HOLOCENE VEGETATION AND PALAEOENVIRONMENTS OF THE SOUTHERN CEDERBERG MOUNTAINS OF SOUTH AFRICA: palynological evidence from fossil hyrax (*Procavia*) dung middens

By: Mamoluoane Seliane

Supervisor: Professor Michael E. Meadows

This Dissertation is submitted as an academic requirement for the fulfilment of an MSc Degree in Environmental and Geographical Science, at the University of Cape Town

DECLARATION

This work has not been previously submitted in whole, or in part, for the award of any degree. It is my own work, each significant contribution and quotations in this dissertation from the works of other people have been attributed, cited and referenced.

Yours Sincerely

signature removed

.....

ACKNOWLEDGEMENTS

I would like to thank the All Mighty God, for granting me the strength and perseverance that were required to complete this thesis. I am very grateful to Him for the fruitful achievement He's allowed me.

A special word of thanks goes to my supervisor, Professor Mike Meadows, who guided me throughout the development of this project. His insightful comments and suggestions were very helpful. I will not forget the encouraging support he granted me; especially during very difficult times.

I am very much indebted to:

i) Dr Brian Chase – for extraction, collection and sampling of midden deposits. He has undoubtedly contributed constructively towards this project. His intelligent advises towards major approaches of the project are greatly appreciated.
ii) Professor Louis Scott – for his willingness for assistance since the beginning of this project until the end. I am very grateful for the specifics and tactics you instilled in my head.
iii) Professor Julia Lee-Thorp – helping out with stable isotope techniques

Ke leboha bo-Nkhono le bo-Ntate-moholo bohle ba Basia le ba Batloung baa seng ba re siile. Nkhono Adel le Nkhono Marah, ke leboha tsehetso ea lona bophelong ba ka. Nkeke ka lebala Mofu Ntate Tanki ka lerato la hae, litakaletso tsa mahlohonolo le katleho bophelong ba ka. Ke leboha boitelo ba hae e le motsoali kholisong ea ka. Ka mehla ke hopola khaitseli ea ka Mofu Ntate Phakiso Makhata ka moo a ileng a nts'ehetsa le ho nkhothatsa ka teng har'a mathata. Ke re le robale ka khotso Basia, Nkhono 'Mamoluoane o ntse a ts'oere letsoho la Ts'ieeng la thuto.

'Mankeng, ke phehella thuto tjena ke khothatsa uena Motloung e motle joalokaha u se u khaohile letsoho le letona. Ke leboha haholo ts'ehetso le boitelo ba hau lithutong tsa ka. U mphile lerato, thabo, khalemelo, le likeletso, 'me ua nkhothatsa ka mehla. Ka hona ke u kopela matla le thlohonolofatso ho Ramaseli.

Ke leboha lerato le bots'ehetsi ba likhaitseli tsa ka le lelapa la Seliane ka kakaretso.

To my loving Sweetheart, Mollo, who gave me support over the years, I thank you for your invariable contribution to this project. It was very sweet of you spending sleepless nights editing my work and assisting out with the organization of data. You have been very sincere to me.

This project was funded by the National Research Fund (NRF) of South Africa.

ABSTRACT

There is a paucity of palaeoenvironmental records in Southern Africa and this requires attention. Late Quaternary vegetation and palaeoenvironments are relatively easy to reconstruct in humid regions as pollen traps (swamps and peat bogs) there are usually abundant. However, arid and semi-arid regions (such as southern Africa) lack fossil pollen because of the scarcity of pollen preserving bodies. This attribute results in difficulties in palynological studies regarding late Quaternary vegetation and palaeoenvironmental reconstruction in arid and semi-arid regions. But the advent of pollen analysis of fossil faunal dung middens in arid and semi-arid areas has enabled palaeoevironmental reconstruction and interpretation in places where this could not have otherwise been easy. This project is based on pollen analysis of hyrax (*Procavia*) dung middens for the reconstruction and interpretation of vegetation history of the Western Cape Province, South Africa, thus filling the void of inadequate palaeoenvironmental records in semi-arid southern Africa. Hyrax (*Procavia*) dung middens from two sites, namely: Katbakkies Pass and Trutjes Kraal are used to reconstruct past vegetation and palaeoenvironments in the Western Cape. Two other independent palaeoenvironmental techniques, namely radiocarbon dating and stable carbon isotope analysis, are also applied. Two middens, KB1-1 and TK4 have been radiocarbon dated, obtaining three and two dates for the middens respectively. TK4, the oldest of the two, recorded a calibrated date of (Pta – 9480) 9509 ± 48 cal yrs BP at bottom and (Pta – 9463) 1314 ± 23 cal yrs BP at the top. KB1-1 yielded a calibrated date of (Pta – 9287) 3684 ± 85 cal yrs BP at the bottom, (Pta – 9288) 1765 ± 56 cal yrs BP in the middle and (Pta – 9285) 599 ± 39 cal yrs BP at the top. Pollen analysis, which is not inconsistent with the stable carbon isotopic analysis, suggests the occurrence of relatively minor vegetation and palaeoenvironmental changes in the southwestern Cape during the investigated intervals. Stable carbon isotopic analysis indicates that the southwestern Cape has been characterised by C_3 vegetation and hence dominated by winter rains for at least the periods in question.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION AND BACKGROUND

The world is currently faced with a challenge of global climate change, which affects different regions of the globe in various different ways. Evidence for the changing climate manifests itself in many ways and over many different timescales. The long-term climatic changes are marked by episodes of global glacial ice expansion and retreat, which together with fluctuating global sea levels have characterised the climate of the Quaternary period (last 2.6 mya) (Lowe and Walker, 1997). Interspersed with these major climatic shifts are short-term climatic changes which operate on timescales of geomorphological processes, prehistoric as well as historic human activities (Bell and Walker, 1992). These include the recent increases in surface temperature and changes in precipitation and atmospheric moisture (IPCC, 2001), all of which have affected Holocene vegetation (Bell and Walker, 1992).

It is normal and natural for the earth's climate to change, but now human activity is exerting its influence on the earth's climate (Oeschger, 2000). Anthropogenic climate change has resulted in increased amounts of greenhouse gases, mainly CO_2 in the atmosphere (MacDonald, 2003; Oeschger, 2000). This enhanced green house effect started about 200 years ago from the burning of fossil fuels, and is estimated to continue rising into the future due to world population growth, increasing demands for fossil fuels as well as changing land use patterns (MacDonald, 2003). Atmospheric CO_2 concentrations have risen from 280 ppm prior to the industrial revolution from the beginning of the 1800s to 360 ppm of today, reaching their highest levels in the last 100 000 years (Jouzel *et al.*, 1993). Based on these increases, global mean temperature is estimated to increase by between 1.4 and 5.8°C by the year 2100 (IPCC, 2001).

It is therefore becoming increasingly necessary to focus research on the potential impacts and implications for the postulated future temperature increase, although there are problems and limitations with the prediction of future climate and its effects on the earth's environment. One way of predicting future climate change is through the use of General Circulation Models (GCMs). These complex computer simulations, however, are only models of the way the future may work out and are reliant on past analogues as well as present analytical data for validation and to determine their predictive abilities and reliability (COHMAP, 1988). Since the Quaternary is important for providing information about past environments and informing us of the current situation and what to expect in the future (Lowe and Walker, 1997), understanding environmental change and patterns during this period is a prerequisite for good model performance and reliability of their output.

There has therefore been of late, more emphasis on the collection and collation of Quaternary evidence for climatic variation, timing, nature and frequency of the events. One means of reconstructing Quaternary palaeoenvironments is through fossil pollen analysis, which is possible because contemporary plant and animal distributions are products of Quaternary environmental change (Huntley, 1996) and, indeed, nearly all of the species from that period are still extant. Known as the analogue approach for reconstructing past vegetation from fossil material, it maintains that vegetation patterns of the present day provide information for the interpretation of past vegetation patterns (Grimm, 1988). Past environments may thereby be inferred from established floral and faunal patterns, and this information may be augmented by a detailed analysis of fossil biota evidence tied to information about contemporary environmental requirements of the organisms concerned.

The distribution of evidence for Quaternary palaeoenvironmental change, however, is skewed between the two hemispheres of the globe. The Northern Hemisphere is more fully represented in this respect than the Southern Hemisphere, and as a result palaeoenvironmental evidence there is relatively well understood such that there is an emerging consensus concerning the patterns as to how Quaternary environments evolved (Meadows, 2001). In southern Africa in particular, there is a notable paucity of Quaternary palaeoenvironmental records (Figure 1.1) (Meadows, 2001; Meadows and Chase, 2004; Scott and Lee-Thorp, 2004). Given the importance of southern

Africa in respect both of its prolific biodiversity and the role that it plays in climate dynamics in general, the situation of lack of evidence for change in the Quaternary certainly warrants attention.

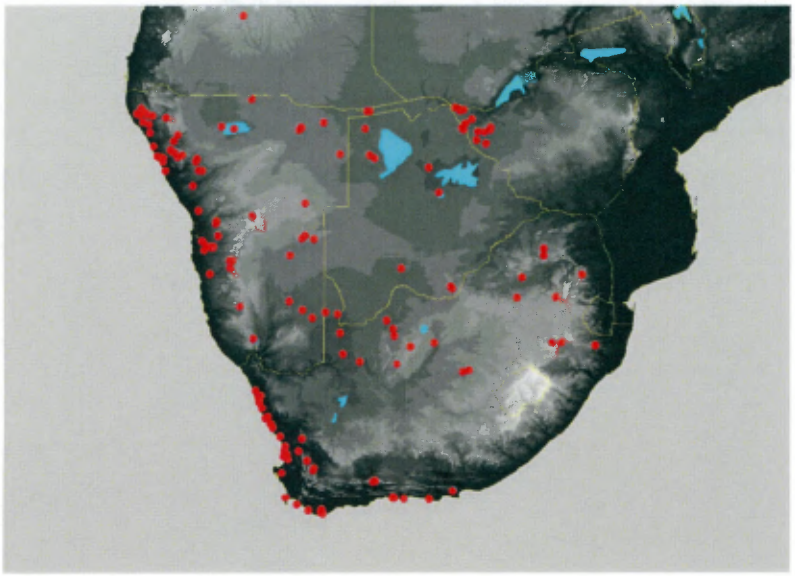

Figure 1.1 Sites (designated by the red dots) with late Quaternary palaeoenvironmental records in southern Africa (from Meadows and Chase (2004)).

The problem of inadequate evidence becomes even more noticeable when silt and carbonate records are excluded (as they are not well dated) from the available record, so that an exhibit of the appropriate biological evidence for the period reveals even more gaps (Figure 1.2). Even greater limitations are apparent over specific time periods such as around the Last Glacial Maximum (LGM) (Figure 1.3).

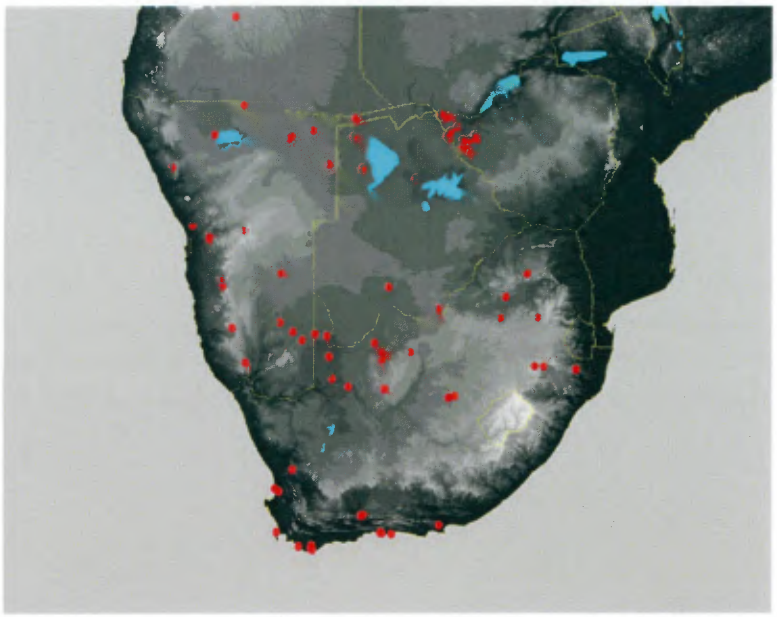

Figure 1.2 Late Quaternary Southern African palaeoenvironmental sites (designated by red dots) with silt and carbonate records excluded (from Meadows and Chase (2004)).

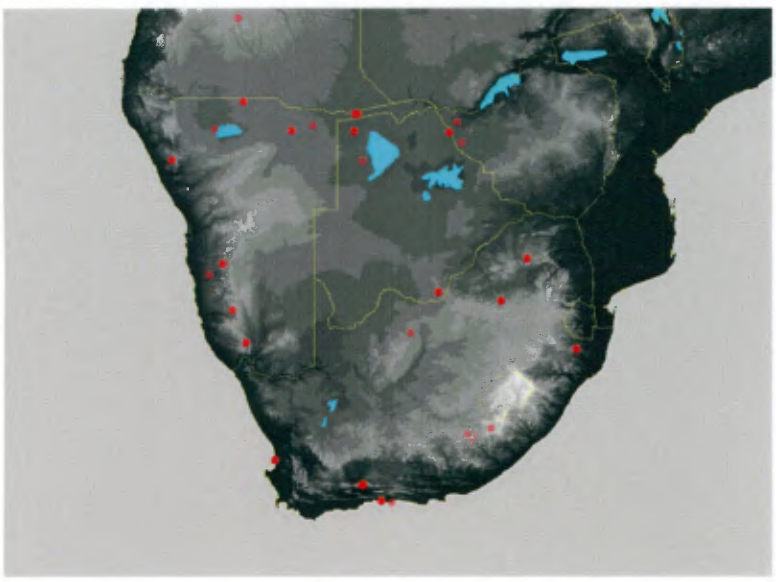

Figure 1.3 Late Quaternary Southern African palaeoenvironmental sites (designated by red dots) around the time of the Last Glacial Maximum (from Meadows and Chase (2004)).

It can be seen that there is a substantial void in terms of evidence for Quaternary palaeoenvironmental change in southern Africa and that biological evidence is even more limited. The ongoing search for such sources, then, might be regarded as a priority to provide a picture of the Quaternary environments in the region with a view to more precise reconstructions.

1.2 PALYNOLOGICAL STUDIES IN SOUTH AFRICA

The study of palynological archives in the country began about four decades ago, but the late 1980's and early 1990's saw more interest in the investigation of late Quaternary vegetational change through pollen analysis in South Africa. Despite these efforts and continuing research, the country is relatively poor in palynological data. Even those that do exist are chronologically problematic and the record is often fragmentary. This paucity of palynological evidence is attributed to the lack of pollen preserving bodies such as swamps and peat bogs (Scott, 1990).

The analysis of hyrax (*Procavia* spp.) dung middens for pollen promises a fruitful body of pollen evidence in the country in the future (Scott and Bousman, 1990). These are deposits formed by continued use of latrines by hyrax colonies and are well preserved in dry environments where there is limited chemical alteration of the deposits. The middens are consolidated faecal heaps (Scott, 2002) containing faecal pellets, sediment, dust, hairs, macro- and micro-plant fragments such as pollen, hardened and preserved by quick drying urine (Scott, 1990; 1996; Scott and Bousman, 1990; Scott and Cooremans, 1992).

Comparatively more studies of hyrax midden pollen analysis have been done in the Free State and Karoo (Scott, 1990; Scott and Bousman, 1990; Scott and Cooremans, 1992), than in the southwestern Cape. The search for these deposits and the analysis of their pollen has potential for Quaternary palaeoenvironmental reconstruction and interpretation, as do swamp derived pollen sources. Although these two palaeoenvironmental methods have different set of biases, hyrax midden pollen analysis provides evidence of changes in vegetation of the area, whereas swamp derived pollen sources are overrepresented by swamp elements which overwhelm the regional pollen signal (Scott and Bousman, 1990).

In broad terms, this project attempts to contribute, from a palynological perspective, to the reconstruction and interpretation of the late Quaternary palaeoenvironments of the southwestern Cape of South Africa based on the following aim and objectives.

1.3 AIM

To use pollen derived from fossil hyrax (*Procavia* spp.) middens to extend the late Quaternary palaeoecological record for the winter rainfall zone (WRZ) of South Africa in order to shed light on the changes in rainfall, temperature, fire regime and human disturbance that have characterised the period.

1.4 OBJECTIVES

- Identify suitable fossil hyrax dung middens in the region.
- Collect and sample fossil hyrax middens.
- Obtain a chronology for the hyrax midden material and establish if there is a logical chronostratigraphy for such deposits.
- Determine proportions of C_3 and C_4 plants in the study area through stable carbon isotope analysis.
- Reconstruct late Quaternary vegetation of the area through pollen analysis of hyrax dung middens.
- Reconstruct broader palaeoenvironmental conditions for the period in question, including climatic, fire regime and human disturbance indicators based on the above analyses.

1.5 CONCLUSION

Having introduced the thesis, and given its aim and objectives, the next chapter reviews the southwestern Cape Holocene palaeoenvironmental evidence from different sources. Chapter 3 constitutes the theoretical background of faunal fossil middens and their role in palaeoecology, and ends with a discussion of methodological procedures applied in conducting the research. Chapter 4 presents the environmental context (geology, climatic conditions and vegetation) of the WRZ and that of the specific study sites. The results of pollen analysis, stable carbon isotope analysis as well as radiocarbon dating are presented in Chapter 5. The discussion, palaeoenvironmental reconstruction, and interpretations form Chapter 6. Chapter 7, wraps up and draws conclusions about the findign of the study.

CHAPTER 2

THE LATE QUATERNARY PALAEOENVIRONMENTAL CONTEXT OF THE SOUTH WESTERN CAPE

2.1 INTRODUCTION

This chapter starts by presenting the significance of the Holocene. The evidence of late Quaternary palaeoenvironmental change, with particular focus on the Holocene in the southwestern Cape, is reviewed. This chapter puts the record obtained in this project in a temporal context, with the review covering environmental evidence from the beginning of the Holocene until about 600 cal yrs BP which is the span of the chronological sequence obtained in this study. Finally, the limitations associated with the reconstructions and interpretations of data are discussed.

2.2 THE SIGNIFICANCE OF THE HOLOCENE

The Quaternary Period spans about the last 2.6 million years (Pillans, 2004a; Pillans, 2004b). Approximately the last 11,500 cal yrs BP make up the Holocene (Mayewski *et al.*, 2004), covering a period during which full interglacial conditions prevailed (Mayewski *et al.*, 2004; Oldfield, 2005).

The Holocene is regarded as an important part in the history of the earth for the following reasons (Oldfield, 2005):

1. it provides the majority of the most recent examples of climatic changes and their variability during warm interglacials
2. it continues to the present day, permitting the calibration measurements of the present day which are required for the reconstruction and interpretation of proxy evidence

3. it is a time frame within which the exploration of the diverse modes of climate variability can be more successful. The understanding of this will inform us about the contemporary situation as well as improve the confidence of future predictions based on model simulations

4. generally, more accuracy is achieved and less problems associated with dating of material of Holocene age especially when using radiocarbon dating and tree rings. Taylor (1987) emphasises that difficulties of radiocarbon dating increase with application in the Pleistocene, as older dates are less reliable.

2.3 EVIDENCE OF HOLOCENE PALAEOENVIRONMENTAL CHANGE IN THE SOUTHWESTERN CAPE

Considerable effort has been put into the investigation of late Quaternary palaeoenvironments of the southwestern Cape. Researchers (Avery, 1990; Chase, 2005; Meadows and Baxter, 1999; Meadows and Baxter, 2001; Meadows *et al.*, 1996; Partridge *et al.*, 1990; Scott, 1994) have collated evidence derived from independent palaeoenvironmental sources in order to give a more coherent picture of the nature of the late Quaternary palaeoenvironmental change in the region. Although the data reveal some temporal gaps as well as several inconsistencies between data sets and in their interpretation, there is a degree of consensus about other important climatic and environmental signals (Meadows and Baxter, 1999).

Three distinct periods characterise the Holocene: the early Holocene, the Holocene Altithermal (HA) and the late Holocene respectively. The Holocene climatic and environmental changes reviewed below will be presented as available evidence from various data sources indicating fluctuations in temperature, precipitation, sea level and human disturbance (where applicable) under the three periods structuring the Holocene. It is important to note at this stage the manner in which ages derived from the various publications will be reported: All uncalibrated radiocarbon ages from other publications have been calibrated using CalPal2004 (www.calpal.de) and these are reported here with the suffix "cal yrs BP". Ages obtained from other methods,

namely U-series dates and dates which use ^{18}O stratigraphies or a combination of ^{18}O stratigraphies and luminescence ages are reported with the suffix "ka".

2.3.1 THE EARLY HOLOCENE (11 500 – 8000 cal yrs BP)

The early Holocene covers the period from the beginning of the Holocene (11 500 cal yrs BP) up to the beginning of the HA (8 000 cal yrs BP). The climate of the entire Holocene, for both the interior and along the south coast, appears to have in general been less pronounced than those during the last glacial and immediate post glacial (Avery, 1990).

2.3.1.1 TEMPERATURE

Generally, the Holocene is regarded as the time of climatic amelioration (Lowe and Walker, 1997) at the beginning of which, following the last glacial, rapid temperature increases were experienced. Indications for increasing temperatures during this period are present from both terrestrial and marine studies. Avery (1982) analysed evidence from micromammalian fossils from Boomplaas Cave (situated in the Cango Valley, Southern Cape) indicating that this is a period of increasing temperatures, although fluctuation is evident during the period between 12 300 and 10 200 cal yrs BP. Within this fluctuation period, an accelerated temperature increase seems to have occurred around 11 500 cal yrs BP. The marine evidence reflects that increasing sea surface temperatures have been recorded at the beginning of 12 000 cal yrs BP until the end of the early Holocene based on alkenone data from marine cores GeoB1711 (Kirst *et al.*, 1999), GeoB1028 and GeoB1016 (Schneider *et al.*, 1995) from a continental slope off Namibia and the Angola Basin east of Equatorial South Atlantic respectively. However, the Partridge *et al.*, (1990) review documents a cooler episode than prevailed before the Holocene based on microfaunal, pollen and charcoal evidence in the southwestern Cape between 10 100 and 8 900 cal yrs BP. Cohen and Tyson (1995) further report cooler SST from marine mollusc shells in the eastern Agulhas Bank.

2.3.1.2 PRECIPITATION

Evidence from the earliest part of the Holocene in the southwestern Cape from biological data has been interpreted as indicating conditions significantly wetter than present (Partridge *et al.*, 1990). Similarly, the occurrence at Elands Bay Cave of hedgehogs, which presently occur at regions receiving an annual rainfall between 300 to 800 mm (Klein and Cruz-Uribe, 1987) and that of large dune molerats (*Bathyergus suillus*) indicate annual rainfall of around 400 mm (Klein, 1991). These reflect more humid conditions at Elands Bay (Klein, 1991; Klein and Cruz-Uribe, 1987) during the earliest part of the early Holocene as the region now only receives about 200 mm of rain per year. The report by Sugden (1989b) and Meadows and Sugden (1991b) of the occurrence of higher frequencies of proteoid fynbos and a restioid understorey to groves of *Widdringtonia* at Sneeuberg around 10 900 cal yrs BP as well as the presence of ericaceous fynbos with an overstorey of cedars at Driehoek around this time, lends support to greater moisture availability during the early Holocene.

However, Avery (1990), reports that there was an indication of relatively more arid conditions at Byneskranskop (about 200 km south of TK on the southwest coast) since the beginning of the early Holocene until about 10 200 cal yrs BP than at present. This is thought to have possibly been caused by the preceding rise in temperature (Avery, 1990). At Bloomplaas as well, micromammal analysis indicates drier early Holocene conditions (Avery, 1982). Micromammalian data from Elands Bay Cave indicates presence of less grassy/restiod vegetation around 8 900 cal yrs BP compared to either before or after this date, which may indicate somewhat lower rainfall at this time (Avery, 1990). Still at Elands Bay Cave, charcoal evidence indicates gradual replacement of mesic thicket taxa by asteraceous shrubs and xeric thicket, at around 11 300 cal yrs BP which prevails throughout the span of the early Holocene (Parkington *et al.*, 2000). Lower Verlorenvlei and adjacent coastline archaeological sites show no evidence of human occupation of the area after about 8 600 cal yrs BP, which has been explained by indications of aridity around this period and after (Meadows *et al.*, 1996; Parkington *et al.*, 1988). Shi *et al.*, (2000) show that arid conditions have also been registered between about 11 000 and 8900 cal yrs BP from pollen analysis of the GeoB1023-5 marine core, which suggests the prominence

of dry and halophytic habitats in this region based on the presence of desert and semi-desert pollen taxa including Chenopodiaceae-Amaranthaceae and *Tribulus*.

2.3.1.3 SEA LEVEL

Compared to the significantly more dramatic sea level fluctuations of the Last Glacial Maximum, sea level changes during the Holocene are considered to have been relatively minor (Chase, 2005). However, relative sea level fluctuation along the West Coast has characterised the evolution of Holocene environments at Verlorenvlei (a large fresh water coastal estuarine lake system situated at Elands Bay which is about 180 km north of Cape Town) and surroundings (Baxter and Meadows, 1999). A sea level curve, based on pollen, sedimentological, archaeological and geochemical analyses of cores derived from Grootdrift indicates that Holocene sea level at the vicinity of Verlorenvlei reflects four distinct phases (Figure 2.1) with a transgression around 8 900 cal yrs BP.

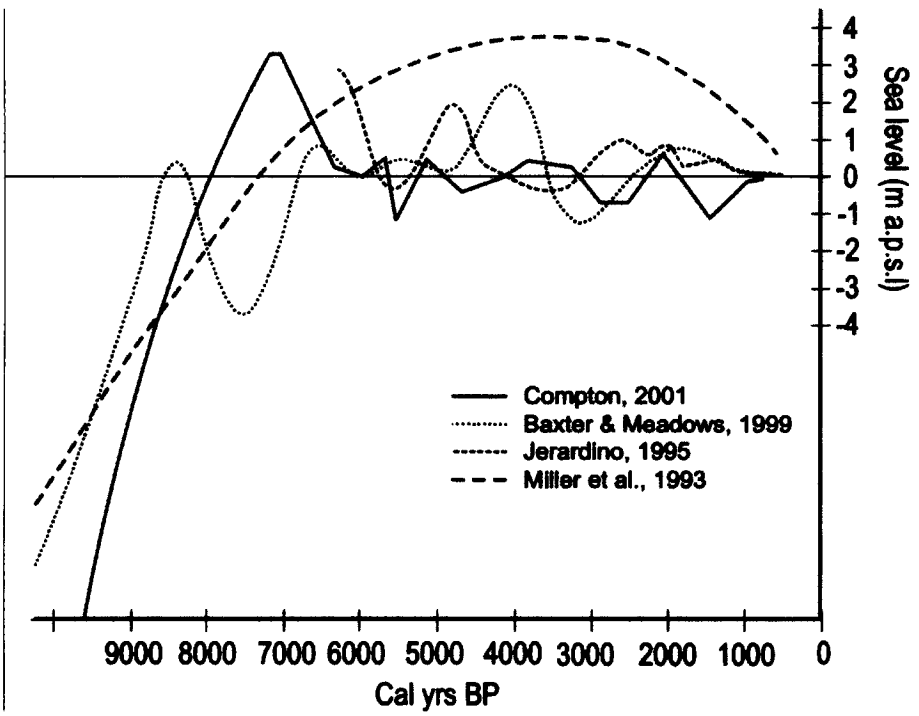

Figure 2.1 Sea level curve from Verlorenvlei (Baxter and Meadows, 1999) compared with studies by Miller et al., (1993), Jerardino (1995) and Compton (2001).

2.3.2 THE HOLOCENE ALTITHERMAL (HA) (8 000 - 6 000 cal yrs bp)

The HA is an important event in the late Quaternary of South Africa and is characterised by the warmest temperatures of the Holocene. This temperature increase is thought to have been regionally variable (Avery, 1990). Palynological evidence suggests that so-called 'optimum' conditions which characterise this period occurred earlier in the north than in the south (Scott, 1993). This period is thought to have lasted from about 8 000 to 6 000 cal yrs BP (Heaton *et al.*, 1986; Partridge *et al.*, 1990; Partridge *et al.*, 1999). In order to accommodate a wider array of available evidence, and also because other evidence suggests this, the interval here is discussed in relation to a longer duration of 8 000 – 4 000 cal yrs BP.

2.3.2.1 TEMPERATURE

Temperatures during the HA are, based on groundwater data thought to have not gone beyond the Holocene average by more than 2° C (Partridge *et al.*, 1990).

Martin (1968) recorded a warming around 7 800 cal yrs BP, even though its nature and duration could not be established due to associated changes in dune activity. The environmental interpretation attained by Martin (1968) was, however, obscured by problems related to pollen taxonomy, the association of the sediments with marine influence and the highly dynamic dune system. Based on pollen evidence from Namibian marine cores, an expansion of dry forest woodland vegetation in the northern Kalahari, under warmer and wetter conditions than today has been suggested between 6 300 and 4 800 cal yrs BP (Shi *et al.*, 2000).

Higher sea surface temperatures relative to the early Holocene are recorded during the beginning of the HA until about 6 000 cal yrs BP from alkenone data from GeoB1711 (Kirst *et al.*, 1999), GeoB1028 and GeoB1016 (Schneider *et al.*, 1995) from continental slope off Namibia and the Angola Basin, respectively. Similarly, warmer sea surface temperatures are inferred at around 8 900 to 6 000 cal yrs BP from marine core GeoB1023-5 based on an increased abundance of dinoflagellate *Polysphaeridium zoharyi* cysts which prefer tropical to subtropical environments (Shi *et al.*, 2000).

After 6 000 cal yrs BP, the lower percentages of *P. zoharyi* are due to increased percentages of *Spiniferites delicates* cysts rather than cooler SSTs, as is also the case with the marine core GeoB1008 (Dupont *et al.*, 1999).

2.3.2.2 PRECIPITATION

Evidence obtained from micromammalian data from Byneskranskop, Boomplaas and Klipfonteinrand (in the Cederberg mountains above Clanwilliam) indicates a shift in rainfall seasonality which was manifested as an extended winter rainfall season in the southwestern Cape region during the HA (Avery, 1993). Avery (1990) infers higher rainfall from the beginning of the Holocene until about 7 400 cal yrs BP from micrommamalian analysis at Byneskranskop. At Driehoek moist conditions are inferred from the presence of a restiod fynbos vegetation with proteoid overstorey during the HA (Meadows and Sugden, 1991b). On the contrary, at Elands Bay Cave, drier conditions during the HA are suggested by the replacement of mesic thicket taxa by asteraceous shrubs and xeric thicket with the former entirely disappearing around 4 700 cal yrs BP as indicated by charcoal evidence (Parkington *et al.*, 2000).

Further support for increasingly arid mid-Holocene climatic conditions is obtained from pollen studies. At around 8 300 cal yrs BP, Baxter (1989) reports drier conditions from pollen analysis of a cave deposit at Cecilia Cave on Table Mountain. In the Cederberg, at Pakhuis Pass, drier conditions are inferred from pollen analysis from 7 700 to 4 400 cal yrs BP (Scott, 1994). Meadows and Sugden (1991b) also indicate that asteraceous fynbos vegetation characterised the HA interval at Sneeuberg, suggesting drier conditions. A dominance of Poaceae, Asteraceae and Chenopodiaceae pollen at Klaarfontein, 18 km inland from Elands Bay Cave between 7 500 and 4 000 cal yrs BP indicates the occurrence of more arid conditions than today (Meadows and Baxter, 2001). The absence of evidence of regular prehistoric human occupation of sites around Verlorenvlei and surrounding archaeological sites (Meadows *et al.*, 1996; Parkington *et al.*, 1988) during the latter part of the early Holocene, lasted until 4 900 cal yrs BP, which follows that arid conditions extended largely into the mid Holocene interval. The mean size measurements of distal humeri of dune molerats excavated both at Elands Bay Cave and Tortoise cave (4 km inland

along the south bank of Verlorenvlei) archaeological sites decreases significantly after 4 900 cal yrs BP, which has been interpreted as indicating a shift to drier conditions during the mid-Holocene (Klein and Cruz-Uribe, 1987).

The idea of an arid mid-Holocene accords with geomorphological activity from the southwestern Cape coast sediments of the 4.4 - 5.8 ka phase, which has been interpreted by Chase (2005) as indicative of increased aridity. Furthermore, younger reticulate dune fields from the south west coast of South Africa covering the period from 4 to 8 ka BP represent a reworking of aeolian deposits as a result of the increased mid-Holocene aridity in the region (Chase, 2005).

2.3.2.3 SEA LEVEL

The available evidence for sea level change points to a higher mid-Holocene sea level stand around the southern African coastline. However, during the early middle Holocene, a sea level regression at around 7 400 cal yrs BP during which a sea level fall of at least 3 m and resulting in sand dune formation on the southern margin of Verlorenvlei, is evident (Figure 2.1) (Meadows and Baxter, 1999). Following this event, the two sea level curves from Jerardino, (1995) and Meadows and Baxter (1999), show a mid-Holocene sea level transgression between about 6 800 and 4 500 cal yrs BP, with the timing of the records certainly different. They indicate that the mid-Holocene sea level was about 2 m higher than that of the present day (Figure 2.1). Further support for higher sea level during the interval of the HA comes from the evidence from sediments in Groenvlei, in the southern Cape, which document a middle Holocene relative sea level rise of around +1.5 m, coinciding with warmer temperatures from about 7 700 cal yrs BP (Martin, 1962; 1968). Additional high sea level (about 3 m) evidence dating to around 6 700 cal yrs BP has been derived from excavations revealing shell beds in Knysna (Marker and Miller, 1993; Marker and Miller, 1995).

2.3.3 THE LATE HOLOCENE

This period is the last portion of the Holocene and extents up to the present. It is characterised by several oscillations of small amplitude in temperature and wetness (Partridge *et al.*, 1990). It is, however, important to take into consideration the fact that during this period human agency played a significant role in the modification of landscapes, thereby making it difficult to interpret data as to whether or not change was naturally or human induced.

