LATE QUATERNARY PALAEOENVIRONMENTS AT VANKERVELSVLEI, NEAR KNYSNA, SOUTH AFRICA

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ABSTRACT

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This dissertation outlines the results of a study undertaken to describe the environmental history of Vankervelsvlei, a *schwingmoor*-type bog near Knysna on the south coast of South Africa. The study relies heavily on the use of fossil pollen as an indicator of vegetation change from which environmental conditions are inferred. Several additional lines of evidence including sedimentological and geochemical data are used to corroborate pollen findings. The narrative of environmental change at the site has been compared with findings from other palaeoecological studies undertaken in the area. Particular reference has been made to the expansion and contraction of afromontane forest vegetation over time to add to existing knowledge of forest history in Southern Africa.

Findings show Vankervelsvlei to provide a longer record of environmental change on the south coast of Southern Africa than any previous project in the area based on palynological evidence. In effect, the evidence provides information spanning the time period 45 000 BP to 3000 BP. It is apparent that forest vegetation has been present throughout the palynological record, but that it has not dominated the landscape during the late Pleistocene or Holocene. Instead, it appears that forest vegetation has formed part of a mosaic of forest and heath vegetation known locally as fynbos. Throughout the time period in question, the dominance of forest within this mosaic has fluctuated, suggesting fluctuations in moisture availability over time. The most productive periods for forest growth occurred between 43 000 BP and 40 000 BP and 4000 BP and 3000 BP.

Although the last glacial maximum (LGM) on the south coast of Southern Africa was obviously colder, it does not appear to have been as dry as other parts of the subcontinent. Forest vegetation was reduced in its extent during this time, but was nevertheless present confirming the availability of a certain degree of moisture. The early Holocene also seems to have behaved somewhat differently to the rest of Southern Africa. In contrast to most subcontinental syntheses of environmental change, the Holocene seems to have experienced drier conditions initially and become somewhat moister closer to the present day.

It is hoped that the information gleaned from this study will be used as a basis upon which further research into vegetation change on the south coast of Southern Africa can be extended. It is obvious that Vankervelsvlei is a rich source of palaeoenvironmental data worthy of more in-depth study and it is recommended that sediments from the site be analysed at a finer resolution. In addition, it is advised that further study sites be identified for palaeoecological investigation in the Wilderness lakes area in order to build a broader database of palaeoenvironmental information on the south coast of the subcontinent.

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" Two are better
than one, because they have
a good return for their labour.
If one falls down,
his friend can help him up,
but pity the man who falls
and has no-one to help him up.
Though one may be overpowered,
two can defend themselves,
a cord of three strands
is not quickly broken "
(Ecclesiastes 4: 9-10, 12).

I dedicate this thesis to my greatest source of strength, Jesus Christ.

JUDY IRVING

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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

In recent years palaeoecological studies have become increasingly applied in the explanation of environmental change in southern Africa. The last ten years in particular have yielded studies providing insight into past environmental conditions using a wide range of palaeoenvironmental indicators (Moore *et al.*, 1991).

Meadows (1987) notes the wide use of fossil pollen analysis on lake sediments and stratified peats in the humid temperate climates of North-western Europe and North America. Extensive work in these areas has provided conclusive evidence concerning the chronology and nature of environmental change spanning the last two million years. However, the predominantly xeric climate in southern Africa has hindered the development of organic sediments in the region (Meadows, 1987). Consequently, the record of environmental change in southern Africa is much less comprehensive than that of the northern hemisphere.

Thus far, palaeoecological work in South Africa has been concentrated in the former Transvaal (Scott, 1982), eastern Orange Free State (Scott, 1985), eastern KwaZulu-Natal (Scott *et al.*, 1992), the Cederberg (Meadows and Sugden, 1989) and the west coast of the former Cape Province (Meadows *et al.*, 1994). Studies have been undertaken along the south coast of southern Africa at Knysna and George (Martin, 1967; Scholtz, 1986). All these accounts contribute towards broadening the comparatively insubstantial understanding of Quaternary environmental change in the southern African region.

Palaeoecological reconstructions based on palynological findings are useful in terms of elucidating vegetation responses to past environmental perturbation which in turn can be used to more accurately predict future responses (Birks and Birks, 1980; Moore *et al.*, 1991). This is of particular concern at present with rising awareness of global climate change. In the African subcontinent, little is understood about long term fluctuations in afromontane forest regions and palynological investigation can contribute valuable knowledge on the subject. This is particularly true of the Knysna area which forms the southernmost limit of the range of afromontane flora in Africa (Werger, 1978). As such, it could be especially vulnerable to changes in environmental conditions.

This chapter goes on to outline current thought surrounding forest history in the Knysna region before describing the importance of Vankervelsvlei as a study site and outlining the aims and objectives of research carried out in the area.

1.2 THE AFROMONTANE DEBATE

Meadows and Linder (1993) outline the confusion surrounding the present status of afromontane forests in southern Africa. Conventional wisdom holds that forests along the Cape south coast were far more widespread than at present. It has been postulated that the entire coastline from Knysna to the Cape Peninsula was once forested and that human disturbance has directly effected the reduction in area of forested land (Phillips, 1931). This theory assumes that present environmental conditions favour forest growth and excludes changing climatic conditions as a factor in forest decline, holding human activity as the sole perpetrator. However, Van Daalen (1980) suggests that forests are in fact relicts of a wetter period and survive in the present day only in areas with wetter microclimates as in the Knysna area close to the Cape Fold Mountains. On the other hand, Meadows and Linder (1993) note that it is possible that forests were in fact not more widespread in the past. It has been implied that forests could be well adapted to present environmental conditions and that protection from further exploitation would result in the recolonisation of much of the coastal plain. It is this academic debate that forms one of the key underpinnings of this research project.

One of the major hindrances to diffusing the debate is the lack of long sequences of palaeoenvironmental information in the subcontinent, the Knysna region being no exception. Although the vegetation history of this area has been quite comprehensively described, palaeoenvironmental reconstruction dates back only 8000 years, and is thus restricted to the Holocene. Little detailed information documents forest fluctuations prior to this time. However, preliminary investigations at Vankervelsvlei indicate a far longer record of environmental fluctuation and provide a potential record of vegetation history within the Knysna Afromontane Region extending well into the late Pleistocene. This affords the site unique status in the southern African palynological arena and along with its unusual geomorphological characteristics grants it considerable significance.

1.3 SIGNIFICANCE OF VANKERVELSVLEI AS A STUDY SITE

The discovery of this geomorphologically rare landform in an interdunal depression on the Cape south coast has provided scope for an extensive interdisciplinary study of late Quaternary environments in the area. Vankervelsvlei is an example of a *schwingmoor*, marsh mat or floating bog. Warner (1993) describes floating bogs as lake-filled bogs with quaking vegetation mats. The occurrence of schwingmoor bogs is well documented in Europe, Scandinavia and Canada, their formation usually attributed to water collection in some sort of depression. Vegetation colonisation of open water begins and through various successional stages the water becomes completely covered and the vegetation mat thickens sufficiently to support terrestrial plant species (Hooper, 1991; Warner, 1993; Swarzenski *et al.*, 1991; Sasser *et al.*, 1991).

Although marsh mats are noted in other parts of the world, for example the Netherlands (French and Moore, 1986), Hawaii (French and Moore, 1986), North America (Warner, 1993), Australia (French and Moore, 1986) and parts of Africa (Swarzenski *et al.*, 1991); these refer only to partial covering of large marsh areas and are not essentially true floating bogs. It would appear that authentic floating bogs are concentrated in the northern hemisphere where glacial conditions have been influential in their development. Thus, Vankervelsvlei may offer a distinctive opportunity to study schwingmoor development in temperate conditions.

In addition to its geomorphological uniqueness, the site also boasts an impressive organic sequence extending well beyond the last glacial maximum (LGM) into the late Pleistocene. Initial dating of basal sediments from the site has yielded a date of approximately 39 900 + 1000 yr BP (Pta-6361) which is nominally infinite considering the methodological limitations of radiocarbon dating (Birks and Birks, 1980). Thus, the site may clarify environmental changes extending even further into the past. This is of particular interest considering the relative scarcity of lengthy organic records of environmental change in southern Africa as a whole (Meadows, 1987).

Climatic conditions in southern Africa, being largely semi-arid and displaying seasonal rainfall characteristics, are often inconsistent as regards pollen preservation. This has contributed to the relative scarcity of long continuous organic records of environmental change in comparison to those found in the northern hemisphere (Meadows, 1987). It has been particularly difficult to reconstruct palaeoenvironments beyond the time of the last glacial maximum using pollen as an indicator. Even landmark sites such as the Pretoria saltpan, which provides palaeoenvironmental information spanning the last 200 000 years, furnishes limited pollen evidence due to the absence of pollen-bearing sediments or poor preservation of pollen during certain time periods (Partridge *et al.*, 1993). Indeed, one such barren period spans the last glacial maximum. The Florisbad Spring site in the Free State has yielded deposits potentially spanning the middle and late Pleistocene, but problems with dating and identification of valid indicators for warming phases have left this organic record similarly incomplete (Scott, 1993). The Wonderkrater sequence in the Northern Province, on the other hand displays a long sequence of well-preserved pollen samples, highlighting environmental change since 34 400 BP. However, the Vankervelsvlei sediments hold even greater potential due to their highly organic nature and pollen richness over a longer time sequence.

It is the occurrence of high mean annual rainfall and reduced seasonality in the southern Cape that has facilitated the development of this long organic sequence at Vankervelsvlei. The capacity of the site to reconstruct pre-glacial maximum conditions is particularly impressive considering that palaeoenvironmental studies in the area to date have been restricted to the Holocene (Martin, 1967; Scholtz, 1986). Accordingly, Vankervelsvlei could prove to be the most important site in southern African Quaternary studies in terms of interpreting environmental change based on the reconstruction of changing vegetation patterns.

Thirdly, the site's significance lies in its geographical location in relation to the distribution of varying vegetation types in southern Africa. The site forms part of an ecotonal boundary between grassy fynbos and afromontane forest. As such, the area surrounding Vankervelsvlei comprises a mosaic of coastal forest patches, coastal renosterveld and grassy mountain fynbos (Geldenhuys, 1993). The age of the sediments therein may provide vital insight into the development of this vegetation mosaic, throwing light onto the continuing debate surrounding the origin of forest patches in southern Africa (Linder and Meadows, 1993). Ultimately, it is assumed that reconstruction of the palaeoenvironment at Vankervelsvlei, and of the vegetation history in the area in particular, will provide an important perspective on the response of vegetation to environmental change in the past. In keeping with the theory underpinning the study of environmental change, it is hoped that knowledge of such responses would aid in refining and improving present day management practices in conserving both afromontane forest and fynbos vegetation (Delcourt and Delcourt, 1991).

1.4 AIMS AND OBJECTIVES

The broad aim of this project is to reconstruct the late Quaternary environmental history of Vankervelsvlei. Particular attention is paid to investigating the fluctuations in forest vegetation in comparison to surrounding vegetation communities in the local environment. Also of interest is the development of the schwingmoor bog at the site considering its geomorphological rarity.

The specific objectives involved are:

I. to add to the existent contemporary pollen reference collection at the University of Cape Town (the Cape Town Collection of Pollen or CTCP) through the collection and preparation of afromontane taxa from herbarium material;

II. to extract chronologically consistent sedimentary sequences, via coring, for palaeoecological analysis;

III. to describe the stratigraphical characteristics of sediment cores taken from Vankervelsvlei;

IV. to produce a chronology for each core through the radiocarbon dating of suitably organic layers;

V. to reconstruct the late Quaternary vegetation history of Vankervelsvlei via analysis of fossil pollen;

VI. to assess the correlation between modern and fossil pollen assemblages from the site to identify possible modern analogues;

VII. to analyse sediments in terms of grain size and geochemical content during the period of deposition and;

VIII. to present a palaeoenvironmental reconstruction for the study site in terms of climate change.

1.5 THESIS OUTLINE

The goal of this chapter has been to introduce the study in terms of the importance of Vankervelsvlei as a palaeoecological database and to outline its principal aim and ensuing objectives. Chapter two focuses on the present day environment of the Knysna Afromontane Region, while chapter three goes on to discuss Quaternary palaeoecology in southern Africa. Chapter four describes in detail the methodological approach adopted in various aspects of the study. A detailed description of the results of analyses and their interpretation is given in Chapter five. Chapter six goes on to draw together major conclusions from the various lines of evidence and presents a scenario of environmental change for Vankervelsvlei. Finally, Chapter seven assesses the extent to which aims and objectives have been addressed and alludes to future work.

CHAPTER 2

PALAEOECOLOGY AND THE LATE QUATERNARY ENVIRONMENTS OF THE KNYSNA AFROMONTANE REGION

2.1 INTRODUCTION

This purpose of this chapter is twofold, firstly to examine the principles underlying palaeoecological research (and palynology in particular); and secondly to summarise the nature of environmental fluctuation in southern Africa during the late Quaternary with particular emphasis on the southern Cape region. The chapter begins with a brief discussion of the tenets upon which environmental reconstructions are based and goes on to describe the fundamental principles and shortcomings of pollen analysis. A review of major environmental fluctuations in the subcontinent and more specifically in the areas encircling Vankervelsvlei follows.

2.2 PRINCIPLES OF PALAEOECOLOGY

2.2.1 The need for palaeoecological research

In recent years, increasing concern relating to climate change has emerged probably as a result of growing awareness of human induced environmental degradation. Issues such as global warming, sea level rise, deforestation and ozone depletion and their consequent effects on biological diversity have brought environmental change under the public spotlight. Although natural forcing is undoubtedly responsible, the role of rapid population growth and expansive industrialisation cannot be ignored (Legget, 1990). Fundamental to the accurate prediction of the effects of future environmental changes is a thorough understanding of the changes that have occurred in the past (Birks and Birks, 1980).

The reconstruction of past environments and the resultant tracing of environmental change through geological time is based on two key assumptions. Firstly, that the impacts of environmental change, though random, conform to the demands of ecological process and secondly that all processes operating within the Earth at present have been operating in time past as well. This concept is known as the 'Principle of Uniformitarianism' (Delcourt and Delcourt, 1991) and was first put forward by Charles Lyell in 1830. The application of this principle to Quaternary palaeoecology lies in the ideal that modern environments, by analogy, provide a record for interpreting the nature of past environments as represented by fossil assemblages. Delcourt and Delcourt (1991, page 1) describe it as "..the study of individuals, populations and communities of plants and animals that lived in the past and their interactions with and dynamic responses to changing environments." According to Birks and Birks (1980), palaeoecology aims to provide a framework in which predictions about the future effects of environmental change can be made based on ecosystem models of the past.

There are many forms of proxy evidence used to elucidate environmental change at varying scales and much of it is biogeographical in nature. Deacon and Lancaster (1988) argue that biogeographical indicators provide the most reliable evidence in terms of late Quaternary environmental changes. This is justified largely by the close relationship enjoyed between living organisms, plants in particular, and prevailing climate (Huntley, 1991). Vegetation forms the bulk of all matter on Earth and any possible biosphere responses to environmental change will undoubtedly be mirrored in vegetation shifting (Burrows, 1990; Huntley, 1991) Thus, if we are to predict the manner in which the biosphere will respond to expected changes in the future, an understanding of past vegetation responses is vital (Delcourt and Delcourt, 1991; Adams and Woodward, 1992).

A primary source of palaeoenvironmental information, in terms of vegetation change, is fossil pollen. Pollen analysis as a technique has in fact become synonymous with palaeoecological reconstruction itself and the remainder of this section is dedicated to describing the rationale behind its success.

2.2.2 Quaternary pollen analysis

Palynology is at present regarded as the primary technique in Quaternary palaeoenvironmental reconstruction and is widely used to produce accounts of vegetation history (Moore *et al.*, 1991). The technique was initially developed for the temperate latitudes of North America and north west Europe, which provided a wealth of pollen-rich deposits due to the easy extraction of sediments. Palaeoenvironmental reconstructions are, however, somewhat impoverished in the subtropics, especially in the southern hemisphere. This is largely due to the scarcity of suitable organic sites (Meadows, 1987; Harwood, 1994), but is compounded by a comparative lack of research institutions. Despite seemingly vast differences in biological diversity and sedimentation patterns at different latitudes, several enduring principles do govern Quaternary pollen analysis. These are briefly outlined below.

