals, and the correlation between representation and Hardness is not unexpected.

### Summary of jackal midden results

The damage inflicted on seal bones is similarly patterned in the two jackal kitchen middens analysed in this research. In both cases the axial and hind limb elements are destroyed according to the Hardness of the bones. Softer bones, and softer parts of the bones are destroyed more often than the harder portions. The elements of the forelimb are destroyed in a curvilinear relation to the Young's Modulus Analogue index. The difference in strategy between the forelimb and the rest of the skeleton is related to the nutritional stress of the jackals. At times of low nutritional stress the forelimb elements are introduced to the midden and the rest of the carcass is abandoned wherever the carcass was found. At times of high nutritional stress the axial and hind limb elements are brought to the midden as well, and more energy is invested in deriving the nutrition from within the bones. The bones are damaged to the extent that the jackals are capable during times of high nutritional stress, whereas during times of low nutritional stress little effort is exerted in trying to eat the bones.

A characteristic of jackal inflicted damage that applies to the bones of the entire skeleton is the destruction of small bones. This results in the preferential destruction of the long bone epiphyses, the carpals and tarsals, metapodials and also the sternum and phalanges. Most of these bones are also very soft so that their destruction may be brought about by a combination of their size and Hardness. In contrast the femur is a little harder and a little larger than the rest of the bones mentioned above. In this case only a small portion of the bone is very hard, and after the softer parts have been destroyed the hard part is small enough to be swallowed.

Jackals represent a very different mode of ravaging from hyaenas. Jackals do not select and destroy entire bones, but instead they chew on the softest parts of the bones. This means that the damage that they inflict is independent of whether or not the bones are articulated. When jackals ravage a human living area the impact on the bones will be a function of the time that they spend on the site. This may be limited if the site is a permanent or semi permanent dwelling, or it may be unlimited if the site is abandoned by the people. In the instances when ravaging time is limited, the jackals will have correspondingly limited impact on the bones that remain in the site, but they may also choose to transport bones away. The analysis of the kitchen middens does not provide a basis from which to speculate about the selection criteria that the jackals may use. In instances of extensive ravaging of a site the softest parts of the seal bones will be destroyed as was noted in the kitchen middens. If domestic dogs are present on the site then the jackal access becomes severely limited, but the dogs themselves will have an immediate and almost unlimited opportunity to ravage the bones that are discarded.

## Identifying carnivore ravaged seal assemblages

The jackal kitchen midden and hyaena maternity den assemblages that are analysed in this chapter are unique because they are made up almost entirely of seal bones, and there is little influence from agents other than the implied carnivores. The bone crushing behaviour of both the jackals and the hyaenas is related to their feeding ecology, and factors such as nutritional stress and the proximity and availability of food resources will determine the eventual appearance of assemblages that they ravage. In this chapter I have concluded that seal bone destruction by carnivores in den-like scenarios is largely related to Hardness. The role of bone grease (Marean *et al.* 1992, Blumenschine & Marean 1993) is not dismissed, but the uniform distribution of bone grease throughout the seal skeleton suggests that the preferential destruction of some bones is related to something other than the quantity of bone grease that is present in the bone matrix. Blumenschine and Marean (1993) suggest that the foremost factor in carnivore ravaging is the relation between cost and benefit of marrow and grease extraction. Future work may focus on the quality of bone grease as a benefit of ravaging that varies within the seal skeleton, but the analysis presented here suggests that the cost of extraction is the principal determining factor in bone destruction. In order to make any statement about ravaging of human sites, the extent to which these observations characterise carnivore ravaging scenarios as opposed to carnivore accumulation scenarios needs to be explored.

Gifford-Gonzalez (1991) has emphasised the importance of defining the boundary conditions to actualistic research. These play an important role in establishing the precision and accuracy of the reconstructions based thereon. It has been argued that carnivore den assemblages do not fulfil the boundary conditions required of actualistic studies of carnivore ravaging (Blumenschine & Marean 1993). The carnivores are presented with bones that are defleshed and often broken when they ravage an abandoned human occupation site, whereas the bones that they obtain otherwise are normally fleshed, or complete, or both. Since the human practice of marrow extraction leaves little that is of interest to the carnivores in the diaphyses of long bones, they ignore the diaphyses and concentrate their efforts, and consequently their impact, on the grease rich articular ends. The result is a profound difference in the representation of, and damage inflicted on, the articular ends and diaphyses in den assemblages relative to carefully controlled actualistic ravaging experiments.

The latter scenario applies to terrestrial faunas where long bones typically include a marrow cavity that is a prime target for humans and carnivores exploitation. In the case of seals the marrow is not concentrated in marrow cavities. Instead it is distributed throughout the cancellous bones of the entire skeleton. This means that there is little that distinguishes the epiphyses and diaphyses of seal bones from a carnivore's perspective, and hence the influence of bone breakage that is profound in terrestrial fauna is not relevant in seal bones. The broken fragments of seal bones, if indeed the humans took the trouble to break them, are just as much a feature of the carnivore menu as the complete bones. The only boundary condition that is not met is that the bones that were observed in the jackal and hyaena assemblages were initially presented with the seal still on the bones, whereas in ravaging scenarios this would not be the case. This will be shown to be relevant for hyaenas but not jackals.

A second boundary condition that is required for actualistic experimentation of carnivore ravaging is control over the effects of deletion versus destruction. Both play an important role in site ravaging as bones may be destroyed immediately by the carnivores, or they may be transported away from the site producing the same results. The jackal and hyaena assemblages represent the end product of transportation and destruction, but in this case the elements that are introduced are precisely those that are deleted elsewhere. Furthermore the bones were articulated and fleshed when the elements were selected for transportation. These limit the absolute characterisation of ravaging scenarios which in turn limits the scope for correcting the representation of an assemblage to its appearance prior to carnivore involvement. Such an approach is proposed by Blumenschine and Marean (1993) and it implies that a very accurate and precise assessment of carnivore ravaging can be made. This is not true of the den assemblages presented here, but there are features of the assemblages that may be used as indicators of carnivore ravaging.

Brown hyaenas seem to make scant distinction between seal flesh and bone. They can destroy every bone in a seal carcass with sufficient ease that there is no reason for them to destroy one bone in favour of another. This may also apply to ravaging by other hyaena species. The effect of hyaena ravaging is therefore the result of bone selection rather than bone destructive ability. The only clue to brown hyaena bone selection is portrayed in the limited destructive capability of the pups. If their behaviour can be extrapolated to the adults then seal bone accumulations that have been subjected to brown hyaena ravaging will be characterised by the underrepresentation of the bones which on average have low Hardness values.

The jackals observations are closer to the scenario that is desired for modelling ravaging than was the case for the hyaenas. The focus that the jackals have on flesh removal leads to the seal carcass being reduced to an almost complete skeleton before any energy is invested in destroying the bones. The damage to the bones in the jackal middens represent the impact that this species has on clean bones although there is still no control of the selective input of elements into the middens. Even without this control it is evident that jackals bring about the partial deletion of the softest parts of the bones. The mechanism of bone destruction is probably similar in the case of dog ravaging, but the excessive exposure that dogs have to the assemblage will bring about more extensive destruction of the bone.

In chapter 5 it was proposed that the effects of abiotic taphonomic processes such as profile compaction would lead to bone destruction that is determined by Hardness. There are characteristics of carnivore inflicted damage that is distinct from that produced by biotic processes. In the case of carnivores there are certain idiosyncrasies in the relation between Hardness and bone destruction that are brought about by the conscious selection of bones. Both jackals and hyaenas, for example, tend to preferentially destroy small bones, and so ravaged seal assemblages will be identified by the underrepresentation of epiphyses, carpals, tarsals and especially the femur. Abiotic processes affect all the bones in an assemblage on a similar basis, bringing about a consistent degree of destruction across all the bones.

# CHAPTER 7

# FOOD UTILITY OF THE CAPE FUR SEAL

## Introduction

The aim of this chapter is to develop criteria that can be used to assess disparities in body part representation of seal bone assemblages that are the result of transport decisions. Transport decisions are a way in which hunter gatherers rationalise situations in which more food is available than can be immediately utilised. This is common when a small hunting group or even an individual is successful at procuring a large carcass. Individuals seldom carry loads in excess of 40 kg (Shipman 1983), and when presented with carcasses of several hundred kilograms it is necessary to discriminate between parts that are to be used and those that are to be discarded. In the case of the Holocene hunter gatherers in southern Africa, the lack of transportation aids (except perhaps in the latter 1500 years during which time draft animals were available) implies that the constraining factor in the transportation of carcasses or parts of carcasses was the ability of each person to carry a load.

Most of the archaeological sites in the western Cape that have produced seal remains are not the locations at which the seals were procured. The few seal colonies that were historically located on the mainland were sensitive to disruption (see chapter 3), and human occupation sites that were exclusively based on exploiting nearby seal colonies have yet to be discovered. Instead of locating sites near a source of seals, the seals were transported to the sites. Seals may have been obtained within a few hundred meters of Elands Bay Cave and the Dunefield Midden as both sites are well situated for the exploitation of reasonably large sections of the coast that carry a high seal biomass in the form of live animals or seasonally washed up carcasses. The seals from the early Holocene layers of Elands Bay Cave must have been transported considerably further as a result of the lower sea levels (Fairbanks 1990, Miller *et al.* 1995). Kasteelberg B is also strategically placed for the exploitation of the seals, but the carcasses had to have been transported uphill for more than 4 km from the coast at its nearest point. In spite of the fact that the carcasses had to be carried in, seals are better represented than any other large mammalian species in coastal archaeological sites. They therefore played a major role in the economy of hunter gatherers in the past, and understanding the exploitation strategy is an important step in constructing the nature of past coastal adaptation.

Numerous ethnographic studies that outline the processes involved in the transportation of large carcasses by hunter gatherers have been undertaken (Woodburn 1968, Yellen 1977, Binford 1978, O'Connell *et al.* 1988, 1990, O'Connell & Marshall 1989). The aim of these studies has not been to establish a catalogue of situations that can be used as analogies by archaeologists, but rather to identify broader principles or themes that govern the hunter gatherers' decisions and that can be applied to the interpretation of archaeological faunas. This has proven difficult because there are many factors that influence the hunter gatherers' response from one situation to another. These include the size of the carcass, the number of people available to process it, the distance over which the meat has to be transported, the time constraints and effort required to partition the carcasses of large animals and the pressure from competing carnivores. The differences in decision making processes are apparent among as well as between different hunter gatherer communities around the world. The members of the same community may, depending on circumstances, choose to process the entire carcass where it is encountered, or they may field butcher it to facilitate transportation to a centralised location where most of the processing takes place. In some instances a carcass may be partially or entirely abandoned while on other occasions the community may translocate to the carcass and very little is wasted. The behavioural aspect of bone deposition is a complex system that may result in the bones from a single animal being deposited at a number of locations. Similarly each bone cluster is a potential archaeological site, and each may have a different behavioural or functional association. In recognition of this diversity numerous attempts have been made to define characteristics that typify sites with different functional histories (for example Isaac 1971).

A concept that has been widely used among archaeologists to make sense of the subtle differences that can be expected between assemblages is *utility*. This concept was first proposed and tested by Binford (1978) in an ethnographic study of Nunamiut Eskimos. He measured the yield of marrow, grease, flesh and fat associated with each bone in the carcasses of two sheep and a caribou. These were considered relative to the cost of extracting the resources from each bone to give the "utility" of each anatomical element. The resulting ranking of the body parts, expressed on a scale of 0-100, was called the General Utility Index (GUI). When the GUI was compared with the bones that the Eskimos transported from a kill site to their homes, Binford noted that some were not handled entirely in accordance with what may have been predicted on the basis of the nutritional yield. Bones of low utility were, in many instances, treated as part of larger anatomical units that included bones of significantly higher utility (for example foot bones are associated with the bones of the lower leg). He called these bones "riders", and he modified the GUI to accommodate this phenomenon. The resulting utility index was called the Modified General Utility Index (MGUI), and it proved to be a very good mediator of bone selection for transportation or abandonment by the Eskimos. Binford developed several other indices relating to the different constituents of each unit (meat, fat, marrow, etc.) that were relevant in a variety of different situations, but none of these has been as widely accepted and used as the MGUI.

It has been suggested that the method for deriving the utility indices was unnecessarily complicated (Jones & Metcalf 1988, Metcalf & Jones 1988). An alternative derivation, based only on the mass of edible material associated with each bone, is shown to produce comparable results. The utility value for any element is based on the average flesh weight (edible tissue weight) across the entire sample of carcasses that was dissected, normalised onto a scale of 0-100. Irrespective of the way in which the index is calculated, the value of the concept of utility, or economic anatomy, is not only its relevance in field butchery and transport decisions by the Nunamiut Eskimos, but in the processing of carcasses by hunter gatherers in many areas around the world. This has been demonstrated in ethnographic studies of the Hadza in Tanzania (O'Connell *et al.* 1988, 1990) and the Alyawara in Australia (O'Connell & Marshall 1989).

Each index that Binford (1978) developed was used to predict the body part representation at Eskimo sites where the meat and bone processing history was known. He identified three strategies that the Eskimos adopted when they discriminated between bones. The first was a "gourmet" strategy in which high utility elements dominated the assemblage; the second was an "unbiased" strategy in which body part representation strictly reflected utility; and the third was a "bulk" strategy in which low utility elements were well represented (Binford 1978). Complementary assemblages are characterised by "reverse utility" (Binford 1978, Grayson 1989). At this point a distinction has to be made between archaeology as it is practiced and ethnography as it is used to inform archaeology. Binford's models for the body part representation at various Eskimo sites were based on a priori knowledge of the function of each site, and the basic concept of utility was adapted accordingly. This is not always possible in the archaeological record. There are very few instances in which the functional association of a site has been determined unequivocally or exclusively on the basis of utility. The "function" of a site in this instance refers to its role as a location to which selected bones were imported, or one at which bones were selectively abandoned. This equates in the broadest of terms to "home bases" on the one extreme and "kill sites" on the other. Without knowledge of the site function it is risky to use the utility of an assemblage to associate behavioural traits such as a hunting or scavenging mode of existence with the accumulators of the bones. This is a particularly appropriate criticism when the application is to Plio/Pleistocene sites.

If the functional association of a site is to be assumed in order to facilitate a behavioural interpretation of the faunal remains, then there are several advantages to using Holocene assemblages. In many instances there may be a degree of cultural continuity between the original occupants of the sites and extant hunting and gathering communities. This means that ethnographic examples can be used, with circumspection, to identify the characteristics that define a site's function. In comparison with Plio/Pleistocene sites, Holocene sites also preserve a greater diversity of contextual evidence that can be used to argue the function of the site. At Kasteelberg B, Elands Bay Cave and the Dunefield Midden associated artifactual material including stone and bone tools of a variety of types and raw materials, ceramics (in layers postdating 2000 BP), the remains of animal species and other foods that must have been exploited in a variety of microhabitats, all argue for these sites functioning as foci for diverse behaviour over a large area surrounding the sites. The substantial accumulation of deposits, in time periods that are well defined with the aid of radiocarbon and other dates, also indicates that these sites were repeatedly used by people. There can be little doubt that in the past these were locations where seal carcasses were shared among community members and at which a great deal of the seal processing and consumption took place. If the conclusion that the sites functioned as "bases" is accepted, then the emphasis in applying utility indices can be on the behavioural influences. In particular the selection of body parts for transportation to the base when confronted with large or abundant carcasses is at issue.

There are no detailed ethnographic accounts of indigenous people exploiting seals in southern Africa and so there is no way to determine if the concept of utility applies in this case. The widely observed selection of bone on the basis of utility in ethnographic studies in other parts of the world supports the use of the concept of economic anatomy in interpreting archaeological assemblages. This has been done in a number of instances (Speth 1983, Thomas & Mayer 1983, Binford 1984, Grayson 1989, Lyman *et al.* 1992). The indices that Binford (1978) developed, however, cannot be used indiscriminately in interpreting all archaeological faunal assemblages. Care has to be taken when the indices are applied to species other than sheep or caribou. In such cases the differential transport of elements may be based on entirely different criteria (Klein 1989*a*, and see Fisher 1988, Grayson 1989). To avoid potential inconsistencies, utility indices have also been derived for kangaroos (O'Connell & Marshall 1989), bison, musk ox, guanaco, and moa birds (respectively: Emerson 1990, Will 1985, Borrero 1990, Kooyman 1984, all cited in Lyman *et al.* 1992) as well as several species of African antelope (Blumenschine & Caro 1986). In particular the anatomy of seals is so different from any terrestrial quadruped that the MGUI and all the other indices based on terrestrial species are of no value in analysing seal bone assemblages. For this reason Lyman *et al.* (1992) derived a utility index specifically for seals. In applying the index they noted that it was a useful tool for understanding the transport decisions of phocid seal (true seals) at sites on the Oregon coast, but its application in the case of otariid seals (fur seals) was not convincing. They postulated that anatomical differences between phocids and otariids were significant enough to necessitate the development of a separate utility index for the latter. The remainder of this chapter is dedicated to establishing a utility index based specifically on the Cape Fur Seal (*Arctocephalus pusillus*). This will also be a step closer to establishing a utility index for otariid seals in general.

### Materials and method

A total of six seal carcasses, obtained by the Division of Sea Fisheries Marine Mammal Research Unit in the course of their research, were made available for dissection. Four of the seals were shot at sea and frozen until dissected. These comprise an immature female weighing 19.5 kg, one mature and two immature males weighing 117.5 kg, 28 kg and 27 kg respectively. They were apparently healthy animals and it is assumed that the distribution of fat and muscle on the body is normal and representative of seals at the given time of year. The other two animals were not healthy. Specimen AP 3532 was a male weighing 25.8 kg that was shot at Gordons Bay in False Bay after it was reported to be unable to swim. The dissection revealed a broken ulna that preventing the animal from hunting. Specimen AP 3538 was a juvenile female of 7.55 kg that was also shot in False Bay after it was found in extremely poor condition. The cause of the animal's distress was not established. The results from these two specimens provide an interesting comparison with those from the healthy animals.

The carcasses were frozen until they were needed at which point they were defrosted in standing water. Dissections did not commence until the carcasses were completely thawed. The dissections were conducted at the Division of Sea Fisheries (Marine Mammals Unit) on a dissection table with a continuous flow of water across the surface. This had the advantage of reducing the effects of drying, but increased the extent of blood loss. The requirements of the Sea Fisheries personnel included the weighing of the major organs, measurement of ventral blubber thickness, inspection of blubber, organs and intestinal tract for parasites and of the fur for state of moult. Where it was considered necessary histological samples were also taken. The stomachs were retained by Sea Fisheries for subsequent analysis of the contents. While this is not considered in this analysis, seal stomachs often contain substantial quantities of fish that may have in the past been incorporated into archaeological deposits. The procedures followed by the Sea Fisheries staff were in accord with the American Society of Mammalogists (1967), and were either conducted in my presence, or the results were made available to me if I was not present.

The carcasses were dissected using knives and scalpels. A remarkable aspect of this was that the dissections were done without prior knowledge of the work of Lyman *et al.* (1992), nor with the advantage of any experience or consultation with anyone with experience in such dissections. The location of skinning cuts around the flippers, and the partitioning of the major units in this study is nevertheless very similar to those in the Lyman *et al.* (1992) dissections.

The basic dissection procedure began by skinning the carcass and at the same time removing the blubber layer. The subcutaneous blubber forms a discrete layer that, together with the skin, is easily separated from the flesh of the animal. This is termed the *sculp* (Lyman *et al.* 1992), and it forms an obvious butchery unit. In removing it, most of the fat is obtained, the skin is maintained for use, and the carcass is prepared for further butchery. In terms of utility, the extraction cost is so low, with such an extraordinarily high energy yield, that the remainder of the carcass has relatively little significance. The removal of the sculp does not involve the separation and differential treatment of any element of the skeleton so this butchery unit does not affect the utility of the different bones in the skeleton. The utility of seal body parts is therefore independent of the blubber layer. Likewise, it is assumed that since the contents of the chest and stomach cavities can easily be extracted without removing any bones, the utility of the thoracic and lumbar regions is independent of the viscera. The musculature that makes up the belly was not considered to be part of the viscera, but was associated with the lumbar vertebrae in this study.

The nutritional value of the sculp relative to the rest of the seal carcass varies because the thickness of the blubber layer is subject to seasonal fluctuations (figure 3.3). This is related to the breeding ecology of the species (see chapter 3), and consequently is most pronounced in sexually mature individuals. Since the utility of the different body parts is independent of the blubber layer it is not necessary to accommodate this fluctuation in the formulation of the utility index. Nevertheless the consistently high return of blubber from juveniles may be an incentive to select for these when animals of diverse sizes are available. The younger animals also tend to have fewer blubber parasites (Meyer pers. comm., pers. obs.) although this may not have been an important consideration to hunter gatherers.

After removing the sculp from each carcass the skeletons were partitioned at the major joints. Variation in the location of partitioning cuts at the major articulations affects the amount of tissue associated with each bone, but this is a source of variability that is unavoidably associated with the method. It may be partly compensated by dissecting several animals assuming that the variability is random. The next step was to carefully remove and weigh the fatty tissue from each element. In contrast to the seals dissected by Lyman *et al.* (1992), the Cape Fur seals contained small amounts of intermuscular fat that was easily removed with a scalpel. There was absolutely no discernible intramuscular fat. The remainder (meat and bone) was weighed, defleshed by boiling, and the remaining bone was weighed again. It was necessary to allow all the bones to dry for an extended period before the weight became consistent. In each case the bones were weighed after a minimum of 6 months from when they were boiled. The total weight of the meat associated with each bone was then calculated (the results of each dissection are presented in Appendix C and summary information is presented in table 7.1).

Binford's derivation of the GUI included consideration of marrow yields of each unit (Binford 1978, Jones & Metcalf 1977). There are no medulary marrow cavities in seal bones but the nutritional contribution that comes from the bone grease is substantial. This is easily extracted by boiling, and seal fatty acid traces in residues on ceramics from Kasteelberg B (Patrick *et al.* 1985) may indicate that this practice was followed in the past. When the bones were boiled in the defleshing process in these dissections the bone grease was also extracted and consequently its mass is included in the mass of the meat. Without an ethnographic frame of reference for the exploitation of seals in southern Africa it is not clear if the bone grease component played a significant role in formulating transport decisions. The inclusion of the bone grease yield in the meat yield is consistent with the revised derivation of the GUI - the Food Utility Index (FUI) (Metcalf & Jones 1988).

## Results

Loss of body fluids during a dissection usually results in a piecemeal mass sum that is less than the original mass of the carcass. The disparity depends on the number of pieces into which the carcass is partitioned, the resulting surface area and the environmental conditions because of its influence on drying rates. Discrepancies of between 0.45 % and 20% have been noted (Bryden 1972, Bryden & Erikson 1976, Lyman *et al.* 1992, Hamilton 1949, Kerley & Bester 1983), and a value of 10 % loss is widely accepted (American Society of Mammalogists 1967). In this study the maximum mass loss is -23 % for specimen AP 3532. Contrary to expectation the piecemeal mass is greater than the original mass. This is also true for two other specimens although the discrepancies are not as large. There are several factors that may cause this. A great deal of blood was lost before the analysis commenced both in the sea after the seals had been shot, and also in the defrosting process. Blood loss is a major contributor to mass loss and the depletion of the blood prior to determining the total mass would reduce the monitored loss. This may have been exacerbated by precautions that were taken to minimise drying of the carcass. During the dissections the carcasses were kept wet by a continuous flow of water over the dissection table, and by regularly spraying water over the pieces. While mass loss through drying was unlikely, the excess water on parts that were weighed may have increased the mass measurement. Another factor is that the limb masses reported in Appendix C are only for the left elements. The right elements were not weighed and so the piecemeal mass is calculated by doubling the mass associated with the left limb bones. Lyman *et al.* (1992) compared the left versus right side masses for the limbs and did not get significant differences.

The Modified Food Utility Index (MFUI) was calculated from the same formula that was used by Metcalf & Jones (1977) and Lyman *et al.* (1992) with the exception of the associated riders. The procedure for dealing with riders is outlined below. The average MFUI values are presented for the three healthy specimens, one of the unhealthy specimens and for all four of the specimens in table 7.1. The ranking of the MFUI values for the healthy and unhealthy specimens is significantly related ($r_s$=0.97), and both are significantly related to the average values for all the specimens ($r_s$=0.99). A second index, calculated on the basis of the bulk masses of the anatomical units, is also presented in table 7.1. This is called the Bulk Utility Index (BUI), and the only difference is the incorporation of the bone mass into the "food value" of the bone. This may not be inappropriate in the light of the associated bone grease. In every instance the MBUI and MFUI calculated for a single carcass is significantly related ($r_s$=0.99 in the worst instance), and also the average values for the healthy, unhealthy and all the animals are all significantly related ($r_s$=0.99 in the worst instance). The reason for considering the BUI is that the skeletons of two dissection specimens were not weighed and so the meat value for each of the bones cannot be calculated, but the BUI can be calculated. Since the BUI and FUI are redundant it is only necessary to consider one of them, and since the BUI is based on the results of six dissections, and the FUI on four, it is better to proceed using the BUI values.

## Constructing a Utility Index for seals

A triangular relation between the method of quantifying archaeological seal bone assemblages, the anatomical basis of a utility index, and the anatomy of the Cape Fur seal dictates the way in which utility should be calculated. Archaeological assemblages in this study are quantified in terms of Minimum Anatomical Units (MAU). The unit was defined by Binford (1978) and used by Lyman *et al.* (1992) because of the ease with which it can be related to anatomical completeness. The total number of a particular element (Minimum Number of Elements - MNE) in an assemblage is divided by the number of times that element occurs in a normal skeleton to give the MAU value. Fractions are possible using this scale, but they have meaning in terms of the equivalence of anatomical units. By this I mean that the MAU for a particular element is the number of times it occurs in the equivalent number of complete skeletons. The bones need not have been parts of complete skeletons when they were introduced into the site and the equivalence concept must be interpreted in terms of a composite of partial introduction events. For this reason MAU is superior to terms such as Minimum Number of Individuals (MNI) as an approximation of the actual food that was introduced. This is particularly true in the case of bilaterally paired anatomical units where the potential exists for the utilisation of only one of the two elements in any particular situation.

In almost every situation in which field butchery has been observed, bilaterally paired elements are separated. If it is assumed that there is no preferential butchery favouring one side over the other, the paired elements can be assumed to be of equal utility, or at least to have equivalent utilitarian potential. There are two issues that need to be addressed here. The first is related to the fact that when two elements have the same utility, all else being equal, the transport bias towards one of the elements should be the same as that towards the other. Theoretically the selection of one element for transportation or abandonment will precede the same treatment for the other element (although in practice this is not always the case). The issue here is that the bias between unpaired anatomical units is based on the total utility of the element, but in the case of paired elements it is based on the utility of only one of the units. This makes sense because the bilateral units are necessarily separated in the butchery process and the utility of the separate butchered units is the basis for discrimination between them. However in applying utility based bias, the theoretical equifinality of elements with equal utility implies that any discrimination has consequences involving the combined utility of both the elements. A paradox emerges between the a priori utility of an element versus its posteriori utility. From an a priori perspective each unit is ranked according to its utility, and so paired - but separated - elements are similarly ranked on the basis of their individual utility. From a posteriori perspective the selection or abandonment of both units in a paired element results in utility benefits or losses equivalent to the combined utility of both elements. Assuming that the paired elements are subject to the same bias, their utility measured in terms of benefit to the consumer may increase and indeed may be greater than that of other elements that on a priori consideration had higher utility.

At this point I return to the use of MAUs as a basis for the analysis. As was established above, MAUs refer to the number of times an element occurs in the equivalent number of complete skeletons, and partially introduced elements are also catered for. In comparing MAUs with utility it is appropriate to use the combined utility of bilaterally paired elements. In comparisons between utility and MNEs the utility should be based on only one of the bilaterally paired elements. This contrast arises because, by definition, the MNE refers to the number of individual bilateral elements that are present while the MAU refers to the number of paired bilateral elements that are present. The concept of utility is based on the differential value of each element as food, and the method of quantification should similarly reflect the differential "food value" of each of the elements of the carcass. Multiplying the food utility value (as per Metcalf & Jones 1977, and Jones and Metcalf 1977) by the MAU should give the total food value, but this is only true if the FUI is based on the combined utility of paired elements. The same value is achieved if the FUI is based on unpaired utility values but this time it is multiplied by the MNE values. The normalisation of the FUI to a percent scale to give %MUI (Lyman *et al.* 1992) or the (%)GUI (Binford 1978, percent symbol added here) does not effect the argument, and the basis of the quantification of utility should still be the combined utility of paired elements if the comparison is with MAUs.

This discussion provides a premise that is required to deal with the second issue that arises when dealing with paired elements. The paired elements of the appendicular skeleton are almost always separated from one another during primary butchery, but this need not be the case with the paired elements of the axial skeleton. The rib racks joined by the thoracic vertebrae and sternum, and the two halves of the pelvic girdle joined at the pubis and the sacrum may be treated as single units in field butchery. Whether these elements are divided or not is critical in determining the suitability of utility indices that are calculated in different ways. Calculating the utility for ribs, for example, from the meat associated with only one of the racks, implies that the ribs *must* be partitioned into two racks for the a priori utility value to be accurate relative to the other elements of the carcass. If they are not separated the utility of ribs will be undervalued. If one accepts the protocol developed above, then the utility of the paired axial elements is calculated from the total mass of the element and not a single half. In this case the posteriori consideration of the food value of the bones is accurately portrayed.

## Riders

The utility index for phocid seals developed by Lyman *et al.* (1992) is based on the average mass of edible tissue associated with only one of the units in paired elements, except for the pelvis which is treated as a single unit incorporating the sacrum and caudal vertebrae. No reason is given why some elements are lumped into single unit while others are split. The bones within the flippers are lumped into single units (although a distinction is made between the left and right, hind and fore flippers). The ribs that make up one rack are separated from the other rack, but they could have been further divided into the individual bones. The same argument applies to subdivision within the different categories of vertebrae (cervical, thoracic and lumbar). The construction of the utility index requires further information on the degree of association or disassociation between conjoining bones that can reasonably be expected in field processing of carcasses. This comes from a combination of common sense based on experience in the field of butchery, and ethnographic observations. Common sense dictates that bones such as the caudal, thoracic and lumbar vertebrae and ribs should be associated within those categories. It is unlikely that transport decisions are going to be made to differentiate between the individual bones within these categories nor between these bones and the other bones in the carcass. Furthermore the analysis and reporting of archaeological faunas is seldom done at such a high level of resolution.

The above assertions are generally supported by ethnographic observations, but in practice it is not unusual for more elements to be associated than are suggested by the logical associations. Binford (1978) correctly noted that the absolute utility values of each of the associated elements did not determine the differential transport of each of the elements in such cases. Utility was still the governing factor, but the utility to which the Eskimos responded was the average for the entire articulated unit. The low utility bones within each unit were called "riders", and their utility value had to be adjusted to account for this effect. Accordingly where a low utility bone articulated with a high utility bone the former was attributed with the average utility of both. Low utility bones that articulated with two higher utility bones were attributed with the average utility of the high utility bones. In this way the General Utility Index (GUI) was modified to give the Modified General Utility Index (MGUI) (Binford 1978). The same procedure was used by Lyman *et al.* (1992) in their derivation of a utility index for seals.

The anatomical differences between terrestrial quadrupeds and seals mean that the riders noted in Binford's (1978) study are not valid in defining a seal utility index. The "riders" phenomenon emerges in almost every ethnographic account of field processing, and it would be inaccurate if it were ignored in the utility index, but there are no appropriate comparative data to establish which elements of the seal carcass would be riders. The historical references to seal utilisation by indigenous people in the western Cape are not detailed enough to establish the elements that were associated in primary butchery units. Ethnographic accounts from the same area are similarly inadequate. No attempt has been made to analyse other sources of ethnographic data on seal butchery. I have relied on the impressions I obtained doing the dissections for this analysis, and on the Lyman *et al.* (1992) definition of riders. In defining the seal %MMUI (Percent Modified Meat Utility Index), Lyman *et al.* (1992) identified riders from an unpublished study of Inuit exploitation of a relatively small species of phocid seal, the Ringed seal (*Phoca hispida*), in Eastern Canada.

In many of the archaeological seal assemblages that Lyman *et al.* (1992) analysed, the representation of body parts shows a clear bias against axial elements relative to limb elements. A possible cause may be that limbs were separated from the rest of the carcass. The utility values against which they are compared, however, were calculated on the basis of the forelimbs as riders to the ribs. Although this was noted ethnographically, the assumed association between these units does not appear to have been appropriate for every site that was analysed. The forelimbs of seals are not articulated with any elements of the axial skeleton, but are rather supported by massive musculature around the scapula and humerus. This is the musculature used to propel the seal on the land and when swimming, and the overall architecture of the shoulder allows substantial manoeuvrability. When dissecting the seals, the removal of the forelimbs was very easily done and was one of the first steps undertaken after the sculp had been removed. It was not necessary to concern myself with accurately placing the cut between the bones of a joint, and at the same time a substantial amount of flesh (this is at least partially the equivalent of "meat easily removed with knives" noted by Lyman *et al.* 1992) was removed. For this reason the elements of the forelimb are treated as potential riders of one another, but not with any of the elements of the axial skeleton.

The bones of the flippers - carpals, metacarpals, tarsals, metatarsals and phalanges - are all considered as single units referred to as "flippers". The flippers were not skinned because it proved to be a very difficult task. Consequently the meat value for these units is overestimated. Lyman et. al (1992) also did not skin the flippers. They compensated for this by halving the utility value on the basis of Bryden & Felts (1974) dissections of four different seal species. Although the seals in the latter study were phocids, the convention is also followed here on the assumption that the correction has little effect on the final ranking of the elements on a utility scale. The ribs, thoracic vertebrae and sternum are treated as a single unit in the dissection, and hence as riders in the utility analysis, although the average value for this entire unit is used for each constituent unit. The same applies to the pelvis, femora, sacrum and caudal vertebrae which were also left in association with one another during dissection. The riders of the hind limb are considered relative to one another, and also to the pelvic unit. The cervical and lumbar vertebrae and the head are treated as riders of one another and of the pelvic and thoracic units.

The innominate, sacrum, femora and caudal vertebrae are tightly articulated into a small compact unit that was extremely difficult to separate and was therefore considered as one unit. The association of the femora with the pelvis rather than the limbs may seem surprising. It is however a relatively simple task to locate the knee joint and to sever the femur from the tibia and fibula. The femur is very short in seals, and the distal femur does not extend beyond the body contour of the abdomen. Separating at this point is a very much simpler task than locating and severing the articulation between the femur and pelvis.

| | (1) FUI | (2) FUI | (3) FUI | (4) MFUI | (5) SMFUI | (6) BUI | (7) BUI | (8) BUI | (9) MBUI | (10) SMBUI | RIDERS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **SCULP** | | | | | 2.47 | 11.08 | 5.42 | 9.19 | | 1.15 | |
| **HEAD** | 0.77 | 0.80 | 1.10 | 2.37 | 0.25 | 1.27 | 0.96 | 1.17 | 2.08 | 0.26 | HEAD + CERVIVCAL VERT. |
| **CERVICAL VERTEBRAE** | 4.44 | 0.95 | 3.65 | 6.58 | 0.69 | 3.98 | 1.00 | 2.99 | 5.50 | 0.69 | CERVICAL + THORACIC VERT. + RIBS |
| **LUMBAR VERTEBRAE & BELLY** | 2.23 | 0.50 | 1.84 | 5.68 | 0.60 | 2.01 | 0.53 | 1.52 | 4.77 | 0.59 | LUMBAR + THORACIC VERT. + RIBS |
| **PELVIS, SACRUM & FEMORA** | 1.15 | 0.41 | 1.00 | 1.42 | 0.15 | 1.13 | 0.45 | 0.90 | 1.21 | 0.15 | PELVIS, SACRUM, FEMUR + LUMBAR VERT. |
| **LEFT TIBIA & FIBULA** | 0.41 | 0.13 | 0.36 | 0.86 | 0.09 | 0.41 | 0.16 | 0.33 | 0.78 | 0.10 | TIBIA, FIBULA + PELVIS, SACRUM, FEMUR |
| **LEFT HIND FLIPPER & SKIN** | 0.53 | 0.26 | 0.49 | 0.60 | 0.06 | 0.54 | 0.28 | 0.45 | 0.55 | 0.07 | 1/2 HIND FLIPPER + TIBIA, FIBULA |
| **LEFT SCAPULA** | 1.82 | 0.32 | 1.48 | 2.95 | 0.31 | 1.66 | 0.35 | 1.22 | 2.44 | 0.30 | |
| **LEFT HUMERUS** | 1.02 | 0.21 | 0.84 | 2.31 | 0.24 | 0.94 | 0.24 | 0.71 | 1.93 | 0.24 | HUMERUS + SCAPULA |
| **LEFT RADIUS & ULNA** | 0.55 | 0.19 | 0.48 | 1.32 | 0.14 | 0.59 | 0.23 | 0.47 | 1.18 | 0.15 | RADIUS , ULNA + HUMERUS |
| **LEFT FRONT FLIPPER & SKIN** | 0.44 | 0.27 | 0.43 | 0.69 | 0.07 | 0.47 | 0.29 | 0.41 | 0.67 | 0.08 | 1/2 FRONT FLIPPER + RADIUS, ULNA |
| **VISCERA** | | | | | 1.96 | 8.41 | 5.05 | 7.29 | | 0.91 | |

**Table 7.1** *The average Food Utility Index (FUI) is given for an unhealthy animal (1), three healthy animals (2) and for the latter combined (3). The units for these values are kilograms. The Modified Food Utility Index (MSFUI in column 4 is based on the values in column 3 and the rules for associating riders outlined in the text. The values are then standardised onto a scale of 0-1 to provide the Standardised Modified Food Utility Index (SMFUI). Note that the values for the sculp and viscera are calculated but they do not play a role in the normalisation. The Bulk Utility Index values are the average unit weight in kilograms for 2 unhealthy animals (6), four healthy animals (7), and the latter combined (8). The Modified Bulk Utility Index (MBUI) accommodates riders (column 9) and is then standardised onto a scale of 0-1 to give the Standardised Modified Bulk Utility Index (SMBUI) in column 10. As in the SMFUI the vales for the sculp and viscera are presented but are not integral to the normalisation of the values. The SMBUI and SMFUI are significantly correlated and since the SBUI is based on more individuals it is preferred.*and when it is standardised onto a scale of 0-1 it changes to the Standardised Modified Bulk Utility Index (SMBUI).

The bulk utility values for combined paired elements, taking into consideration the effect of riders, are presented in table 7.1. The modification of a utility index to account for riders is conventionally accompanied by an acronym change, and so the BUI becomes the Modified Bulk Utility Index (MBUI),

## Discussion

The "bulk", "unbiased" or "gourmet" characteristic of assemblages (Binford 1978, Thomas & Mayer 1983) is not the outcome of a single event, but rather the averaged result of many events in which bones were introduced into the site. In dealing with a single carcass, the decision to abandon or remove elements is assumed to be based on the relative economic value of all the elements present. Elements that are abandoned have lower utility than elements that are transported, and *vica versa*. The resulting relation between representation and utility is a step function (elements have a limited number of discrete MAU values - in the case of a single event values of 1 and 0 corresponding to present or absent, and as the number of events increases so the number of possible values increases). In dealing with many carcasses, as in a mass kill, transport decisions should be based on utility applied to the whole assemblage as if it were a single carcass. In this instance the choice of elements for transportation or abandonment should be similar for elements across all the carcasses. If the contribution of individual events is regularly spread over a period of time the step function nature of the assemblage is averaged. In order to achieve either a bulk or gourmet profile the assemblage must either consist of a limited number of mass events, or multiple event that for some reason have similar utility thresholds. An unbiased strategy can only be achieved if the assemblage comprises multiple events with a diversity of utility threshold values.

A further consequence of the fact that assemblages are made up of individual events, each of which has the characteristics of a step function, is that the overall assemblage is also a step function. Since certain representation values are theoretically impossible (by definition of a step function), an interval scale of representation is not strictly accurate. While an interval scale is used to portray the relation between an assemblage and utility, particularly when identifying the biasing strategy, the test of significance of any relation between the two variables should be done using an ordinal scale (Speth 1983, Thomas & Mayer 1983, Lyman *et al.* 1992).

The utility values obtained by Lyman *et al.* (1992) and the MFUI values obtained in this analysis can be compared to test if the anatomy of phocid and otariid seals differ sufficiently to warrant separate utility indices. Some values have to be adjusted because of the differences in the way that the dissections were conducted in the two studies. The average flesh weights presented by Lyman *et al.* (1992) are for unpaired elements, and so the values for appendicular elements must be doubled to be comparable with the MFUI values presented in table 7.1. The flesh mass for the femur must be added to the pelvis, and also the value for the sternum must be added to the ribs and thoracic vertebrae because of the association

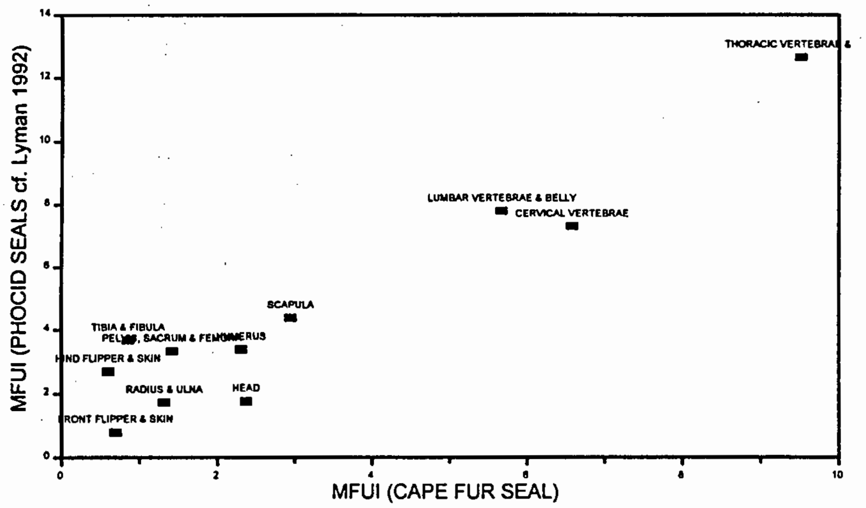

**Figure 7.1** *The difference between the anatomy of phocid and otariid seals is restricted to the mass of the pelvis and the head. The values for phocid seals are constructed from the values reported by Lyman et al. (1992:540 table 6) using the procedure outlined in this study.*

of these elements in the MFUI. The accommodation of riders is according to the approach outlined above. A Spearman's Rank Order Correlation between the MFUI for otariid seals and the reconstructed values for phocid seals, indicates that the anatomical differences between the two are not significant at the 0.01 level ($r_s$=0.78). Plotting the values against one another (on an interval scale) shows that the differences between the true and fur seals are are confined to the elements of the pelvis and hindlimbs which are heavier in phocid seals than in otariid seals, and the head and neck which is slightly heavier in the otariid seals (figure 7.1). These do not appear to be significant, but the different methods of calculating the utility indices tend to exaggerate the differences (figure 7.2). The approach used by Lyman *et al.* (1992) resulted in higher values for the pelvis and scapula than are obtained in this study. It is interesting that the decision to assign utility on the basis of the combined mass of paired units did not result in an apparent overemphasis of SMBUI values for appendicular elements relative to the %MMUI.

The utility values that are derived in this chapter are based on six seal specimens covering a spectrum of individuals including males and females of various sizes. The coherent results obtained for these individuals is an indication of the low variability of the anatomy of Cape Fur Seals in general, and hence the suitability of the results in archaeological applications. A possible complication, however, is the exploitation of a specific subset of the seal population that may have different utility associations. Here I am referring to the seals that die seasonally as a result of nutritional stress, that may have been the target for exploitation in areas where mainland colonies did not occur in the past. The comparison between the healthy and unhealthy specimens indicated that the only change that occurs is in the ranking of the skull relative to the other bones of the skeleton, but a plot of the SMBUI for these samples (figure 7.3) shows how insignificant this change is.