2.3.3.1 TEMPERATURE

An accelerated increase in temperature is evidenced from miromammalian evidence around 1 900 cal yrs BP at Bloomplaas (Avery, 1982). However, the data also indicate temperature fluctuation around 1 500 cal yrs BP. Isotopic evidence from the Cango Cave stalagmite shows that during the late Holocene, temperatures did not diverge by more than about 2° C from the present mean (Talma and Vogel, 1992). Martin (1968) suggests somewhat cooler conditions in the southern Cape than those experienced during the mid-Holocene through lower incidence of forest taxa coupled with higher grass component in pollen from levels dated to approximately the last 1900 cal yrs BP. Around this time, reduced SSTs are documented from decreased oxygen isotope records from molluscs derived from the southwestern Cape coastal archaeological sites dating to between 3 136 and 2 200 cal years BP (Cohen *et al.*, 1992).

2.3.3.2 PRECIPITATION

In the Cederberg, subtle vegetation changes based on pollen records from Driehoek and Sneeuberg vleis are recorded (Meadows and Sugden, 1990; 1991a; 1991b; 1993). However interpretation of the pollen sequences indicated that more xeric conditions, manifested by the replacement of restios by ericaceous fynbos and the progressive decline of the endemic Clanwilliam cedars, were evident in the region from about 3 400 cal yrs BP. In contrast, micromammal evidence from Elands Bay Cave and Byneskranskop indicate moister conditions after 3 200 and 2 000 cal yrs BP

respectively (Avery, 1983; 1990). Similarly, at Klaarfontein, conditions moister than the mid-Holocene seem to have prevailed until about 1800 cal yrs BP, after which the presence of saline conditions indicates possibly more xeric conditions in the proximity of the site.

2.3.3.3 HUMAN DISTURBANCE

According to (Deacon, 1992) pre-colonial populations in the fynbos region increased around 15 900 cal yrs BP and again after about 4 400 cal yrs BP. While the first phase is generally thought not to have had significant effects as such on the environment, the changes related to the second increase are viewed as having been relatively destructive to some extent in varying degrees and timing at different regions. The Olifants River valley, therefore, would have been occupied by San hunter-gatherers mainly after about 4 400 cal yrs BP (Parkington pers. comm), during which Scott (1994) records slight increases in *Stoebe*-type and ericoid pollen from a hyrax midden sequence at Pakhuis Pass, which were suggestive of a disturbed environment.

Increases in taxa such as Fumariaceae, Liliaceae, Oxalidaceae, Ranunculaceae, *Stoebe*-type and Campanulaceae at Driehoek around 900 cal yrs BP indicates increased disturbance and possibly more frequent fires (Meadows and Sugden, 1991b), which could be due to increased pressure on the environment after the arrival of Khoi herders around 1 700 cal yrs BP. As at Sneeuberg, corresponding decreases of fire sensitive taxa such as Amaryllidaceae, Santalaceae and Myricaceae, plus the gradual decline of the *Widdringtonia*, strongly suggest that humans were at least in part, responsible for these changes. A reduction in grass pollen around 1 800 cal yrs BP in the Verlorenvlei catchment is attributed to the occupation of the area by pastoralists (Meadows and Baxter, 2001) who introduced domesticated livestock to the region that may have resulted in some local overgrazing.

A decrease in *Podocarpus* pollen, representing Afromontane forest decline after 2 000 cal yrs BP off the southwestern African shore from core GeoB1023-5 has also been attributed to human disturbance (Shi *et al.*, 2000).

2.3.3.4 SEA LEVEL

The two sea level curves Baxter and Meadows (1999) and Jerardino (1995) (Figure 2.1) show sea level regressions below contemporary levels some time after 3 700 cal yrs BP, and then a minor recovery at 1 400 cal yrs BP.

2.4 LIMITATIONS IN DATA INTERPRETATIONS

All techniques and approaches to palaeoenvironmental reconstruction and interpretations have their respective inherent strengths and limitations. There are in addition, specific problems associated with the material used in this study, and those related to chronology or sample size that must also be considered to have a potential effect with respect to the reconstruction and interpretation of data.

Meadows and Baxter (1999) point out that temperature evidence is often more easily reconstructed than precipitation, and that evidence of rainfall changes is contentious and may prove difficult and or problematic to interpret. This difficulty may perhaps be owing to the fact that precipitation is a composite climate parameter, with elements of distribution and quantity and cannot be reconstructed on the basis of proxy evidence alone. The lack of suitable organic deposits and sites in general may contribute to this problem. This has led to the fact that the quantity and seasonality of rainfall during the Holocene (Meadows and Baxter, 1999) in the southwestern Cape has proved difficult to reconstruct.

Another problem affecting reconstructions is the issue of taphonomy. Taphonomic and other mechanical distortions to which data sources are exposed, as well as their effect in the reconstructions, have to be considered in the compilation of evidence for palaeoenvironmental change. Poor and sparse preservation of diagnostic fossils or organic materials studied coupled with the short, fragmented nature of the temporal development of sequences, have also proven problematic in the interpretation of data (Avery, 1993).

Valuable to palaeoenvironmental reconstructions is the approach of using multiple proxies, which is advantageous as the reliability of reconstructions is increased when more than one types of evidence point to the occurrence of the same event (Avery,

1990; Meadows *et al.*, 1996). However, the lack of dateable material from localised deposits, as well as the fact that sites of high palaeoenvironmental significance are widely spaced, still remains problematic (Meadows and Baxter, 1999). Therefore, more studies of past environmental change are required to contribute to the existing data and to permit the multiple proxy approach for the reliability of reconstructions. Palaeoenvironmental reconstructions and interpretations have among other things been complicated by the reporting of dates, especially in older publications, which remain confusing as authors sometimes fail to mention whether or not dates being presented are calibrated dates, raw radiocarbon ages, or are derived from other dating techniques. This often renders date comparison and site correlations complex and potentially produces unreliable reconstructions. Another common problem is that of not making it clear in publications what type of material was dated.

2.5 CONCLUSION

To summarise, palaeoenvironments in South Africa have experienced considerable regional heterogeneity (Meadows and Baxter, 1999), and more research is undoubtedly required to reduce the differences and uncertainties in interpretations. The apparent inconsistencies in the reconstructions may be a result of the ambiguity around the seasonality and quantity of rainfall during the Holocene in the south-western Cape. In addition, because the evidence is based on data from different sources, which sometimes respond differently to environmental change, this could be a possible reason for the discordance inherent in the reconstruction and interpretation of data. The major challenge facing the unravelling of past environments in the south-western Cape however remains that of lack of suitable palaeoecological sites. Even those that exist are chronologically discontinuous, resulting in sometimes conflicting interpretations. The rather vague picture of palaeoenvironmental data in the southern Hemisphere in general and southern Africa and the southwestern Cape in particular has resulted in unsatisfactory future climatic and environmental predictions.

CHAPTER 3

METHODS AND TECHNIQUES

3.1 INTRODUCTION

This chapter starts by presenting the theoretical information pertaining to fossil faunal middens, as well as their role as tools for palaeoenvironmental reconstruction. Biological and ecological aspects of the animals that build the middens are included briefly. This is followed by the basis and principles of palynology, stable carbon isotope techniques for palaeoecological reconstruction and radiocarbon dating technique. Methods employed in carrying out the project are then presented.

3.2 THE MIDDEN

'Midden' is an archaeological term defined by (Renfrew and Bahn) (1991):p. 489, as "The accumulation of debris and domestic waste product resulting from human use. The long-term disposal of refuse can result in stratified deposits, which are useful for relative dating." It seems, then, from the above definition that the word 'midden', as used by palaeoecologists, is a borrowed one. Although it is hard to tell why and who first referred to these animal deposits as 'middens', it is a justifiable and useful term because the deposits are indeed debris and waste material with long-term accumulation of some deposits resulting in stratified layers as would happen in the case of archaeological middens.

Unlike archaeological middens, herbivore middens have the potential to reconstruct past environmental conditions based on their macro and micro plant (including pollen) material analysis. The discovery of the potential of fossil midden analysis in palaeoenvironmental reconstruction has improved the knowledge and understanding of Quaternary environments, especially in arid and semi-arid regions where lakes and swamps, which preserve pollen better, are scarce (Horowitz, 1992; Scott, 1990; Scott, 1996; Scott and Bousman, 1990). Due to geographic distribution of the animals that build the middens, different regions have specific midden building candidates, which

produce characteristic deposits, including packrat (*Neotoma* spp.) middens in America (Betancourt *et al.*, 1990; King and van Devender, 1977; Thompson, 1985), hyrax (*Procavia* spp. and *Heterohyrax* spp.) middens in Africa (Scott, 1990; Scott and Bousman, 1990; Scott and Cooremans, 1992; Scott and Vogel, 1992) and the Middle East (Fall *et al.*, 1990), dassie rat (*Petromus* spp.) middens also in Africa (Scott, 1996; Scott and Bousman, 1990) and stick-nest rat (*Leporillus* spp.) middens in Australia (Nelson *et al.*, 1990).

Plant remains trapped in midden deposits have provided the best source of preserved, recognisable and datable palaeobotanical fragments in arid and semi-arid regions where organic remains are scarce (Horowitz, 1992; Scott, 1990; Scott and Bousman, 1990). This justification lies in the fact that dried concentrated urine of the midden builder seals and cements together the plant fragments as well as other midden contents, forming a very hard matrix (Scott, 1990; Scott, 1996; Spaulding *et al.*, 1990; Vaughan, 1990), which suppresses microbial and chemical activity, favouring mummification and thus protecting the plant fragments from decay (Scott, 1996). The hypotonic property of urea achieves mummification of plant material in much the same way as packing it in salt (Spaulding *et al.*, 1990). Wells (1976) indicates that most insect consumers, including termites, carpet beetles and dung beetles, avoid organic matter saturated in amberat, perhaps due to its chemical properties. The same is probably true for hyrax middens cemented by hyracium. Furthermore, the sheltered places where the middens often occur ensure protection of the midden against erosion by water.

Despite the fact that one of the first radiocarbon dated fossil hyrax midden analyses was accomplished in Africa by Pons and Quezel (1958), and not America, packrat midden analysis is a more developed Quaternary environmental reconstruction technique in the New World (Dial and Czaplewski, 1990; Wells, 1976) than hyrax midden analysis in Africa. This may be because the contribution and significance of Pons and Quezel's (1958) report was unappreciated in the African continent until about three decades later (Scott, 1990; Scott and Bousman, 1990). Discovered only in 1960 (Spaulding et al., 1990), fossil faunal midden analysis in arid western America has since fuelled research interest in this discipline.

3.3 THE THEORY AND ROLE OF MIDDENS IN QUATERNARY PALAEOENVIRONMENTAL RECONSTRUCTION

Plants constitute the diet of herbivorous animals (Scott and Bousman, 1990; Scott and Cooremans, 1992). Sometimes, macro and micro plant remains, such as pollen grains, pass through digestive systems of these animals incompletely digested and hence reappear in their faeces (Horowitz, 1992). An alternative way in which plant material gets incorporated into faunal deposits would be when the airborne plant material or even that carried on the animals' fur, gets trapped in the sticky urine and faeces (Betancourt *et al.*, 1990; Dial and Czaplewski, 1990; Finley, 1990; Horowitz, 1992; Scott, 1990; Scott and Bousman, 1990; Scott and Cooremans, 1992; Spaulding *et al.*, 1990). These urinary and faecal deposits are useful instruments for palaeoenvironmental reconstruction in relatively arid regions as demonstrated by (Finley, 1990; Scott, 1990; Scott and Bousman, 1990; Scott and Cooremans, 1992; Spaulding *et al.*, 1990; Van Devender, 1990).

In addition to crystallized urine (amberat or hyracium) and faecal pellets, the deposits may contain macro and micro plant fragments such as pollen grains, bone, sediment and hairs (Betancourt *et al.*, 1990; Scott and Bousman, 1990; Spaulding *et al.*, 1990). These contents become saturated, and then sealed and cemented in the deposits by concentrated urine of the animal as it dries, encasing them in an amber-like matrix (Scott, 1990; Scott, 1996; Scott and Bousman, 1990; Scott and Cooremans, 1992; Spaulding *et al.*, 1990). These indurated faunal urinary and faecal fossil deposits are referred to as 'middens'.

3.3.1 THE MIDDEN BUILDERS

3.3.1.1 WOOD RAT OR PACKRAT (*Neotoma* spp.)

3.3.1.1.1 Identification

The species of *Neotoma* packrats are responsible for the fossil dung deposits found in North and Central America (Wells, 1976). Packrats are small herbivorous animals (Spaulding *et al.*, 1990; Van Devender, 1990; Vaughan, 1990). Vaughan (1990) reports that wood rats (*Neotoma* spp.) (Figure 3.1) are rodents of about 100 - 400g adult weight while according to Wells (1976) these animals may vary in weight from 95 – 585g and in length from about 25 to 45 cm, including the long hairy tail. They have large ears and prominent eyes with strongly built feet adapted for climbing trees and rocks (Vaughan, 1990).

Figure 3.1 *Neotoma cinerea*. From Vaughan (1990).

3.3.1.1.2 Diet

Generally, packrats associated with high plant species diversity tend to be dietary generalists, while packrats of communities with low plant species diversity become specialists. They are unable to conserve water, so they pass out excess urine and maintain their water balance by eating moist forage (Wells 1976, Vaughan 1990).

3.3.1.1.3 Adaptations

Packrat adaptations such as den and nest building help reduce the energetic cost of thermoregulation by providing protection from temperature extremes and lowering the rate of heat dissipation from the animal while resting (Vaughan, 1990). The den and nest are also built to provide protection against predation.

3.3.1.1.4 Distribution

There are about 20 species of the genus *Neotoma* and these are widely distributed in North and Middle America, where this genus is endemic. Most of the *Neotoma* species occur in the western part of North America (Figure 3.2). Four wide ranging species inhabiting western North American rock shelters are responsible for the Quaternary record of *Neotoma* middens (Wells, 1976). These are *N. cinerea, N. lepida, N. albigula, and N. mexicana.* The only boreal species, *N. cinerea,* inhabits the coniferous spire forests from central Arizona to the Yukon south. This species is also known to inhabit xerophilous woodlands where junipers and mountain mahogany are present. *N. lepida* is a small (25 – 34 cm and 95 – 160g) desert wood rat which overlaps in montane woodland habitat with *N. cinerea* although the latter extends downward reaching Baja California. Where the two occur sympatrically, the smaller *N. lepida* occupies crevices too small for *N. cinerea* (45 cm and 585g), hence providing a good idea as to which genus a midden belongs based on the size of the hole (Wells, 1976).

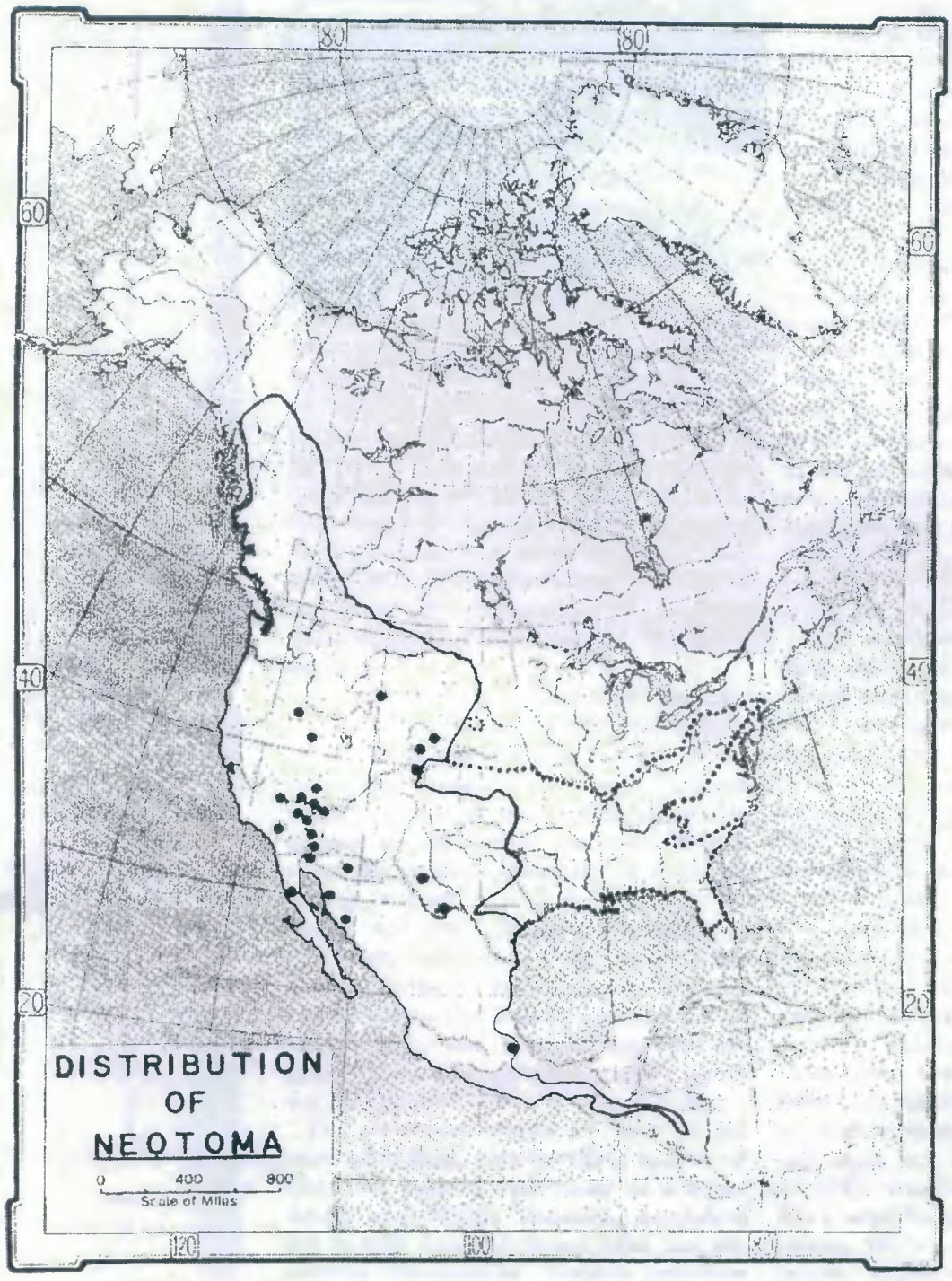

Figure 3.2 Map of North and Central America, showing the modern distribution of the genus Neotoma. The dotted line indicates the range of the eastern wood rat (*N. floridana*) and the continous line delimits the combined ranges of the 19 western species, extending from the Yukon to Nicaragua. Localities where Quaternary *Neotoma* middens have been collected are marked by larges dots. A wider application of the method seems likely wherever dry caves favour preservation. (From Wells (1976).

3.3.1.1.5 Habitat

Packrats, as the name suggests, collect plant fragments and put them together to build nests. The deposits commonly occur in dry protected environments such as caves, cliffs, rock shelters or rock crevices (Betancourt *et al.*, 1990). Packrats therefore usually inhabit places with patches of dense vegetation, forests, rocks, crevices and caves (Spaulding *et al.*, 1990; Vaughan, 1990). Packracts are also known to occupy alpine and desert environments.

3.3.1.1.6 Habits

Generally, the genus *Neotoma* is nocturnal, known for accumulating large amounts of macro plant material (within 30 to 100m) for the construction of massive middens and sometimes stick-houses in rock shelters (Vaughan, 1990; Wells, 1976). It is these plant fragments, the majority of which form a significant part of the packrats' diet, that are cemented together with the pellets by the urine to form the midden (Figure 3.3) (Dial and Czaplewski, 1990; Spaulding *et al.*, 1990; Vaughan, 1990). This happens because packrats habitually defeacate and urinate on their nests, gluing the midden constituents together with the crystallizing urine.

Figure 3.3 Packrat (*Neotoma* spp.) midden. From Spaulding *et al.*, (1990).

3.3.1.2 DASSIE RATS (*Petromus* spp.)

The dassie rats (Petromuridae) of Africa (Figure 3.4) have a similar nest building behaviour to packrats (Scott, 1990; 1996). They acquired their colloquial name 'dassie rats' from their rocky habitat confinement similar to that of dassies (= hyrax) (Skinner and Chimimba, 2005).

Figure 3.4 Dassie rat (*Petromus typicus*). From Smithers (1983).

3.3.1.2.1 Identification

Dassie rats have a mean adult mass of 220g and are squirrel-like in appearance without bushy tails, having long hairs over the terminal three-quarters of their tail (Skinner and Chimimba, 2005).

3.3.1.2.2 Diet

Their diet consists mainly of plant material, including stems, leaves and flowering heads of grasses (Skinner and Chimimba, 2005).

3.3.1.2.3 Distribution

Although they are endemic in the extremely arid southwestern Africa, occurring largely in the Namib Desert (Scott, 1990; Skinner and Chimimba, 2005) they are also

present in the northwestern parts of the Cape Province and the south western parts of Angola (Skinner and Chimimba, 2005) (Figure 3.5).

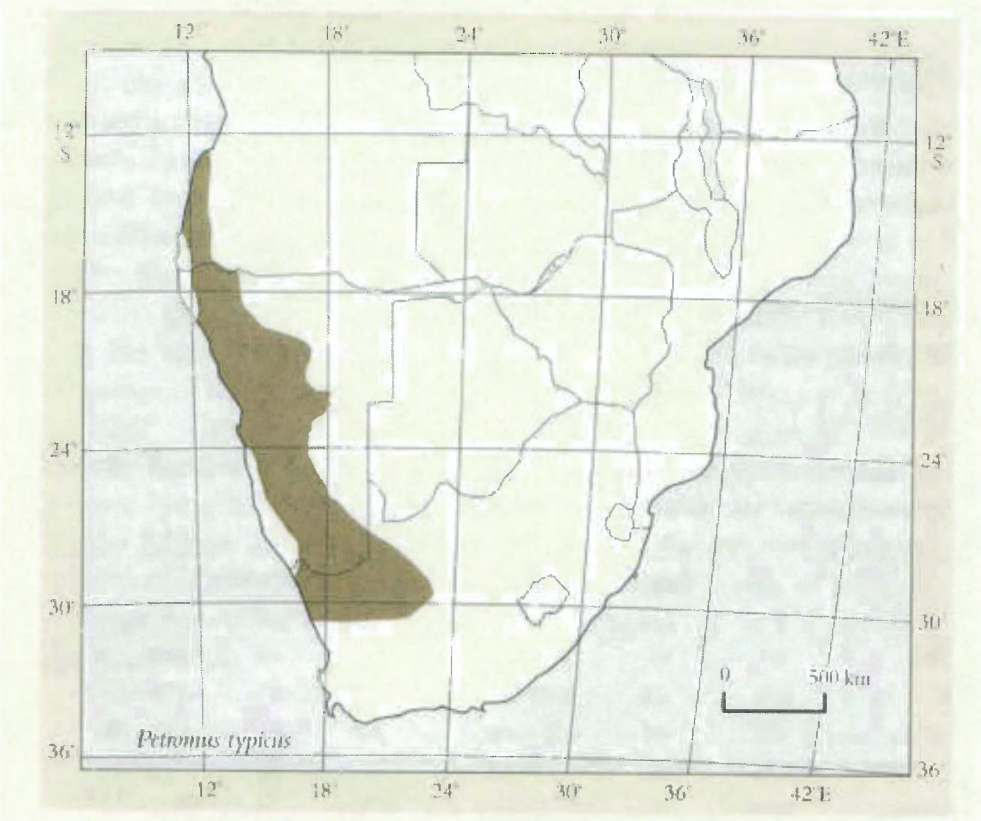

Figure 3.5 Dassie rat (Petromuridae) distribution. From Skinner and Chimimba (2005).

3.3.1.2.4 Habitat

'Dassie rats' are generally confined to rocky habitats (Skinner and Chimimba, 2005).

3.3.1.2.5 Habits

Dassie rats are diurnal, being most active in the early morning or late afternoon. Like American packrats, they are plant collectors too, accumulating midden materials and building nests (Scott, 1990; Scott, 1996; Scott and Bousman, 1990; Scott and Cooremans, 1992). Dassie rats tend to urinate in latrines (toilets) but they will defaecate anywhere within their home ranges (Skinner and Chimimba, 2005). The faeces, plant fragments and other debris may come into contact with the urine, which may glue the contents together forming a midden, which will be preserved due to the chemicals present in the urine. Such middens also have a palaeoecological

significance by providing palaeoenvironmental conditions during the formation of the midden (Scott, 1996).

3.3.1.3 STICK-NEST RAT (*Leporillus*: Muridae)

3.3.1.3.1 Identification

Stick-nest rats (*Leporillus* spp.) (Figure 3.6) are large rats with blunt noses and large ears like those of the rabbit rats (Metthews, 1971; Nelson *et al.*, 1990).

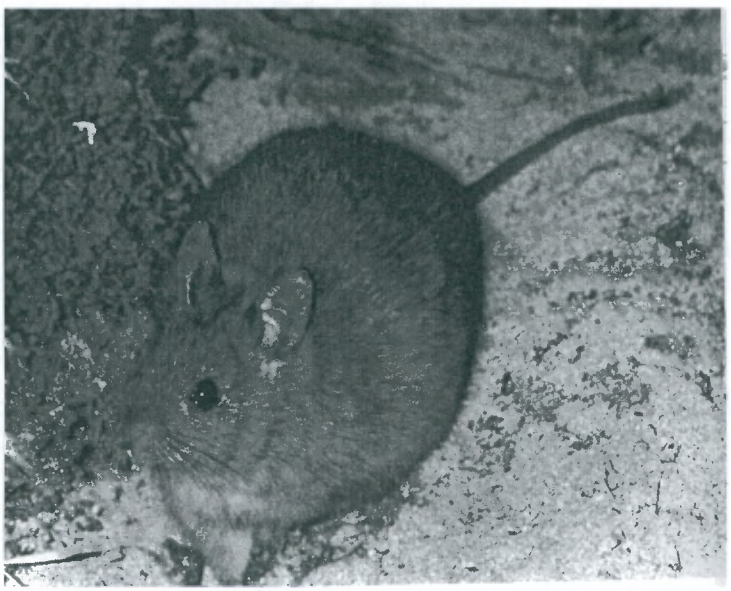

Figure 3.6 *Leporillus conditor*. From Nelson *et al.*, (1990).

3.3.1.3.2 Diet

Stick-nest rats are herbivorous animals (Nelson *et al.*, 1990).

3.3.1.3.3 Distribution

They are endemic in the arid regions of Central Australia. They are decreasing in numbers due to human settlement, domestic stock over-grazing and the introduction

of European foxes and domestic cats into Australia (Metthews, 1971; Nelson *et al.*, 1990).

3.3.1.3.4 Habits

Stick-nest rats build shelters (Figure 3.7) in caves, rock shelters or crevices. Often the core midden made of small sticks, grasses, faeces and herbaceous material glued together by urine, develops within a shelter.

Figure 3.7 A stick-rat nest. From Nelson *et al.*, (1990).

In contrast to packrats, the shelters built by stick-nest rats may be occupied by a pair or even colonies of these animals (Nelson *et al.*, 1990). Stick nest rats collect plant material and use this to build their massive middens. The plant material gets into contact with the faeces and urine of the stick nest rat. As the urine dries, the midden contents are cemented together forming a consolidated deposit.

3.3.1.4 HYRAXES (Procaviidae)

Hyraxes (Procaviidae), otherwise known as dassies in South Africa (Scott, 1990; Scott and Bousman, 1990; Skinner and Chimimba, 2005), also have fossil deposits (latrines) with the potential for Quaternary environmental interpretation in the African continent (Scott, 1990; 1994; 1996; Scott and Bousman, 1990; Scott and Cooremans,

1992; Scott and Vogel, 1992). Hyrax is a Greek word meaning shrew (Turner and Watson, 1965). 'Dassie', colloquially used in South Africa, is Afrikaans and is derived from the Dutch *das* (badger), which was the name used by Dutch settlers to refer to the genus *Procavia* (Skinner and Chimimba, 2005).

Researchers recognise three hyrax genera, namely *Procavia* (Figure 3.8), *Heterohyrax* (Figure 3.9) and *Dendrohyrax* (Figure 3.10) (Metthews, 1971; Sale, 1960; Sale, 1966; Skinner and Chimimba, 2005). *Heterohyrax* is sometimes, regarded as a subgenus of *Dendrohyrax* by others (Ellerman *et al.*, 1953; Hayman, 1964) based on their undoubted anatomical similarities such as features of the skull and teeth.

3.3.1.4.1 Habitat

Procavia and *Heterohyrax* are rock hyraxes, while *Dendrohyrax* is a tree hyrax. The rock hyraxes live in colonies in existing cavities in rocky outcrops (Sale, 1966), rock crevices, cliffs and scrub (Metthews, 1971; Skinner and Chimimba, 2005) while the tree hyrax, as the name implies lives in forests using holes in trees and the shelter from thick foliage of trees for resting (Skinner and Chimimba, 2005). However, Sale (1966) indicates that it is mentioned in Roberts (1951) that rock hyraxes sometimes live in the abandoned holes of other animals or culverts if need be.

Hyraxes show a considerable tolerance to altitude and temperature (Scott, 1990) being distributed in both lowland and mountainous regions. For example, Sale (1966) shows that in East Africa hyraxes are found both in Magadi and Mt. Kenya. Magadi (613 m above sea level and has a mean maximum temperature of 35°C and a mean minimum temperature of 17.8°C) and Mt. Kenya (altitude of about 4,200 m and a mean maximum temperature of 10°C with a mean minimum temperature of -5°C) (Sale, 1966). In South Africa they are abundantly found in elevations between 0 to 2500 m. *Procavia Johnstoni mackinderi* Thomas is the only specialised species which inhabits the cold alpine zone of Mount Kenya (Sale, 1966).

3.3.1.4.2 Identification

Procavia (Figure 3.8) are larger and dark brown in colour above and lighter below, with dark feet (Turner and Watson, 1965). An adult male *Procavia* skull has a maximum length of about 100 mm. The upper back molars have a transverse breadth of 8-9 mm. The *Dendrohyrax* (Figure 3.9), like *Heterohyrax* (Figure 3.10) is smaller than *Procavia* (Sale, 1965a; 1966; Turner and Watson, 1965). It is grey in colour above, white below with a sharp line of demarcation and pale feet. The skull of an adult *Dendrohyrax* male is about 84 mm and the upper back molars have a transverse breadth of 6 mm (Turner and Watson, 1965). A few anatomical features that accord the rock hyraxes their respective genera (Sale, 1960) include those given in Table 3.1.

Figure 3.8 Rock hyrax (*Procavia* spp.)

Figure 3.9 *Dendrohyrax* spp.. From Smithers (1983).

Figure 3.10 *Heterohyrax* spp.. From Smithers (1983).

The name bush hyrax is sometimes given to *Heterohyrax*, which places it in an intermediate position in terms of habitat preference between *Procavia* and *Dendrohyrax,* but this idea is disputed on the grounds that *Heterohyrax* is as much a rock dweller as *Procavia*, and hence there is no need to name the two based on separate and or different habitats (Sale, 1966). It is not only habitat selection that is common to rock hyraxes but other aspects of social behaviour and ecology have been observed to be shared by the two species (Sale, 1960; Sale, 1965c; Sale, 1966). There is not much known about the tree hyrax (Sale, 1960) and its habitat refutes the possibility of midden preservation, the statements in the following discussion refer to rock hyraxes, except where specifically stated.

Table 3.1 Anatomical features of *Procavia* and *Heterohyrax* (Sale, 1960).

Feature	*Procavia*	*Heterohyrax*
Hairs surrounding dorsal glandular spot	Black	White or chestnut
Molar teeth	Broad	Tend to be narrower than Procavia
Upper incisors	Very strong: close together	Weaker than Procavia: wider apart

3.3.1.4.3 Diet

Hyraxes are herbivores, choosing from a wide range of plants species which include grasses, and leaves and barks of shrubs and trees (Hoeck, 1975; Skinner and Chimimba, 2005). Studies in Kenya by Sale (1965a) indicate that the diet of the rock hyrax is basically of a browsing animal. Shrubs seem to be preferred to trees, which might have to do with the difficulty of climbing trees that hyraxes have. However, travellers in the Sahara observed that acacias constituted the sole diet of hyraxes living in the rocky outcrops in the desert (Sale, 1965a), which indicates that they can climb trees. Hyraxes do not have the same dietary preferences; De Niro and Epstein (1978) report one grazer species and a browsing one from the same habitat. It appears that if hyraxes obtain sufficient moisture from their diet, they can spend long periods of time without drinking water (Sale, 1965a). However, it is also stated in Sale (1965a) that Coe (1963) reports that a colony in the Mount Kenya drinks regularly because their diet does not provide sufficient moisture. To demonstrate that hyraxes have the ability to survive without water for long periods, a captive colony of Mount Kenya hyrax living predominantly on a dry diet thrived for six months without water during 1963, including the hot dry season from January to March (Sale, 1965a).

3.3.1.4.4 Distribution

Procavia has the widest distribution of the three genera. It occurs throughout southern Africa and extends through most of Africa, up to Syria and Israel (Figure 3.11).

Dendrohyrax occurs mainly in the humid central parts of the continent where there are tropical forests (Figure 3.11). *Heterohyrax* is endemic to the eastern extremes of Africa (Figure 3.11) (Sale, 1960; Scott, 1990).

Although both *Procavia* and *Heterohyrax* produce middens with the potential for palaeoenvironmental reconstruction in Africa, *Heterohyrax* does not occur in South Africa and therefore, it is evident from the distribution that the middens sampled in this project belong to *Procavia* and not *Heterohyrax*.

Figure 3.11 Hyrax distribution (from Sale (1960)).