2.2.2.1 Principles of pollen analysis

Faegri and Iversen (1975); Birks and Birks (1980); Birks and Gordon (1985); Feagri *et al.* (1989) and Moore *et al.* (1991) highlight the fundamental principles underpinning pollen analysis. These have been succinctly summarised as follows:

I. Flowering plants produce pollen in vast quantities, few of which fulfil their reproductive role in fertilisation. Most pollen grains are dispersed by wind or water;

II. Pollen is well mixed by atmospheric turbulence and falls almost uniformly to the ground as pollen rain;

III. The organic compounds (sporopollenin in particular) comprising the pollen wall are resistant to decay under non-oxidising conditions, as commonly found in bogs, lakes and fens;

IV. Distinguishing morphological characteristics of pollen grains allows differentiation between parent taxa at least to the family level. This is particularly true of the vegetation of the northern hemisphere where detailed pollen 'keys' have been established;

V. The composition of pollen rain is dependent upon the composition of the vegetation which produced it. Thus, composition of a sample of that pollen rain preserved within sediments will reflect the nature of the vegetation at that point in space and time;

VI. If a sample of pollen rain preserved in peat or mud of known age is examined and the fossil pollen identified and counted; then the resultant pollen spectrum reflects the vegetation surrounding the site at the time of deposition. Owing to the small size and abundance of pollen grains, often only small samples (0.5-1cm^3) are required for analysis;

VII. If pollen samples from distinct levels within a stratified deposit are examined, the stratigraphic records of the past vegetation and its development through time are represented;

VIII. If stratified pollen assemblages from several points in space are examined, it is possible to compare concurrence and dissimilarity through time at different localities.

The first step in this procedure is to reconstruct changes in abundance of individual plant taxa over time. From there, former vegetation communities can be postulated on the basis of compositional changes in fossil assemblages over time. Bearing in mind that fluctuations in the composition of natural vegetation are indicative of oscillations within the environment, it is imaginable that records of environmental change can be interpreted from stratified fossil pollen sequences.

2.2.2.2 Limitations of pollen analysis

Birks and Birks (1980), Feagri *et al.* (1989) and Lowe and Walker (1996) give detailed accounts of the problems plaguing pollen analysis. These are most commonly associated with differential pollen production, preservation and dispersal of different taxa. The implications of these inequalities vary among taxa, but are nevertheless inherent and attempts need to be made to counteract their influence if possible. One suggested approach is to cultivate a thorough understanding of the relationship between modern pollen spectra and contemporary vegetation (Birks and Birks, 1980). This is particularly important in southern Africa in terms of the extreme biogeographical and climatological variability and the consequent complexity of vegetation within the subcontinent. Also of concern are the analytical problems intrinsic in the processing, identification, counting and statistical treatment of fossil pollen. These difficulties, and the approaches adopted to minimise their influence, are discussed in more detail in chapter 4.

Despite these shortcomings, palynological studies have made a valuable contribution towards palaeoecological research in southern Africa. The relevance of palaeoecological research is now discussed with reference to changes manifest in the subcontinent during the late Quaternary.

2.3 PALAEOECOLOGY AND QUATERNARY ENVIRONMENTAL CHANGE

Many studies focusing on the nature, scale and extent of past climate change have concentrated on the period spanning approximately the last two million years, that is, the Quaternary. There are various reasons for this, the first being that the Quaternary documents the emergence of human interaction with the environment and thus potentially holds the key to predicting future human impacts. Furthermore, the Quaternary appears to have been a period of great environmental variability, experiencing oscillations from full glacial to interglacial phases. It is uncertain whether the Earth has experienced extremes of conditions on such a grand scale in any preceding time period (Birks and Birks, 1980; Birks and Gordon, 1985).

The late Quaternary has attracted particular interest, notably the late Pleistocene and Holocene. This can largely be attributed to the emergence of warmer conditions following the LGM circa 18000 BP, which encouraged the accumulation of organic fossil-bearing sediments in the subcontinent, supplying a wealth of potential records of environmental change (Goudie, 1981). Furthermore, the limits of techniques such as radiocarbon dating constrain the age determination of many biogeographical indicators to approximately 40 000 years. Human influence has undoubtedly increased in the recent past, making detailed study of the Holocene and late Pleistocene of unique significance (Goudie, 1981; Delcourt and Delcourt, 1991).

Despite the increased awareness of the importance of Quaternary studies, far less data have been collected and analysed in the southern latitudes in comparison to the northern hemisphere. This is partly a function of the maturing of palaeoecological procedures in Europe and Scandinavia (Feagri *et al.*, 1989) and in Southern Africa also a consequence of the dearth of prospective study sites. In terms of pollen analysis, preservation of pollen grains is usually dependent upon the availability of moist, acidic conditions (Birks and Birks, 1980; Feagri *et al.*, 1989; Deacon and Lancaster, 1988) which are scarce considering widespread aridity throughout much of the subcontinent (Tyson, 1986).

Thus far, palaeoecological evidence for environmental change in southern Africa has been restricted to specific localities, often remote from one another (Figure 2.1 on preceding page) providing little opportunity for a thorough appraisal of changes on a subcontinental scale. Indeed, Meadows and Meadows (1988) express concern about overgeneralisation of southern African climate change and restate the need to expand the database on which large scale reconstructions are made. Thus, an increase in the number of detailed case studies at the local level is required.

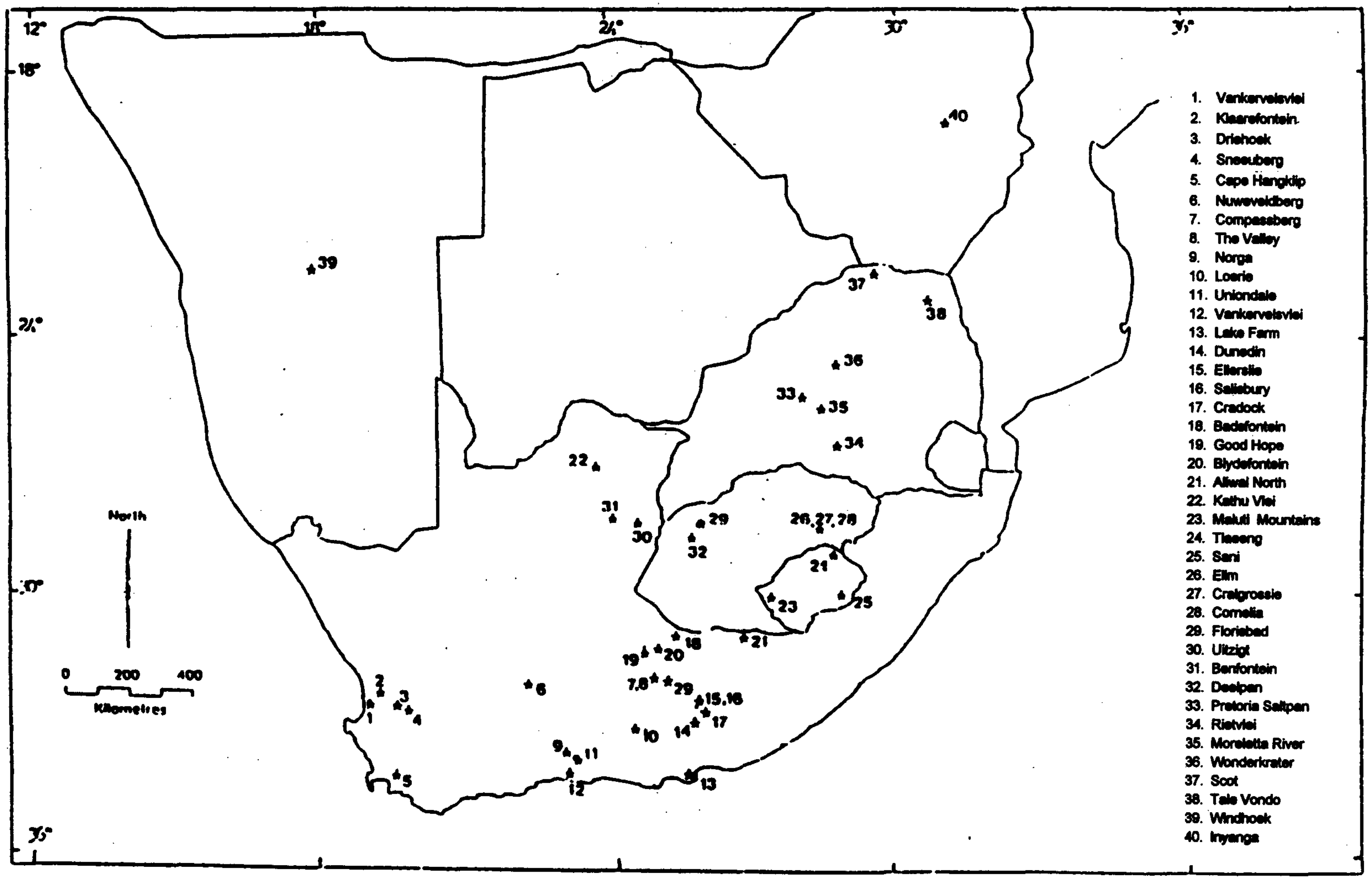


Figure 2.1: Location of organic sediment deposits in southern Africa (After Harwood, 1994).

2.4 EVIDENCE FOR ENVIRONMENTAL CHANGE IN SOUTHERN AFRICA

This review aims briefly to address some of the evidence for environmental change which applies to the subcontinent as a whole. Thereafter, attention is focused on evidence collected and collated from various sources relating expressly to the Knysna Afromontane Region (KAR). The timespan covered in the critique relates explicitly to the period spanned by the palaeoenvironmental record manifest in the Vankervelsvlei sediments. Thus, evidence spanning the late Pleistocene, LGM and Holocene will be examined.

2.4.1 The subcontinental context - southern Africa in perspective

Attention to reconstruction of palaeoenvironments in southern Africa is on the increase. This is primarily a consequence of intensifying awareness of the need to understand the effects of past environmental perturbations to accurately forecast the outcome of fluctuations yet to occur (Meadows *et al.*, 1993). The need for comprehension at a variety of scales is obvious and has prompted attempts at regional syntheses by several authors (Deacon *et al.*, 1983; Tyson, 1986; Deacon and Lancaster, 1988; Partridge *et al.*, 1990). These syntheses concur that:

I. the LGM displayed conditions between 5 and 9°C cooler than present;

II. conditions during the early Holocene were warmer and moister than present, peaking at 2°C warmer between 5000 and 8000 BP;

III. climatic amelioration continued during the late Holocene with conditions becoming increasingly moist.

On the other hand; the need for more sources of palaeoenvironmental information is highlighted by the inconsistency within these three syntheses. The discrepancies no doubt arise from the numerous differing sources from which the palaeoenvironmental information is derived as well as the subjectivity in interpretation by a diverse group of researchers. One common conclusion does, however, persist; that southern Africa has not responded uniformly to environmental changes in the late Quaternary. In fact, regions within the subcontinent appear to have behaved uniquely. Discrepancies concerning the degree of moisture availability during the LGM are notably contentious, specifically between the western and southern coastal regions. It is thus evident that studies conducted at the regional level are of great significance in elucidating the varying conditions encountered and in terms of contributing detailed information to the ever expanding subcontinental database.

Large-scale environmental changes have been summarised in Table 2.1 overleaf. Data has been collected from a wide range of sources including Deacon *et al.* (1983), Tyson (1986), Deacon and Lancaster (1988), Partridge *et al.* (1990), Scott (1993) and Cockroft (1987).

TIME (yrs BP)	SUBCONTINENTAL SCALE	REGIONAL SCALE
3000 - 0	• late Holocene characterised by several fluctuations of small amplitude in temperature and precipitation (Partridge et al, 1990); • no greater fluctuation than 2°C from present mean (Partridge et al, 1990); • generally wetter than present (Partridge et al, 1990)	• eastern regions wetter than present (Partridge et al, 1990)
5000 - 3000	• moister and warmer conditions than present (Partridge, 1993)	• increase of rainfall in Karoo after 5000 BP (Partridge, 1993)
10000 - 5000	• general desiccation in the early Holocene (Scott, 1993) • warmer than present (Scott, 1993); • warm phase corresponds to the global hypsithermal (Deacon and Lancaster, 1988)	• central and western regions moister than present (Partridge et al, 1990); • eastern regions dryer than present (Partridge et al, 1990)
12000 - 10000	• corresponds to younger Dryas on the global scale (Deacon and Lancaster, 1983)	• pronounced desiccation throughout interior (Partridge, 1993)
16000 - 12000	• rapid warming after 16000 BP (Partridge, 1993)	• temperature amelioration; cool and moist conditions throughout interior (Partridge et al, 1990); • generally cool and moist conditions in present day winter rainfall region, with few exceptions (Deacon and Lancaster, 1988)
18000-16000 (LGM)	• 5-8°C cooler than present (Deacon and Lancaster, 1988); • periglacial conditions in highlying areas (Partridge et al, 1990)	• drought conditions in interior (Partridge et al, 1990); • enhanced El Nino; potential increase in precipitation in present day winter rainfall region (Deacon and Lancaster, 1988)
20000 - 18000	• 5-6°C cooler than present (Partridge et al, 1990); • widespread aridity (Partridge et al, 1990)	
25000 - 20000	• 4-5°C cooler than present (Partridge et al, 1990); • widespread aridity (Partridge et al, 1990; Partridge, 1993)	• Namib and Kalahari moister than present (Partridge et al, 1990)
40000 - 25000	• temperatures low in all regions but not as low as at the time of the Last Glacial Maximum (Partridge, 1993)	• eastern regions drier than today (Partridge et al, 1990) • all other regions moister (Partridge et al, 1990)

Table 2.1:Summary of environmental changes in southern Africa circa 40000 BP to the present day (Deacon and Lancaster, 1983; Deacon and Lancaster, 1988; Partridge et al, 1990; Partridge, 1993 and Scott, 1993).

2.4.2 Late Quaternary environmental change and the Knysna Afromontane Region

2.4.2.1 Introduction

This section accords special attention to the past environmental conditions of the south coast of southern Africa which relate specifically to the KAR and provide a historical context from which to interpret data collected from Vankervelsvlei. Details of previous research are highlighted and a regional summary put forward.

2.4.2.2 A regional synthesis

In terms of the vegetation histories of the west and southern coasts of southern Africa, differences in present day regional species richness suggest divergent palaeoenvironmental chronicles (Cowling, 1992). The Cape Floristic Kingdom, which broadly approximates the winter rainfall region, supports roughly twice as many species in its western reaches than are manifest on the southern coastal plain where the Knysna afromontane forests form part of its complement (Cowling, 1992). This is true even in sites with similar soil, topographical and other environmental characteristics. This suggests incongruous climatic histories leading to potentially accelerated speciation in the west. The western Cape appears to have experienced cold and moist conditions at the height of the LGM approximately 18 0000 BP. The southern coastal area, including the Knysna region, however, may have encountered dessication at this time (Baxter, 1997).

Palaeoecological research conducted within the KAR comes from a variety of sources and relates to several lines of evidence. Palynological data have been collected and analysed from Groenvlei (Martin, 1967) and the Norga Peat (Scholtz, 1986), while Klein (1980) based his research of palaeoecological change at Boomplaas and Nelson Bay caves on animal macrofossil evidence. Each of these important sites is described briefly below in terms of their situation and the methods of palaeoecological inquiry used to elucidate environmental change. A summary of the major findings at each site is also provided.

I. **Groenvlei:** Martin's (1967) comprehensive study undertaken at Groenvlei provides the most well known account of Holocene environmental history for the KAR. Groenvlei is a coastal lake situated approximately 5km to the south west of Vankervelsvlei, and as such its palaeoenvironmental record is likely to provide the closest benchmark for comparison with Vankervelsvlei evidence. Martin (1967) makes use of both palynological and diatom evidence to produce his synthesis spanning the period 8000 BP to the present day. The study shows conditions to have been dry between 8000 BP and 7200 BP with forest vegetation restricted and heath dominating the landscape. Forests at this time are interpreted as showing characteristics of dry forest types. From 7200 BP to 6300 BP it is possible that moister conditions were evident with associated forest spread occurring. Between 6300 BP and 2500 BP, Martin (1967) provides two possible scenarios for environmental change. In both cases, he cites vegetation cover to be limited, the first suggestion attributing this to dry, hot conditions and allied restriction of forest extent. The second alternative suggests possible forest spread with vegetation cover being hindered by sand movement. The next 1000 years are characterised by more favourable conditions - an increase in moisture linked to forest spread. The last 500 years document a reduction in forest extent, possibly through dessication and almost undoubtedly exacerbated by forest clearance.