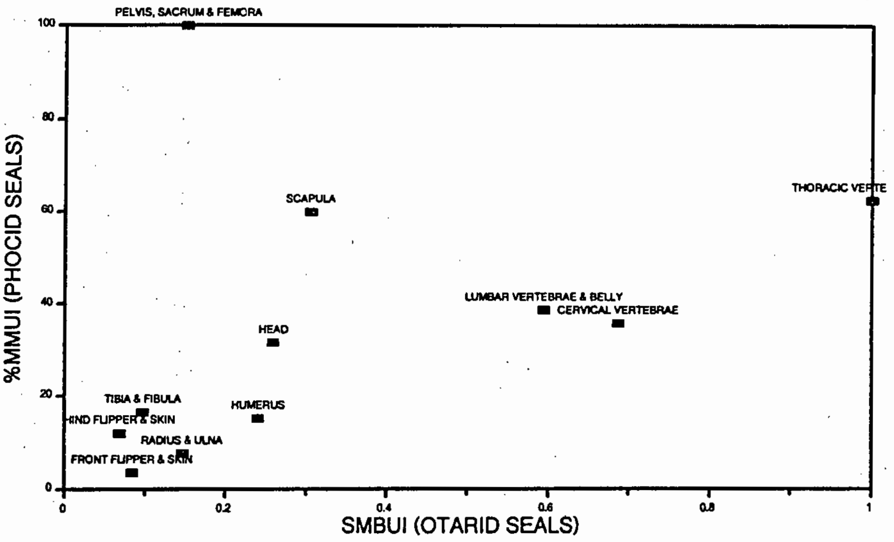

**Figure 7.2** *The difference between the %MMUI (Lyman et al. 1992:540 table 6) for phocid seals and the SMBUI for otariid seals is based largely on the procedure that is used to calculate the indices*

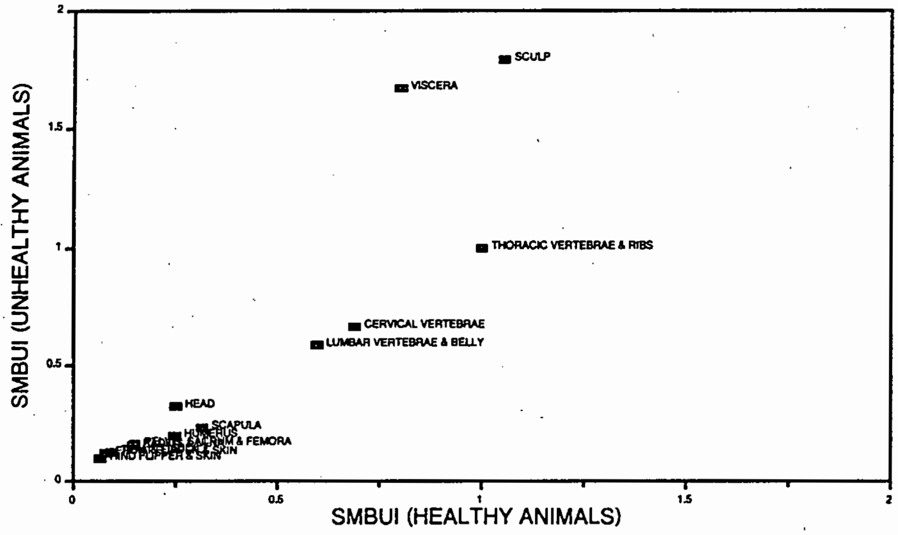

**Figure 7.3** *The anatomical changes that occur under conditions of nutritional stress do not affect the relative utility of the elements of the seal skeleton. The high values for the viscera and sculp of the unhealthy specimens may indicate that the first manifestation of nutritional stress is in the condition of the bone marrow.*

The utility of the sculp and viscera are calculated relative to the rest of the anatomical elements in table 7.1 (although they do not play a role in standardising the values for the elements that have associated bones). In contrast to what may be expected these elements have relatively higher utility in the nutritionally stressed individuals. There are two mechanisms that could cause this: either an increase in the relative mass of the sculp and viscera in the latter individuals, which seems unlikely, or a reduction in the relative mass of the meaty elements. The total absence of intermuscular fat in the latter individuals is insufficient to reduce the utility of the meaty elements relative to the sculp and viscera, and so the loss of bulk in the meat or marrow must be the cause. The physiological reason for this is unclear, but it is manifest uniformly across the entire skeleton except the skull (this may be an indication that the marrow quality is the major component that is affected). The conclusion that can be reached is that the utility values for the six specimens dissected in this study can be used to address the exploitation of wash-up seals as well as healthy animals. The results are applied to the seal assemblages from Kasteelberg B, Elands Bay Cave and the Dune Field Midden in chapter 11.

# CHAPTER 8

# SEAL MEAT PRESERVATION

## Introduction

When reconstructing past diets, different preservation biases apply to different categories of food remains. Bones are better preserved than plant remains which may lead to the overemphasis of the former. Buchanan (1985, 1987) suggested that the diet reflected in the remains recovered from the Elands Bay area comprised 65% protein, 30% fat and 5% carbohydrates, and for the inhabitants of the South Western Cape in general it was made up of 61% protein, 35% carbohydrates and 4% fat. Such a diet would lead to severe poisoning because of the high levels of protein intake (Speth 1987, Noli & Avery 1988). In energetic terms the amount of energy that can safely be derived from protein intake is limited to 20-50% of the total needs depending on the duration for which the diet is followed. The protein sources that Buchanan identified (mostly in the form of shellfish remains and mammalian bones) must have been part of a broader diet that included either a large quantity of carbohydrate in the form of plants that were not preserved, or large quantities of fat, or both.

Fat is scarce in the diet of modern hunter-gatherers because of the low fat levels of terrestrial bovids. Fat in the form of blubber, however, may contribute up to 50% of a seal's weight at the beginning of the breeding season (see chapter 7), which would make this species a prime candidate for exploitation. The low risk involved in hunting seals in comparison to other high fat yielding species, such as hippopotami, would also be a reason for emphasising their exploitation. In general marine mammals contain vast amounts of fat relative to terrestrial mammals, and historical accounts of the exploitation of stranded whales illustrate the premium that was placed on the resource by the indigenous inhabitants of the Cape:

Backhouse (1844:33) reported that on the Namaqualand coast "Whales ... form feasts for the Hottentots who often remove to their vicinity and, preserving their flesh by burying it in the sand, live principally upon it for several weeks together". The Dutch East India Company Journal record for 6 March 1654 also indicates: "These Hottentots were busy engaged in boiling down train-oil from the blubber of the dead whale washed ashore in the bay. This they stored in dried sea bamboo (kelp) which may always be seen drifting here round the Cape and washes ashore everywhere. They explained that they smeared themselves with the oil, and when we gave them bread they sopped it in the oil before eating it" (Thom 1952:218).

An interesting observation that emerges from these accounts is the practice of burying whale meat in the beach presumably to preserve it for later consumption. This is confirmed by several accounts (Schapera

& Farrington 1933:57, Thom 1952:217, Raven-Hart 1970:17 with reference to the incident in Table Bay reported above, and Budack 1977:26 with reference to an ethnographic observation of this practice among the ≠Aonin of the Lower Kuiseb Valley in Namibia).

Seals were obviously an important component of the diet of coastal hunter-gatherers in the past, but few references to their exploitation or to the storage of seal meat are forthcoming from the historic literature. One reference is enlightening because it indicates both a procurement strategy, and the practice of storing meat. In 1836 James Alexander made the following observation on the Namaqualand coast: "To this rocky island the Namaquas swim from the mainland from which it is not far distant, and, in the months of November and December, they find abundance of seals there for the purpose of breeding. The old ones will not leave the island as long as the whelps are on it, and are thus knocked on the head with six-feet poles. In the end of 1835 two traders (Eddington and Kennedy) with the assistance of the Namaquas, had got between four and five hundred seal skins off the island. These the Namaquas willingly gave up for five or six shillings each ... The natives dry the flesh of the seals and subsist on it." (Alexander 183:85 cited in Skead 1980). Preserving meat by drying it is a fairly common modern practice in southern Africa, and it is also used by the ≠Aonin in Namibia (Budack 1977). The meat of most animal species can be dried to make *biltong*, but it is a technique that has limited value in preserving fat because of its low moisture content. It is inconceivable that a means of preserving fat would have been used for cetaceans but not for seals when the latter became available in large quantities either through natural mortality, or through mass procurement strategies.

A report made by Gordon in 1799 indicates that the consumption of toxic meat by indigenous people sometimes had fatal consequences. He reported: " a fish had been washed ashore and that these coastal peoples having eaten some of it had all died" (Raper & Boucher 1988:260). The ability to store meat and particularly fat would have a significant positive effect on the economy of hunter-gatherers, but the means that were available prior to historical contact must have had practical limits. Irrespective of the manner in which animal products were stored, the danger of poisoning would always exist. An experiment was conducted to establish the length of time for which seal meat could be stored in beach sand before it became fatally toxic. The experiment was partially motivated by the research direction of this thesis, but also partially by that of Andrew Smith whose interest in cetacean exploitation is related to the economy of the Kasteelberg inhabitants. The bacterial analyses in this experiment were made by E.C. Lamprecht and F.R. Riley of the Fishing Industry Research Institute, and the results have been jointly published (Smith *et al.* 1992).

### Experiment design

This experiment was conducted using seal carcasses that were made available by the Division of Sea Fisheries. The carcasses were brought to the laboratory on the same day that they were killed and portions of approximately 0.5 kg were removed. Samples included skin, fur, flesh, blubber and bone. Two samples were analysed immediately for their bacterial content. A further 15 samples were buried in three transects across a beach from the dry sand at the landward side of the active beach, to the saturated sand at the low water mark. The five samples in each transect were buried in holes that were 5m apart and 70 cm deep. Survey stakes were installed above the high water mark and the location of each sample accurately determined to facilitate recovery.

Samples were buried during low tide on 7 August 1989. At the same time sediment samples were taken in stoppered glass vials for the analysis of moisture content and salinity. The results for transect A are presented in table 8.1. It is clear from these figures that the samples were located in each of the four zones defined by Bally (1981). These zones are horizontal divisions in the sediment (beach) profile that comprises the saturation zone, the resurgence zone, the retention zone and the drying zone. Each zone has a characteristic moisture content that is related to the tidal cycle. The saturation zone is at and below the low water level, the resurgence and retention zones are successive layers between the low and high water levels, and the drying zone is above the high water level. Samples were located in each of the zones to establish the optimum conditions of salinity and air exposure for maximum preservation of the meat.

| Zone | Sample | % Moisture | % Soluble salt |
|---|---|---|---|
| Drying | A1 | 0.51 | 0.115 |
| Retention | A2 | 7.38 | - |
| Retention | A3 | 7.40 | 0.189 |
| Resurgence | A4 | 21.10 | - |
| Saturation | A5 | 21.22 | 0.988 |

**Table 8.1** *Characteristics of the beach environments in which seal meat samples were buried.*

The samples were recovered from each transect after 10, 15 and 35 days respectively. It was immediately apparent that certain zones of the beach were not suitable for storage. Samples in the saturation zone were never found even with the aid of surveying facilities. Samples that were buried in the drying zone putrefied quickly and the structure of the sample broke down. The recovery of these samples was impossible because of their liquid nature. The samples that were buried in the zones of resurgence and retention combined the practical advantage of being the samples that were most easily recovered and that preserved the best on the basis of their visual appearance. After recovery the samples were submitted to the Fishing Industry Research Institute for analysis of bacterial content.

A second set of samples was buried on 16 October 1990 and recovered after 3 and 21 days.

At every stage of the field work, care was exercised to avoid contamination of the samples. The seals were killed, butchered and the samples buried in the minimum time that was possible. This period never exceeded a day. Samples were stored in sterile plastic bags and kept at low temperatures in an insulated container when being transported. The samples were buried in a beach at the Cape Point Nature Reserve that is closed to public access. In one instance the beach sand was mixed with vegetable matter (kelp) during high winter seas, and after one week the meat that was buried was highly pungent and proved to be contaminated.

The procedures that were used to determine the bacterial content and species composition were set by the Fishing Industry Research Institute personnel who specialise in such analyses. The methods are presented in appendix D.

## Results

Most of the bacteria that normally occur on marine mammals are not pathogenic to humans, but they do include proteinaceous spoilage organisms such as *Pseudomonas* and *Moraxella.* These may cause bad odours and will eventually cause the breakdown of the structure of buried seal meat. Organisms that may occur and that are detrimental to human health include *Staphylococcus aureus*, *Salmonella*, clostridia and *Escherichia coli.* During the analysis of the buried samples, the former group of species were incubated at 20 °C and the latter required incubation at 30-37 °C. The bacterial population recovered at both temperatures is plotted as a function of time in figure 8.1 and the counts per gram of sample for the human pathogens is given in table 8.2.

The growth and decay of the micro-organisms through time are similar for those species incubated at 20 °C and those incubated at 30-37 °C. This shows a logarithmic growth during the first three weeks of burial and then a decline that is not an unusual pattern for food contamination (Frazier 1967). The level of contamination is still within an acceptable level for human consumption ($10^7$-$10^8$ counts.g$^{-1}$) after 7-15 days. After 21 days the contamination decreases as the samples denature and become totally putrid.

Although the total organism counts may be acceptable, the presence of pathogens could have potentially fatal consequences. *Staphylococcus aureus* was only recovered from one of the control samples (that had not been buried), and could have come from contamination of the skin during dissection. The large numbers of organisms that flourished on the samples may have competed with this species and inhibited its growth in the buried samples (see Noleto *et al.* 1987). Clostridia was recovered from most of the buried samples. *Clostridium botulinum* is extremely toxic, but it is also a rare occurrence in the soils of

| Days | 0 (I) | 0 (II) | 3* | 3 | 10 (I) | 10 (II) | 15 | 21 | 35 |
|---|---|---|---|---|---|---|---|---|---|
| Total viable count (g$^{-1}$) 37 °C | 0.0038 | 0.0027 | 138.7 | 0.135 | 37.45 | 27.7 | 58.5 | 4060 | 6.85 |
| Total viable count (g$^{-1}$) 20 °C | 0.0255 | 0.0283 | 159.6 | 0.177 | 27.9 | 18.95 | 31.0 | 3730 | 21.75 |
| *Coliforms* MPN 100 g$^{-1}$ | 24K+ | 24K+ | 240K+ | 24K+ | 24K+ | 24K+ | 240K+ | 35K+ | 240K+ |
| *Escherichia coli* MPN 100 g$^{-1}$ | 190 | 270 | 2.8K | N.R | 16K | 320 | 240K+ | N.R | 36K |
| *Staphylococcus aureus* g$^{-1}$ | N.R | 80 | N.R | N.R | N.R | N.R | N.R | N.R | N.R |
| Clostridia | N.R | N.R | R | R | R | R | R | N.R | R |

**Table 8.2** *Bacterial content of seal meat after burial in beach sand (* Sample was contaminated by rotten kelp after 3 days). N.R - not recovered, R - recovered.*

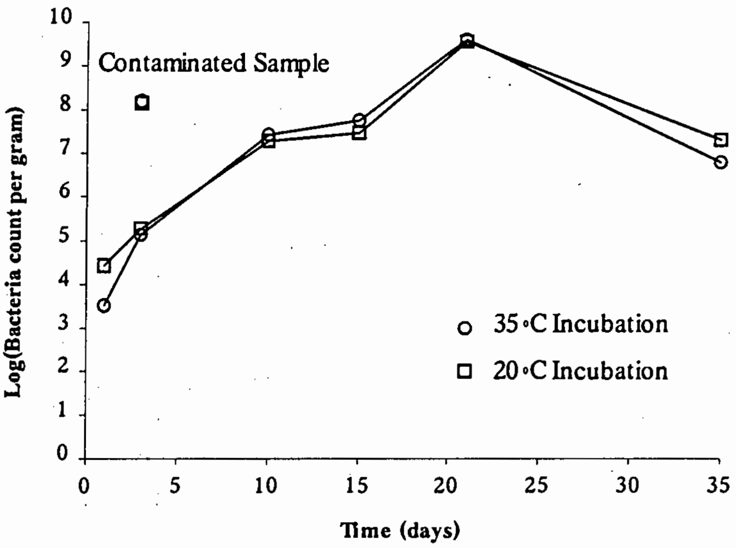

**Figure 8.1** *Bacteria on seal meat buried in beach sand shows a logarithmic growth up to 21 days.*

South Africa (Knock 1952). The species that is represented is likely to be *Clostridium perfringens* which, although still toxic, is less likely to cause death if ingested (Peterson & Johnson 1978).

## Discussion

The environmental conditions in which the samples were buried are prime determinants in the micro-organism ecology that develops. The pH was measured at 7.4 and the temperature was assumed to be similar to that of the west coast sea water which fluctuates between 12 and 14 °C, but does drop as low as 9 °C. It was assumed that the factor that favoured the zones of resurgence and retention for preservation was the high salt water content. The samples that were buried in these zones were located in sea water that emerged at the bottom of the holes. The recovery of aerobic sporeformers, *Bacillus* spp., and the high occurrence of coliforms indicates that the environment was not entirely anaerobic, and that the salt content was insufficient for brining to be the principle preservation mechanism (Smith *et al.* 1992). The aerobic environment, however, would prevent the growth of *Clostridium botulinum*.

The samples that were buried in this experiment contained a mixture of meat, fat, skin and fur as well as bone. If the blubber layer was removed and buried separately it would contribute to the development of an anaerobic environment. Burying the blubber in the saturation zone of the beach may also create a more anaerobic environment. Both of these measures may produce better conditions for preservation but there are several factors that make the latter option impractical. Firstly it is difficult to dig holes in this zone without them filling with sand at the level of the watertable, and secondly the recovery of samples buried here is contingent on low tides and even then finding the hoard is not guaranteed.

## Conclusion

It is possible to store chunks of seal carcasses in damp beach sand for up to two weeks before they become highly toxic. The rate of decay depends on the environment in which the chunks are buried. The optimum location is low in the intertidal range of the beach, preferably deep below the sand surface in the salt water where the environment is cool and anaerobic. If the environment is too dry the meat rapidly putrefies, and if the burial point is too low in the saturated zone it is unlikely that the chunk will be recovered. Avoiding the inclusion of contaminating sources such as rotting seaweed is imperative.

The ability to store food would allow hunter-gatherers a degree of latitude in their coastal adaptation. An obvious advantage is the potential to retain a resource for use on occasions when it would not normally be available. A two week storage period would offer the kind of benefit to hunter-gatherers that a refrigerator offers modern urban dwellers. With the option of storage it is also possible to adapt the exploitation strategy that is employed. By killing more seals on fewer occasions the disruption of a seal colony would be minimised and the sustained exploitation of the resource would be more likely.

It has not been established that the prehistoric inhabitant of the western Cape stored seal meat or fat in beaches. Archaeological testing of this proposal is impossible because the practice does not leave any tangible indications on the bones of the seals, nor does it have consequences for the body parts that are introduced onto the site. It is an archaeologically transparent practice that might have been a significant part of the exploitation strategy that was exercised in the past. If seals could be stored for months rather than weeks it would have reduced the necessity for hunter-gatherers to have exercised seasonal transhumance, and it would have important consequences for the use of this species as a seasonal indicator. The experiment in seal meat preservation indicates the potential duration of beach storage is in the order of two weeks. This at least sets the boundary conditions for the interpretation of archaeological seal remains.

# CHAPTER 9

# A MODEL FOR APPLYING TAPHONOMIC INDICES

## Introduction

The foregoing chapters contain observations and indices that can be used to model past seal exploitation on the basis of the bones that are preserved in archaeological sites. Some of the observations, such as the review of seal ecology (chapter 3) and the study of seal meat preservation (chapter 8), are informative but they do not have a direct influence on the bones that are recovered. Others, such as the hardness index (chapter 5), the utility index (chapter 7), the carnivore consumption sequence and the model for carnivore ravaging (chapter 6), are aimed at discerning differential representation of body parts. The method for aging archaeological seals (chapter 4) provides taphonomic information that is apparently independent of the other indices. The way in which the whole range of observations can be integrated to provide a coherent picture of seal exploitation is the subject of this chapter. This is accomplished by considering the taphonomic scenarios that may have occurred, and then demonstrating how the indices can be used to distinguish the different scenarios from one another.

## Scenarios for seal bone destruction

The indices outlined in the previous chapters provide a set of theoretical constructs that can be used to gauge the extent to which various processes have influenced seal bones from archaeological sites. In order to clarify how these are applied, various scenarios are considered. The range of taphonomic possibilities are outlined in a flow diagram format in figure 9.1.

A. The scenarios begin when seals come ashore and become a potential resource to people and carnivores. This usually occurs at colonies or haul outs - each of which has a characteristic age and sex structure that is distinct from the population of seals which either randomly come ashore to rest, or which die at sea and are later washed up on the coast. Establishing age (mortality) profiles for sexed seal remains from archaeological sites will indicate from which scenario people obtained the animals.

B. Besides providing information on the geographical location of sealing, the scenario in which seals are obtained plays an important role in dictating the procurement strategy that is adopted. Since seals are available in abundance at a colony/haul out, there seems to be little reason for people not to take

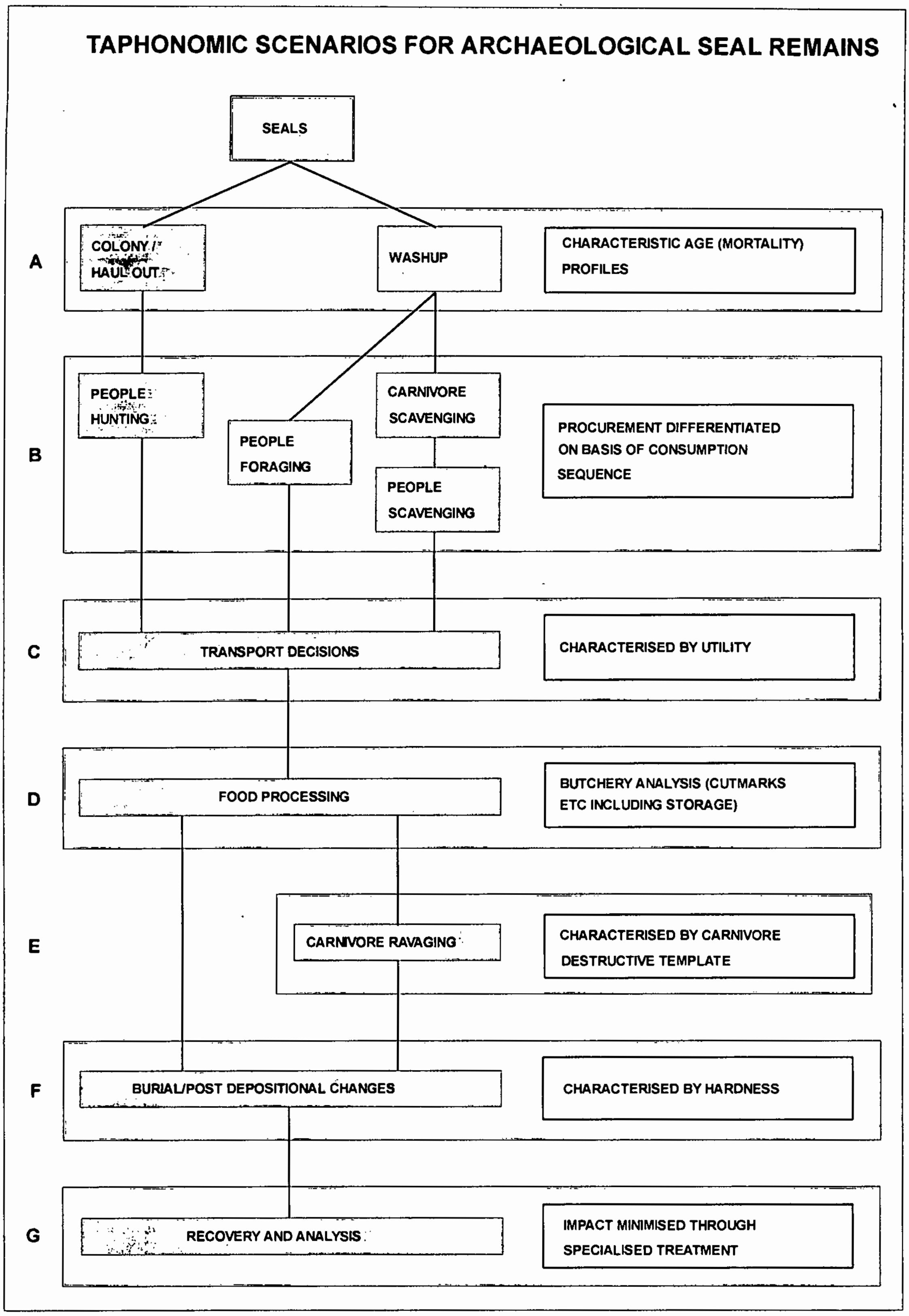

**Figure 9.1** *By modelling the taphonomic scenarios for seal remains, it is possible to predict the characteristics of hypothetical assemblages in terms of the indices developed in this study.*

animals of their choosing. Without competition from carnivores, complete seal carcasses should be available and so the only bias in the bones that are introduced to the site will result from transport decisions. Such a scenario I have considered to represent *hunting*.

Where seals are obtained from strandings and wash-ups, there are two possible scenarios. First people may gain access to a carcass soon after it becomes available. This I have called *foraging*. Although the resulting body part representation will be similar to that of hunting, foraging is distinct in that the animal need not have been dispatched to expedite its utilisation. In the second scenario carnivores gain first access to the carcass, but they are driven from it and a partially depleted seal skeleton is introduced into the archaeological site. This I have termed *scavenging*, and it refers to a strategy in which people do not kill the seal but rely on chance encounters with carcasses even if they have been partially exploited by other carnivores. The resulting departure from anatomical parity in the latter scenario can be characterised in terms of the carcass consumption sequence.

C. After the seal carcass is procured, irrespective of the strategy that is used, it has to be transported back to the encampment. If the seal is large it may be field butchered and certain parts abandoned. The most economical strategy to follow would be to maximise the returns for the amount of labour required. The best prediction of what would be transported lies in the use of the utility index derived here specifically for seals.

D. Once the carcass has been introduced to the site there may be further destruction of body parts through butchery or bone utilisation in tool manufacture. This must be determined from cut, chop and percussion marks preserved on the bone surface. The butchery evidence from the assemblages considered here has already been studied (Klein & Cruz Uribe 1987, 1989). Smith & Poggenpoel (1988) have also considered bone tool manufacture at Kasteelberg B. The evidence for butchery and other bone modification processes have not been further explored in this research.

An aspect that is also relevant in food preparation is the ability to store the resource for belated utilisation. In the prehistory of the south western Cape the most likely scenario involves the burial of seal flesh in beach sand. This, though, is not likely to affect the final body part representation.

E. Following disposal on the site the seal bones may either be ravaged by carnivores or pass directly into the depositional matrix. The ravaging action represents the ultimate act of resource extraction. What remains is of no value to humans or carnivores. The hardness index used to model the effects of this is based on precisely the same behaviour monitored among jackals and brown hyaenas on Namibian seal colonies.

F. The bones then enter into the depositional matrix. Here their survival is dependent on the time that they spend in the ground, and on their ability to resist the mechanical and chemical forces to which they are subjected. Differential survival in this instance is related to bone hardness.

G. Besides the technical difficulties related to sub sampling of sites, the act of recovery and analysis introduces various biases. These range from bone breakage during excavation and transportation, to loss through sieves and misidentification. The effect that these have on the body part representation must be addressed by the specialists involved in each step of the recovery and analysis.

## Applying the model

Rationalising the above scenarios in terms of an approach to analysing seal assemblages is accomplished as follows:

1. It is assumed that the analysis of the bones is directed at establishing the abundance of each skeletal element in the seal assemblage, and that this is a true reflection of what was present on the archaeological site.

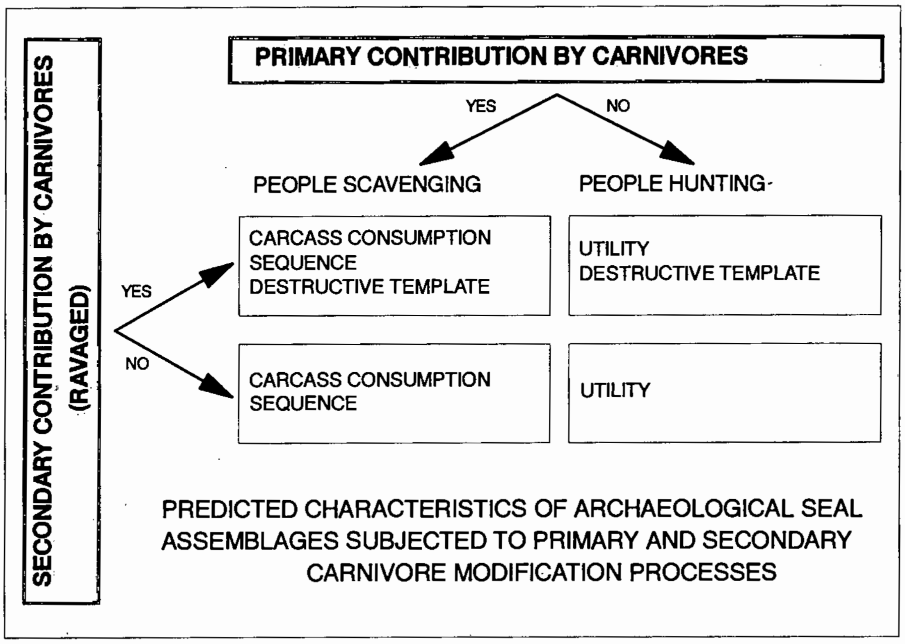

**Figure 9.2** *A model predicting the characteristics of a hunted or scavenged bone assemblage that has been subjected to primary and secondary carnivore ravaging.*

2. The body part representation is compared to the hardness index. If the two are closely related it is likely that the patterning is an artefact of geological processes, and no further behavioural information can be derived in terms of this analytical approach. If the patterning is not related to preservation, then it is valid to consider the behavioural implications.

3. The evidence for butchery should be considered in order to establish the likelihood of this practice being the cause of the patterning.

4. Provided the sample is large enough, the age of death and sex of the seals should be established and presented as mortality profiles.

5. The scenarios based on steps B, C & E can be rationalised in terms of the presence or absence of primary and secondary carnivore activity. Primary carnivore activity refers to the competition for initial access to seal carcasses. Secondary carnivore activity is the ravaging of bones that have already been discarded by people. Each of the four possible scenarios should result in assemblages that have slightly different characteristics. The indices for which positive correlations are predicted are presented in figure 9.2. The final step in the analysis, therefore, involves comparing the body part representation of the archaeological assemblage with the carcass consumption sequence, the model of carnivore ravaging and the utility index.

The taphonomic indices that were developed in chapters 5, 6 and 7 for seal remains were originally conceptualised for other species to address the evolution of hunting in the context of Plio-Pleistocene archaeology. The procedure outlined above is based on the way in which the indices were originally used, but in applying them in the context of Later Stone Age archaeolgy a great deal more can be achieved. For example, procurement strategies have been an important issue in establishing the "humaness" of hominids, but the research direction is not a central issue in Later Stone Age archaeology. It is accepted that the LSA people in southern Africa were capable of hunting through the Holocene (Klein 1989*b*). At the same time the distinction between hunting and scavenging does not hold the same significance for seals as as it does for terrestrial prey species. Seals are so vulnerable to human predation when they are on land that the difference between hunting, foraging and scavenging is trivial. However if the research emphasis is shifted away from merely identifying the procurement strategy towards identifying why the strategy was adopted, then there are some important questions that can be addressed. Here the emphasis is on the social context of hunting and scavenging. There are circumstances in which mobility patterns and aspects of the social organisation of past hunting and gathering societies can be addressed through the discernment of seal procurement strategies. Where hunter gatherers resided at the coast and foraged daily along the beaches and immediate hinterland, they would have detected a dead or weary seal very soon after it came ashore. The only constraint they would have in exploiting the animal would be their ability to transport the carcass, whole or dismembered, to the nearby base. If, however, they lived in the hinterland and scheduled their visits to the beach, perhaps to coincide with low tide when the returns from shell fish gathering are guaranteed, then the carnivores scavenging along the beach would have had first access to any seal carcasses that became available. Any element of the carcass consumed by the carnivores would effectively be deleted from the menu available to the hunter gatherers. The less time the hunter gatherers spent on the coast, the more likely it would be that the seal menu would be narrowed by carnivores.

## Index redundance

When the body part representation of a seal assemblage is compared with the indices according to the protocol outlined above, it is assumed that there is no interdependence between the different indices. The possibility that two or more of the indices are redundant may be coincidental or it may result from a causal link between the characteristics that form the basis the indices. Speth (1991) has noted that there is a relation between the MGUI and potential influence on an anatomical element by fluvial transport. A significant negative correlation also exists between bulk density and MGUI (Lyman 1985, 1992) which implies that assemblages that correlate with utility may result from density mediated destruction rather than human behaviour. While the former example may be coincidental, in the latter instance the link between density and utility may be causal. The weight bearing bones are structured in a way that is adaptive to their function (see chapter 5) and accordingly they may be denser, but they are also the bones that are associated with the larger muscle groups.

It is imperative that the different indices are independent of one another if they are to be used to distinguish between different taphonomic scenarios. Since many of the indices for modelling differential representation are developed on ordinal scales it is necessary to check their redundance with an appropriate statistical procedure. This is done with a Spearman's Rank Correlation (Ebdon 1985). The ranking for each bone in the skeleton and for each of the indices is presented in table 9.1. These values are derived from the relevant tables in the preceding chapters (table 5.1 for the hardness values, table 6.3 for the jackal midden data, table 6.1 for the carcass consumption sequence and table 7.1 for the utility values). The hardness values were used in the comparison although the same result would be obtained if the Youngs Modulus analogue values were used since the two are highly correlated ($r_s$=0.31, $\rho$<0.005). Similarly the North Cliff Midden values were used for the jackal destruction template because this is the larger of the two jackal midden collections. Both of these are also significantly correlated ($r_s$=0.496, $\rho$ <0.05). It is also noted that the template is not in the strictest sense a template of carnivore ravaging (see chapter 6), but it does portay the diagnostic features that are believed to be indicative of ravaging.

| | **Carnivore Consumption Sequence** | **North Rock Midden** | **Hardness** | **Utility** |
|---|---|---|---|---|
| **Mandible** | 18 | 18 | 15 | 13 |
| **Cervical Vertebrae** | 1 | 9 | 10 | 16 |
| **Thoracic Vertebrae** | 17 | 5.5 | 2 | 17.5 |
| **Ribs** | 16 | 8 | 12 | 17.5 |
| **Lumbar Vertebrae** | 13 | 5.5 | 4 | 15 |
| **Sacrum** | 14.5 | 7 | 1 | 9 |
| **Pelvis** | 14.5 | 10 | 9 | 9 |
| **Femur** | 12 | 11 | 18 | 9 |
| **Tibia** | 10.5 | 13 | 11 | 5.5 |
| **Fibula** | 10.5 | 13 | 7 | 5.5 |
| **Tarsals** | 9 | 1.5 | 3 | 2.5 |
| **Metapodials** | 6.67 | 1.5 | 6 | 2.5 |
| **Phalanges** | 6.67 | 3.5 | 5 | 2.5 |
| **Scapula** | 2 | 13 | 14 | 14 |
| **Humerus** | 6.67 | 17 | 17 | 12 |
| **Radius** | 6.67 | 16 | 16 | 9 |
| **Ulna** | 6.67 | 15 | 13 | 9 |
| **Carpals** | 6.67 | 3.5 | 8 | 2.5 |

**Table 9.1** *Ranking of the body parts from smallest values (=1) to largest values (=18) on the basis of the taphonomic indices developed in this research.*

The matrix of rank correlations is presented in table 9.2. The significance is presented for a two tailed test on the assumption that the indices may be either positively or negatively correlated if they correlate at all.

| | **CCS** | **NRM** | **H** | **U** |
|---|---|---|---|---|
| **Carcass Consumption Sequence** | - | - | - | - |
| **North Rock Midden** | 0.13 | - | - | - |
| **Hardness** | -0.15 | 0.79* | - | - |
| **Utility** | 0.30 | 0.31 | 0.21 | - |

**Table 9.2** *The matrix of Spearman Rank Correlation coefficients ($r_s$) indicates that the only significant correlation that exists is between Hardness and the representation in the jackal midden ($\rho$>0.1 in all cases except the value marked* for which $\rho$<0.01)*

## Conclusions

The only indices that are significantly related are Hardness and the representation at the North Rock Midden. This is not surprising since hardness was used to model survival of seal bones in jackal middens (chapter 6). A slightly different approach from that presented here was used to establish the relations between jackal midden bone representation and hardness. Instead of using the ordinal ranking of the indices, the interval scale values were used. This highlighted idiosyncratic deviations from a typically linear relation that can be attributed to specific aspects of carnivore ravaging. In particular this refers to the deletion of small bones irrespective of their Hardness.

In order to establish a positive correlation between the archaeological seal bone representation and the carcass consumption sequence, and the hardness and utility indices, it is sufficient to use the ordinal scale Spearman Rank Correlation, but the effects of secondary ravaging can only be detected by comparing the assemblage with the jackal midden material on an interval scale.

# CHAPTER 10

# AGE PROFILES AND SEASONALITY

## Introduction

In this chapter the method of determining the ontogenic age of seals that was developed in chapter 4 is applied to the assemblages from Elands Bay Cave (EBC), Dunefield Midden (DFM) and Kasteelberg B (KBB). The location of each of these sites places demographic constraints on the age and sex structure of the seal population, and these constraints will be reflected, with some latitude, in the age structure of the cropped population. A major distinction between the sites is that KBB is near to a breeding colony while the Elands Bay sites are not. At both EBC and DFM the site catchment in terms of seals comprises mainly carcasses that wash-up seasonally in large numbers and animals that occationally haul out on Baboon Point. During most of the year the exploitable seal population would not have had a distinctive demographic signature unless a more permanent hauling out colony existed in the past. The nature of seal availability at the sites is reviewed in detail in chapter 3. A very important aspect at each of these sites is the expected change in the availability of seals of different ages throughout the year. The relations between the available populations and the archaeological populations can be used to address aspects of past human ecology at several levels. The season of exploitation and by extension the season during which the sites were occupied can be determined from the age of the seals. The strategy or technology that was used to procure the seals may also be indicated. At the broadest ecological level the niche that the people occupied in terms of hunting and scavenging may also be portrayed.

The predicted age value for each of the mandibles in the archaeological samples is first used to construct age (mortality) profiles, and where there are suitable examples in the assemblages, the age profiles are then resolved on an annual scale that portrays the season of death. The interpretation is based on the shape of these plots, and so it is necessary to explore the contributing factors. The most important factors are the ecology of the prey and of the people, and the aim is to resolve the interplay between the two.

## The shape of mortality profiles

An age profile is a graphic portrayal of the age structure of a spatially and temporally defined population. The profile shows the number of individuals that fall into each of a number of age categories. Under natural circumstances every population will reach a state of equilibrium in which the number of births is offset by the number of deaths, and it is the relation between births (recruitment) and deaths (mortality) that is of interest for archaeologists. Among new-born animals, the chances of dying from natural causes such as predation, disease or other misfortune is high, and so fewer animals than are born are expected to survive to the next age category. Those that do survive are still vulnerable to the same pressures, and so the number of animals that survive through one age category to the next will always be less than the recruitment for that category. The result is that a live population that is neither in growth nor decline has a structure in which each successive age category includes fewer individuals. Such a structure is described as "L-shaped" (Lyman 1987*a*, Stiner 1991*c*). If a death assemblage (as opposed to a live population) has such a profile it has been termed a "catastrophic profile" (Klein 1982, Lyman 1987*a*).

Individuals in each age group are subject to slightly different cropping pressures, and they also possess varying abilities to cope with the pressures. Typically immature animals are highly vulnerable and the composition of a natural death assemblage includes a high number of these animals. As animals mature they become less vulnerable and the mortality rate decreases. Animals that reach old age are once again vulnerable and are represented in higher numbers in natural death assemblages. Death assemblages that reflect the normal attrition of the living population will therefore have a bimodal representation with a high representation of very young and very old individuals but relatively few animals in there prime. This is called a "U-shaped" (Lyman 1987*a*, Stiner 1991*c*) or an "attritional" (Klein 1982) profile.

U-shaped and L-shaped profiles are related to one another. Within each age category the number of animals that die contributes to the U-shaped profile while those that survive contribute to the following age category in the L-shaped profile (figure 10.1a-c). In terms of population dynamics these are models of attrition and survival respectively.

There are no statistical procedures for distinguishing between catastrophic and attritional profiles in archaeological assemblages although the distinction is central to many analyses (Lyman 1987*a*, Stiner 1991*c*). From a theoretical perspective a catastrophic death assemblage (or archaeological assemblage) might reflect the selection of prime, healthy animals and hence would support a scenario in which people hunted. An attritional profile may support a scenario in which people scavenged carcasses of wild animals, or in the case of domestic animals, it may indicate the herd management practices. Such a simplistic approach assumes that the characteristics of a death assemblage are exclusively the domain of the procurement strategy. In fact they are critically affected by the scale of the exploitation, the ecology of the prey species and by taphonomic factors. Because of this the meaning given to each of the different mortality profiles in archaeology is open to a variety of interpretations (Stiner 1990).

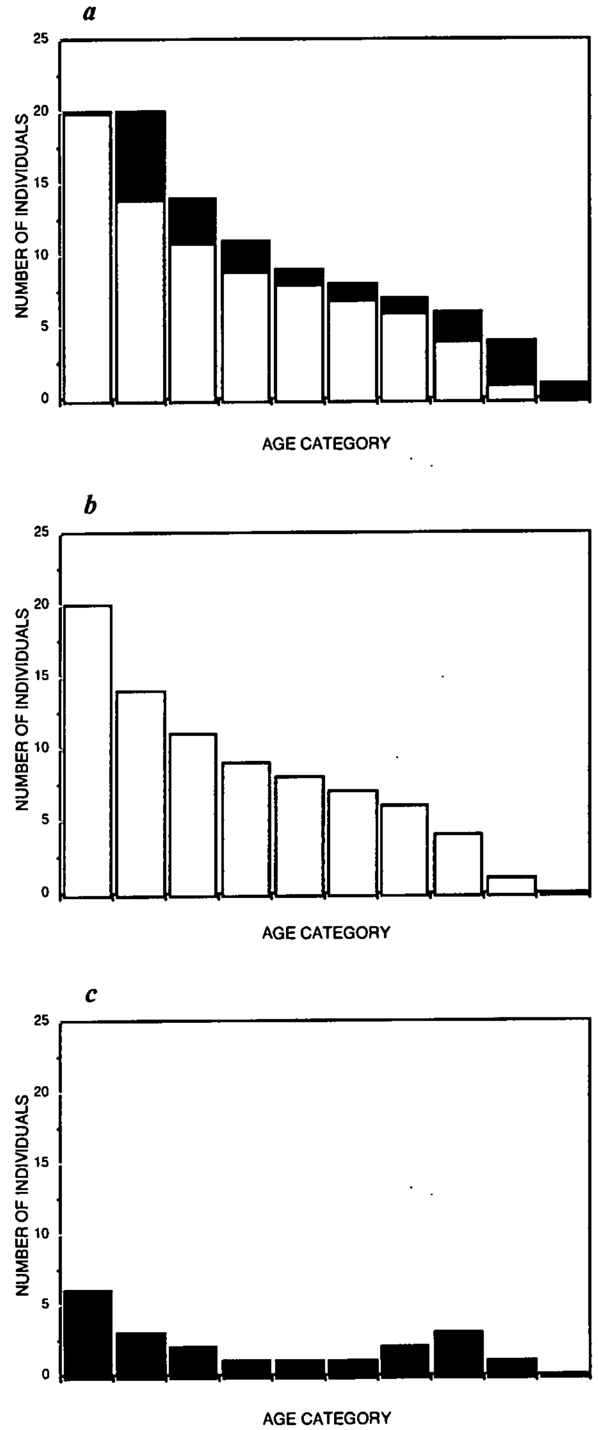

**Figure 10.1** *In a stable population the number of individuals in successively older age categories decreases. The relation between the individuals that survive between age categories and those that do not is illustrated in (a). The population of survivors will normally have an L-shaped age profile (b). When an archaeological assemblage (death assemblage) portrays this profile it is also called a "catastrophic" profile. The population that dies will have a U-shaped profile (c). This profile normally reflects a death assemblage, and it is also called an "attritional profile".*

## 1. The effect of scale on mortality profiles

Klein attributed the catastrophic profiles of eland at Klasies River Mouth and Nelson Bay Cave to a mass culling practice such as might occur if entire herds were killed by driving them over cliffs or into traps (Klein 1975*a*, 1978). On a local scale such a practice would have a catastrophic appearance in the death assemblage and it would also be catastrophic in its effect on the live population, but in a larger context such as the whole southern Cape Eland population, the demise of a few herds would likely be offset by population growth in other areas. This argument becomes important in the context of specialisation among predators. Stiner (1991*a*) argues that cursorial predators (those that run down their prey) select the young and/or weak and thus would be expected to obtain prey that conform with attritional expectations. Ambush predators are more likely to kill prey that reflects the live structure of the prey population. The point is that these predators are all part of the natural attritional pressure on the prey species, but the predatory specialisation targets different segments of the prey population. The combined effect of all the predators that prey on a species is the natural attrition of the prey, but each predator has a niche that produces only a specific portion of the attritional profile. In the context of the eland example the catastrophic profiles would have been part of attrition at a larger scale. In the context of a general approach to interpreting mortality profiles it is important to note that an archaeological assemblage is a relatively small scale observation, and that mortality profiles on small scale observations are open to interpretation. Attritional profiles could reflect scavenging, but they could also reflect selective predation. Catastrophic profiles could reflect hunting, but they could also reflect a specialised scavenging niche.