3.3.1.4.5 Habits

The rock hyraxes are gregarious diurnal animals, being mostly active in the morning, at least two hours after sunrise and in the late afternoon (Metthews, 1971; Sale,

1965b; 1966). Fox (1933), however, states that the south-western Cape hyrax (= *P. capensis*) feeds chiefly at night, with similar evidence in Mount Kenya where Coe (1962) comments that the hyraxes are active at night (although not specifically mentioning feeding in the dark). Fourie (1971) has also observed hyraxes from the Free State feeding under the moonlight. This means that South African hyraxes may be different from Kenyan communities in this respect. *Dendrohyrax*; however differs from its cousins because it is a solitary and strictly nocturnal animal (Sale, 1965a). *Procavia* and *Heterohyrax* have common behaviour and habitat preference as far as lowland areas are concerned, such that the two have been seen feeding together, sharing latrines, and rocks when basking (Turner and Watson, 1965), hiding and/or as living holes.

Rock hyraxes have communal urinating and defaecating places (Sale, 1960), a habit which is advantageous in palaeoecology as these toilets may constitute stratigraphic palaeoenvironmental records. Unlike packrats, dassie rats and stick nest rats, rock hyraxes do not bring food to their holes. They feed and return to their holes without the garbage (Sale, 1965a). Therefore, the plant fragments contained in the midden deposits are mostly consumed and digested material or accidentally trapped material.

Except when engaging in two brief but intensive feeding periods in the morning and late evening, hyraxes are generally inactive mammals (Sale, 1965a; 1966). Evidence from watching captive animals inside an artificial warren under red illumination confirms that there is little activity inside the holes, with approximately 95% of the day spent in inactivity (Sale, 1965a).

There is a saying in Sesotho related to the inactive or rather lazy behaviour of the hyrax, "*Pela e ne e hloke mohatla ke ho romeletsa.*" (The hyrax does not have a tail because he was too lazy to fetch it himself and sent someone else for it). Accompanying the saying is a tale[1].

[1] Legend has it that in the beginning all animals didn't have tails. One day, God decided to give them tails to complete their appearance and so that they could wave away the irritating flies. He made each of them a suitable tail. So when the time came all animals were summoned to a place far away to collect their tails. Everyone made their way there, but the hyrax didn't go. Instead he was making his way sluggishly towards a rock outcrop to bask when his friend the jackal passed.
The jackal said: "Good morning my friend, I hope you heard that today is the big day."

Hyraxes usually emerge from their holes shortly after sunrise (Metthews, 1971). They catch the morning sun to warm themselves to get ready for feeding. They group together in three basic ways, named by Sale (1970) as heaping, huddling and solitary resting. Heaping also takes place inside the holes and in both cases it occurs in order to keep the group warm. Huddling also occurs inside and outside the hole when it is cold but not cold enough for the animals to induce the heaping behaviour. Solitary resting however differs from the above mentioned patterns as the animals lie down scattered around and with no physical contact (Sale, 1970).

3.3.1.4.6 Differences between hyrax and packrat, dassie rat and stick nest rat middens

In terms of building strategy and contents, packract, dassie rat and sticknest rat middens appear to be similar. These middens are very different from those associated with hyraxes. The main differences between the groups are shown in Table 3.2. Based on the differences between midden structure and content, the type of palaeoenvironmental reconstruction achieved by hyrax middens is different from that revealed by packrats, dassie rats and stick nest rat middens (Nelson *et al.*, 1990; Scott and Bousman, 1990; Scott and Cooremans, 1992). The biggest limitation in palaeoenvironmental reconstruction using faunal middens is that they can only be used to to reconstruct palaeoenvironments in arid and semi-arid regions because they are not preserved in relatively humid ones due to microbial decomposition.

"Oh that! I'd completely forgotten, you know, my days are very busy lately. Like today, my day is packed. Tell you what, could you do me a favour and collect that tail for me, I'll be waiting right here when you come back." Said the hyrax, pretending he had forgotten.
"Not a problem old friend, after all that's what friends are for isn't it? Replied the jackal. So all the animals went to collect their tails. And the hyrax, well, he just sat there waiting for the jackal to deliver his tail. Towards the late afternoon some of the faster animals like the hare were already arriving back waggling their beautiful tails happily. And the hyrax kept asking everyone "Have you seen the jackal with my tail, what does it look like?"
They said "Yes, its exquisite, he should be arriving soon." The hyrax waited in his usual laid back manner. Just before sunset, the elephant passed by unhurriedly. He said to the hyrax, "Are you still waiting for the jackal cousin hyrax? Well, I wouldn't wait any longer if I were you 'cause I's the last one on the route back. The jackal took a different route. And I heard that he ate your tail. Apparently he enjoyed it so much that I think he will be coming for you next." Since then, the jackal has enjoyed the hyrax for his meals. And so even today the hyrax does not trust the jackal and he never got his tail. Hence "*Pela e ne e hloke mohatla ke ho romeletsa.*"

Table 3.2 Differences in palaeoenvironmental records preserved in hyrax and packrat, dassie rat and stick nest rat middens (Betancourt *et al.*, 1990; Nelson *et al.*, 1990; Scott, 1990; Scott and Bousman, 1990; Vaughan, 1990).

Hyrax middens	**Packrat, dassierat and stick nest rat middens**
Dominated by micro plant fragments	Dominated by macro plant fragments
May display stratigraphic integrity	No stratigraphy
May document extended time periods	Represent single points in time
Vegetation reconstruction represents changes, variation and other dynamics of vegetation over time.	Do not reflect and vegetation dynamics as only single points in time are recorded

3.3.1.5 ADVANTAGES OF HYRAX MIDDENS OVER PACKRAT, DASSIE RAT AND STICNEST RAT MIDDENS AS PALAEOECOLOGICAL ARCHIVES

i) hyrax middens to preserve stratified sequences, unlike packrat, dassie rat and sticknest rat middens which do not have stratified sequences (Scott and Bousman, 1990).

ii) hyrax middens, therefore, document changes in vegetation over time (Scott and Bousman, 1990) unlike packrat, dassie rat and sticknest rat middens which represent single points in time.

iii) hyraxes do not have complex feeding behaviours as compared to the marked differences in feeding and collecting behaviour among the different species of packrats (Vaughan, 1990).

3.3.1.6 RELIABILITY OF HYRAX DEPOSITS IN PALAEOECOLOGY

These points indicate why hyrax deposits are reliable as palaeoecological archives.

i) no exposure to water because middens are deposited in dry protected environments, which protects against dissolution (Scott, 1990).

ii) hyracium in hyrax middens ensures no microbial attack and thus preserve the middens (Scott, 1990; Scott and Bousman, 1990).

iii) no mixing of deposit by termites, ants or beetles as these are prevented from visiting by chemicals in the animal's urine (Scott, 1990).

iv) the transport distance of midden material from its source is fairly relatively short (30 to 100m), ensuring minimal possible inclusion of material from outside the midden assemblage site (Scott and Bousman, 1990).

3.4 PALYNOLOGY AS A PALAEOENVIRONMENTAL TOOL

In this project, the means chosen by which to reconstruct Quaternary environments of the area in question is through pollen analysis. Pollen data record responses of ecosystems to human impacts and provide empirical evidence of the behaviour of vegetation when subjected to major climatic and environmental changes (Prentice, 1988).

3.4.1 THE POLLEN GRAIN

The primary role of pollen is to ensure the multiplication and passing on to the next generation the species of flowering plants through reproduction (Faegri and Iversen, 1989). It is produced in large quantities by the anthers with the expectation that it will finally reach the stigma where fertilization will take place. However, not all the produced pollen fulfils its biological function. The pollen gets deposited on the ground and in sediments and sometimes gets preserved.

The structure of the pollen grain attributes to its preservation. Its outer layer, the exine, has a resistant waxy coat called sporopollenin, which has the effect of preserving pollen grains in ancient deposits or sediments when almost all other organic parts are reduced to structureless and hence unrecognisable components (Lowe and Walker, 1997).

3.4.2 RELIABILITY OF POLLEN ANALYSIS AS A METHOD

Palynology is one of the most widely applied methods in palaeoenvironmental investigations (William *et al.*, 1998) because it is a reliable method for the following reasons (Birks and Birks, 1980; Birks and Gordon, 1985; Faegri and Iversen, 1989; Lowe and Walker, 1997):

- pollen grains and spores are the most abundant type of fossil preserved in Quaternary terrestrial sediments and can be found in those deposists where other fossil types would not survive. Their wide dispersal provides a broad picture of surrounding vegetation
- pollen grains are resistant to decay due to their outer layer, called exine, which consists of sporopollenin, a resistant waxy coat which protects it from decay. This distinctive structural patterning allows identification of parent plants at reasonable taxonomic levels
- unlike other techniques which demand the use of beetles, mollusks, vertebrates and plant macrofossils for example, palynology requires relatively small amounts of sample because pollen grains are small (5 – 100μm), produced in enormous numbers and are evenly spread
- the taxonomy of pollen grains is relatively well known and identification under the light microscope is relatively easy. However, constant refinements are being made with the use of the scanning electron microscope
- fossil pollen grains provide a reconstruction of former vegetation. Vegetation is crucial in a landscape as it controls the kinds of animals which inhabit it to a large extent. In addition, vegetation is very sensitive to environmental change and hence will respond to environmental factors, thus enabling a deduction of these factors from a reconstruction of past vegetation.

Nevertheless, as discussed in chapter 1, the application of pollen analysis in arid and semi-arid regions, such as southern Africa, has been hampered by the scarcity of pollen preserving bodies (Horowitz, 1992; Scott and Bousman, 1990; Scott and Cooremans, 1992), a situation which has been improved through the advent of fossil faunal dung midden analysis (Scott, 1990; 1994; 1996; Scott and Bousman, 1990; Scott and Cooremans, 1992).

3.4.3 POLLEN TRANSPORT AND DEPOSITION ON THE MIDDENS

Hyrax dung middens contain a larger proportion of micro-plant fragments (such as pollen) to macro-plant fragments (Scott and Bousman, 1990) because they are not deliberate plant collectors. Pollen gets incorporated into the hyrax dung midden in several ways (Figure 3.12). One is a direct route whereby airborne pollen gets trapped by the fresh sticky surface of the midden. The second involves the diet and drink water of the hyrax, where pollen is ingested, survives digestion and is deposited in the faeces which are incorporated in the midden. Thirdly, pollen from the vegetation may adhere to the body of the hyrax and end up being deposited in the midden when the animals visit the latrine.

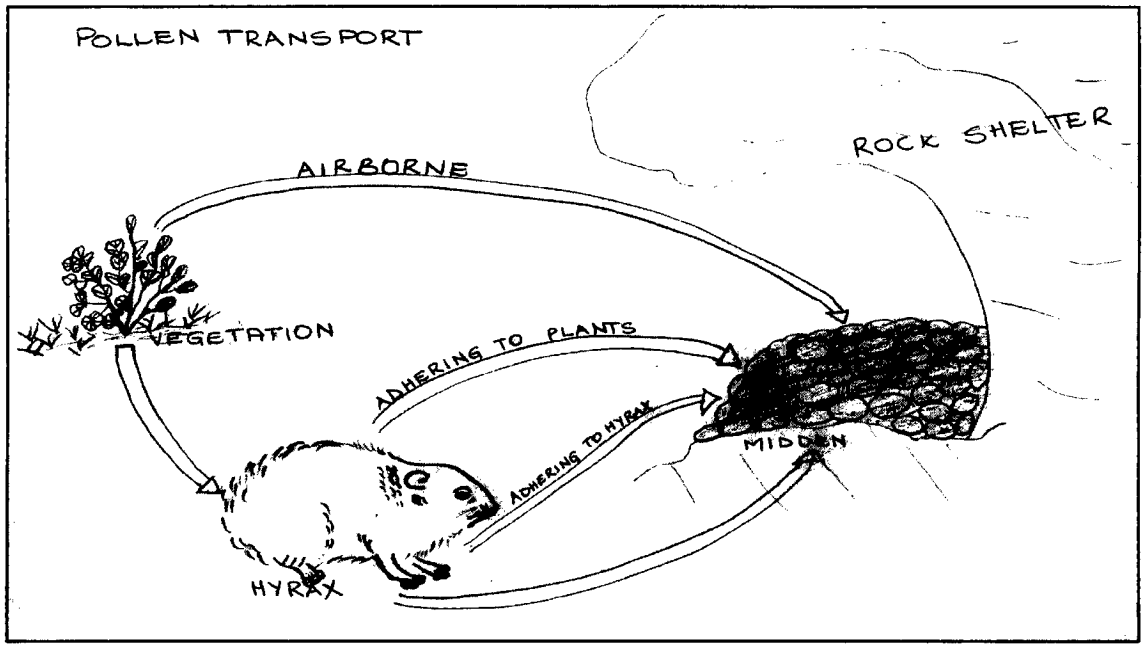

Figure 3.12 Pollen transport routes in relation to hyrax middens.

3.5 STABLE CARBON ISOTOPIC TECHNIQUES

3.5.1 RATIONALE

Stable carbon isotopes $^{13}C/^{12}C$, are among the most widely applied ecological tools (Sealy, 2001). Isotopic assessments of plants and animals constitute vital parts in biochemical, biological and environmental studies (Dawson and Brooks, 2001). Stable isotopes are expressed as parts per thousand or per mil (‰) relative to an internationally accepted standard, using the delta notation. The delta value is calculated as thus:

$$dX_{standard} = \left(\frac{R_{sample}}{R_{standard}} - 1 \right) X \quad 1000$$

where $dX_{standard}$ is the isotope ratio in delta units relative to a standard, and R is the ratio of rare (heavy) to abundant (light) isotope. R_{sample} and $R_{standard}$ are the heavy to light isotope ratios of the sample and standard respectively (Dawson and Brooks, 2001). Therefore to calculate isotopic ratio of carbon, which was the material used in this analysis, the formula would be:

$$d^{13}C = \left(\frac{^{13}C/^{12}C_{sample}}{^{13}C/^{12}C_{standard}} - 1 \right) X \quad 1000$$

$d^{13}C$ values are reported relative to Peedee Belemnite (PDB); a marine limestone (Dawson and Brooks, 2001; Sealy, 2001; van der Merwe *et al.*, 1988).

All internationally accepted standards have a $d^{13}C$ value of 0‰ (Dawson and Brooks, 2001). These standards are available from the international Atomic Energy Agency in Vienna, Austria and the National Institute of Standards and Technology in the United States. However, everyday isotopic analysis work can not possibly be based on the internationally accepted standards because of their associated high cost. Therefore internal working standards are the basis of daily isotopic facilities. The internal working standards have to be calibrated against an international standard for the validity of the analysis (Dawson and Brooks, 2001). Two internally working standards at UCT: acacia and chocolate were used for the analysis in this project.

Isotopic analysis of carbon is commonly used to investigate dietary shifts and feeding behaviour of animals and humans, as well as in making inferences about habitat utilisation by mammalian herbivores (Cerling *et al.*, 2003; Sponheimer *et al.*, 2003; Tieszen *et al.*, 1979; van der Merwe *et al.*, 1988; Vogel, 1978). This application is

based on the metabolic processes that plants undertake and the fact that the anatomy and physiology of these plants differ (Codron *et al.*, 2005). The result is distinct, non-overlapping carbon isotopic ratios in the different plant groups as atmospheric carbon dioxide fixation takes place (Sponheimer *et al.*, 2003).

There are three associated photosynthetic pathways: In the Calvin-Benson or C_3 pathway, the first product of photosynthesis is a 3-C compound. Plants which fall in this group discriminate very strongly against ^{13}C, resulting in a $d^{13}C$ mean value of about -27‰ (Sealy, 2001) ranging from -22 to -35‰ (Koch, 1998). Trees, fruits and vegetables are all C_3 plants. On the other hand, in the Hatch-Slack (Kranz leaf anatomy) or C_4 pathway, carbon is fixed initially into a 4-C compound but discrimination against ^{13}C is to a lesser extent than in C_3 plants. The mean $d^{13}C$ value for C_4 plants is about -13‰, ranging from -8 to -16‰ (Koch, 1998; Sealy, 2001). Grasses such as maize, sorghum, sugarcane and millet are of the C_4 type. Other plants have the ability to fix CO_2 by switching from either C_3 or C_4 photosynthetic pathways (Koch, 1998; Sealy, 2001; van der Merwe *et al.*, 1988). These are succulent plants, adapted to arid regions and use the crassulacean acid metabolism (CAM) pathway. Depending on environmental conditions, CAM plants may exhibit $d^{13}C$ values which vary between those of C_3 and C_4. With the exception of the Eastern Cape Province, where palatable CAM plants constitute more than half of the plant-cover percentage, these plants do not contribute significant quantities in animal diets because they are often unpalatable (van der Merwe *et al.*, 1988). Therefore CAM plants have little importance in animal dietary tracing (van der Merwe, 1982) and are not considered further in this analysis.

3.5.2 APPLICATION

Stable carbon isotope analysis can be applied to both fossil (Koch, 1998; Sealy, 2001), and modern material (Codron *et al.*, 2005; Sponheimer *et al.*, 2003). Furthermore, the stable carbon isotope analysis can be carried out on different kinds of materials including tooth enamel, bone collagen, nails, hair, faeces and urine depending on the requirement of the research question (Sponheimer *et al.*, 2003). Hard body tissues such as enamel and bone collagen have longer turnover periods,

which qualify them as long-term ecological tracers (Sealy, 2001; van der Merwe *et al.*, 1988). Tooth enamel particularly is durable and can preserve well for thousands of years. Past diets of herbivorous animals and humans going back up to thousands of years ago, can therefore be reconstructed using tooth enamel and adult bone collagen. Nails and hair generally record diets of relatively shorter time periods. Faeces integrate carbon isotopic signals of food taken for the last few days only (Codron *et al.*, 2005). But fossil hyrax middens can be used to reconstruct past diets of hyraxes going back thousands of years because they constitute preserved fossil faeces of the animals.

Carbon isotope ratios of animals are determined by the food they consume (Sealy, 2001). Generally, grazers exhibit bone collagen $d^{13}C$ of around -8‰, while browsers show $d^{13}C$ of about -22‰. It is important to note that the bone collagen $d^{13}C$ values of these animal groups are about 5 per mil units more positive than their diets. Although its mechanisms are poorly understood (Sealy, 2001), this process is known as isotopic fractionation and results from metabolic processes involved in the production of body tissue from food (De Niro and Epstein, 1978; Sealy, 2001). A similar process takes place when food waste is expelled from the body such that faeces and urine have their respective fractionation values. Codron *et al.*, (2005) and Sponheimer (2003) suggest that diet-faeces fractionation is about -0.9‰. However, this may not necessarily be the case with hyrax dung middens because of their mixed complex compositions. The effects of diagenesis are also expected to shift isotopically depleted $d^{13}C$ of browsing animals towards being more enriched (Lee-Thorp and Beaumont, 1995).

Another application of stable carbon isotope analysis is in environmental reconstruction (Scott and Vogel, 2000). The more enriched (more positive) $d^{13}C$ values indicate higher temperatures and or arid conditions, while the more depleted (more negative) $d^{13}C$ values may suggest lower temperatures and or wetter conditions (Scott and Vogel, 2000; Tiezen, 1991). Alternatively, the more positive values may be due to inclusion of C_4 or CAM plants in the diets of the animals.

Hyrax dung middens constitute the fossil diet of the animals and their $d^{13}C$ content may indicate past vegetation and environmental changes (Scott and Vogel, 2000). The $d^{13}C$ content does not record vegetation directly but shows hyrax diets.

3.6 METHODOLOGICAL PROCEDURES

This project was carried out in two stages. Stage 1 was the fieldwork and Stage 2 involved laboratory procedures for concentration of the pollen as well as counting.

3.6.1 FIELDWORK

Fieldwork involved the location and collection of hyrax dung middens. Fieldwork assistance was obtained in relation to more inaccessible middens and Dr Brian Chase did the actual climbing of the cliffs and overhangs to extract the middens (Figure 3.14).

Figure 3.13 Dr Brian Chase in his midden extraction gear aiming for midden KB1.

Massive middens such as that found at KB1, located at 32˚09` S and 19˚06` E (Figure 3.15), were impossible to extract as a whole, so sections of the deposit were cut off from the main midden (Figure 3.16). Two sections were sliced of from midden KB1 with an angle grinder and were named KB1-1 and KB1-2 (Figure 3.15 and Figure

3.16). An angle grinder and a hammer were used to cut off these sections. Slicing off pieces of the deposit proved difficult as hyracium both hard and brittle.

Figure 3.14 KB1 hyrax midden.

Figure 3.15 Midden at KB1 showing section KB1-1.

Five middens were discovered at Truitjes Kraal (TK) (see Appendix A), which is located 32°30.718` S and 19°18.727` E. These were named as TK1, TK2, TK3, TK4 and TK5. Unlike the middens at KB, TK middens were smaller and all were extracted in their entirety

3.6.2 LABORATORY PREPARATION

In the laboratory, physical and chemical treatment of samples took place to prepare for the intended pollen analyses.

3.6.2.1 PHYSICAL TREATMENT

3.6.2.1.1 Sample preparation 1 (before drilling)

The middens were first brushed off lightly on the surfaces on which samples were going to be taken. This was done to ensure minimum contamination of samples. To further control possible contamination of the samples, midden faces which were previously unexposed were created and used for sampling. KB1-2 was sampled on the side/face which was previously attached to the mother deposit. TK4 and TK5 were cut vertically in the middle and only one section in each case was sampled.

Surface, dry and fresh pellets samples were crushed using a crucible and hammer. These were then sieved using a tea strainer to get rid of the coarse vegetative material. Afterwards the samples were weighted and their masses recorded.

3.6.2.1.2 Drilling

Sub-sampling was carried out using an electric drill (Figure 3.17). The dust that comes out of the drill hole is the sample. This device does not damage the pollen in the midden because of its microscopic size. The 3 mm steel drill bit was used throughout the drilling process. It is important not to reach drilling speeds which cause the material to smoke and hence stick to the sides of the hole. Samples were

taken perpendicular to the estimated bedding planes at intervals of approximately 1 - 2 cm. During drilling, the samples were collected on clean white paper, which were discarded after collecting each sample. Afterwards, the samples were placed individually in air-tight containers and labelled accordingly. After drilling each hole, the sample was collected and the fan of the drill directed to the hole to sweep off the remaining finer particles of the sample with its air outlets so as to avoid mixing of samples and to minimise contamination from dust from other holes. The drill bit was carefully cleaned with a brush to remove the midden particles adhering to it and then wiped with a cloth dipped in isopropyl alcohol which cleans well and dries quickly (Chase 2006 Pers. comm.).

Figure 3.16 Drilling KB1-2 at intervals of about 1-2 cm.

3.6.2.1.3 Sample preparation 2 (after drilling)

3.6.2.1.3.1 Pollen samples

The samples stored in airtight containers were shared between pollen and stable carbon isotopic analyses. For pollen analysis, samples were crushed to powder using a crucible and hammer – this was necessary as the drill produced coarse, sticky samples along with the fine powder. They were then weighed on a balance and the masses recorded. These samples, of known masses, were put in small plastic vials ready for chemical treatment.

3.6.2.1.3.2 Stable carbon isotope analysis samples

Stable carbon isotopic analysis took place at the UCT Archaeology Department Archaeometry Unit. As with the pollen samples, these samples were crushed to powder using a crucible and hammer. An electric balance was used to measure weights of samples. Two standards, acacia and chocolate were used in the analysis. After measuring their weight, the samples and standards were wrapped in small tin foil cups, and placed in a tray. Sample weights, and positions were recorded on a data sheet. The samples and standards were analysed with a Thermo Finningan Delta Plus XP mass spectrometer connected to a Thermo Flash EA 1112 by a Conflo III device (Lanham pers. comm. 2005).

All middens samples were subjected to the carbon isotopic analysis except those of midden KB1-2 which was assumed to have similar isotopic signals to KB1-1 as these were pieces derived from a similar stratigraphic position in midden KB1. The carbon isotopic signals of KB1-1 are thought to be broadly representative of the variation of the whole midden.

3.6.2.1.3.3 Radiocarbon dating samples

Two middens: KB1-1 which was 20 cm long (Figure 3.18) and TK4, 11 cm from bottom to top, were sampled for conventional radiocarbon age determination. This requires that samples first be prepared for organic matter content calculation (Goh, 1991). They were oven-dried at 105˚C and then weighed. Then they were put in a furnace at 400˚C for 8 hours and afterwards let to cool in a dessicator, before being reweighed and the results used to calculate organic matter index (Smith and Atkinson, 1975) (see Appendix B). Given that conventional counting equipment requires larger samples than the accelerator counters (Goh, 1991; Pilcher, 2005), samples weighing 35.3g, 51.7g and 51.76g corresponding to the top (0-3 cm), middle (9-11 cm) and base (17-20 cm) respectively were obtained from KB1-1 (Figure 3.18) while from TK4 two samples from top (0-2 cm) and bottom (9-11 cm), weighing 21.37g and 19.80g respectively were obtained (Figure 3.19). Goh (1991) advises that larger samples should be handed in to increase precision and results in large errors or standard deviations. Although no specific reference is made in this publication of the

minimum amount of sample weight required for conventionally dating hyracium from hyrax middens, sufficient quantities of samples were submitted in such that 10% of datable carbon was available. Because bigger samples were required, a hammer was used to cut pieces from the middens. The radiocarbon dating samples were sent to QUADRU for analysis.

Radiocarbon dated ages for this project will be calibrated using CalPal2004 (www.calpal.de) and will have the suffix cal yrs BP.

Figure 3.17 KB1-1 divided into three parts for radiocarbon dating.

Figure 3.18 TK4 showing where the two samples for radiocarbon dating were taken. The green shape represents the bottom sample while the yellow shows the top sample.

3.6.2.2 CHEMICAL TREATMENT

3.6.2.2.1 Marker grains

Lycopodium spore tablets, batch no. 483216 were used as marker grains and their counts formed the basis of pollen abundance determination.

3.6.2.2.2 Pollen concentration

The sample was first digested with 5% KOH to remove humic acids. This was followed by washing the sample in 10% HCl to get rid of carbonates. A heavy mineral separation method using $ZnCl_2$ solution of Specific Gravity 2, prepared with 10% HCl instead of water was used to remove the silica content, but this approach did not work successfully as the resultant slides were still obscured by silica particles.

New samples therefore had to be prepared, which necessitated drilling and sub-sampling of the middens again, this time using HF treatment to get rid of the silica. However, section KB1-1, which got destroyed when taking radiocarbon dating samples, was not available for the second pollen sub-sampling. Cellulose material was removed through acetolysis. No stain was used on the samples because the midden material already is dark and hence does not require staining. A detailed step by step procedure for the pollen preparation is given in Appendix C.

3.6.2.3 COUNTING

Pollen identification and counting was achieved with the help of a Carl Zeizz electron microscope at a magnification of 400x. 630x magnification and the oil immersion microscopy were used to identify obscured grains.

A minimum pollen count of 250 grains per slide was achieved. However, in cases where pollen preservation was better over 300 counts were made per slide. Pollen grains referred to as being 'unknown', are those that could not be identified even though they were not obscured and still had the necessary features for identification. Those that were classified as 'unidentified' included those grains that had lost some features due to mechanical damage, degradation, corrosion or were obscured by detritus on the slide. Pollen counts per sample and the corresponding pollen concentrations are given in Appendix D.

3.6.2.4 DATA PRESENTATION

Pollen data from stratified sediments are generally displayed graphically in the form of a pollen diagram (Moore *et al.*, 1991), plotting different pollen and spore taxa plotted against their stratigraphic depth or age (Birks and Birks, 1980). The pollen diagrams were constructed using Tilia Version 2.0.b 4 and Tiliagraph Version 2.0.b.5.

3.7 CONCLUSION

This chapter has presented the theory, role and potential of faunal dung middens in palaeoecological reconstruction. Some biological and ecological and behavioural aspects of the associated animals have also been discussed as these are important in the reconstruction and interpretation of respective midden material. The theoretical background to the three techniques on which the project is based, has also been provided, with pollen analysis receiving more attention as the back bone of the research.

CHAPTER 4

REGIONAL AND LOCAL ENVIRONMENTAL CONTEXT OF THE STUDY SITES

4.1 INTRODUCTION

This chapter describes the broader context of the study region which is located within the so called Fynbos Biome. The description includes information on the climate, geology, geomorphology and soils and vegetation. The specific details of the study sites follow thereafter.

4.2 CLIMATE OF THE SOUTHWESTERN CAPE

The southwestern Cape is defined as the region extending from Vanrhynsdorp in the north and Port Elizabeth in the east. This region experiences a so-called 'Mediterranean' type climate, characterised by cool, wet winters and warm, dry summers (Cowling *et al.* 1992). More than 66 % of the precipitation in a year falls from the winter months of April to September (Figure 4.1). Of all the southern African biomes, the Fynbos Biome has parts with the largest annual rainfall range and there is great complexity (amounts and seasonality) in the rainfall pattern in the region due to the high and rugged relief (Schulze, 1996). In particular, mountainous regions have very steep rainfall gradients, varying from below 200 to over 3000 mm per annum. Jonkershoek is the wettest part in the southwestern Cape (and indeed in the whole of South Africa), recording an annual average of an estimated 3345 mm (Schulze, 1996). In general, coastal regions of the south-western Cape have an annual precipitation of around 400 mm. Separated from the sea by at least two mountain ranges, the Karoo interior is the driest part of this south-western Cape. This temporal and spatial rainfall pattern is mainly influenced by frontal depressions from the circumpolar westerly belt in winter and by the high pressure over the South Atlantic Ocean in summer (Tyson, 1986).

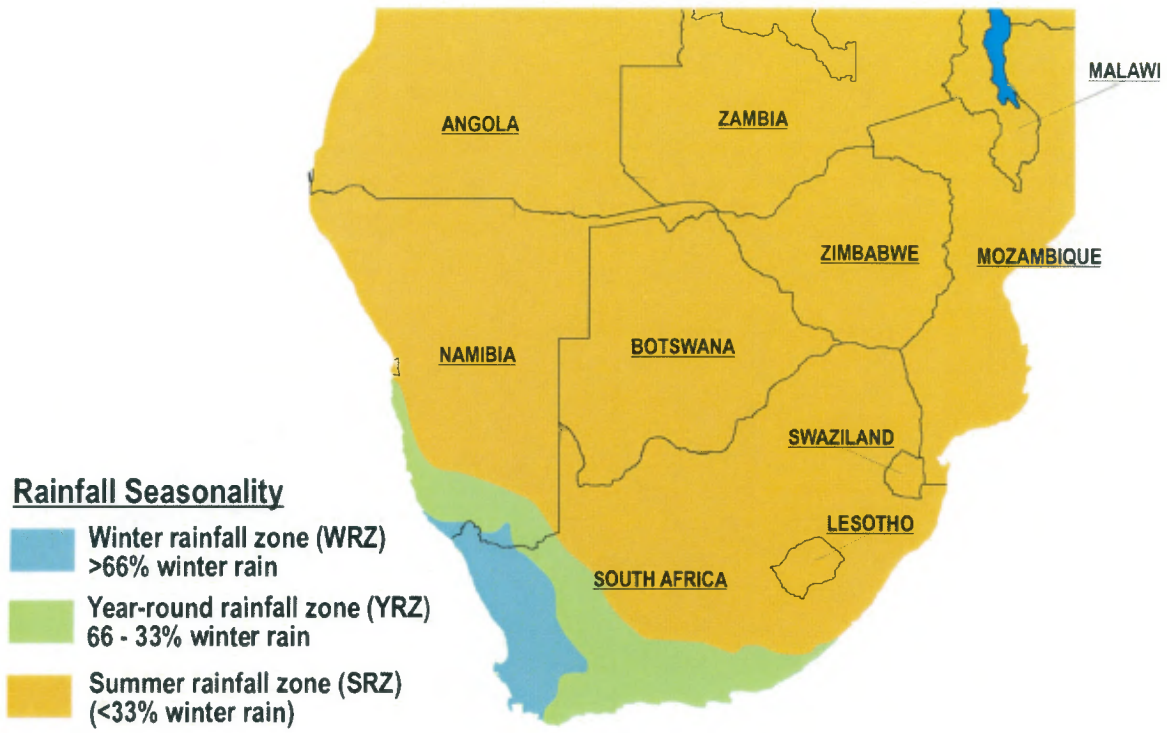

Figure 4.1 Southern African rainfall zones based on winter (April to September) rainfall percentages. (Chase (2005), data from Diechmann and Eklundh (1991)).

The moderating effect of the ocean results in smaller variations in temperature near the coast (Scott and Lee-Thorp, 2004) and, as a result, frost is uncommon here. Winter temperatures are lower in the interior than on the coast and summer temperatures are higher. The cool air from the Benguela Current reduces temperatures on the coast in summer. In the mountains, frost and snow are common in winter due to the low temperatures associated with high altitude (Linder *et al.*, 1993; Schulze, 1996). In the southwestern Cape mountains, the frequency of snow falls is about 5.4 snow-falls per year of which 3.2 occur between June to August (Schulze and McGee, 1978).

The southwestern Cape is dominated by southeasterly winds in summer and northwesterlies in winter (Tyson, 1986). However, in the northern part of the region, in the vicinity of the two sites studied here, these seasonal winds are less persistent(Tyson, 1986). Ahead of frontal systems, hot dry northerly 'berg' winds are

a feature and significantly increase the fire hazard in the dry season (Linder *et al.*, 1993).

4.3 GEOLOGY, GEOMORPHOLOGY AND SOILS OF THE SOUTHWESTERN CAPE

The southwestern Cape sits on the edge of the African continent. A long chain of erosion resistant quartzitic sandstone mountains, the Cape Fold Belt, underlain by softer shales and mantled with younger siliceous and calcareous sediments at the coastal margin (Cowling *et al.*, 1996), dominates the landscape. These mountains extend about 700 km from Port Elizabeth and run to the Cape coast where they make a right angle turn continuing a further 250 km north of Cape Town as the Cederberg Range (Figure 4.2) and (Compton, 2004). It is important to take note of the Cederberg as these have been referred to several times in the text. The highest peaks of the Cape Fold Belt reach heights of about 2200 m. This chain of mountains was formed between 280 and 235 million years ago as the South American and the African continents collided to form Pangaea.