II. **Norga:** Scholtz' (1986) research yields a 4000 year sequence of environmental history based on palynological evidence. The Norga site is slightly further afield than Groenvlei, situated close to George approximately 50 km from the site. The Norga account documents an all-seasonal rainfall regime between 4000 BP and 2800 BP and forest in the valley being more widespread than in the present day. Conditions from 2800 BP to about 1500 BP are comparatively dry and forest extent is reported to be somewhat less than in the present day. From 1500 BP to the present, Scholtz (1986) denotes environmental conditions to be similar to those currently prevailing and makes note of peat formation.

III. **Boomplaas and Nelson Bay Caves:** Klein (1980) provides a considerably longer record of environmental history in the KAR, although his choice of palaeoenvironmental indicator differs. The palaeoecological account is based on the fossil remains of large mammals and provides a less direct form of proxy evidence than fossil pollen. Nelson Bay Cave is situated westwards of Knysna on the coast and as such is in close proximity to Vankervelsvlei. Boomplaas cave on the other hand is found about 400 km to the north of Knysna, providing more of a regional signal in comparison to that of Nelson Bay. At approximately 33 000 BP conditions are said to be cool with rain only falling in winter. By 21 000 BP the climate appears to have ameliorated somewhat with rainfall extending into the summer. Karroid scrub vegetation and grassland is favoured at this time over forest vegetation. At 17 000 BP, conditions are obviously cold and dry throughout the year and again scrub and grassland is favoured over forest. However, by the late Pleistocene at approximately 14 000 BP, moist conditions have set in as a result of all year rainfall allowing for expansion of mesic vegetation types. This trend continues with conditions becoming increasingly moist until 12 000 BP. The early Holocene is documented as being cooler than the late Holocene and somewhat drier and more seasonal than the terminal Pleistocene in terms of rainfall. By 6000 BP conditions have dried out considerably and this period is cited by Klein (1980) as the driest in the Holocene. Summers are thought to have been long, dry and hot, with little or no rain falling in the warmer months. The possibility of a reduction in temperature is noted at 2400 BP enforcing a contraction in forest extent at this time.

Broadly speaking, then, in terms of vegetation change over the past 40 000 years, the following trends are apparent:

I. Late Pleistocene: Cold and dry conditions - Klein (1980) reports the prevalence of frost shattered debris at Nelson Bay Cave, De Kelders Cave 1 and Boomplaas Cave A, suggesting relatively cold intervals since frost is not present at these localities in the present day. It is assumed that colder periods were drier due to the great atmospheric stability promoted by the weakening of the warm Agulhas current off the southern coastline. Expansion of grass at the expense of fynbos, woody shrubs and forest vegetation is proposed for this time period.

II. LGM (±18 000 - 20 000 ka): Extremely cold and dry conditions - Klein (1980) provides the only evidence available for this time period. This evidence is non-polliniferous in nature - fossils of large mammals suggest cold, dry conditions at approximately 17 500 BP. Associated with such conditions is the predominance of scrub and grassland vegetation. Prior to the height of glaciation at approximately 18 000 BP, slightly ameliorated conditions existed and karroid and grassland vegetation persisted.

III. Holocene: Dry early Holocene; moister late Holocene - Palynological evidence from Norga (Scholtz, 1986) and Groenvlei (Martin, 1967) proposes a drier earlier Holocene and moister late Holocene leading to the possible establishment of the Knysna forests in their historic form. This is confirmed by corresponding faunal shifts at Nelson Bay cave documented by Klein (1980).

It is obvious that the bulk of evidence, specifically the palynological work of Martin (1967) and Scholtz (1986), concentrates on vegetational changes of the Holocene with no evidence available pertaining to Pleistocene variations. The value of the lengthy record uncovered at Vankervelsvlei is thus verified since it will extend present knowledge of vegetation patterns in the KAR to unprecedented levels.

2.4.3 Human occupation of the Knysna Afromontane Region

This section aims to summarise the nature of human occupation of the KAR from the late Pleistocene through to the early Holocene, in other words, for the period of time represented by the Vankervelsvlei palaeoecological record. The section begins with a short explanation of the differences between middle and late stone age peoples and goes on to describe fluctuations in population density, size of social groupings and land management practices during the latter parts of the late Quaternary.

According to Volman (1984), hominids have lived in southern African for at least three million years, but knowledge about human behaviours and capabilities is very limited before the upper Pleistocene. It is, however, noteworthy that human occupation of the KAR occurred throughout the period recorded in the Vankervelsvlei sediments with Middle Stone Age (MSA) and Late Stone Age (LSA) peoples recorded in the landscape (Deacon, 1984; Volman, 1984, Deacon, 1995). It appears that population densities fluctuated over time according to the favourability of the prevailing environmental conditions (Volman, 1984; Deacon, 1995).

Dating of the transition from MSA to LSA in southern Africa is difficult largely because the small number of observations in the relevant time range are not entirely consistent (Deacon, 1984). Estimates for the dating of the transition vary considerably. Some protagonists claim that the change occurred over 40 000 years ago beyond the limits of radiocarbon dating, while others propose that MSA communities may have survived well into the Holocene. Deacon (1995) makes an estimate for the change at 32 000 BP based on dated MSA artefacts from several southern African sites, one of which (Boomplaas) falls within the KAR (a much older date from Border cave appears anomalous). Generally, however, it is accepted that the transition took place sometime between 32 000 BP and 20 000 BP (Deacon, 1984). As a result of this uncertainty, the distinction between MSA and LSA assemblages are made not on the basis of time, but rather according to differences in the production and size of flake blades (Deacon, 1984; Deacon, 1995).

Deacon (1984) identifies four sub-stages in human occupation from 40 000 BP to the present day. These are listed below along with their prominent characteristics. The conclusions of Volman (1984), Von den Driesch and Deacon (1985) and Deacon (1995), whose work is based on archaeological findings from all over southern Africa, are also discussed. Of particular interest are the findings of Von den Driesch and Deacon (1985) whose research is based at Boomplaas in the Cango Valley and Deacon (1995) who bases many of his conclusions on work undertaken at Klasies River near Plettenberg Bay. Both these sites are in the southern Cape and in relatively close proximity to Vankervelsvlei.

1. 40 000 BP - 12 000 BP: Low archaeological visibility in the landscape is evidenced by the low density of identified archaeological assemblages for this time period. Appropriate to the deteriorating conditions, people appear to have taken shelter in caves and rock dwellings. Faunal assemblages include more gregarious taxa than do later collections suggesting that people were probably organised into large groups that are likely to have occupied quite large territories (Deacon, 1984). Social groupings would have required broader ranges than in more favourable conditions in which to collect food and other resources in order to sustain themselves. It is important to note, however, that occupation did continue throughout the harshest conditions of the LGM as evidenced by tools and other materials found in dated assemblages. It is assumed that population densities at these times would have been lower than during interstadial times and that social groupings would have had wider mobility and social networks (Deacon, 1995).

2. 10 000 BP - 7 500 BP: Towards the end of the Pleistocene and during the early Holocene a noticeable decrease in cave and rock shelter occupations is noted, presumably in response to ameliorated conditions. A corresponding shift towards non-gregarious antelope suggests the reorganisation of populations into more mobile units (Deacon, 1984). Thus, hunter-gathering would have continued into the Holocene although ranges are likely to have been smaller due to the availability of resources.

3. Mid-Holocene: Holocene feeding patterns appear geared towards regular exploitation of small antelope and intensive plant food collection. This pattern is evidenced in a large number of assemblages covering a broad geographic range. It would appear

that smaller groups of people occupied smaller territories at this time and are likely to have moved seasonally according to the growth of plant foods. The southern and eastern Cape regions have been identified as two of several preferred areas for habitation in mid-Holocene southern Africa (Deacon, 1984). Deacon (1995) notes the increase of archaeological visibility in the landscape during this period and an increase in the social complexity at archaeological sites from about 5 000 BP. This does not necessarily intimate an increase in population in the area, but it is a likely possibility that occupation intensified.

4. Late Holocene: This phase is characterised by the introduction of pottery to archaeological assemblages and the first signs of a herding economy. This is visible in the relatively sudden appearance of potsherds and bones of exotic domesticated animals in deposits over a wide geographic area at approximately 2 000 BP (Deacon, 1984, Van Drieschen and Deacon, 1985). There is also some evidence for the practice of land management at this time in the form of veld burning to promote the growth of geophytes and later to stimulate suitable grazing for livestock (Deacon, 1984).

To summarise, it appears as if a hunter-gatherer lifestyle perpetuated itself for thousands of years amongst MSA and LSA peoples in the KAR and indeed throughout southern Africa. This lifestyle seems to have been remarkably adaptable to environmental change whether through adjustments in population distribution, shifts in staple foods or the adaptation of different tool designs (Deacon, 1984). Indeed, Deacon (1995) and (Volman, 1984) claim there is no evidence to support the idea that archaic populations were replaced by modern ones. It seems that lifestyles changed only during the latter part of the Holocene with the influx of settled agriculturalists, both Iron Age and European (Deacon, 1984). It can thus be deduced that environmental, or rather habitat, changes were the most important determinant of distribution and densities of people in the landscape until the late Holocene (Deacon, 1995). It is important to note that human impact on the environment from the late Pleistocene through to the Mid-Holocene is likely to have been minimal. Even though fire was used in land management, technology of the MSA and LSA peoples was limited and their numbers are unlikely to have been sufficient to exact much impact before 2 000 BP (Roberts, 1989).

2.4.4 Conclusion: the way forward

Regional interpretations of late Quaternary environmental history in southern Africa are becoming increasingly inadequate in accurately interpreting climatic changes. With specific reference to the relationship between moisture availability and temperature, it is clear that subcontinental inconsistencies exist. A shift towards multidisciplinary site-specific studies could provide one solution, earmarking Vankervelsvlei as significant. The length of the record is particularly important considering the dearth of information describing LGM and late Pleistocene conditions on southern Africa's south coast. The Holocene record here is somewhat more established although evidence from Vankervelsvlei should prove useful in confirming and amplifying existing knowledge.

CHAPTER 3

CONTEMPORARY ENVIRONMENTS OF THE KNYSNA AFROMONTANE REGION

3.1 INTRODUCTION

The sections outlined in this chapter aim to familiarise the reader with the physical characteristics of the study area as well as the specific nature of the study site - Vankervelsvlei. The chapter begins with a description of the afromontane region of which the Knysna forests constitute a part. This provides a contextual background in which to describe the Knysna Afromontane Region (KAR) and its unique attributes. The unusual nature of the schwingmoor bog at Vankervelsvlei also requires attention and its development and ecology are explored.

3.2 THE AFROMONTANE REGION

Afromontane vegetation is relatively widespread within the African continent, the so-called 'afromontane region' extending from Sierra Leone in the west to Somalia in the East and from the Red Sea hills in the North as far south as the Cape Peninsula (Meadows and Linder, 1993). The afromontane region comprises seven regional mountain systems (Figure 3.1) characterised by an unusual vegetation mosaic. Throughout the region forest vegetation, which is commonly located on high peaks, is connected to lowland vegetation by transitional vegetation types such as woodland. This transition zone has, however, been almost entirely destroyed by cultivation or fire (White, 1983). Thus, understanding of the former pristine nature of transitional vegetation must be deduced from surviving relicts and circumstantial evidence (Von Breitenbach, 1972; Werger, 1978).

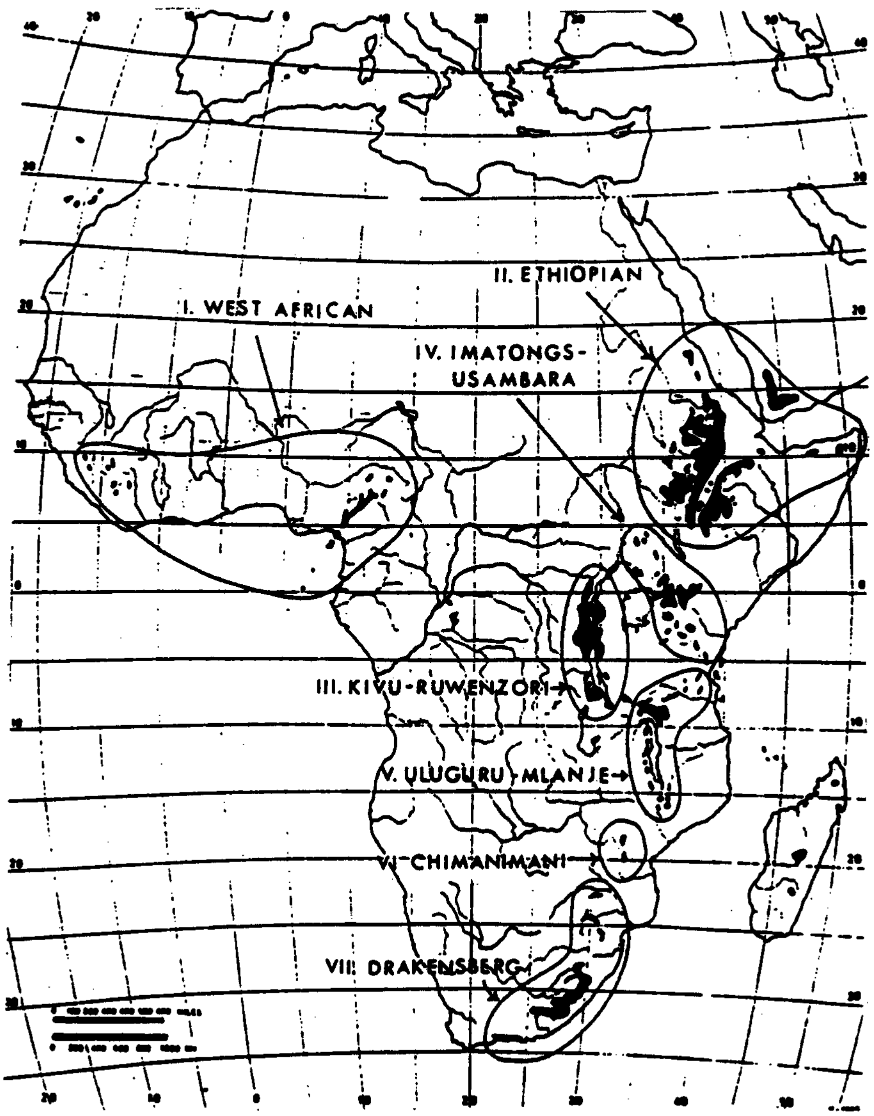


Figure 3.1: Map showing the distribution of the islands of the afromontane archipelago in the seven regional mountain systems of Africa (after Werger, 1978).

The character of afromontane islands in South Africa is somewhat different from their northern counterparts. Increasing latitude compensates for altitude allowing the forest component of the flora to extend almost to sea level (Von Breitenbach, 1972; Werger, 1978; Geldenhuys, 1988). In the Eastern and Western Cape provinces of South Africa, afromontane vegetation is represented by the forest component only with transitional types being absent. Forests are no longer associated with the crests and summits of mountains, but are confined to their lower slopes and the coastal plain (Martin, 1967; Werger, 1978).

The classification of the afromontane flora as a distinct phytochorion lies in its obvious continuity and conformity over a remarkable distance (Phillips, 1931; Geldenhuys, 1972; Werger, 1978). Forests are evergreen and structurally complex, especially in areas with more favourable moist climates (Meadows and Linder, 1993). Across the African continent, the total flora exceeds 4000 species, with more than 3000 of these being endemic. Endemism at the family level is poor, however, with a maximum of three plant families holding this status. Approximately 20% of all tree genera are endemic with a somewhat smaller proportion of smaller plant genera earning such standing. The majority of genera and species are widely distributed despite the enormous longitudinal and latitudinal extent of the afromontane archipelago. On any particular mountain within the seven documented systems, few common species are likely to occur; however, all the complexes are intimately linked through an elaborate series of intermediate taxa. Interestingly, this phytochorion can be defined almost entirely with reference to twelve tree species (Werger, 1978). These are listed below:

I. *Apodytes dimidiata*
II. *Halleria lucida*
III. *Ilex mitis*
IV. *Kiggelaria africana*
V. *Nuxia floribunda*
VI. *Nuxia congesta*
VII. *Ocotea bullata*
VIII. *Afrocarpus falcata*
IX. *Prunus africana*
X. *Rapanea melanophleos*
XI. *Xymalus monospora*

No single species occurs throughout, but the assemblage is represented on virtually every island, usually by various species. Of the seven islands, the flora of the East African mountains is the richest and most floristically diverse. In comparison, the flora of the southern islands is very much impoverished (Von Breitenbach, 1972; Geldenhuys, 1993). The very nature of the archipelago dictates the occurrence of disjunct taxa between disparate islands. The incidence of very wide disjunctions within islands, mostly as a consequence of human intervention in the recent past, further complicates the already complex nature of the afromontane flora as a whole (Werger, 1978).