Further consideration must be given to prey species that are spatially differentiated. Migratory antelope species in the Serengeti provide seasonally distinct populations (Blumenschine 1991). In this instance the same type of predator exploiting the same prey population, but in a different location or at a different time of the year, will produce different death assemblages. Such differences can occur if bone assemblages result from any spatially or temporally differentiated accumulation processes, such as annual flooding (Lyman 1987*a*).

The scale referred to here is specifically geographical. With respect to seals the geographic scale of exploitation is restricted to the narrow coastal ribbon where the range of seals and that of the prehistoric inhabitants of the south western Cape overlapped. The variability within this range is enormous, but it is best understood in terms of the biology of the seals (see chapter 3). The relevance of the scale is measured, to a large extent, by the size of the death assemblage. Lyman has argued on the basis of a known catastrophic event (the eruption of Mt. St. Helens) that a minimum of 25-30 animals is required to distinguish between attritional and catastrophic profiles (Lyman 1987*a*).

## 2. The effect of prey biology on mortality profiles

A great deal of emphasis has been placed on identifying the form of mortality patterns in archaeology although there is no definitive meaning for catastrophic or attritional profiles (Stiner 1991*c*). In every instance the context of the profile needs to be considered - and the most important consideration is the behavioural ecology of the prey species (Stiner 1991*c*, Lyman 1987*a*). The migratory species that was used to illustrate the effects of geographic scale is one example. Cape fur seals are not migratory but the population is subject to seasonal changes in composition. This has been summarised in chapter 3 and an interpretative framework was established there. An important conclusion is that on a local scale it is unlikely that people could have exploited a seal population with an L-shaped profile. A U-shaped death assemblage is similarly unlikely.

The importance of prey ecology is highlighted in the debate surrounding the seal remains from Klasies River Mouth. Adult seals are exploited in the lower MSA deposits but this changes to the exploitation of juveniles in the recent MSA deposits. Binford (1986*a*) reasoned on the basis of the archaeological evidence that this was a development from the scavenging of adult wash-ups to the hunting of pups. On consideration of the availability of seals of different ages, Marean (1986*a*) proposed that the juvenile dominated assemblage is also likely to be the result of scavenging. He argued that the only place at which young seals could be hunted was at a rookery, and if one were in the vicinity of Klasies River Mouth, and this is unlikely, any attempt to despatch the pups would be met with a hazardous response from territorial bulls and protective cows. Marean's argument is that the hunting of pups would necessarily involve the killing of adult animals. Instead of a change in procurement strategy, he suggests a change in season of exploitation. Klein (1976) argues for a change from encounter procurement during the MSA to seasonally timed exploitation during the LSA.

Binford (1986*b*) accepts the shortcomings of not considering the ecology of seals, but even Marean's exposition of seal behaviour is incomplete. During the months after the bulls leave the breeding colonies, but before the pups are weaned, a situation exists in which pups can be selected without much danger to the hunter (pers. obs.). Marean's interpretation may not be incorrect (although the aging criteria must also be reconsidered) but the issue does illustrate the importance of animal ecology in determining the shape of mortality profiles.

Understanding certain aspects of the behaviour of prey species is essential to the reconstruction of past exploitation strategies. The success of mass hunting strategies such as driving herds into traps or over jumps is contingent on certain criteria. Lack of attention to these details could lead to poor hunting success or to injury to the hunters (Frison 1991). A similar argument applies to the exploitation of seals. A critical issue with Cape fur seals is the degree of disruption that they will tolerate during the breeding season, and the rate of attrition that can be maintained. Indiscrininant culling destroyed the Cape breeding colonies during colonial times, and also led to the establishment of mainland and other colonies during this century (David 1987, Shaughnessy 1987). At present the South African Sea Fisheries Research Institute sets culling quotas of 32% of pups (Shaughnessy & Best 1982), but this is carried out when the pups are weaned - not during the breeding season. Namibian culling exceeded this rate and prior to 1985 that seal population was declining (Shaughnessy 1985).

Cape fur seals have a very high recruitment rate. The number of pups born each year is approximately a quarter of the total population (Shaughnessy 1982*b*, 1987). Attrition of a species with a high recruitment rate may appear the same as a catastrophic profile because of the higher death rate among middle aged individuals (Klein 1982).

### 3. The effect of taphonomy on mortality profiles

Any processes that may differentiate between bones of different aged animals, for example the destruction of bones during food processing (see Voigt 1983 for an example), are relevant here. The expectation is that the bones of younger animals will tend to be softer than those of adults and will thus be underrepresented in archaeological assemblages. In fact in many sites the bones of younger animals are often more complete than those of older animals because they are smaller and are less likely to be subject to large stresses after they have been buried (Klein 1989*a*). The specific bone that is used to age seals in this analysis is the mandible, and in most instances its preservation appears to be very good. In the case of observed attrition of seal bones by carnivores, the mandible was shown to one of the more common bones to survive.

Another possible bias may result from the excavation and analysis of the bones. If large sieves are employed then the smaller bones of younger animals, or fragmented specimens may be lost (Klein 1989*a*, Turner, A. 1989). The use of the mandible to predict the age of seals is likely to circumvent these problems. The mandible is very often preserved complete and even juvenile mandibles or slightly damaged examples are not likely to be lost through coarse sieves. It is also convenient that the three sites considered here were screened through 5 mm or less sieves. The mandibles are therefore unlikely to be underrepresented in any age category.

### Interpreting age (mortality) profiles

It has already been stated that archaeological analysis of mortality data is preoccupied with the recognition of catastrophic and attritional profiles. The distribution of seals along the coast is too complicated to expect the classic characteristics of these profiles to be manifest in archaeological assemblages. The emphasis in this analysis is to establishing whether an assemblage resulted from selective or non-selective sampling of the seal population, and the identification of the type of population that was exploited. To identify the type of population that was exploited the age and sex characteristics of the sample will be compared with the model of the seal population structure developed in chapter 3. To distinguish selected from non-selected sampling strategies the "discreteness of age classes" (Klein 1982, Lyman 1987*a*) approach is adopted. This technique can only be employed if the population comprises of generations or cohorts that differ in age from one another by a distinct multiple of a year. The prey species must therefore have a well constrained annual birth season (Craig & Oertel 1966) - a criterion that seals fulfil very well. If the animals in each age category died in the same month then it is reasonable to expect that the procurement was an "event" and that there was no selection of the prey. If the mortality in each age category spans more than 5 months of the year then the profile will be the result of many encounters and a degree of selection is implied (Klein 1982).

The "discreteness of age classes" is dependent on the ability to precisely determine the age of the archaeological specimens (Lyman 1987*a*). Using the technique developed in chapter 4 it is necessary to limit the application to seals of less than three years of age at death. After this the errors become unacceptably large and it is not valid to expect the "discreteness of age classes" to hold real meaning. Even seals aged less than three years have a degree of variability associated with ontogenic age predictions that makes the 1 month and 5 month limits a little ambitious. Instead the emphasis here will be on inter- and intra- site comparisons in the "discreteness of age classes".

The profiles that are generated have an X-axis scaled in years (fig 10.2-5, 10.7-8). For the animals that are determined to be less than three years of age, profiles based on the month of death are generated (fig 10.2-5, 10.9). Ontogenic age is initially calculated from the month of death, and in the strictest statistical terms, portraying the sub-three year old profile on an annual (monthly) scale is valid.

## Results

### Dunefield Midden

The DFM sample consists of two cohorts, one about ten months old, the other a year older (figure 10.2, appendix E.1). The first cohort almost certainly represents the seasonal mortality of weaned seal pups between June and October. The second cohort, on the other hand, is available year round. The coherent seasonal signature from both cohorts is an indication of the duration of the occupation at DFM. Both cohorts suggest occupation between June and January, but almost certainly between July and October. The predicted peak sampling period is October.

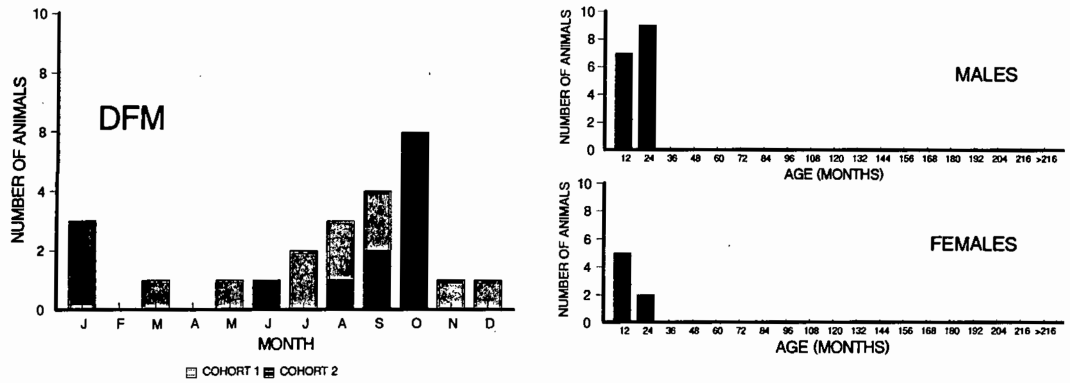

**Figure 10.2** *The age (mortality) profile for the DFM seal assemblage is dominated by juveniles that were killed in the spring months.*

## DFM Extension

At least two other campsites were discovered, and partially sampled, in the course of excavating DFM. These overlap one another and also partially overlap the DFM deposit, although they result from occupations at different times. The older site dates to approximately 950 BP and the most recent to about 500 BP. Stratigraphically it was not always possible to distinguish the sites from one another and so the 31 seal mandibles recovered from the overlapping portions of the sites were treated as a single entity. It is called, for the moment, DFM Extension. The value of this sample is that it represents an accumulation of several occupation events, similar to that found in cave sites. The seals killed during the DFM occupation, but which were included in the DFM Extension deposits, must have the same seasonal signature as DFM. The averaging effect that occurs when a temporal scale is applied and the site consists of a multicomponent system can be tested in this case where the seasonal signature for at least one of the occupations is known.

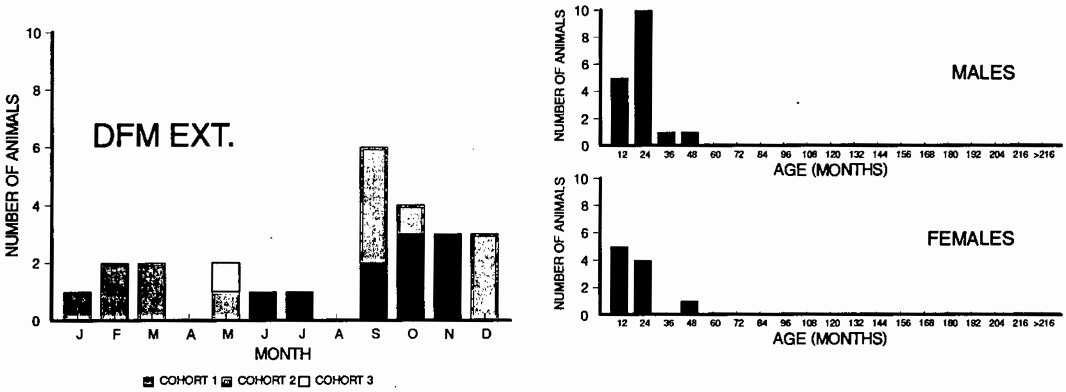

**Figure 10.3** *The seals in the DFM Extension assemblage are also juveniles, but the overall seasonal signature is dominated by animals killed during the early summer months.*

The DFM Extension seasonal signature is similar to DFM with a peak in September (appendix E.1 and figure 10.3). There are first year pups represented through to December, and there is a better representation of second and third year animals, some from the height of summer. This deviation from the DFM pattern may result from at least one of the DFM Extension sited being occupied at a later time of the year, perhaps in December, or for a longer period of time, or both.

## Elands Bay Cave

Elands Bay Cave presents a different scenario from that at DFM but not very different from that at DFM Extension. Occupation debris accumulated from many visits to the site over a substantially longer time period. Because of the location of the Cave in a cliff face overlooking a beach and rocky promontory, the inhabitants of this site had easy access to seals. The Elands Bay Cave seal assemblage is divided into two: EBC Upper was deposited between 1400 BP and 500 BP and is thus roughly comparable in age with DFM, and EBC Lower dating to between 10000 BP and 9500 BP.

The EBC Upper assemblage has very similar seasonal and mortality characteristics to that of DFM. First year animals killed in the winter and spring months dominate (Appendix E.2 and figure 10.4). This implies that visits to the mouth of the Verlorenvlei by hunter-gatherers in the immediate pre-colonial period were part of a coherent seasonal strategy of occupation timed for the winter and spring. Duration of visit is only approximately predictable from the seal mandibles but is clearly in the order of weeks or months rather than days or years.

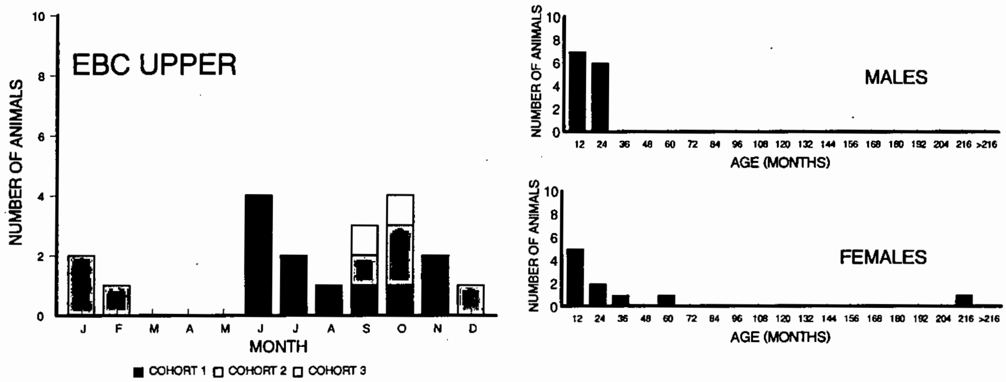

**Figure 10.4** *The mortality characteristics of the EBC Upper seal assemblage are similar to those from DFM. The sample is dominated by juveniles killed in the late winter and spring months.*

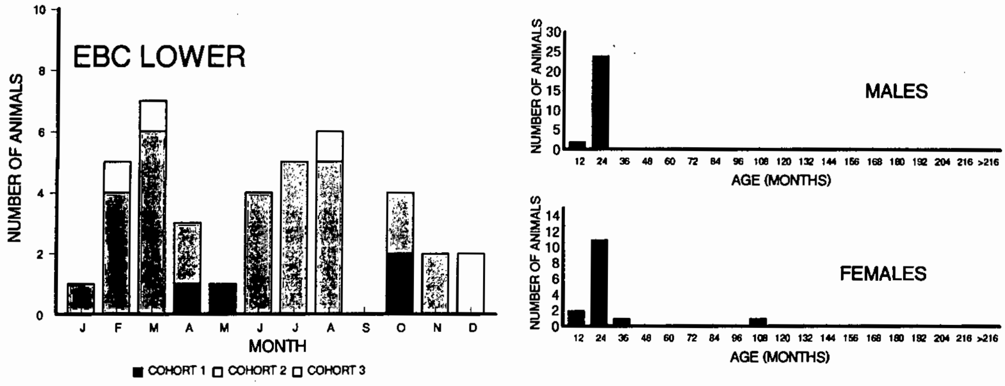

**Figure 10.5** *The EBC Lower assemblage contrasts with EBC Upper and DFM assemblages because it is dominated by yearling seals. There is no seasonal focus in the sealing.*

EBC Lower presents an entirely different sealing signature. There appears to be no seasonal focus to the occupation, and the seals that were taken were predominantly in their second year (appendix E.2 and figure 10.5). This age (mortality) profile is most likely to have derived from the exploitation of a hauling out site because this is where most of the second year animals are to be found. The rocky promontory at Baboon Point, which is overlooked by EBC, is a likely location, and is also a site at which, on recent field trips, seals have been seen hauling out.

### Conclusions for sites in the Elands Bay area

The seasonal signature that characterises the DFM and EBC Upper seal assemblages indicates a distinctly seasonal culling practice that was practiced during the terminal Holocene. This contrasts sharply with the EBC Lower assemblage. At both the cave site and the open sites the exploitation includes a high proportion of first year animals that presumably reflects the availability of tired or sick weaned pups. Regular monitoring of the beaches would have produced a consistent supply of these animals as they washed ashore. During excavations at the DFM site in early December 1990, 14 seals were encountered either still alive or very recently washed ashore along the 2 km stretch between the Verlorenvlei river mouth and DFM.

On the basis of a wide range of seasonal indicator, including the age at death of seals, Parkington (1972, 1976, 1977, 1981) suggested that the Elands Bay area was only occupied seasonally, most likely in the winter or early spring. The results obtained in this reanalysis of the seal mortality profiles appears to support, in principle, Parkington's notion of highly seasonal occupation at the coast. The late winter, spring and early summer exploitation of seals do not agree entirely with Parkington's original prediction of winter occupation of the coast, nor do they contradict it. The evidence from DFM and EBC appears

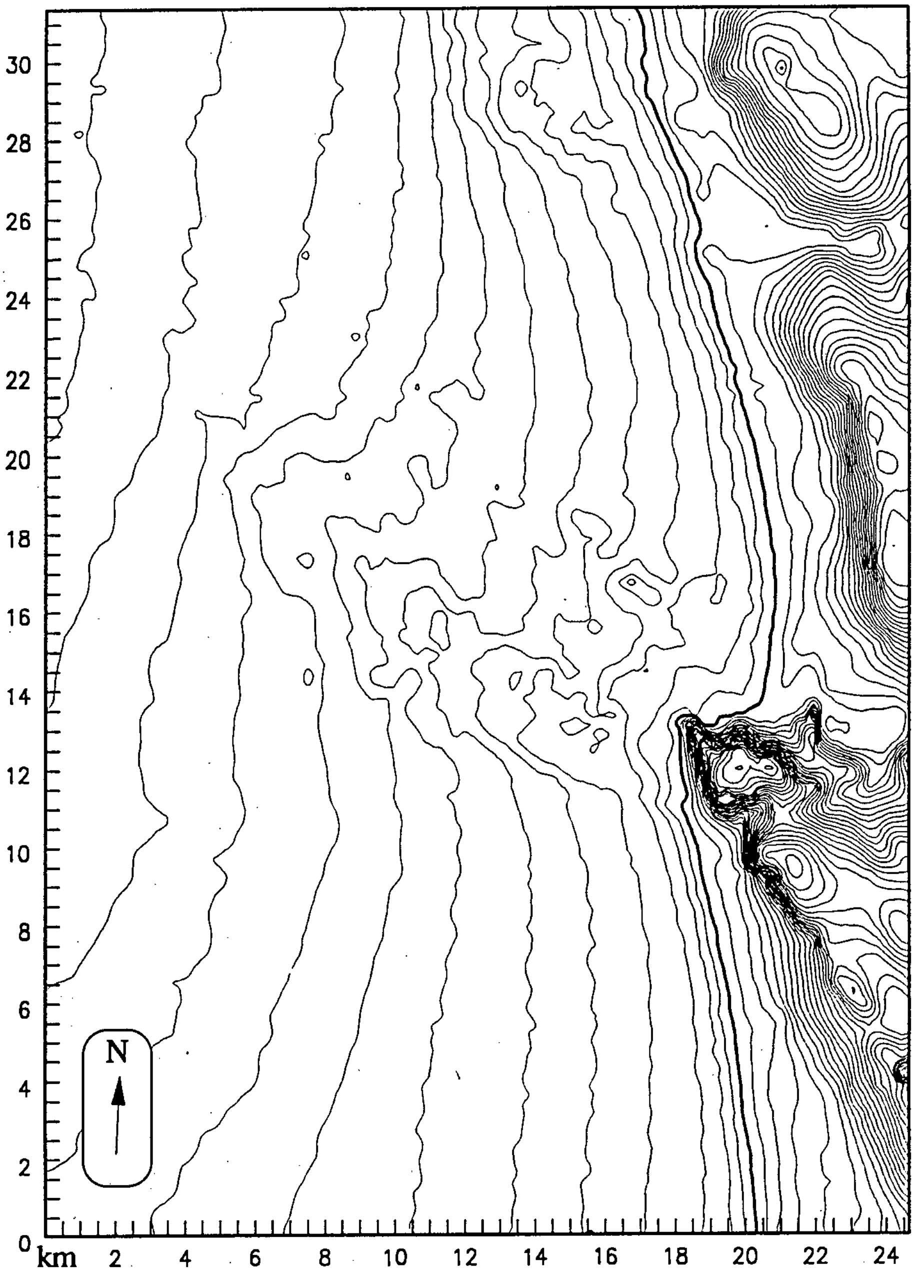

**Figure 10.6** *A sumerged reef off the coast at Elands Bay would have ensured the existence of a rocky intertidal zone through most of the Holocene when sea levels were lower than present. The contour interval is 7.5 m and the bold contour represents the modern coast line.*

to indicate a coherent strategy of land use on a local and regional scale, and the high proportion of seals in the faunal assemblages from this time suggests that they played a large role in defining this strategy.

It is almost certain that the poor representation of first year animals in the EBC lower assemblage reflects the lowered sea level at this time (Fairbanks 1990, Miller *et al.* 1995). Depth soundings taken offshore from Elands Bay show that the coastline in the area would have had many of its modern characteristics through most of the Holocene (figure 10.6). A rocky promontory immediately in front of the cave would have divided a sandy beach to the South from a bay to the North. This feature is an extension of the reefs presently located off Baboon Point and South Point. Although the sea was apparently within exploitable range during the early Holocene, it is likely that it was several kilometres distant, and the occupants of the cave did not have the same advantage for beach monitoring that the late Holocene occupants enjoyed. The most reliable source of seals for people that lived inland would be a hauling out colony if there were one present, and the seasonal pup wash-ups. The pups that currently wash ashore at Elands Bay come from a breeding colony located at the Great Paternoster Point (figure 3.1). With lower sea levels this colony would cease to exist. It is not known if any likely breeding locations existed along the early Holocene shoreline. The results from EBC suggest that there were none. The most likely scenario is, therefore, the existence of a hauling out colony on the paleo-equivalent of Baboon Point.

The lack of any seasonality in the EBC Lower assemblage implies that people did not occupy the site as part of a seasonal transhument strategy during the early Holocene. There is no consistent season of abandonment when occupation might have shifted to the coast or elsewhere. This may mean that people made visits of short duration to the site, variously timed from year to year, but a more acceptable scenario is that of relatively sustained occupations, which show up archaeologically as extremely dense concentrations of diverse faunal and artefactual assemblages. The observation that the mean sizes of limpet species are here the lowest in the site (Parkington pers.comm.) may support this scenario.

**Kasteelberg B (KBB)**

The age (mortality) profiles of the KBB seals are shown by layer in figure 10.7, but the low number of mandibles in many of the layers makes the groupings by level in figure 10.8 more informative. In contrast to the sites at Elands Bay large numbers of sexually mature females (48 months and older) are represented through most of the sequence. This part of the population is the most constrained by the breeding cycle, and these animals are concentrated at breeding colonies from November though to August. The implication is that a breeding colony was being exploited. The contrast with the Elands Bay mortality profiles may be related to the proximity of Great Paternoster Point breeding colony, but it may also indicate the existence of a mainland breeding colony prior to the large scale European exploitation of the last three centuries.

Another feature of the KBB mortality profiles that is in sharp contrast to those from Elands Bay is the surprisingly low representation of first year animals. A possible scenario is that KBB was occupied seasonally, but at a time of the year when pup mortality is low. The seasonal information (figure 10.9) shows that many of the sub-three year old animals were killed in spring and early summer, which is precisely when pup mortality is high. The natural attrition at a breeding colony is dominated by pups, so if people restricted their activities to foraging along the beaches they could have obtained a more or less continuous supply of seals. The relative absence of pups and the high representation of adults,

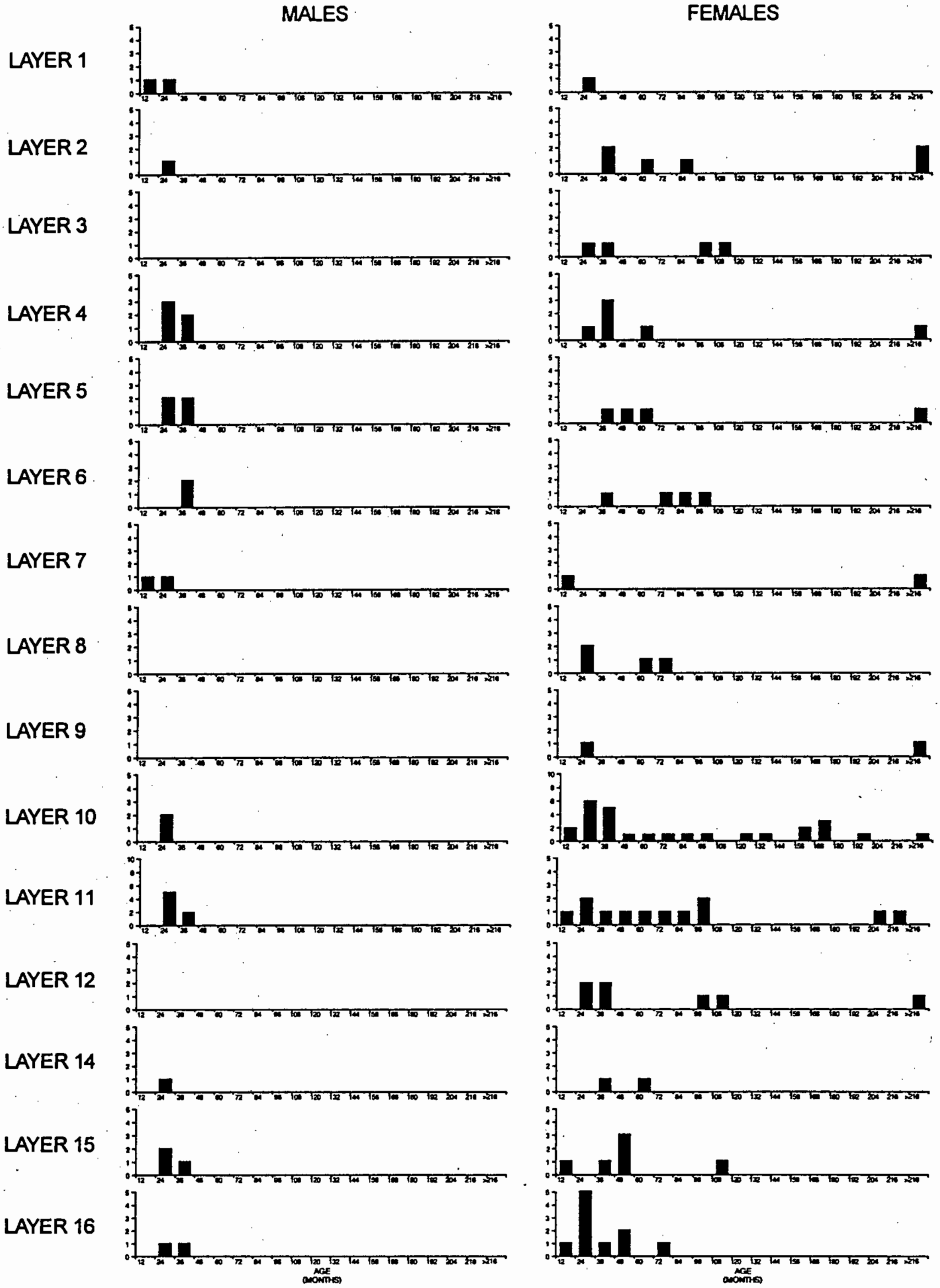

**Figure 10.7** *Age (mortality) profiles for each of the excavated layers at KBB.*

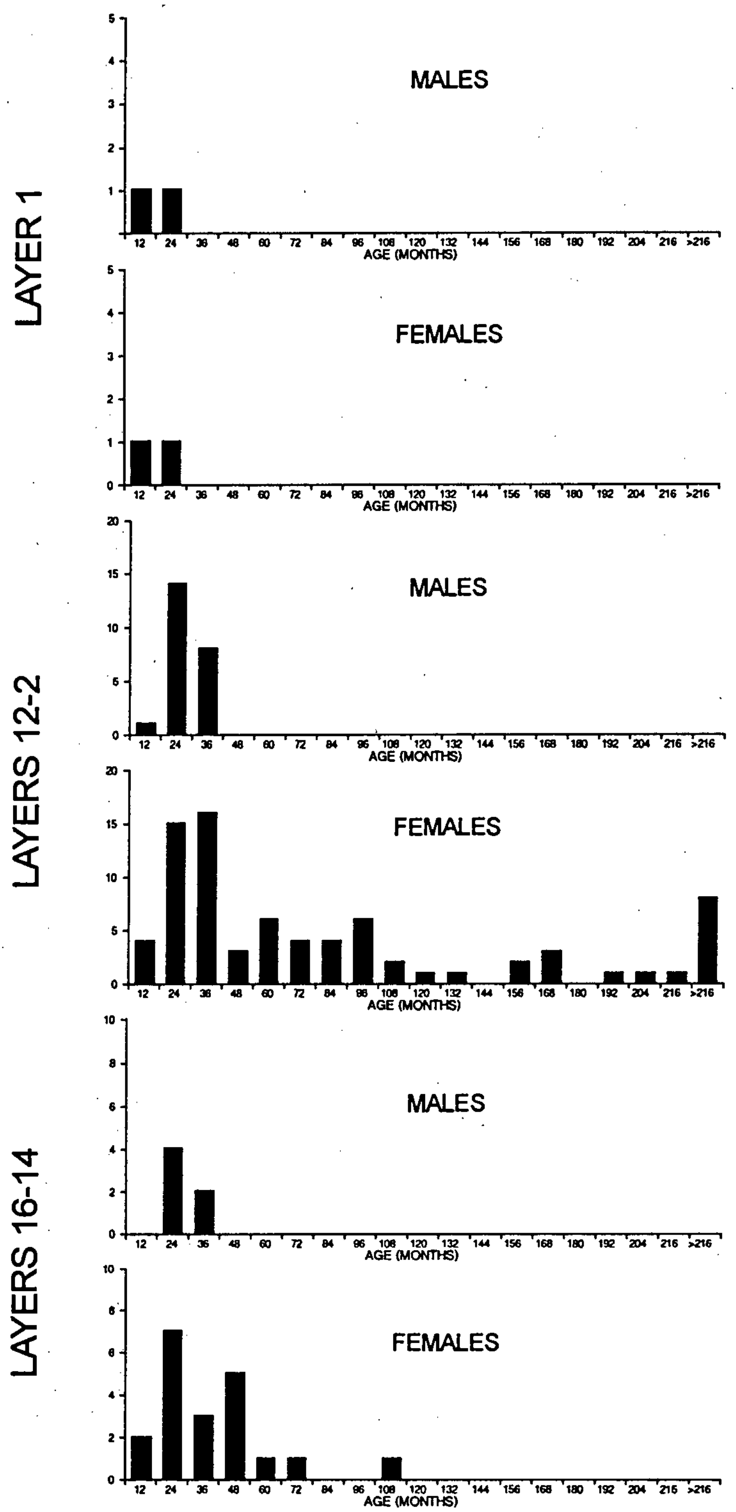

**Figure 10.8** *By combining the layers into the three occupation levels, the sample size problem that invalidates the direct interpretation of figure 10.7 is at least partially overcome. The high representation of adults in this sample suggests that a breeding colony was being exploited.*

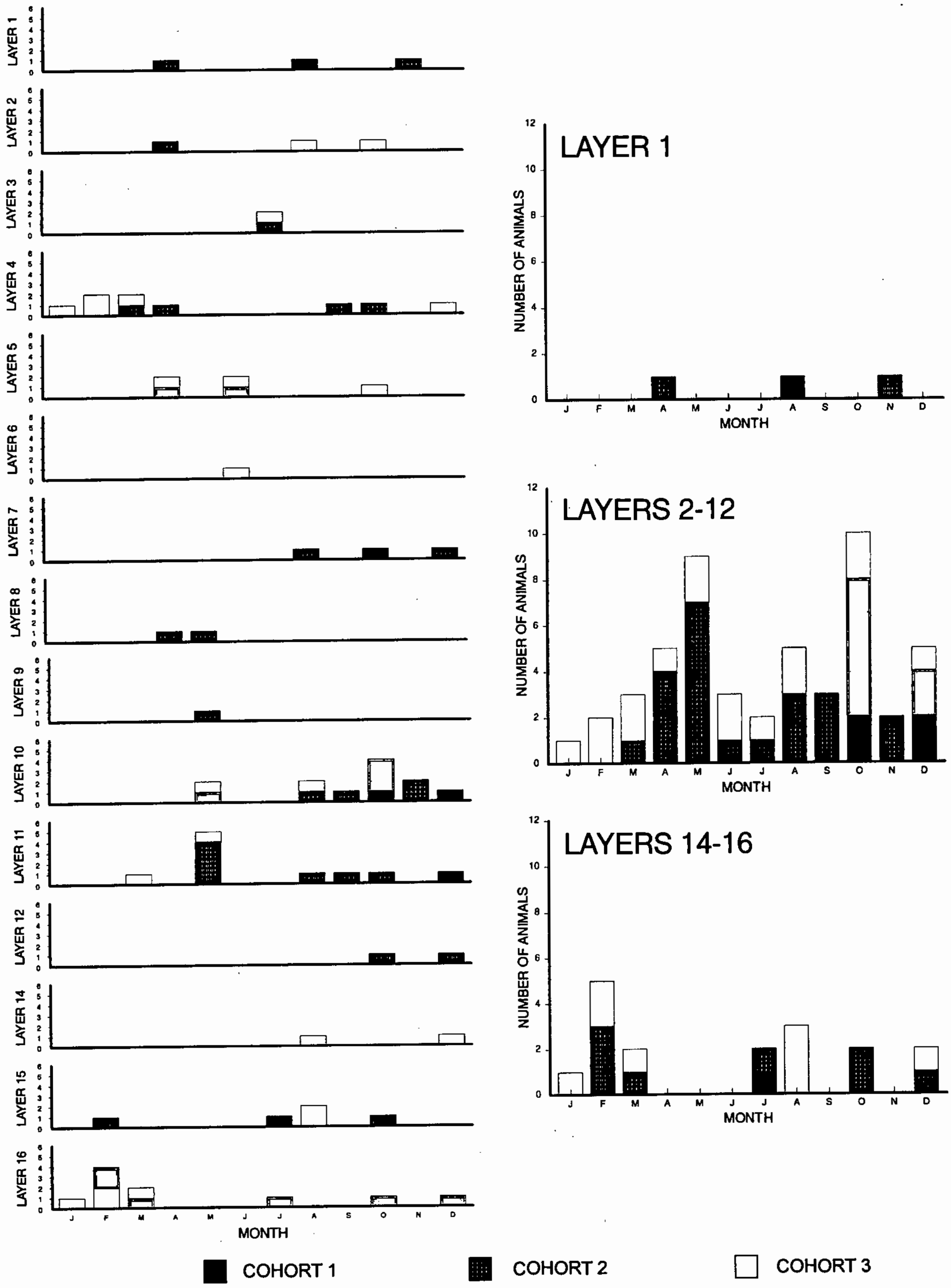

**Figure 10.9** *The seasonal information for the Kasteelberg B seals is derived from the specimens that were determined to be less than 3 years old at death. Although the first cohort is subject to very high natural mortality around September, few of these animals are present. There appears to have a bimodal season of occupation in the lower two levels. A slight shift in the timing of the occupation between these two levels may be relate to the changing pastoral economy at the site. The sample size in the surface level is too small to interpret.*

especially in layers 12-2, could only have resulted from selective cropping. Similarly the absence of bulls may be related to their relatively low numbers at breeding colonies, but it is more likely that they were avoided by hunters because of their size and aggressive disposition.

The selection of adult females and at the same time avoidance of stranded animals implies that the principal mode of procurement at KBB was hunting. A possible scenario is that hunting expeditions were mounted with the specific intention of obtaining a large number of seals - more than could be obtained at any point in time by foraging for stranded animals. One-off, large scale hunting expeditions would have had several consequences. The degree of disruption for the colony would have been less than that of ongoing small scale exploitation. This would have had a positive effect for sustained exploitation. A second consequence would be the procurement of large amounts of meat and, perhaps more importantly, fat. During April many of the females would also have been lactating. The quantity of food that would have been obtained in a short period of time is consistent with a relatively high human population density. This supports Smith's (1990*c*) belief that KBB was an aggregation location for several pastoral groups.

A change in seasonality of occupation also seems to take place through time (figure 10.9). The lowest level was occupied in summer and winter, but not during the fall months of April-June. This is in sharp contrast to the middle level where the two peaks show intensifying occupation in autumn (April/May) and again in the spring (September/October). This pattern may be related to the pastoral economy of the inhabitants of the site. The domestic animals from the lower level are predominantly sheep with a ratio of 10.2 identified individuals for every large bovid. In the middle level the importance of large stock had increased and the ratio of small to large stock reduced to 4:1. The first season of occupation in the middle level (April/May) is also the lambing period in that area (Hugo 1968). The early winter pasture is ideal for the young sheep and the ewes, and even today the area around the site is used by the farmer, Mr. P. Kotze, as his lambing area. The second peak in October is around the time when the cattle are mated for spring calving. This is also when the lambs were culled at KBB (Smith & Woodborne 1994).

### Conclusions for Kasteelberg B

Kasteelberg B has been interpreted as a specialised sealing and stock post on the basis of the extraordinarily high representation of seals and sheep (Klein & Cruz-Uribe 1989). The age (mortality) profiles and seasonal culling pattern established in the latter study using the seal's distal humerus medio-lateral dimension as a seasonal indicator are not supported by the mandible results presented above. Many more mature animals are believed to be represented on the basis of the mandibles, and the sub-three year old animals show a bimodal seasonal signature for sealing instead of a single peak in

September. Possible reasons for this contradiction may lie in the suitability of the different bones for aging purposes. The arguments supporting the use of the mandible are presented in chapter 4.

The age (mortality) profiles for KBB that were constructed from the mandibles suggest that the seals were obtained at a breeding colony. Two notable departures from the predicted mortality pattern for a breeding colony are the lack of pups and mature bulls in the assemblage. This may be related to prey selection, which suggests that the mode of procurement was hunting. Furthermore the pups could be obtained by foraging along the coast, and their absence indicates that hunting expeditions were undertaken to obtain more than was available on the beaches. The nearest source of seals at present is the breeding colony on the Great Paternoster Point. Access to the boulders on which the seals haul out is limited without the use of boats, and the possibility that a mainland colony existed in the past must be entertained.

The biannual spacing of sealing suggests that the occupation at KBB was not continuous. The pastures of the Vredenberg Peninsula were probably used by the herders throughout the winter, but the groups remained dispersed and mobile. KBB, it is believed, functioned largely as the focus of ritual activities (Smith 1990*c*). At these times groups aggregated, and hunting expeditions were mounted with the specific intention of obtaining seals. The reason for targeting seals was partially for the meat, but especially for the fat which played an important role in the ritual lives of the herders (Smith & Woodborne 1994).

The changes in the season of occupation reflect a shift from predominantly sheep herding to that of cattle keeping, and that the first peak in April/May of the middle level reflected the needs of the animals (lambing and calving). The second peak, which conforms with the sheep culling pattern, strongly suggests that it was the human needs that were being served.

# CHAPTER 11

# RESULTS

## Introduction

In chapter 9 it was suggested that the body part representation of seal assemblages be compared with the hardness index, the carnivore consumption sequence, the carnivore destructive template and the utility index to distinguish between different taphonomic scenarios. Before this is done it is important to consider how the comparison is to be made. In most instances the factors that bias the representation of archaeological bones do not act uniformly over all the bones of a carcass. For example the abandonment of elements on the basis of their utility operates on a threshold value. All the bones that are abandoned are biased in one way even though their utility values may differ, and conversely the bones that are not abandoned may have a diversity of utility values but the end result is an equivalent representational bias. Similar arguments apply to the bias brought about by each factor that has been considered in the taphonomic scenarios with the exception of abiotic bias such as crushing through trampling and profile compaction. In assemblages that are made up of multiple events, each of which is biased by the same factor but with a slightly different threshold value, the representation will show a correlation with the index that mediates that bias. The extent to which the threshold value varied between different depositional events will determine the exact relation between the index and the representation of the body parts, and this may vary from one assemblage to another. The only prediction that can be made is that the ranking of the body part representation should match the ranking of the index. The comparison is achieved using an ordinal scale and the significance of the relation can be determined using the Spearman Rank Correlation (Ebdon 1985).

In the case of abiotic biasing factors there are no threshold criterion that influence the relation between the index that mediates the bias and the body part representation. For example, in an assemblage that is gradually crushed as the deposit accumulates, a bone that has double the hardness of another will be subject to half the amount of destruction. In this case the index that mediates the bias and the body part representation can be compared on an interval scale. If a significant correlation exists between the two it will be manifest as a linear trend on an x-y plot of the values. The significance can then be measured by the *coefficient of determination* ($r^2$) (Ebdon 1985).

Comparisons between the seal bone representation from Kasteelberg, Elands Bay Cave and the Dunefield Midden and each of the indices, except hardness, can be made with a Spearmans rank order correlation. The use of an interval scale when making comparisons with hardness is because, first, it has been proposed that hardness determines abiotic bone destruction (chapter 5) and, second, carnivore destruction of seal bones also results in a linear relation between representation and hardness (chapter 6). Either of the latter factors may produce a significant rank correlation between hardness and representation, but by plotting them against one another on an interval scale, the idiosyncrasies that distinguish carnivore damage from natural destruction become apparent.

## Results

Spearmans Rank Correlation values for comparisons between the seal assemblages from Kasteelberg B, Eland Bay Cave and Dunefield Midden and the various taphonomic indices are presented in table 11.1. Body part representation is calculated in MAU units based on the identification by Dr. Richard Klein which he kindly made available for this analysis. It is important to note that the MAU values are based on all identified specimens listed by Klein, and not the identifiable articular ends that he uses to determine Minimum Number of Individuals (MNIs). The MAU values are summarised in appendix F.