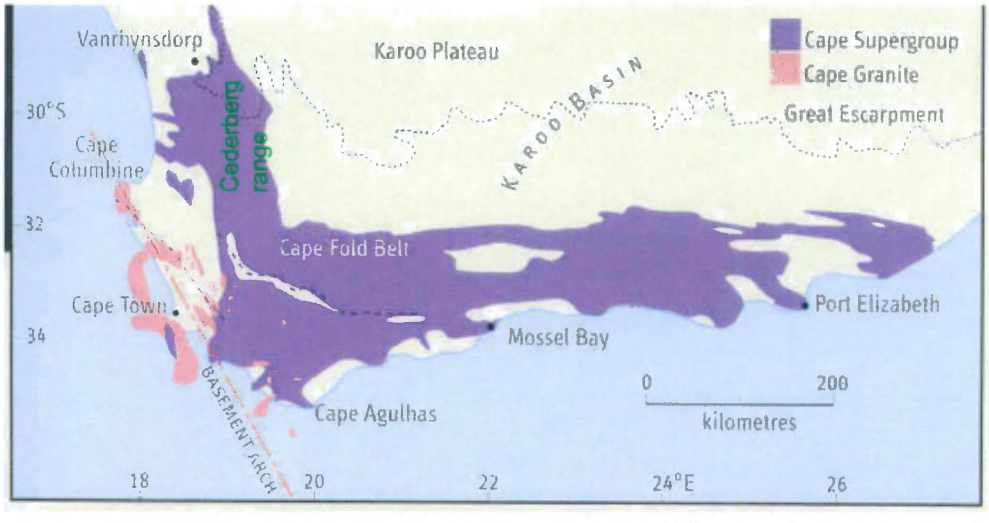

Figure 4.2 Map of the southwestern Cape showing the Cape Fold Belt Mountains

The high lying mountains and hills in the southwestern Cape, are generally made up of the more resistant sandstone and hard granite while the easily eroded shales constitute low lying flat areas (Compton, 2004; Theron, 1984). The Table Mountain Group sandstone consists almost exclusively of quartz, which is largely impervious to

the reactions of acids and oxygen carried in water, thus making the sandstone even harder and more resistant to weathering, creating prominent steep cliffs above the underlying weathered shale and granite which are readily attacked by the acids and oxygen (Compton, 2004).

The geology of an area is important as it influences what vegetation grows in the area because it determines the soil types (Compton, 2004). For instance, the high chemical reactivity of granite and shale allows these rocks to develop deeper and more nutrient rich soils than the sandstone, which produces generally infertile, nutrient poor, shallow soils which are often only a few centimetres of sandy soil resting on bedrock. Therefore, soils of mountainous regions of the Cape tend to be more acidic and less nutrient rich than soils of lower slopes derived from the finer grained, nutrient rich shale rocks (Compton, 2004; Cowling *et al.*, 1996). The coastal plains to the west and southwest and south have relatively fertile clay rich and duplex soils derived from Malmesbury Group and Bokkeveld Group respectively. The coastal margin however, is a sequence of infertile, acidic and alkaline deposits of aeolian and marine origin (Compton, 2004).

4.4 VEGETATION OF THE SOUTHWESTERN CAPE

The study region falls within the fynbos biome (Figure 4.3) (Cowling *et al.*, 1997, Low and Rebelo 1998) of the Cape Floristic Region (Cox, 2001).

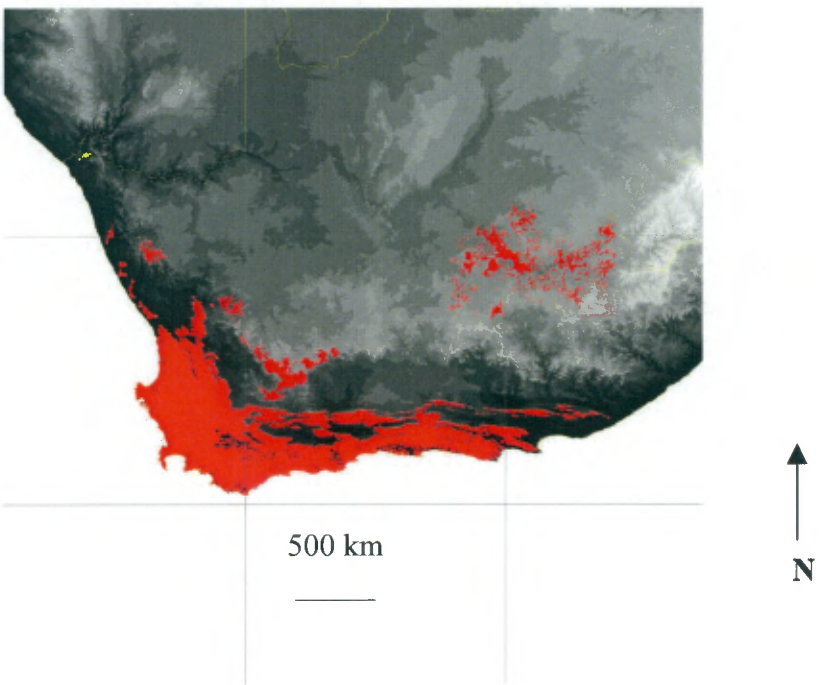

Figure 4.3 The fynbos biome in southern Africa. From Mucina and Rutherford (2003).

Within the biome there are more than 8 000 plant species in an area of only around 90 000 sq km (Rebelo, 1998). This richness rivals even the South American rain forests and makes it one of the world's biodiversity hotspots (Myers *et al.*, 2000). Between 70 - 80% of the total plant species of the Cape flora are endemic to the region, constituting the highest level of endemisim of any region (Cowling, 1992; Cox, 2001; Rebelo, 1998). In South Africa, more than one third of the total number of plant species is found within the Cape Floristic Region even though this occupies less than 6 % of the total area of the country (Rebelo, 1998). Picker and Samways (1996) have shown that the rich plant flora of the Cape Peninsula is home to correspondingly high faunal species diversity.

Three plant families characterise the fynbos vegetation: Ericaceae (heath types), Proteaceae (protea type) and Restionaceae (Cape reeds) (Campbell, 1985; Cowling *et al.*, 1997a; Cowling *et al.*, 1997b; Rebelo, 1998; Taylor and Leistner, 1996). These are characteristically dwarf evergreen plants which have fine stems and small leathery leaves, hence the term 'fynbos' (fine leaved bush) (Cowling *et al.*, 1997b). Restios particularly have reduced or no leaves and tough wiry stems, a characteristic shared by sedges and many grasses in the fynbos vegetation. The heath types comprise plants with small, narrow, rolled leaves with thick-walled cells on the upper leaf

surface and hairs on the lower surface (Rebelo, 1998). Proteaceae are the dominant overstorey elements in this vegetation. The seven endemic or near-endemic plant families are Bruniaceae, Geissolomaceae, Grubbiaceae, Penaeaceae, Retziaceae, Roridulaceae, and Stilbaceae (Rebelo, 1998). The various leaf physiognomies found in the three characteristic plant families clearly represent adaptations to strong summer aridity. The characteristic sclerophyllous leaves of many fynbos shrubs are an adaptation to the strong seasonal aridity. This way the plants do not lose large amounts of water due to evapotranspiration especially during the hot dry summers when temperatures and wind frequencies increase (Cowling *et al.*, 1997a). Fynbos plants are also adapted to soils with low nutrient status. This is so because these plants have the capability of retaining whatever nutrients that come their way, be it sea salts transported by wind and rain, ash deposited after a fire, or Karoo dust which supplies potassium and calcium to the plants (Compton, 2004).

Periodic fire is a natural phenomenon in fynbos (Brown, 1993) and fire is an integral component in the management of fynbos vegetation, although if misused it poses a serious threat on the natural vegetation (Cowling *et al.*, 1997a; Cowling, 1992). If fires are too frequent, seeds are not allowed to set, burning in a season other than late summer, as well as when fires are too cold or too hot, fynbos species get eliminated. In order to sustain its plant species, fynbos should burn at intervals between 6 and 45 years (Cowling *et al.*, 1997a; Cowling, 1992; Van Rooyen *et al.*, 1999). The heat from the fire helps fracture hard seed coats and stimulates seed embryos while the ethylene and ammonia, as well as other unknown chemical factors in plant derived smoke and smoke extracts, stimulate germination (Brown, 1993).

Renosterveld is a non-fynbos vegetation type that also occurs within the Fynbos Biome. It generally lacks the characteristic fynbos elements (restiod, proteoids and ericoids) (Cowling *et al.*, 1997b; Rebelo, 1998) and is distinguished by the dominance of members of the Asteraceae Family, especially Renosterbos *Elytropappus rhinocerotis* from which this vegetation gets its name (Rebelo, 1998). Other dominant elements include other plants from the family Asteraceae, such as species of the genera *Eriocephalus*, *Felicia*, *Helichrysum*, *Pteronia*; and Fabaceae, including species of *Aspalathus*; Rubiaceae, in particular members of *Anthospermum*. Other prominent families include Sterculiaceae: (*Hermannia)*; and Thymelaeaceae:

(*Passerina*). Most species have characteristically small, tough grey leaves as an adaptation to the seasonally xeric conditions. Renosterveld also has a high diversity of geophytic plants including a large number of species belonging to the families Iridaceae and Liliaceae (Rebelo, 1998).

Renosterveld seems to favour the fine grained fertile clays and silts derived from the shales of the Malmesbury Group, Bokkeveld Groups and Karoo Sequence (Compton, 2004; Cowling *et al.*, 1997b; Rebelo, 1998). However, in drier regions it may also occur on soils derived from the Cape Granite Suite. Renosterveld vegetation occurs where annual rainfall is between 250 and 600 mm. Where rainfall is less than 250 mm, the Succulent Karoo vegetation types replace Renosterveld, while in areas where it is greater than 600 mm, soils become leached and Renosterveld is replaced by Asteraceous Fynbos (Cowling *et al.*, 1997a). Renosterveld is a highly disturbed formation and is now restricted to isolated hills were cultivation is not possible as the nutrient-rich soils of the region known as the Swartland have been extensively cultivated for wheat and vineyards (Compton, 2004). It is thus currently faced with extinction in the lowlands, due to the replacement of natural vegetation there by cultigens (Rebelo, 1998).

According to Rebelo (1998), fynbos and Renosterveld, which occur in the Fynbos Biome comprise altogether of 10 vegetation types each characterised by several plant species (Table 4.1).

Table 4.1 Vegetation types of the Fynbos Biome (Based on Rebelo (1998)).

Vegetation	Vegetation types	Characteristic species include:	Climate	Geology and soil
Fynbos	Grassy Fynbos	Genera: *Brachiaria, Eragrostis, Heteropogon, Themeda and Trachypogon.*	Where the summer rainfall component increases	Sandy soils derived from the Cape Supergroup sandstones
	Laterite Fynbos	Elim Conebush *Leucadendron elimense*, Roughleaf Conebush *L. modestum* and Bredasdorp Conebush *L. laxum*, Blombos *Metalasia muricata*, Fine Featherbush *Phylica ericoides*, Elim Gonna *Passerina galpinii*, *Disparago anomala*	Annual winter rainfall between 440 & 460 mm. Average annual temperature ranges between 15 and 16°C.	Soils derived from a variety of depositional landscapes with gravelly, lateritic and seasonally waterlogged soils
	Limestone Fynbos	*Protea obtusifolia, Leucadendron meridianum, Leucospermum truncatum, Erica propinqua, Protea susannae, Thamnochortus muirri, Restio triticeus, Elegia muirii.*	Winter and autumn-spring rainfall ranging from 350 – 600 mm per yr. Mean daily temperatures range from 12 to 22°C averaging 17°C	Calcareous, neutral to alkaline, shallow sands overlying limestone and associated with calcretes of Bredasdorp Formation
	Sand Plain Fynbos	Heath: *Erica mammosa, Starface Phylica cephalantha*, Baboonface *P. stipularis*, Restiods:*Thamno obtusus*, Strandveld Thatching Reed *T. punctatus*	Mediterranean with summer drought. Rainfall from 200 to 500 mm per yr mainly in winter.	Deep acid soils of the West Coast, most of which are Tertiary aeolian and podsolized. Some of these soils are derived from the Cape Granite Suite and Table Mountain Group sandstones
	Mountain Fynbos	Merely fynbos on the Fynbos Biome mountains	Winter rainfall varying from 200 to over 2000 mm per yr	Largely soils derived from the Cape Supergroup sandstones. Where rainfall is high (> 300 to 400 mm annually), it occurs on leached soils

Table 4.1 continued

				derived from granites, and on shales as well where annual rainfall is greater than 600 to 800 mm.
Renosterveld	North-western Mountain Renosterveld	*Elytropappus rhinocerotis, Eriocephalus africanus, Euryops lateriflorus, Nylandtia spinosa*	Winter rain and summer drought. Annual rainfall varies from 250 to less than 350 mm	Deep loamy soils derived from granites and gneisses
	Escarpment Mountain Renosterveld	*Elytropappus rhinocerotis, Relhania genistifolia*	Annual winter rainfall ranging from 200 to 300 mm	Clays and silts derived from the Karoo Sequence shales
	Central Mountain Renosterveld	*Acacia karroo*, Bitter *Aloe ferox*, Common Guarri *Euclea undulata*, *Rhus* spp.	Annual winter rainfall ranging from 250 to 400 mm	Bokkeveld and Witteberg Group and rare on Karoo Sequence shales
	West Coast Renosterveld	*Elytropappus rhinocerotis, Eriocephulus africanus, Leysera gnaphalodes, Anthospermum aethiopicum.* C_3 grasses - Genera: *Ehrharta, Pentaschistis Merxmuellera.* Redgrass *Themeda triandra, Cymbopogon marginatus.* Geophytes: Iridaceae, Liliaceae. Annual grasses: *Oats Avena*, Quaking Grass *Briza* and Ryegrass *Lolium.*	Mediterranean climate with winter rainfall. Annual rainfall varying from 300 to 600 mm.	Confined largely to Malmesbury Group shales, Cape Granite Suite and Klipheuwel Formation shales which produce loamy soils
	South and South-west Coast Renosterveld	*Elytropappus rhinocerotis, Relhania genistifolia, Hermannia flammea, Relhania cuneata, Helichrysum anomalum*	Rainfall tends to occur during spring and autumn months with a summer component increasing in the east	Clays and silts derived from Bokkeveld and Kango Group shales and Uitenhage Group conglomerates.

4.5 THE STUDY SITES

The research here focuses on two study sites, namely: Katbakkies Pass and Truitjes Kraal (Figure 4.4), which are located in the southwestern Cape in the northern part of the fynbos biome. These sites occur within the mountains known as the Cederberg. The drier parts of Cederberg landscape (especially its eastern margins) generally have low rainfall associated with a modified fynbos vegetation penetrated on its eastern and western sides by tongues of Karoo-like shrubland and sandveld respectively (Taylor and Leistner, 1996). The Cederberg has a challenging climate for plant life, with extreme summer drought and heat. There are a variety of habitats including those that would favour species from the drier northern and eastern regions as well as from moister regions further south. Since there are no direct climatic observations for the two sites, the climatic parameters for the specific sites presented here are interpolated values from works of (Schulze, 1996).

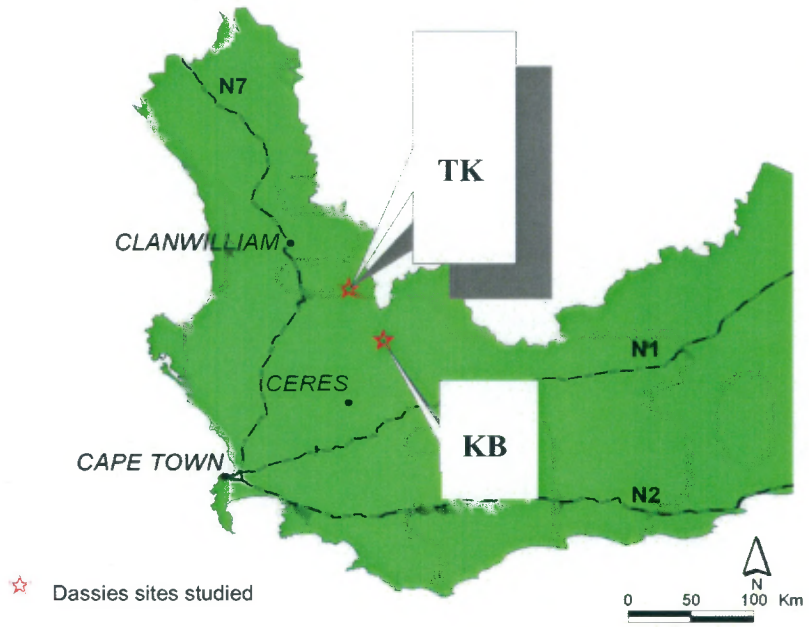

Figure 4.4 Map of the Western Cape Province showing the two study sites (TK and KB), the main towns and national roads.

4.5.1 KATBAKKIES PASS SITE

An extensive hyrax dung midden was discovered at KB. This was referred to as KB1 (Figure 4.4). The KB1 midden faces north and is about 30 m from the Katbakkies Pass Roads.

4.5.1.1 THE LOCATION OF THE KB STUDY SITE

The Katbakkies Pass is a secondary road which leads from Ceres to the Tanqua Karro. The Katbakkies Pass site lies some 70 km northeast of Ceres and is about 1190 m above sea level, occurring nearly at the top of the pass (Figure 4.5). The site is located at 32° 0.9` S and 19° 0.6` E. It occurs in rugged and rocky terrain, which is a typical habitat for hyraxes. The KB1 midden was found in a north-facing rock overhang and sits on a horizontal ledge, which is about 5 – 6 m off the ground (Figure 4.6). The midden is approximately 20 cm thick with a maximum gap of about 15 cm between the midden top and the roof of the overhang. This midden has a horizontal extent of about 3 x 1 m.

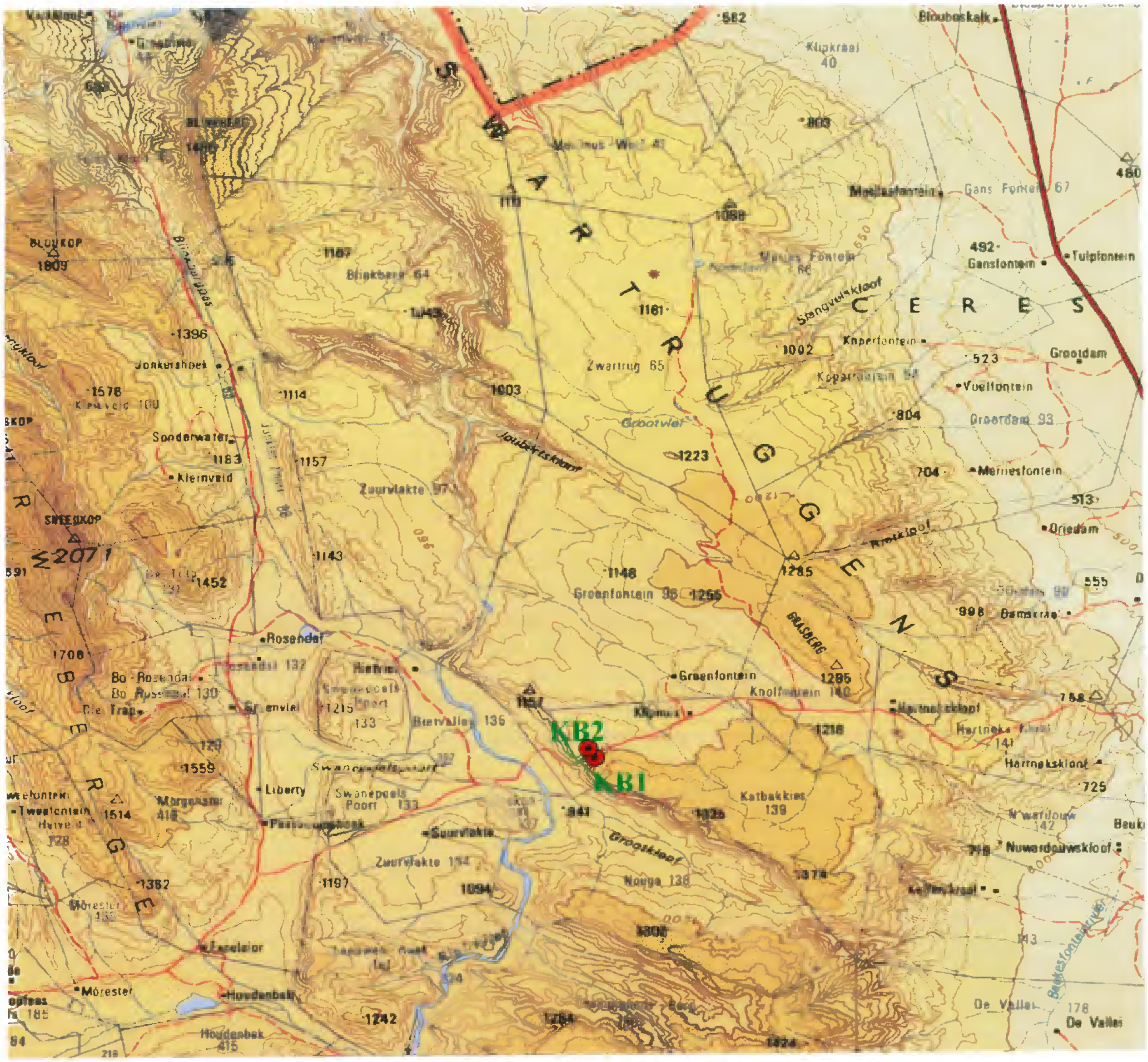

Figure 4.5 Part of 1:250 000 Clanwilliam 3218 map sheet showing the location (represented by the red and black dots) of KB site.

Figure 4.6 KB1 Hyrax midden

4.5.1.2 CLIMATE OF KB

KB falls within the WRZ of South Africa, where more than 66 % of the rain falls April and September (Figure 4.7). The mean annual rainfall at KB is about 355 mm (Schulze, 1996). The winters are cool and wet with hot dry summers. The average maximum and minimum temperatures are given in Figures 4.8 and 4.9 respectively. KB is some distance from the moderating effect of the ocean, such that in winter temperatures decrease considerably allowing frost and snow to form on this high altitude terrain. There is an average of about 32 days of frost in winter in this area (Schulze, 1996).

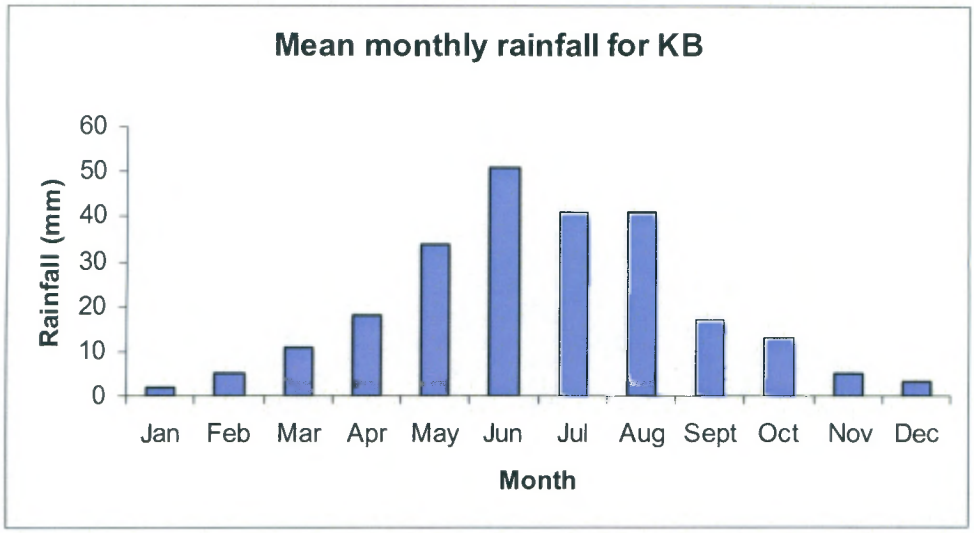

Figure 4.7 The mean monthly rainfall for KB (Data from (Schulze, 1996)).

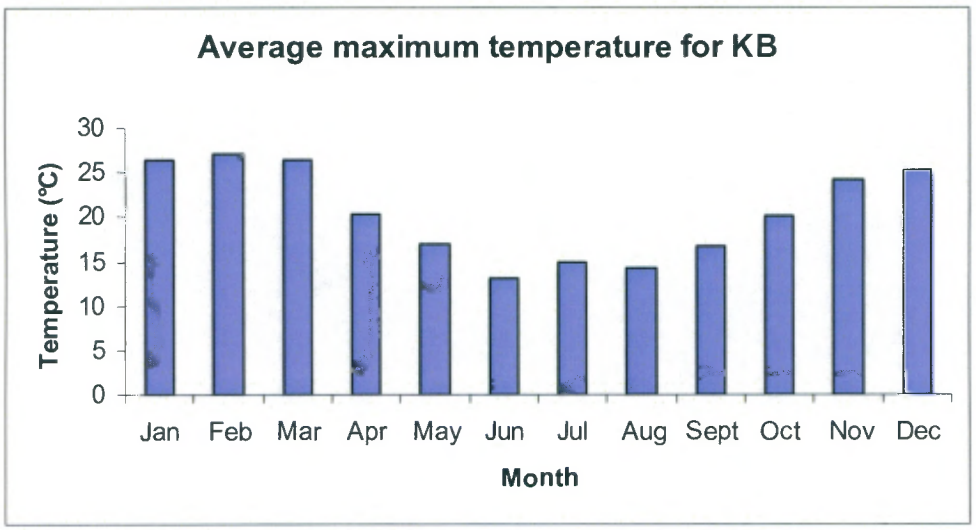

Figure 4.8 Average maximum temperature for KB (Data from (Schulze, 1996)).

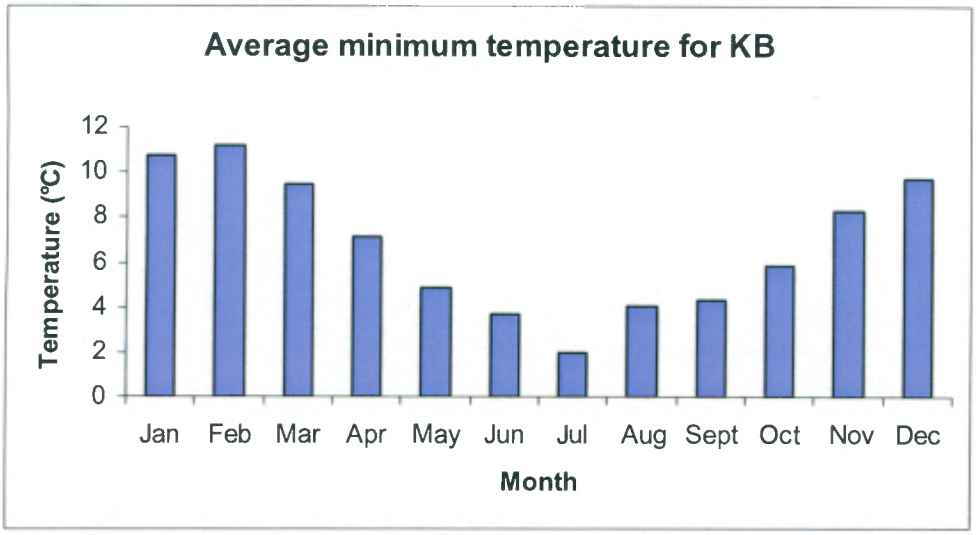

Figure 4. 9 The average minimum temperature for KB (Data from (Schulze, 1996)).

4.5.1.3 GEOLOGY OF KB

The KB site occurs on the massively bedded quartzitic sandstone of the Table Mountain Group designated C3Q2 on the 1:250 000 Geological Series Clanwilliam 3218 map sheet (Figure 4.10). West of the study site the geology changes to sandy shale and siltstone with sandstone bands (C3S2). Tongues of sandy soil (Q1) along river channels penetrate the C3S2 substrate to the west of the study site. To east of the KB site occurs a complex geological combination of tillite, partially bedded with boulder beds and thin chert, shale, mudstone, argillaceous limestone and siltstone bands (KIG). The sandstone geology at KB has produced the shallow nutrient poor soils on which the vegetation near the site grows. The sandy soil drains quickly retaining little moisture.

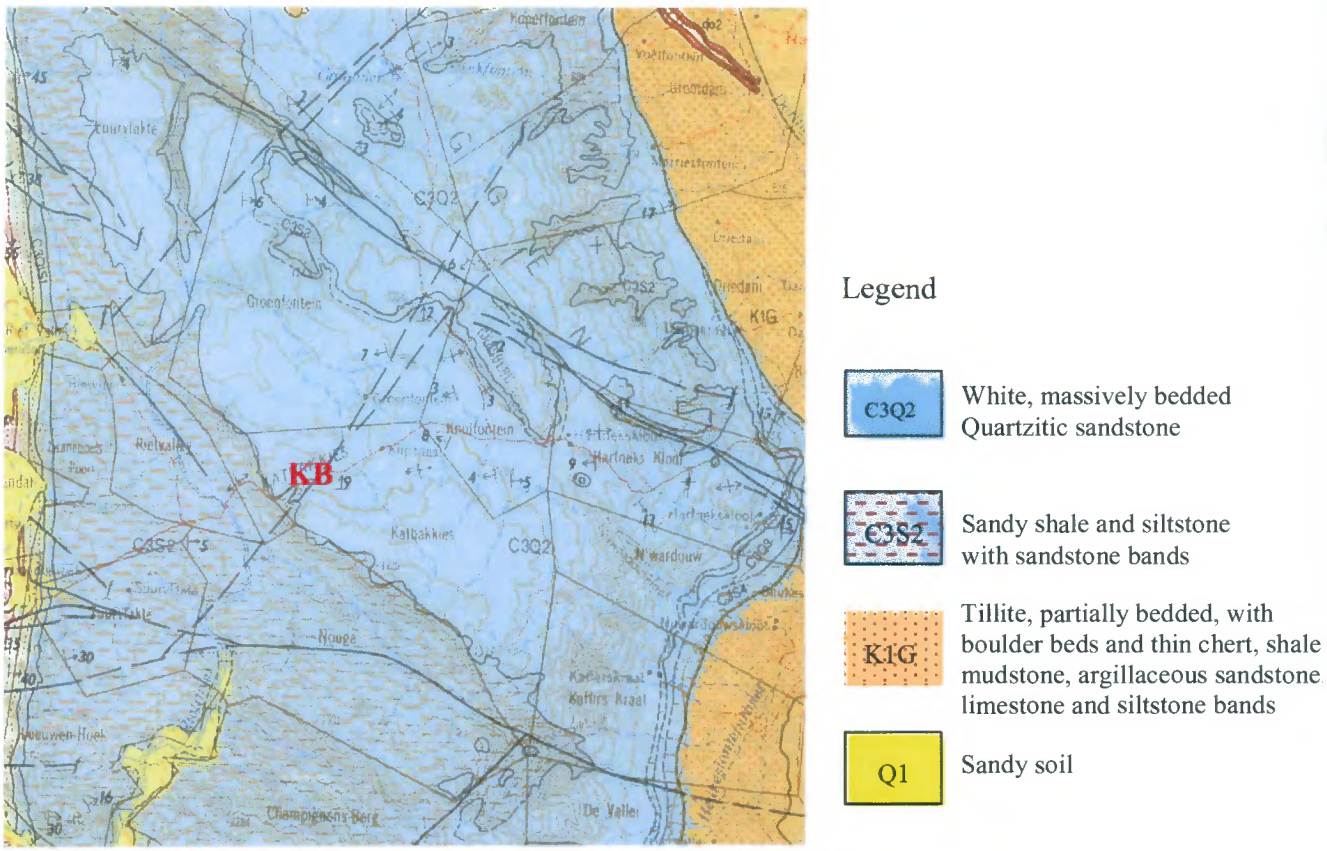

Figure 4.10 Part of 1:250 000 Geological Series Clanwilliam 3218 map sheet showing the geology of KB.

4.5.1.4 VEGETATION IN THE VICINITY OF KB1

The KB site occurs on the vegetation transitional zone between the Fynbos and Succulent Karoo Biomes (Figure 4.11). The vegetation immediately adjacent to and surrounding the midden site at KB1 (Figure 4.12) falls under what Acocks (1988) and Rebelo (1998) refer to as Mountain Renosterveld (Veld Type 43) and Central Mountain Renosterveld (Vegetation Type 61) respectively. According to Acocks (1988), this veld type does not include all the elements of Renosterveld found on the mountains of the Cape but comprises of only the so-called falsely karroid part of the renosterbos, which appears to be the dominant natural component. This suggests that the nutrient deficient sandy soils in this area cannot support the non- karroid Renosterveld species as these prefer the nutrient rich loamy soils derived from shales. The characteristic species according to Acocks (1988) include: *Elytropappus rhinocerotis, Relhania sqarrosa, Eriocephalus africanus, Euryops lateriflorus,*

Pentzia incana, Chrysocoma ciliata, Polygala myrtifolia, Helichrysum hamulosum, Walafrida saxatilis articulata, Ruschia multiflora pungens, Galenia africana var. africana, Zygophyllum spinosum, Felicia filifolia, Tylecodon wallichii subsp. *wallichii* and many others.

Rebelo (1998) refer to this vegetation type as an open to medium-dense cupressoid and small leaved, low to mid-high shrubland. The overstorey components are scattered and include Sweet Thorn *Acacia karroo*, Bitter Aloe *Aloe ferox*, Common Guarri *Euclea undulata* and *Rhus* spp. The understorey lacks grasses when overgrazed and contains various densities of herbaceous plants with a high proportion of succulents.