Within the broader African context, the Knysna forests lie at the southernmost tip of the afromontane archipelago, which stretches from Central Africa southwards in pockets of varying sizes to the southern Cape coast of South Africa (Werger, 1978). They represent the largest refuge of forested land on the southern rim of the subcontinent and are protected by the arc of the Outeniqua-Tsitsikamma mountains. The barrier effect of these coastal ranges and the overlapping of the winter and summer rainfall in the area produce a fairly humid and almost unseasonal environment permitting the survival of evergreen broadleaf forest formations (Von Breitenbach, 1972; Martin, 1967). A few small isolated pockets do occur further westwards along the coast and even within the Cape Peninsula under certain conditions (Werger, 1978). However, the southernmost area of forested land of considerable expanse is found near Knysna (Von Breitenbach, 1972; Werger, 1972; Geldenhuys, 1993).

3.3 PHYSICAL CHARACTERISTICS OF THE KNYSNA AFROMONTANE REGION

Firstly, it is vital that the term 'Knysna Afromontane Region' be clearly defined. This term refers broadly to one of seven islands of afromontane vegetation forming part of the afromontane archipelago in Africa. Werger (1978) combines the Knysna forests with others in South Africa under the name of the 'Drakensberg' island. However, for the purposes of this study, the afromontane flora restricted to the coastal regions stretching along the south coast of southern Africa is referred to as the 'Knysna Afromontane Region'. This area is bounded by the Gouritz river to the west, the Kromme River to the east, the Indian Ocean coastline to the south and the crests of east-west trending mountains of the Cape Fold Belt to the north (Figure 3.2 overleaf) (Geldenhuys, 1993). The area is conventionally associated with the small coastal town of Knysna, from which the forests have historically taken their name.

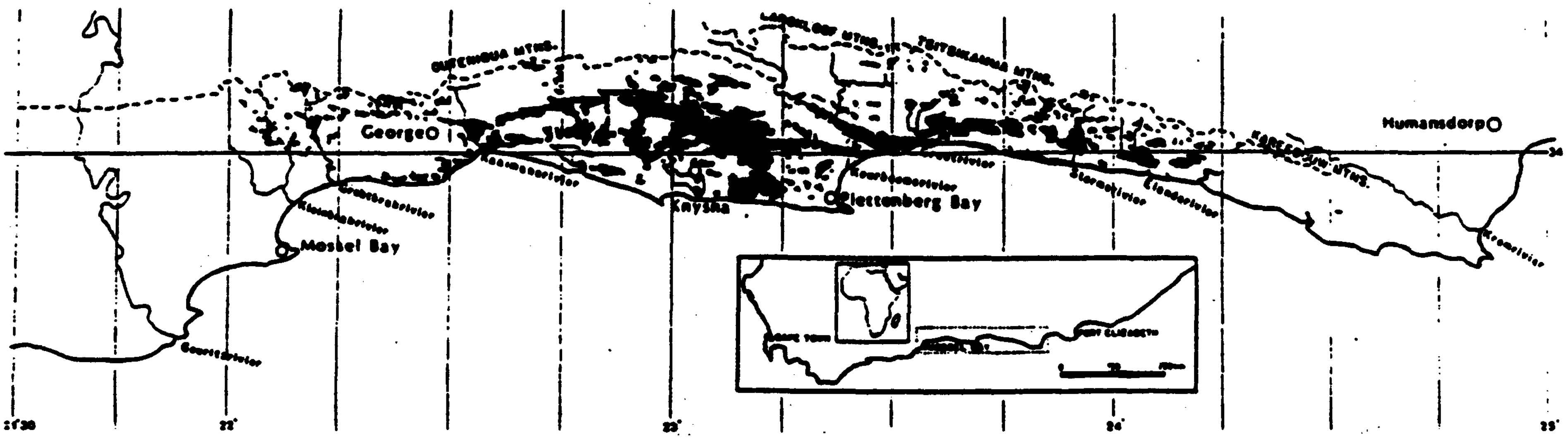


Figure 3.2: Map showing boundaries of the Knysna Afromontane Region (KAR) (After Geldenhuys, 1988).

3.3.1 Geology, Geomorphology and soils

3.3.1.1 Geology

The oldest rocks in the area are of Precambrian age and are found south of the Outeniqua mountains to the west of Knysna. These are mainly contorted bands of schist, phyllites and quartzites of the Koumans formation (Toerien, 1979). Adjoining outcrops of intrusive gneissic granite lie further to the west. Most of the area comprises rocks of the Table Mountain Group including Peninsula, Cedarberg, Tchando and Kouga formations. These are supermature quartz sandstones which constitute the mountain ranges of the Cape Fold Belt and are believed to be marine in origin (Toerien, 1979; Grindley, 1985; Geldenhuys, 1993). Deposits of Enon pebble conglomerates at Knysna are indicative of climate change under strongly oxidising conditions during the Cretaceous-early Tertiary period (Miller, 1963; Du Toit, 1966; Butzer and Helgren, 1972; Toerien, 1979). More recent deposits of Tertiary and Quaternary age include fixed dunes and dune rock (Grindley, 1985). Younger vegetation bound dunes reach far inland on the marine platform of Tertiary duration.

3.3.1.2 Geomorphology

The geological characteristics of the KAR have to a large degree dictated the nature of the geomorphological landforms visible in the landscape today. The most important features to note are the Cape Fold Mountain ranges, the coastal platform and the various cordons of contemporary and fossil dunes present in the region (Fig 3.3).

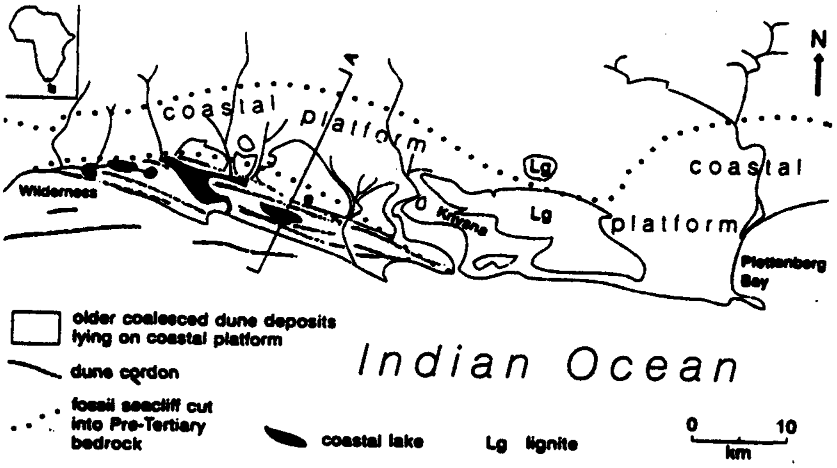


Figure 3.3: The coastal area from Wilderness to Plettenberg Bay showing dune cordons deposited in the wave-cut Wilderness embayment and older coalesced dune deposits on the coastal platform (After Illenberger, 1996).

The KAR is bounded on the landward face by several ranges of the Cape Fold mountain group, namely, the Outeniqua, Tzitzikamma and Kareedouw ranges. These coastal mountains rise from a narrow coastal plain to a height of 1200-1500m above mean sea level (amsl) between 16 and 25km from the coast (Martin, 1967). The mountain ranges separate the moist coastal regions from the more arid Karoo regions, while undulating foothills divide the mountains from the relatively level coastal plain. Many rivers run south from their sources in the mountains forming deep, narrow incisions in the coastal forelands (Geldenhuys, 1993).

The coastal plain itself constitutes a series of plateaux arising 200m beneath the Indian Ocean and ascending gradually inland. The first of the three plateaux forms the Aghulhas bank. The second rises abruptly from its shoreward margin as a cliff faced terrace. Sea breezes have resulted in the build up of dune cordons along the margins of this plateau separating the sea from the Wilderness lakes. The remaining plateau stretches to the foothills of the coastal ranges and is dissected by narrow, deep valleys separated by rounded ridges (Phillips 1931; Illenberger, 1996).

The Wilderness dune cordons (of varying ages) mentioned above consist of steep sided ridges and are separated by coastal lakes scattered along the coastal plain. Three major contemporary cordons are at present in evidence on land, while several others are submerged offshore down to a depth of 50m. Their development is probably a consequence of accretion of transgressive dunefields and imbricate parabolic dunes driven by predominating westerly winds (Illenberger and Burkinshaw, 1996). Older fossil dune cordons lie landward of these reaching heights of 200-260 m. Some of these lie on the coastal platform (Illenberger and Burkinshaw, 1996). The first suite of fossil dunes dates back to the Pliocene and reaches its maximum height at approximately 270m amsl while the second, more recent, association climbs to only 170m amsl (Marker, personal communication). Sea level highstands during the Pleistocene interglacials are surely responsible for initiating the development of fossil dunes in the wavecut embayment between the present day towns of Wilderness and Knysna. Interglacials would have provided the onshore conditions necessary for sand accumulation and for such dune formation to begin (Illenberger and Burkinshaw, 1996).

Individual cordons would have resulted from phases of dune formation during successive highstands of sea level (Illenberger, 1996; Illenberger and Burkinshaw, 1996). Vankervelsvlei itself lies in a swale formed in an interdunal depression thought to be of Pliocene age.

3.3.1.3 Soils

Phillips (1931) notes that the physical, chemical and biological nature of the soils of the region as a whole has received very little attention in terms of documented research. However, those areas utilised for plantations have been studied in some detail. Much of the soil lies in situ; affording the assumption that parent material would fundamentally affect its characteristics. However, in many cases the reverse has been shown to be true. Soils derived from Malmesbury shales, TMS and granites have proved to differ very little in terms of physical, chemical and biological properties (Phillips, 1931). Soils are generally acidic, leached, shallow and nutrient deficient (Phillips, 1931; Geldenhuys, 1988; Geldenhuys, 1993). Soil depth varies considerably, ranging from depths of several cm to approximately 1m with subsoils consisting largely of clay material. Five major classes of soil have been distinguished by Phillips, (1931); namely heavy or modified clays, clay loams, sandy loams, littoral bush sands and dune sands.

3.3.2 Contemporary climate

It is the moderate nature of the present day climate that has allowed for the survival of typical afromontane vegetation in the area as well as for the accumulation of lengthy sequences of highly organic sediment on the coastal plain and thus at Vankervelsvlei.

According to Geldenhuys (1988) the region experiences the all year rainfall prevalent along the Cape south coast with the mean annual average varying between 500 and 1200mm (Geldenhuys, 1993). The coastal mountains in the area provide the forests with the main source of moisture - orographic rain. Bergwinds occur during winter and cold fronts during spring and autumn (Geldenhuys, 1993) further contributing to impartial distribution of rainfall throughout the year with no less than 50mm falling within any one month (Martin, 1967). Rainfall maxima occur bimodally in the early and late summer months (Geldenhuys, 1993). Temperatures are generally uniformly mild throughout the year (Toerien, 1979); the average yearly temperature reaching 16.9°C. Mean annual maximum temperatures at Knysna rise to 25°C in the summer months and 18°C during the winter period (Grindley, 1985). Mean daily maximum temperatures reach 23.8°C in

February dropping to 18.2°C in August. Mean daily minimum temperatures over the same interval approach 19.7°C and 8.9°C respectively (Geldenhuys, 1993). South westerly winds predominate in the region as has been the case for the past several million years (Illenberger 1996).

Climatic conditions most applicable to Vankervelsvlei are well summarised in Figure 3.4 showing data for Knysna, which lies approximately 15 km from the site.

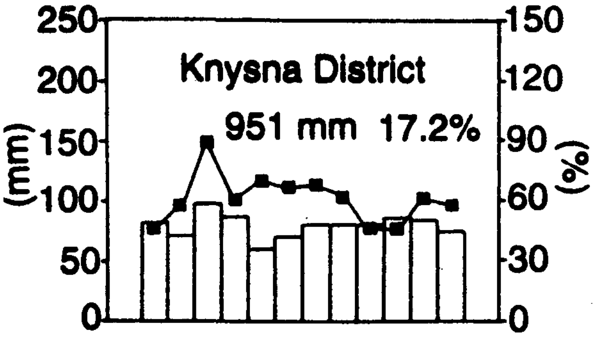


Figure 3.4: Representative rainfall data for the Knysna district. Rainfall data are an artificial sequence of monthly total generated for 30 years (Zucchini, 1990). Bars refer to mean monthly rainfall and lines to coefficients of variation for monthly rainfall (After Cowling, 1992).

3.3.3 Natural vegetation

In contrast to the general pattern of afromontane forest development, forest is the sole type of vegetation found in the Cape islands of afromontane flora (Werger, 1978). The forests within the region are overwhelmingly afromontane in character, but they do grade into scrub forest, bushland and thicket as conditions become drier. These transitional communities are transgressed by taxa mainly from the Cape Floral Kingdom (CFK) (Werger, 1978). As such, it was originally thought that the Knysna forests formed part of the Cape Region; however their floristic similarity to the forests of tropical Africa negate this possibility (Phillips,1931), linking them instead to the Palaeotropic Floral Kingdom. The floristic character of the area is further complicated by its location at the limit of the distribution range of many karroid and bushveld taxa (Von Breitenbach, 1972; Cowling, 1983). As such it is situated in what could be termed a 'tension' zone of great phytochorological complexity (Cowling, 1983). In light of these observations, Martin (1967) describes the Knysna forests as occurring in a complex pattern of wet and dry types combined with scrub and patches of fynbos. This account is intended to highlight the major characteristics of indigenous communities within the Knysna region as well as describe briefly the manifestation of human intervention in the landscape over the past few hundred years.

3.3.3.1 Afromontane forest

Geldenhuys (1993) produced a revised synthesis of the floristics of the Knysna forests based on work compiled by a number of authors over an extended period of time. These included Phillips (1931), Fourcade (1941), Von Breitenbach (1974), Goldblatt, (1978), Bond and Goldblatt (1984), and Geldenhuys (1989, 1991). This synthesis brought to light new species and extended distribution ranges of several already known species.

Generally it is agreed that the Knysna forests, in common with other South African forests, are of a decidedly mixed nature. There are few pure communities as far as dominant species are concerned and general mixing of species occurs (Phillips, 1931; Werger, 1978). The forests are not truly tropical, with the bulk of the species reflecting adaptations to extratropical conditions. The tree flora in South African afromontane forest is remarkably uniform, although certain small enclaves within the Western and Eastern Cape are somewhat floristically impoverished (Von Breitenbach, 1972). This is particularly evident in areas with biseasonal precipitation maxima as is the case in the Knysna region (Meadows and Linder, 1993). South African afromontane forests are generally depauperate in terms of that species richness, but do have a higher percentage of local endemics than their northern counterparts. These however, have extensive ranges within the subcontinent, affording the Knysna region itself with little incidence of endemism. Local endemism among grass and fynbos taxa may be quite high, but not as significant as that within the CFK (Cowling, 1983).

Acocks (1988) recognised various vegetation types within the Knysna region. The first and most obvious being high and scrub forest (veld type 4) which was observed to be surrounded by differing types of shrubland. These included mountain fynbos (veld type 70) and small enclaves of coastal fynbos (veld type 47), coastal renosterbos (veld type 46) and valley bushveld (veld type 23). In terms of high and scrub forest, Von

Breitenbach (1972) categorises forest vegetation into eight climax types with respect to soil type, depth, moisture and drainage. These are summarised in Table 3.1 below.