The three stratigraphic layers in the Kasteelberg sequence and the two units in the Dunefield Midden assemblage are defined in chapter 10 with reference to the ageing of the seals. The Elands Bay Cave sequence is divided into three units (instead of the two in chapter 10) on the basis of pulses of seal bone deposition in the cave (Parkington pers. comm.). EBC 1 dates between 2200 BP and the historical period. EBC 2 dates between 4500 BP and 3000 BP while EBC 3 comprises all the seal remains pre-dating 8000 BP. The unit that is described as EBC Upper in chapter 10 is a combination of EBC 1 and EBC 2. This

| Assemblage | Carnivore Consumption Sequence | Jackal Destructive Template | Hardness | Utility |
|---|---|---|---|---|
| KBB Layer 1 | -0.05 | 0.592 | 0.671 | 0.041 |
| KBB Layer 2 | 0.075 | 0.667 | 0.659 | 0.167 |
| KBB Layer 3 | -0.02 | 0.587 | 0.596 | 0.268 |
| EBC 1 | -0.16 | 0.564 | 0.602 | 0.062 |
| EBC 2 | 0.087 | 0.52 | 0.588 | -0.14 |
| EBC 3 | 0.236 | 0.49 | 0.383 | 0.019 |
| DFM | 0.039 | 0.841 | 0.848 | 0.258 |
| DFM Extension | -0.08 | 0.839 | 0.832 | 0.111 |
| DFM Total | 0.036 | 0.872 | 0.835 | 0.257 |

**Table 11.1** *Spearman Rank Correlation coefficients between the post-cranial body part representation of archaeological seal bones and the taphonomic indices summarised in chapter 9. Values of $r_s$ that are greater than 0.476 are significant at the 0.05 level (two tailed test assuming that a negative correlation may exist between representation and any of the indices).*

was done so that adequate numbers of mandibles could be analysed in the aging study. The mandibles from EBC 3 are attributed to EBC Lower in chapter 10.

All of the assemblages show significant correlation coefficients with hardness and the jackal destructive template, but the correlations with the carnivore consumption sequence and the utility index are poor. The implication is that the body part representation did not result from a scenario of human selection for transportation, nor is it the result of any specific mode of procurement that involved competition with other carnivores. The highly significant correlations between the assemblages and the jackal midden material in all cases, and with hardness in all cases except one, is what might be expected either from carnivore ravaging by dog sized carnivores, or from abiotic post-depositional destruction of the bones. Both of these scenarios are biasing processes that have an impact after the bones have been discarded on the site. Any process that occurred prior to deposition would be obscured by the post-depositional signature and so the poor correlations with utility and the carnivore consumption sequence do not imply that the relevant taphonomic scenarios did not occur. The conclusion is that the seal body part representation from these sites cannot be used to test if transportation bias occurred, nor can it be used to determine the extent of carnivore competition for the resource.

In order to discriminate between carnivore ravaging and post-depositional destruction as the reason for anatomical disparities in the seal bone representation, the latter is plotted against hardness in figures 11.1 to 11.3. The acronyms that are used to symbolise the different body parts are presented in appendix F.

### Dunefield Midden

Figures 11.1*a* - 11.1*c* show a linear, or slightly curvilinear relation between hardness and representation for all the DFM assemblages. In the plot for DFM Ext. the femur, radius and mandible appear to be slightly underrepresented, while in the DFM assemblage and the combined DFM Total assemblage the scapula and mandible are underrepresented. The important feature of these plots is that the femur, ribs and phalanges are not significantly underrepresented. Because of the high hardness values associated with small portions of the bones, they were identified in the analysis of the jackal midden material as markers for carnivore ravaging. Jackals tended to destroy them - probably by swallowing them. Since they are not underrepresented it must be concluded that the body part representation at the Dunefield Midden is not the result of ravaging by dog sized carnivores. The seal bones from this site do show distinctive and extensive carnivore damage (Cruz-Urine & Klein 1994), but the evidence presented here supports Stynder's (1994) conclusion that the damage that was inflicted did not result in the destruction of entire bones. The deviation from anatomical parity in the seal bones from DFM is likely the result of mechanical attrition of the bones - probably trampling and weathering on this open site.

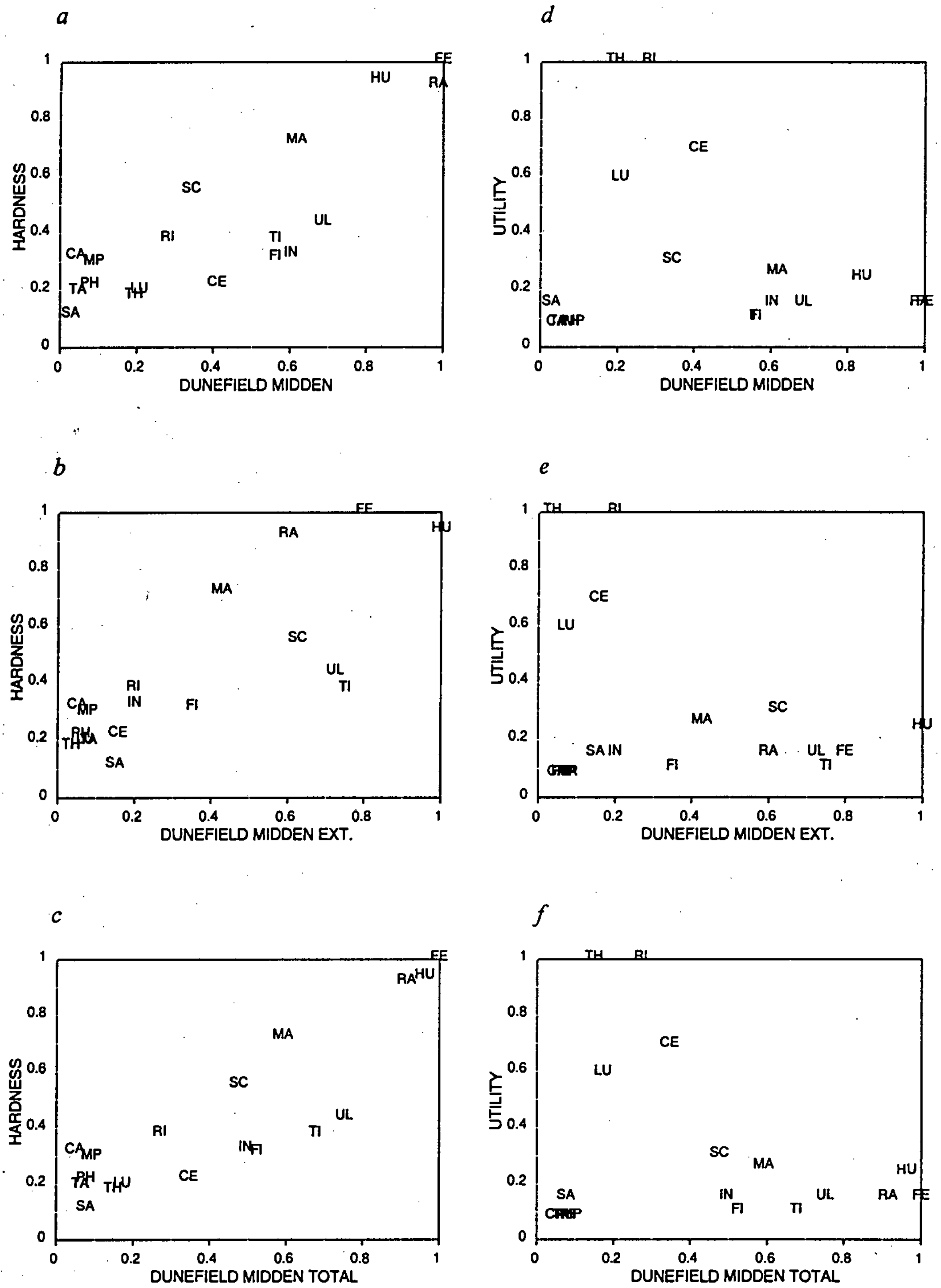

**Figure 11.1** *The normalised body part representation for the Dunefield Midden, Dunefield Midden Extension and the combined assemblages are plotted against hardness (a-c), and against utility (d-f). The linear appearance of the hardness plots suggests that the taphonomic factor that shaped the assemblage is mechanical attrition. The utility plots appear to be "reverse utility curves", but the hardness plots suggest that this is not related to procurement patterns.*

### Kasteelberg B

The patterning in the plots of body part representation versus hardness for the KBB assemblages (figures 11.2*a* - 11.2*c*) is very similar to that at the Dunefield Midden. Again there is a linear or curvilinear trend in the plots with some elements underrepresented. In both layer 2 and layer 3 the humerus, mandible and scapula are underrepresented, while in layer 1 only the humerus and scapula deviate significantly from the general trend. As was the case at DFM the markers for carnivore ravaging, the femur, ribs and phalanges, are not underrepresented. This implies that carnivores did not determine the patterning in the body part representation. There is evidence that carnivore ravaging took place at KBB (Cruz-Uribe & Klein 1994), but the same scenario that is presented for DFM applies. Carnivores damaged the bones but they did not lead to their destruction. Kasteelberg is also an open site and the same scenario of mechanical attrition through trampling, weathering and in this case crushing in the deposit, is posited as the biasing factor behind the seal body part representation.

### Elands Bay Cave

The seal assemblages from Elands Bay Cave are plotted against hardness in figures 11.3*a* to 11.3*c*. There are weak trends in these plots that are similar to those at both the Dunefield Midden and Kasteelberg B. There may be a linear or curvilinear relation with the femur, humerus and mandible underrepresented in the EBC 1 assemblage, the femur, humerus mandible and scapula underrepresented in the EBC 2 assemblage, and the humerus, mandible, scapula and radius underrepresented in the EBC 3 assemblage. These trends, however are not very convincing, particularly in the EBC 3 assemblage. This is also the assemblage that did not correlate with hardness even at a 0.1 significance level (table 11.1), and although the correlation with the jackal destructive template is significant it is not persuasive. These assemblages demand closer scrutiny.

If there is a trend in the EBC 1 and EBC 2 assemblages, then the femur, and ribs are underrepresented in both cases. These are the bones that are deleted by carnivores and so it may be proposed that carnivores were involved in shaping these assemblages. However there is little evidence for gnawing on the EBC seal bones (Parkington pers. comm.). This apparent incongruity can be explained in the light of the field observations of carnivore consumption strategies (chapter 6). Brown hyaenas were observed to select bones for consumption, and then destroy them entirely. They did not leave partially damaged bones anywhere except at a den. Jackal scavenging of disarticulated seal bones was never observed, nor were they seen gnawing on bones. Even though the observations were made during the time of maximum

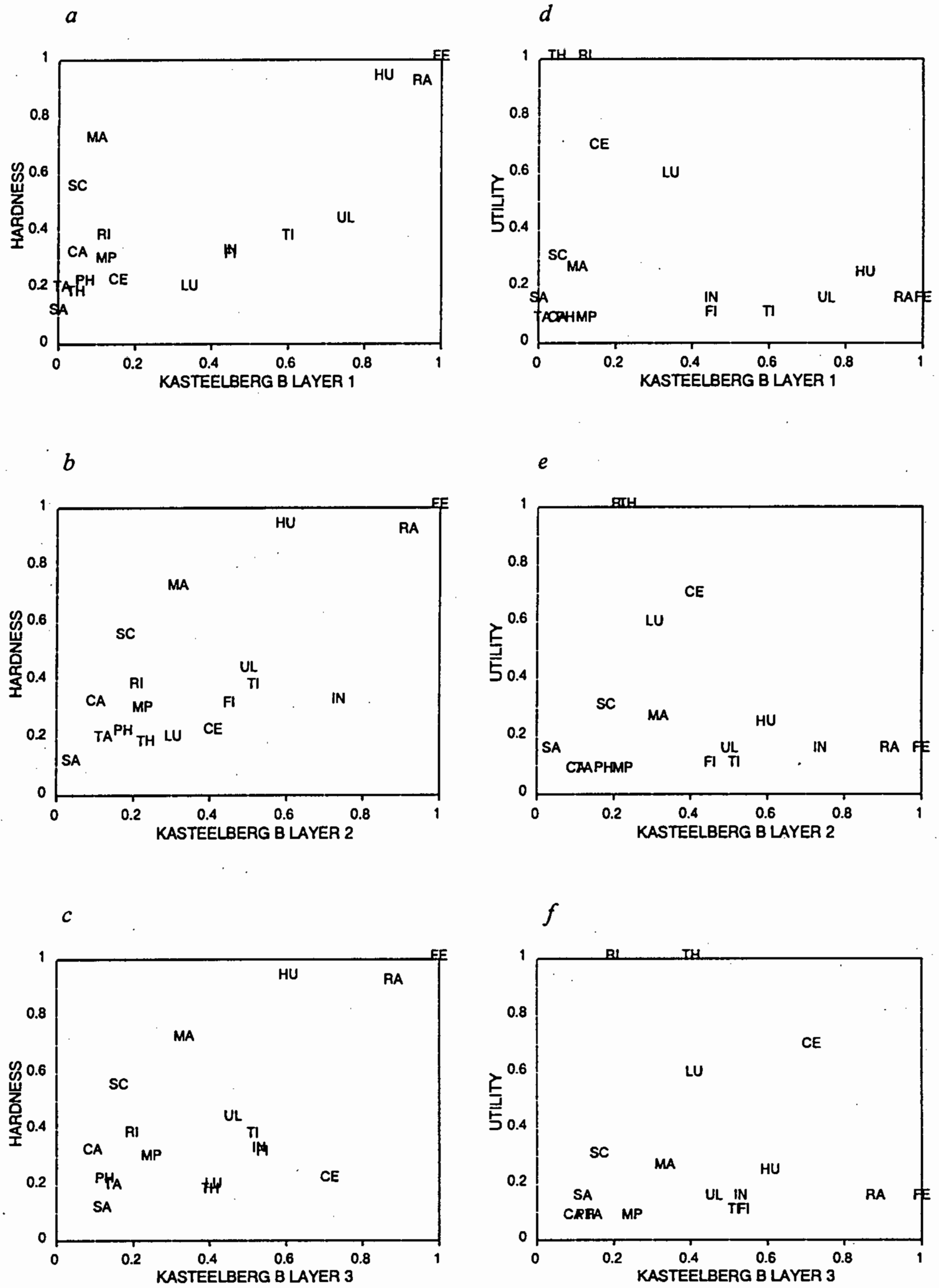

**Figure 11.2** *The normalised body part representation for the layers 1, 2 and 3 from Kasteelberg B are plotted against hardness* (a-c), *and against utility* (d-f). *The linear or curvilinear appearance of the hardness plots is similar to that from Dunefield Midden. As in the latter case this suggests that the taphonomic factor that shaped the assemblage is mechanical attrition. The utility plots appear to be "reverse utility curves" as was also noted for the Dunefield Midden assemblage, but the hardness plots suggest that this is not related to procurement patterns.*

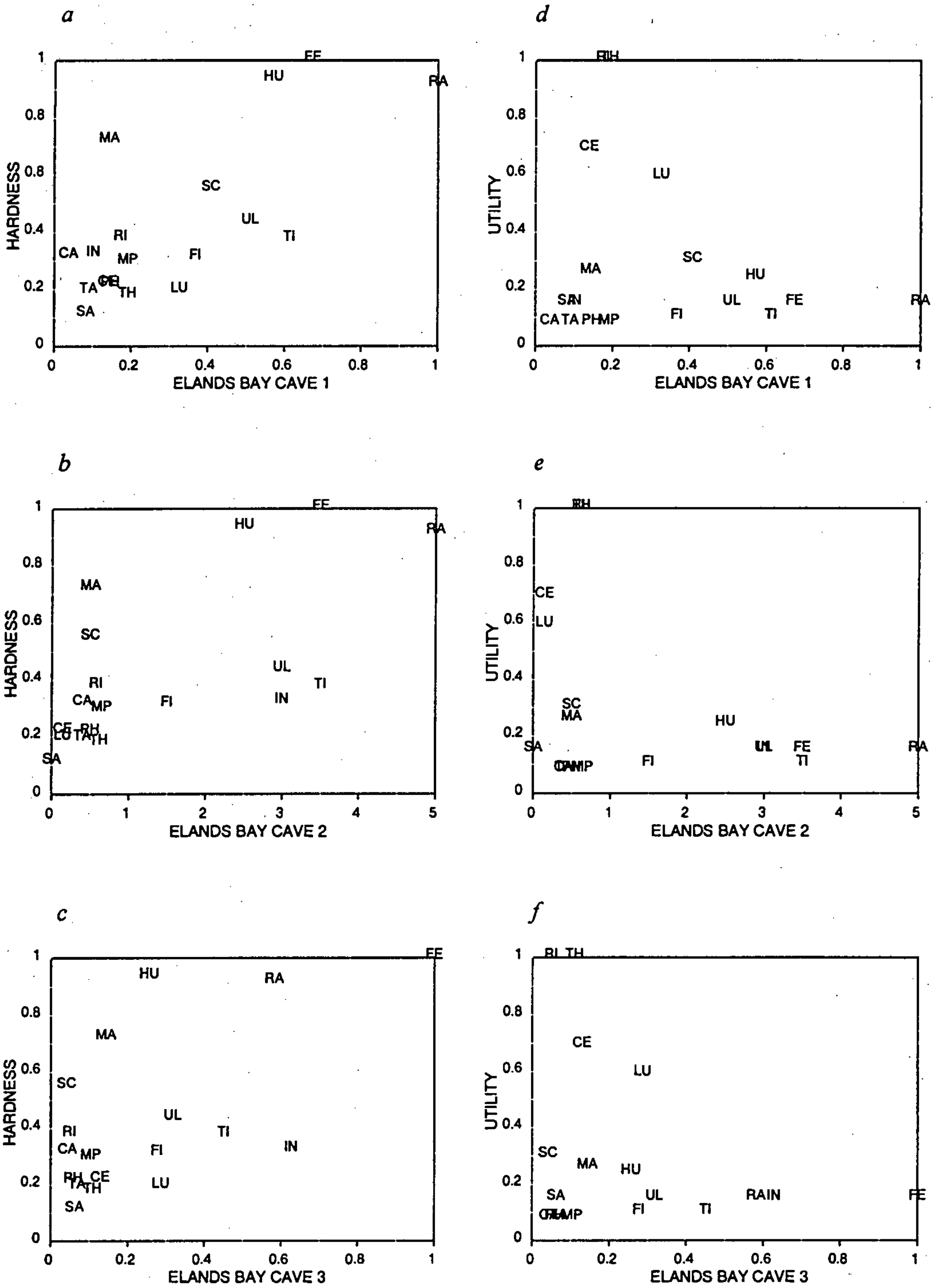

**Figure 11.3** *The normalised body part representation for the EBC 1, EBC 2 and EBC 3 from Elands Bay Cave are plotted against hardness (a-c), and against utility (d-f). The linear or curvilinear appearance of the hardness plots for EBC 1 and EBC 2 are similar to those from Dunefield Midden and Kasteelberg B. In the latter cases this was used to argue that the assemblages were the outcome of mechanical attrition, but in the EBC assemblages the underrepresentation of the humerus and ribs suggests that carnivores played a significant role in determining the body part representation. The EBC 3 assemblage is not related to hardness. The utility plots also appear to be "reverse utility curves" but the results from the Dunefield Midden and Kasteelberg B suggest causion in relating this to procurement patterns.*

nutritional stress on the jackals, they did not gnaw on the bones of their quarry. The damage that they inflicted occurred exclusively in the process of meat removal. If jackals were to scavenge disarticulated seal bones discarded after human consumption, then they may operate in the same way that hyaenas do and select entire bones that they either consume or carry away. Under such a scenario it is possible that the underrepresentation of the femur and ribs was brought about by carnivore ravaging even though there is no evidence for gnawing.

The scenario presented for the EBC 1 and EBC 2 assemblages presents a problem for the interpretations presented above for the DFM and KBB assemblages. Why did carnivores gnaw bones at these open sites and not destroy them, while at EBC the carnivores did not gnaw the bones, but the conclusion is still that ravaging occurred? It cannot be explained in terms of time or place because all three sites are in roughly the same ecological biome and were occupied at roughly the same time. The reason is almost certainly the presence or absence of dogs. If they were present on the site they would gnaw the bones as dogs do - seldom destroying them, and at the same time they would act as a major deterrent to wild carnivores such as jackals and as an alarm to the presence of larger carnivores such as brown hyaenas. Where dogs were absent there would have been little to stop the wild scavengers and the converse would occur. The site would be scavenged over by the wild carnivores that select and delete entire bones leaving few gnawed bones. Cruz-Uribe & Klein (1994) note that carnivore gnawing is rare in faunal assemblage that pre-date 2000 BP, while it is relatively common after this date. They conclude that dogs were introduced to the Cape at this time by pastoralists that migrated into the area. Dogs have been identified at KBB (Klein & Cruz-Uribe 1989) and it is widely accepted that this site was occupied by herders. The same suggestion has been made for DFM although dogs have not been identified here (Cruz-Uribe & Klein 1994).

On the basis of carnivore ecology it is suggested that the evidence for gnawing at KBB and DFM is consistent with the keeping of dogs at these sites, and the lack of gnawing combined with other evidence for carnivore ravaging reflects the absence of dogs at EBC. Ascribing the patterning in the EBC 2 assemblage to wild carnivore ravaging and not dog ravaging is consistent with the proxy evidence for dogs post-dating 2000 BP. Although the first introduction of dogs into the Cape coincides with the arrival of pastoralists, any evidence for dogs on a site that post-dates 2000 BP does not imply that it was occupied by pastoralists. Nevertheless it is interesting that two sites as near to one another as EBC and DFM should be occupied by people keeping dogs on the one hand, and people without dogs on the other.

The EBC 3 assemblage is characterised by the underrepresentation of ribs, but this is unlikely to be related to carnivore ravaging since the bone that they delete most often (relative to its hardness), the femur, is the most common bone in the assemblage (figure 11.3*c*). The significant correlation obtained between the jackal destructive template and the body part representation (table 11.1) is, therefore, probably spurious. It is hard to detect any trend in figure 11.3*c*, and so it is unlikely that the patterning resulted from mechanical attrition. None of the taphonomic scenarios presented in chapter 9 appear to accommodate this assemblage. A possible reason for this may lie in the hypothesis that EBC was an inland site at the time that most of these seal remains were deposited. If this is the case then the occupants of the site may have obtained seal remains by trade with coastal dwellers rather than by venturing to the coast on seal hunting forays themselves. None of the taphonomic indices was developed to address this scenario, and this interpretation must be considered as speculative.

## Conclusions

The disparities in the body part representation of seal bones at Kasteelberg B and the Dunefield Midden is the result of non-destructive gnawing by carnivores - probably dogs - and then mechanical attrition through trampling and weathering on these open sites. At Elands Bay Cave the late Holocene assemblages (EBC 1 and 2) were ravaged by wild carnivores. The most probable agent was the brown hyaena but the role of jackals cannot be excluded. The extent to which weathering occurred is reduced in the cave, and the poor trends in the hardness versus representation plots indicate that mechanical attrition was not as significant here as it was at KBB and DFM. The early Holocene assemblage at Elands Bay Cave (EBC 3) does not conform to the taphonomic scenarios that are addressed in this thesis, and it is proposed that the body part representation here is the outcome of trade between the inhabitants of the cave and coastal dwellers.

A common trend in all of the assemblages is the apparent underrepresentation of the mandible, scapula and to a lesser extent the humerus. It is not evident why this combination of bones should consistently be biased in this fashion. The scapula and humerus are among the first elements deleted by carnivores, but if this was the reason for the pattern then a second reason must be evoked to explain the behaviour of the mandible. Furthermore it would imply that scavenging was the principle mode of procurement, and at least at Kasteelberg B, this is unlikely (see chapter 10). In order to ascertain whether this was the result of a common behavioural trait the representation was plotted against utility for each of the assemblages (figures 11.1 to 11.3, *d* to *f*). Assuming that the mandible represents the entire head, and that the scapula and humerus represent the upper forelimb elements, then the utility of these elements falls in a discrete band. They are the elements that contain some meat (unlike the flippers and lower limb bones) but not as much as the high utility elements of the axial skeleton. They are the elements with the minimum practical utility, but which can easily be removed without disarticulating the entire seal skeleton. It may be the case that they were elements that were eaten in the field, particularly if foraging activities took up a substantial part of the day.

The latter conclusion is speculative, but the plot in figures 11.1 to 11.3, *d* to *f* illustrate a point that is of fundamental importance in the use of utility indices in faunal analysis. Each of these plots has a scatter of points that would be described as a "reverse utility curve" (Binford 1978, Thomas & Mayer 1983, Lyman 1985). Lyman (1985) demonstrated that utility is related to density, and so any behavioural interpretation of a "reverse utility curve" must be tempered by the fact that it could also result from attritional processes. The utility of seals is not significantly related to hardness, but the same phenomenon seems to occur. Assemblages that have been shown above to result from attritional factors that are entirely independent of utility produce "pseudo reverse utility curves". In this study the danger of misinterpretation was avoided by the lack of any significant correlation between body part representation and utility. In the study of other species for which indices that determine mechanical attrition such as hardness or density do not exist, there is a danger that the shape of the "pseudo reverse utility curve" will mislead the analyst. The analysis of seal remains using a utility index alone by Lyman (1992) is questionable, especially since the analysis produced many "reverse utility curves" of marginal significance.

# CHAPTER 12

# CONCLUSIONS

## Introduction

A lack of the basic taphonomic information on seals has previously constrained the interpretation, or led to inadequate interpretations, of many coastal faunal collections. A major objective in this thesis has been to establish a comprehensive set of taphonomic parameters that make up the tool kit for analysing archaeological seal remains. The taphonomic parameters that are presented include:

1. A means of determining ontogenic age of seals from mandible dimensions
2. A hardness measure for seal bones
3. A carnivore consumption sequence
4. A template of carnivore inflicted damage to seal bones
5. A utility measure for the Cape Fur Seal anatomy

Each of the taphonomic indices has been used previously in the analysis of one or other terrestrial species (with the exception of hardness where density or photodensity has been widely used instead). The unique feature of this analysis is the presentation of the entire suite of indices for a single species. Combining several indices provides a robust body of comparative data that decreases the likelihood of errors in interpretation. In several of the Cape west coast assemblages that are analysed here for example, there appears to be an inverse relation between utility and body part representation that is commonly referred to as a "reverse utility" relation. If utility were the sole basis of the analysis then the interpretation would likely focus on human behaviour, but because the same assemblages show a strong relation to hardness the interpretation can be tempered to accommodate other possibilities. The interpretation that is favoured is not that the seal body part representation is the outcome of human behaviour, but rather that it is the result of carnivore ravaging and mechanical attrition. This example illustrates the shortcomings of using a limited range of taphonomic indices, or in applying the indices to an assemblage on an individual basis. An integrated approach in which the relation between the assemblage and each of the indices is synthesised at the same instant is required. Such an integrated approach to seal bone taphonomy is presented in chapter 9.

The second objective of this thesis was to apply the taphonomic approach to seal remains from several archaeological sites on the Cape west coast. The aim was to assess both the synchronic and diachronic aspects of human ecology that relate to seal exploitation, and to establish whether it was part of a larger adaptation to the coastal environment. In order to address the subject of coastal adaptations I will focus on two aspects of seal exploitation that have emerged from the foregoing analyses. These are the cultural identity of the inhabitants of the sites, and the seasonality of site occupation.

## Holocene coastal adaptation in the western Cape

The information that can be gleaned from the seal remains is more informative about the economic identity of the site inhabitants than it is about their cultural affinities. The distinction between the cultural and economic identity of the western Cape inhabitants is a vociferously debated subject (Elphick 1977, Parkington 1977, 1984, Schrire 1980, 1984, 1992, Schrire & Deacon 1989, Smith 1990*a*, 1990*b*, Smith *et al.* 1991), and the observations presented here may contribute to the ultimate resolution of this debate. The relevant aspect of the economy is the proxy evidence for the presence of dogs on the sites, and the association of dogs with a pastoral economy.

It is believed that dogs were introduced to the western Cape by pastoralists approximately 2000 years ago (Cruz-Uribe & Klein 1994). Of the assemblages that are analysed here, Kasteelberg B, Dunefield Midden and the uppermost assemblage at Elands Bay Cave date to this period. Carnivore gnaw marks that are believed to have been inflicted by dogs are widespread in assemblages that post-date 2000 BP (Cruz-Uribe & Klein 1994), and while they are common at Kasteelberg B and Dunefield Midden, they are not so at Elands Bay Cave. The analysis presented in chapter 11 suggests that the body part representation at both Kasteelberg B and the Dunefield Midden is the result of domestic dogs whereas the terminal Holocene assemblage at Elands Bay Cave is likely to have been modified by wild carnivores. Furthermore the representation of sheep and cattle is higher relative to wild species at Kasteelberg B and Dunefield Midden than it is at Elands Bay Cave. On the basis of this limited sample of sites, it appears as if a high frequency of gnaw marks is associated with high frequencies of domestic stock and domestic carnivore attrition of seal bones in some sites, while the absence of gnawing is associated with typical wild carnivore attrition and relatively few bones from domestic stock in others. Despite the obvious association between open versus cave sites it is tempting to interpret this pattern as evidence for the co-existence of a stock keeping economy that includes the keeping of domestic dogs, and a hunting and gathering economy that does not include the keeping of dogs.

By adopting an economic strategy that could possibly have been anywhere in the continuum from domestic stock tending to hunting and gathering for resources, the Later Stone Age inhabitants of the Cape west coast set the limits for the development of a specifically coastal adaptation. The seasonality of sealing at Kasteelberg B suggests that the site was occupied at the beginning and the end of winter visits to the Vredenberg Peninsula. Sealing may have persisted throughout the winter when the flocks and herds were fattened on the winter pastures, but there is little evidence on any other site in the area that seals were taken in large numbers. The age profiles suggest that when Kasteelberg B was occupied, the sealing activities were extremely intense. These occasions are likely to have been associated with group aggregation and possibly ritual and festival occasions. Altogether the pattern of sealing that emerges from Kasteelberg B does not indicate a sustainable coastal adaptation. High intensity sealing at a breeding colony is extremely disruptive and would not be possible on more than a handful of occasions during the year. The indication is that people utilised seals as a resource in a manner that could not be sustained, but with relative impunity to the consequences because it was not the economic basis of their existence. The seasonality of their movements was almost certainly geared towards the maintenance of domestic stock, and as such the cultural adaptation of the inhabitants must be seen as adaptive to the terrestrial environment rather than the marine environment.

Several interesting comparisons emerge between Kasteelberg B and the other late Holocene assemblages under discussion. The seal remains from the Dunefield Midden are taphonomically very similar to those from Kasteelberg B. They show dog like carnivore impact and are associated with proportionally high representation of domestic stock. In contrast the sealing practice at the Dunefield Midden is more closely aligned with that seen in the Elands Bay Cave upper deposits (where domestic stock is rare as is carnivore damage). Both of the latter sites indicate the exploitation of seals in their first and second year, at or near the season when natural mortality is high. It appears as if the season of occupation at these sites was determined by the availability of marine resources rather than any requirements of the terrestrial resources. This similarity between the assemblages is surprising because the Kasteelberg B results would have suggested that the Dunefield Midden would have portrayed a distinctive terrestrial based economy. Perhaps the environmental constraints on herding limited degree to which this was the dominant economic activity in the sandveld that surrounds Elands Bay.

In terms of the definition of a "coastal adaptation" outlined in chapter 1, the recognition of a past adaptation requires two lines of evidence. They are the nature of the human adaptation, and the impact that this had on the resource. To the extent that sealing portrays the extent of strategic marine resource utilisation, the late Holocene assemblages from Elands Bay reflect a well-developed coastal adaptation. The seasonal mobility was adaptive to seal availability, and the utilisation of natural mortality dictates that this form of exploitation was imminently sustainable.

The taphonomic history of the early Holocene seal assemblage from Elands Bay Cave is not clear. The deposits antedate the arrival of pastoralists and dogs, and it is assumed that a hunting and gathering economy existed. The site was probably well inland, and speculation is that many of the seal bones were obtained by trade with coastal dwellers. If this scenario is true then it too would reflect a highly organised adaptation to the exploitation of marine resources. This conclusion, however, must remain speculative.

## Conclusion

The research that is presented in this thesis synthesises many different taphonomic problems, and the innovative ways that these problems have been previously solved. The solutions are all combined and applied to the analysis of seal bones from archaeological sites. It is my intention that this work contribute to our knowledge of southern African coastal archaeology, and toward this end the approach has been used to assess Holocene coastal adaptations on the Cape west coast. It is also my aim to provide faunal analysts with an interest in coastal archaeology with a method and the means to analyse seal remains around the world. In this respect the taphonomic indices should be widely applicable. The final objective is to illustrate the potential of emphasising a single species in faunal analysis, and perhaps to motivate others to complete the taphonomic repertoire for other species.

# APPENDIX A

## REGRESSION ANALYSIS OF VARIANCE TABLE

The following analysis of variance (ANOVA) tables refer to the regression analysis presented in chapter 4.

| | REGRESSION BASED ON ALL ANIMALS | | | | | | | | REGRESSION EXCLUDING RAND ANIMALS | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | MALES | | | | FEMALES | | | | MALES | | | | FEMALES | | | |
| | SS | df | MS | Fs | SS | df | MS | Fs | SS | df | MS | Fs | SS | df | MS | Fs |
| MODEL 1 : ALL AGES | | | | | | | | | | | | | | | | |
| **GROUPS** | 24693.2 | 67 | 368.6 | 80.5 | 17714.5 | 54 | 328 | 56.98 | 19440.8 | 58 | 335.2 | 74.18 | 5923.4 | 43 | 137.8 | 15.37 |
| **LINEAR** | 21717.9 | 1 | 21717.9 | 481.8 | 12484 | 1 | 12484 | 126.5 | 17592 | 1 | 17592 | 542.5 | 4149.3 | 1 | 4149 | 98.23 |
| **DEV.** | 2975.3 | 66 | 45.08 | 9.85 | 5230.5 | 53 | 98.68 | 17.14 | 1848.4 | 57 | 32.43 | 7.18 | 1774.1 | 42 | 42.2 | 4.713 |
| **ERROR** | 247.2 | 54 | 4.58 | | 161.2 | 28 | 5.76 | | 234.9 | 52 | 4.52 | | 125.5 | 14 | 8.93 | |
| **TOTAL** | 24940.4 | 121 | | | 17875.7 | 82 | | | 19675.8 | 110 | | | 6048.9 | 57 | | |
| MODEL 2 : ALL AGES | | | | | | | | | | | | | | | | |
| **GROUPS** | 24693.2 | 67 | 368.6 | 80.5 | 17714.5 | 54 | 328 | 56.98 | 19440.8 | 58 | 335.2 | 74.18 | 5923.4 | 43 | 137.8 | 15.37 |
| **LINEAR** | 23013.4 | 1 | 23013.4 | 904.2 | 16159 | 1 | 16159 | 550.6 | 18366.7 | 1 | 18366.7 | 974.6 | 5434.7 | 1 | 5434.6 | 467 |
| **DEV.** | 1679.8 | 66 | 25.45 | 5.56 | 155.4 | 53 | 29.4 | 5.1 | 1074.1 | 57 | 18.84 | 4.17 | 488.7 | 42 | 11.64 | 1.3 |
| **ERROR** | 247.2 | 54 | 4.58 | | 161.2 | 28 | 5.8 | | 235 | 52 | 4.519 | | 125.5 | 14 | 8.96 | |
| **TOTAL** | 24940.4 | 121 | | | 17875.7 | 82 | | | 19675.8 | 110 | | | 6048.9 | 57 | | |
| MODEL 3 : ALL ANIMALS | | | | | | | | | | | | | | | | |
| **GROUPS** | 1.07695 | 67 | 0.0161 | 61.72 | 1.13611 | 54 | 0.021 | 55.4 | 0.74627 | 58 | 0.0129 | 51.37 | 0.27069 | 43 | 0.0063 | 15.39 |
| **LINEAR** | 0.85727 | 1 | 0.8573 | 257.6 | 0.71376 | 1 | 0.7138 | 89.57 | 0.64058 | 1 | 0.6406 | 345.5 | 0.17857 | 1 | 0.1786 | 81.42 |
| **DEV.** | 0.21968 | 66 | 0.0033 | 12.78 | 0.42235 | 53 | 0.008 | 20.98 | 0.1057 | 57 | 0.0019 | 7.4 | 0.09212 | 42 | 0.0022 | 5.36 |
| **ERROR** | 0.01406 | 54 | 0.0003 | | 0.01063 | 28 | 0.0004 | | 0.01303 | 52 | 0.0003 | | 0.00573 | 14 | 0.0004 | |
| **TOTAL** | 1.09101 | 121 | | | 1.14675 | 82 | | | 0.74627 | 110 | | | 0.27642 | 57 | | |
| MODEL 4 : ALL ANIMALS | | | | | | | | | | | | | | | | |
| **GROUPS** | 1.07695 | 67 | 0.0161 | 61.72 | 1.13611 | 54 | 0.021 | 55.4 | 0.74627 | 58 | 0.0129 | 51.37 | 0.27069 | 43 | 0.0063 | 15.39 |
| **LINEAR** | 1.04493 | 1 | 1.0449 | 2154 | 1.08723 | 1 | 0.0872 | 1178.7 | 0.71886 | 1 | 0.7189 | 1494.7 | 0.24764 | 1 | 0.2475 | 451.2 |
| **DEV.** | 0.03202 | 66 | 0.0005 | 1.863 | 0.04889 | 53 | 0.0009 | 2.43 | 0.02741 | 57 | 0.0005 | 1.9199 | 0.02305 | 42 | 0.0005 | 1.34 |
| **ERROR** | 0.01406 | 54 | 0.0003 | | 0.01063 | 28 | 0.0004 | | 0.01303 | 52 | 0.0003 | | 0.00573 | 14 | 0.0004 | |
| **TOTAL** | 1.09101 | 121 | | | 1.14675 | 82 | | | 0.7593 | 110 | | | 0.27669 | 57 | | |

*...continues*

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MODEL 1 : ANIMALS AGED <36 MONTHS | | | | | | | | | | | | | | | | |
| **GROUPS** | 5107.4 | 43 | 118.8 | 25.75 | 8393.3 | 38 | 220.9 | 62.96 | 2669.3 | 34 | 78.51 | 17.28 | 1850.2 | 27 | 68.53 | 14.5 |
| **LINEAR** | 4377.1 | 1 | 4377.06 | 251.7 | 7860.3 | 1 | 7860.3 | 545.7 | 2396.3 | 1 | 2396.3 | 289.7 | 1743.1 | 1 | 1743.1 | 423.3 |
| **DEV.** | 730.3 | 42 | 17.39 | 3.77 | 532.9 | 37 | 14.4 | 4.11 | 273.9 | 33 | 8.27 | 1.82 | 107.1 | 26 | 4.12 | 0.87 |
| **ERROR** | 212.2 | 46 | 4.61 | | 87.7 | 25 | 3.51 | | 199.9 | 44 | 4.54 | | 52 | 11 | 4.73 | |
| **TOTAL** | 5319.5 | 89 | | | 17875.7 | 63 | | | 2869.1 | 78 | | | 1902.2 | 38 | | |
| MODEL 2 : ANIMALS AGED <36 MONTHS | | | | | | | | | | | | | | | | |
| **GROUPS** | 5107.4 | 43 | 118.8 | 25.75 | 8393.25 | 38 | 220.9 | 62.96 | 2669.3 | 34 | 78.51 | 17.28 | 1850.2 | 27 | 68.53 | 14.5 |
| **LINEAR** | 4778.1 | 1 | 4778.1 | 609.5 | 7695.5 | 1 | 7695.5 | 408 | 2409 | 1 | 2409 | 305.4 | 1679.8 | 1 | 1679.7 | 256.2 |
| **DEV.** | 329.3 | 42 | 7.84 | 1.7 | 697.5 | 37 | 18.86 | 5.38 | 260.3 | 33 | 7.89 | 1.74 | 170.4 | 26 | 6.56 | 1.387 |
| **ERROR** | 212.2 | 46 | 4.61 | | 87.7 | 25 | 3.51 | | 199.2 | 44 | 4.54 | | 52 | 11 | 4.73 | |
| **TOTAL** | 24940.4 | 89 | | | 8481 | 63 | | | 2869.2 | 78 | | | 1902.2 | 38 | | |
| MODEL 3 : ANIMALS AGED <36 MONTHS | | | | | | | | | | | | | | | | |
| **GROUPS** | 0.32488 | 43 | 0.0076 | 26.79 | 0.64007 | 38 | 0.0168 | 53.79 | 0.13855 | 34 | 0.0041 | 15.02 | 0.09837 | 27 | 0.0036 | 13.72 |
| **LINEAR** | 0.25685 | 1 | 0.2568 | 158.6 | 0.57142 | 1 | 0.5714 | 308 | 0.12154 | 1 | 0.1215 | 235.81 | 0.09232 | 1 | 0.0923 | 396.6 |
| **DEV.** | 0.06804 | 42 | 0.0016 | 5.74 | 0.06865 | 37 | 0.0019 | 5.93 | 0.01701 | 33 | 0.0005 | 1.9 | 0.00605 | 26 | 0.0002 | 0.878 |
| **ERROR** | 0.01297 | 46 | 0.0003 | | 0.00783 | 25 | 0.0003 | | 0.01194 | 44 | 0.0003 | | 0.00292 | 11 | 0.0003 | |
| **TOTAL** | 0.33786 | 89 | | | 0.6479 | 63 | | | 0.15049 | 78 | | | 0.1013 | 38 | | |
| MODEL 4 : ANIMALS AGED <36 MONTHS | | | | | | | | | | | | | | | | |
| **GROUPS** | 0.32488 | 43 | 0.0076 | 26.79 | 0.64007 | 38 | 0.0168 | 53.79 | 0.13855 | 34 | 0.0041 | 15.021 | 0.09837 | 27 | 0.0036 | 13.72 |
| **LINEAR** | 0.30865 | 1 | 0.3087 | 798.7 | 0.61148 | 1 | 0.61215 | 791.17 | 0.12413 | 1 | 0.1241 | 284.03 | 0.08979 | 1 | 0.0898 | 271.8 |
| **DEV.** | 0.01623 | 42 | 0.0004 | 1.37 | 0.0286 | 37 | 0.0008 | 2.47 | 0.01442 | 33 | 0.0004 | 1.61 | 0.00859 | 26 | 0.0003 | 1.24 |
| **ERROR** | 0.01297 | 46 | 0.0003 | | 0.00783 | 25 | 0.0003 | | 0.01194 | 44 | 0.0003 | | 0.00292 | 11 | 0.0003 | |
| **TOTAL** | 0.33786 | 89 | | | 0.6479 | 63 | | | 0.15049 | 78 | | | 0.1013 | 38 | | |

## APPENDIX B.1

## SEAL BONE HARDNESS VALUES

The following table presents the ultimate strength and Young's Modulus analogue values obtained during hardness testing of seal bones. Ultimate strength values are the maximum values obtained in the stress/displacement curves presented in appendix B.2. Young's Modulus analogue values represent the gradient of the linear portion of the curves.