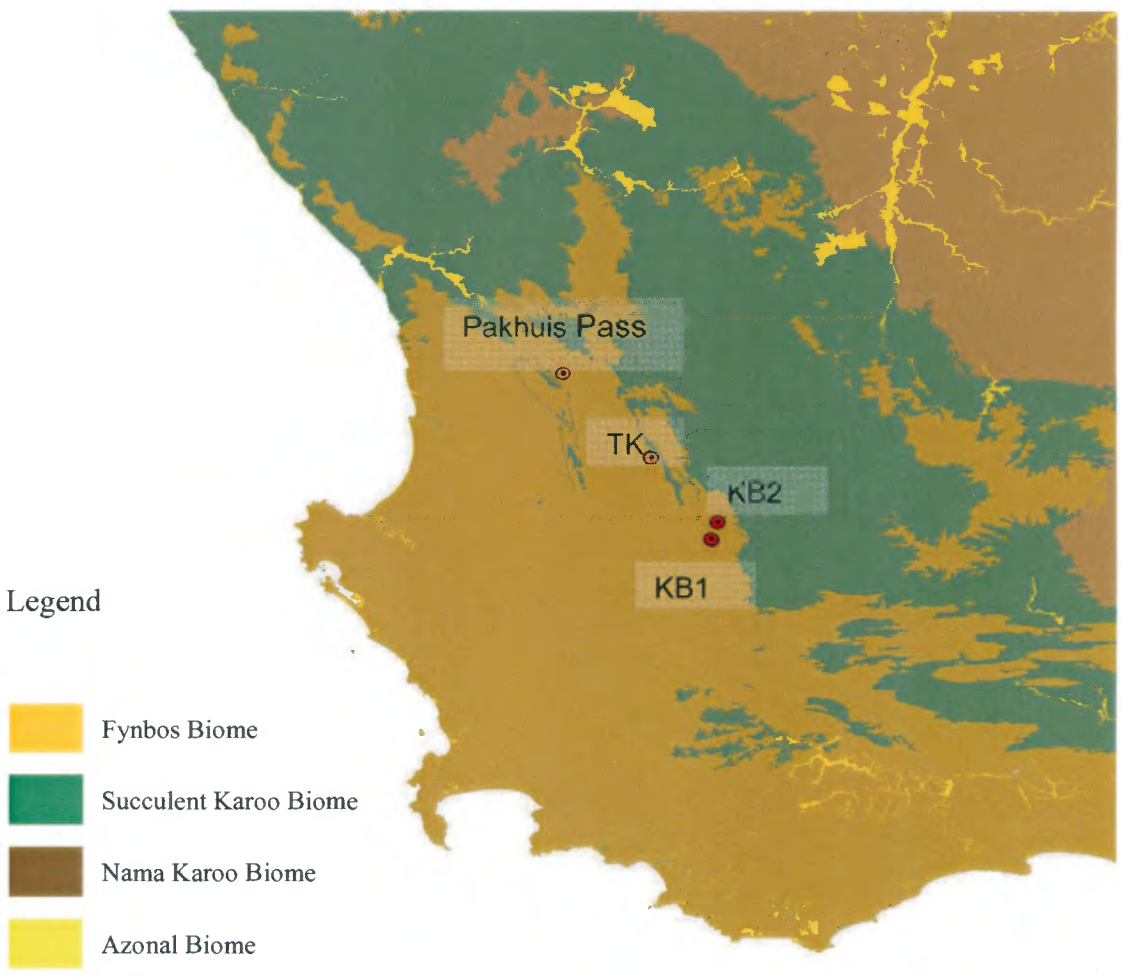

Figure 4.11 Vegetation map of South Africa showing the position of the study sites, with Pakhuis Pass (Scott, 1994) also shown for comparison (data from Mucina and Rutherford (2003)).

Figure 4.12 The vegetation in the vicinity of KB1

Indeed at KB the dominant element of the contemporary vegetation is renosterveld, dominated by *Elytropappus rinocerotis*. Several other asteraceous shrub species, including *Euryops* spp. were also identified in the vicinity of the site. Other prominent families occurring include: Roseaceae – *Cliffortia* spp., Crassulaceae – *Tylecodon* spp., and Myrtaceae. Acanthaceae – *Rhus* spp., formed scattered overstorey elements and especially occurred near the rock outcrops. Reeds of the Restionaceae family seem to be associated more with the higher and more exposed parts of the pass than at lower elevations. A few species of Proteaceae are found, in particular *Protea repens*. Grasses belonging to an unknown species also formed part of the vegetation in the vicinity of the midden site. *Stoebe* spp., common in this veld type, were not identified in the immediate vicinity, but most like occur in the general area, especially where the landscape has been disturbed.

The Riet River runs about 2.5 km in the north westerly direction of the KB1 site. The river valley is relatively densely vegetated, dominants being several sedge species, restios and grasses. The restios and grasses grow more densely on this floodplain and are much taller than anywhere else in the immediate surroundings of the site.

4.5.2 TRUITJES KRAAL SITE

One midden, TK4 was analysed from this site.

4.5.2.1 LOCATION OF TRUITJES KRAAL SITE

The TK site lies some 63 km southeast of the town of Clanwilliam in the Cederberg (Figure 4.13). This site, located at 32° 30.718`S and 19° 18.727`E occurs about 40 m south of the secondary road that leads from Clanwilliam to Ceres. The TK site has an altitude of about 890 m. The middens was located in a 25-30 m high north-facing cliff face, which formed an overhang at about 5 m from base (Figure 4.14). The Driehoek River runs about 1.25 km north of the site.

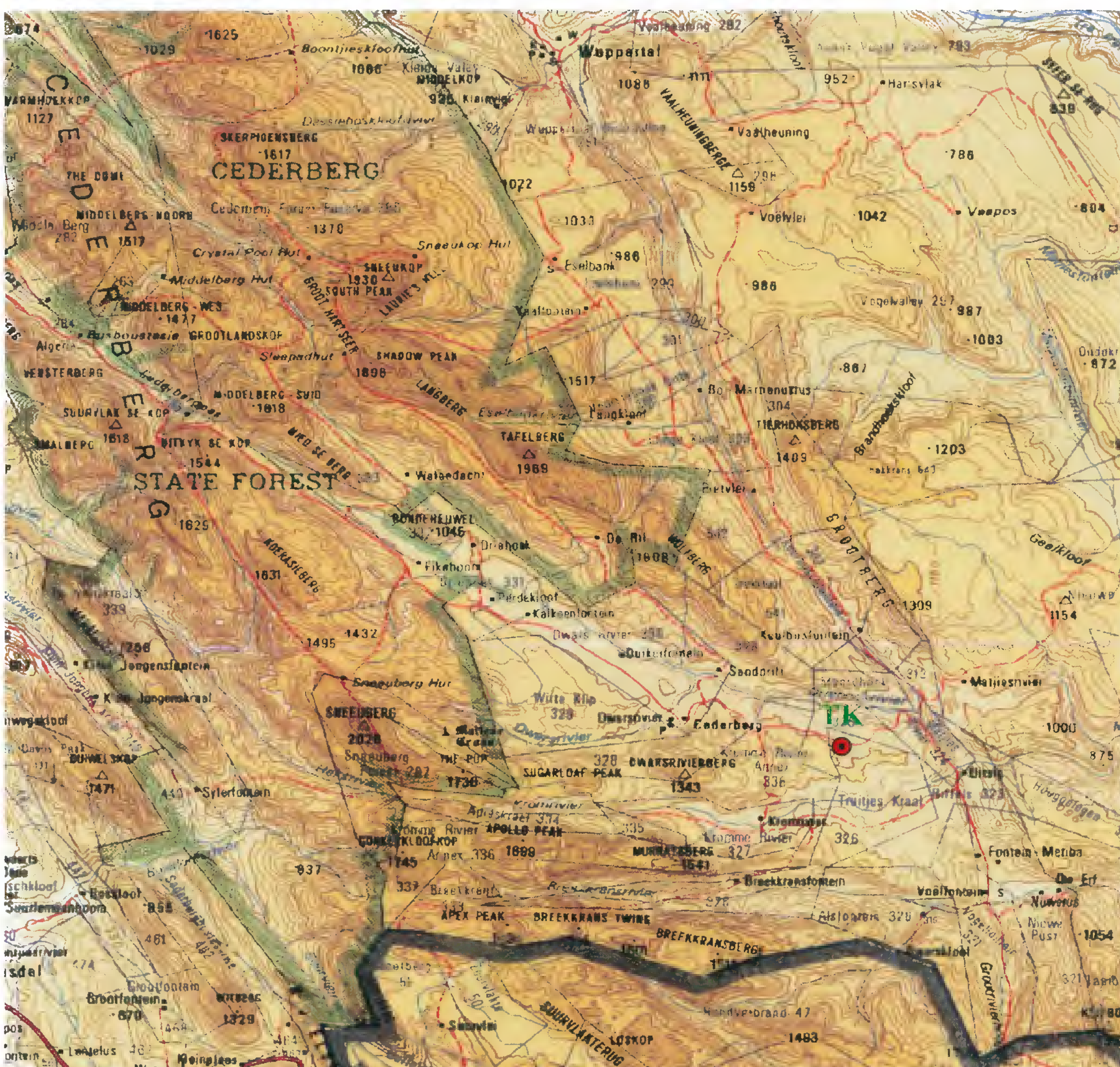

Figure 4.13 1:250 000 Clanwilliam 3218 map sheet showing the location of the TK site (represented by the red dot).

Figure 4.14 The location of the TK middens.

4.5.2.2 CLIMATE AT TRUITJES KRAAL

The TK site occurs within the winter rainfall region of South Africa, this again being the so-called Mediterranean climate region, where the majority of the rain, more than 60 % falls in winter. The mean annual rainfall is about 257 mm (estimated value from precipitation maps of Schulze (1996)). The site is found on the eastern side of the Cederberg and is most likely influenced by the drier climates of the succulent Karoo as this site lies only a short distance to the south of this. The monthly precipitation values are shown in (Figure 4.15). The winters here are cool and wet while the summers are hot and dry. The average maximum temperature and the average minimum temperature for TK are shown in (Figures 4.16 and 4.17) respectively. The

high average maximum temperatures contribute to the high evaporative index (Schulze, 1996) in the area, which the xeric conditions, further intensified by the freely draining soils there. Due to relatively high elevation and distance from the sea, frost occurs at TK in winter with an average of about 17 days of frost in a year (Schulze, 1996).

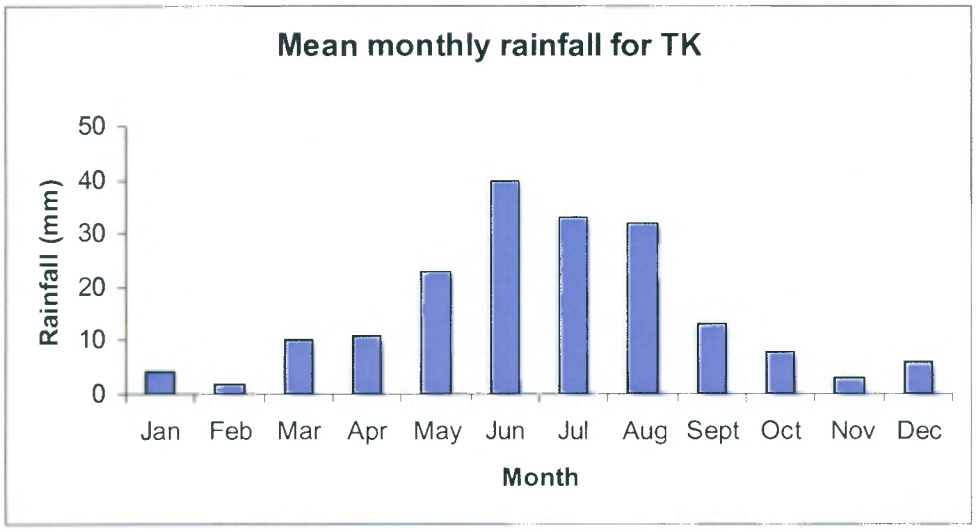

Figure 4.15 Mean monthly rainfall for TK (Data from Schulze (1996)).

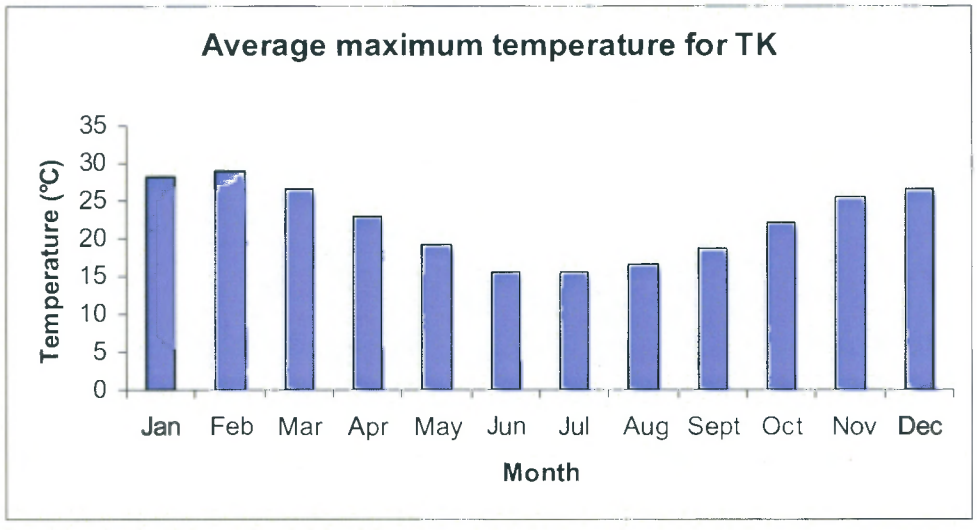

Figure 4.16 Average maximum temperature for TK (Data from Schulze (1996)).

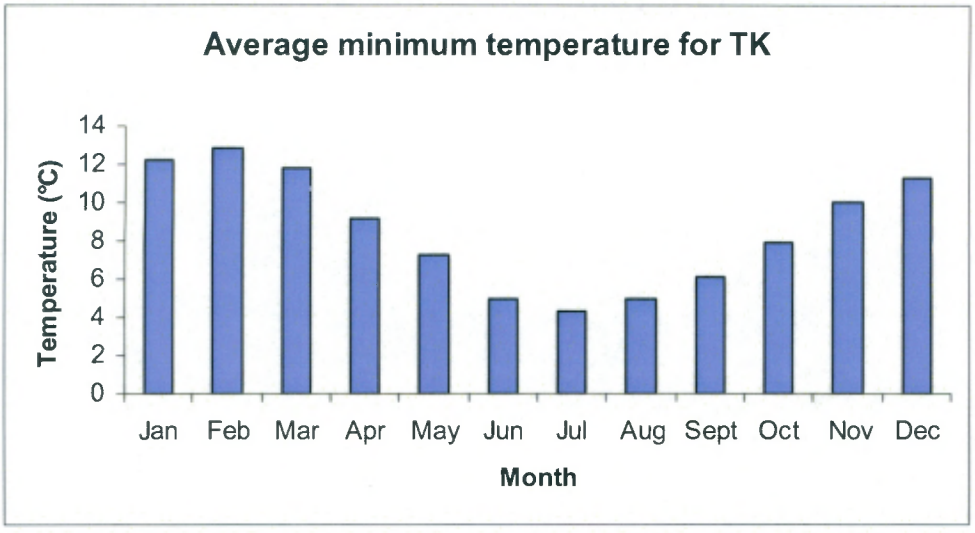

Figure 4.17 Average minimum temperature for TK (Data from Schulze (1996)).

4.5.2.3 THE GEOLOGY OF TRUITJES KRAAL

The TK site occurs on relatively high relief terrain consisting of quartzitic sandstone rocks of the Nardouw Formation of the Table Mountain Group, which comprise of thin lenses of Bokkeveld shales and conglomerates, designated C1Q2 on the 1:250 000 Geological Series Clanwilliam 3218 map sheet (Figure 4.18). These TK rock types have produced the deep sandy substrate which is nutrient deficient. The Table Mountain Group quartzitic sandstones extend to the west, northwest and southwest of TK substrate, but these extensions only have minor shale and conglomerate lenses associated with them (C1Q1). Shale rocks of the Bokkeveld Group, arenaceous shale tillite, grit and conglomerate form narrow bands which intrude between these quartzitic sandstones of varying shale and conglomerate lenses (C1S2G). A band of shale, siltstone and thin fine-grained sandstone lies to the east of the TK substrate (C2S2). Parallel to this is a siltstone and arenaceous shale band. Adjacent to this band is an extensive terrain of sandy shale and siltstone predominated by quartzitic Table Mountain sandstones.

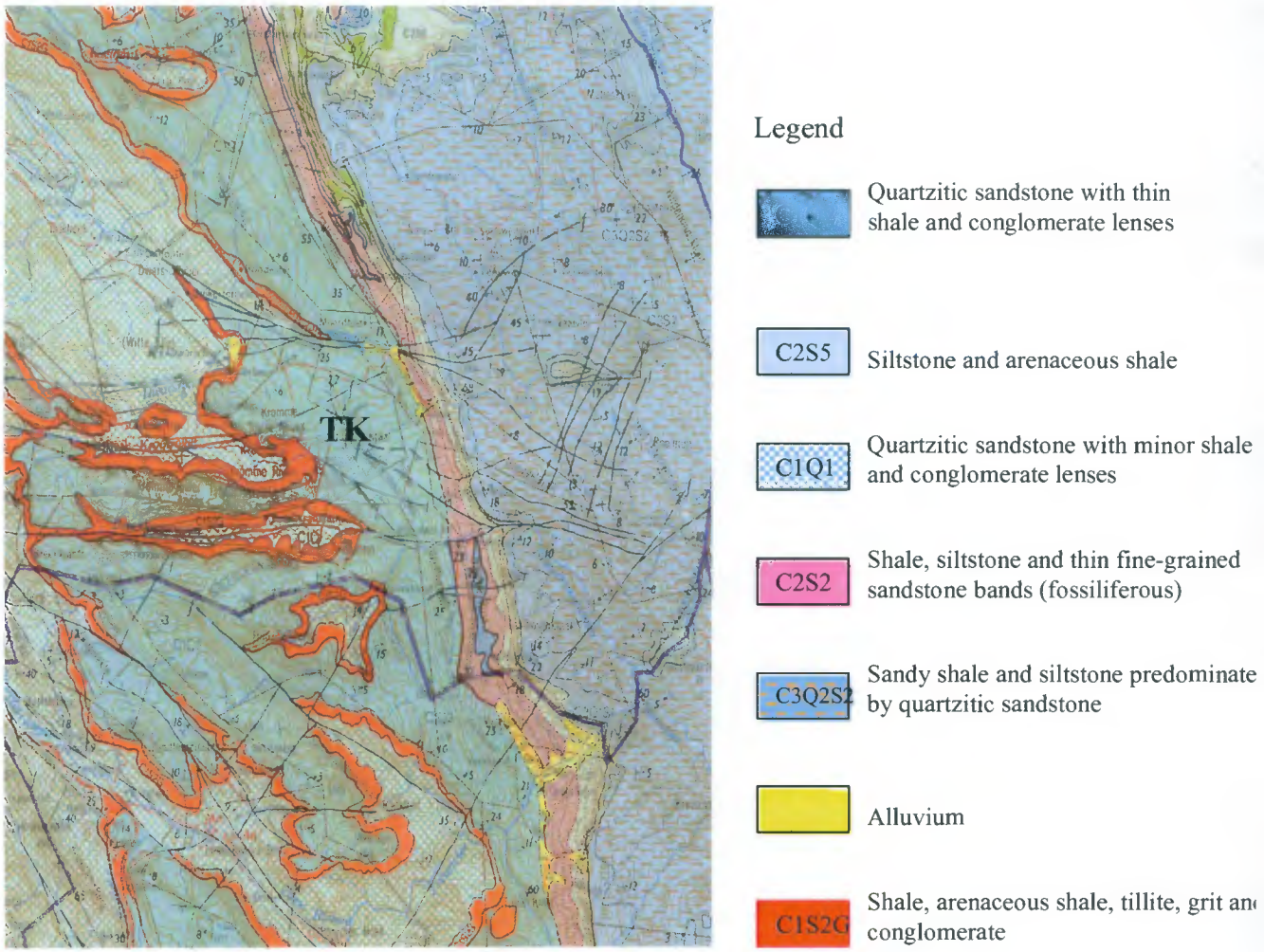

Figure 4.18 1:250 000 Geological Series Clanwilliam 3218 map sheet showing the location of TK.

4.5.2.4 VEGETATION AT TK

The TK site falls almost on the border of the Fynbos Biome (Figure 4.11), to the north of which lies the Succulent Karoo Biome. The vegetation at TK is similar to the Community 18 of local sandy flats of Taylor and Leistner (1996). This vegetation community has been described by Taylor and Leistner (Taylor and Leistner, 1996) as restioland with a low shrub understorey with or without overstorey or emergents. The common elements include restioid hemicryptophytes: *Thamnochortus platypteris*, *Ischyrolepis monanthos* and *Willdenowia arescens*, and sometimes sedges: *Tetraria compar*, *T. nigrovaginata* and *Ficinia bulbosa*, shrubs: *Metalasia agathosmoides*, *Stoebe leucocephala*, *Macrostylis tenuis/decipiens*, succulents: *Lampranthus laetus*,

Proteiods: *Protea acaulos* and chamaephytes: *Pelargonium coronopifolium*. Emergent shrubs of up to 1 – 2 m tall include: sclerophylls *Cliffortia ruscifolia*, *Anthospermum aethiopicum*, *Athanasia oligophylla*, proteoids: *Leucadendron salignum* and *L. loranthifolium* and fleshy microphyllous *Othonna parviflora*. The dominant species include both restioids, associated usually with sandy flats and shrubs which are usually taller adjacent to rocky outcrops such as that associated with the TK middens.

Taylor and Leistner (1996) state that this vegetation community is found at altitudes between 700 and 1100 m on well drained deep sandy substrate. TK falls in this altitudinal range, reaching and elevation of about 890 m with the vegetation growing on deep sandy soils with good drainage. There are few overstorey elements are few away from the koppies, but near the outcrops shrubs of up to 2 m tall are found including: members of the Anacardiaceae such as *Rhus undulata*., and Celastraceae such as *Maytenus oleoides* (Figure 4.19). Other species identified in the vicinity of the study site are the dense restioid vegetation *Thanmochortus platypteris, Willdenowia incurvata.* Asteraceous species such as *Elytropappus rhinocerotis* and *Eriocephalus* spp. are also present. Dwarf succulent shrubs belonging to the Crassulaceae, *Crassula brevifolia* susp. *brevifolia* and those of the Mesembryanthemaceae, such *Carpobrotus edulis* and *Lampranthus cedarbergensis* also form part of the vegetation in the vicinity of the site.

Figure 4.19 Vegetation of the TK koppies.

4.6 CONCLUSION

This chapter has presented the diversity of the environmental context of the southwestern Cape. Experiencing a different climate regime with steep climatic gradients from the rest of the country for thousands of millennia, due to factors including its position relative to sea, the environmental evolution of this region has correspondingly resulted in the unique relics evident in the present day. The diverse geology (terrain and their substrate) and the high species richness of the vegetation, among the world's most diverse flora, are some of the main features which characterise the region and distinguish it from the rest of South Africa.

CHAPTER 5

RESULTS

This chapter presents results from the radiocarbon analysis, and the two independent palaeoenvironmental techniques applied in the project, namely stable carbon isotope and pollen analysis.

5.1 RADIOCARBON DATING RESULTS

Radiocarbon ages (Tables 5.1 and 5.2 and Figures 5.1 and 5.2) were obtained from CSIR, Quaternary Dating Research Unit (QUADRU) laboratory. These were as follows (calibrated dates using CalPal2004 (www.calpal.de) are also given in the tables):

Table 5.1 showing radiocarbon dating results for KB1-1.

Laboratory analysis no.	**Sample designation**	**d ^{13}C (‰PDB)**	**Radiocarbon age, yrs BP**	**Calibrated age, cal yrs BP** based on (CalPal2004) (www.calpal.de)
Pta-9285	KB1-1-1, 0-2 cm	-25.12	610 ± 50	599 ± 39
Pta-9288	KB1-1-2, 9-11 cm	-26.05	1 830 ± 50	1 765 ± 56
Pta-9287	KB1-1-3, 17-20 cm	-25.41	3 420 ± 60	3 684 ± 85

Table 5.2 showing radiocarbon dating results for TK4.

Laboratory analysis no.	**Sample designation**	**d ^{13}C (‰PDB)**	**Radiocarbon age, yrs BP**	**Calibrated date, cal yrs BP** based on (CalPal2004)
Pta-9463	TK4-1, 0-2 cm	-25.2	1 400 ± 40	1 314 ± 23
Pta-9480	TK4-2, 9-11 cm	-26.5	8 520 ± 80	9 509 ± 48

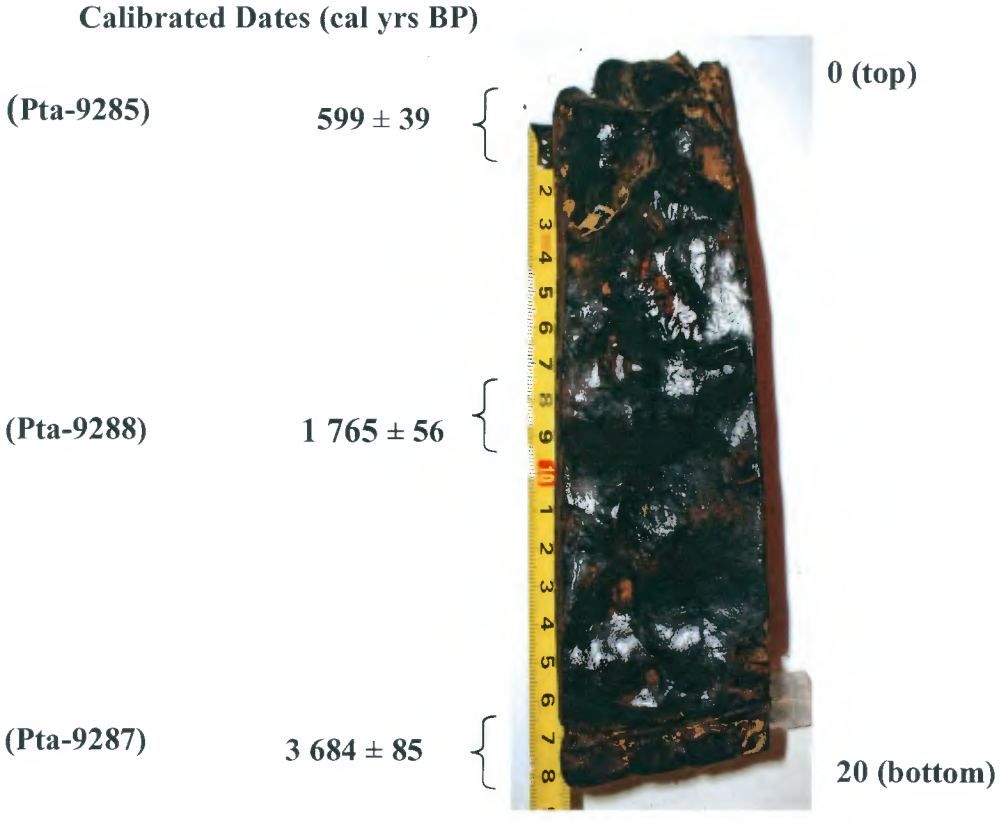

Figure 5.1 Midden KB1 showing calibrated dates.

Figure 5.2 Midden TK4 showing calibrated dates.

The ages were obtained through conventional radiocarbon dating. The age precision could, however, have been affected by a large amount of material, covering about 2 cm of depth at every dated point, which was used. This may well have resulted in the combination of older and more recent carbon. The ages should therefore be taken as estimates defining roughly the period of development of the two middens. A further age precision problem is associated with the transfer of ages obtained for midden KB1-1 to KB1-2, which was the section analysed for pollen. While these two sections belong to the same mother midden, the ages from KB1-1 should only be regarded as estimates for KB1-2. Assuming constant rates of midden accumulation, midden KB1 (based on radiocarbon ages from KB1-1) accumulated about 1 cm of material every 130 to 210 yrs and TK4 accumulated 1 cm of material every 600 to 900 yrs. The causes of differential midden accumulation rates are however not known, but factors including hyrax population densities, colony size, ratio of pellets to hyracium, frequency and length of latrine use could be used to explain different rates of hyrax dung midden accumulations (Scott and Bousman, 1990). It is also, of course, possible that the rate of accumulation is not constant for the time periods on question and that the approximately 8 000 year sequence at TK was interrupted by periods of non-accumulation or even erosion of midden material.

5.2 STABLE CARBON ISOTOPE ANALYSIS

Only the carbon isotope analyses results from the dated middens, KB1-1 are reported here (Table 5.3, Table 5.4 and Figure 5.3). The samples from the two middens show consistent depletion in ^{13}C, thus depicting negative $d^{13}C$ values very close to -26‰, which is the accepted mean $d^{13}C$ value for C_3 plants (Sealy, 2001). The strong C_3 plant signals portrayed over the respective periods investigated, are consistent with the shrubby, predominantly C_3 fynbos vegetation of the southwestern Cape (Scott and Vogel, 2000; Stock *et al.*, 1993).

The $d^{13}C$ values from KB and TK vary but within tightly defined limits. At KB, the difference between the lowest and highest $d^{13}C$ value in the whole sequence is 0.84 units representing only 7% variation, while this value is 0.6 units for TK, portraying

5% variation. The stable carbon isotope results therefore infer very limited palaeoenvironmental change through the period of sedimentation.

Table 5.3 Stable carbon isotopic results: KB1-1. (NB: Column heading explanations given in page 82).

Sample	Weight mg	Ampl 44 mv	Area 44	%C	d 13C/12C	Standard corrected d 13C/12C
KB 1-1-1	1.002	16589	339.9	39.97	-26.28	-25.73
KB 1-1-2	1.040	16591	347.5	39.47	-26.07	-25.53
KB 1-1-3	1.069	19051	400.3	44.78	-25.96	-25.43
KB 1-1-4	1.052	20616	428.0	52.47	-26.19	-25.65
KB 1-1-5	1.037	18532	393.8	48.96	-26.05	-25.52
KB 1-1-6	1.024	19055	389.9	45.22	-26.15	-25.61
KB 1-1-7	1.075	18934	391.1	43.20	-26.32	-25.77
KB 1-1-8	1.063	19862	402.4	44.97	-26.42	-25.86
KB 1-1-9	1.049	20578	419.2	47.47	-26.37	-25.82
KB 1-1-10	1.060	20918	425.5	47.69	-26.44	-25.89
KB 1-1-11	1.081	21134	432.2	47.50	-26.26	-25.72
KB 1-1-12	1.012	18251	375.3	44.04	-26.36	-25.81
KB 1-1-13	1.082	21218	432.9	47.54	-26.55	-25.99
KB 1-1-14	1.047	19746	398.4	45.20	-26.27	-25.73
KB 1-1-15	1.065	16448	348.2	38.81	-25.67	-25.15

Table 5.4 Stable carbon isotopic results: TK4.

Sample	[2]Weight mg	[3]Ampl 44 mv	[4]Area 44	[5]%C	[6]d 13C/12C	Standard corrected [7]d 13C/12C
TK 4-1	1.026	20167	411.6	47.53	-26.86	-26.29
TK 4-2	1.076	20686	417.0	45.96	-26.81	-26.24
TK 4-3	1.094	20806	423.1	45.91	-26.80	-26.22
TK 4-4	1.056	24553	505.9	57.60	-26.89	-26.32
TK 4-5	1.037	19321	389.0	44.23	-26.92	-26.34
TK 4-6	1.078	19964	403.2	44.23	-26.78	-26.21
TK 4-7	1.055	19356	387.9	43.34	-26.72	-26.16
TK 4-8	1.086	18855	380.3	41.21	-26.64	-26.07
TK 4-9	1.005	18834	377.4	44.17	-26.82	-26.25
TK 4-10	1.067	16615	339.9	37.10	-26.50	-25.94
TK 4-11	1.046	15679	325.5	36.08	-26.28	-25.74

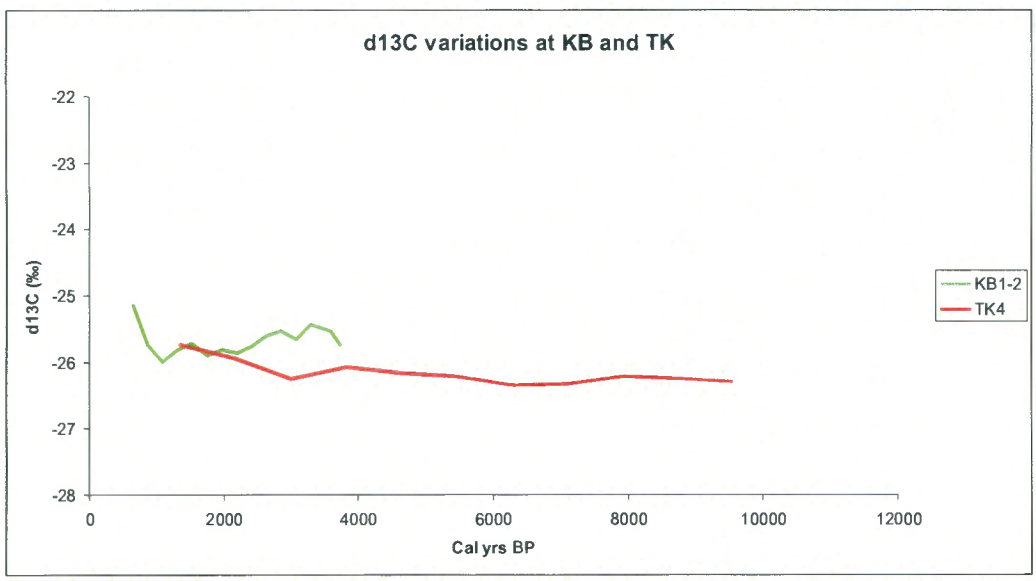

Figure 5.3 KB and TK4 carbon isotopic variation overtime.