CLIMAX COMMUNITY	TYPICAL SITES	DESCRIPTION	COMMON GENERA
very very dry Scrub (vvv-S)	sites with hot, dry climates and shallow soils. Often rocky or sandy eg littoral dunes, steep escarpments	• 2-5m high • groups of shrubs with occasional stunted trees	• shrubs: *Rhus, Passerina, Maytenus, Euclea, Cassine, Myrica* • trees: *Sideroxylon*
very dry Scrub forest (vd-SF)	sites with fairly hot and dry climate, shallow easily drained soils eg ridges.	• dense mix of 3-6m high shrubs and 6-12m high stunted trees • poor ground flora	• shrubs: *Polygala, Maytenus, Scutia* • small trees: *Pterocelastrus, Apodytes, Olinia, Canthium, Euclea* • taller trees: *Podocarpus*
dry High Forest (d-HF)	sites with moderately hot and dry climate, deep easily drained soils eg ridges.	• dense forest of small-medium tall trees 10-18m high • open and low undershrub layer • rich ground flora	• small trees: *Olea, Podocarpus, Diospyros* • medium-tall trees: *Pterocelastrus, Podocarpus, Rapanea, Olea, Olinia, Rhus*
Medium-moist High forest (mm-HF)	sites with temperate and fairly humid climate. Shallow-moderately deep moist soils.	• two dense tree strata, 16-22m and 6-12m high	• main canopy trees: *Olea, Podocarpus, Apodytes, Rapanea, Olinia* • intermediate story trees: *Halleria, Diospyros, Maytenus*
moist High Forest (m-HF)	Sites with temperate and humid climate. Moderately deep-deep soils-very moist throughout the year.	• three medium dense irregular tree strata. • dense to open undershrub layer. • luxuriant shrub layer.	• trees: *Olea, Podocarpus, Apodytes, Ilex, Rapanea, Curtisia, Halleria, Diospyros, Maytenus* • undershrubs: *Trichocladus*, fern taxa
wet High Forest (w-HF)	sites with a cool and wet climate. Shallow-moderately deep well-drained soils, usually moist throughout the year.	• medium dense two storey forest, 12-20m and 6-12m high • dense tree fern storey, 3-6m high • luxuriant ground flora with shrubs	• canopy trees: *Ocotea, Podocarpus, Rapanea* • lower storey trees: *Halleria, Olea, Curtisia* • ground layer: tree fern taxa
very wet Scrub Forest (vw-SF)	sites with very cool and wet climate and shallow soils.	• mixture of 6-10m high trees and 3-6m high shrubs • dense ground layer	• trees: *Podocarpus, Ocotea, Halleria, Ilex, Olea* • ground layer: fern taxa
very very wet Scrub (vvw-S)	sites with cold and misty wet climate and extremely shallow soils.	• 3-5m high shrubs • small groups bushy trees • dense ground layer	• tall shrubs: *Protea, Cassine, Halleria, Leucadendron, Myrica* • ground layer: fern taxa, *Erica, Passerina*

Table 3.1: Summary of climax forest communities (source: Von Breitenbach, 1972)

3.3.1.2 Peripheral communities

Peripheral communities are largely composed of an intricate mixture of Cape flora, karroid and tropical bushveld flora and of allied locally adapted forms of the latter (Von Breitenbach, 1972). With the onset of drier conditions, subtropical and Cape species are likely to encroach followed by invasion of karroid elements as dry conditions perpetuate (Cowling, 1983).

The intrusion of the CFK (mountain and coastal fynbos) into the Knysna afromontane region is evidenced in the presence of all four major fynbos elements; namely the families *Restionaceae, Proteaceae* and *Ericaceae* and several geophytic components. The CFK is particular to the south western portion of the southern African continent and is the richest known flora in the world in terms of species per unit area. Endemism at the species level reaches an impressive 70 % while 20% of all genera are endemic to the region (Jarman, 1986). This is especially significant considering the very small area occupied by this sclerophyllous shrubland. It covers a mere 4% of southern Africa yet boasts almost 50% of known plant species on the entire subcontinent (Bond and Goldblatt, 1984). Mountain and coastal fynbos are to be found occupying mountain fringes and parts of the coastal foreland (Acocks, 1988).

3.3.1.3 Present day land-use

It should be noted that human intervention in the landscape has rendered significant change within the last 300 years (Werger, 1978). The indigenous forests of the Knysna region have in the past been exploited for their timber but are now largely protected in forest reserves (Von Breitenbach, 1972). By 1996 the total area covered by protected indigenous forest reached 60 561 hectares (Geldenhuys, 1993). Though these are no longer commercially exploited, plantation agriculture has become widespread. Several exotic species are farmed, the most prominent included in the genus *Pinus* (Von Breitenbach, 1972). Vankervelsvlei itself is immediately surrounded by a pine plantation indicating the influence of human disturbance in the recent past. The coastal plain as a whole is also inundated with a variety of tourist related ventures centred around the small coastal towns of Knysna, Sedgefield and Plettenberg Bay.

3.4 LOCATION AND DESCRIPTION OF THE VANKERVELSVLEI BASIN

3.4.1 Introduction

The underlying premise behind undertaking palaeoenvironmental research at Vankervelsvlei lies in the suitability of the site as a receptacle for the accumulation and preservation of pollen grains. As a result of the small size of the catchment, the pollen signature obtained from the site is likely to represent vegetation change on the local scale rather than in the regional context. However, a larger basin, Groenvlei, lies in close proximity to Vankervelsvlei, being only 5km distant and has yielded palaeoenvironmental data of a more regional type over a period spanning the past 8000 years (Martin, 1967). Following a broad regional description of the Knysna Afromontane Region, this section aims to describe more particularly the conditions within the immediate surroundings of Vankervelsvlei itself.

Fundamental to a mature understanding of the character of the site is consideration of the unique ecology of floating bogs, of which Vankervelsvlei is a rare example on the subcontinent.

3.4.2 Description of floating bogs

Floating bogs, known colloquially in European countries as 'schwingmoors' or 'kesselmoors', derive their name from the nature of the floating mat of vegetation covering the water surface. Warner (1993) describes them as lake filled bogs with quaking vegetation mats. The literal meaning of the word 'schwingmoor' is 'swinging bog' and describes the characteristic floating mat. The vegetation is often thick enough to support the weight of a person (French and Moore, 1986; Sasser *et al.*, 1991; Swarzenski *et al.*, 1991), but is unstable and may move up and down when walked upon (Hooper, 1991).

3.4.2.1 Ecology

Little is known about the ecology of floating bogs, though it is expected that their ecological dynamics would differ from those of conventional marshes due to the ability of the vegetation to adjust to variations in water level (Sasser *et al.*, 1991). Warner (1993) suggests that the floating mat is an adaptation to radical changes in basin water volumes on a seasonal basis. This allows for maintenance of a constant chemical regime and protects vegetation from becoming submerged.

Several theories have been put forward in an attempt to explain the development of these unusual geomorphological landforms. Several authors including Waterman (1926); Warner, (1993); Warner *et al.* (1989, 1990, 1991); Warner, Kubiw and Hanf (1989); Hooper (1991); Hogg and Wein (1986); Swarzenski *et al.*, (1991) and Mallik (1988) reach consensus on the following points:

I. Firstly, it is necessary that a depression develop in which water can collect. Such depressions are documented to form as a result of a variety of processes, for example the solution of limestone, the collapse and slumping of parent material, formation of kettle holes through ice action, and more recently, the digging of reservoirs by people;

II. Once water has collected, aquatic plants with floating stems or rhizomes colonise open water directly; building a root mat thick enough to provide support for emerging vascular vegetation. Vegetation breaking free from the underlying substratum adds to the constituent mass of the mat;

III. With the rapid accumulation of matter, water depth decreases driving the succession from marsh to bog-like conditions. As the floating mat thickens and spreads laterally, the entire basin is filled, although small areas of open water may remain;

IV. With time soil conditions reach a stage suitable for upland plants to take hold. The increasing density and dryness of the mat allows the development of terrestrial plant communities on its periphery;

V. Eventually, it is possible that trees may colonise the surface of the mat as well. However, as these grow older and heavier and the roots penetrate the mat, they drown in the water and the trees die. For this reason, floating bogs are often characterised by the presence of dying and fallen trees.

Thus, formation of floating bogs involves the concentric development of a gradual continuum of open water macrophytes and loose floating aquatic plants near the centre of basins to terrestrial communities around the margin (Warner, 1993). Figure 3.5 depicts a schematic view of the floating bog at Vankervelsvlei showing the transition from aquatic vegetation to transitional fynbos/scrub forest and mature pine communities.

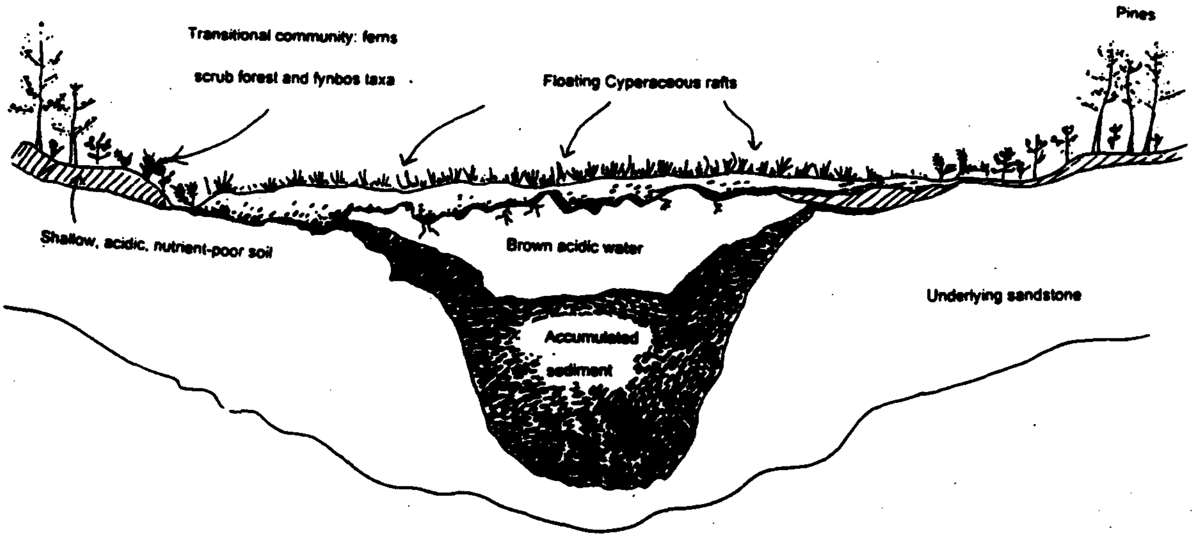


Figure 3.5: Schematic diagram of the schwingmoor bog at Vankervelsvlei showing the transition from open water aquatic taxa to terrestrial communities (Adapted from Hooper, 1991).

3.4.2 Vankervelsvlei

3.4.2.1 Introduction

Vankervelsvlei is an enclosed interdunal depression lying 15km west of Knysna and 10km north of Buffelsbaai between latitude 34°0'71"S and longitude 22°54'22"E (Figure 3.6). This small catchment is situated only a few kilometres inland of the coastal lake of Groenvlei, where Martin (1967) described the first thorough account of Holocene environmental history along the south coast of southern Africa. The site is accessible by road and lies several kilometres north of the N2 between Knysna and Sedgefield.

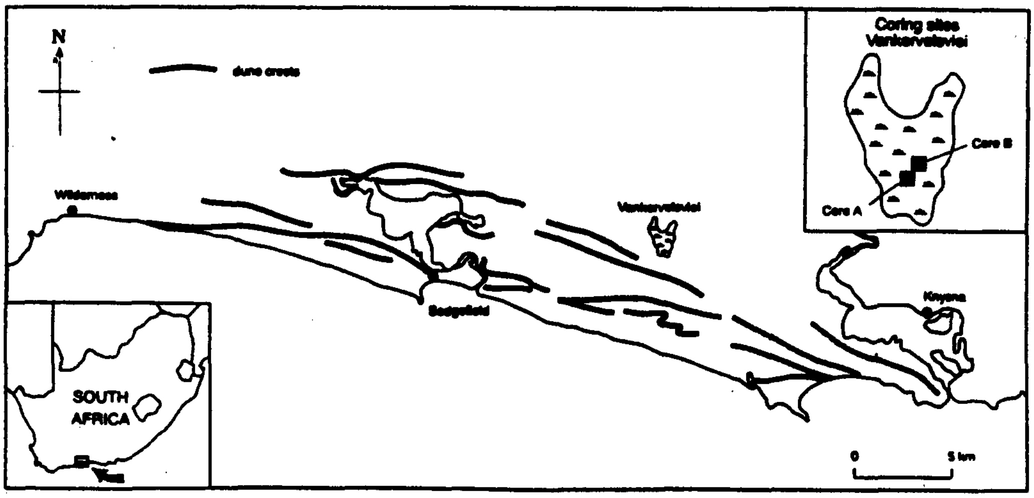


Figure 3.6: Location of Vankervelsvlei (After Irving and Meadows, 1997).

The catchment itself occupies an area some 1km by 0.5km in extent and is nestled among steeply sloping fossil dunes which are at present vegetated as part of the Thiessen's pine plantation in the area. The site lies on the coastal plain at a height of approximately 150m amsl. The water surface is at present completely concealed by a dense covering of matted Cyperaceous vegetation to a depth of approximately 2m. The covering of vegetation is dense enough to support the weight of a number of people as well as several hundred kilograms of coring equipment as was witnessed during two coring operations. The water body is entirely endorheic and isolated in terms of surface hydrology as there is no obvious contemporary surface inflow or outlet. This is likely to have caused minimal disturbance in terms of movement of the sediment over time allowing for relatively consistent accumulation of material. The basin is irregular in shape as shown in Figure 3.6.

3.4.2.2 Current land-use at Vankervelsvlei

In terms of present day landuse, vegetation patterns in the immediate vicinity of the site, the proof of human interference is overwhelming. During the initial coring expedition in 1992, the site was observed to be entirely surrounded by mature plantations of the northern hemisphere genus *Pinus*. Windbreaks had been planted dividing the plantation. These comprised trees of the Australian genus *Eucalyptus*, one of several genera belonging to the family *Rhamnaceae* of which some are indigenous to southern Africa. These two alien taxa currently dominate the landscape, though a second field excursion to the site in 1996 revealed the emergence of fynbos dominated pioneer communities in the wake of pine forest clearance to the north of basin. The most common genera present included *Passerina, Erica, Leucadendron and Restio.* The aquatic vegetation covering the surface of the water, belonging to the family *Cyperaceae*, grows to a height of approximately 2m. Several dead tree trunks were located close to the margin of the water body and several unidentified species of Bryophytes were found growing close to the waters edge and indeed throughout the vegetation mat level. These created a dense mat at the base of the Cypercaeous layer and formed a substantial portion of several of the surface samples collected for analysis of contemporary vegetation surrounding Vankervelsvlei. Transitional vegetation between the vlei edge and the pine forest enclosing the water body consisted largely of taxa from the CFK as well as various Spermatophytes. The representative genera observed were similar to those pioneers found occupying the recently cleared plantation on the northern banks. However, in addition to the fynbos taxa present, scrub forest elements and several fern taxa were also noted. Of these, the genera *Cassine, Kiggelaria* and *Euclea* were easily recognisable. The scrub forest elements appeared relatively stunted, reaching heights of only one to two metres.

The settlement at Keurvlei on the southwestern bank of the basin appeared uninhabited by the second visit to the site in 1996. Although populated in 1992 when the first exploratory coring excursion was undertaken, the small collection of houses appeared derelict and deserted by March 1996. The area is in fact restricted to public access since it forms part of a privately owned plantation and entry is attained by special permission only. The access roads to the site are rudimentary and presumably provide pathways into the plantation for foresters to monitor the plantations.

3.5 CONCLUSION

The Knysna Afromontane Region, as the largest forest complex in southern Africa, forms the southernmost island of the afromontane archipelago in Africa. Having described its relationship to the other six systems in Africa as well as the region's specific physical characteristics, the importance of contextualising the study site has been accomplished. The next chapter aims to describe in detail the methodological approach adopted in terms of various analyses carried out on the Vankervelsvlei sediments.

CHAPTER 4

METHODOLOGY AND LABORATORY TECHNIQUES

4.1 INTRODUCTION

4.1.1 Outline of chapter

This chapter details the various methods employed in this study as well as a basic rationale for methodological decisions made. The main topics under discussion are as follows:

I. The preparation of modern pollen for reference slides;

II. Fossil pollen preparation, counting and identification;

III. Grain size resolution;

IV. Statistical methods used in analysis and presentation of pollen data;

V. Determination of organic matter content of sediments;

VI. Analysis of geochemical composition of sediments.

The chapter begins with a brief explanation of the methodological background to the study. A basic understanding of the tenets of palaeoecology in general and palynology in particular is assumed and the reader is referred to general texts for further detail (Birks and Birks, 1980; Lowe and Walker, 1984; Feagri *et al.* ,1989; Moore *et al.*, 1991). Pollen analysis is discussed in greatest detail since it forms the basis of reconstructing the vegetation history at Vankervelsvlei. This is particularly important in explaining the development of the schwingmoor bog at the site.