| Anatomical Unit | Ultimate strength (kN) | Young's Modulus analogue (kN/cm) | TEST LOCATION |
|---|---|---|---|
| ATL101 | 2.04 | 0.93 | Atlas - Anterior articular condyle |
| ATL102 | 0.98 | 0.12 | Atlas - Lateral spine |
| ATL103 | 1.99 | 0.68 | Atlas - Posterior articulation |
| ATL104 | 1.92 | 0.67 | Atlas - Posterior articulation |
| AXI101 | 1.30 | 0.51 | Axis - Anterior articulation |
| AXI102 | 0.63 | 0.20 | Axis - Centrum, ventral |
| AXI103 | 0.33 | 0.45 | Axis - Dorsal spine |
| C401 | 0.74 | 0.55 | Cervical 4 - Lateral Spine |
| C402 | 0.61 | 0.23 | Cervical 4 - Centrum, posterior |
| C403 | 0.67 | 0.36 | Cervical 4 - Centrum, ventral |
| C405 | 0.62 | 0.30 | Cervical 4 - Dorsal spine |
| C301 | 0.90 | 0.39 | Cervical 3 - Centrum, ventral/lateral |
| C302 | 0.51 | 0.27 | Cervical 3 - Centrum, ventral |
| C303 | 0.60 | 0.20 | Cervical 3 - Lateral spine, dorsal |
| C304 | 0.84 | 0.42 | Cervical 3 - Lateral spine, ventral |
| C305 | 0.58 | 0.46 | Cervical 3 - Dorsal spine |
| CAR101 | 1.89 | 1.38 | Carpal 1 |
| CAR102 | 0.72 | 0.19 | Carpal 1 |
| CAR203 | 0.88 | 0.54 | Carpal 2 |
| CAR304 | 0.95 | 0.84 | Carpal 3 |
| CAR305 | 1.18 | 0.56 | Carpal 3 |
| CAR406 | 0.56 | 0.36 | Carpal 4 |
| CAU101 | 0.46 | 0.43 | Caudal 1 - Centrum posterior |
| CAU102 | 0.52 | 0.28 | Caudal 1 - Centrum lateral |
| CAU103 | 0.62 | 0.35 | Caudal 1 - Dorsal spine |
| CAU204 | 0.32 | 0.20 | Caudal 2 - Centrum anterior |
| CAU205 | 0.78 | 0.36 | Caudal 2 - Centrum lateral |
| CAU206 | 0.55 | 0.38 | Caudal 2 - Dorsal spine |
| FEM101 | 5.97 | 3.56 | Femur - Midshaft |
| FEM102 | 1.25 | 0.46 | Femur - Distal shaft |
| FEM103 | 1.22 | 0.82 | Femur - Proximal shaft |
| FEM105 | 0.49 | 0.20 | Femur - Distal Epiphysis |
| HUM101 | 3.40 | 1.34 | Humerus - Medial midshaft |
| HUM102 | 1.06 | 0.62 | Humerus - Proximal posterior |
| HUM103 | 0.47 | 0.37 | Humerus - Olecranon fossa |
| HUM104 | 0.83 | 0.75 | Humerus - Distal anterior |
| HUM105 | 1.17 | 0.51 | Humerus - Distal lateral/anterior |
| HUM106 | 1.27 | 0.87 | Humerus - Distal lateral/anterior |
| HUM107 | 4.48 | 1.59 | Humerus - Lateral Midshaft |
| HUM108 | 4.16 | 1.56 | Humerus - Lateral midshaft |
| HUM109 | 5.58 | 3.16 | Humerus - Lateral deltoid process |
| HUM110 | 0.86 | 0.57 | Humerus - Proximal medial |
| HUM111 | 1.51 | 0.67 | Humerus - Proximal epiphysis |

| | | | |
|---|---|---|---|
| HUM112 | 0.28 | 0.23 | Humerus - Proximal trochanter |
| HUM113 | 1.68 | 0.61 | Humerus - Distal epiphysis |
| HUM114 | 1.34 | 0.36 | Humerus - Distal epiphysis |
| JAW101 | 1.09 | 0.98 | Mandible - Medial posterior of symphesis |
| JAW102 | 0.88 | 0.56 | Mandible - Medial below diastema |
| JAW103 | 1.06 | 0.57 | Mandible - Ventral diastema margin, medial |
| JAW106 | 1.44 | 0.73 | Mandible - Lateral ventral margin of ramus |
| JAW107 | 2.65 | 1.69 | Mandible - Lateral posterior of diastema |
| JAW108 | 4.30 | 1.75 | Mandible - Lateral below tooth row |
| JAW109 | 1.40 | 0.96 | ? |
| JAW110 | 1.87 | 0.80 | Mandible - Mandibular condyle |
| TOOTH1 | 2.50 | 2.43 | Tooth 1 - Dentine (root: lingual-buccal) |
| TOOTH2 | 1.79 | 1.10 | Tooth 2 - Enamel (crushing: tip-root) |
| LUM101 | 0.36 | 0.26 | Lumbar 1 - Centrum, anterior |
| LUM102 | 1.16 | 0.68 | Lumbar 1 - Centrum, ventral/lateral |
| LUM103 | 0.73 | 0.59 | Lumbar 1 - Lateral spine |
| LUM104 | 0.56 | 0.28 | Lumbar 1 - Posterior articular surface |
| LUM206 | 0.40 | 0.17 | Lumbar 2 - Dorsal spine |
| LUM207 | 0.63 | 0.35 | Lumbar 2 - Posterior articular surface |
| LUM208 | 0.54 | 0.31 | Lumbar 2 - Centrum, posterior |
| LUM209 | 1.10 | 0.60 | Lumbar 2 - Centrum, ventral/lateral |
| MCAR101 | 0.66 | 0.22 | Metacarpal 1 - Dorsal midshaft |
| MCAR102 | 0.86 | 0.46 | Metacarpal 1 - Dorsal proximal shaft |
| MCAR103 | 0.45 | 0.37 | Metacarpal 1 - Distal lateral shaft |
| MCAR204 | 0.90 | 1.02 | Metacarpal 2 - Distal dorsal shaft |
| MCAR205 | 0.86 | 0.46 | Metacarpal 2 - Proximal dorsal shaft |
| MTAR101 | 0.88 | 0.50 | Metatarsal 1 - Distal dorsal |
| MTAR102 | 1.65 | 0.78 | Metatarsal 1 - Midshaft dorsal |
| MTAR103 | 0.36 | 0.22 | Metatarsal 1 - Proximal dorsal |
| MTAR204 | 0.36 | 0.20 | Metatarsal 2 - Proximal ventral |
| MTAR205 | 1.76 | 0.87 | Metatarsal 2 - Midshaft ventral |
| MTAR206 | 0.82 | 0.54 | Metatarsal 2 - Distal ventral |
| PEL101 | 1.07 | 0.11 | Pelvis - Dorsal, acetabulum |
| PEL102 | 1.69 | 0.87 | Pelvis - Ishium |
| PEL103 | 1.92 | 1.13 | Pelvis - Ileum |
| PHA101 | 0.22 | 0.04 | Phalange 1 - Proximal dorsal |
| PHA102 | 1.28 | 0.60 | Phalange 1 - Midshaft dorsal |
| PHA103 | 1.00 | 0.82 | Phalange 1 - Distal dorsal |
| PHA204 | 0.56 | 0.19 | Phalange 2 - Distal |
| PHA205 | 0.41 | 0.22 | Phalange 2 - Proximal |
| PHA306 | 0.24 | 0.14 | Phalange 3 - Midshaft |
| RAD101 | 0.83 | 0.30 | Radius - Distal lateral |
| RAD102 | 5.47 | 2.38 | Radius - Midshaft lateral |
| RAD103 | 4.81 | 1.39 | Radius - Proximal lateral |
| RAD104 | 2.20 | 1.41 | Radius - Distal epiphysis |
| RAD105 | 3.14 | 2.11 | Radius - Proximal epiphysis |
| RIB101 | 0.82 | 0.61 | Rib 1 - Proximal anterior |
| RIB102 | 2.25 | 1.79 | Rib 1 - Shaft proximal, medial |
| RIB103 | 2.23 | 1.66 | Rib 1 - Shaft proximal, medial |
| RIB104 | 1.96 | 1.24 | Rib 1 - Shaft distal, medial |
| RIB105 | 0.70 | 0.39 | Rib 1 - Distal medial |
| RIB201 | 0.25 | 0.32 | Rib 2 - Proximal anterior |
| RIB202 | 0.84 | 0.47 | Rib 2 - Proximal anterior |
| RIB203 | 1.89 | 1.39 | Rib 2 - Shaft proximal, medial |
| RIB204 | 2.53 | 2.10 | Rib 2 - Midshaft medial |
| RIB205 | 1.84 | 1.68 | Rib 2 - Shaft distal, medial |
| RIB206 | 1.33 | 1.13 | Rib 2 - Shaft distal, medial |
| RIB207 | 0.64 | 0.49 | Rib 2 - Distal medial |

| | | | |
|---|---|---|---|
| RIB301 | 0.55 | 0.33 | Rib 3 - Proximal anterior |
| RIB302 | 1.38 | 1.16 | Rib 3 - Shaft proximal, anterior |
| RIB303 | 1.80 | 1.44 | Rib 3 - Shaft distal, medial |
| RIB304 | 0.43 | 0.17 | Rib 3 - Distal medial |
| SAC101 | 0.55 | 0.23 | Sacrum - Centrum dorsal, anterior |
| SAC102 | 0.59 | 0.35 | Sacrum - Centrum ventral |
| SAC103 | 0.66 | 0.46 | Sacrum - Innominate articulation |
| SAC104 | 0.51 | 0.32 | Sacrum - Dorsal spine |
| SCAP101 | 0.45 | 0.23 | Scapula - Glenoid lateral |
| SCAP102 | 0.86 | 0.80 | Scapula - Inferior, lateral ridge |
| SCAP103 | 3.27 | 1.41 | Scapula - Superior, distal, medial ridge |
| SCAP104 | 0.92 | 0.44 | Scapula - Superior, proximal, medial ridge |
| SCAP105 | 1.06 | 0.47 | Scapula - Glenoid medial |
| SCAP106 | 0.10 | 0.06 | Scapula - Blade |
| SCAP107 | 0.75 | 0.40 | Scapula - Margin |
| FIB101 | 0.40 | 0.33 | Fibula - Lateral proximal shaft |
| FIB102 | 1.85 | 1.52 | Fibula - Lateral midshaft |
| FIB103 | 0.53 | 0.14 | Fibula - lateral distal |
| FIB104 | 1.56 | 1.57 | Fibula - Medial distal |
| TAR101 | 1.11 | 1.05 | Astragalus |
| TAR102 | 0.51 | 0.39 | Astragalus |
| TAR103 | 1.08 | 0.61 | Astragalus |
| TAR104 | 0.88 | 0.55 | Astragalus |
| TAR205 | 0.55 | 0.32 | Calcaneum |
| TAR206 | 1.10 | 0.80 | Calcaneum |
| TAR207 | 0.89 | 0.33 | Calcaneum |
| TAR308 | 1.15 | 0.92 | Cuboid |
| THO101 | 1.05 | 0.34 | Thoracic 1 - Centrum anterior |
| THO102 | 0.66 | 0.58 | Thoracic 1 - Centrum anterior |
| THO103 | 0.88 | 0.48 | Thoracic 1 - Centrum anterior |
| THO104 | 0.62 | 0.35 | Thoracic 1 - Centrum anterior |
| THO105 | 1.05 | 0.51 | Thoracic 1 - Centrum, lateral |
| THO106 | 0.22 | 0.22 | Thoracic 1 - Centrum, lateral |
| THO107 | 0.67 | 0.32 | Thoracic 1 - Lateral spine |
| THO108 | 0.79 | 0.43 | Thoracic 1 - Dorsal spine |
| THO109 | 0.61 | 0.41 | Thoracic 1 - Dorsal spine |
| THO210 | 0.36 | 0.13 | Thoracic 2 - Centrum posterior |
| THO211 | 0.48 | 0.14 | Thoracic 2 - Centrum lateral |
| THO212 | 0.24 | 0.12 | Thoracic 2 - Centrum ventral |
| THO213 | 0.61 | 0.36 | Thoracic 2 - Dorsal spine |
| TIB101 | 0.90 | 0.59 | Tibia - Distal shaft, dorsal |
| TIB102 | 2.15 | 1.77 | Tibia - Midshaft ventral |
| TIB103 | 1.02 | 0.48 | Tibia - Proximal dorsal |
| TIB104 | 2.24 | 1.63 | Tibia - Proximal epiphysis |
| TIB105 | 0.71 | 0.48 | Tibia - Distal |
| TIB106 | 0.78 | 0.48 | Tibia - Distal epiphysis |
| ULNA101 | 0.57 | 0.15 | Ulna - Distal lateral |
| ULNA102 | 1.21 | 0.77 | Ulna - Midshaft lateral |
| ULNA103 | 0.61 | 0.37 | Ulna - Olecranon lateral |
| ULNA104 | 2.60 | 0.99 | Ulna - Shaft, below articulation |
| STE101 | 0.70 | 0.36 | Sternum 1 |
| STE102 | 0.69 | 0.34 | Sternum 1 |
| STE103 | 1.61 | 0.86 | Sternum 1 |
| STE204 | 0.56 | 0.49 | Sternum 2 |
| STE205 | 0.57 | 0.30 | Sternum 2 |
| STE206 | 0.38 | 0.29 | Sternum 2 |

# APPENDIX B.2

## SEAL BONE HARDNESS ANALYSES

The following graphs form the basis of hardness analysis of seal bones. An Rockwell A, C or D indenter (a diamond cone with internal angle of 120° and a diametre of 4 mm) is forced into the bone surface at a constant rate of 0.07 mm/s. The force required to maintain this rate of penetration is plotted against the depth of penetration. The gradient of the linear portion of the graph is called the "Youngs Modulus Analogue" and the maximum force value is called the "ultimate strength" in appendix B.1. Note that the tooth and fibula analyses were destroyed between the initial analysis and the production of these graphs.

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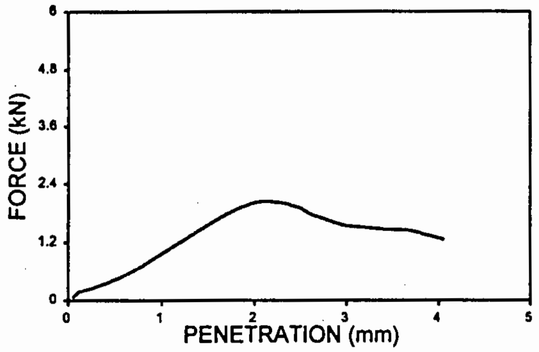

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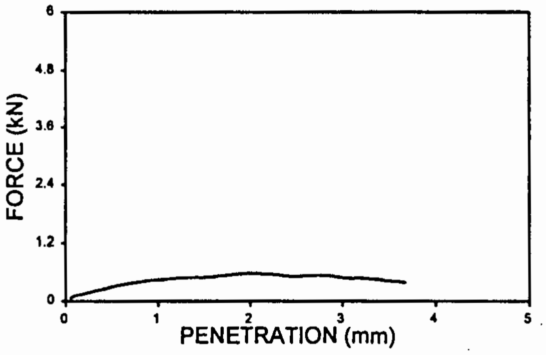

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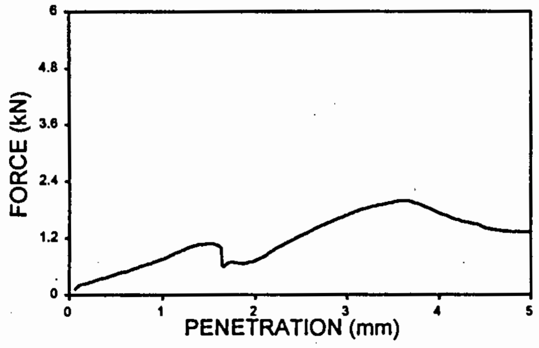

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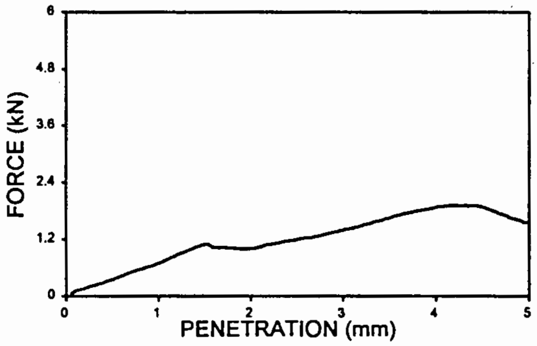

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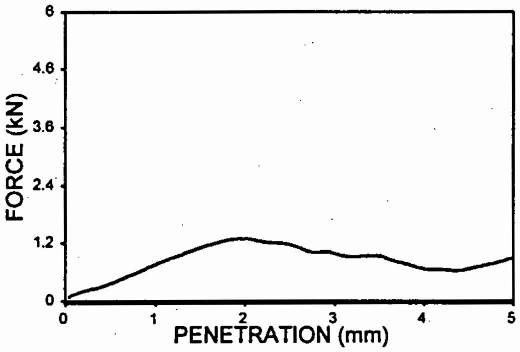

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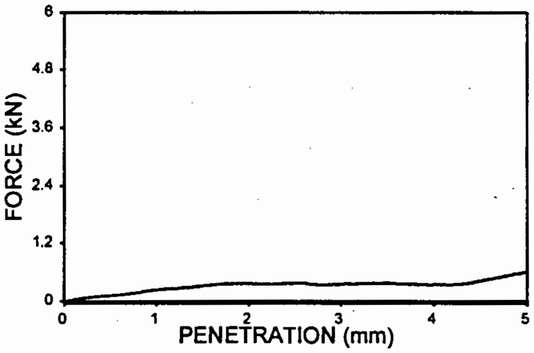

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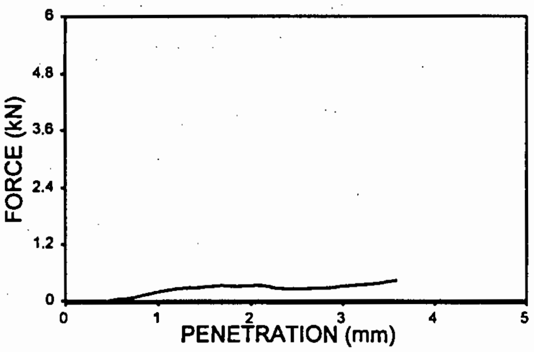

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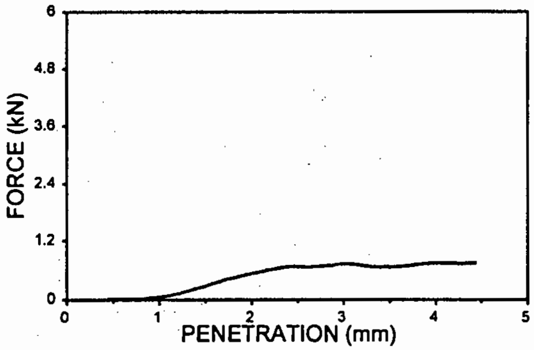

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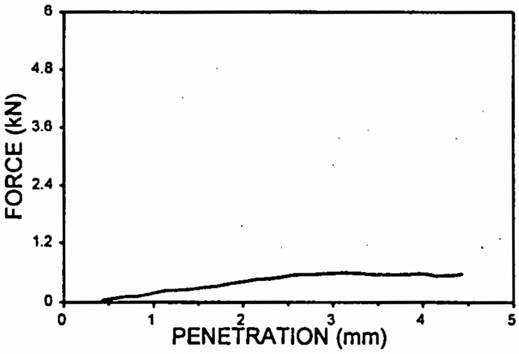

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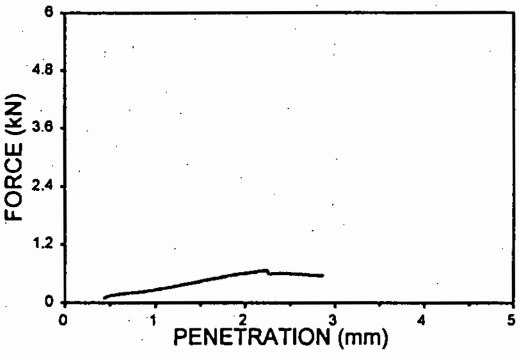

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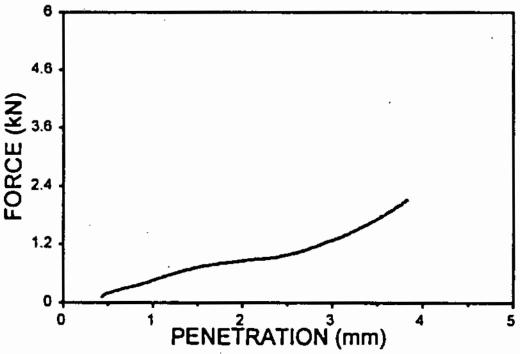

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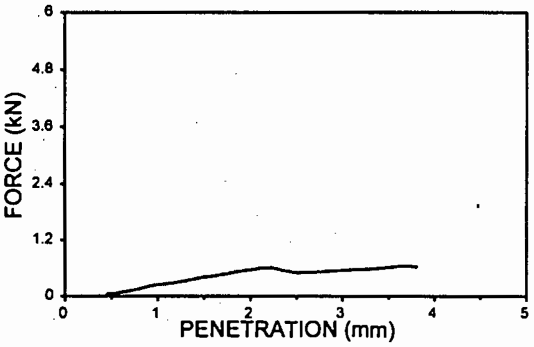

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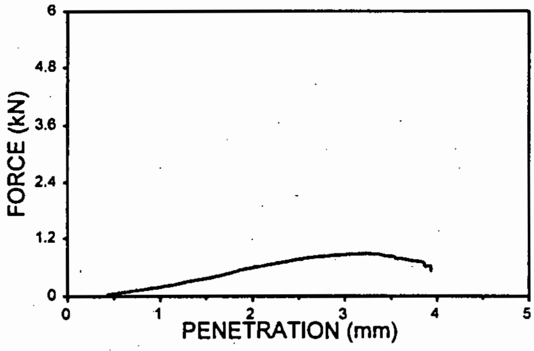

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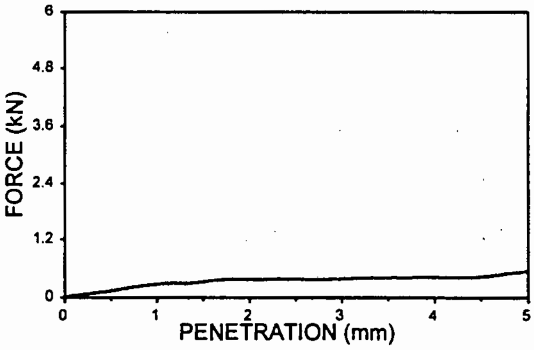

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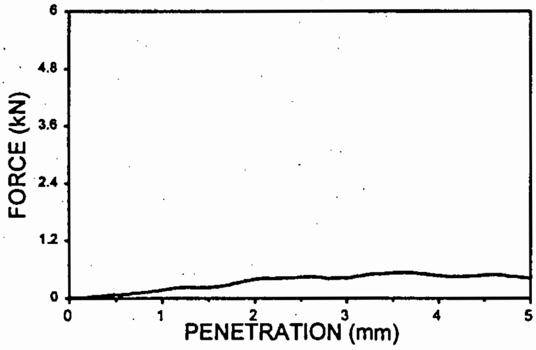

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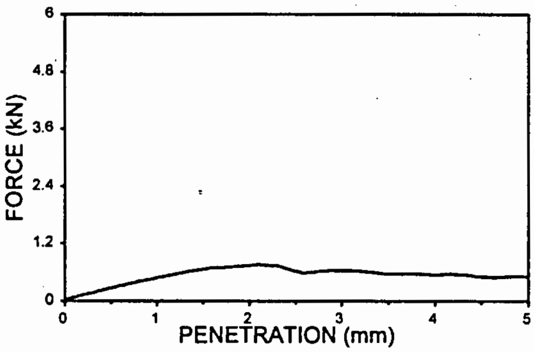

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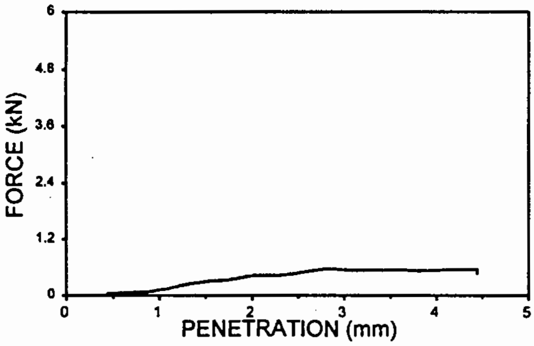

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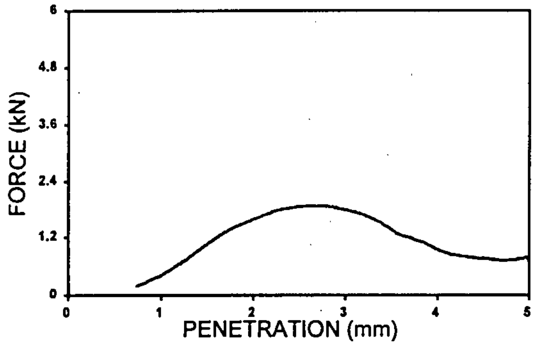

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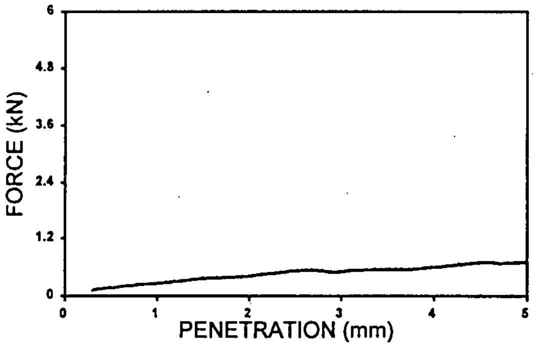

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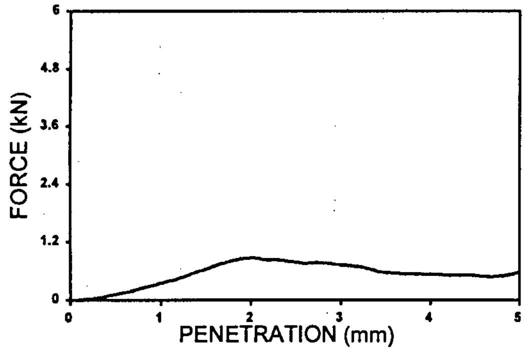

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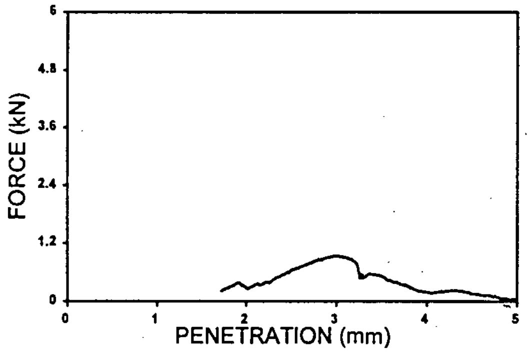

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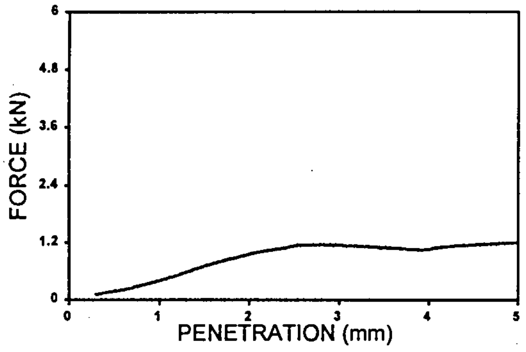

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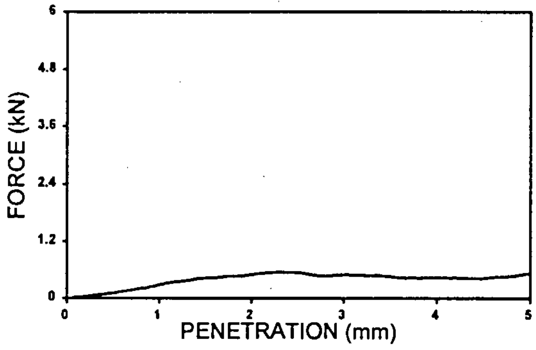

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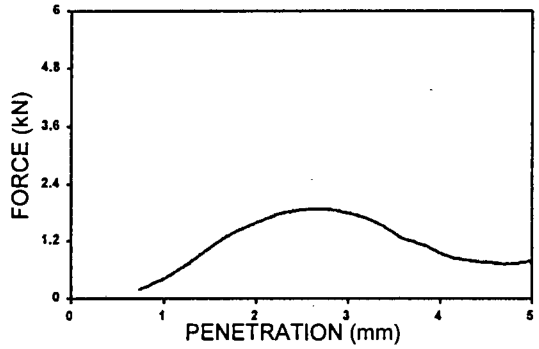

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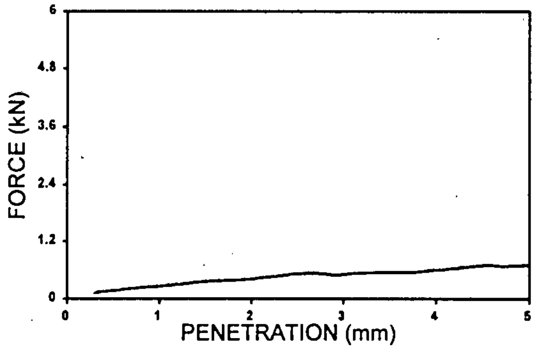

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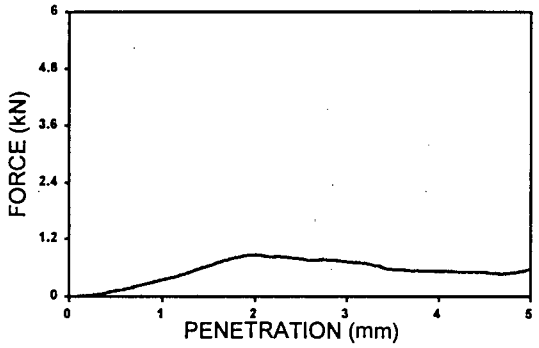

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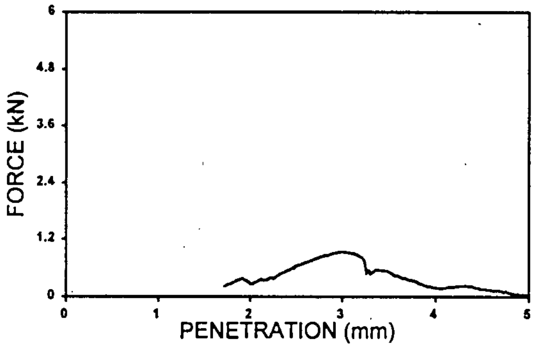

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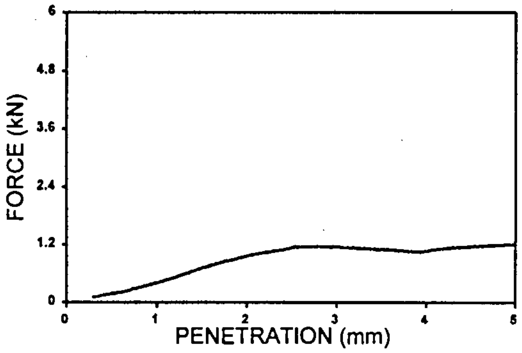

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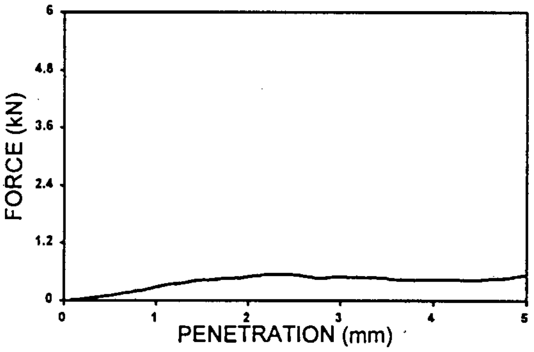

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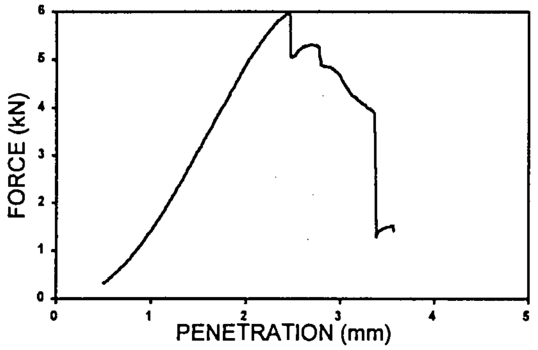

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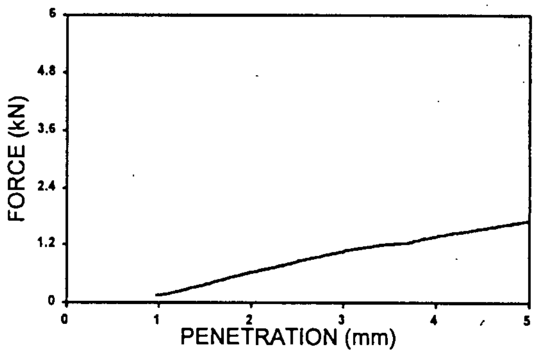

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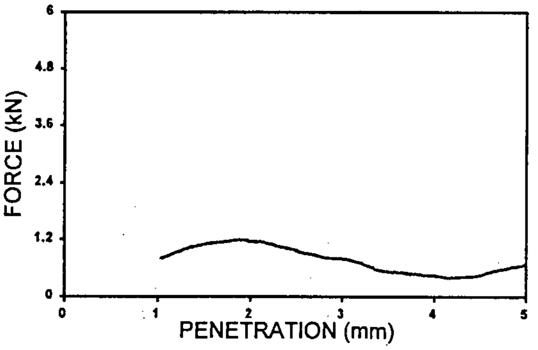

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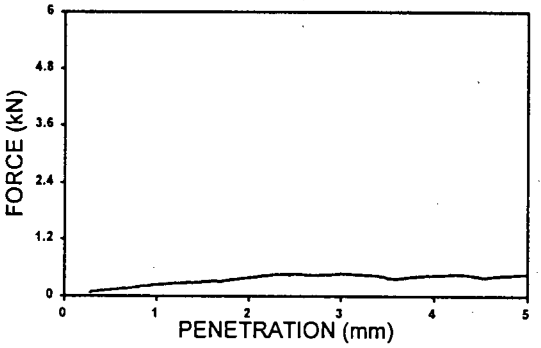

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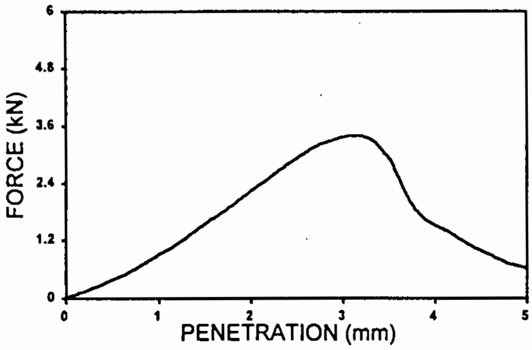

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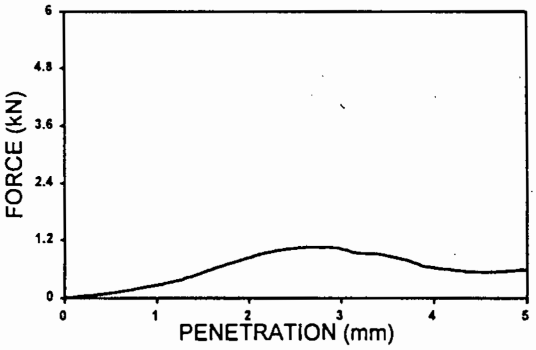

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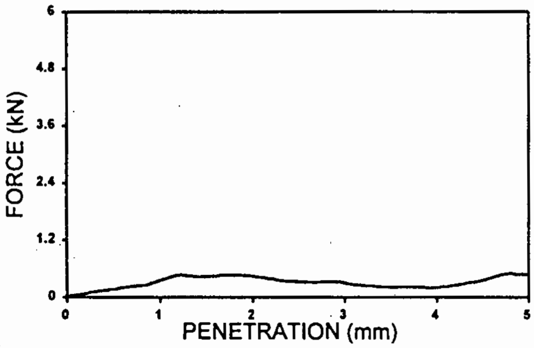

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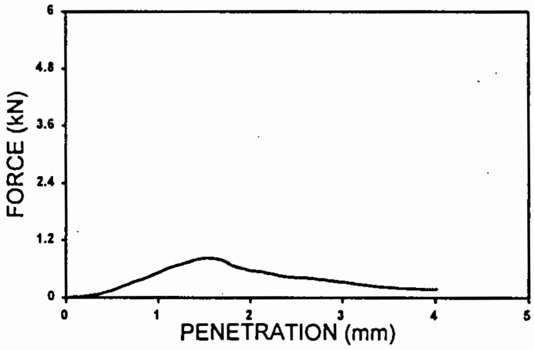

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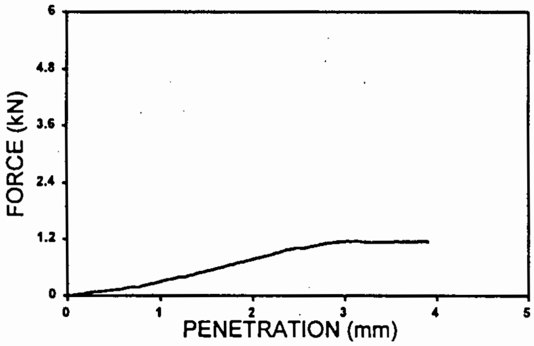

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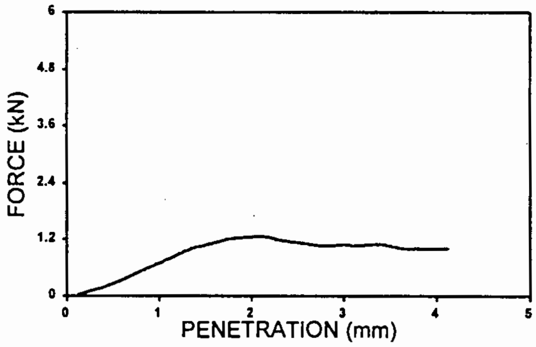

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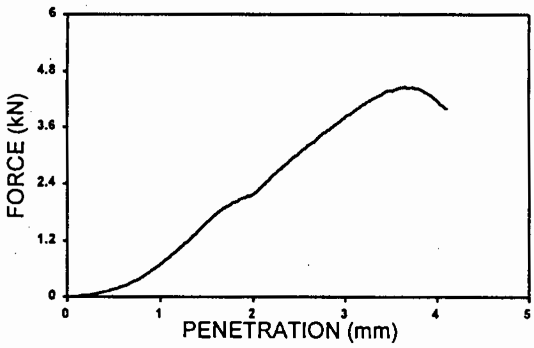

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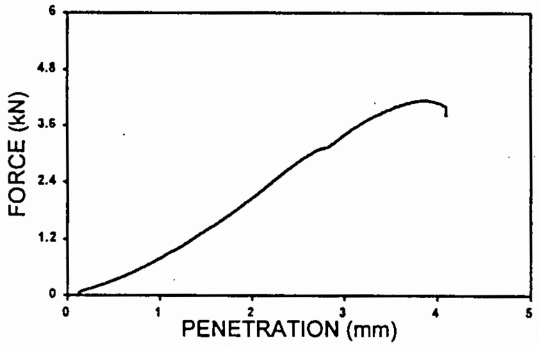

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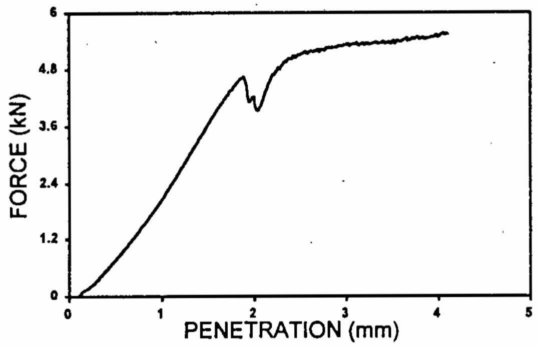

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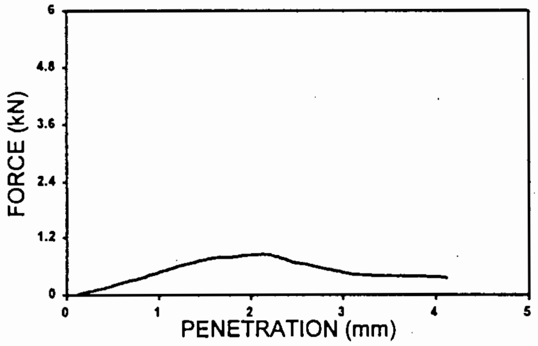

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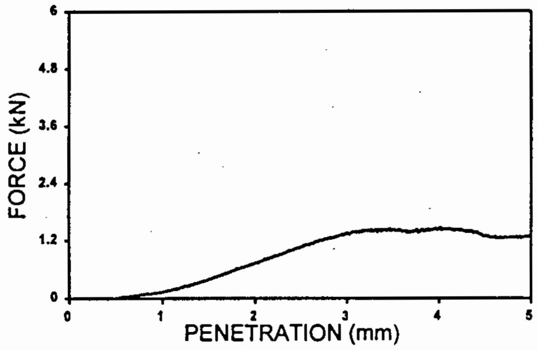

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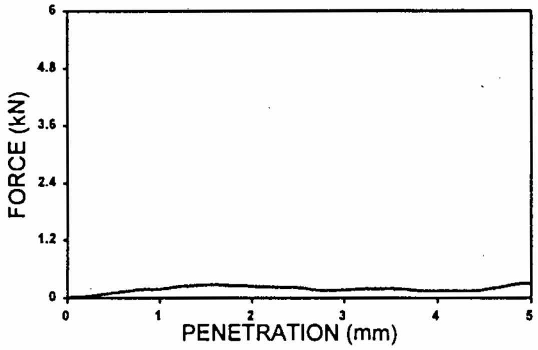

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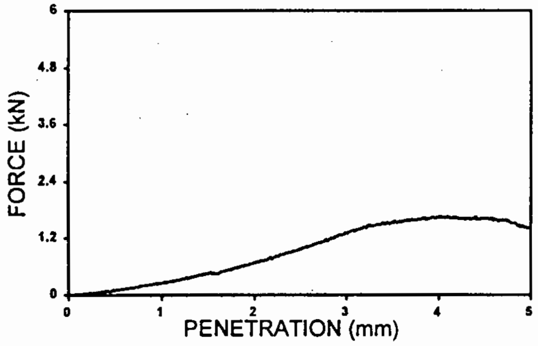

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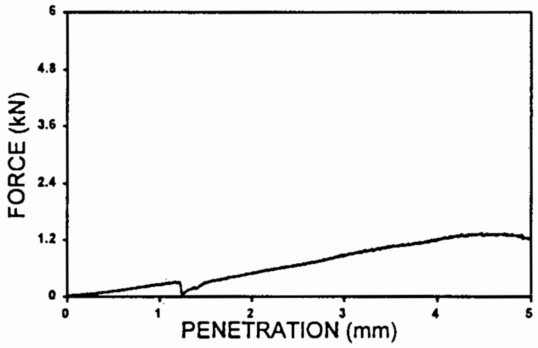

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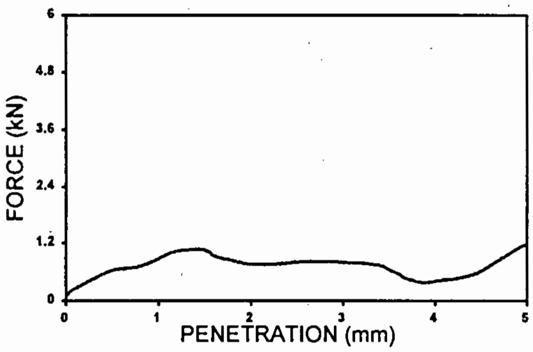

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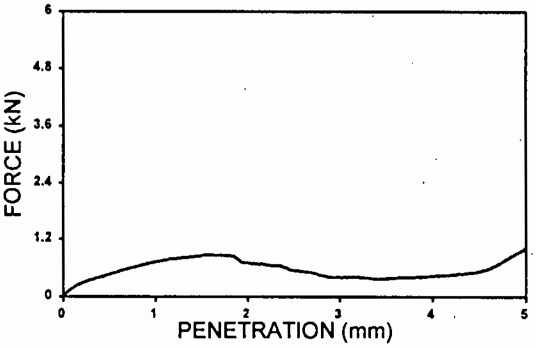