[2] Weight of sample

[3] Voltage

[4] Area under curve

[5] Percentage carbon by weight

[6] Raw d13C/d12C values

[7] Corrected d13C/d12C values

5.3 POLLEN ANALYSIS

5.3.1 HYRAX PELLETS

The pollen transport route presented in Chapter 3 demonstrates the three ways in which pollen grains can get incorporated into middens, one of which is through hyrax diet. The various components of the hyrax food chain have hence systematically been examined for their pollen content by examining fresh and dry hyrax pellets. The pollen investigation of these however showed that the dry pellets had insufficient pollen concentrations to facilitate analysis. Therefore, no pollen analysis results for the dry hyrax pellets are presented. An explanation of this is given later.

The pollen data from fresh pellets were used together with that from modern soil surface collections from the respective sites to give a picture of contemporary vegetation. This information has been presented together with the fossil spectra from the two sites in the form of percentage pollen diagrams (Figures 5.4 & 5.5).

5.3.2 POLLEN DIAGRAMS

The pollen diagrams (Figures 5.4 and 5.5) represent pollen percentage accumulations plotted against midden stratigraphies and depositional time. These pollen sequences have been divided into assemblage zones on the basis of their pollen content (Moore *et al.*, 1991). The identification of zones was mainly based on the increase or decrease of taxa. The spectra from KB and TK both appear to be characterised by low pollen diversity. For instance, the average pollen concentrations of 5 x 10^4 grains per gram at TK and 3.8 x 10^4 grains per gram at KB are relatively low compared to swamp pollen concentrations attained in other studies such as Meadows and Sugden (1991b) in the Cederberg, where Sneeuberg (which is approximately 25 km west of TK and situated over 500 m higher than TK) and Driehoek (about 18 km north west of TK) exhibited pollen concentrations of 8.3 x 10^4 and 10.9 x 10^4 grains per gram respectively. However, the average pollen concentrations from both TK and KB are greater than pollen densities per gram averaging around 10 x 10^3 grains per gram obtained from swamp sediments at Verlorenvlei by Meadows *et al.*, (1994). Scott

(1994) does not reflect on pollen concentrations, which would constitute the most appropriate comparison between pollen concentrations per gram given that the source of pollen would be same as that in this study. However, pollen concentrations from TK and KB are comparable to those found in middens from the Karoo (Scott and Bousman, 1990) and Clarens in the Free State (Scott, 1990), in that they are generally below 100 000 grains per gram.

5.3.2.1 POLLEN DIAGRAM FOR MIDDEN KB1-2

Two zones are identified from the KB1-2 sequence (Figure 5.4). Possible misidentifications have been noted:

- Asclepiadaceae pollen is not to be expected in middens and this may be a misidentification as it usually comes in the form of pollinia.
- Onagraceae pollen is also possibly a misidentification as this is common in aquatic environments
- Myrtaceae is probably mistaken for Eucalyptus especially because this is a surface sample

Comprehensive pollen diagram for midden KB1-2

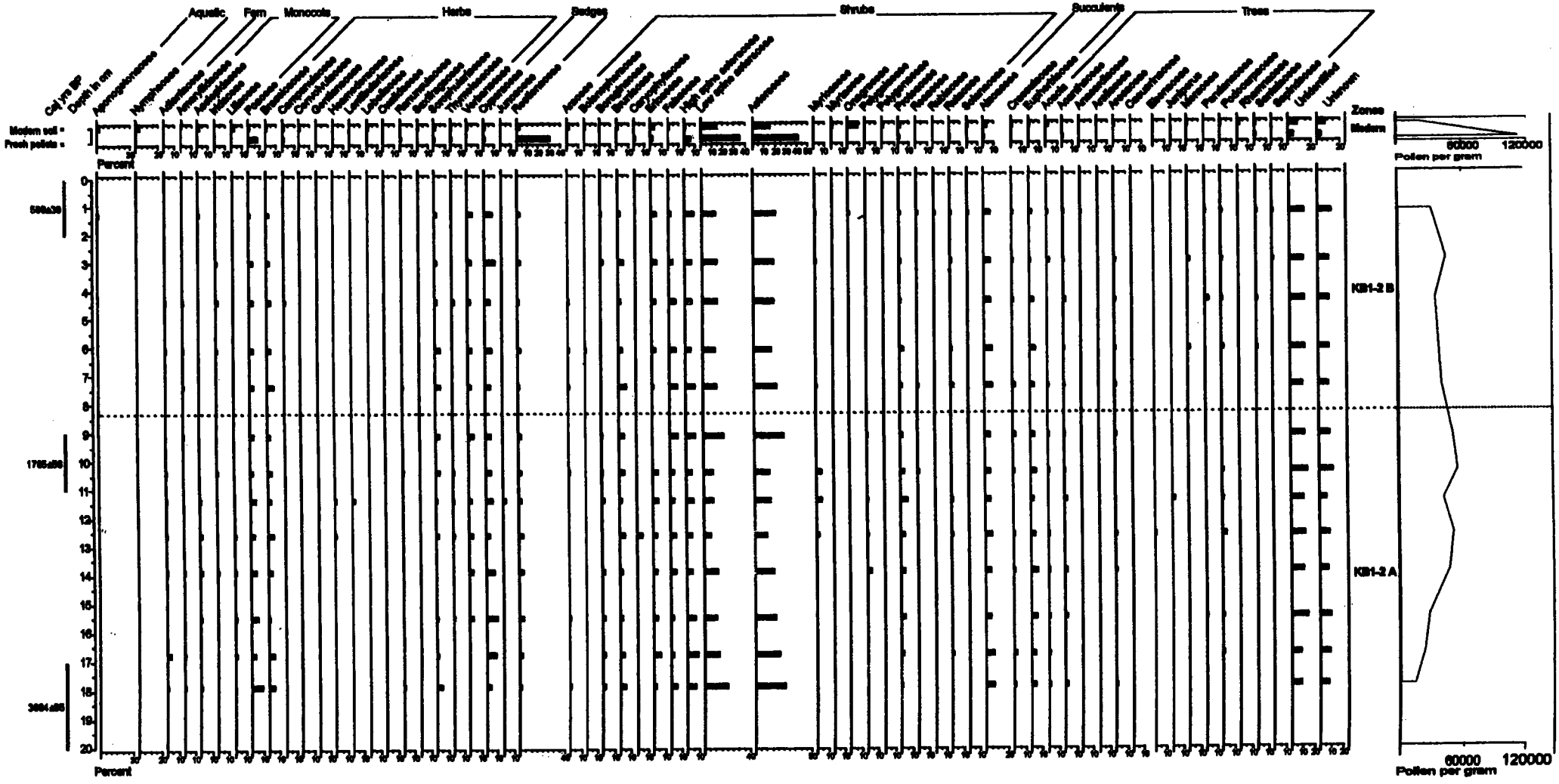

Figure 5.4 Pollen percentage diagram for midden KB1-2

5.3.2.1.1 Zone KB1-2A (from depth 20 – 8.3 cm, ~ 3 700 – 1 600 cal yrs BP)

This is the earliest zone in KB1-2 and corresponds to the lower half of the midden section up to approximately 8.3 cm. It is characterised by high proportions of Asteraceae pollen especially near the base and again towards the top. Other taxa represented include: Asclepidaceae, which reach their highest values in this zone. Poaceae begin with concentrations higher than anywhere in the fossil midden sequence. Scrophulariaceae frequencies are relatively low in this zone. Although Cyperaceae pollen decrease towards the end of the zone, in the lower levels their proportions are relatively high. Juncaceae occur only in this zone and Restionaceae are more abundant in this zone than in KB1-2B. Polygalaceae are present only in this zone, declining at the end. Proteaceae concentrations are higher in this zone that elsewhere in zone KB1-2B. Aizoaceae have remained constant throughout the sequence while Euphorbiaceae have greater proportions in this than the zone above. Among the woody elements, Podocarpaceae achieve highest concentrations in the middle of the zone, *Juniperus*, which occur only in this zone, also reach highest values at a depth of 11.2 cm, while *Acacia* and Acanthaceae more or less maintain their low but steady concentrations throughout the zone.

5.3.2.1.2 Zone KB1-2B (from depth 8.3 to 0 cm, ~ 1 600 – 600 cal yrs BP)

This zone represents vegetation changes in the upper 8.3 cm of KB1-2. It is marked by relatively lower concentrations of Asteraceae pollen compared to KB1-2A. Asclepidaceae pollen are relatively infrequent in this zone compared to KB1-1B and there is slightly less Poaceae concentrations. There are slightly higher proportions of Scrophulariaceae, particularly below a depth of 4.5 cm. Cyperaceae are lower at the start of the zone and increase towards the end. Juncaceae have disappeared completely, while Ericaceae pollen display an increase towards the top of the zone. Restionaceae decrease slightly compared to the older zone. There are fewer Proteaceae pollen in general and these gradually decrease until the end of the zone. Aizoaceae remain throughout while Euphorbiaceae show relatively decreases.

5.3.2.1.3 Modern pollen spectra for KB1-2

The modern pollen spectra were derived from modern surface soil and fresh hyrax pellets collected from the sites.

5.3.2.1.3.1 KB1-2 Modern surface soil

The pollen content of the modern surface soil from KB1 shows the dominance of Asteraceae, >15%, most being low-spined varieties that would include *Elytropappus* spp and *Stoebe*. Onagraceae concentrations are highest, about 5% in the modern surface collection and appear not to have occurred in the fossil midden material except in the uppermost level of zone KB1-2B. Aponogetonaceae exhibits slightly higher concentrations compared to zone KB1-2B. Nymphaceae, which were recorded in the midden sequence are present in the surface soil. Asclepidaceae show increased levels compared to the youngest zone in the midden. Convolulaceae and Lobeliaceae exhibit slight increases in the modern soil. Cyperaceae are found at lower frequencies compared to the upper midden sequence. Restionaceae, however, increase slightly here. Ericaceae concentrations drop slightly in relation to the topmost levels in the midden sequence. Myrtaceae pollen is present in the surface soil but not in the midden. Proteaceae show a slight increase in the modern soil compared to higher up in the midden, while Aizoaceae and Euphorbiaceae are slightly decreased. Most of the tree pollen also decrease compared to the upper levels of the midden section.

5.3.2.1.3.2 KB1-2 fresh hyrax pellets

In the hyrax pellets the most prominent pollen is that of Asteraceae, accounting for >40%, of which >35% represents the low-spine varieties. Asteraceae in the fresh pellets are more than double their concentrations in the surface soil, and are followed by Restionaceae, registering >30%. Higher Poaceae concentrations are recorded in the pellets than in both modern soil and midden sequence. Compared to the modern soil, Aizoaceae levels are lower in the pellets.

5.3.2.2 POLLEN DIAGRAM FOR MIDDEN TK4

Two pollen assemblage zones are also recognized in this midden (Figure 5.5). There are high proportions of unidentified and unknown pollen types. Pandanaceae pollen and Blenchnaceae are possibly misidentified. I attempted to distinguish to the best possible degree, Casuarinaceae and Myricaceae pollen although Coetzee and Praglowski (1984) suggest that this is not feasible without a special SEM or high magnification study. Juncaceae and Restios have been grouped under sedges based on their ecological and physiognomic attributes.

5.3.2.2.1 Zone TK4A (depth 11 – 7 cm, ~ 9 500 – 7 000 cal yrs BP)

This zone is distinguished from TK4B by the occurrence of relatively lower, less than 20%, asteraceaous pollen concentrations. Aponogetonaceae have lower proportions in this bottom zone than TK4B. Poaceae show a slight increase with time, while Brassicaceae pollen frequencies decrease. Scrophulariaceae display their highest concentration in this zone, while Verbanaceae are low in base samples and gradually increase reaching highest numbers just prior to the top of the zone. Compared to the above zone, Cyperaceae and Restionaceae pollen are slightly lower in this zone. Boraginaceae are lower at the base but gradually increase throughout the zone. Caryophyllaceae occurs only in this zone. Ericaceae pollen increases slightly towards the top of the zone. Myricaceae show relatively higher numbers at the beginning of the zone but then decrease gradually throughout the remaining depths. Proteaceae show a gradual decrease up the zone. Rosaceae are very low at the start of the zone but increase towards the middle before decreasing again. Rubiaceae are relatively low compared to TK4B. Aizoaceae, Chenopodiaceae and Euphorbiaceae are represented by relatively higher frequencies in comparison with TK4B. Arboreal pollen types reach highest concentrations in this zone, including: Anacardiaceae, Pandanaceae and Santalaceae. Sapindaceae appears to be constant throughout the sequence.

5.3.2.2.2 TK4B (depth 7 to 0 cm, ~ 7 000 – 1 300 cal yrs BP)

This zone is clearly separated from TK4A by the highest (about 35% at peak) occurrence of Asteraceae pollen. Levels of Apogenotonaceae have increased compared to the older zone. Although Poaceae are low at the beginning of zone, they show highest numbers towards 1300 cal yrs BP. Verbanaceae decrease slightly up the zone, as does Cyperaceae pollen, which start off with slightly higher concentrations before decreasing after 6 cm. Amaranthaceae are present only in this zone. Boraginaceae are more abundant at the bottom than the top of zone. Ericaceae pollen increase marginally towards the top of the zone. Myricaceae are represented by lower numbers compared to the previous zone and these eventually disappear before its conclusion. Proteaceae, Rubiaceae and Rutaceae all record their highest concentrations in the entire midden here. Aizoaceae concentrations are slightly decreased compared to the zone below while Chenopodiaceae and Euphorbiaceae also show low numbers in the upper zone relative to the lower ones. Blechnaceae and Casuarinaceae show their highest proportions in this zone. Santalaceae have decreased when compared to the zone below.

5.3.2.2.3 Modern pollen spectra for TK4

5.3.2.2.3.1 TK4 modern surface soil

The modern soil collection is dominated by the low-spine Asteraceae reaching values approaching to 30%. Higher concentrations of Aizoaceae, about 20% are also present. Each of Restionaceae, Rosaceae, Euphorbiaceae and Moraceae contribute about 5% of the total pollen in the modern soil. Poaceae and Cyperaceae show slightly decreased levels compared to the upper levels of the midden sequence.

5.3.2.2.3.2 TK4 fresh hyrax pellets

Restionaceae account for >25% of the taxa found in the fresh pellets. Asteraceae, mainly low-spine, follows with proportions slightly below 25%. Each of Poaceae, Rosaceae, Aizoaceae, Crassulaceae and Rhamnaceae contribute around 5% of the

fresh hyrax pollen. Fewer Scrophulariaceae pollen occur here than in the surface soil, although there are slightly more Cyperaceae present here. Marginally lower Proteaceae pollen frequencies are apparent compared to the midden sequence, while these are completely absent in the modern soil.

Comprehensive pollen diagram for midden TK4

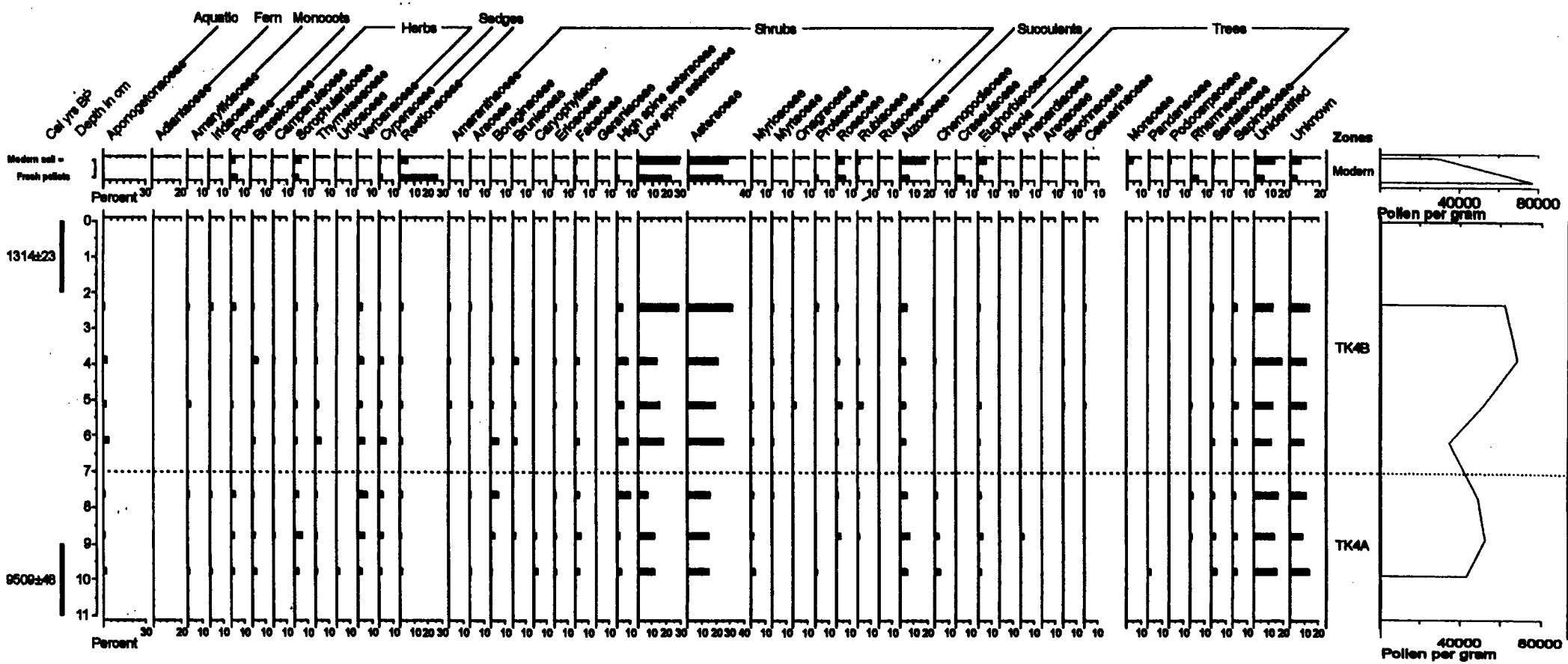

Figure 5.5 Pollen percentage diagram for midden TK4

5.4 CONCLUSION

Although quite small in comparison to the extensive KB1 midden, the TK4 midden is the oldest of the two, covering approximately the last 9 000 cal yrs BP. This sequence represents the later part of the early Holocene, from about 9 000 cal yrs BP, the entire HA interval and part of the late Holocene until about 1 300 cal yrs BP. Midden KB1-2 is younger but shows greater pollen diversities than TK4. The KB1-2 midden represents the early late Holocene from around 3 700 cal yrs BP up to about 600 cal yrs BP. The fresh pellets from both middens seem to have the highest pollen concentrations compared to the other samples.

CHAPTER 6

DISCUSSION, INTERPRETATION AND PALAEOENVIRONMENTAL RECONSTRUCTION

6.1 INTRODUCTION

The difficulties associated with the reconstruction of past environments and the interpretation of fossil pollen assemblages have long been recognised (Scott, 1982). This has been attributed to the fact that the percentages of pollen taxa are not necessarily the equivalent of the proportion of parent plants in an area, which results from differences in production, dispersal, accumulation and preservation of the various pollen types. However, an assessment of the fossil pollen assemblages from the two hyrax middens in question and viewed in the context of appropriate modern pollen spectra, can facilitate palaeovegetation and palaeoenvironmental reconstruction for the sites during the time periods covered.

Various taxa associated with the vegetation types from the two sites as well as their likely ecological conditions (Table 6.1) have been used to inform the interpretation and palaeoenvironmental reconstruction achieved in this study. Indicator taxa, especially in the form of trees, are scarce in the two areas, a factor which has complicated the interpretation of palaeoclimates in the region. Stable carbon isotope analysis has contributed to the interpretation of data.

The longest record is from TK and this covers a large portion of the Holocene, from about 9 500 to 1 300 cal yrs BP, assuming of course that there are no interruptions in accumulation over that period. Although other families are represented, both TK and KB sequences are dominated by Asteraceae, mainly the low-spine varieties which include *Elytropappus* and *Stoebe*-type. Palaeoecological reconstruction in the two sites is, therefore, based predominantly on the fluctuations of this dominant family and other pollen types contribute relatively little to the sequences.

Table 6.1 TK and KB dominant pollen taxa and their likely ecological conditions (Based on Scott (1989; 1994), Meadows *et al.*, (1994), Meadows *et al.*, (1996), (Meadows and Baxter, (2001), Parkington *et al.*, (2000)).

TK		**KB**	
Moisture indicators		**Moisture indicators**	
Dry	Wet	Dry	Wet
High spine Asteraceae (*Stoebe*-type & *Elytropappus* spp.) frequencies	Low spine Asteraceae (*Stoebe*-type & *Elytropappus* spp.) frequencies High tree taxa concentrations Aponogetonaceae Poaceae	High spine Asteraceae (*Stoebe*-type & *Elytropappus* spp.) frequencies Crassulaceae Euphorbiaceae	Cyperaceae Poaceae

Note: The indicators are different even though the sites are close to each other because of the different pollen concentrations of each taxa at sites.

6.2 CHRONOLOGY AND STRATIGRAPHY

One of the objectives of this study was to obtain a chronology for the hyrax midden material and to establish if there is a logical chronostratigraphy for such deposits. The radiocarbon dating sampling approach adopted in this study was different from Scott (1994), where collected middens were arranged in chronological sequence with the help of dates. Here, samples for radiocarbon dating were obtained from the bottom of the midden up with the results showing older ages of material at the bottom and younger ages of midden material at the top. Although only a few radiocarbon ages have been obtained per midden, the chronostratigraphy of the TK and KB middens suggests normal chronological accumulation of hyrax dung midden deposits. This is an important result and suggests that, in the case where there are insufficient funds for a comprehensive series of age determinations, it is possible to interpolate ages from

middens and create age-depth curves to estimate the ages of intervening samples. More dates per midden are however required to develop a reliable age model.

The records extending from about 9 500 to 1 300 cal yrs BP and 3 700 to 600 cal yrs BP for TK and KB respectively are assumed to be complete from the beginning to the end of the time span represented. The reason for the termination of deposition for KB is not known but it is possible that the animals abandoned this midden because they ran out of space between midden top and roof of overhang to comfortably fit during a visit to the latrine. This is evident at KB where, although the space between top of midden and roof of overhang was not measured, it appears to be insufficient for continued accommodation of the animals into the latrine (Figure 6.1). Skinner and Chimimba (2005) record average total lengths of male and female hyraxes from the Free State to be about 56 and 55 cm respectively. The size variation for hyraxes from the southwestern Cape would not deviate greatly from these values. It therefore seems impossible that animals of this length would fit comfortably in the conventional position for defecating in the available space, a factor which could cause a midden to be abandoned. It is also possible that the animals decided to leave the middens or even perhaps the sites for an unknown reason.

Figure 6.1 Midden KB1, with the maximum available space between midden top and roof of overhang indicated by the blue arrow.

6.3 HOLOCENE VEGETATION HISTORY AND PALAEOENVIRONMENTS AT TK

A continuous midden material accumulation rate of about 1 cm every 600 – 900 yrs is assumed in the TK4 midden age-depth profile. Compared to average midden pollen concentrations of 5 x 10^4 per gram, concentrations reach a minimum, constituting about 3.4 x 10^4 grains per gram during the mid-HA period around 6 000 cal yrs BP which may be attributed to the aridity associated with this interval elsewhere in the southwestern Cape (Baxter, 1989; Meadows and Baxter, 2001; Parkington *et al.*, 2000; Scott, 1994). It is assumed that the arid conditions during this period may have resulted in low pollen production and preservation. Although pollen concentrations per gram at TK are greater than those at KB, higher frequencies of pollen grains per gram of material than at TK are recorded from swamp sediments at both Sneeuberg and at Driehoek vlei samples.

6.3.1 9 500 – 7 000 cal yrs BP

A summary of interpretations from TK is given in Table 6.2. At the beginning of the TK record, that is, Zone TK4A, from around 9 500 until about 7 000 cal yrs BP, there are relatively low Asteraceae frequencies <15% as well as the occurrence of very slightly higher tree pollen and Poaceae pollen concentrations compared to the period after 7 000 cal yrs BP. This suggests perhaps slightly moister conditions in the area around the early Holocene. The suggestion of wetter conditions however, is inconsistent with the relatively higher proportions of Aizoaceae, Chenopodiaceae and Euphorbiaceae pollen in this zone. All such taxa tend to be associated with warmer, drier habitats, and constitute slightly higher percentages in this zone. In addition, there are lower concentrations of Aponogetonaceae (aquatics) in this zone, which are again inconsistent with possible wetter conditions. The presence of a mixed palaeovegetation signal at TK during this early Holocene interval could be explained as the occurrence of different proportions of various habitats within the landscape, whereby for example one part of the landscape supports the growth of succulents while aquatics are favoured in another.

The suggestion from TK of a possible early Holocene moist phase in the region generally has parallels in evidence from other key palaeoenvironmental sites in the southwestern Cape. Klein (1991) and Klein and Cruz-Uribe (1987) infer a wetter early Holocene at Elands Bay Cave, about 100 km to the west of TK, from the associated presence of the hedgehog and dune molerat *Bathyergus suillus* in their fossil faunal sequence. At Sneeuberg, which is approximately 25 km west of TK and situated over 500 m higher than TK in the Cederberg mountains, the vlei pollen analysis reveals possible increased moisture availability manifested in the occurrence of higher frequencies of proteoid fynbos and an interpreted restioid understorey to groves of *Widdringtonia* around 10 900 cal yrs BP (Meadows and Sugden, 1991b; Sugden, 1989a). At Driehoek, about 18 km north west of TK the early Holocene is thought to have supported ericaceous fynbos with an overstorey of cedars, possibly an indication of wetter habitats in the area (Meadows and Sugden, 1991b; Sugden, 1989b).

Table 6.2 Summary of palaeoenvironmental interpretation from pollen analysis at TK.

Zone/ Period	Vegetation	Environmental conditions
Present	Restioland with low shrub understorey	Drier than the entire Holocene record
TK4B 1 300 – 7 000 cal yrs BP)	Asteraceous shrubland	Drier than early Holocene
TK4A (9 500 – 7 000 cal yrs BP)	Asteraceous elements with an overstorey of woody elements	Moister than the period between 7 000 and 1 300 cal yrs BP?

Another site which produces data consistent with possibly greater moisture availability at the beginning of the Holocene as recorded at TK is Byneskranskop about 200 km south of TK on the southwest coast, where micromammalian data suggest relatively higher rainfall in the region from about 10 200 until about 7 400 cal yrs BP (Avery, 1990), as well as dominant grass vegetation from around 12 000 cal yrs BP (Avery, 1993). In contrast to these, at Elands Bay Cave, lower rainfall around 8 900 cal yrs BP is suggested by micrommalian analysis (Avery, 1990). The presence of restioid vegetation on hillsides and a smaller component of scrub at Klipfonteinrand, north west of TK above Clanwilliam does not support the occurrence of moist conditions around the early Holocene as compared to the present (Avery, 1993). Parkington *et al.*, (2000) also report drier conditions during the early Holocene than presently prevail, from pollen and charcoal analyses at Elands Bay Cave, which lies about 100 km slightly to the northwest of TK. The offshore pollen record from the marine core GeoB1023-5 also indicates the prevalence of drier conditions than the present between about 11 000 and 8 900 cal yrs BP (Shi *et al.*, 2000).

Avery (1982) also records an indication of a relatively drier early Holocene than currently occur at Bloomplaas, about 220 km slightly to the southeast of TK in the Cango Valley from micromammal analysis. At Pakhuis Pass, which is located 80 km northwest of TK however, despite relatively higher concentrations of Cyperaceae and

Restionaceae pollen, wetter conditions are considered unlikely due to higher proportions of Aizoaceae-type pollen, representative of succulents (Scott, 1994), which could be a signal indicating wetter higher altitude and slightly drier conditions at lower elevations.

6.3.2 7 000 – 1 300 cal yrs BP

After 7 000 cal yrs BP there is an increase in Asteraceae pollen, which is thought to reflect drier conditions compared to the beginning of the Holocene. This relatively dry period at TK between 7 000 and 6 000 cal yrs BP coincides with the widespread mid-Holocene aridity recorded elsewhere in the southwestern Cape (Chase, 2005; Cohen *et al.*, 1992; Klein and Cruz-Uribe, 1987; Meadows and Baxter, 2001; Meadows *et al.*, 1994; Meadows and Sugden, 1991b; Parkington *et al.*, 2000; Parkington *et al.*, 1988; Scott, 1994). In addition, the slightly lower tree pollen concentrations at the onset of the dry interval compared to the early Holocene are suggestive of more xeric conditions during the HA as noted elsewhere during this interval.

There is a slight decline in asteraceous pollen between 5 500 and 3 500 cal yrs BP although concentrations remain higher than those of the early Holocene. This indicates that, between around 5 500 and 3 500 cal yrs BP, conditions remained less dry than during the height of the mid-Holocene altithermal period. Thereafter, significant increases in Asteraceae, which includes substantial frequencies of *Stoebe*-type and *Elytropappus* pollen, reaching their highest concentrations of the entire sequence, are evident around 2 300 cal yrs BP. Although a climatic reason for this cannot be ruled out, it is interesting to note that this time period corresponds to the occupation of the Olifants River valley by hunter-gatherers (San) and may, therefore, be attributed to increased environmental disturbance after 4 400 cal yrs BP as suggested by Parkington (Pers. comm.).

Unlike at Sneeuberg where moist conditions are experienced around 1 800 cal yrs BP, vegetation at Driehoek shows increases in asteraceous fynbos around this time and this has been interpreted as indicating dry conditions (Meadows and Sugden, 1991b).

Disturbance indicators such as Montiniaceae, Plantaginaceae, Fumariaceae, Liliaceae, Oxalidaceae, Ranunculaceae, *Stoebe*-type and Campanulaceae are also witnessed to increase during the last 900 cal yrs BP or so of the Driehoek and Sneeuberg sequences, partly attributable to Khoi-San activities as certainly some of the changes predate the arrival of the colonial settlers (Meadows and Sugden, 1991b).

6.4 HOLOCENE VEGETATION HISTORY AND PALAEOENVIRONMENTS AT KB

The midden accumulation rate at KB approximates 1 cm of material every 130 to 210 years. As at TK, this midden is assumed to have accumulated continuously without gaps in the sequence. The pollen sequence at KB1-2 of course is much shorter than the TK record, covering vegetation changes between about 3 700 and 600 cal yrs BP.

6.4.1 3 700 to 1 600 cal yrs BP

A summary of modern and palaeoenvironmental interpretation from KB is given in Table 6.3. The older zone (3 700 – 1 600 cal yrs BP) is characterised by generally higher frequencies of asteraceous pollen indicating possibly drier conditions at KB than after 1 600 cal yrs BP. In general the vegetation shows higher grass pollen with Cyperaceae, Restionaceae and Proteaceae also relatively high. A similar observation of high grass pollen concentrations has also been made in Grootdrift after 4 900 cal yrs BP (Meadows *et al.*, 1994; Meadows *et al.*, 1996). Meadows *et al.*, (1994)'s interpretion is that the salt marsh environment of Verlorenvlei was surrounded by a catchment more xeric than today while Meadows *et al.*, (1996) suggest that the sequence accumulated in an estuarine environment obviously due to higher sea levels at the time around this coastal site. Avery (1990) also suggests grassy conditions from the early late Holocene lasting until about 1900 cal yrs BP, and this was interpreted as indicating higher rainfall in the Olifants river valley at Andriesgrond and Renbaan which lie about 135 km and 127 km respectively to the northwest of KB.

Table 6.3 Summary of palaeoenvironmental interpretation from pollen analysis at KB.

Zone/Period	Vegetation	Environmental conditions
Present	Mountain Renosterveld	Drier than reconstructed Holocene record?
KB1-2B (1 600 – 600 cal yrs BP)	Lower frequencies of asteraceous elements than earlier, interspersed with ericaceous fynbos	Moister than before 1600 cal yrs BP
KB1-2A (3 700 – 1600 cal yrs BP)	Asteraceous shrubland with grassy and restiod elements under a scattered proteoid overstorey	Drier than period between 1 600 and 600 cal yrs BP

The pollen evidence at KB during this period is problematic as it reflects a mixed signal with a good representation of groups indicative of both dry conditions (Crassulaceae and Euphorbiaceae) coupled with those suggestive of moist conditions (Cyperaceae, Poaceae). The seemingly contradictory evidence as far as moisture is concerned during this time could be a consequence of human disturbance and climate acting together on the environment or that the sources of pollen accumulating in the midden, as also suggested for TK, were from a wide range of habitats supporting different pollen types within the landscape.

The beginning of the KB1-2B zone is distinguished by perhaps moister conditions than before, as registered in the correspondingly lower asteraceous pollen from 1 600 until the termination of the sequence around at 600 cal yrs BP. As with the earlier zone, vegetation is well represented by taxa from groups suggesting both moister (Cyperaceae) and drier (Euphorbiaceae) conditions and this could be explained with similar reasoning. Similarly lower concentrations of asteraceous elements are recorded at Sneeuberg around this time leading to the interpretation that mesic environmental conditions prevailed there around 1 800 cal yrs BP than is presently the case (Meadows and Sugden, 1991b). In contrast to this, at TK, a combination of drier conditions and human interaction may have resulted in higher asteraceous pollen occurring between 2 300 and 1 300 cal yrs BP.

As at Sneeuberg, Driehoek (Meadows and Sugden, 1991b; Sugden, 1989b) and TK, decreases in pollen frequencies of taxa such as Amaryllidaceae and Myricaceae at KB

may be supportive of suggestions of human activities in the environment around 1 800 cal yrs BP, which is also attributed to the Khoi-San hunter gatherers, who reportedly occupied this area after 4 400 cal yrs BP (Parkington pers. comm.). These observed human induced disturbances might explain the lower but significant Poaceae percentages after 1 800 cal yrs BP which may be due to changing fire regimes.