4.1.2 Methodological background

This study is founded on palaoecological principles and falls within the theoretical context of descriptive, historical science. Broadly speaking, the aim of Quaternary palaeoecology is to reconstruct and describe past environments by inferring biotic and abiotic components of ecosystems from fossil organisms and fossil-bearing sediment.

Fundamental to the understanding of palaeoecology is the principle of uniformitarianism which allows the palaeoecologist to use the present to "model the past" (Birks and Birks, 1980) by extending observations about processes within present ecosystems backwards in time (Lowe and Walker; 1984).

Of the many palaeoenvironmental indicators available to researchers, fossil pollen is widely considered to represent one of the more reliable forms due to the close relationship enjoyed between climate and vegetation (Moore *et al.*, 1991). This, along with the pollen-rich nature of the sediments extracted from Vankervelsvlei, has led to the choice of fossil pollen analysis as the major investigative tool in this study. The foundation of fossil pollen analysis, or palynology, rests upon the assumption that fossil pollen provides a basic picture of the botanical setting in which it was released. In turn, it is assumed that the vegetation reflects the prevailing environmental conditions that would have influenced its composition (Faegri *et al.* , 1989). Thus, it is believed that environmental change can be inferred from studying changes in pollen concentrations over time. Fossil pollen is usually preserved in moist acid conditions (Moore *et al.*, 1991) and is thus commonly encountered in vleis and lake catchments such as Vankervelsvlei. It should however be noted that several lines of evidence should be used to accurately reflect and reconstruct past conditions at a particular site over time(Birks and Birks, 1980). This is particularly true in southern Africa, where the semi-aridity and seasonal rainfall often hamper preservation of pollen grains (Meadows, 1987). Thus, a multidisciplinary approach has been adopted in order to trace broad environmental changes at Vankervelsvlei during the late Pleistocene and Holocene.

4.1.3 Methodological problems

Despite its effectiveness as proxy evidence for environmental change, the analysis of fossil pollen has numerous methodological complications which must be born in mind when interpreting any pollen record. These can be divided into two main groups, those relating to the differential production, dispersal and preservation of pollen and those associated with laboratory, data presentation and interpretive techniques. The first group of problems are largely unavoidable and fall outside of the realm of responsibility of the researcher. However, it is possible to minimise the effects of the second group through careful preparation of material for analysis, statistical manipulation of data and consultation with experts in interpretation of results. In an attempt to bolster the accuracy of reconstructions based on pollen evidence, sedimentological and geochemical data have also been generated.

4.2 POLLEN EVIDENCE

4.2.1 Pollen reference collection of the Knysna Afromontane Region

The success of Quaternary palynological studies rests upon the accurate identification of fossil pollen grains through comparison with grains of known contemporary taxa (Moore *et al.*, 1991). Thus, the compilation of a comprehensive collection of modern reference material is intrinsic to the resolution of vegetation changes over time. Naturally, the value attributed to any palaeoecological interpretation will largely depend on the level of taxonomic clarification accomplished by the researcher (Birks and Birks, 1980). Ideally, identification of fossil grains should be carried out to species level. In reality, however, resolution beyond family level is seldom achieved in the southern part of the subcontinent.

Due to the incredible taxonomic diversity within southern African (approximately 21 350 species) and considerable regional variation within the same area, it has not yet proved possible to produce a single pollen atlas serving the entire subcontinent (Bond and Goldblatt, 1984). Consequently, various regional collections have been established, one of which is housed at the University of Cape Town. The Cape Town Collection of Pollen (CTCP) was first established in 1985 and stocked with pollen from taxa representative of Karoo and fynbos vegetation. The collection has subsequently been augmented with pollen from the West Coast sandveld (Baxter, 1997). The vegetation from the KAR includes both Karoo and fynbos elements, but also encompasses taxa from afromontane vegetation (Geldenhuys, 1988). As such the CTCP did not adequately fulfill its role in providing reference material relevant to the Vankervelsvlei site and it became necessary to supplement the collection with pollen representative of afromontane taxa. Details of the procedures used to collect and prepare the necessary sample material can be found in Appendices A1 and A2.

4.2.2 Fossil pollen analysis

The fundamental purpose of subjecting fossil pollen samples to treatment is firstly to concentrate any pollen grains and spores within the sample; and secondly to prepare them for efficient and easy counting and identification. Through a succession of chemical modifications as much non-polleniferous material as possible is removed from the sample. However, before chemical processing can begin, a calculated sampling strategy specific to the nature of the investigation and the particular research questions considered, is required. This section outlines the sampling strategy adopted during this research and goes on to describe in more detail the methods used to concentrate, identify and count fossil grains from Vankervelsvlei.

4.2.2.1 Subsampling of material for fossil pollen and other analyses

Sampling of the Vankervelsvlei basin followed the identification of the site as an appropriate source of extremely organic-rich sediments ideal for use in pollen analysis. The strategy behind the choice of coring sites focused on the derivation of cores that would provide, if possible, sequences of vertically aligned depth-equitable sediment over as long a time period as possible. Lowe and Walker (1984) propose that coring close to the centre of lake basins is likely to provide the longest and least disturbed record of Quaternary environmental change. Based on this premise, coring sites for VVVA and VVVB were selected. Coring site B was located 140,3m from the eastern shore and coring site A slightly further from the shoreline.

Two cores have been extracted from close to the centre of the vlei using a vibracorer, as adapted by that designed by Lanesky *et al.* (1979) by AJ Baxter of the University of Cape Town (Baxter, 1997). This apparatus facilitates the extraction of sediments with minimal disturbance and enabled the recovery of stratigraphically consistent material from the lake bed. The first core (VVVA) was retrieved in early 1992 and yielded 7,6m of pollen-rich sediment. A second core (VVVB) was taken in March 1996 which provided a further 5,3m of sediment.

Following a visual appraisal of stratigraphic changes in the core profile, suitably organic samples were selected for radiocarbon dating purposes. Samples of between 150-300g were chosen from points of significant stratigraphic variation and submitted to the radiocarbon dating laboratory of the Council for Scientific and Industrial Research (CSIR) in Pretoria. Choice of samples was also based on the need to acquire a good range of dates from each core in order to establish a sound chronology for the palaeoecological record. Subsampling was undertaken with extreme caution so as to ensure minimal possibility of contamination with external sources of carbon. In total, eight radiocarbon dates have been obtained for the site at Vankervelsvlei, four for VVVA and four for VVVB.

The Vankervelsvlei sediments have been earmarked for various analyses aimed at elucidating broad environmental changes at the site during the late Quaternary. Fossil pollen analysis has, however, been highlighted as the primary and most reliable source of evidence and as such the sampling strategy has been carefully considered. Weinstein-Evron (1987) recommends broad resolution subsampling at a predetermined regular interval if reliable reconstructions are to be gained from deep sequence cores as is the case at Vankervelsvlei. Subsequent analyses may require finer resolution sampling should more detailed information be required (Weinstein-Evron 1987). Sampling on either side of obvious stratigraphic or chronological boundaries is also considered a viable strategy for initial investigations (Birks and Birks, 1980). However, it was decided that a more regular sampling approach would better fulfill the need to reconstruct broad environmental changes at the site. This is largely a function of the length of the cores in question and their relatively simplistic stratigraphy.

In the case of the Vankervelsvlei cores, stratigraphic variance appeared minimal and this method was disregarded in favour of regular sampling. A sampling interval of 5cm was chosen to make provision for fine resolution analysis, but it was decided that analysis of every fifth sample was feasible, providing a record of changes every 25cm down the length of each core. To preclude contamination, care was taken to avoid removing sediment close to the tube walls which may have been disturbed during core extraction. A sterile scalpel was used to transfer sediment to labelled vials for storage. Approximately 5cm^3 of material was removed at individual levels to be used in pollen and related analyses.

4.2.2.2 Preparation of fossil pollen

Preparation of fossil pollen for examination is somewhat more complicated than that for contemporary pollen. In the case of modern pollen, grains are comparatively easy to isolate since they do not form part of a sediment matrix (Birks and Birks, 1980). However, it is necessary to concentrate fossil pollen through the removal of sediment particles, organic material and other substances which may obscure clear viewing under a microscope. As is the case with modern pollen, this involves a series of chemical treatments each designed to remove a specific unwanted element of the sediment. Texts such as Birks and Birks (1980), Faegri *et al.* (1989) and Moore *et al.* (1991) provide general guidelines for pollen processing, but there is no single conclusive set of techniques applicable to all sediments. Instead, it appears necessary to compile treatment procedures specifically appropriate to each set of samples, depending on their composition. Details of the processing procedure specific to the Vankervelsvlei cores can be found in Appendices D1 and D2.

Fortunately, few problems were encountered during the period of sample preparation. Although clays found in typically lacustrine deposits traditionally prove resistant to degradation, the clays comprising large proportions of both cores responded well to HF treatment. Interestingly, several washes with dilute NAOH were required to finally remove the obscuring influence of humic acids produced during the decay of vegetative matter. This was particularly true of the highly organic peats of VVVA. Fortunately, the sediments proved to be highly pollen-rich necessitating the processing of only small quantities of sediment (less than 5g per sampling interval). As a result, the frustrating and time-consuming delays of processing large samples was avoided. This was especially advantageous considering the limited resources available in the Palaeoecology Laboratory at the University of Cape Town. It is possible that some of the more delicate pollen types could have been damaged during prolonged exposure to HF and by the extreme potency of acetolysis digestion. A sincere attempt was made to ensure that these processes were carried out for as short a period as possible. However, it should be considered that some families may be underrepresented in the pollen record as a result of processing techniques.

4.2.2.3 Counting and identification of fossil pollen

This phase of the pollen analysis process is crucial since all further palaeoecological interpretations are based upon the data produced during counting and identification (Birks and Birks, 1980; Moore *et al.* 1991).

4.2.2.3.1 Approach to pollen counting

Due to its many interpretive advantages, the use of absolute frequency counting has been favoured over the relative counting method. This technique aims to appraise the absolute number of pollen grains per unit volume or per unit area per unit time (Birks and Gordon, 1985). Absolute counting facilitates the estimation of individual pollen frequencies independent of changes in the frequencies of other pollen taxa within a given volume of sediment (Moore *et al.*, 1991; Feagri *et* al, 1989). When combined with estimated sedimentation rates, this measure of pollen concentration allows annual pollen accumulation rates to be calculated (Birks and Gordon, 1985). In this case, however, the number of dates acquired relative to the length of the cores was considered to be insufficient in order to derive accurate sediment accumulation rate and thus pollen accumulation rates have been omitted. Although the absolute counting approach has been adopted in this study to facilitate the production of pollen diagrams based on pollen concentrations rather than percentage data, percentage pollen diagrams have also been produced.

The use of the absolute pollen counting approach has profound implications for the choice of pollen sum. Theoretically, absolute counting dictates that all pollen, or at least a representative proportion of all pollen on a microscope slide be counted and identified (Moore *et al.*, 1991; Faegri *et al.*, 1989; Birks and Gordon, 1985). Certain practical difficulties encountered during the counting phase made appraisal of each and every grain unfeasible. In some cases, the sheer density of grains on a slide precluded the counting of all of a possible 50 traverses (at X400 magnification) per sample. Conversely, some samples displayed such low pollen frequencies that even the counting of numerous slides produced extremely low pollen counts. Thus, it was decided to count a fixed number of grains per sample regardless of the number of slides required to reach that predetermined objective.

In the case of VVVA, between 300 and 500 grains per sample have been counted whereas the pollen sum for all samples from VVVB was set at approximately 300 grains. A pollen sum of 300-500 grains is considered to be sufficient to provide reliable estimates of pollen frequency. Birks and Gordon (1985) deem this to be the level at which relatively constant percentages of pollen types is achieved in relation to the pollen sum in cases where broad scale reconstructions have been proposed. This strategy has proved successful in yielding reproducible results in research conducted by Baxter (1997) along the Cape West coast.

4.2.2.3.2 Absolute counting

The theoretical differences between relative and absolute counting extend to practical slide preparation as well as counting technique. In general, slides for each particular sample were prepared immediately prior to counting, thus minimising the possibility of contamination and formation of air bubbles under the coverslip. All counting and identification was performed using a Zeiss light microscope (model 16-8055) customarily at a magnification of x400. Occasionally, it was necessary to make use of a x640 objective, usually in cases where differences between grains of different afromontane forest trees were indistinct. The pollen-wall characteristics of several afromontane tree taxa are uncommonly similar, making accurate identification difficult (personal observation). This problem is compounded by the small size of these grains which makes identification of dissimilarities even more problematic. Several palynology texts note the tendency of pollen grains to disperse beneath the coverslip according to size (Birks and Birks, 1980; Jemmet and Owen, 1990; Moore *et al.*, 1991). Larger grains are inclined to be trapped closer to the centre of the coverslip, while lighter, smaller grains appear to migrate to the edges, especially when mounted in a highly fluent medium such as glycerol. Consequently, care was taken to count a representative proportion of traverses to prevent a bias toward smaller or larger grains.

4.2.2.3.3 Pollen identification

Pollen identification is largely a subjective exercise, whereby fossil grains are classified according to their degree of similarity to contemporary analogues drawn from the present day source area. The assumption is made that morphological evolution since the time of fossil deposition has been minor (Birks and Birks, 1980).

The most common criteria upon which distinctions between taxa are made are as follows (Moore *et al.*, 1991):

I. Size, shape and position of apertures.-these include pores(pori) and furrows (colpi). Some taxa display both;

II. Texture/sculpture of pollen walls;

III. Size and shape of grains.

Ideally, identification of grains should be resolved to species level (Birks and Birks, 1980). However, this is often impossible and most identifications for VVVA and VVVB reached only genus or family level. The precision of identification is often dependent on the range of reference material utilised (Moore *et al.*, 1991). In addition to reference slides prepared by the author, use was made of a large collection of reference photographs housed in the Department of Environmental and Geographical Science as part of the CTCP. In order to familiarise the author with the pollen morphology of South coast taxa, sketches of the pollen grains of 72 families were made, highlighting their outstanding features. Grains were drawn in both polar and equatorial views.

Despite this vast amount of preparatory work, the identification of certain taxa, especially afromontane forest tree pollen, proved extremely laborious. A certain proportion of indeterminable pollen has also been recorded. Initially, this was divided into 3 major categories; namely obscured, broken and crumpled grains. These have, however, been combined into a single category for presentation purposes.

4.2.2.4 Statistical techniques and data presentation

The importance of producing meaningful results in any academic study is obviously considerable. The clear presentation of these results and testing of their validity goes even further in producing research of lasting quality. In light of these comments, Birks and Gordon (1985), Faegri *et al.* (1991) and Moore *et al.* (1991) discuss the statistical validity of pollen counts. This is undoubtedly justified considering that pollen counts are in reality merely statistical estimates of the true values of the frequency of pollen taxa occurring in the natural environment. Most authors, including the authoritative Birks and Gordon (1985) note the advantages of applying statistical analysis of pollen data sets.

However, they also caution against their inappropriate application which can lead to misinterpretation of results. The presentation and statistical manipulation of results in terms of stratigraphic pollen diagrams is discussed below as is the choice of a simple yet effective statistical approach in the Vankervelsvlei study.

4.2.2.4.1 Presenting results: the pollen diagram

Pollen analyses produce vast amounts of tabular data that are difficult to interpret in this form. Thus, the use of pollen diagrams has become common practise. Pollen diagrams provide a basis upon which thorough and easy interpretation of a large quantity of numerical data can be appraised at a glance. Conventions as to the construction of such diagrams have been established within the palynological community and various texts outline these quite extensively (Birks and Birks; 1980, Faegri *et al.*, 1989; Moore *et al.*, 1991). Consequently, these are not specifically addressed in this text, except to say that the use of continuous curves rather than histograms has been used. This choice is largely justified by the greater visual appeal of continuous curves which highlight changing trends in vegetation patterns with ease.