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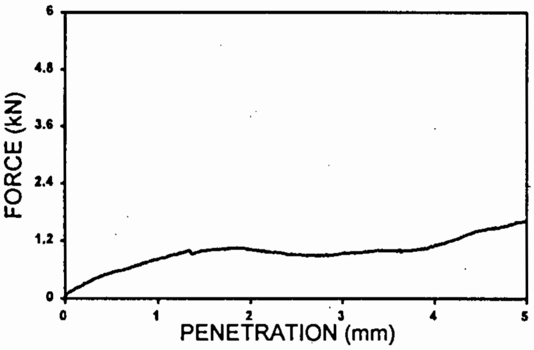

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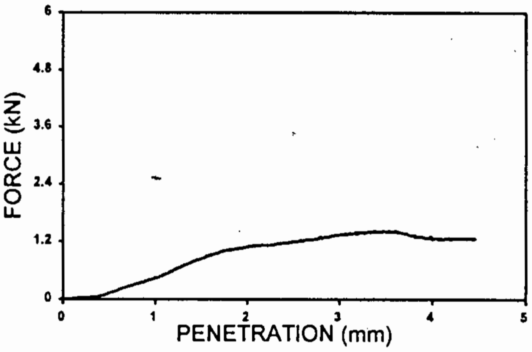

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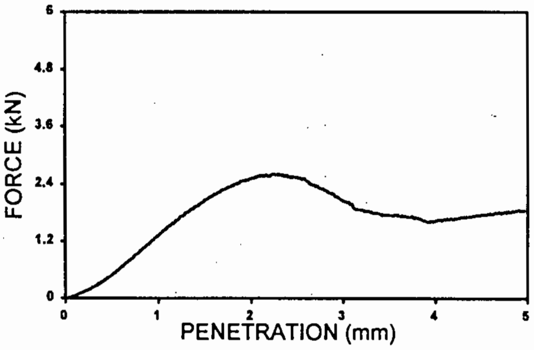

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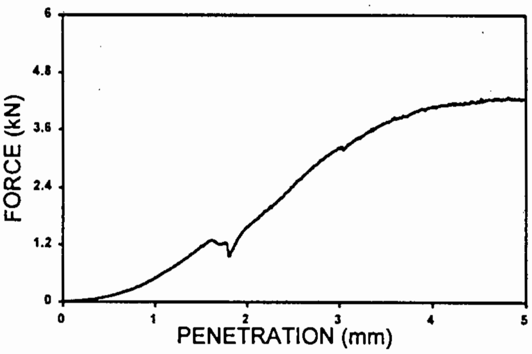

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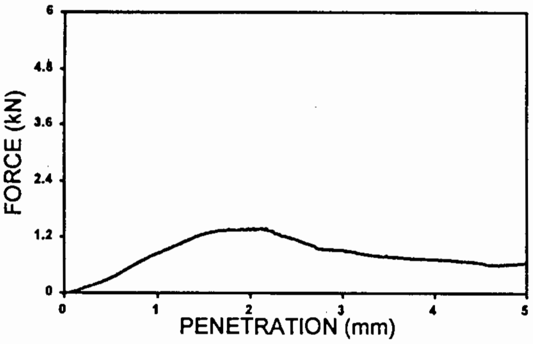

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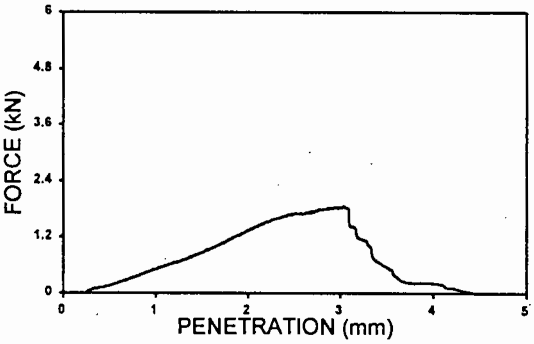

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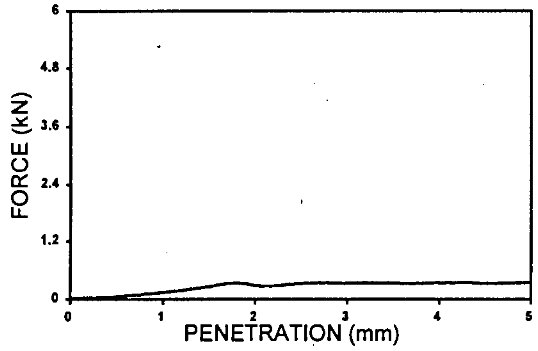

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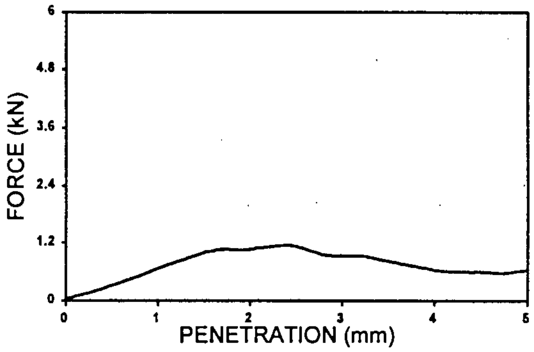

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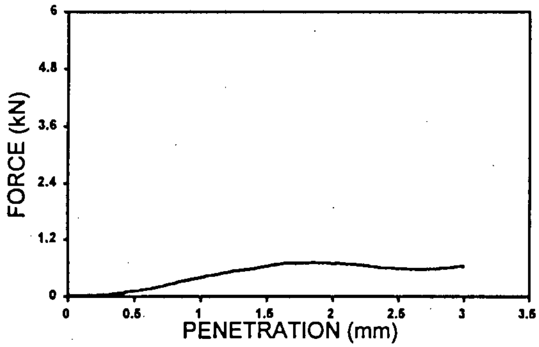

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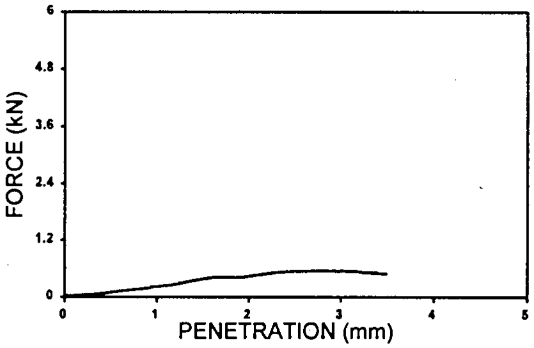

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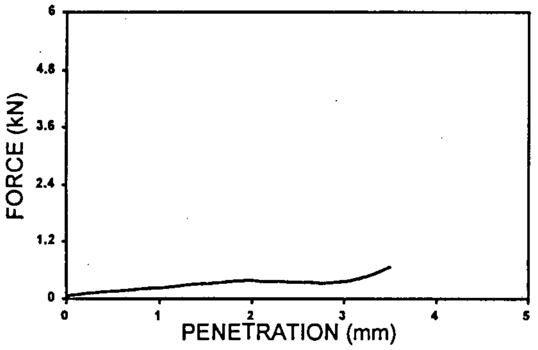

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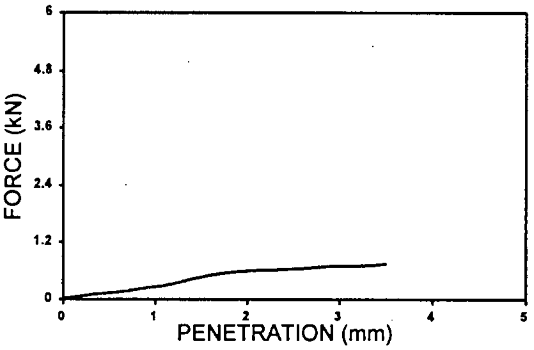

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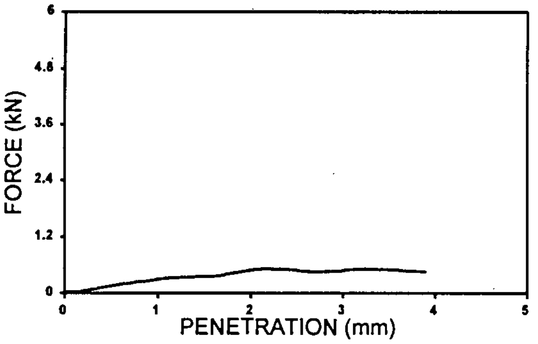

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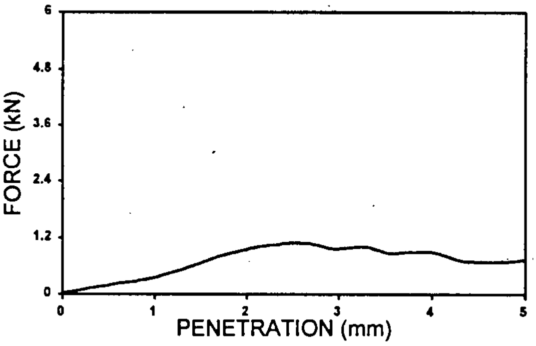

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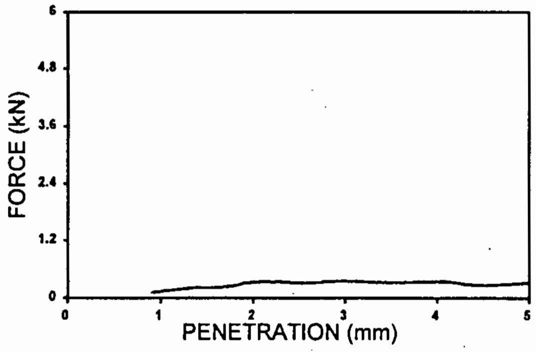

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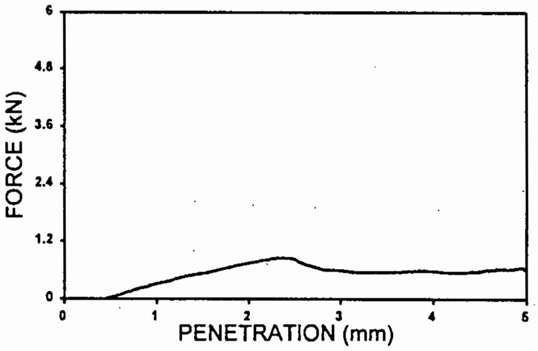

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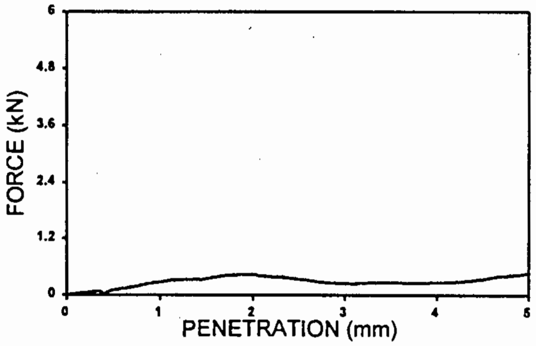

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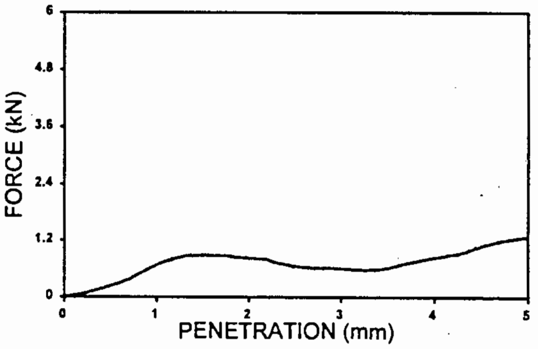

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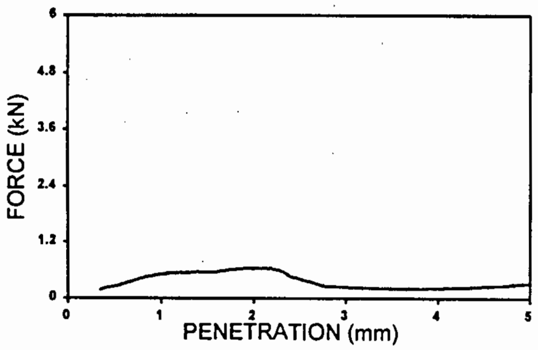

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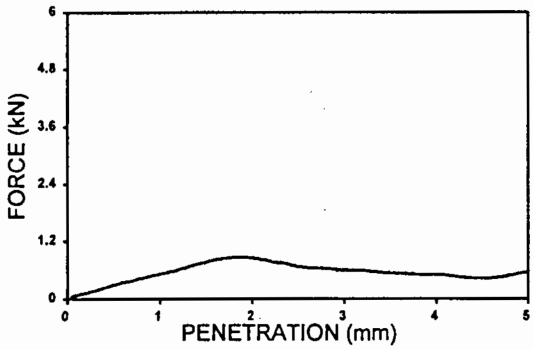

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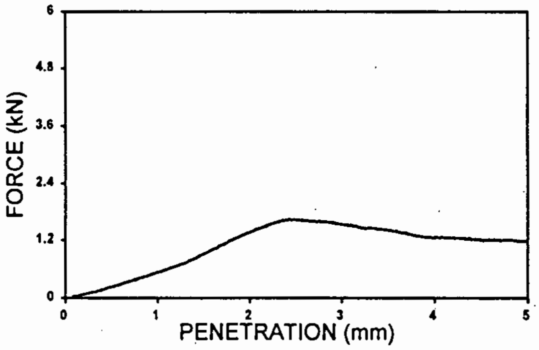

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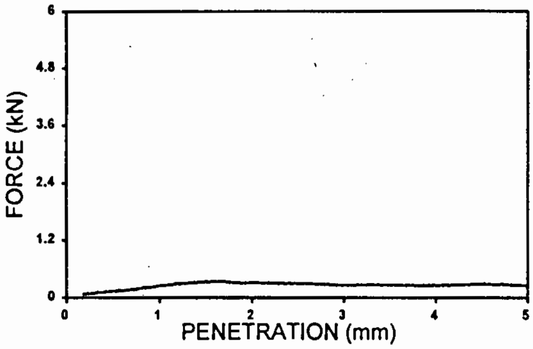

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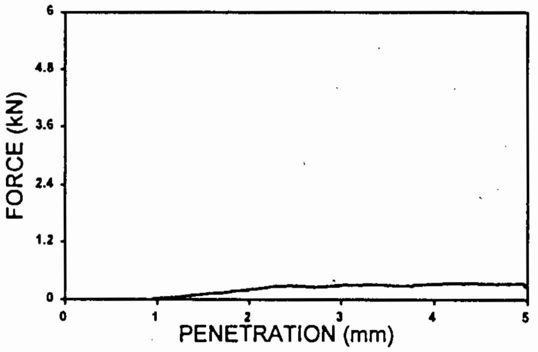

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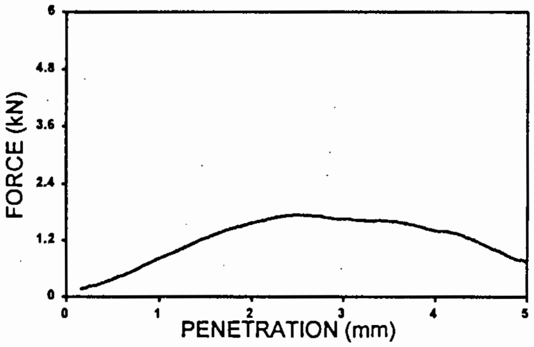

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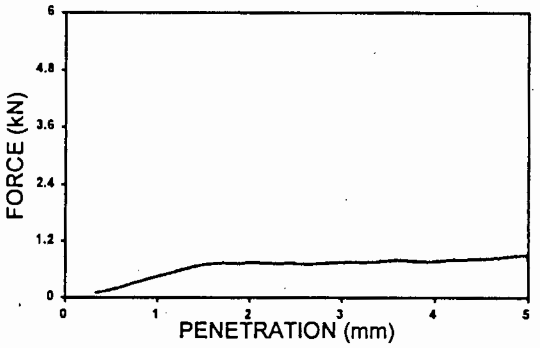

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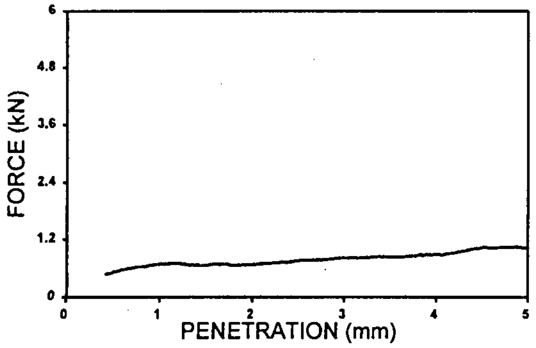

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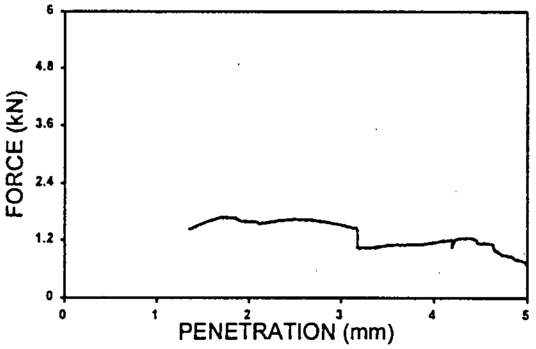

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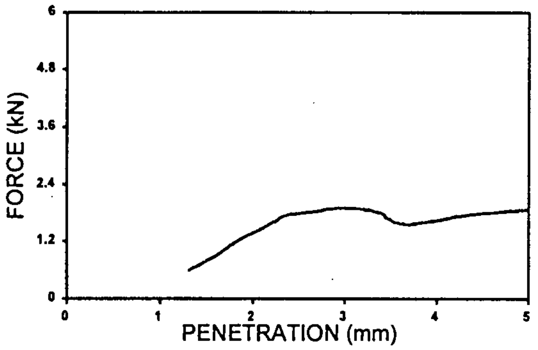

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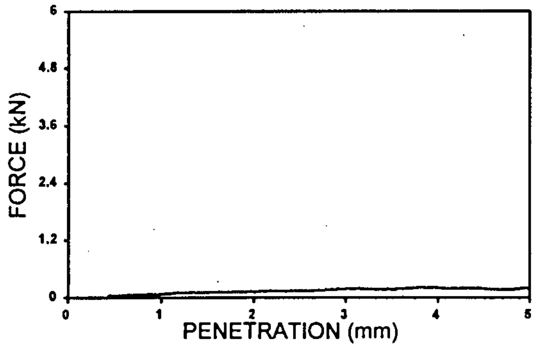

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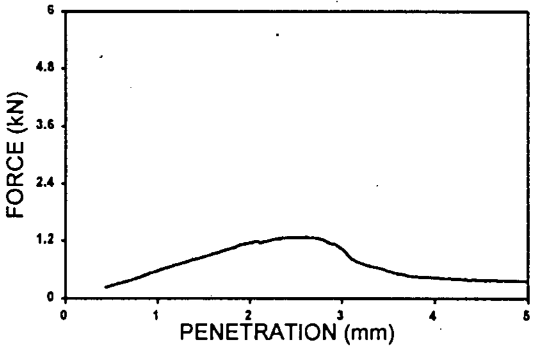

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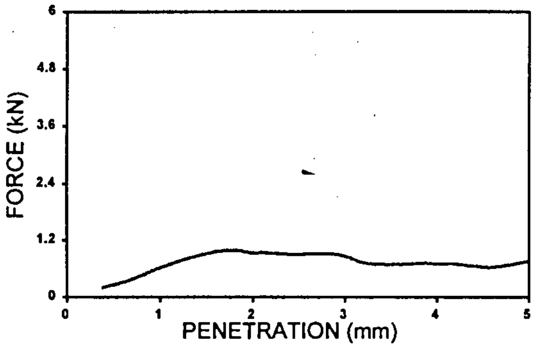

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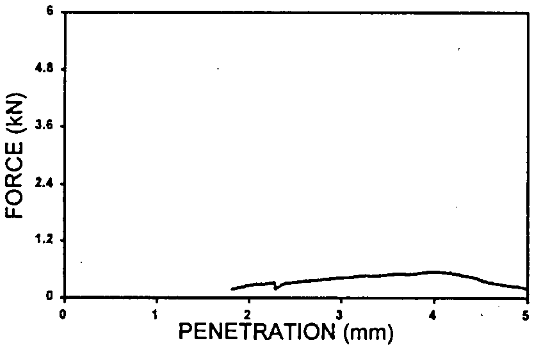

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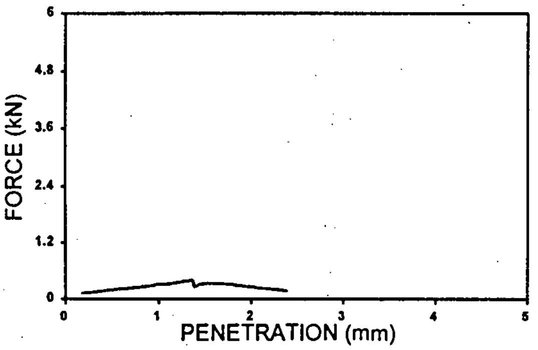

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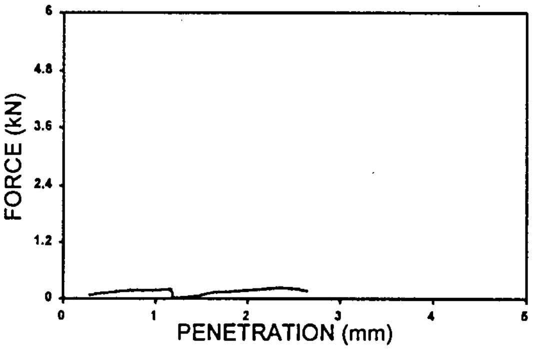
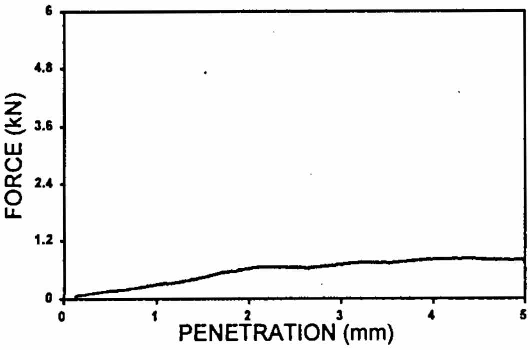


RAD101



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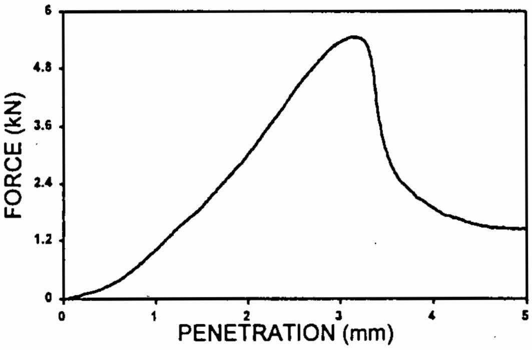

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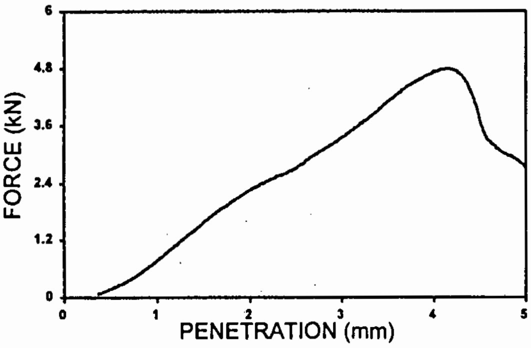

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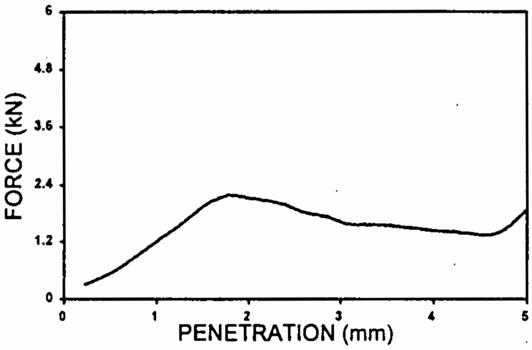

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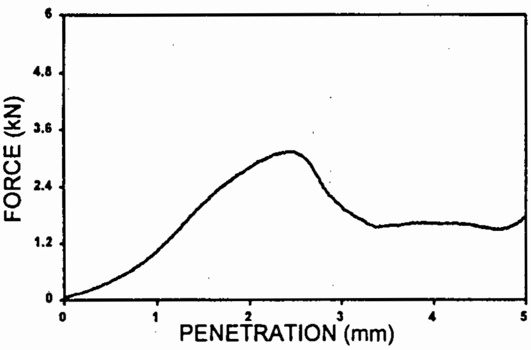

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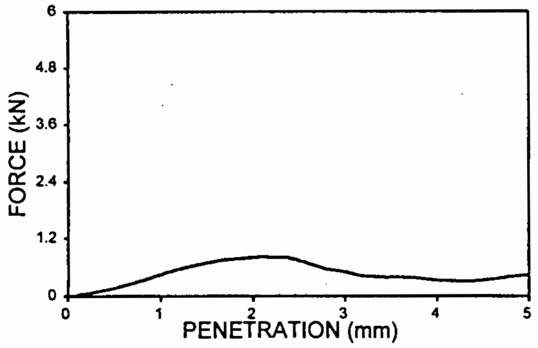

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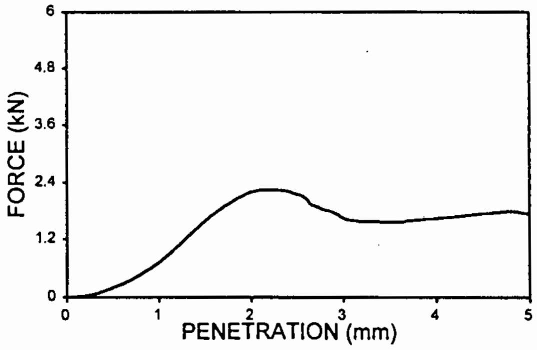

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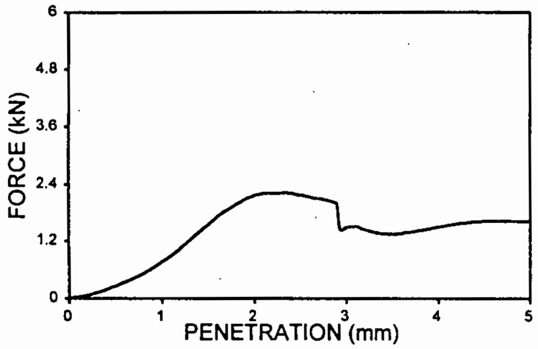

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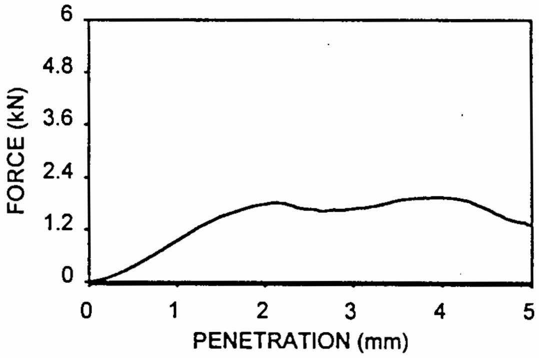

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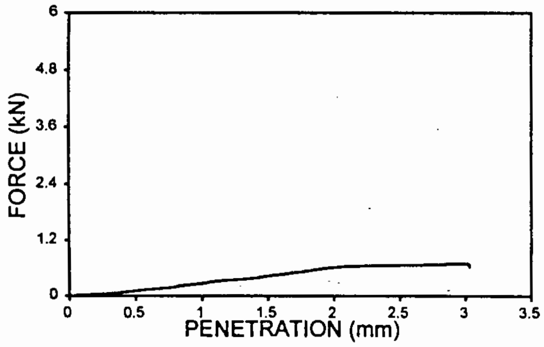

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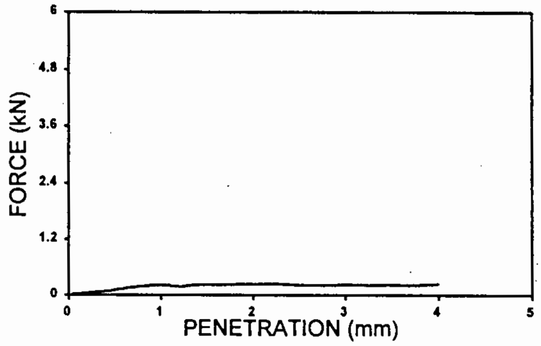

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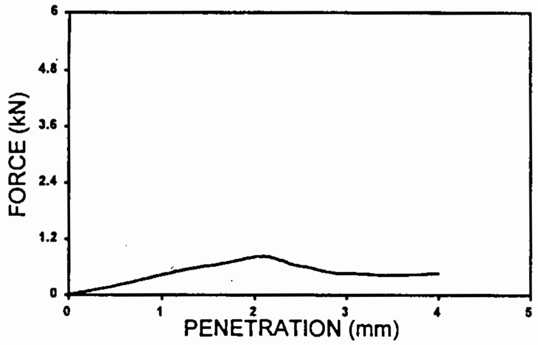

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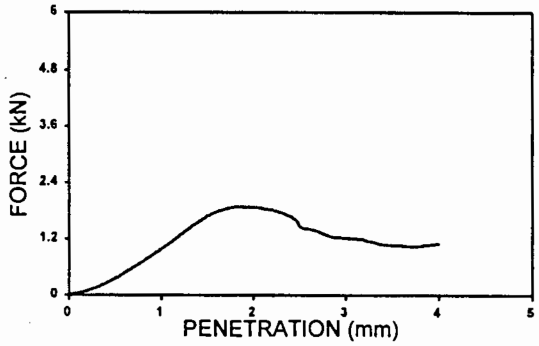

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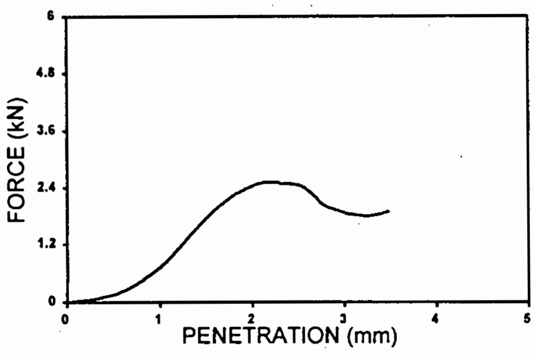

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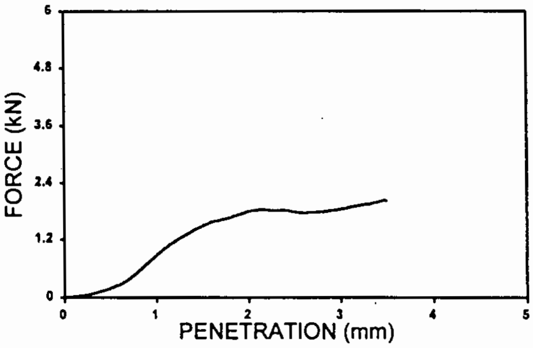

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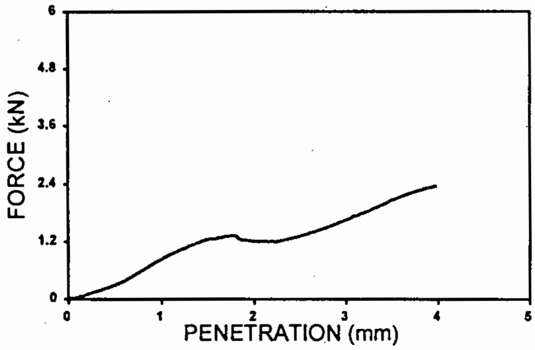

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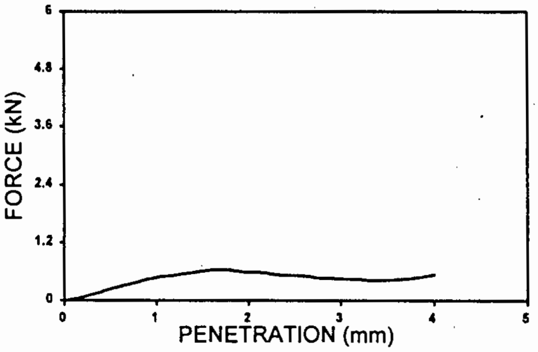

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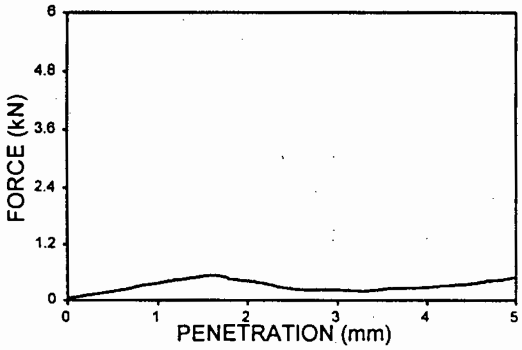

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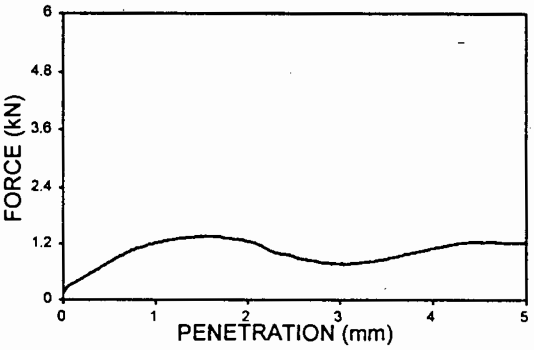

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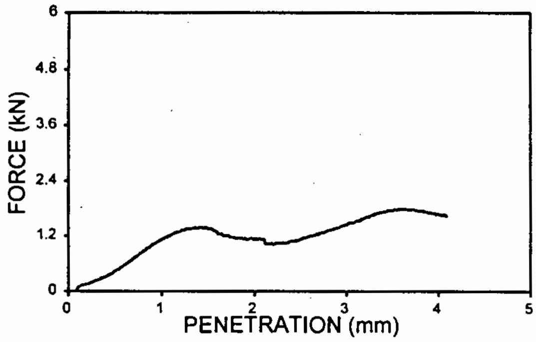

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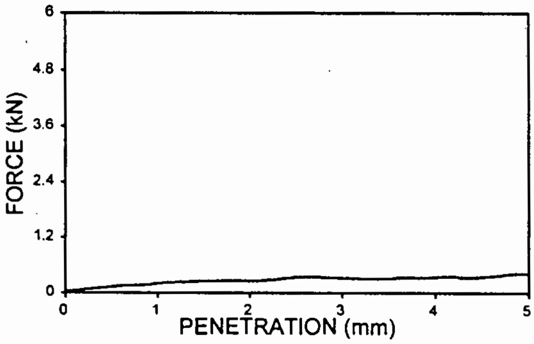

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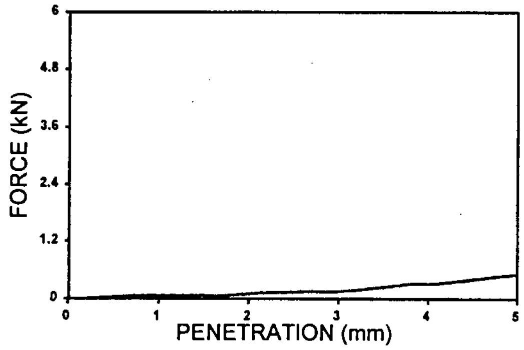

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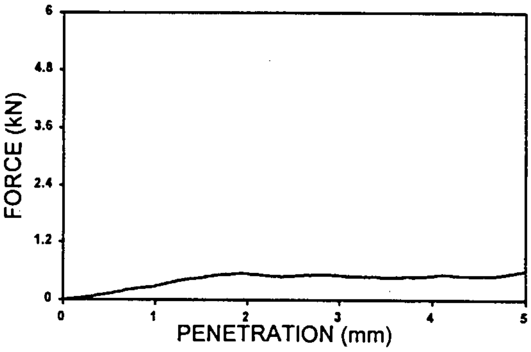

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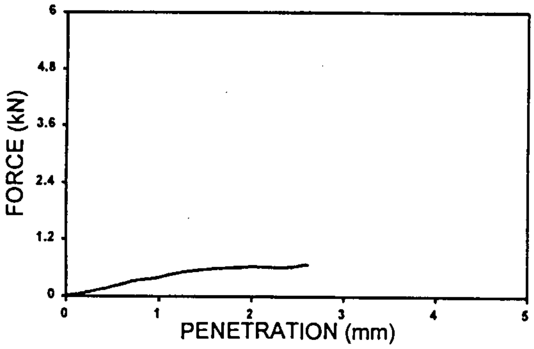

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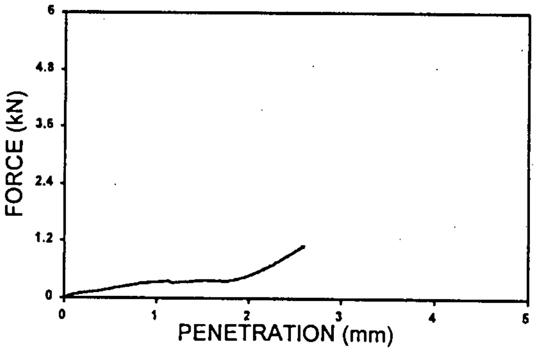
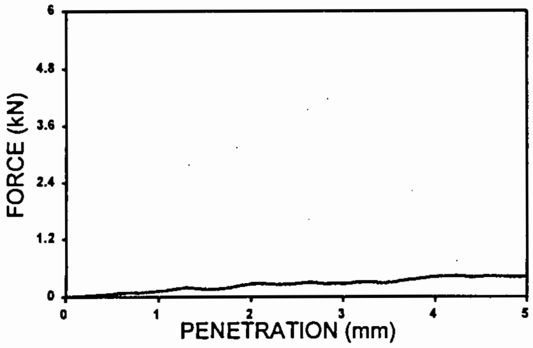


SCAP101



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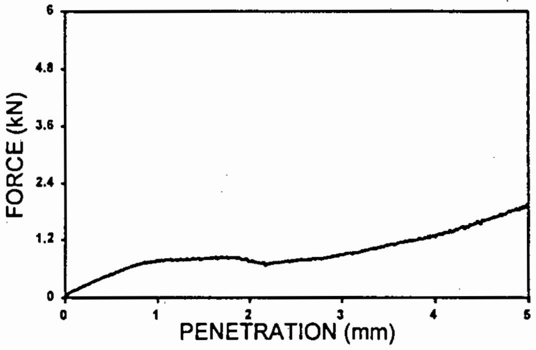

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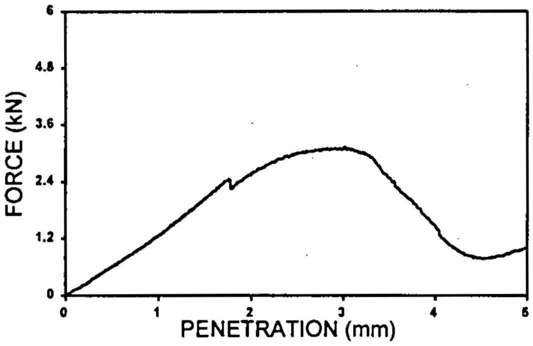

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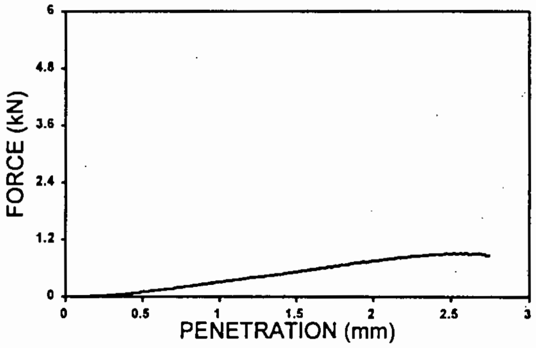

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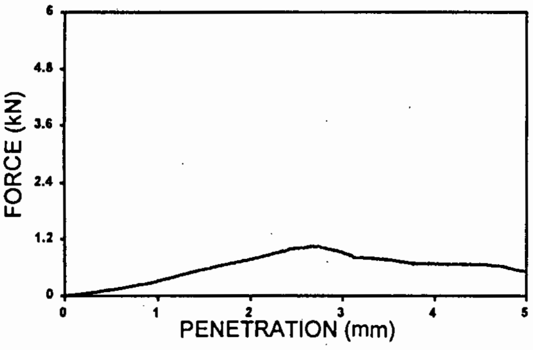

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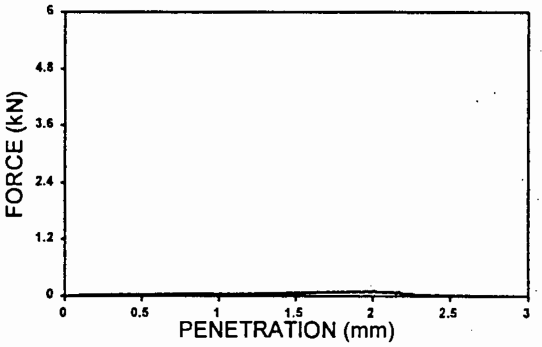
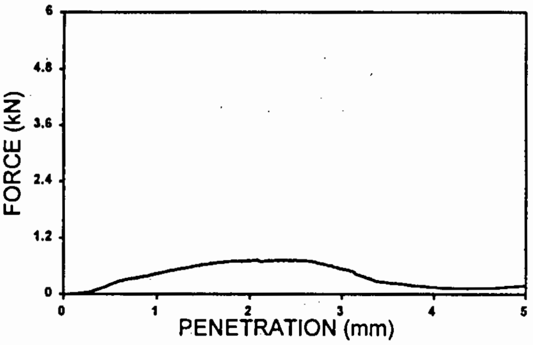
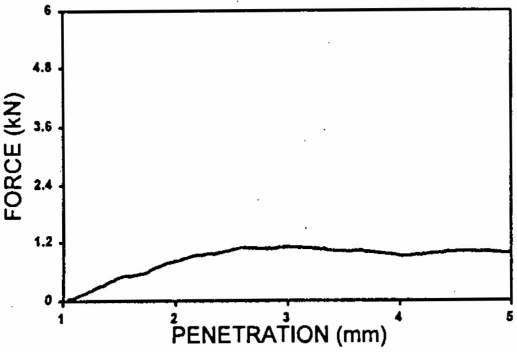


SCAP107



TAR101



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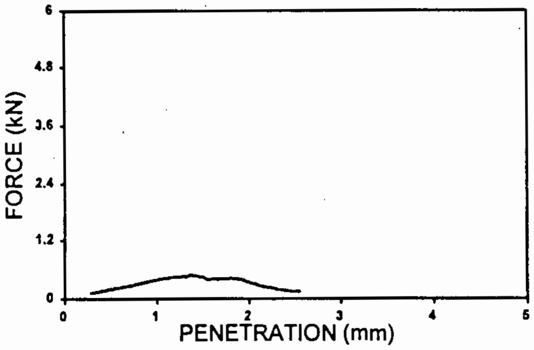

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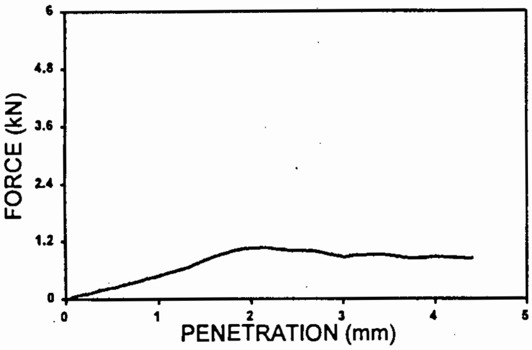