6.5 MODERN POLLEN CHARACTERISTICS

Modern pollen was obtained from surface soil and fresh hyrax pellets. The fresh pellets from both TK and KB have greater pollen concentrations per gram than their surface soil counter parts (see Figures 5.4, 5.5). The absence of pollen in the dry hyrax pellets has been attributed to the following:

i) The dry pellets may have been formed in a relatively pollen free season where the animals incorporated mostly the vegetal material in their diet – not flowers from where pollen would have been derived (Scott, Pers. comm).

ii) Given that the fresh pellets have pollen and dry ones do not, a possible explanation is that the pollen in the dry pellets has been oxidised and/or decomposed by microbes. Pellets have pockets of air in them and in the presence of food (in this case pollen), this condition is conducive to microbial activity. This degenerative process may cause pollen to disappear from pellets. By contrast, hyrax middens may have preserved pollen in them because hyracium deters microbial attack there.

No age determination was conducted on dry pellets, however, but they are presumed to be relatively modern (< 10 years). If explanation (ii) is correct it is not possible to provide the exact time frame required for the dry pellets to have lost their pollen.

6.6 CONTEMPORARY VEGETATION AT TK

Surface soil pollen concentrations per gram at TK are greater than those at KB while fresh pellets concentrations at TK have lower pollen concentrations per gram than fresh pellets from KB. The contemporary vegetation at TK as reflected by modern soil samples and fresh pellets seem to be characterised by Restioid elements, asteraceous shrubland elements, with succulents such as Aizoaceae, Crassulaceae and Euphorbiaceae also present. The modern TK vegetation is similar to what Taylor and Leistner (1996) refer to as restioland with a low shrub understorey with or without overstorey or emergents. The modern spectra and the current vegetation composition at TK (Figure 4.9) lacks woody vegetation, which suggests that the restioland with a low shrub understorey at TK (Taylor and Leistner, 1996) generally has little or no overstorey emergents.

The lower frequencies of pollen from tree taxa in the modern samples compared to Holocene sequences indicate that Holocene environmental conditions were more suited to supporting woody vegetation. The same observation was made at Pakhuis Pass and it is not clear whether or not this was caused by recent changes in climatic conditions or that the trees were exploited or burned down (Scott, 1994; Taylor *et al.*, 1999) or a combination of both.

6.7 CONTEMPORARY VEGETATION AT KB

While the surface soil pollen concentrations per gram at KB are lower than their TK equivalents, the fresh pellets from KB have greater pollen concentrations per gram than fresh pellets from TK. Modern conditions show a dominance of Asteraceae which includes high proportions of *Elytropappus* and *Stoebe*-type. Restionaceae pollen is also high as indicated by the fresh pellets, which may suggest hyrax diet preference. At the site today, Restionaceae occurs in greater proportions at higher elevations than lower ones. The contemporary KB vegetation as depicted by pollen analysis of modern spectra, which is in agreement with the vegetation composition of the site today, has been described as Mountain Renosterveld (Acocks, 1988; Rebelo, 1998). The modern pollen analysis results are in general consistent with contemporary

vegetation composition at KB, which promises correspondingly reasonably accurate picture of past vegetation from the KB fossil midden. As with the record at TK, most tree elements have diminished. It is thought that contemporary climatic conditions coupled with human disturbance activities on the environment at KB, may have resulted in the disappearance of trees in the region.

6.8 TK AND KB COMPARISON

6.8.1 POLLEN EVIDENCE

In general, the pollen evidence from the two study sites portrays relatively little vegetation variation over the time scale investigated. The inferred palaeoenvironmental conditions are thus similarly limited. The pollen data are, in this sense, consistent with the stable carbon isotope determinations which illustrate only subtle variations throughout the sequences. This is similar to that reported for Sneeuberg and Driehoek, where only minor changes in characteristic vegetation are thought to have been experienced there since the last 14 700 yrs (Meadows and Sugden, 1991a; Meadows and Sugden, 1991b; Meadows and Sugden, 1993; Sugden, 1989a). A few reasons have been suggested to explain the apparent lack of environmental change in Sneeuberg and Driehoek. These include the fact that fynbos vegetation composition depends on a particular soil substrate and that this vegetation might not be affected by precipitation changes especially if the magnitude of climatic fluctuations is not sufficient to result in fynbos composition and or distribution changes. Given the fact that fynbos is known to survive a range of climatic extremes, it is possible that the climatic fluctuations experienced in the study region during the Holocene, were not of sufficient magnitude to have caused noticeable effects on fynbos vegetation. Another possibility is that fynbos may have been affected by the changing climate and that these effects have directly affected the composition and distribution of the vegetation at species level, which unfortunately can not be revealed by pollen analysis as this is conducted at a higher taxonomic level. If the latter is the case, this exposes one of the weaknesses of pollen analysis as a palaeoecological method.

In an attempt to resolve the reasons for the subtle vegetation and environmental change was in action in the Cederberg, Meadows and Sugden (1993) rule out the possibility of large environmental changes as contemporary conditions there suggest that vegetation composition tracks environmental gradients closely. They indicate that if large environmental change had occurred, then correspondingly notable shifts would have been produced in vegetation patterns and plant community composition. The other possibility, of the fossil pollen assemblage failing to reflect vegetation change due to similarity in pollen morphology, has also been ruled out on the basis of the knowledge that Cederberg plant community composition varies along environmental gradients and that an analysis of modern pollen rain (Meadows and Sugden, 1990; Meadows and Sugden, 1991a) reveals that contemporary pollen spectra are a good reflection of their associated plant communities. This led to the acceptance of the conclusion that limited late Quaternary environmental change occurred in the Cederberg. It has therefore been hypothesised that the low amplitude climatic fluctuations of the late Quaternary in the southwestern Cape have promoted allopatric speciation, which in part, explains the floristic richness of the region (Meadows and Sugden, 1993). The study area for this research being in the Cederberg, the same conclusion by Meadows and Sugden (1993) of the occurrence of only subtle environmental change during the Holocene there is adopted for this study.

6.8.2 STABLE CARBON ISOTOPIC EVIDENCE

Isotopic carbon analysis has been applied on hyrax dung in other sites in the southwestern Cape such as Pakhuis Pass in the Cederberg, which is located slightly to the north east of the town of Clanwilliam (Scott and Vogel, 2000) and is about 80 km and 165 km to the northeast of TK and KB respectively (Figure 6.2). The Pakhuis Pass isotopic data are derived from two localities in the Cederberg mountains, namely the lower lying (450 m) Pakhuis Pass Shelter on the drier eastern side of the range (Scott, 1994) and Wolfberg which is at a higher altitude (1200 m) in the southern side of the range (Scott and Vogel, 2000). The isotopic analysis data from KB and TK are compared with results from Pakhuis Pass (Figure 6.3) to show the difference in isotopic variation in the three sites located in the uplands of the fynbos biome. The Pakhuis Pass record is longer, covering the time around the Last Glacial Maximum,

but only data covering the last 9120 cal yrs BP are considered for the comparison. Although at Pakhuis Pass the record still indicates strong $\delta^{13}C$ C_3 plant signals, there is a little more variation in the sequence which possibly reflects unstable conditions during the Holocene (Scott and Vogel, 2000) than at the two sites studied here. Isotopic enrichment at certain times has been attributed to the inclusion of C_4 and CAM plants. The isotopic depletion around 1000 cal yrs BP at Pakhuis Pass has been suggested to probably be a sign of relatively higher proportions of C_3 plants and cooler or wetter conditions. At KB and TK on the other hand, the $\delta^{13}C$ values do not show distinct fluctuations revealing little about environmental changes, and or C_4 and CAM plants influences.

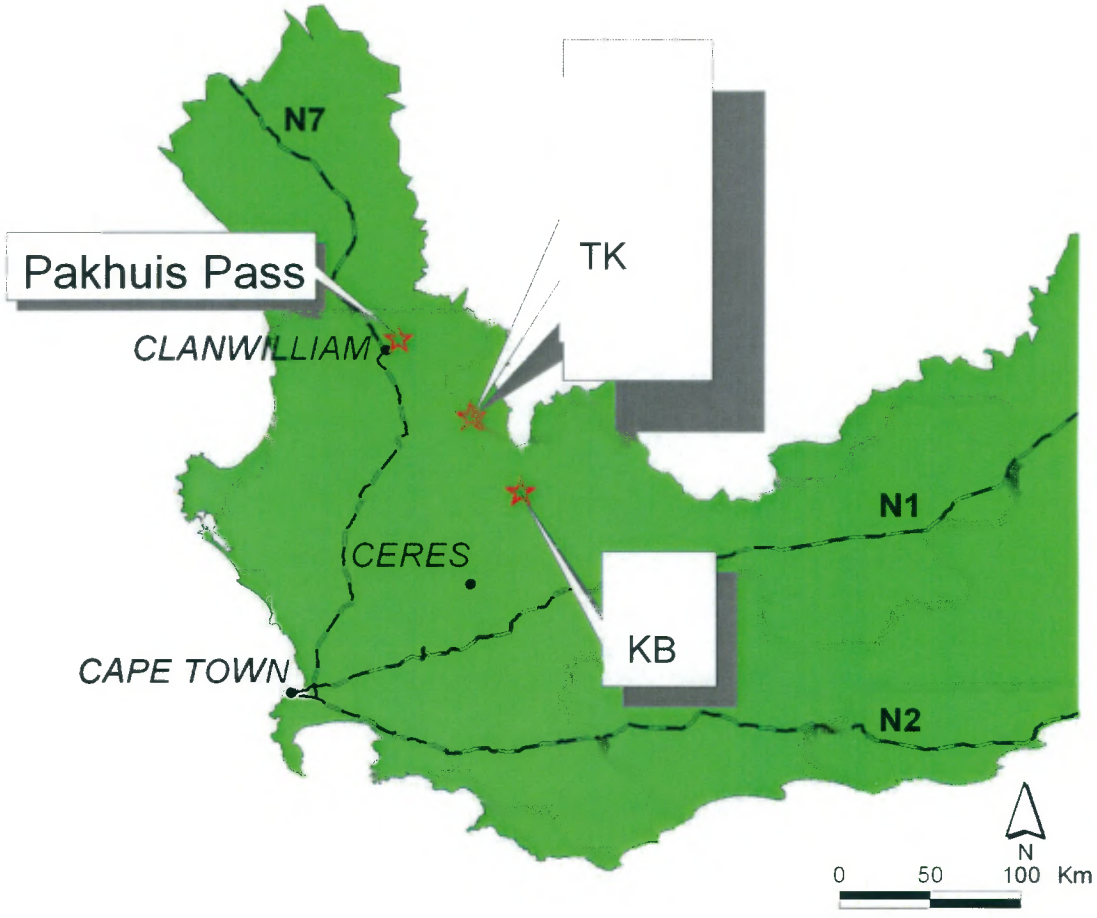

Figure 6.2 Map showing the location of Pakhuis Pass relative to KB and TK.

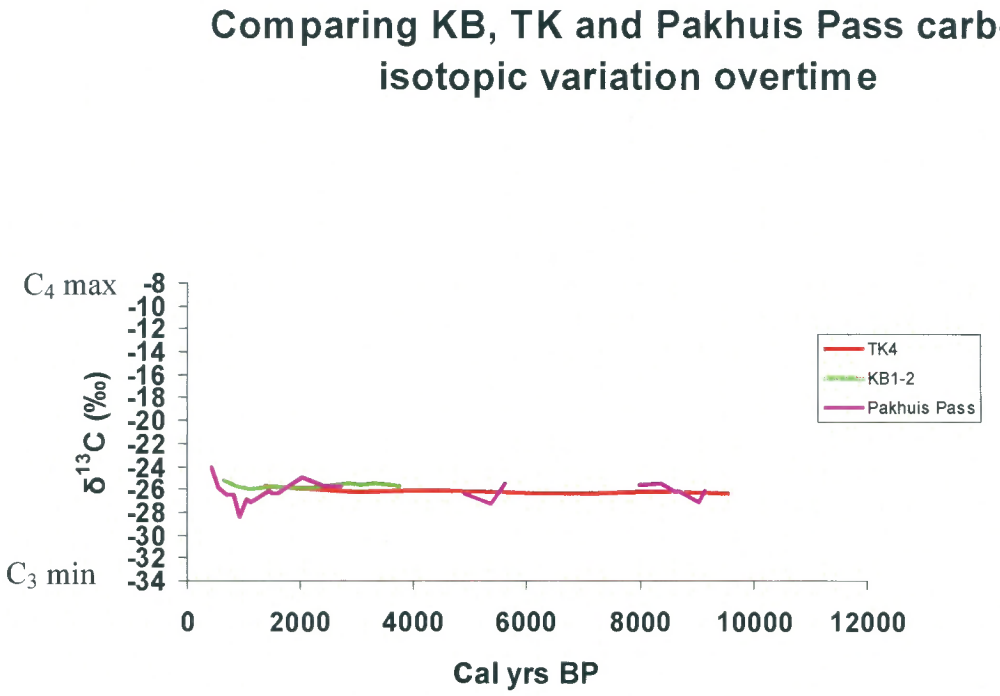

Figure 6.3 Comparison of KB1-1, TK4 and Pakhuis Pass carbon isotopic analysis.

Although derived from sources other than hyrax dung, the carbon isotope signal in the fossilised tooth enamel of grazing and browsing herbivores at Equus Cave in the Northern Cape (Lee-Thorp and Beaumont, 1995) shows greater variation than any of the above three records, and has been used to demonstrate the wider potential ranges of $\delta^{13}C$ values that can be obtained (Figure 6.3). This contextualises the isotopic record from KB and TK and illustrates just how little change is registered in these samples. The Equus Cave scenario has been very instrumental in the reconstruction of palaeoenvironments in the region, suggesting less rainfall seasonality as enhanced winter rainfall periods are indicated by relatively high proportions of C_3 plants from grazer diets (Lee-Thorp and Beaumont, 1995). Based on the lack of variation at KB and TK, therefore, the carbon isotope record suggests little variation between C_3 and C_4 vegetation types.

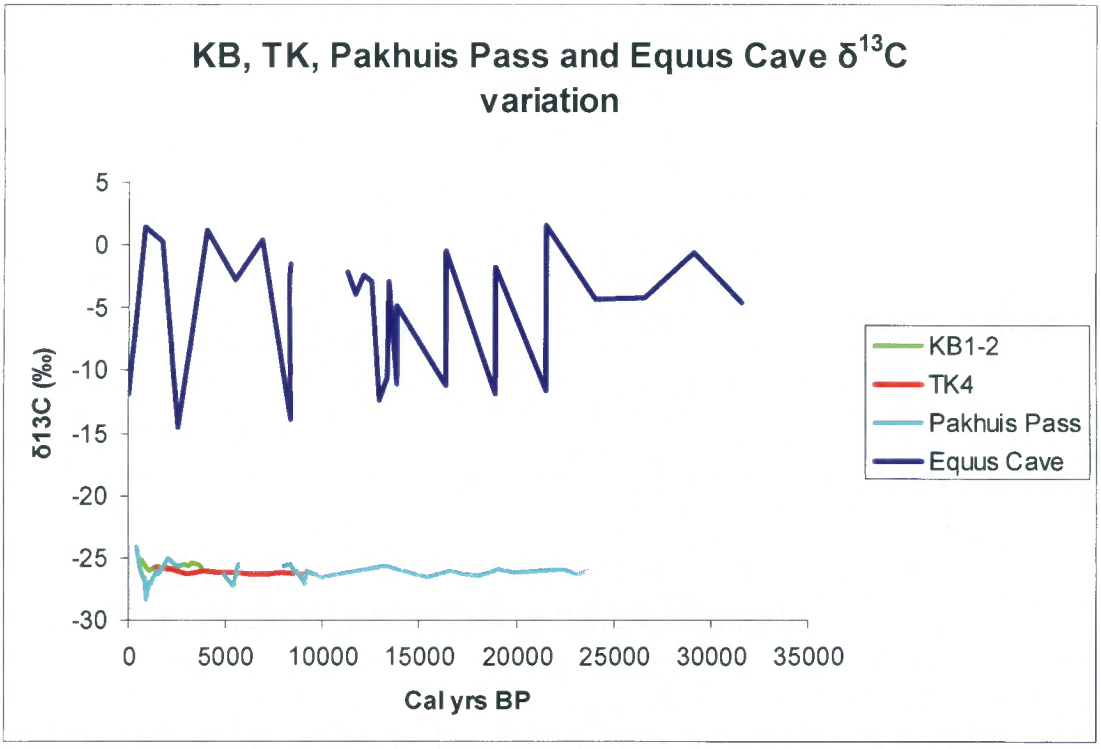

Figure 6.4 Demonstration of possible carbon isotopic variation using the Equus Cave record.

In fact, stable carbon isotope results from KB and TK are consistent with the pollen evidence. The more or less constant C_3 vegetation signal shows that hyraxes from the southwestern Cape almost exclusively feed on C_3 plants, with particular preference for Restionaceae as indicated from the fresh pellets. Other elements of the diet may include fruits, leaves, barks and pods of C_3 woody plants and shrubs. This consistently depleted $\delta^{13}C$ values from KB and TK throughout the respective periods may indicate that in the region C_3 vegetation has been supported there at least for the investigated periods, with winter rain dominance throughout (Scott and Vogel, 2000). Scott and Vogel (2000) also suggest that the southwestern Cape was dominated by winter rains at least since the Last Glacial Maximum as indicated by the stable carbon isotope analysis from Pakhuis Pass.

The stable carbon isotopic data from Pakhuis Pass (Scott and Vogel, 2000) by comparison shows slightly more variation than at either KB or TK. This may be because the Pakhuis Pass graph consists of isotopic analyses from two localities (Pakhuis Pass Shelter and Wolfberg). Scott and Vogel (2000) indicate that it is possible that data from Wolfberg may have skewed the results. Even then, the data from Pakhuis Pass also show that C_3 vegetation and winter rains have continued there

for at least the last 24 000 cal yrs BP, confirming that hyrax diet there consists of almost exclusively C_3 (Scott, 2002). Hence, based on the stable carbon isotopic evidence from KB, TK and Pakhuis Pass, it could be concluded that the local and regional vegetation in the southwestern Cape never changes sufficiently to impact on the stable carbon isotope record from hyrax midden deposits at least during the periods in question.

6.9 LIMITATIONS TO INTERPRETATIONS

The dark midden material produced generally unclear slides, obscuring pollen grains and making identification difficult. In addition to this, some grains were corroded and damaged and could not be identified, while other grains could not be identified at all. These, together with the counting error could have in a way introduced a bias in the representativity of pollen taxa. Furthermore, it appears that the middens were affected by problems associated with pollen preservation, which in turn affected pollen identification. Resolving pollen taxonomy in a highly species rich environment such as the Fynbos Biome was also difficult (Meadows and Sugden, 1993) and may have in a way complicated the reconstructions and interpretations attained in the study.

6.10 CONCLUSION

This chapter has achieved the reconstruction of the Holocene vegetation history from TK and KB from pollen and stable carbon isotope analyses. The different lines of evidence have been interpreted and inferences about palaeoenvironments for the respective sites made. The pollen evidence is not inconsistent with the stable isotope evidence as both suggest that only subtle palaeoenvironmental change occurred in the southwestern Cape during the time periods of the Holocene represented in the middens.

CHAPTER 7

CONCLUSION

The Holocene vegetation and palaeoenvironments of two mountain sites, Katbakkies Pass and Truitjies Kraal in the southwestern Cape, South Africa have been reconstructed through pollen analysis of hyrax (*Procavia* spp) dung middens. The KB sequence has recorded vegetation changes between about 3 700 and 600 cal yrs BP while TK provided a much longer record starting close to the beginning of the Holocene around 9 500 cal yrs BP, recording the mid-Holocene Altithemal and continuing until 1 300 cal yrs BP. Chronologies from these sites indicate that hyrax dung deposits accumulate in a logical chronostratigraphical manner.

KB recorded aridity during the beginning of the sequence, in the early part of the late Holocene until about 1 560 cal yrs BP after which slightly moister conditions prevailed in the region until 600 cal yrs BP. At TK slightly possibly moister conditions prevailed from the beginning of the record until about 7 000 cal yrs BP. The most important striking element of the TK record is the reflection of the effects of the widespread mid Holocene aridity between 7 000 and 6 000 cal yrs BP, which has also been detected elsewhere in the southwestern Cape. Support for occurrence of this period at TK as having been possibly associated with aridity has been shown by a decrease in tree pollen around 6 000 cal yrs BP as already seen.

It is concluded from the pollen analysis, consistent with carbon isotopic investigation, that only minor vegetation and environmental changes were experienced in these parts of the southwestern Cape during the Holocene. This is somewhat surprising as the Holocene has been characterised by considerable climatic fluctuations in other parts of the southern African subcontinent. In addition to recording hyrax fossil diets at the two sites, stable carbon isotopic analysis has shown that the C_3 vegetation has remained dominant throughout the Holocene, which indicates that the region has of course remained characterised by winter rains during this period.

The usefulness of fresh versus dry pellets as reservoirs of pollen as revealed by this study, needs further investigation with more samples and radiocarbon dates. The fresh hyrax pellets pollen from KB and TK display hyrax diet preferences and selection. The consistency demonstrated between contemporary vegetation at the two sites and that revealed by pollen analysis of fresh hyrax pellets and surface soil confirms the validity of pollen archives in middens as a reflection of vegetation history and, in turn, the reliability of hyrax midden deposits in palaeoenvironmental interpretation. However more studies are required to further confirm the power of such deposits in palaeoenvironmental reconstructions.

This study has not only contributed to existing evidence of past vegetation and environmental changes in the winter rainfall region of South Africa, but has also further proven the potential of hyrax dung middens in palaeoenvironmental interpretation in the region. This is regarded as a valuable technique for the investigation of late Quaternary vegetation and environmental changes because of its ability to preserve pollen in arid and semi-arid regions such as southern Africa where suitable pollen traps are limited (Scott, 1990; Scott and Bousman, 1990; Scott and Cooremans, 1992).

The palaeoenvironmental reconstruction from this study supports other palaeoenvironmental investigations derived from pollen analysis as well as different lines of evidence in the southwestern Cape region suggesting reasonable reliability in the reconstructions. However, more radiocarbon ages as well as further investigation of the palynology of other middens of similar ages in the areas studied are required for the confirmation of this record. It is also crucial that the ecology and behaviour of South African, including southwestern Cape hyraxes be studied more intensively, as it is the understanding of the biology of these animals that may permit more reliable reconstructions and interpretations of past environments to be made from pollen of hyrax midden deposits.

RECOMMENDATIONS AND FURTHER STUDIES

Perhaps most significantly, a greater degree of chronological precision is required through obtaining further radiocarbon ages on these middens as this would improve the interpretation of the results in relation to other studies.

Further research on the ecology and biology of South African hyraxes (including in the southwestern Cape) is required to improve our understanding of their ecology and behaviour, which is essential in the interpretation. Part of the research around the ecology and behaviour of the animals should include field observational studies throughout the year in order to contribute to the knowledge of these aspects through close interactions over extended periods.

More hyrax middens need to be identified in the region Cape so that a wider regional picture of vegetation history and palaeoenvironments can be achieved. Other faunal deposits such as hyena coprolites from the region should also be analysed for pollen to increase the reliability of interpretations.

Quantitative vegetation surveys are required in order to compare local vegetation with that recorded by hyrax midden deposits as well as vegetation from other faunal deposits.

Eye witnessed fresh pellets and urine should be collected and taken for both pollen and stable carbon isotopic investigation

Hyrax middens generally do not contain abundant macro-remains of plants, but analysis of both micro and macro fossils, where possible, could markedly improve the validity of reconstructions from these deposits.

Research on differential pollen survival in hyrax digestive systems and the relationship between hyrax pellets pollen and that in the dung midden would be useful for the determination of the relative contribution of the respective pollen accumulation routes into the midden deposit.

REVIEW OF AIM AND OBJECTIVES

The aim of this project was to use pollen derived from fossil hyrax (*Procavia* spp.) dung middens to improve the Holocene palaeoecological record for the southwestern Cape in order to shed light on the changes in rainfall, temperature, fire regime and human disturbance that have characterised the period. With the help of the outlined research objectives, the aim was achieved to a limited degree. This research demonstrated reasonable reliability of hyrax middens as a palaeoecological archive but the mechanisms influencing change are still to be teased out.

Firstly, suitable fossil hyrax middens in the region were identified, collected and sampled. Radiocarbon dating chronologies, which suggest logical chronostratigraphies for the hyrax midden deposits, were obtained. The vegetation composition in the study sites was determined in respect to relative proportions of C_3 and C_4 plants through stable carbon isotope analysis. The knowledge of the types of plants (C_3 and C_4) occupying the two sites provided information about the rainfall regime of the southwestern Cape during the time investigated. A reconstruction of Holocene vegetation of KB and TK was achieved through pollen analysis of hyrax dung middens, indicating minimal changes in vegetation. This allowed further reconstructions of broader palaeoenvironmental conditions for the period in question, although these suggested relatively little in climatic, rainfall, fire regime changes and human disturbance indicators.

REFERENCES

Acocks, J. P. H. (1988). Veld types of South Africa. *Memoirs of the Botanical Society of South Africa* **57,** 1 - 147.

Avery, D. M. (1982). Micromammals as palaeoenvironmental indicators and an interpretation of the late Quaternary in the southern Cape Province, South Africa. *Annals of the South African Museum* **85,** 183-377.

Avery, D. M. (1983). Palaeoenvironmental implications of small Quaternary mammals. *In* "Fynbos Palaeoecology: A Preliminary Synthesis." (H. J. Deacon, Q. B. Hendey, and J. J. N. Lambrechts, Eds.), pp. 139-155. South African National Science Programmes Report.

Avery, D. M. (1990). Holocene climatic change in southern Africa: the contribution of micromammals to its study. *South African Journal of Science* **85,** 407-412.

Avery, D. M. (1993). Last Interglacial and Holocene Altithermal environments in South Africa and Namibia: micromammalian evidence. *Palaeogeography, Palaeoclimatology, Palaeoecology* **101,** 221-228.

Baxter, A. (1989). "Pollen analysis of a Table Mountain cave deposit." Unpublished BSc (Hons) thesis, University of Cape Town.

Baxter, A. J., and Meadows, M. E. (1999). Evidence for Holocene sea level change at Verlorenvlei, Western Cape, South Africa. *Quaternary International* **56,** 65-79.

Bell, M., and Walker, M. J. (1992). "Late Quaternary Environmental Change: *Physical and Human Perspectives.*" Longman Group.

Betancourt, J. L., van Devender, T. R., and Martin, P. S. (1990). "Packrat Middens: The Last 40,000 Years of Biotic Change." University of Arizona Press, Tucson.

Birks, H. J. B., and Birks, H. H. (1980). "Quaternary palaeoecology." Edward Anold Publishers.

Birks, H. J. B., and Gordon, A. D. (1985). "Numerical methods in Quaternary pollen analysis." Academic Press.

Brown, A. N. C. (1993). Promotion of germination of fynbos seeds by plant-derived smoke. *New Phytologist* **123,** 575-584.

Campbell, B. M. (1985). "A classification of the mountain vegetation of the fynbos biome." Botanical Research Institute, Dept. of Agriculture and Water Supply, [Pretoria] South Africa.

Cerling, T. E., Harris, J. M., and Passey, H. (2003). Diets of East African bovidae based on stable isotope analysis. *Journal of Mammalogy* **84,** 456-470.

Chase, B. (2005). "Late Quaternary palaeoenvironments of the west coast of South Africa: the aeolian record." Unpublished DPhil thesis, The University of Oxford.

Codron, D., Codron, J., Sponheimer, M., Lee-Thorp, J. A., Robinson, T., Grant, C. C., and de Ruiter, D. (2005). Assessing diet in savanna herbivores using stable carbon isotope ratios of faeces. *Koede* **48,** 115-124.

Coe, M. J. (1962). Notes on the habits of the Mount Kenya Hyrax Procavia johnstoni mackinderi Thomas. *Proceedings of the Zoological Society of London* **138,** 639-644.

Coetzee, J. A., and Praglowski, J. (1984). Pollen evidence for the occurrence of Casuarina and Myrica in the Tertiary of South Africa. *Grana* **23,** 23-41.

Cohen, A. L., Parkington, J. E., Brundrit, G. B., and van der Merwe, N. J. (1992). A Holocene marine climate record in mollusc shells from the southwest African coast. *Quaternary Research* **38,** 379-385.

Cohen, A. L., and Tyson, P. D. (1995). Sea surface temperature fluctuations during the Holocene off the south coast of Africa: implications for terrestrial climate and rainfall. *Holocene* **5,** 304-312.

COHMAP. (1988). Climatic changes of the last 18,000 years: observations and model simulations. *Science* **241,** 1043-1052.

Compton, J. S. (2001). Holocene sea-level fluctuations inferred from the evolution of depositional environments of the southern Langebaan Lagoon salt marsh, South Africa. *Holocene* **11,** 395-405.

Compton, J. S. (2004). "The rocks and mountains of Cape Town." Double Storey Books, Cape Town.

Cowling, R., Richardson, D. M., and Pierce, S. M. (1997a). "Vegetation of southern Africa." Cambridge University Press.

Cowling, R. M. (1992). "The Ecology of Fynbos : nutrients, fire, and diversity." Oxford University Press, Cape Town.

Cowling, R. M., Macdonald, I. A. W., and Simmons, M. T. (1996). The Cape Peninsula, South Africa: physiographical, biological and historical background to an extraordinary hot-spot of biodiversity. *Biodiversity and Conservation* **5,** 527-550.

Cowling, R. M., Richardson, D. M., and J., M. P. (1997b). Fynbos. *In* "Vegetation of Southern Africa." (R. M. Cowling, D. M. Richardson, and S. M. Pierce, Eds.), pp. 99-130. Cambridge University Press, Cambridge.

Cox, B. C. (2001). The biogeographic regions reconsidered. *Journal of Biogeography* **28,** 511 - 523.

Dawson, T. E., and Brooks, P. D. (2001). "Fundermentals of stable isotope chemistry and measurement." Kluwer Academic Publishers, London.

De Niro, M. J., and Epstein, S. (1978). Carbon isotopic evidence for different feeding patterns in two hyrax species occupying the same habit. *Science* **201,** 907-908.

Deacon, H. J. (1992). Southern Africa and modern human origins. *Philosophical Transactions of the Royal Society of London Series B-Biological Sciences* **337,** 177-183.

Dial, K. P., and Czaplewski, N. J. (1990). Do woodrat middens accurately represent the animals' environmets and diets? The Woodhouse Mesa Study. *In* "Packrat Middens: The last 40 000 of biotic change." (J. L. Betancourt, T. R. Van Devender, and P. S. Martin, Eds.), pp. 467. University of Arizona Press.

Diechmann, U., and Eklundh, L. (1991). Global digital data sets for land degradation studies: a GIS approach. *In* "GRID Case Study Series No. 4." UNEP/GEMS and GRID, Nairobi, Kenya.

Dupont, L. M., Schmüser, A., Jahns, S., and Schneider, R. (1999). Marine-terrestrial interaction of climate changes in West Equatorial Africa of the last 190,000 years. *Palaeoecology of Africa* **26,** 85-101.

Ellerman, J. R., Morrison, T. C. S., and Hayman, R. W. (1953). "Southern African mammals 1758-1946: a reclassification." Trustees, British Museum (Natural History).

Faegri, K., and Iversen, J. (1989). "Textbook of Pollen Analysis." Wiley, Chichester.

Fall, P. L., Lindquist, C. A., and Falconer, S. E. (1990). Fossil hyrax middens from the Middle East: A record of paleovegetation and human disturbance. *In*

"Packrat Middens: The last 40 000 years of biotic change." (J. L. Betancourt, T. R. Van Devender, and P. S. Martin, Eds.). University of Arizona Press.
Finley, R. B. J. (1990). Woodrat ecology and behaviour and the interpretation of paleomiddens. *In* "Packrat Middens: The last 40 000 years of biotic change." (J. L. Betancourt, T. R. Van Devender, and P. S. Martin, Eds.). University of Arizona Press.
Fourie, P. B. (1971). A method for trapping the rock dassie. *Southern African Wildlife Management Association* **2,** 29-30.
Fox, H. (1933). Some notes upon the nature, health and maintenance of the hyrax. *Proceedings of the American Philosophical Society.* **72,** 1-24.
Goh, K. M. (1991). "Carbon dating." Academic Press.
Grimm, E. C. (1988). "Vegetation history: data analysis and display." Kluwer Academic Publishers, London.
Hayman, R. W. (1964). "Letter dated 29 October 1964 to C.R.S." Pitman, British Museum of Natural History.
Heaton, T. H. E., Talma, A. S., and Vogel, J. C. (1986). Dissolved gas paleotemperatures and O^{18} variations derived from groundwater near Uitenhage, South Africa. *Quaternary Research* **25,** 79-88.
Hoeck, H. N. (1975). Differential behaviour of the sympatric hyrax *Procavia johnstone* and *Heterohyrax brucei. Oecologia* **22,** 15-47.
Horowitz, A. (1992). "Palynology of Arid lands." Elsevier Science Publishers.
Huntley, B. (1996). Quaternary palaeocology and ecology. *Quarternary Science Reviews* **15,** 591-606.
IPCC. (2001). IPCC Third Assessment Report: Climate Change 2001: The Scientific Basis.
Jerardino, A. (1995). Late Holocene Neoglacial episodes in southern South-America and southern Africa: a comparison. *Holocene* **5,** 361-368.
Jouzel, J., Barkov, N. I., Barnola, J. M., Bender, M., Chappellaz, J., Genthon, C., Kotlyakov, V. M., Lipenkov, V., Lorius, C., Petit, J. R., Raynaud, D., Raisbeck, G., Ritz, C., Sowers, T., Stievenard, M., Yiou, F., and Yiou, P. (1993). Extending the Vostok ice core record of paleoclimate to the penultimate glacial period. *Nature* **364,** 407-412.
King, J. E., and van Devender, T. R. (1977). Pollen analysis of fossil packrat middens from the Sonoran Desert. *Quaternary Research* **8,** 191-204.
Kirst, G. J., Schneider, R. R., Muller, P. J., von Storch, I., and Wefer, G. (1999). Late Quaternary temperature variability in the Benguela Current System derived from alkenones. *Quaternary Research* **52,** 92-103.
Klein, R. G. (1991). Size variation in the Cape dune molerat (*Bathyergues suillus*) and late Quaternary climatic change in the southwestern Cape Province, South Africa. *Quaternary Research* **36,** 243-256.
Klein, R. G., and Cruz-Uribe, K. (1987). Large mammal and tortoise bones from Elands Bay Cave and nearby sites, western Cape Province, South Africa. *In* "Papers in the Prehistory of the Western Cape." (J. Parkington, and Hall, M., Ed.), pp. 132-163. British Archaeological Reports International Series, Oxford.
Koch, P. L. (1998). Isotopic reconstruction of past continental environments. *Annual Review of Earth and Planetary Sciences* **26,** 573-613.
Lee-Thorp, J. A., and Beaumont, P. B. (1995). Vegetation and seasonality shifts during the late Quaternary deduced from 13C/12C ratios of grazers at Equus Cave, South Africa. *Quaternary Research* **43,** 426-432.