Traditionally, taxa are arranged in a particular order across a pollen diagram. Arboreal forms are commonly placed on the extreme left, since these dominated in the early palynological studies carried out in Europe. Less dominant herbs and shrubs were placed further to the right of the diagrams (Feagri *et al.*, 1989). In the case of Vankervelsvlei, arboreal pollen is present and is indeed a focal point in the study; however, its pollen is not dominant relative to other taxa that produce voluminous amounts of pollen. As such, it has been decided for interpretive clarity to arrange pollen taxa from left to right on the pollen diagram according to growth form as described by Geldenhuys (1993). Graminoid elements have been placed on the extreme left, followed by characteristically fynbos elements, woody shrub elements and true forest elements. There are undoubtedly taxa that fit into more than one category, yet the allocation of taxa into specific groups was considered appropriate for interpretive purposes. Aquatic components of the assemblages have been placed to the extreme left of the diagrams. In the local environment, these have played a dominant role, especially in light of the complete covering of the water surface at Vankervelsvlei. They do not, however, represent any part of progressive development towards high forest and have as such been separated from the other taxa for interpretation. All pollen diagrams produced in this thesis were constructed with the assistance of PSIMPOLL (version 2.23 © Copyright K.D. Bennett, 1994). See Appendix J for pollen concentration equations.

4.2.2.4.2 Zonation of the pollen diagram

Following construction of the pollen diagram, it is commonplace to separate graphs into series of pollen zones in order to delineate sequences of significant change over time. A pollen zone is a biostratigraphic unit defined entirely on the basis of its pollen content (Moore *et al.*, 1991). Zone boundaries are placed at points where changes in composition of pollen spectra have been most marked. Originally this process was entirely subjective, however, numerical methods have since introduced greater objectivity. Cluster analysis has been applied in both pollen diagrams produced for Vankervelsvlei. Cluster analysis is useful in delimiting local pollen assemblage zones for independent pollen sequences. This applies directly to Vankervelsvlei which focuses on a single site of small surface area providing palaeoenvironmental information on a local scale. As part of PSIMPOLL, a program known as CONNISS was used to zone both pollen diagrams for Vankervelsvlei. This program uses constrained cluster analysis by agglomeration to perform the zoning operation (Bennett, 1994). This method broadly defines pollen zones, but leaves further division into subzones to the discretion of the analyst.

4.2.2.4.3 Summary pollen diagrams

The richness of taxonomic diversity in the southern African flora can lead to difficulty in the accurate interpretation of pollen diagrams (Baxter, 1997). The Vankervelsvlei diagrams presented between 25 and 35 taxa on each diagram, making it difficult to identify different vegetation communities. For this reason, it was decided to produce summary pollen diagrams for both VVVA and VVVB allowing for the easy comparison of the dominance of groups of ecologically grouped taxa over time. This is made possible by plotting the prominence of each grouping at any given depth as a percentage of 100 %. The taxa displayed in the comprehensive pollen diagrams were divided into ecological categories based on habitat descriptions and growth form data gleaned from checklists of Knysna forest taxa (Geldenhuys, 1993; Von Breitenbach (1978). The taxa were assigned to one of four groups, namely aquatic elements, graminoid elements, fynbos or heath elements and forest elements. Graminoid elements included grasses and restioid taxa, while heath elements comprised low-growing shrubs, for example genera from the families *Ericaceae and Asteraceae*. Forest elements included taxa described as canopy or subcanopy trees, woody shrubs, soft shrubs, lianes and vines.

This method of presenting data provides a good visual summary of the somewhat more complex pollen diagram and was thus considered useful in the case of Vankervelsvlei. This is particularly true considering the aim of this study to elucidate the fluctuation of afromontane forest vegetation, allowing for the isolation of the forest component of the pollen signal for analysis.

4.2.2.4.4 Comparison of fossil and contemporary pollen spectra

A total of seven contemporary pollen samples were collected for comparison with fossil samples. Surface soil specimens were collected from selected sites in March 1996. Four of the samples were gathered at Vankervelsvlei itself while three others are representative of vegetative communities in the greater Knysna area (scrub forest, high forest and fynbos). The samples collected at Vankervelsvlei followed a continuum beginning at the coring site of VVVB near the centre of the vlei and extending to the point of the pine plantation transition. These were treated in the laboratory following a similar procedure to that adopted for fossil pollen preparation. Counting techniques were analogous to fossil counts except that alien pollen has been omitted from the pollen sum. Considering that the fossil record between 3000 BP and the present day is missing and that the introduction of alien species to the area occurred only within the past few hundred years, it was considered inappropriate and possibly misleading to include them.

Modern pollen assemblages are useful in establishing patterns of relationship between a range of modern vegetation associations and their resultant pollen signatures. This provides a foundation for further comparison between modern pollen assemblages and associated fossil pollen spectra on the basis of overall similarity between the two. This principle forms the base on which reconstruction of past plant communities is founded (Birks and Birks, 1980; Birks and Gordon, 1985; Moore *et al.*, 1991). Similarities between the composition of fossil and contemporary vegetation associations allows the researcher to propose that the two were produced by similar vegetation communities at different times and that the modern community acts as an analogue of the older (Moore *et al.*, 1991). If no satisfactory match can be located, it is assumed that past communities are without contemporary analogues.

There are several means by which modern and fossil pollen spectra can be compared. In cases where few taxa are under consideration, visual comparisons by means of tabulated percentages or pollen diagrams appear to be sufficient. However, it becomes necessary to make use of numerical methods when larger and more complex data sets are involved. This is to ensure that bias is averted and to allow all pollen types to be considered concurrently (Birks and Gordon, 1985). Pollen spectra are assigned independent regions in multidimensional space with residual space between samples representing the affiliation of each spectrum (Birks and Gordon, 1985).

Principal Components Analysis (PCA), Components Analysis (CA) and Canonical Variates Analysis (CANOCO) are common methods employed to compare fossil and contemporary pollen assemblages in this manner (Birks and Gordon, 1985; Moore *et al*, 1991). Even though these techniques are widely used, they are liable to lose unpredictable amounts of information in attempting to reduce multidimensional data to two or three dimensional plots in order to calculate degrees of similarity between samples. There is also substantial potential for distortion (Overpeck *et al.,* 1985). It is thus possible that samples may appear to be relatively 'close' to one another as a result of their geographical position on the graph whilst they are in reality relatively dissimilar. By the same token, another preferred method of comparison, Multiple Discriminant Analysis (MDA) also has its limitations. This method allows for a degree of subjectivity as samples are classified into groups before analysis. In the case of VVV, where the data set of taxa is large and complex, it seems possible that the shortcomings of these methods may inadvertently distort the findings. Consequently, it was decided to make use of a technique using 'best modern analogues' or 'nearest neighbours' which Ter Braak (1994) praises for its ability to overcome dimensionality where the species response is unimodal.

Nearest Neighbour Analysis (NNA) makes use of the entire pollen data set to compute similarities between communities. The algorithm used in this project was developed by Professor L Underhill of the Statistical Sciences Department at the University of Cape Town. Details of the algorithm are given in Appendix G. This technique has been successfully demonstrated in the work of Baxter (1997) on pollen data from the Sandveld along the west coast of southern Africa.

Nearest Neighbour Analysis is based upon the calculation of Euclidean distance between each modern assemblage and each fossil assemblage without the bias related to other techniques. Euclidean distances are determined by converting each sample to its taxonomic composition in proportions. The final output allows each fossil spectrum to be considered in terms of a comparable factor to its closest modern analogue. This factor is known as the 'Nearest Neighbour Index' (NNI). It is expressed as a value ranging between 0 and 1, with values closer to 1 indicating close affinity and values close to 0 suggesting the absence of a contemporary analogue. This technique is especially useful considering its use of all taxa in the comparisons made irrespective of their rarity within any one pollen spectrum.

4.3 PHYSICAL AND CHEMICAL PROPERTIES OF SEDIMENTS

4.3.1 Introduction

Laboratory analysis of Quaternary sediments is an integral part of environmental reconstruction. Both physical and chemical properties of sediments are useful sources of palaeoenvironmental information. Almost all Quaternary sediments contain within their matrix important clues about their mode of deposition and often about the climatic regime in which the sediments accumulated (Birks and Birks, 1980; Birks and Gordon, 1985; Lowe and Walker, 1984; Moore *et al.*, 1991). Lowe and Walker (1984) and Tucker (1988) note that sedimentary evidence should not be evaluated in isolation, but suggest that it be integrated with other forms of evidence if a useful synthesis of environmental change is to be produced. Thus, the generation of grain size and geochemical data for VVVA and VVVB was considered to be invaluable in justifying or refuting evidence provided by the fossil pollen record.

It has been attempted to provide corroborating evidence for the pollen signal through determining organic matter content, chemical composition and sedimentological characteristics of sediment. A similar rationale has been applied to subsampling for these analyses as was adopted in the case of pollen and in most instances sediment from the same subsamples has been used.

4.3.2 Organic matter content

Calculation of organic matter content is traditionally carried out in order to highlight stratigraphic sections within sediment cores that are sufficiently organic to justify analysis of pollen content. However, initial visual examination of both VVVA and VVVB left little doubt that pollen would indeed be preserved. Almost all strata displayed characteristic dark tones associated with the decay of organic material. Thus, subsampling for pollen analysis was carried out without an initial appraisal of organic matter content. However, this analysis was later performed in order to supplement pollen evidence and confirm changes in productivity of the system over time.

Organic matter content was determined by loss on ignition (Appendix B) as described by Smith and Atkinson (1975) and was favoured over the Walkley-Black titration method due to its simplicity and the rapidity with results can be obtained. Although, more accurate (Atkinson, 1975), the Walkley-Black procedure also requires a significantly larger proportion of sediment for analysis. It was considered more important to utilise the limited sample available for analyses such as geochemical composition and thus accuracy was forfeited in this case.

4.3.3 Particle size analysis

Measurement of particle size is considered to be a very important sedimentary technique in terms of understanding sediment transport, deposition and the energy dynamics of past catchments (Lowe and Walker, 1984; Reineck and Singh, 1980). Methods used to determine grain size vary greatly and no one method applies throughout the entire grain size spectrum (Tucker, 1988). The sediments at Vankervelsvlei consist largely of fine material, which would ordinarily limit the choice of analysis to sedimentation methods (Lowe and Walker, 1984). These methods usually require large amounts of sediment for analysis so that statistically meaningful data can be produced (Tucker, 1988; Goudie, 1990). This precluded the use of sedigraph or hydrometer analysis and necessitated rethinking of the need and mode of sedimentological inquiry.

The amount of material available for analysis has been restricted by the amount of sediment extracted from the site using the modified vibracorer. Of the 5cm subsampled at 25 cm intervals, less than 15g remained for sedimentological analysis after pollen, organic matter and geochemical analyses had been carried out. The possibility of making use of a Malvern particle sizer was investigated since this apparatus requires very small amounts of material. The idea was discarded, however, due to the documented uncertainties associated with the analysis of clay-type materials by this method (McCave, Cook and Coughanowr, 1986). The consequent inability to resolve a procedure for classification of the silt-clay range led to a decision to undertake a very much simplified sedimentological investigation.

4.3.3.1 Wet-sieving

Wet sieving is recommended as a sound method of initially separating sediments into two size fractions. Usually, further breakdown of each fraction is carried out whereby sands and finer material are separated into smaller size classes. Separation of the coarse from the fine components is usually made at 63 µ(Tucker, 1988; Goudie, 1990). Due to the paucity of material available for processing, it was considered likely that analysis beyond this primary level would yield potentially misleading results. Thus, sedimentological investigation has been confined to distinguishing between sands and muds (combination of silts and clays, all material smaller than 63 µ. Wet-sieving has been selected in favour of dry-sieving as is customary when sediments are dominated by fine material (Goudie, 1990).

The wet-sieving process is relatively simple and undisputed. The basic procedure used is based on the method outlined by Tucker (1988) and Goudie (1990). The major steps involved are described below and greater detail provided in Appendix E:

I. Initial weighing of sample after oven-drying overnight;

II. Treatment of sample with a dispersant, in this case Calgon;

III. Washing of sample through 63 µ sieve to separate sand and mud fractions;

IV. Oven drying of separated fractions ;

V. Weighing of separated fractions;

Calculation of relative proportions of sand and muds in each sample. These have been expressed as percentages.

4.3.4 Chemical composition of sediments

Analysis of the metallic ion content of sediments provides information relating to factors such as soil conditions and the erosion history of the study site in question (Birks and Birks, 1980; Lowe and Walker, 1984). Twenty subsamples (each weighing approximately 10g) from VVVB were submitted to the Department of Geology at the University of the Witwatersrand in Johannesburg. The samples were analysed in terms of major element composition quoted as a percentage (%) of the total; as well as trace element content expressed in parts per million (ppm). The X-ray fluorescence (XRF) method was used to identify chemical elements. The principle underlying XRF spectrometry is based on the assumption that atoms of each element emit rays of characteristic energy and wavelength when bombarded with x-ray beams (Goudie *et al.*, 1990). A Phillips 1400 Spectrometer was used to analyse the chemical constituents of the sediments.

Although data were received for a variety of major and trace elements, only certain of these have been isolated for detailed interpretation. Those selected for interpretation were the elements commonly cited in the literature as having palaeoecological significance (Birks and Birks, 1980; Mason, 1982; Lowe and Walker; 1984, Moore *et al.*, 1991). These include:

I. Phosphorus (P_2O_5), Sodium (Na) and Magnesium (Mg) whose variation with time highlight fluctuations in vegetation cover;

II. Iron (Fe) and Calcium (Ca) content which also indicate changes in vegetation cover in certain cases;

III. Iron (Fe) and Magnesium (Mg), high levels of which mark the prevalence of waterlogging and peat formation (Lowe and Walker, 1984).

4.4 CONCLUSION

Fundamental to the accuracy of fossil pollen analysis is the accurate identification of fossil pollen grains. This necessitated the expansion of the CTCP via collection of herbarium pollen to include afromontane taxa applicable to the KAR. Fossil pollen preparation followed facilitating the removal of extrinsic material, thereby concentrating pollen and favouring easy identification and counting. Comparison of fossil and contemporary pollen assemblages through the application of statistical techniques allowed for greater interpretative clarity. Analysis of the chemical and sedimentological characteristics of the Vankervelsvlei sediments provided corroborating evidence to confirm trends highlighted by the pollen data. The need for such multidisciplinary research is becoming increasingly recognised.

CHAPTER 5

RESULTS

5.1 INTRODUCTION

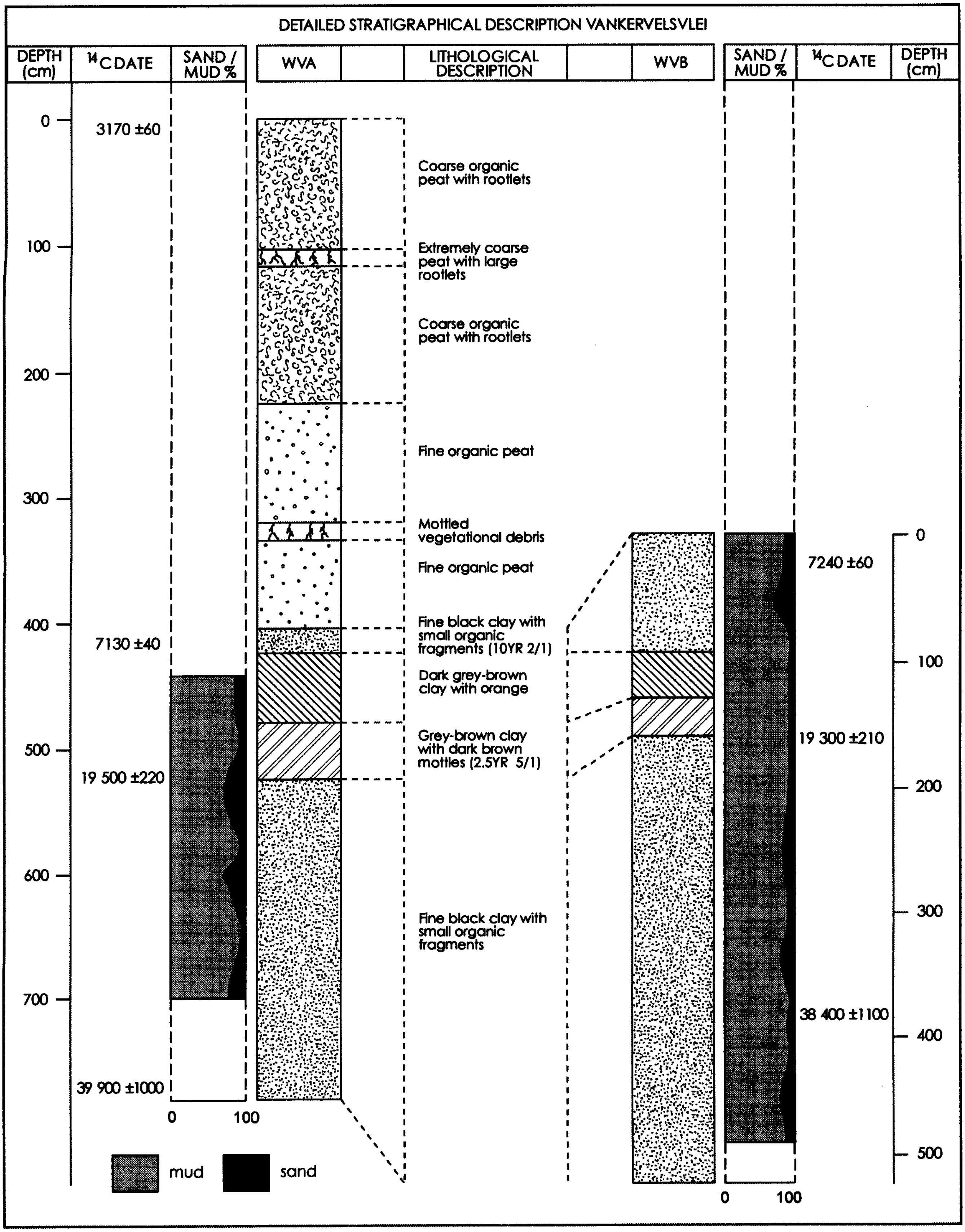
This chapter details results of multidisciplinary research efforts in the Vankervelsvlei basin. Palynological, sedimentological and geochemical data are presented. It has been attempted to summarise data as much as possible, allowing for easier synthesis of the information gathered from varying data sources. Various graphical, diagrammatic and tabular methods are employed. This chapter provides a descriptive account of the results obtained and also draws more detailed inferences from the data before the broader context is discussed in Chapter 6.