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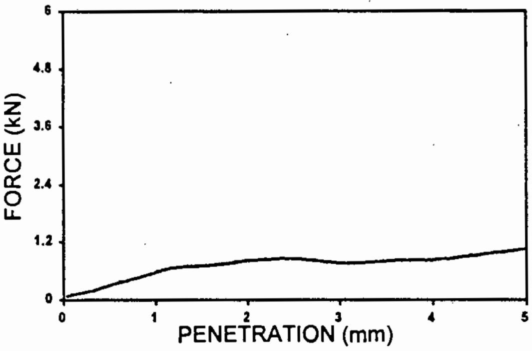

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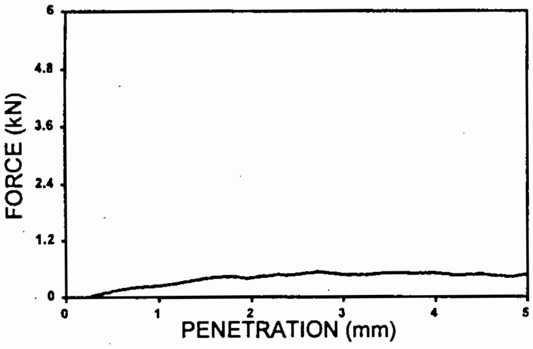

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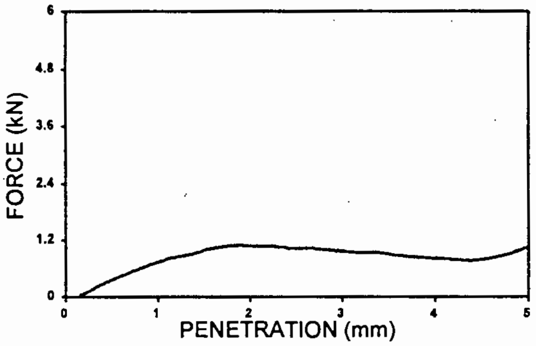

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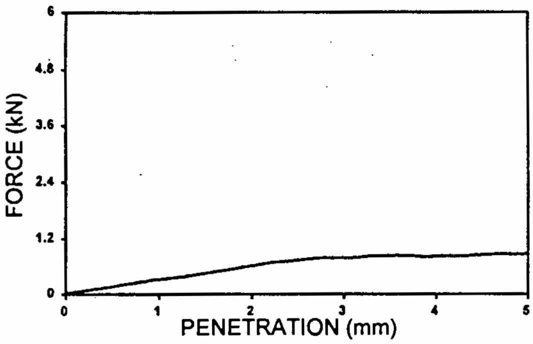

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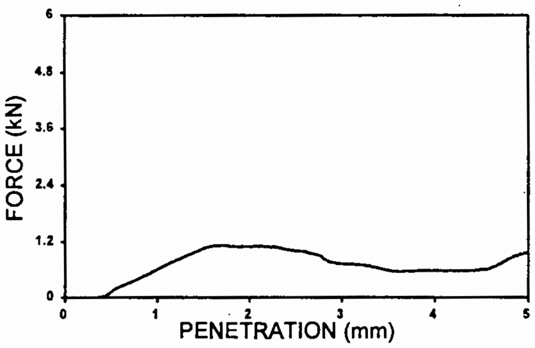
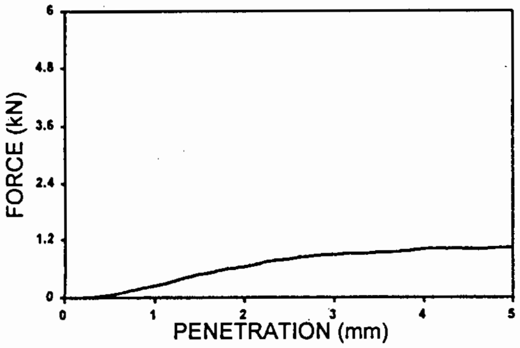


THO101



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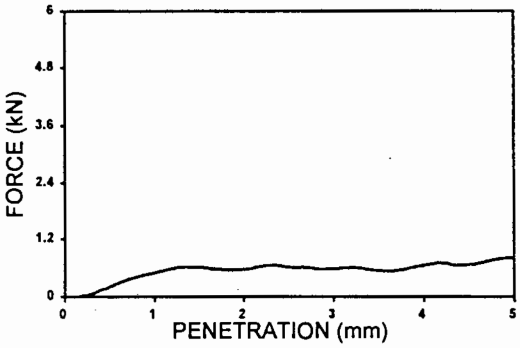

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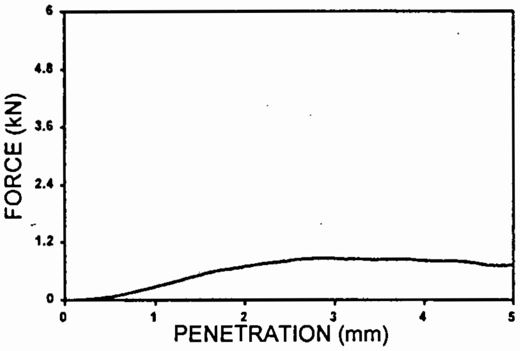

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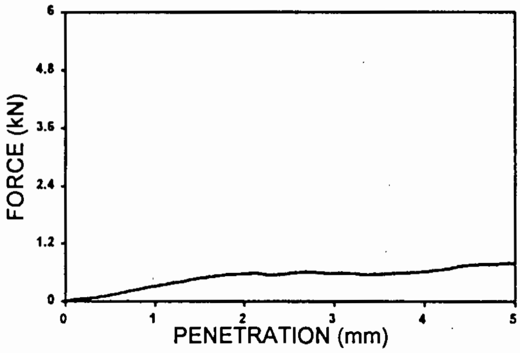

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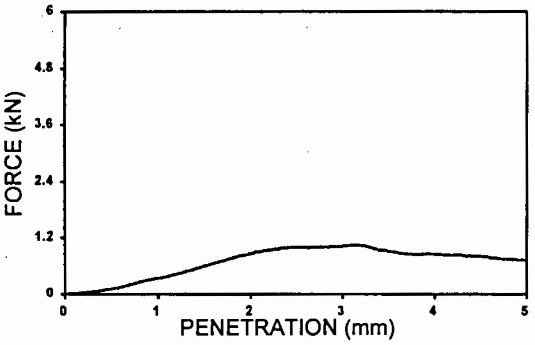

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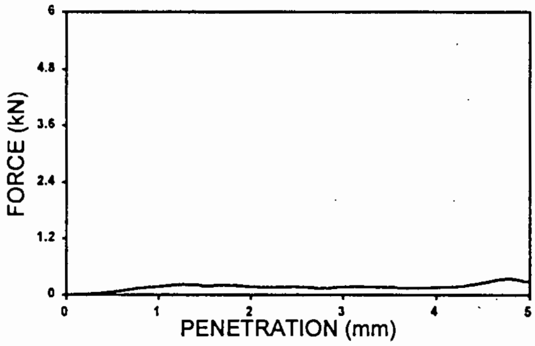

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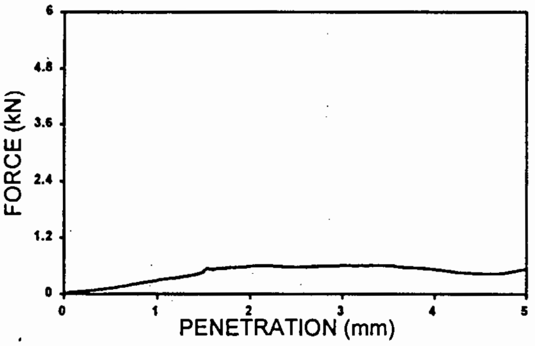

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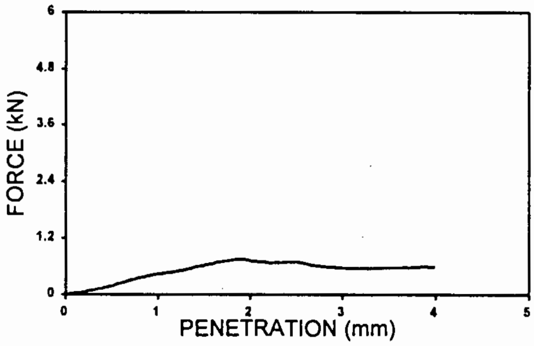

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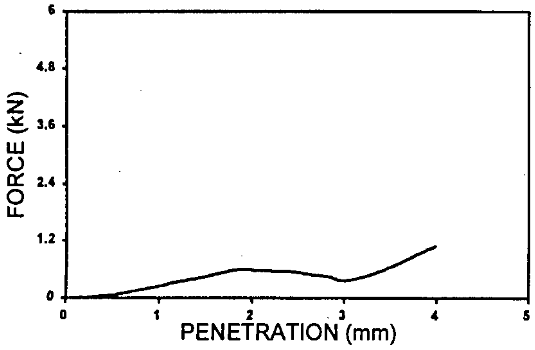
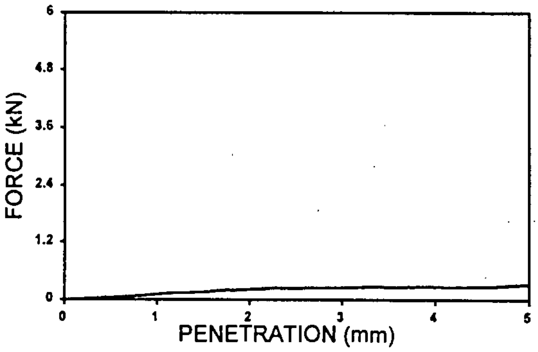


THO210



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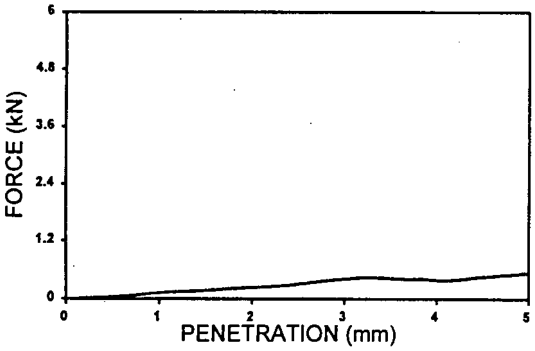
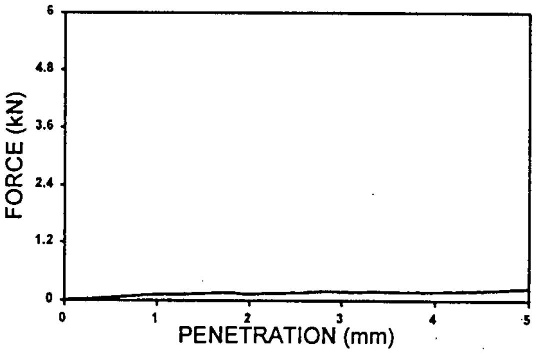
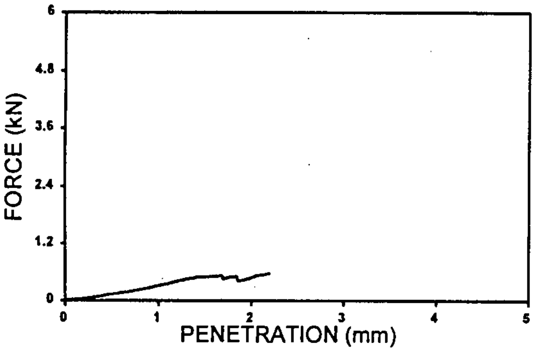


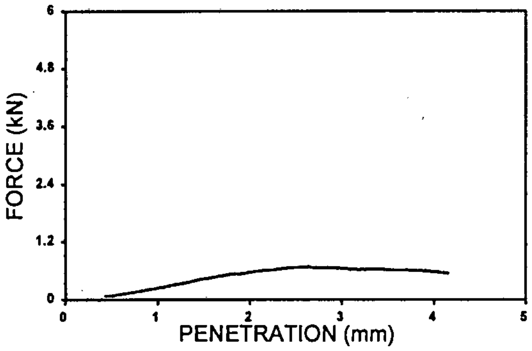
THO212



THO213



TIB101



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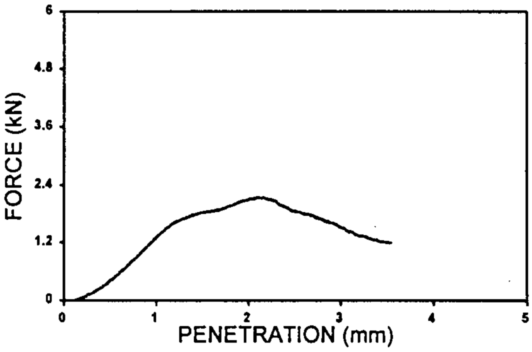

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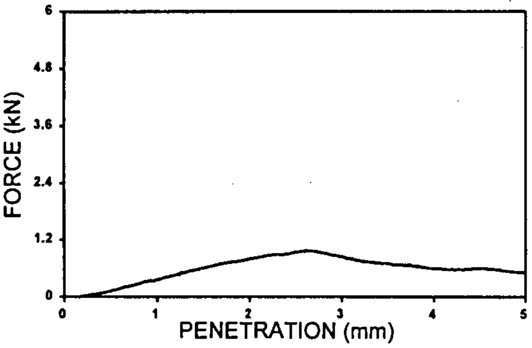

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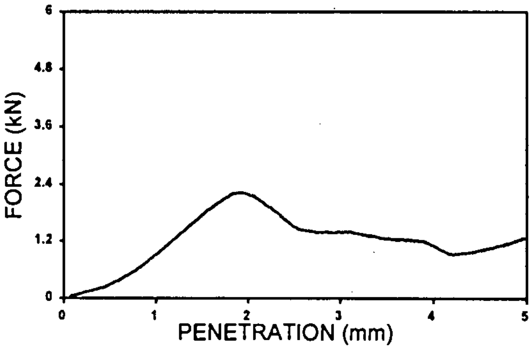

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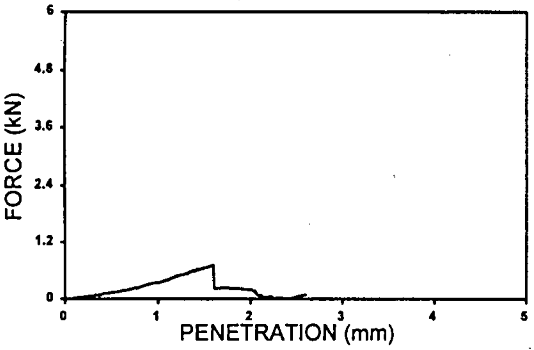
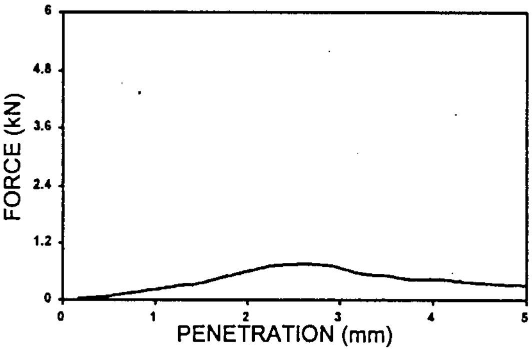
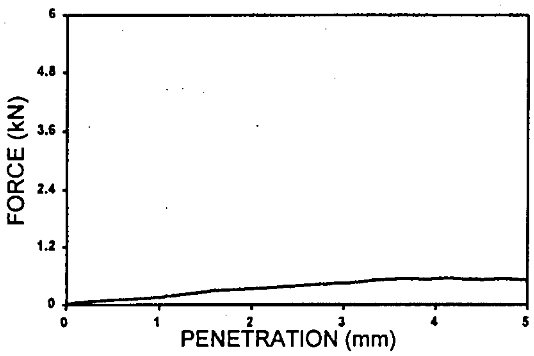


TIB106



ULNA101



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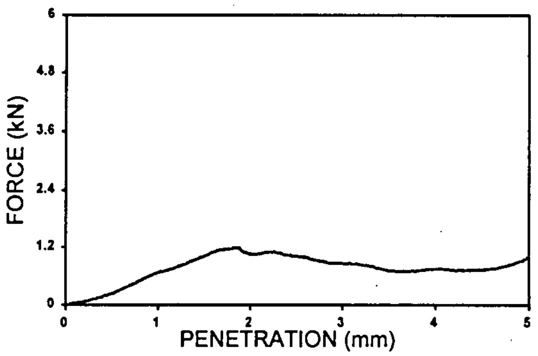

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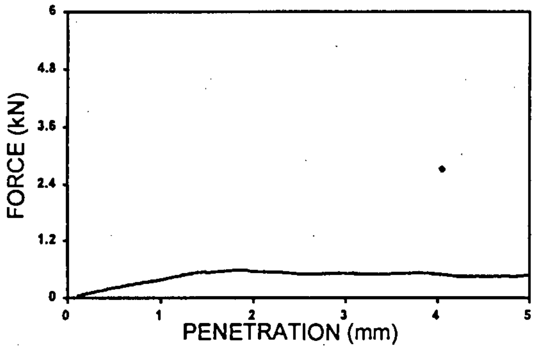
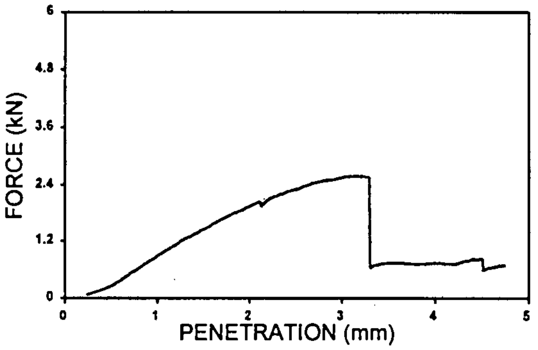


ULNA104



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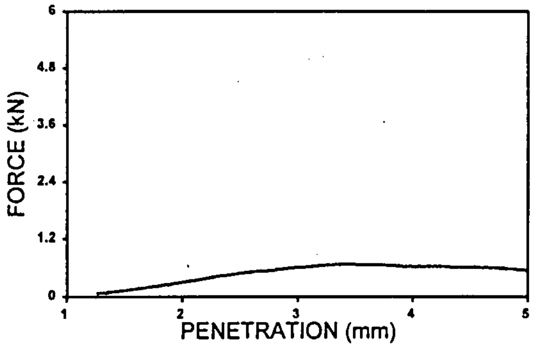

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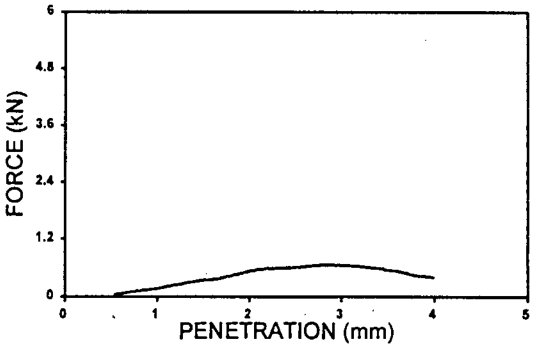
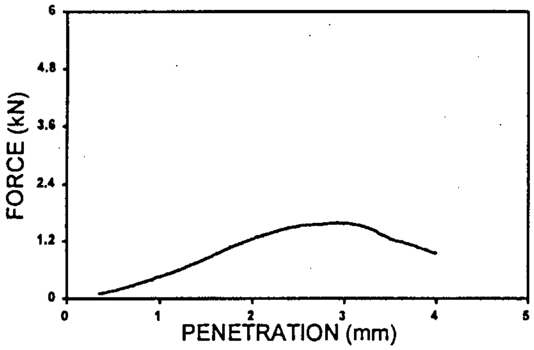


STE103



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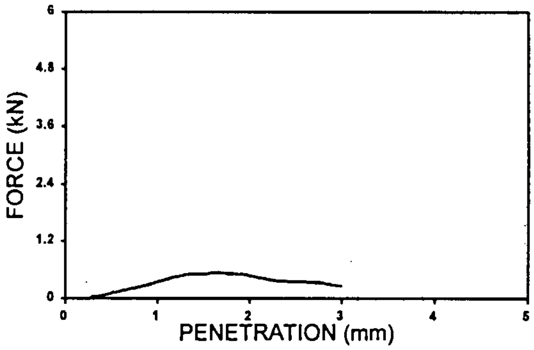

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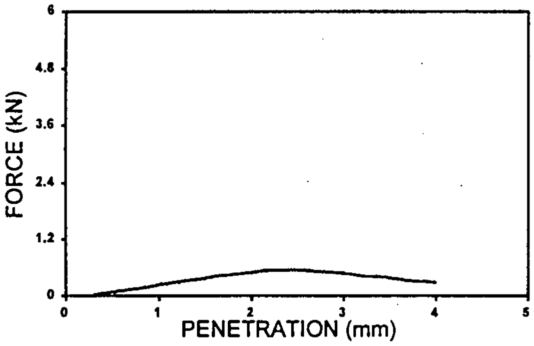
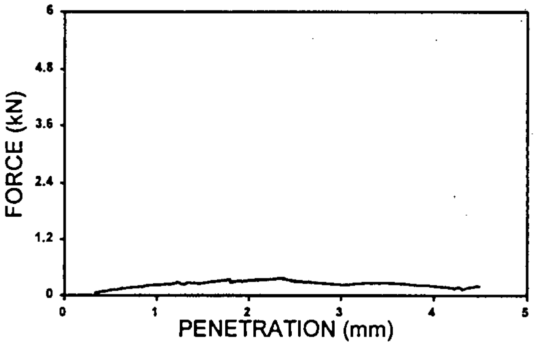


STE206



# APPENDIX C

## UTILITY DISSECTIONS

### Introduction

Six carcasses were dissected in order to determine the relative quantities of meat and fat associated with the different anatomical elements of the Cape Fur Seal. The masses reported in the following tables are in kilograms. The term "weight" removed by boiling, and its mass was calculated as the difference between the total weight and the sum of the interstitial fat and bone weights.

The acronyms, FUI, MFUI, SMFUI, MBUI and SMBUI represent: Food Utility Index, Modified Food Utility Index, Standardised Modified Food Utility Index, Modified Bulk Utility Index and Standardised Modified Bulk Utility Index respectively. The meanings of these terms are given in chapter 7.refers to the total mass of a unit including the meat, fat and bone, but not including the skin and blubber (with the exception of the flippers and sculp). Interstitial fat was removed and weighed during the dissections. The meat was

### Results

| SEAL - AP 3532 | MALE SHOT AT GORDONS BAY 2/2/89 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| LENGTH: 108.5cm | CONDITION: POOR | | | | | | | | |
| TOTAL MASS:25.8 kg | BLUBBER THICKNESS: 1.2cm | | | | | | | | |
| PIECEMEAL MASS: 31.79 | WEIGHT | INT.FAT | BONE | MEAT | FUI | MFUI | SMFUI | MBUI | SMBUI |
| SCULP | 9.04 | | | | | | 2.04 | | 1.94 |
| HEAD | 1.15 | 0.000 | 0.16 | 0.99 | 0.99 | 1.21 | 0.27 | 1.32 | 0.28 |
| CERVICAL VERTEBRAE | 1.49 | 0.000 | 0.05 | 1.43 | 1.43 | 2.93 | 0.66 | 3.07 | 0.66 |
| THORACIC VERTEBRAE & RIBS | 4.66 | 0.000 | 0.23 | 4.43 | 4.43 | 4.43 | 1.00 | 4.66 | 1.00 |
| LUMBAR VERTEBRAE & BELLY | 0.78 | 0.000 | 0.03 | 0.75 | 0.75 | 2.59 | 0.58 | 2.72 | 0.58 |
| PELVIS, SACRUM & FEMORA | 0.66 | 0.000 | 0.04 | 0.61 | 0.61 | 0.68 | 0.15 | 0.72 | 0.15 |
| LEFT TIBIA & FIBULA | 0.23 | 0.000 | 0.02 | 0.21 | 0.21 | 0.51 | 0.12 | 0.56 | 0.12 |
| LEFT HIND FLIPPER & SKIN | 0.40 | 0.000 | 0.02 | 0.38 | 0.38 | 0.39 | 0.09 | 0.43 | 0.09 |
| LEFT SCAPULA | 0.51 | 0.000 | 0.03 | 0.48 | 0.48 | 0.96 | 0.22 | 1.02 | 0.22 |
| LEFT HUMERUS | 0.32 | 0.000 | 0.03 | 0.29 | 0.29 | 0.77 | 0.17 | 0.83 | 0.18 |
| LEFT RADIUS & ULNA | 0.31 | 0.000 | 0.04 | 0.27 | 0.27 | 0.56 | 0.13 | 0.63 | 0.14 |
| LEFT FRONT FLIPPER & SKIN | 0.42 | 0.000 | 0.02 | 0.40 | 0.40 | 0.47 | 0.11 | 0.52 | 0.11 |
| VISCERA | 8.64 | | | | | | 1.95 | | 1.85 |

SEAL - AP 3930 MALE SHOT ON MMCC16 CRUISE 15/2/89
LENGTH: 175cm CONDITION: HEALTHY
TOTAL MASS: 117.5kg BLUBBER THICKNESS: 2.1cm

| PIECEMEAL MASS: 125.27 | WEIGHT | INT.FAT | BONE | MEAT | FUI | MFUI | SMFUI | MBUI | SMBUI |
|---|---|---|---|---|---|---|---|---|---|
| SCULP | 26.40 | | | | | | 1.03 | | 0.98 |
| HEAD | 2.01 | 0.000 | 0.45 | 1.57 | 1.57 | 6.29 | 0.25 | 6.66 | 0.25 |
| CERVICAL VERTEBRAE | 11.31 | 1.550 | 0.29 | 9.47 | 11.02 | 18.35 | 0.71 | 19.16 | 0.71 |
| THORACIC VERTEBRAE & RIBS | 27.00 | 2.800 | 1.32 | 22.88 | 25.68 | 25.68 | 1.00 | 27.00 | 1.00 |
| LUMBAR VERTEBRAE & BELLY | 5.20 | 0.635 | 0.18 | 4.38 | 5.02 | 15.35 | 0.60 | 16.10 | 0.60 |
| PELVIS, SACRUM & FEMORA | 3.00 | 0.470 | 0.27 | 2.26 | 2.73 | 3.87 | 0.15 | 4.10 | 0.15 |
| LEFT TIBIA & FIBULA | 1.00 | 0.063 | 0.12 | 0.81 | 0.88 | 2.24 | 0.09 | 2.50 | 0.09 |
| LEFT HIND FLIPPER & SKIN | 1.30 | 0.000 | 0.14 | 1.16 | 1.16 | 1.46 | 0.06 | 1.65 | 0.06 |
| LEFT SCAPULA | 4.20 | 0.275 | 0.16 | 3.77 | 4.04 | 8.08 | 0.31 | 8.40 | 0.31 |
| LEFT HUMERUS | 2.80 | 0.106 | 0.23 | 2.46 | 2.57 | 6.61 | 0.26 | 7.00 | 0.26 |
| LEFT RADIUS & ULNA | 1.40 | 0.002 | 0.23 | 1.17 | 1.17 | 3.73 | 0.15 | 4.20 | 0.16 |
| LEFT FRONT FLIPPER & SKIN | 1.10 | 0.000 | 0.14 | 0.96 | 0.96 | 1.65 | 0.06 | 1.95 | 0.07 |
| VISCERA | 18.35 | | | | | | 0.71 | | 0.68 |

SEAL - AP 3918 MALE SHOT ON MMCC16 CRUISE 15/2/89
LENGTH: 111cm CONDITION: HEALTHY
TOTAL MASS: 28 kg BLUBBER THICKNESS: 1.8cm

| PIECEMEAL MASS: 30.07 | WEIGHT | INT.FAT | | | | | | MBUI | SMBUI |
|---|---|---|---|---|---|---|---|---|---|
| SCULP | 6.90 | | | | | | | | 1.18 |
| HEAD | 1.25 | 0.000 | | | | | | 1.53 | 0.26 |
| CERVICAL VERTEBRAE | 1.80 | 0.115 | | | | | | 3.83 | 0.65 |
| THORACIC VERTEBRAE & RIBS | 5.85 | 0.415 | | | | | | 5.85 | 1.00 |
| LUMBAR VERTEBRAE & BELLY | 1.10 | 0.260 | | | | | | 3.48 | 0.59 |
| PELVIS, SACRUM & FEMORA | 0.62 | 0.070 | | | NO | DATA | | 0.86 | 0.15 |
| LEFT TIBIA & FIBULA | 0.25 | 0.055 | | | | | | 0.56 | 0.10 |
| LEFT HIND FLIPPER & SKIN | 0.30 | 0.000 | | | | | | 0.40 | 0.07 |
| LEFT SCAPULA | 0.90 | 0.030 | | | | | | 1.80 | 0.31 |
| LEFT HUMERUS | 0.35 | 0.015 | | | | | | 1.30 | 0.22 |
| LEFT RADIUS & ULNA | 0.40 | 0.020 | | | | | | 0.75 | 0.13 |
| LEFT FRONT FLIPPER & SKIN | 0.30 | 0.000 | | | | | | 0.55 | 0.09 |
| VISCERA | 5.75 | | | | | | | | 0.98 |

| SEAL - AP 3945 | FEMALE SHOT ON MMCC? CRUISE ? | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| LENGTH: 105cm | CONDITION: HEALTHY | | | | | | | | |
| TOTAL MASS:19.5 kg | BLUBBER THICKNESS: 1.8cm | | | | | | | | |
| PIECEMEAL MASS: 19.42 | WEIGHT | INT.FAT | BONE | MEAT | FUI | MFUI | SMFUI | MBUI | SMBUI |
| SCULP | 4.25 | | | | | | 1.14 | | 1.09 |
| HEAD | 0.85 | 0.003 | 0.11 | 0.73 | 0.74 | 0.92 | 0.25 | 1.00 | 0.26 |
| CERVICAL VERTEBRAE | 1.15 | 0.070 | 0.04 | 1.04 | 1.11 | 2.42 | 0.65 | 2.53 | 0.65 |
| THORACIC VERTEBRAE & RIBS | 3.90 | 0.085 | 0.18 | 3.64 | 3.72 | 3.72 | 1.00 | 3.90 | 1.00 |
| LUMBAR VERTEBRAE & BELLY | 0.67 | 0.065 | 0.02 | 0.58 | 0.65 | 2.19 | 0.59 | 2.29 | 0.59 |
| PELVIS, SACRUM & FEMORA | 0.36 | 0.010 | 0.04 | 0.31 | 0.32 | 0.48 | 0.13 | 0.51 | 0.13 |
| LEFT TIBIA & FIBULA | 0.17 | 0.005 | 0.02 | 0.14 | 0.15 | 0.31 | 0.08 | 0.34 | 0.09 |
| LEFT HIND FLIPPER & SKIN | 0.26 | 0.000 | 0.02 | 0.24 | 0.24 | 0.27 | 0.07 | 0.30 | 0.08 |
| LEFT SCAPULA | 0.56 | 0.003 | 0.02 | 0.53 | 0.53 | 1.07 | 0.29 | 1.11 | 0.28 |
| LEFT HUMERUS | 0.23 | 0.003 | 0.03 | 0.20 | 0.20 | 0.73 | 0.20 | 0.79 | 0.20 |
| LEFT RADIUS & ULNA | 0.24 | 0.005 | 0.03 | 0.20 | 0.21 | 0.40 | 0.11 | 0.46 | 0.12 |
| LEFT FRONT FLIPPER & SKIN | 0.22 | 0.000 | 0.02 | 0.19 | 0.19 | 0.30 | 0.08 | 0.34 | 0.09 |
| VISCERA | 3.83 | | | | | | 1.03 | | 0.98 |

| SEAL - AP 3538 | FEMALE STRAND WASH-UP | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| LENGTH: 85.4 cm | CONDITION: POOR | | | | | | | | |
| TOTAL MASS: 7.55kg | BLUBBER THICKNESS: 1.1 cm | | | | | | | | |
| PIECEMEAL MASS: 8.64 | WEIGHT | INT.FAT | | | | | | MBUI | SMBUI |
| SCULP | 1.79 | | | | | | | | 1.30 |
| HEAD | 0.77 | 0.000 | | | | | | 0.65 | 0.47 |
| CERVICAL VERTEBRAE | 0.52 | 0.000 | | | | | | 0.95 | 0.69 |
| THORACIC VERTEBRAE & RIBS | 1.38 | 0.000 | | | | | | 1.38 | 1.00 |
| LUMBAR VERTEBRAE & BELLY | 0.28 | 0.000 | | | | | | 0.83 | 0.60 |
| PELVIS, SACRUM & FEMORA | 0.25 | 0.000 | | | NO | DATA | | 0.26 | 0.19 |
| LEFT TIBIA & FIBULA | 0.09 | 0.000 | | | | | | 0.21 | 0.15 |
| LEFT HIND FLIPPER & SKIN | 0.17 | 0.000 | | | | | | 0.17 | 0.12 |
| LEFT SCAPULA | 0.19 | 0.000 | | | | | | 0.38 | 0.28 |
| LEFT HUMERUS | 0.17 | 0.000 | | | | | | 0.36 | 0.26 |
| LEFT RADIUS & ULNA | 0.15 | 0.000 | | | | | | 0.31 | 0.22 |
| LEFT FRONT FLIPPER & SKIN | 0.16 | 0.000 | | | | | | 0.22 | 0.16 |
| VISCERA | 1.46 | | | | | | | | 1.06 |

| SEAL - AP 3952 | MALE SHOT MMCC17 CRUISE 10/4/89 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| LENGTH: 111.2 cm | CONDITION: HEALTHY | | | | | | | | |
| TOTAL MASS: 27kg | TAGGED: M2101, KLEINZEE, DEC 1986 | | | | | | | | |
| PIECEMEAL MASS: 28.95 | BLUBBER THICKNESS: 1.4 cm | | | | | | | | |
| | WEIGHT | INT.FAT | BONE | MEAT | FUI | MFUI | SMFUI | MBUI | SMBUI |
| SCULP | 6.78 | | | | | | 1.36 | | 1.27 |
| HEAD | 0.98 | 0.000 | SKULL RETAINED BY SFRI | | | | | 1.31 | 0.25 |
| CERVICAL VERTEBRAE | 1.65 | 0.175 | 0.09 | 1.38 | 1.55 | 3.26 | 0.66 | 3.49 | 0.65 |
| THORACIC VERTEBRAE & RIBS | 5.33 | 0.130 | 0.35 | 4.84 | 4.97 | 4.97 | 1.00 | 5.33 | 1.00 |
| LUMBAR VERTEBRAE & BELLY | 1.08 | 0.020 | 0.07 | 0.99 | 1.01 | 2.99 | 0.60 | 3.20 | 0.60 |
| PELVIS, SACRUM & FEMORA | 0.55 | 0.030 | 0.08 | 0.44 | 0.47 | 0.74 | 0.15 | 0.81 | 0.15 |
| LEFT TIBIA & FIBULA | 0.22 | 0.005 | 0.03 | 0.18 | 0.19 | 0.42 | 0.09 | 0.49 | 0.09 |
| LEFT HIND FLIPPER & SKIN | 0.30 | 0.000 | 0.11 | 0.18 | 0.18 | 0.28 | 0.06 | 0.37 | 0.07 |
| LEFT SCAPULA | 0.98 | 0.025 | 0.04 | 0.91 | 0.93 | 1.86 | 0.37 | 1.95 | 0.37 |
| LEFT HUMERUS | 0.38 | 0.010 | 0.06 | 0.31 | 0.32 | 1.25 | 0.25 | 1.30 | 0.24 |
| LEFT RADIUS & ULNA | 0.33 | 0.015 | 0.06 | 0.25 | 0.27 | 0.59 | 0.12 | 0.71 | 0.13 |
| LEFT FRONT FLIPPER & SKIN | 0.28 | 0.000 | 0.11 | 0.16 | 0.16 | 0.35 | 0.07 | 0.46 | 0.09 |
| VISCERA | 5.72 | | | | | | 1.15 | | 1.07 |

| AVERAGE VALUES | ALL ANIMALS (6) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | WEIGHT | INT.FAT | BONE | MEAT | FUI | MFUI | SMFUI | MBUI | SMBUI |
| SCULP | 9.19 | | | | | | 2.47 | | 1.15 |
| HEAD | 1.17 | 0.00 | 0.24 | 1.10 | 1.10 | 2.37 | 0.25 | 2.08 | 0.26 |
| CERVICAL VERTEBRAE | 2.99 | 0.32 | 0.12 | 3.33 | 3.65 | 6.58 | 0.69 | 5.50 | 0.69 |
| THORACIC VERTEBRAE & RIBS | 8.02 | 0.57 | 0.52 | 8.95 | 9.52 | 9.52 | 1.00 | 8.02 | 1.00 |
| LUMBAR VERTEBRAE & BELLY | 1.52 | 0.16 | 0.08 | 1.68 | 1.84 | 5.68 | 0.60 | 4.77 | 0.59 |
| PELVIS, SACRUM & FEMORA | 0.90 | 0.10 | 0.11 | 0.90 | 1.00 | 1.42 | 0.15 | 1.21 | 0.15 |
| LEFT TIBIA & FIBULA | 0.33 | 0.02 | 0.05 | 0.34 | 0.36 | 0.86 | 0.09 | 0.78 | 0.10 |
| LEFT HIND FLIPPER & SKIN | 0.45 | 0.00 | 0.07 | 0.49 | 0.49 | 0.60 | 0.06 | 0.55 | 0.07 |
| LEFT SCAPULA | 1.22 | 0.06 | 0.06 | 1.42 | 1.48 | 2.95 | 0.31 | 2.44 | 0.30 |
| LEFT HUMERUS | 0.71 | 0.02 | 0.09 | 0.81 | 0.84 | 2.31 | 0.24 | 1.93 | 0.24 |
| LEFT RADIUS & ULNA | 0.47 | 0.01 | 0.09 | 0.47 | 0.48 | 1.32 | 0.14 | 1.18 | 0.15 |
| LEFT FRONT FLIPPER & SKIN | 0.41 | 0.00 | 0.07 | 0.43 | 0.43 | 0.69 | 0.07 | 0.67 | 0.08 |
| VISCERA | 7.29 | | | | | | 1.96 | | 0.91 |

| AVERAGE VALUES | HEALTHY ANIMALS (4) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | WEIGHT | INT.FAT | BONE | MEAT | FUI | MFUI | SMFUI | MBUI | SMBUI |
| SCULP | 11.08 | | | | | | 0.98 | | 1.05 |
| HEAD | 1.27 | 0.00 | 0.18 | 0.77 | 0.77 | 2.60 | 0.23 | 2.62 | 0.25 |
| CERVICAL VERTEBRAE | 3.98 | 0.48 | 0.14 | 3.96 | 4.44 | 7.87 | 0.70 | 7.25 | 0.69 |
| THORACIC VERTEBRAE & RIBS | 10.52 | 0.86 | 0.62 | 10.45 | 11.31 | 11.31 | 1.00 | 10.52 | 1.00 |
| LUMBAR VERTEBRAE & BELLY | 2.01 | 0.25 | 0.09 | 1.98 | 2.23 | 6.77 | 0.60 | 6.27 | 0.60 |
| PELVIS, SACRUM & FEMORA | 1.13 | 0.15 | 0.13 | 1.00 | 1.15 | 1.69 | 0.15 | 1.57 | 0.15 |
| LEFT TIBIA & FIBULA | 0.41 | 0.03 | 0.06 | 0.38 | 0.41 | 0.99 | 0.09 | 0.97 | 0.09 |
| LEFT HIND FLIPPER & SKIN | 0.54 | 0.00 | 0.09 | 0.53 | 0.53 | 0.68 | 0.06 | 0.68 | 0.06 |
| LEFT SCAPULA | 1.66 | 0.08 | 0.07 | 1.73 | 1.82 | 3.63 | 0.32 | 3.32 | 0.32 |
| LEFT HUMERUS | 0.94 | 0.03 | 0.11 | 0.99 | 1.02 | 2.84 | 0.25 | 2.60 | 0.25 |
| LEFT RADIUS & ULNA | 0.59 | 0.01 | 0.11 | 0.54 | 0.55 | 1.57 | 0.14 | 1.53 | 0.15 |
| LEFT FRONT FLIPPER & SKIN | 0.47 | 0.00 | 0.09 | 0.44 | 0.44 | 0.77 | 0.07 | 0.83 | 0.08 |
| VISCERA | 8.41 | | | | | | 0.74 | | 0.80 |

| AVERAGE VALUES | UNHEALTHY ANIMALS (2) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | WEIGHT | INT.FAT | BONE | MEAT | FUI | MFUI | SMFUI | MBUI | SMBUI |
| SCULP | 5.42 | | | | | | 1.22 | | 1.79 |
| HEAD | 0.96 | 0.00 | 0.16 | 0.80 | 0.80 | 0.88 | 0.20 | 0.98 | 0.33 |
| CERVICAL VERTEBRAE | 1.00 | 0.00 | 0.05 | 0.95 | 0.95 | 1.87 | 0.42 | 2.01 | 0.67 |
| THORACIC VERTEBRAE & RIBS | 3.02 | 0.00 | 0.23 | 2.79 | 2.79 | 2.79 | 0.63 | 3.02 | 1.00 |
| LUMBAR VERTEBRAE & BELLY | 0.53 | 0.00 | 0.03 | 0.50 | 0.50 | 1.64 | 0.37 | 1.77 | 0.59 |
| PELVIS, SACRUM & FEMORA | 0.45 | 0.00 | 0.04 | 0.41 | 0.41 | 0.45 | 0.10 | 0.49 | 0.16 |
| LEFT TIBIA & FIBULA | 0.16 | 0.00 | 0.02 | 0.13 | 0.13 | 0.34 | 0.08 | 0.38 | 0.13 |
| LEFT HIND FLIPPER & SKIN | 0.28 | 0.00 | 0.02 | 0.26 | 0.26 | 0.27 | 0.06 | 0.30 | 0.10 |
| LEFT SCAPULA | 0.35 | 0.00 | 0.03 | 0.32 | 0.32 | 0.64 | 0.15 | 0.70 | 0.23 |
| LEFT HUMERUS | 0.24 | 0.00 | 0.03 | 0.21 | 0.21 | 0.53 | 0.12 | 0.59 | 0.20 |
| LEFT RADIUS & ULNA | 0.23 | 0.00 | 0.04 | 0.19 | 0.19 | 0.40 | 0.09 | 0.47 | 0.16 |
| LEFT FRONT FLIPPER & SKIN | 0.29 | 0.00 | 0.02 | 0.27 | 0.27 | 0.32 | 0.07 | 0.37 | 0.12 |
| VISCERA | 5.05 | | | | | | 1.14 | | 1.67 |

# APPENDIX D

# LABORATORY PROCEDURES FOR BACTERIA CONTENT ANALYSIS OF SEAL MEAT

## Introduction

The analysis of seal meat contamination requires expert knowledge in the field of food preservation, and a dedicated laboratory to ensure sterile working conditions at all times. The analytical methods were not learned in the course of this study but rather referred to the Fishing Industry Research Institute personnel who regularly conduct such analyses. The analyses was conducted by E.C. Lamprecht and F.R. Riley. The methods that were employed are presented as an appendix for the benefit of those who are versed in the field of bacteria analysis, and for those who may wish to use the method in future. The following description is quoted verbatim from the published account (Smith *et al.* 1992:174-177), and the original text was written by Lamprecht and Riley.

## Laboratory Method

The procedures used here are described in the South African Government Gazette (1987), with additional references to Collins & Lyne (1985).

### *Sample preparation*

Some 20 g of seal meat was weighed into a sterile 500 ml reagent bottle. Sterile 0.1% peptone water was added to make a 200 g 1:10 dilution and blended for 45 s in a sterile blender. Further 1:10 dilutions were prepared with sterile Ringers solution.

### *Total plate count*

Tubes of sterile melted Plate Count agar (15-20 ml) were placed in a water bath at 45 °C. Aliquots (1ml) of each dilution were pipetted into duplicate sterile Petri dishes. Melted agar (15 ml) was poured into each Petri dish and swirled to mix. The plates were left to set, then inverted for incubation. Since different incubation periods have previously been found to be significant when analysing fish (Simmonds & Lamprecht 1979), the seal meat samples were incubated at 37 °C for 48 h, and 20 °C (in a sea-water based nutrient medium) for 96 h. Plates with 30-300 colonies were selected where possible, and individual colonies counted using a colony counter. From these the number of bacteria.$g^{-1}$ sample was calculated.