Linder, H. P., Vlok, J. G., McDonald, D. J., Oliver, E. G. H., Boucher, C., Van Wyk, B.-E., and Schutte, A. (1993). The high altitude flora and vegetation of the Cape Floristic Region, South Africa. *Opera Botanica* **121,** 247-261.

Lowe, J. J., and Walker, M. J. C. (1997). "Reconstructing Quaternary environments." Longman Group Ltd.

MacDonald, G. M. (2003). "Biogeography: Introduction to space, time and life." John Wiley & Sons.

Marker, M. E., and Miller, D. (1993). A Mid-Holocene high stand of the sea at Knysna. *South African Journal of Science* **89,** 100-101.

Marker, M. E., and Miller, D. E. (1995). Further evidence of a Holocene high sea-level stand and Knysna. *South African Journal of Science* **91,** 392.

Martin, A. R. H. (1962). Evidence relating to the Quaternary history of the Wilderness lakes. *Transactions of the Geological Society of South Africa* **65,** 19-42.

Martin, A. R. H. (1968). Pollen analysis of Groenvlei lake sediments, Knysna (South Africa). *Review of Palaeobotany and Palynology* **7,** 107-144.

Mayewski, P. A., Rohling, E. E., Curt Stager, J., Karlen, W., Maasch, K. A., David Meeker, L., Meyerson, E. A., Gasse, F., van Kreveld, S., and Holmgren, K. (2004). Holocene climate variability. *Quaternary Research* **62,** 243-255.

Meadows, M., and Sugden, J. M. (1990). Late Quaternary vegetation history of the Cederberg, southwestern Cape Province. *Palaeoecology of Africa* **21,** 269-282.

Meadows, M. E. (2001). The role of Quaternary environmental change in the evolution of landscapes: case studies from southern Africa. *Catena* **42,** 39-57.

Meadows, M. E., and Baxter, A. J. (1999). Late Quaternary palaeoenvironments of the southwestern Cape, South Africa: a regional synthesis. *Quaternary International* **57-8,** 193-206.

Meadows, M. E., and Baxter, A. J. (2001). Holocene vegetation history and palaeoenvironments at Klaarfontein Springs, Western Cape, South Africa. *Holocene* **11,** 699-706.

Meadows, M. E., Baxter, A. J., and Adams, T. (1994). The late Holocene vegetation history of lowland fynbos, Verlorenvlei, Southwestern Cape Province, South Africa. *Historical Biology* **9,** 47 - 59.

Meadows, M. E., Baxter, A. J., and Parkington, J. (1996). Late Holocene environments at Verlorenvlei, Western Cape Province, South Africa. *Quaternary International* **33,** 81-95.

Meadows, M. E., and Chase, B. (2004). The Last Glacial Maximum in the winter rainfall zone of South Africa: towards a revised regional synthesis. *In* "XI International Palynological Congress." Granada.

Meadows, M. E., and Sugden, J. M. (1991a). The application of multiple discriminant-analysis to the reconstruction of the vegetation history of fynbos, southern Africa. *Grana* **30,** 325-336.

Meadows, M. E., and Sugden, J. M. (1991b). A vegetation history of the last 14,000 years on the Cederberg, southwestern Cape Province. *South African Journal of Science* **87,** 34-43.

Meadows, M. E., and Sugden, J. M. (1993). The late Quaternary palaeoecology of a floristic kingdom: the southwestern Cape, South Africa. *Palaeogeography, Palaeoclimatology, Palaeoecology* **101,** 271-281.

Metthews, L. H. (1971). "The life of mammals." Trinity Press.

Moore, P. D., Webb, J. A., and Collinson, M. E. (1991). "Pollen analysis." Blackwell Scientific Publications.

Mucina, L., and Rutherford, M. C. (2003). Vegetation Map of South Africa, Lesotho and Swaziland: Shapefiles of basic mapping units. Beta version 2.0, 15. National Botanical Institute, Cape Town.

Nelson, D. J., Webb, R. H., and Long, A. (1990). Analysis of Stick-nest rat (Leporillus: Muridae) middens from Central Australia. *In* "Packrat middens: The last 40 000 years of biotic change." (J. L. Betancourt, T. R. Van Devender, and P. S. Martin, Eds.), pp. 428-434. University of Arizona Press.

Oeschger, H. (2000). Perspectives on global change science: isotopes in the earth system, past and present. *Quaternary Science Reviews* **19,** 37-44.

Oldfield, F. (2005). Introduction: the Holocene, A Special Time. *In* "Global Change in the Holocene." (A. Mackay, R. Battarbee, J. Birks, and F. Oldfield, Eds.). Arnold.

Parkington, J., Cartwright, C., Cowling, R. M., Baxter, A., and Meadows, M. (2000). Palaeovegetation at the Last Glacial Maximum in the Western Cape, South Africa: wood charcoal and pollen evidence from Elands Bay Cave. *South African Journal of Science* **96,** 543-546.

Parkington, J., Poggenpoel, C., Buchanan, B., Robey, T., Manhire, T., and Sealy, J. (1988). Holocene coastal settlement patterns in the western Cape. *In* "The archaeology of prehistoric coastlines." (G. Bailey, and J. Parkington, Eds.), pp. 22 - 41. Cambridge University Press.

Partridge, T. C., Avery, D. M., Botha, G. A., Brink, J. S., Deacon, J., Herbert, R. S., Maud, R. R., Scholtz, A., Scott, L., Talma, A. S., and Vogel, J. C. (1990). Late Pleistocene and Holocene climatic change in southern Africa. *South African Journal of Science* **86,** 302-306.

Partridge, T. C., Scott, L., and Hamilton, J. E. (1999). Synthetic reconstructions of southern African environments during the Last Glacial Maximum (21-18 kyr) and the Holocene Altithermal (8-6 kyr). *Quaternary International* **57-8,** 207-214.

Pilcher, J. R. (2005). Radiocarbon dating and environmental radiocarbon studies. *In* "Global change in the Holocene." (A. Mackay, R. W. Battarbee, H. J. B. Birks, and F. Oldfield, Eds.), pp. 63-74. Hodder Arnold.

Pillans. (2004a). Update of defining the Quaternary. *Quaternary Perspectives: INQUA newsletter* **14,** 88-89.

Pillans, B. (2004b). Revision of the Geological Time Scale. *Quaternary Perspectives: INQUA newsletter* **14,** 124-125.

Pons, A., and Quezel, P. (1958). Premieres remarques sur l'etude palynologique d'un guano fossile du Hoggar. *Comptes rendus des seances de l'Academie des Sciences* **244,** 2290-2292.

Prentice, C. (1988). "Records of vegetation in time and space: the principles of pollen analysis." Kluwer Academic Publishers, London.

Rebelo, A. G. (1998). Fynbos Biome. *In* "Vegetation of South Africa, Lesotho and Swasiland." (A. B. Low, and A. G. Rebelo, Eds.), pp. 62-74. Department of Environmental Affairs and Tourism, Pretoria.

Renfrew, C., and Bahn, P. (1991). "Archaeology: Theories, methods and practice." Thames and Hudson Ltd.

Sale, J. B. (1960). Hyracoidea: a review of the systematic position and biology of the hyrax. *Journal of the East Africa Natural History Society.* **23,** 185-188.

Sale, J. B. (1965a). The feeding behaviour of rock hyraces (genera *Procavia* and *Heterohyrax*) in Kenya. *East African Wildlife Journal* **3,** 1-18.

Sale, J. B. (1965b). Hyrax feeding on a poisonous plant. *East African Wildlife Journal* **3,** 127.
Sale, J. B. (1965c). "*Some aspects of the behaviour of rock hyraces* (*genera* Procavia and Heterohyrax), *in Kenya.*" Unpublished Ph.D. thesis.
Sale, J. B. (1966). The habitat of the rock hyrax. *Journal of East African Natural History Society.* **25,** 205-214.
Sale, J. B. (1970). The behaviour of the resting rock hyrax in relation to its environment. *Zoologia Africana* **5,** 87-99.
Schneider, R. R., Müller, P. J., and Ruhland, G. (1995). Late Quaternary surface circulation in the east Equatorial South Atlantic: evidence from alkenone sea-surface temperatures. *Paleoceanography* **10,** 197-219.
Schulze, R. E. (1996). Atlas of Agro-Hydrology & Agro-Climatology. University of Natal, Pietermaritzburg.
Schulze, R. E., and McGee, E. (1978). Climatic indices and classifications in relations to the biogeography of southern Africa. *In* "Biogeography and ecology of southern Africa." (M. J. A. Werger, Ed.), pp. 19-52. W. Junk, Ilague.
Scott, L. (1982). Late Quaternary fossil pollen grains from the Transvaal, South Africa. *Review of Palaeobotany and Palynology* **36,** 241-278.
Scott, L. (1989). Climatic conditions in Southern Africa since the Last Glacial Maximum, inferred from pollen analysis. *Palaeogeography, Palaeoclimatology, Palaeoecology* **70,** 345-353.
Scott, L. (1990). Hyrax (*Pocaviidae*) and dassie rat (*Petromuridae*) middens in palaeoenvironmental studies in Africa. *In* "Packrat Middens: The Last 40,000 Years of Biotic Change." (J. L. Betancourt, T. R. van Devender, and P. S. Martin, Eds.), pp. 408-427. University of Arizona Press, Tucson.
Scott, L. (1993). Palynological evidence for late Quaternary warming episodes in Southern Africa. *Palaeogeography, Palaeoclimatology, Palaeoecology* **101,** 229-235.
Scott, L. (1994). Palynology of Late Pleistocene hyrax middens, southwestern Cape Province, South Africa: a preliminary report. *Historical Biology* **9,** 71-81.
Scott, L. (1996). Palynology of hyrax middens: 2000 years of palaeoenvironmental history in Namibia. *Quaternary International* **33,** 73-79.
Scott, L. (2002). Grassland development under glacial and interglacial conditions in southern Africa: review of pollen, phytolith and isotope evidence. *Palaeogeography, Palaeoclimatology, Palaeoecology* **177,** 47-57.
Scott, L., and Bousman, C. B. (1990). Palynological analysis of hyrax middens from Southern Africa. *Palaeogeography, Palaeoclimatology, Palaeoecology* **76,** 367-379.
Scott, L., and Cooremans, B. (1992). Pollen in recent Procavia (hyrax), Petromus (dassie rat) and bird dung in South Africa. *Journal of Biogeography* **19,** 205-215.
Scott, L., and Lee-Thorp, J. A. (2004). "Holocene climatic trends and rhythms in southern Africa." Springer.
Scott, L., and Vogel, J. C. (1992). Short-term changes of climate and vegetation revealed by pollen analysis of hyrax dung in South Africa. *Review of Palaeobotany and Palynology* **74,** 283-291.
Scott, L., and Vogel, J. C. (2000). Evidence for environmental conditions during the last 20,000 years in Southern Africa from ^{13}C in fossil hyrax dung. *Global and Planetary Change* **26,** 207-215.

Sealy, J. (2001). Body tissue chemistry and palaeodiet. *Handbook of Archaeological Sciences*, 269-279.

Shi, N., Dupont, L. M., Beug, H.-J., and Schneider, R. (2000). Correlation between vegetation in southwestern Africa and oceanic upwelling in the past 21,000 years. *Quaternary Research* **54,** 72-80.

Skinner, J. D., and Chimimba, C. T. (2005). "The mammals of the southern African Subregion." Cambridge University Press.

Smith, R. T., and Atkinson, K. (1975). "Techniques in pedology: a handbood for environmental and resource studies." Paul Elek (Scientific books) Ltd.

Smithers, R. H. N. (1983). "The Mammals of the Southern African Subregion." University of Pretoria Press, Pretoria.

Spaulding, W. G., Betancourt, J. L., Croft, L. K., and Cole, K. L. (1990). Packrat middens: Their composition and methods of analysis. *In* "Packrat middens: the last 40 000 years of biotic change." (J. L. Betancourt, T. R. Van Devender, and P. S. Martin, Eds.), pp. 467. University of Arizona Press., United States of America.

Sponheimer, M., Robinson, T., Ayliffe, L., Passey, B., Roeder, B., Shipley, L., Lopez, E., Cerling, T., Dearing, D., and Ehleringer, J. (2003). An experimental study of carbon-isotope fractionation between diet, hair, and feces of mammalian herbivores. *Canadian Journal of Zoology-Revue Canadienne De Zoologie* **81,** 871-876.

Stock, W. D., Bond, W. J., and le Roux, D. (1993). Isotope evidence from soil carbon to reconstruct vegetation history in the south-western Cape Province. *South African Journal of Science* **89,** 153-154.

Sugden, J. M. (1989a). "Late Quaternary palaeoecology of the central and marginal uplands of the Karoo, South Africa." University of Cape Town.

Sugden, J. M. (1989b). "Late Quaternary palaeoecology of the central and marginal uplands of the karoo, South Africa." Unpublished PhD thesis, University of Cape Town.

Talma, A. S., and Vogel, J. C. (1992). Late Quaternary paleotemperatures derived from a speleothem from Cango Caves, Cape Province, South Africa. *Quaternary Research* **37,** 203-213.

Taylor, D., Marchant, R. A., and Robertshaw, P. (1999). A sediment-based history of medium altitude forest in central Africa: a record from Kabata Swamp, Ndale volcanic field, Uganda. *Journal of Ecology* **87,** 303-315.

Taylor, H. C., and Leistner, O. A. (1996). "Cederberg vegetation and flora." National Botanical Institute, Pretoria.

Taylor, R. E. (1987). "Radiocarbon dating: an Archaeological perspective." Academic Press.

Theron, J. N. (1984). "The geology of Cape Town and environs: explanations of sheets 3318CD and DC and 3418AB, AD and BA." Geological Survey of South Africa, Pretoria.

Thompson, R. S. (1985). "Palynology and *Neotoma* Middens." *American Association of Stratigraphic Palynologist Contribution Series.* **16,** 89-112.

Tieszen, L., Hein, D., Qvortrup, S., Troughton, J., and Imbamba, S. (1979). Use of $\delta^{13}C$ values to determine vegetation selectivity in east African herbivores. *Oecologia* **37,** 351-359.

Tiezen, L. (1991). Natural variation in the carbon isotope values of plants: implications for archaeology, ecology and palaeoecology. *Journal of Archaeological Science* **18,** 227-248.

Turner, M. I. M., and Watson, R. M. (1965). An introduction study on the ecology of hyrax (*Dendrohyrax brucei and Procavia johnstoni*) in the Serengeti National Park. *East African Wildlife Journal* **3,** 49-60.

Tyson, P. D. (1986). "Climatic Change and Variability in Southern Africa." Oxford University Press, Cape Town.

van der Merwe, N. J. (1982). Carbon isotopes, photosynthesis, and Archaeology: Different pathways of photosynthesis cause characteristic changes in carbon isotope ratios that make possible the study of prehistoric human diets. *American Scientist.*

van der Merwe, N. J., Lee-Thorp, J. A., and Bell, R. H. V. (1988). Carbon isotopes as indicators of elephant diets and African environments. *African Journal of Ecology* **26,** 163-172.

Van Devender, T. R. (1990). Late Quaternary vegetation and climate of the Chihuahuan Desert, United States and Mexico. *In* "Packrat middens: the last 40 000 years of biotic change." (J. L. Betancourt, T. R. Van Devender, and P. S. Martin, Eds.), pp. 467. University of Arizona Press, United States of America.

Van Rooyen, G., Steyn, H., and de Villiers, R. (1999). "South African wild flower guide 10. Cederberg: Clanwilliam and Biedouw,." Botanical Society of South Africa.

Vaughan, T. A. (1990). Ecology of living packrats. *In* "Packrats middens: the last 40 000 years of biotic change." (J. L. Betancourt, T. R. Van Devender, and P. S. Martin, Eds.), pp. 467. University of Arizona Press.

Vogel, J. C. (1978). Isotopic assessment of the dietary habits of ungulates. *South African Journal of Science* **74,** 298-301.

Wells, P. V. (1976). Macrofossil analysis of woodrat (*Neotoma*) middens as a key to the Quaternary vegetational history of arid America. *Quaternary Research* **6,** 223-248.

William, M., Dunkerly, D., De Deckker, P., Kershaw, P., and Chappell, J. (1998). "Quaternary Environments." Arnold, New York.

APPENDIX A

Midden Sampling

Midden TK4

Midden KB1-2

Midden KB1-1

APPENDIX B

Method for preparing samples for organic matter index calculation (Smith and Atkinson, 1975)

1. Air-dry samples overnight in an oven at 105° C to remove hygroscopic moisture.
2. Weigh samples and record (initial weight)
3. Put the samples in a furnace for about 8 hours (not > 24 hrs)
4. Let them cool in a dessicator to avoid moisture regaining
5. Reweigh the samples (final weight) and calculate the organic matter index using the following equation:

$$\% \text{ Organic Matter Index} = \frac{\text{Initial} - \text{Final weight of sample}}{\text{Initial weight of sample}} \times 100$$

APPENDIX C

Step by step fossil pollen preparation procedure for samples from arid environments

- Contamination of sample material should be avoided as much as possible by maintaining a sterile working environment
- Protective clothing (gloves, glasses and lab coats) is indispensable
- All centrifuging to be done at 3500 rpm for minutes unless otherwise stipulated

Step 1: Removal of Humic Acids

1. Place a known amount of sediment in a plastic vial and drop one lycopodium tablet in each.
2. Add distilled water and stir.
3. Stand for a day or two to allow for dispersal of the lycopodium tablets. Centrifuge this mixture and decant.
4. Break up in 5% potassium hydroxide and shake well. Centrifuge and decant. Repeat three times.
5. Wash sample thoroughly in distilled water, stir centrifuge and decant. Repeat until the supernatant becomes clear.

Step 2: Removal of Colloidal Silicates

1. Add 10% hydrochloric acid to remove colloidal silicates. Centrifuge and decant.

Step 3: Removal of course material

1. Sieve the samples using a 106 micron sieve to remove course material

Step 4: Removal of course fraction and fine siliceous matter

1. Add 20 – 30 ml of a saturated solution of zinc chloride (ZnCl2) (relative density: 1.9), mix thoroughly and leave to stand for 10 minutes to allow heavier non-polliniferous materials to settle out. If clastic material fails to accumulate at the bottom of the tube, gently centrifuge at 800 rpm for 5 minutes.
2. Collect the supernatant in a clean centrifuge tube. This becomes the new sample. Conduct a quick check to see if there is no pollen among the clastic material in the original tube. If there is, repeat process, if not discard the clastics.
3. Dilute sample with HCl (which eliminates a white precipitate that may have formed during ZnCl2 treatment) and centrifuge for 5 minutes. Discard the supernatant.
4. Wash with distilled water, centrifuge and decant.

Step 5: Acetolysis digestion of extraneous organic detritus

1. Add glacial acetic acid, stir, centrifuge and decant.
2. Add 10 ml of the acetolysis mixture – comprising 9 parts acetic anhydride and 1 part concentrated sulphuric acid – and place in water bath for 3 minutes. Add glacial acetic acid to stop reaction. Stir with a dry rod, centrifuge and decant.
3. Add glacial acetic acid, stir, centrifuge and decant.
4. Transfer suspension to a 10 ml glass pyrex centrifuge tube using distilled water, centrifuge and decant.
5. Add 9 ml distilled water and 1 ml sodium hydroxide to obtain neutral pH. Stir, centrifuge and decant.
6. Wash with distilled water three times.

Step 6: Final preparation of samples for absolute counting

1. Use a sterile micropipette to carefully transfer the glycerol-phenol suspension from the centrifuge tube to a graduated 10 ml storage vial. Ensure that the last remaining residue in the centrifuge tube and the pipette tip is transferred by repeatedly flushing with glycerol-phenol solution.
2. Suspend the pollen evenly throughout the glycerol-phenol solution by subjecting the sealed vial to a high frequency vibrator for 2 minutes.

Step 7: Mounting

1. Place a single drop of glycerol on a prewarmed sterile glass microscope slide.
2. Use a micropipette to carefully extract 100 ml of the glycerol-phenol – pollen suspension.
3. Carefully release the contents of the pipette, drop by drop, onto the glycerol, leaving the pollen residue suspended in the glycerol mounting medium.
4. Using the tip of the pipette mix the pollen residue with the glycerol.
5. Place a coverslip over the glycerol suspension and place on warming table until the mixture has spread to all the edges.
6. Using a micropipette, draw melted glycerine jelly and then apply it, like glue, to the circumference of the coverslip. Administer the molten jelly in a thin line around the edge of the coverslip to seal it.

APPENDIX D

Pollen Taxa	KB1-2-1	KB1-2-2	KB1-2-3	KB1-2-4	KB1-2-5	KB1-2-6	KB1-2-7	KB1-2-8	KB1-2-9	KB1-2-10	KB1-2-11	KB1-2-12	KB1-2-13
Aponogetonaceae	0	0	0	0	0	0	0	0	0	2	3	0	6
Nymphaceae	0	0	0	0	0	0	0	0	0	0	0	0	0
Adiantaceae	4	14	1	2	2	5	3	0	1	3	2	1	0
Amaryllidaceae	5	5	0	5	3	0	0	3	3	4	3	1	2
Asclepidaceae	1	0	3	7	5	2	0	0	0	0	0	0	1
Iridaceae	0	0	0	4	0	0	3	1	0	3	7	2	1
Lilliaceae	1	7	5	5	4	2	3	0	0	0	2	0	0
Poaceae	36	13	19	17	13	17	8	12	12	10	11	13	1
Brassicaceae	18	20	4	13	18	9	11	11	20	12	13	9	11
Campanulaceae	0	0	0	0	3	3	0	3	0	1	7	2	4
Convulaceae	0	0	0	0	0	0	0	0	0	0	0	0	0
Gentianaceae	0	0	0	2	0	3	0	1	1	0	0	0	0
Heamodoraceae	0	0	0	0	2	3	0	0	0	0	0	0	0
Lentibulariaceae	0	0	0	0	0	10	0	0	0	0	0	0	0
Lobeliaceae	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxalidaceae	0	0	0	0	0	0	0	0	0	0	0	0	0
Ranunculaceae	4	0	0	0	0	0	5	0	3	1	1	2	1
Saxifragaceae	0	0	0	0	0	4	0	0	0	0	0	0	0
Scropulariaceae	18	6	5	0	7	7	11	15	18	17	10	11	8
Thymelaeceae	0	0	4	0	5	6	3	0	0	0	8	2	3
Verbanaceae	0	0	11	10	11	8	0	14	8	11	7	10	18
Cyperaceae	12	32	36	28	14	28	17	20	16	21	16	36	29
Juncaceae	0	0	3	0	4	14	0	0	0	0	0	0	0
Restionaceae	4	6	14	13	13	8	6	7	3	6	5	9	8
Araceae	2	1	3	0	0	0	3	0	6	3	3	0	0
Bolanophoraceae	0	0	0	0	3	0	2	0	0	4	0	3	0

APPENDIX D *continued*

Pollen Taxa	KB1-2-1	KB1-2-2	KB1-2-3	KB1-2-4	KB1-2-5	KB1-2-6	KB1-2-7	KB1-2-8	KB1-2-9	KB1-2-10	KB1-2-11	KB1-2-12	KB1-2-13
Boraginaceae	6	7	7	7	0	7	3	2	0	0	0	7	4
Bruniaceae	17	12	10	8	20	12	15	19	25	15	7	17	9
Caryophyliaceae	0	0	0	0	19	0	0	0	0	0	0	0	0
Ericaceae	10	22	14	14	15	21	14	0	4	11	11	18	19
Fabaceae	19	12	9	20	22	19	13	28	27	22	21	17	10
High spine asteraceae	25	33	23	18	18	25	16	31	30	17	20	20	32
Low spine asteraceae	75	48	40	43	25	38	29	67	43	40	46	52	46
Myricaceae	0	0	0	0	7	21	14	1	2	0	0	2	5
Myrtaceae	0	0	0	0	0	0	0	0	0	0	0	0	0
Onagraceae	0	0	0	0.0	0	0	0	0	0	0	0	0	0
Polygalaceae	1	1	0	13	3	4	1	2	0	0	0	0	0
Polygonaceae	0	0	0	0	0	0.0	0	0	0	0	0	0	0
Proteaceae	3	8	12	13	13	23	12	6	7	11	5	3	1
Roseaceae	0	0	1	0	0	0	3	1	3	1	0	0	4
Rubiaceae	0	2	0	0	0	0	0	0	0	0	1	3	5
Rutaceae	0	5	0	0	4	4	0	0	7	5	0	3	4
Solanaceae	0	0	0	0	0	0	0	0	0	0	0	0	0
Aizoaceae	25	25	15	16	24	20	16	16	24	24	18	21	21
Crassulaceae	3	8	0	3	4	0	3	6	8	0	4	3	2
Euphorbiaceae	12	15	15	24	15	12	17	12	11	20	11	5	10
Acacia	4	6	5	7	6	4	4	6	4	3	3	10	6
Acanthaceae	6	0	7	6	0	7	4	4	3	1	6	3	3
Anacardiaceae	0	0	0	0	0	0	0	0	0	0	0	0	0
Aralianceae	0	0	0	0	0	0	0	0	0	0	0	2	2
Arecaceae	2	0	0	4	3	1	0	5	3	3	2	4	1
Casuarinaceae	0	0	0	0	0	0	0	0	0	0	0	0	0
Ebenaceae	0	0	0	0	5	0	0	0	0	0	0	0	0
Juniperus	3	3	3	0	0	14	0	0	0	0	0	0	0
Moraceae	0	0	0	0	0	0	0	0	0	9	0	6	0
Pandanaceae	0	0	4	0	0	0	0	0	0	0	12	2	3
Podocapaceae	0	1	1	0	12	3	1	0	0	7	1	2	2
Rhamnaceae	0	0	0	0	0	0	0	0	0	0	0	0	0

APPENDIX D continued

Pollen Taxa	KB1-2-1	KB1-2-2	KB1-2-3	KB1-2-4	KB1-2-5	KB1-2-6	KB1-2-7	KB1-2-8	KB1-2-9	KB1-2-10	KB1-2-11	KB1-2-12	KB1-2-13
Santalaceae	0	0	0	0	0	0	2	0	0	6	7	3	5
Sapindaceae	0	0	0	0	0	0	0	0	0	0	0	4	2
Unidentified	34	30	50	40	47	49	46	46	41	48	48	48	49
Unknown	26	31	33	25	31	27	39	36	30	36	33	35	46
Total counts	384	376	373	357	367	400	440	327	375	363	377	354	391
Grains/g	14399	23076	28053	47225	51464	42549	56129	50774	41038	38849	35382	45306	31796

Absolute modern pollen counts for KB

Pollen Taxa	surface sample	fresh pellets
Aponogetonaceae	18	0
Nymphaceae	27	0
Adiantaceae	0	0
Amaryllidaceae	0	0
Asclepidaceae	24	0
Iridaceae	0	0
Lilliaceae	19	0
Poaceae	12	27
Brassicaceae	19	0
Campanulaceae	11	2
Convolvulaceae	17	0
Gentianaceae	0	0
Heamodoraceae	0	0
Lentibulariaceae	2	0
Lobeliaceae	14	0
Oxalidaceae	5	0
Ranunculaceae	0	0
Saxifragaceae	7	0
Scropulariaceae	21	3
Thymellaeceae	9	5
Verbanaceae	13	0
Cyperaceae	19	4
Juncaceae	3	0
Restionaceae	31	97
Araceae	18	0
Bolanophoraceae	5	0
Boraginaceae	3	0
Bruniaceae	8	0
Caryophyllaceae	0	3
Ericaceae	29	5
Fabaceae	13	0
High spine asteraceae	10	17
Low spine asteraceae	147	113
Myricaceae	0	0
Myrtaceae	15	0
Onagraceae	85	0
Polygalaceae	0	0
Polygonaceae	5	0
Proteaceae	23	4
Rosaceae	0	0
Rubiaceae	0	2
Rutaceae	0	3
Solanaceae	15	0
Aizoaceae	36	5
Crassulaceae	23	0
Euphobiaceae	14	0
Acacia	18	0
Acanthaceae	0	3

Absolute modern pollen counts for KB continued

Pollen Taxa	surface sample	fresh pellets
Anacardiaceae	11	0
Araliaceae	0	0
Arecaceae	9	0
Casuarinaceae	8	0
Ebenaceae	5	0
Juniperus	0	0
Moraceae	1	0
Pandanaceae	2	0
Podocarpaceae	6	0
Rhamnaeceae	20	0
Santalaceae	12	4
Sapindaceae	4	0
Unidentified	76	15
Unknown	70	10
Totals	962	322
Grains per gram	20837	111216

Absolute fossil pollen counts for TK4

Pollen Taxa	TK4-1	TK4-2	TK4-3	TK4-4	TK4-5	TK4-6	TK4-7
Aponogetonaceae	6	4	3	12	5	8	3
Nymphaceae	0	4	0	0	0	0	0
Adiantaceae	2	0	2	2	2	1	0
Amaryllidaceae	1	0	2	0	5	0	2
Iridaceae	5	0	5	1	0	0	9
Poaceae	8	9	13	1	4	0	4
Brassicaceae	12	10	5	7	5	15	6
Campanulaceae	2	5	2	3	7	4	2
Scrophulariaceae	12	28	16	8	9	6	7
Thymellaeceae	4	4	4	12	7	3	5
Urticaceae	7	0	0	0	0	0	0
Verbanaceae	12	22	29	15	12	13	13
Cyperaceae	8	12	14	16	7	9	5
Restionaceae	7	3	8	8	9	8	7
Amaranthaceae	0	0	0	1	5	2	3
Araceae	3	0	2	0	5	0	1
Boraginaceae	1	12	23	18	7	6	3
Bruniaceae	2	12	3	12	11	14	3
Caryophyllaceae	12	9	0	0	0	0	0
Ericaceae	5	4	7	2	4	5	4
Fabaceae	12	17	13	11	6	12	6
Geraniaceae	0	3	0	1	0	0	0
High spine asteraceae	14	11	43	25	19	28	15
Low spine asteraceae	48	53	29	61	61	48	109
Asteraceae	62	64	72	86	80	76	124
Myricaceae	13	9	10	9	7	0	0
Myrtaceae	0	0	4	2	1	1	1
Onagraceae	0	0	0	0	5	0	0
Proteaceae	6	3	3	1	1	2	10
Rosaceae	2	14	7	5	17	8	4
Rubiaceae	0	6	4	5	16	4	1
Rutaceae	0	0	0	2	3	1	4
Aizoaceae	22	31	22	13	15	14	18
Crassulaceae	0	0	0	0	0	0	0
Chenopodiaceae	15	10	8	0	3	1	0
Euphobiaceae	9	14	11	5	9	3	7
Acacia	3	0	0	0	1	3	0
Anacardiaceae	1	8	0	0	0	2	1
Arecaceae	2	3	2	0	1	0	0
Blechnaceae	2	0	0	0	5	5	4
Casuarinaceae	0	3	0	0	4	2	3
Moraceae	0	0	0	0	0	2	0
Pandanaceae	7	0	0	0	2	0	0
Podocapaceae	1	0	0	1	2	1	1
Rhamnaeceae	0	4	8	0	5	0	0
Santalaceae	15	11	10	8	6	6	5
Sapindaceae	12	14	9	10	5	7	5
Unidentified	67	61	75	40	55	71	50
Unknown	55	37	53	31	45	40	52

Totals	477	514	521	434	478	431	497
Grains per gram	42264	51370	48206	33657	50550	67345	61201

Absolute pollen counts for modern spectra at TK

Pollen taxa	Surface sample	Hyrax pellets
Aponogetonaceae	0	0
Nymphaceae	0	0
Adiantaceae	0	0
Amaryllidaceae	0	0
Iridaceae	0	0
Poaceae	5	19
Brassicaceae	0	0
Campanulaceae	0	0
Scrophulariaceae	17	13
Thymellaeceae	0	0
Urticaceae	0	0
Verbanaceae	0	0
Cyperaceae	5	9
Restionaceae	24	101
Amaranthaceae	0	0
Araceae	0	0
Boraginaceae	0	0
Bruniaceae	0	0
Caryophyllaceae	0	0
Ericaceae	0	5
Fabaceae	4	3
Geraniaceae	0	0
High spine asteraceae	0	5
Low spine asteraceae	108	85
Asteraceae	108	90
Myricaceae	0	0
Myrtaceae	0	0
Onagraceae	0	0
Proteaceae	0	7
Rosaceae	21	17
Rubiaceae	7	4
Rutaceae	0	0
Aizoaceae	67	24
Crassulaceae	4	20
Chenopodiaceae	3	1
Euphobiaceae	20	9
Acacia	0	0
Anacardiaceae	0	0
Arecaceae	0	0
Blechnaceae	0	0

Absolute pollen counts for modern spectra at TK continued

Pollen taxa	Surface sample	Hyrax pellet
Casuarinaceae	0	0
Moraceae	14	0
Pandanaceae	0	0
Podocapaceae	2	0
Rhamnaeceae	0	16
Santalaceae	5	0
Sapindaceae	0	12
Unidentified	50	21
Unknown	24	12
Totals	488	473
Grains per gram	28717	77086