*Staphylococcus aureus*

Some 0.5 ml amounts of each dilution was pipetted on to the surface of duplicate plates of Baird-Parker agar, and evenly spread over the surface using a sterilised bent glass rod. The plates were incubated at 37 °C for 24-48 h. The suspect colonies, identified by their black, smooth, shiny appearance surrounded by clear zones, were counted. In addition a D-Nase test was performed by streaking the suspect colonies on D-Nase agar plates and incubating at 37 °C for 24 h. The plates were then flooded with N-HCl, and any positive reaction was noted from the formation of clear zones around the growth.

*Coliforms (MPN method)*

Some 10 ml of the 1:10 dilution was pipetted into each of five tubes containing 10 ml of double sample McConkey's broth; 1 ml of the 1:10 dilution was pipetted into each of five tubes of 5 ml single sample McConkey's broth; and 1 ml of the 1:100 dilution was pipetted into each of five tubes of 5ml single sample McConkey's broth.

Incubation took place at 37 °C for 48 h, and both acid and gas formation was noted. The number of positive tubes per dilution was recorded, and an MPN reading was made from MPN tables. Either presumptive or total coliforms were recorded. The dilution was plated on EMB agar and incubated at 37 °C for 18 h.

*Escherichia coli*

Tubes of tryptone water and Brilliant Green Bile broth (BGB) were preheated at 44 °C±0.25 °C in a thermo-statically controlled water bath. Tubes were inoculated with colonies showing greenish-black growth with a metallic sheen, and incubated at 44 °C for 24 h. Any gas in BGB tubes was noted and the indole formation in the corresponding tryptone water cultures was determined by adding 0.1-0.5 ml Kovacs Reagent. The number of cultures showing a positive indole and gas reaction in BGB was recorded, and the MPN determined. Confirmatory tests were also carried out, e.g. replating on EMB, growth in citrate medium and the Methyl Red test.

*Coliforms (Plate method)*

Violet Red Bile agar was dissolved by steaming, and the melted agar was maintained at 45 °C. 1 ml aliquots of the dilution were pipetted into duplicate sterile Petri dishes, and 15 ml melted agar added to each plate, swirled and allowed to set. Each plate was then inverted and incubated at 37 °C for 18 h. Dark red colonies (0.5-2.0 mm in diameter) were counted and recorded for total coliforms.

*Escherichia coli*

Red colonies surrounded by bile deposits were selected. The acid in BGB and indole formation at 44 °C (as described MPN for method) was determined.

*Clostridia*

Tubes containing 10 ml of freshly sterilised cooked meat medium were inoculated with 1 g of sample or 1-2 ml of a 1:10 dilution. The tubes were heated at 80 °C for 10-15 min and overlain with 2-3 ml of sterile 2% melted agar. The samples were then incubated at 37 °C for up to 14 days. Gas formation (seen from lifting of the agar layer) was noted, and the cultures were examined microscopically, as well as assessed on turbidity (as an indication of growth), to determine the presence of Gram-positive sporing rods (*Clostridium*).

# APPENDIX E.1

## ONTOGENIC AGE AND SEASONALITY PREDICTIONS FOR DUNEFIELD MIDDEN

The following table presents the age predictions for the Dunefield Midden seal mandibles. Age 1 is the predicted age in months using equations 6a and 6b and is valid for individuals aged less than 40 months at death. These values were used to determine the month of death (Month) and to construct the seasonality plot in figures 10.2 and 10.3. Age 2 is the predicted age in months using equations 5a and 5b. These values were used to construct the age (mortality) profiles presented in figures 10.2 and 10.3. UL and LL refer to the upper and lower confidence limits of Age 1.

| DFM Seals | Short Length (mm) | Age 1 | Month | UL | LL | Age 2 |
|---|---|---|---|---|---|---|
| | Cohort 1 | Males | | | | |
| TOM 78 | 55.5 | 10.9 | 10.9 | 18.8 | 6.0 | 10.6 |
| TOM 78-13 | 55.5 | 10.9 | 10.9 | 18.8 | 6.0 | 10.6 |
| ANN 13 | 54.8 | 10.1 | 10.1 | 17.6 | 5.6 | 10.0 |
| PET 9 | 54.6 | 9.9 | 9.9 | 17.3 | 5.5 | 9.8 |
| BER 50 | 54.45 | 9.8 | 9.8 | 17.0 | 5.4 | 9.7 |
| ELA 80 | 53.4 | 8.8 | 8.8 | 15.4 | 4.8 | 8.8 |
| ELA 85 | 50.8 | 6.6 | 6.6 | 11.8 | 3.4 | 6.8 |
| | | Females | | | | |
| KIR 70 | 54.6 | 10.7 | 10.7 | 29.7 | 3.3 | 9.4 |
| ELA 98-11 | 54.4 | 10.4 | 10.4 | 28.9 | 3.2 | 9.1 |
| ELA 85 | 54.4 | 10.4 | 10.4 | 28.9 | 3.2 | 9.1 |
| | Cohort 2 | Males | | | | |
| ELA 52 | 63.3 | 21.7 | 9.7 | 36.6 | 12.6 | 19.8 |
| ELA 77 | 63.2 | 21.5 | 9.5 | 36.3 | 12.5 | 19.6 |
| ELA 86 | 62.85 | 20.9 | 8.9 | 35.3 | 12.1 | 19.1 |
| BER 58 | 62.73 | 20.7 | 8.7 | 35.0 | 12.0 | 19.0 |
| TOM 99-17 | 62.3 | 20.0 | 8.0 | 33.8 | 11.6 | 18.4 |
| TOM 99 | 61.7 | 19.0 | 7.0 | 32.2 | 11.0 | 17.6 |
| KIR 70 | 59.2 | 15.3 | 3.3 | 26.1 | 8.7 | 14.5 |
| NIC 15 | 58.1 | 13.9 | 1.9 | 23.7 | 7.9 | 13.2 |
| TOM 90-30 | 57.8 | 13.5 | 1.5 | 23.1 | 7.6 | 12.9 |
| | | Females | | | | |
| ELA 85 | 60.8 | 23.6 | 11.6 | 63.0 | 8.4 | 19.7 |
| ELA 59 | 58.3 | 17.5 | 5.5 | 47.0 | 6.0 | 14.9 |
| KIR 92 | 56.5 | 13.9 | 1.9 | 37.8 | 4.6 | 12.0 |
| BER 18 | 55.7 | 12.5 | 12.5 | 34.2 | 4.0 | 10.8 |

| DFM Extension | Short Length (mm) | Age 1 | Month | UL | LL | Age 2 |
|---|---|---|---|---|---|---|
| | Cohort 1 | Males | | | | |
| DFM 4 | 54.6 | 9.4 | 9.4 | 17.7 | 4.6 | 9.8 |
| FRA 58 | 54.7 | 9.5 | 9.5 | 17.9 | 4.7 | 9.9 |
| FRA 72 | 55.9 | 10.7 | 10.7 | 20.1 | 5.4 | 11.0 |
| SHA 41 | 56 | 10.8 | 10.8 | 20.2 | 5.4 | 11.1 |
| SHA 1/14 | 56.9 | 11.8 | 11.8 | 22.1 | 6.0 | 12.0 |
| | | Females | | | | |
| SHA 62DP | 52.6 | 6.6 | 6.6 | 28.2 | 0.7 | 7.1 |
| SHA 62DP | 53.1 | 7.2 | 7.2 | 30.4 | 0.9 | 7.6 |
| FRA 65 | 55.7 | 10.9 | 10.9 | 44.3 | 1.9 | 10.8 |
| FRA 66 | 56 | 11.4 | 11.4 | 46.3 | 2.1 | 11.2 |
| FRA 85 | 56.2 | 11.8 | 11.8 | 47.6 | 2.2 | 11.5 |
| | Cohort 2 | Males | | | | |
| FRA 58 | 57.3 | 12.3 | 12.3 | 22.9 | 6.3 | 12.4 |
| SHA 13 | 57.8 | 12.9 | 12.9 | 24.1 | 6.7 | 12.9 |
| FRA 46 | 58.3 | 13.6 | 1.6 | 25.2 | 7.0 | 13.4 |
| FRA 61 | 59.5 | 15.3 | 3.3 | 28.3 | 8.0 | 14.8 |
| FRA 82 | 59.5 | 15.3 | 3.3 | 28.3 | 8.0 | 14.8 |
| FRA 61 | 63 | 21.3 | 9.3 | 39.3 | 11.5 | 19.3 |
| FRA 96 | 63.1 | 21.5 | 9.5 | 39.7 | 11.6 | 19.5 |
| SHA 62DP | 63.2 | 21.8 | 9.8 | 40.1 | 11.7 | 19.6 |
| FRA 62 | 63.2 | 21.8 | 9.8 | 40.1 | 11.7 | 19.6 |
| SHA 62DP | 63.5 | 22.4 | 10.4 | 41.2 | 12.1 | 20.0 |
| | | Females | | | | |
| FRA 86 | 58.7 | 17.2 | 5.2 | 68.2 | 3.7 | 15.6 |
| FRA 96 | 56.8 | 12.9 | 12.9 | 51.9 | 2.5 | 12.4 |
| SHA 52 | 57.6 | 14.6 | 2.6 | 58.2 | 2.9 | 13.7 |
| FRA 86 | 57.7 | 14.8 | 2.8 | 59.1 | 3.0 | 13.8 |
| | Cohort 3 | Males | | | | |
| SHA 4 | 66.3 | 29.1 | 5.1 | 53.6 | 15.9 | 24.4 |
| | > Cohort 3 | Males | | | | |
| SHA 52 | 74.2 | 60.1 | 12.1 | 111.7 | 33.3 | 40.5 |
| | | Females | | | | |
| SHA 3 | 68.7 | 72.3 | 12.3 | 283.6 | 18.7 | 43.9 |

## APPENDIX E.2

## ONTOGENIC AGE AND SEASONALITY PREDICTIONS FOR ELANDS BAY CAVE

The following table presents the age predictions for the Elands Bay Cave seal mandibles. Age 1 is the predicted age in months using equations 6a and 6b and is valid for individuals aged less than 40 months at death. These values were used to determine the month of death (Month) and to construct the seasonality plot in figures 10.4 and 10.5. Age 2 is the predicted age in months using equations 5a and 5b. These values were used to construct the age (mortality) profiles presented in figures 10.4 and 10.5. UL and LL refer to the upper and lower confidence limits of Age 1.

| Unit | Short Length (mm) | AGE 1 | MONTH | UL | LL | AGE 2 |
|---|---|---|---|---|---|---|
| EBC Upper | Cohort 1 | Males | | | | |
| EDDI G5 | 50.7 | 6.5 | 6.5 | 11.7 | 3.4 | 6.7 |
| EDDI G5 | 51 | 6.7 | 6.7 | 12.0 | 3.5 | 6.9 |
| DOLL E10 | 52.2 | 7.7 | 7.7 | 13.6 | 4.1 | 7.8 |
| JECH G7 | 52.5 | 8.0 | 8.0 | 14.1 | 4.3 | 8.0 |
| DOLL E1 | 52.6 | 8.1 | 8.1 | 14.2 | 4.3 | 8.1 |
| SURF Y6 | 55.1 | 10.4 | 10.4 | 18.1 | 5.8 | 10.2 |
| BARN F10 | 56.1 | 11.5 | 11.5 | 19.8 | 6.4 | 11.2 |
| | | Females | | | | |
| GEOB G4 | 51.4 | 6.7 | 6.7 | 19.2 | 1.7 | 6.0 |
| DOLL E9 | 51.6 | 6.9 | 6.9 | 19.8 | 1.8 | 6.1 |
| EDDI G4 | 54 | 9.9 | 9.9 | 27.4 | 3.0 | 8.6 |
| GEOB G4 | 55 | 11.4 | 11.4 | 31.2 | 3.6 | 9.9 |
| | Cohort 2 | Males | | | | |
| CLGS H2 | 57.2 | 12.8 | 12.8 | 21.9 | 7.2 | 12.3 |
| CKEE F8 | 58 | 13.8 | 1.8 | 23.5 | 7.8 | 13.1 |
| DOLL F10 | 58.9 | 14.9 | 2.9 | 25.5 | 8.5 | 14.1 |
| DOL2 G9 | 63.4 | 21.8 | 9.8 | 36.9 | 12.7 | 19.9 |
| JECH G6 | 63.7 | 22.4 | 10.4 | 37.8 | 13.0 | 20.3 |
| EDDI F8 | 63.8 | 22.6 | 10.6 | 38.1 | 13.1 | 20.5 |
| | | Females | | | | |
| NETO X6 | 56.1 | 13.2 | 1.2 | 35.9 | 4.3 | 11.4 |
| | Cohort 3 | Females | | | | |
| EDDI E6 | 61.1 | 24.5 | 12.5 | 65.2 | 8.8 | 20.4 |
| GEOB E8 | 61.2 | 24.8 | 12.8 | 65.9 | 8.9 | 20.6 |
| EDDI G7 | 64.5 | 35.8 | 11.8 | 94.8 | 13.2 | 29.2 |
| | > Cohort 3 | Females | | | | |
| DOLL F10 | 71 | 69.3 | 9.3 | 183.8 | 26.4 | 54.3 |
| JECH G6 | 88.1 | 298.2 | 10.2 | 811.1 | 114.2 | 212.3 |

| EBC Lower | Cohort 1 | Males | | | | |
|---|---|---|---|---|---|---|
| BSB1 C6 | 49.3 | 5.5 | 5.5 | 10.0 | 2.8 | 5.8 |
| BSBP D5 | 54.8 | 10.1 | 10.1 | 17.6 | 5.6 | 10.0 |
| | | Females | | | | |
| CLGS | 48.8 | 4.3 | 4.3 | 13.1 | 0.8 | 3.9 |
| BSBP F4 | 54.5 | 10.6 | 10.6 | 29.3 | 3.3 | 9.2 |
| | Cohort 2 | Males | | | | |
| BRNE A3 | 57.7 | 13.4 | 1.4 | 22.9 | 7.6 | 12.8 |
| GBAN F4 | 58.7 | 14.7 | 2.7 | 25.0 | 8.3 | 13.9 |
| BSBP D3 | 58.9 | 14.9 | 2.9 | 25.5 | 8.5 | 14.1 |
| BSB1 C4 | 59.2 | 15.3 | 3.3 | 26.1 | 8.7 | 14.5 |
| BSB2 C3 | 59.5 | 15.7 | 3.7 | 26.8 | 9.0 | 14.8 |
| NEPT A4 | 59.5 | 15.7 | 3.7 | 26.8 | 9.0 | 14.8 |
| BSB1 E5 | 59.6 | 15.9 | 3.9 | 27.0 | 9.1 | 14.9 |
| BSB2 C6 | 59.7 | 16.0 | 4.0 | 27.3 | 9.2 | 15.0 |
| GBAN F4 | 60.3 | 16.9 | 4.9 | 28.7 | 9.7 | 15.8 |
| BSBP E3 | 61.4 | 18.5 | 6.5 | 31.4 | 10.7 | 17.2 |
| BSBP C2 | 61.4 | 18.5 | 6.5 | 31.4 | 10.7 | 17.2 |
| BENE Y2 | 61.4 | 18.5 | 6.5 | 31.4 | 10.7 | 17.2 |
| NEPT Z3 | 61.7 | 19.0 | 7.0 | 32.2 | 11.0 | 17.6 |
| NEPT A5 | 61.9 | 19.3 | 7.3 | 32.7 | 11.2 | 17.8 |
| NEPT A3 | 61.9 | 19.3 | 7.3 | 32.7 | 11.2 | 17.8 |
| BSB2 C4 | 62.4 | 20.1 | 8.1 | 34.1 | 11.7 | 18.5 |
| BENE Y3 | 62.4 | 20.1 | 8.1 | 34.1 | 11.7 | 18.5 |
| NEPT A3 | 62.5 | 20.3 | 8.3 | 34.4 | 11.8 | 18.6 |
| BSB2 C6 | 62.6 | 20.5 | 8.5 | 34.6 | 11.9 | 18.8 |
| BSB2 C4 | 62.9 | 21.0 | 9.0 | 35.5 | 12.2 | 19.2 |
| BSBP D5 | 64.2 | 23.3 | 11.3 | 39.3 | 13.6 | 21.1 |
| JIME E5 | 64.2 | 23.3 | 11.3 | 39.3 | 13.6 | 21.1 |
| | | Females | | | | |
| BSB1 C4 | 56.6 | 14.1 | 2.1 | 38.2 | 4.7 | 12.1 |
| BSBP E4 | 56.7 | 14.3 | 2.3 | 38.7 | 4.7 | 12.2 |
| BSBP E4 | 57.1 | 15.0 | 3.0 | 40.7 | 5.0 | 12.9 |
| DECE B4 | 57.4 | 15.6 | 3.6 | 42.2 | 5.3 | 13.3 |
| BSBP E3 | 58.9 | 18.8 | 6.8 | 50.5 | 6.5 | 15.9 |
| BSBP D4 | 59.1 | 19.3 | 7.3 | 51.7 | 6.7 | 16.3 |
| BSBP D4 | 59.2 | 19.5 | 7.5 | 52.3 | 6.8 | 16.5 |
| NEPT Z4 | 60.2 | 22.0 | 10.0 | 58.8 | 7.8 | 18.5 |
| BSBP1 C5 | 60.3 | 22.3 | 10.3 | 59.5 | 7.9 | 18.7 |
| | Cohort 3 | Males | | | | |
| NEPT A3 | 65 | 24.8 | 12.8 | 41.8 | 14.5 | 22.3 |
| BSBP E5 | 65.7 | 26.2 | 2.2 | 44.1 | 15.3 | 23.4 |
| | | Females | | | | |
| BSBP E4 | 61 | 24.2 | 12.2 | 64.5 | 8.7 | 20.2 |
| BSB1 C5 | 62 | 27.1 | 3.1 | 72.2 | 9.8 | 22.5 |
| BSBP D4 | 63.6 | 32.4 | 8.4 | 86.1 | 11.9 | 26.6 |
| | > Cohort 3 | Females | | | | |
| BURN A2 | 78.9 | 141.9 | 9.9 | 379.6 | 54.5 | 106.1 |

# APPENDIX E.3

## ONTOGENIC AGE AND SEASONALITY PREDICTIONS FOR KASTEELBERG B

The following table presents the age predictions for the Kasteelberg B seal mandibles. Age 1 is the predicted age in months using equations 6a and 6b and is valid for individuals aged less than 40 months at death. These values were used to determine the month of death (Month) and to construct the seasonality plot in figure 10.9. Age 2 is the predicted age in months using equation 5a and 5b These values were used to construct the age (mortality) profiles presented in figures 10.7 and 10.8. UL and LL refer to the upper and lower confidence limits of Age 1.

| Layer | Unit | Short Length | Age 1 | Month | UL | LL | Age 2 |
|---|---|---|---|---|---|---|---|
| | MALES | | | | | | |
| 1 | H4 LBS | 60 | 16.4 | 4.4 | 28.0 | 9.4 | 15.4 |
| 1 | I4 SU | 52.9 | 8.3 | 8.3 | 14.6 | 4.5 | 8.4 |
| | FEMALES | | | | | | |
| 1 | G7 LBS | 60.6 | 23.1 | 11.1 | 61.6 | 8.2 | 19.3 |
| | MALES | | | | | | |
| 2 | G7 PL | 59.8 | 16.2 | 4.2 | 27.5 | 9.2 | 15.2 |
| | FEMALES | | | | | | |
| 2 | I4 SDG1 | 63.5 | 32.1 | 8.1 | 85.1 | 11.8 | 26.3 |
| 2 | G6 ML | 64.2 | 34.6 | 10.6 | 91.8 | 12.8 | 28.3 |
| 2 | F5 SDG1 | 75.5 | 105.3 | 9.3 | 280.4 | 40.3 | 80.3 |
| 2 | F6 SDG | 70.9 | 68.7 | 8.7 | 182.0 | 26.1 | 53.8 |
| 2 | F6 SDG1 | 98 | 609.3 | 9.3 | 1691.3 | 231.0 | 413.5 |
| 2 | I6 SDG1 | 89 | 319.3 | 7.3 | 869.9 | 122.1 | 226.3 |
| | FEMALES | | | | | | |
| 3 | H5 FM | 59.3 | 19.8 | 7.8 | 53.0 | 6.9 | 16.7 |
| 3 | G6 FM | 63.3 | 31.4 | 7.4 | 83.3 | 11.5 | 25.8 |
| 3 | G7 S&A | 77.3 | 123.6 | 3.6 | 329.7 | 47.4 | 93.2 |
| 3 | H7 FM | 77.9 | 130.2 | 10.2 | 347.7 | 49.9 | 97.9 |
| | MALES | | | | | | |
| 4 | H7 CS | 71.5 | 40.0 | 4.0 | 67.2 | 23.6 | 34.3 |
| 4 | H7 CS | 70.5 | 37.3 | 1.3 | 62.7 | 21.9 | 32.2 |
| 4 | J7 CS | 63.5 | 22.0 | 10.0 | 37.2 | 12.8 | 20.0 |
| 4 | G4 CS | 64.7 | 24.2 | 12.2 | 40.9 | 14.1 | 21.8 |
| 4 | G4 CS | 63.2 | 21.5 | 9.5 | 36.3 | 12.5 | 19.6 |
| | FEMALES | | | | | | |
| 4 | G4 CS | 57.7 | 16.2 | 4.2 | 43.8 | 5.5 | 13.8 |
| 4 | G4 CS | 65.4 | 39.4 | 3.4 | 104.4 | 14.7 | 31.9 |
| 4 | F5 CS | 65.3 | 39.0 | 3.0 | 103.3 | 14.5 | 31.6 |
| 4 | F7 CS | 65.1 | 38.2 | 2.2 | 101.1 | 14.2 | 31.0 |
| 4 | J7 CS | 70.6 | 66.7 | 6.7 | 176.7 | 25.3 | 52.4 |
| 4 | G6 CS | 100.6 | 726.1 | 6.1 | 2026.9 | 274.4 | 486.9 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | MALES | | | | | | |
| 5 | J7 FMP | 60.3 | 16.9 | 4.9 | 28.7 | 9.7 | 15.8 |
| 5 | F4 MPM | 67 | 28.9 | 4.9 | 48.7 | 16.9 | 25.6 |
| 5 | H4 FMP | 61.1 | 18.1 | 6.1 | 30.7 | 10.4 | 16.8 |
| 5 | G4 MPM | 67.6 | 30.2 | 6.2 | 50.9 | 17.7 | 26.7 |
| | FEMALES | | | | | | |
| 5 | F6 MPM | 64.2 | 34.6 | 10.6 | 91.8 | 12.8 | 28.3 |
| 5 | J7 FPM | 68.8 | 55.9 | 7.9 | 148.0 | 21.1 | 44.4 |
| 5 | I7 MPM | 71.5 | 72.7 | 12.7 | 192.8 | 27.7 | 56.8 |
| 5 | I5 HBMPM | 88.5 | 307.5 | 7.5 | 836.8 | 117.7 | 218.4 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | MALES | | | | | | |
| 6 | H6 BSBBMM | 71.8 | 40.8 | 4.8 | 68.6 | 24.1 | 35.0 |
| 6 | I6 BSBBMM | 67.5 | 30.0 | 6.0 | 50.5 | 17.6 | 26.5 |
| | FEMALES | | | | | | |
| 6 | I6 BSBBMM | 66.4 | 43.8 | 7.8 | 115.9 | 16.4 | 35.3 |
| 6 | I7 BSBBMM | 77.1 | 121.4 | 1.4 | 323.9 | 46.6 | 91.7 |
| 6 | I7 BSBBMM | 74.7 | 98.0 | 2.0 | 260.6 | 37.5 | 75.0 |
| 6 | I6 BSBBMM | 73.4 | 87.0 | 3.0 | 231.0 | 33.2 | 67.1 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | MALES | | | | | | |
| 7 | F5 BSWFM | 62.4 | 20.1 | 8.1 | 34.1 | 11.7 | 18.5 |
| 7 | F6 BSWFM | 54.7 | 10.0 | 10.0 | 17.4 | 5.5 | 9.9 |
| | FEMALES | | | | | | |
| 7 | H5 BSWFM | 55.5 | 12.2 | 12.2 | 33.3 | 3.9 | 10.5 |
| 7 | F5 BSWFM | 90.8 | 365.3 | 5.3 | 998.7 | 139.5 | 256.5 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | FEMALES | | | | | | |
| 8 | J6 CSL | 74.1 | 92.8 | 8.8 | 246.5 | 35.5 | 71.3 |
| 8 | J4 CSL | 69.9 | 62.3 | 2.3 | 165.0 | 23.6 | 49.1 |
| 8 | G4 CSL | 58.1 | 17.0 | 5.0 | 45.9 | 5.8 | 14.5 |
| 8 | J7 CSL | 57.8 | 16.4 | 4.4 | 44.3 | 5.6 | 14.0 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | FEMALES | | | | | | |
| 9 | G5 ONWS | 94.5 | 477.5 | 9.5 | 1315.6 | 181.7 | 329.4 |
| 9 | H4 ONWS | 58.1 | 17.0 | 5.0 | 45.9 | 5.8 | 14.5 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | MALES | | | | | | |
| 10 | I5 BSL2 | 60.8 | 17.6 | 5.6 | 29.9 | 10.1 | 16.4 |
| 10 | I5 BSL2 | 63.6 | 22.2 | 10.2 | 37.5 | 12.9 | 20.2 |
| | FEMALES | | | | | | |
| 10 | G7 BSL2 | 32 | -1.2 | 10.8 | -0.6 | -1.4 | -1.1 |
| 10 | J4 BSL2 | 42.8 | 0.9 | 12.9 | 4.6 | -0.6 | 0.9 |
| 10 | H4 BSL2 | 59.7 | 20.7 | 8.7 | 55.5 | 7.3 | 17.5 |
| 10 | J4 HadjSL2 | 59.9 | 21.2 | 9.2 | 56.8 | 7.5 | 17.9 |
| 10 | H6 OGAL | 60.3 | 22.3 | 10.3 | 59.5 | 7.9 | 18.7 |
| 10 | J4 HadjBSL2 | 60.3 | 22.3 | 10.3 | 59.5 | 7.9 | 18.7 |
| 10 | H4 BSL2 | 60.6 | 23.1 | 11.1 | 61.6 | 8.2 | 19.3 |
| 10 | H6 OGAL | 60.6 | 23.1 | 11.1 | 61.6 | 8.2 | 19.3 |
| 10 | G7 BSL2 | 62.8 | 29.7 | 5.7 | 78.8 | 10.8 | 24.5 |
| 10 | G7 BSL2 | 63.6 | 32.4 | 8.4 | 86.1 | 11.9 | 26.6 |
| 10 | F7 BSL2 | 66.1 | 42.4 | 6.4 | 112.3 | 15.8 | 34.2 |
| 10 | F2 BSL2 | 66.2 | 42.9 | 6.9 | 113.5 | 16.0 | 34.6 |
| 10 | F7 BSL2 | 66.6 | 44.7 | 8.7 | 118.3 | 16.7 | 36.0 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 10 | F2 BSL2 | 68.6 | 54.8 | 6.8 | 145.0 | 20.7 | 43.5 |
| 10 | H7 OGAL | 71.5 | 72.7 | 12.7 | 192.8 | 27.7 | 56.8 |
| 10 | I4 BSL2 | 72.5 | 80.0 | 8.0 | 212.2 | 30.5 | 62.0 |
| 10 | I4 BSL2 | 74.7 | 98.0 | 2.0 | 260.6 | 37.5 | 75.0 |
| 10 | F6 BSL2 | 76.9 | 119.3 | 11.3 | 318.2 | 45.7 | 90.2 |
| 10 | G5 BSL2 | 80 | 155.8 | 11.8 | 417.5 | 59.8 | 115.8 |
| 10 | G5 BSL2 | 80.8 | 166.6 | 10.6 | 447.1 | 64.0 | 123.3 |
| 10 | G7 BSL2 | 83.3 | 204.6 | 12.6 | 551.4 | 78.5 | 149.3 |
| 10 | G7 BSL2 | 83.4 | 206.3 | 2.3 | 556.0 | 79.2 | 150.5 |
| 10 | G7 BSL2 | 83.9 | 214.7 | 10.7 | 579.4 | 82.4 | 156.2 |
| 10 | J4 BSL2 | 84.3 | 221.7 | 5.7 | 598.6 | 85.1 | 161.0 |
| 10 | I5 OGAL | 84.6 | 227.1 | 11.1 | 613.5 | 87.1 | 164.6 |
| 10 | I5 OGAL | 86.2 | 257.6 | 5.6 | 697.9 | 98.7 | 185.2 |
| 10 | F2 BSL2 | 90.4 | 354.6 | 6.6 | 968.8 | 135.5 | 249.5 |
| | MALES | | | | | | |
| 11 | I6 GWSWS | 62.9 | 21.0 | 9.0 | 35.5 | 12.2 | 19.2 |
| 11 | F5 GWSWS | 66.1 | 27.0 | 3.0 | 45.5 | 15.8 | 24.1 |
| 11 | F5 GWSWS | 67.2 | 29.3 | 5.3 | 49.4 | 17.2 | 26.0 |
| 11 | F4 GWSWS | 60.8 | 17.6 | 5.6 | 29.9 | 10.1 | 16.4 |
| 11 | J6 GWSSWS | 60.8 | 17.6 | 5.6 | 29.9 | 10.1 | 16.4 |
| 11 | F4 GWSWS | 60.8 | 17.6 | 5.6 | 29.9 | 10.1 | 16.4 |
| 11 | J6 GWSSWS | 60.8 | 17.6 | 5.6 | 29.9 | 10.1 | 16.4 |
| | FEMALES | | | | | | |
| 11 | H5 GWSSWS | 40.3 | 0.1 | 12.1 | 2.6 | -0.9 | 0.1 |
| 11 | H4 GWSSWS | 60 | 21.5 | 9.5 | 57.5 | 7.6 | 18.1 |
| 11 | H4 GWSSWS | 60.3 | 22.3 | 10.3 | 59.5 | 7.9 | 18.7 |
| 11 | F6 GWSWS | 66.5 | 44.2 | 8.2 | 117.1 | 16.5 | 35.6 |
| 11 | F6 GWSWS | 66.9 | 46.1 | 10.1 | 122.0 | 17.3 | 37.0 |
| 11 | H5 GWSSW/S | 71.7 | 74.1 | 2.1 | 196.6 | 28.2 | 57.8 |
| 11 | H5 GWSSWS | 73 | 83.8 | 11.8 | 222.4 | 32.0 | 64.8 |
| 11 | H5 GWSSW/S | 76 | 110.2 | 2.2 | 293.4 | 42.2 | 83.7 |
| 11 | I5 GWSSWS | 76.9 | 119.3 | 11.3 | 318.2 | 45.7 | 90.2 |
| 11 | I5 GWSWS | 77.2 | 122.5 | 2.5 | 326.8 | 47.0 | 92.4 |
| 11 | H5 GWSSWS | 87.2 | 278.4 | 2.4 | 755.7 | 106.6 | 199.1 |
| 11 | H5 GWSSW/S | 87.8 | 291.5 | 3.5 | 792.2 | 111.6 | 207.8 |
| | FEMALES | | | | | | |
| 12 | J5 LBSWS | 60.2 | 22.0 | 10.0 | 58.8 | 7.8 | 18.5 |
| 12 | H5 BSM | 61.2 | 24.8 | 12.8 | 65.9 | 8.9 | 20.6 |
| 12 | F6 BSM | 66.1 | 42.4 | 6.4 | 112.3 | 15.8 | 34.2 |
| 12 | F6 BSM | 66.3 | 43.3 | 7.3 | 114.7 | 16.2 | 34.9 |
| 12 | G7 BSM | 76.6 | 116.2 | 8.2 | 309.7 | 44.5 | 88.0 |
| 12 | H5 HadjBSM | 78.9 | 141.9 | 9.9 | 379.6 | 54.5 | 106.1 |
| 12 | G7 BSM | 94 | 460.8 | 4.8 | 1268.3 | 175.5 | 318.6 |
| | MALES | | | | | | |
| 14 | I4 B&SM | 64.6 | 24.0 | 12.0 | 40.5 | 14.0 | 21.7 |
| | FEMALES | | | | | | |
| 14 | G6 DGSWS | 63.5 | 32.1 | 8.1 | 85.1 | 11.8 | 26.3 |
| 14 | F5 BSBBSM | 69.9 | 62.3 | 2.3 | 165.0 | 23.6 | 49.1 |
| | MALES | | | | | | |
| 15 | J6 DBSWS | 58.6 | 14.5 | 2.5 | 24.8 | 8.3 | 13.8 |
| 15 | H7 DBSWS | 63.8 | 22.6 | 10.6 | 38.1 | 13.1 | 20.5 |
| 15 | I7 LBMM | 68.7 | 32.8 | 8.8 | 55.1 | 19.3 | 28.7 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | FEMALES | | | | | | |
| 15 | H4 DBSS | 52.2 | 7.6 | 7.6 | 21.5 | 2.1 | 6.7 |
| 15 | I7 DBSWS | 63.7 | 32.8 | 8.8 | 87.0 | 12.1 | 26.9 |
| 15 | G7 DBSWS | 68.9 | 56.5 | 8.5 | 149.5 | 21.3 | 44.8 |
| 15 | F4 DBSWS | 68 | 51.6 | 3.6 | 136.5 | 19.4 | 41.1 |
| 15 | I7 LBMM | 66.7 | 45.2 | 9.2 | 119.5 | 16.9 | 36.3 |
| 15 | I6 OBSWS | 78.1 | 132.5 | 12.5 | 353.9 | 50.8 | 99.5 |
| | MALES | | | | | | |
| 16 | J7 PIT INFILL | 71.8 | 40.8 | 4.8 | 68.6 | 24.1 | 35.0 |
| 16 | J4 DBLWS | 62.2 | 19.8 | 7.8 | 33.5 | 11.5 | 18.2 |
| | FEMALES | | | | | | |
| 16 | I7 PIT INFILL | 55.8 | 12.7 | 12.7 | 34.6 | 4.1 | 10.9 |
| 16 | I7 PIT INFILL | 56.6 | 14.1 | 2.1 | 38.2 | 4.7 | 12.1 |
| 16 | J7 PIT INFILL | 56.9 | 14.6 | 2.6 | 39.7 | 4.9 | 12.6 |
| 16 | J7 PIT INFILL | 57.1 | 15.0 | 3.0 | 40.7 | 5.0 | 12.9 |
| 16 | G4 BBLWS | 60.5 | 22.8 | 10.8 | 60.9 | 8.1 | 19.1 |
| 16 | J7 PIT INFILL | 61.3 | 25.0 | 1.0 | 66.7 | 9.0 | 20.8 |
| 16 | H5 HDBLWS | 61.8 | 26.5 | 2.5 | 70.6 | 9.6 | 22.0 |
| 16 | H7 DBLWS | 61.9 | 26.8 | 2.8 | 71.4 | 9.7 | 22.2 |
| 16 | J7 PIT INFILL | 65.4 | 39.4 | 3.4 | 104.4 | 14.7 | 31.9 |
| 16 | J7 DBLWS | 67.4 | 48.5 | 12.5 | 128.4 | 18.2 | 38.8 |
| 16 | H7 DBSLWFS | 68.6 | 54.8 | 6.8 | 145.0 | 20.7 | 43.5 |
| 16 | J7 PIT INFILL | 72.2 | 77.7 | 5.7 | 206.2 | 29.6 | 60.4 |
| | MALES | | | | | | |
| ? | F7 ML-1 | 99.6 | 201.0 | 9.0 | 347.2 | 116.1 | 146.8 |
| ? | F7 BSL2 | 97.8 | 184.1 | 4.1 | 317.1 | 106.6 | 135.6 |
| ? | B4 140-145 | 78.9 | 65.0 | 5.0 | 109.5 | 38.3 | 53.1 |
| ? | B4 75-80 | 78.2 | 62.2 | 2.2 | 104.8 | 36.7 | 51.1 |
| ? | F7 ML-1 | 77.5 | 59.5 | 11.5 | 100.2 | 35.1 | 49.1 |
| ? | A3 RAS | 72.2 | 42.0 | 6.0 | 70.6 | 24.7 | 35.9 |
| ? | F37 SP3 | 69.3 | 34.2 | 10.2 | 57.6 | 20.1 | 29.8 |
| ? | G5 WS | 69 | 33.5 | 9.5 | 56.3 | 19.7 | 29.3 |
| ? | NSectionCleanings | 64.3 | 23.5 | 11.5 | 39.6 | 13.7 | 21.2 |
| ? | CLEANINGS | 64.2 | 23.3 | 11.3 | 39.3 | 13.6 | 21.1 |
| ? | F12 SP10 | 61.8 | 19.2 | 7.2 | 32.5 | 11.1 | 17.7 |
| ? | F12 SP10 | 60.6 | 17.3 | 5.3 | 29.4 | 9.9 | 16.1 |
| ? | F22 SP5 | 44.4 | 2.7 | 2.7 | 5.5 | 1.1 | 3.2 |
| | FEMALES | | | | | | |
| ? | F7 CLEANINGS | 37.9 | -0.4 | 11.6 | 1.2 | -1.1 | -0.4 |
| ? | A3 GCL1 | 52 | 7.3 | 7.3 | 20.9 | 2.0 | 6.5 |
| ? | F17 SP8 | 52.8 | 8.3 | 8.3 | 23.4 | 2.4 | 7.3 |
| ? | A3 GCL | 56.5 | 13.9 | 1.9 | 37.8 | 4.6 | 12.0 |
| ? | C2 55-60 | 56.8 | 14.4 | 2.4 | 39.2 | 4.8 | 12.4 |
| ? | F47 SP3 | 57.8 | 16.4 | 4.4 | 44.3 | 5.6 | 14.0 |
| ? | B4 95-100 | 58.9 | 18.8 | 6.8 | 50.5 | 6.5 | 15.9 |
| ? | TP9 | 59.1 | 19.3 | 7.3 | 51.7 | 6.7 | 16.3 |
| ? | TP4 | 60 | 21.5 | 9.5 | 57.5 | 7.6 | 18.1 |
| ? | A3 BAS1 | 60.3 | 22.3 | 10.3 | 59.5 | 7.9 | 18.7 |
| ? | F37 SP3 | 60.4 | 22.5 | 10.5 | 60.2 | 8.0 | 18.9 |
| ? | F37 SP4 | 60.8 | 23.6 | 11.6 | 63.0 | 8.4 | 19.7 |
| ? | A4 75-80 | 61.9 | 26.8 | 2.8 | 71.4 | 9.7 | 22.2 |
| ? | G4 GBSWS | 64.6 | 36.2 | 12.2 | 95.9 | 13.4 | 29.5 |
| ? | A3 SAS | 66.1 | 42.4 | 6.4 | 112.3 | 15.8 | 34.2 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| ? | I7 GNWS | 67 | 46.6 | 10.6 | 123.3 | 17.5 | 37.4 |
| ? | I5 HBG | 67.4 | 48.5 | 12.5 | 128.4 | 18.2 | 38.8 |
| ? | A2 70-75 | 68 | 51.6 | 3.6 | 136.5 | 19.4 | 41.1 |
| ? | F32 SP6 | 68 | 51.6 | 3.6 | 136.5 | 19.4 | 41.1 |
| ? | TP8 | 72.5 | 80.0 | 8.0 | 212.2 | 30.5 | 62.0 |
| ? | C2 105-110 | 74.3 | 94.5 | 10.5 | 251.1 | 36.1 | 72.5 |
| ? | F22 SP5 | 76 | 110.2 | 2.2 | 293.4 | 42.2 | 83.7 |
| ? | A3 RAS | 77.5 | 125.7 | 5.7 | 335.6 | 48.2 | 94.7 |
| ? | C2 65-70 | 84 | 216.5 | 12.5 | 584.1 | 83.1 | 157.4 |
| ? | A3 BL | 84.1 | 218.2 | 2.2 | 588.9 | 83.7 | 158.6 |
| ? | TP6 | 96.4 | 545.7 | 5.7 | 1509.5 | 207.2 | 373.0 |

# APPENDIX F

## MAU VALUES FOR ARCHAEOLOGICAL SEAL BODY PART REPRESENTATION

The following table presents the Minimum Animal Units (MAU) for the seal bone assemblages referred to in chapter 11. The values are extracted from Dr. Richard Klein's faunal identification list with his kind permission. Note that the MAU values are based on all identified specimens listed by Klein, and not the identifiable articular ends that he uses to determine Minimum Number of Individuals (MNIs).

| | | | KBB | | EBC 1 | EBC 2 | EBC 3 | DFM | DFM | DFM |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Layer 1 | Layer 2 | Layer 3 | | | | | Ext. | Total |
| **Mandible** | (MA) | 1.0 | 50.0 | 19.5 | 3.5 | 0.5 | 28.0 | 22.5 | 8.5 | 31.0 |
| **Cervical vertebrae** | (CV) | 1.6 | 64.9 | 41.9 | 3.4 | 0.1 | 25.3 | 12.0 | 3.1 | 18.1 |
| **Thoracic vertebrae** | (TV) | .5 | 37.0 | 23.5 | 4.7 | 0.6 | 21.3 | 7.1 | 0.7 | 7.8 |
| **Ribs** | (RI) | 1.2 | 33.2 | 11.5 | 4.2 | 0.6 | 9.5 | 10.2 | 3.9 | 14.2 |
| **Lumbar vertebrae** | (LV) | 3.4 | 48.3 | 24.0 | 8.0 | 0.1 | 56.0 | 7.6 | 1.4 | 9.0 |
| **Sacrum** | (SA) | 0.0 | 6.0 | 7.0 | 2.0 | 0.0 | 12.0 | 1.0 | 3.0 | 4.0 |
| **Innominate** | (IN) | 4.5 | 117.0 | 31.0 | 2.5 | 3.0 | 122.5 | 22.0 | 4.0 | 26.0 |
| **Femur** | (FE) | 10.0 | 158.5 | 58.5 | 16.5 | 3.5 | 195.0 | 36.5 | 16.0 | 52.5 |
| **Tibia** | (TI) | 6.0 | 81.5 | 30.0 | 15.0 | 3.5 | 88.0 | 20.5 | 15.0 | 35.5 |
| **Fibula** | (FI) | 4.5 | 71.5 | 31.5 | 9.0 | 1.5 | 54.0 | 20.5 | 7.0 | 27.5 |
| **Tarsals** | (TA) | 0.1 | 19.5 | 8.6 | 2.2 | 0.4 | 13.4 | 1.7 | 1.6 | 3.3 |
| **Metapodials** | (MP) | 1.3 | 35.6 | 14.5 | 4.7 | 0.7 | 20.4 | 3.3 | 1.6 | 4.8 |
| **Phalanges** | (PH) | 0.7 | 27.7 | 7.4 | 3.6 | 0.5 | 11.5 | 2.9 | 1.2 | 4.1 |
| **Scapula** | (SC) | 0.5 | 28.5 | 8.5 | 10.0 | 0.5 | 5.0 | 12.5 | 12.5 | 25.0 |
| **Humerus** | (HU) | 8.5 | 94.5 | 35.5 | 14.0 | 2.5 | 50.0 | 30.5 | 20.0 | 50.5 |
| **Radius** | (RA) | 9.5 | 145.5 | 51.5 | 24.5 | 5.0 | 113.5 | 36.0 | 12.0 | 48.0 |
| **Ulna** | (UL) | 7.5 | 79.5 | 27.0 | 12.5 | 3.0 | 62.0 | 25.0 | 14.5 | 39.5 |
| **Carpals** | (CA) | 0.5 | 16.1 | 5.5 | 0.9 | 0.4 | 8.5 | 1.5 | 1.0 | 2.5 |

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