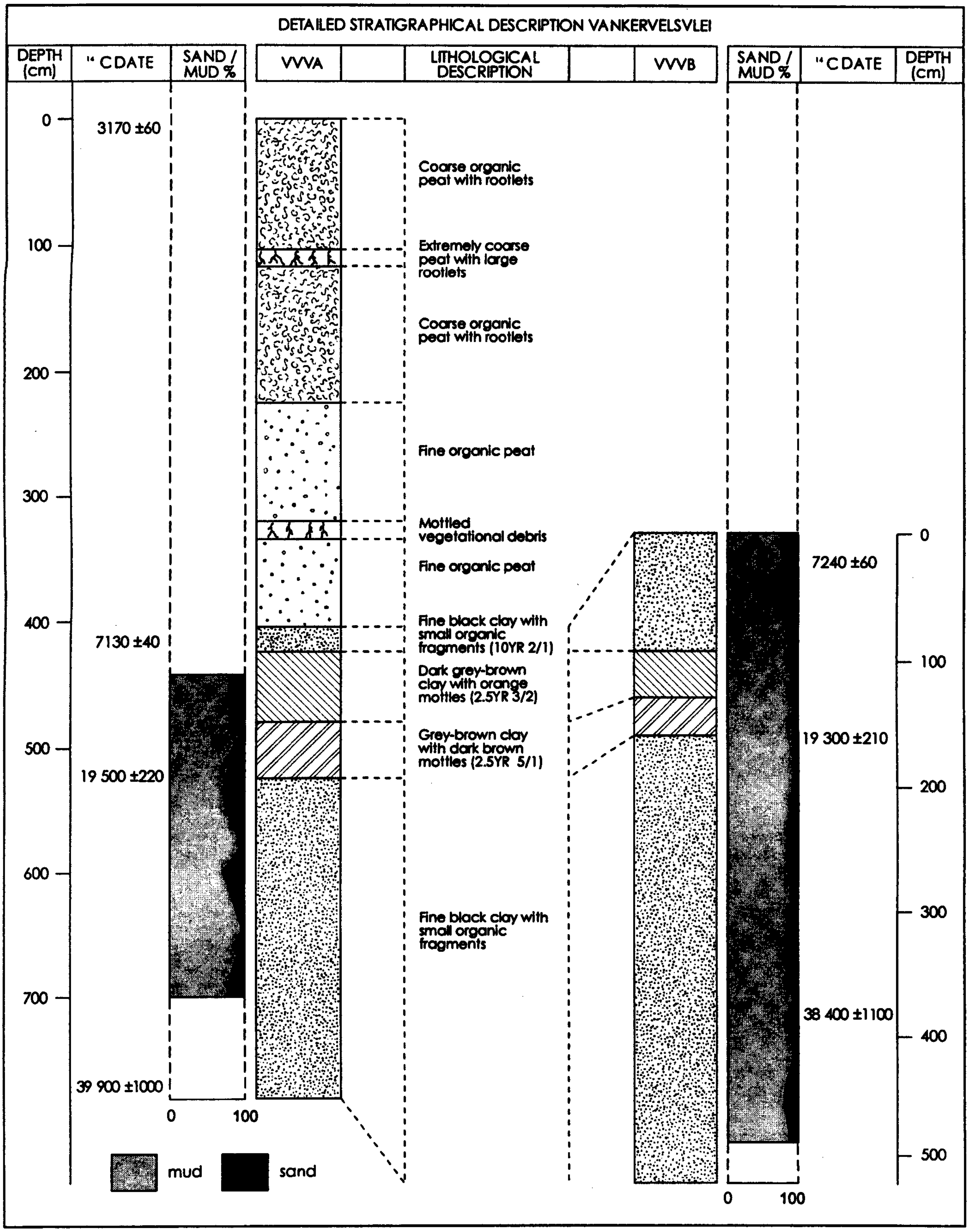
Throughout this chapter, the two cores extracted from Vankervelsvlei (VVVA and VVVB) are described in terms of depth. It is important to note that the depth measurements used for this purpose relate to an artificial core 'surface'. After extraction from Vankervelsvlei, VVVA and VVVB each measured approximately 16m. Of this, only the lowermost 7,6m of VVVA and 5,3m of VVVB comprised sediment. The remainder of the cores consisted of water and the uppermost 2m was made up of Cyperaceous plant material forming a floating mat on the surface of the water. This is characteristic of schwingmoor or floating bogs whose development is described in detail in Chapter 3. The upper limit or 'surface' of sampled sediment (in relation to the total length of the cores) is 640cm in VVVA and 870cm in VVVB. These 'surfaces' have been standardised to zero and thus sediments span the intervals 0cm - 760cm in the case of VVVA and 0cm - 530cm in the case of VVVB.

5.2 SEDIMENTOLOGICAL EVIDENCE

5.2.1 Stratigraphy

The Vankervelsvlei cores, VVVA and VVVB, produced cores measuring 7,6m and 5,3m in length respectively. Prior to subsampling, the stratigraphy of both cores was described in detail and is logged in Figure 5.1. Grain size data have been graphed alongside stratigraphical logs, making Figure 5.1 a useful summary of the results of


DETAILED STRATIGRAPHICAL DESCRIPTION VANKERVELSVLEI
DEPTH (cm)
¹⁴C DATE
SAND / MUD %
WVA
LITHOLOGICAL DESCRIPTION
WVB
SAND / MUD %
¹⁴C DATE
DEPTH (cm)
0
100
200
300
400
500
600
700
3170 ±60
7130 ±40
19 500 ±220
39 900 ±1000
0
100
Coarse organic peat with rootlets
Extremely coarse peat with large rootlets
Coarse organic peat with rootlets
Fine organic peat
Mottled vegetational debris
Fine organic peat
Fine black clay with small organic fragments (10YR 2/1)
Dark grey-brown clay with orange
Grey-brown clay with dark brown mottles (2.5YR 5/1)
Fine black clay with small organic fragments
7240 ±60
19 300 ±210
38 400 ±1100
0
100
200
300
400
500
0
100
mud
sand


DETAILED STRATIGRAPHICAL DESCRIPTION VANKERVELSVLEI
DEPTH (cm)
14C DATE
SAND / MUD %
VVVA
LITHOLOGICAL DESCRIPTION
VVVB
SAND / MUD %
14C DATE
DEPTH (cm)
0
100
200
300
400
500
600
700
3170 ±60
7130 ±40
19 500 ±220
39 900 ±1000
0
100
mud
sand
Coarse organic peat with rootlets
Extremely coarse peat with large rootlets
Coarse organic peat with rootlets
Fine organic peat
Mottled vegetational debris
Fine organic peat
Fine black clay with small organic fragments (10YR 2/1)
Dark grey-brown clay with orange mottles (2.5YR 3/2)
Grey-brown clay with dark brown mottles (2.5YR 5/1)
Fine black clay with small organic fragments
7240 ±60
19 300 ±210
38 400 ±1100
0
100
200
300
400
500
0
100

sedimentological inquiry. Stratigraphical layers have been described using notation from the 'Munsell Soil Colour Charts' (1975) system. Radiocarbon dates have been noted alongside the stratigraphical diagrams at appropriate depths to aid in easy interpretation.

5.2.1.1 VVVA

Between the base of VVVA at 760cm and 525cm, sediments comprise fine black clay with small organic fragments. The section from 525cm to 480cm consists of grey-brown clay with dark brown mottles. Dark grey-brown clay with orange mottles is found between 480cm and 425cm. A narrow stratum from 425cm to 400cm consists of fine organic clay similar to that noted in the lower part of the core. Between 400cm and 225cm, the sequence consists of fine organic peat interrupted by a narrow layer of matted vegetational debris between 310cm and 320cm. The upper portion of the core comprises coarse organic peat with rootlets which is partitioned by the presence of a layer of extremely coarse peat with large rootlets at 110cm.

5.2.1.1 VVVB

The section of sediment between the base of VVVB and 160cm consists of fine black clay with small organic fragments. From 160cm to 120cm grey-brown clay with dark brown mottles is present. Dark grey-brown clay with orange mottles is found between 120cm and 95cm. The remainder of the core comprises fine black clay with small organic fragments analogous to that found in the lower portions.

5.2.2 Chronology

In total, eight radiocarbon dates have been obtained for the site at Vankervelsvlei. The dates are divided between the two cores, four for each stratigraphical sequence. Of the eight dates, one obtained from the base of VVVB is anomalous, suggesting contamination of the subsampled sediment. Table 5.1 summarises this information.

Core	**Sample reference number**	**Depth from core surface (cm)**	**^{14}C age (yrs BP)**	**^{13}C (‰)**
VVVA	Pta -6583	6 - 16	3170±60	-28.0
VVVA	Pta - 6585	407 - 413	7130±40	-20.9
VVVA	Pta - 6584	500 - 507	19500± 20	-25.5
VVVA	Pta - 6361	695 - 700	39900±1000	-30.3
VVVB	Pta - 7258	19 - 23	7240±60	-21.6
VVVB	Pta - 7130	117 - 124	19300±210	-26.4
VVVB	Pta - 7259	378 -381	38400±1100	-26.8
VVVB	Pta - 7124	520 - 528	31600±1200	-25.9

Table 5.1: Summary of radiocarbon dates procured from Vankervelsvlei.

Four dates from VVVA indicate a long Quaternary record of sedimentation. A sample from the core 'surface', i.e. from the surface of sedimentation below the humus-rich water in the basin, has yielded a date of 3170 ± 60 yr BP (Pta-6583) and the beginning of deposition of clay-type material dates to approximately 7130 ± 40 yr BP (Pta-6585). Sediments taken from just below the aforementioned light coloured clay layers date to 19500 ± 220 yr BP (Pta-6584) suggesting that this period of low productivity dates back to the period of the LGM. A nominally infinite basal date of 39 900 ± 100 yr BP (Pta-6361) was determined from the organic clays at the lower limit of core penetration. Four dates obtained from VVVB strongly substantiate the claim that the grey-brown clays date back to the period spanning the LGM. The surface of VVVB dates back to 7240±60 yr BP(Pta-7258) . Material taken from the base of the mottled clay layers recorded a date of 19300 ± 210 yr BP (Pta-7130); which correlates almost exactly with the date at the equivalent depth in VVVA. Chronological consistency at this level is encouraging, confirming the depth of sediments dating back to the time of the LGM.

Two further dates obtained from VVVB have yielded ages of 38400±1100 yr BP (Pta-7259) at approximately 3,8m depth and 31600 ± 1200 yr BP (Pta-7124) at the base of the core. It is thought possible that contamination of the basal sediments could have occurred during core extraction accounting for this age discrepancy.

Assuming that the combined chronostratigraphical evidence from VVVA and VVVB provides evidence describing sediment accumulation at the site over the past 40 000 years, it is evident that two major depositional phases have taken place. The earlier phase, evident in both sequences, is characterised by finer inwashed material in the form of clays and the more recent phase, visible in VVVA, is dominated by peaty, organic-rich sediments. Lowe and Walker (1984) note the tendency of lake basins to silt up over time which is usually reflected within the sedimentary record by a succession from clays/muds to peats. The stratigraphy of Vankervelsvlei is suggestive of a hydroseral succession process through the transition from fine clay to fine peat to coarser peat closer to the present day.

5.2.3 Sedimentation rates

Determining the rate of sedimentation through time by examining the sedimentology of a core is often problematic. This is clearly the case in terms of the Vankervelsvlei cores for which only eight radiocarbon dates are available over an extremely long period of sedimentation.

Chronostratigraphical evidence (Figure 5.1) suggests the possibility of a hiatus in sedimentation at approximately 420cm in VVVA and at the corresponding depth of 100cm in VVVB. These depths mark the margin of grey-brown mottled clay strata extending to a depth of 520m in VVVA and 120cm in VVVB. An abrupt change in colour of sediment at these points combined with remarkable differences in radiocarbon ages over apparently short periods of sedimentation advocates the probability that sediment is missing from the record. Sedimentation rate data provide further confirmation of the postulated hiatus and calculations for each of the two cores have been reviewed in tabular form below.

Core	**Depth (cm)**	**Radiocarbon years**	**Sedimentation rate (mm yr^{-1})**
VVA	412 - 11	3960	1.01
VVA	504 - 412	12370	0.07
VVA	760 - 504	20400	0.13
VVA	**760 - 11**	**36730**	**0.08**
VVB	121- 21.5	12060	0.08
VVB	379.5 - 121	19100	0.14
VVB	**379.5 - 20.5**	**31160**	**0.11**

Table 5.2: Summary of sedimentation rates at Vankervelsvlei

Data for VVA shows a relatively rapid decrease in sedimentation rate from 1.01 mm yr^{-1} between 420cm and 100cm to a mere 0.07 mm yr^{-1} between 500cm and 420cm. Thereafter sedimentation rates pick up again to reach a level of 0.13 mm yr^{-1}, but never again reach initial rates. Radiocarbon dates record the age of sediments at the onset and termination of the laying down of the clay layers in question. The ^{14}C age of the sediment at 420cm is 7130 ± 40 yr BP and that recorded at 500cm is 19 500 ± 20 yr BP. Thus the time period in which the 92cm of grey-brown clay was deposited spans 12 370 years.

Similarly, a slower sedimentation rate of 0.08 mm yr-1 is calculated between 120cm and 20cm in VVB. Rates increase to 0.14 mm yr-1 between 380cm and 120cm. The ^{14}C date calculated for 20cm is 7240 ± 60 yr BP while the base of the grey-brown mottled clays dates to 19 300 ± 210 yr BP. Thus, 100cm of sediment is representative of 12 050 years of sedimentation, a slower rate than previously. It is possible that a loss of sediment in the sequence is reflected in this change, although not certainly, and the sudden colour change marking the onset of deposition of the lighter grey-brown clays proposes a likely breaking point should this be the case.

5.2.4 Grain size analysis

Basic sedimentological inquiry in the form of elementary grain size analysis has been summarised graphically to easily display changing proportions of sands versus muds within the sedimentary record. Appendix F gives full details of results of grain size analysis and these are graphically represented in Fig 5.2 in section 5.2.1 The curves have been juxtaposed against those of the stratigraphical sequences of VVVA and VVVB for ease of interpretation of several lines of evidence simultaneously. This will be of particular importance when attempting to draw together all evidence for the purpose of palaeoenvironmental reconstruction in Chapter 6. Again, depths have been recorded in cm and proportions of sand and mud are documented as percentages.

Textural data are not available for a large proportion of VVVA considering its highly organic nature. Pilot attempts at grain size analysis of the peat layers revealed negligible quantities of sand and muds, if any clastic sediment at all, and further investigation was abandoned. Due to the use of subsampled material for a variety of analyses and the partial loss of material at the base of the cores, sediment was not available for processing throughout the sedimentary record.

With reference to sand versus muds curves displayed in Figure 5.1, it is obvious that the stratigraphical record at Vankervelsvlei is dominated by sediments smaller than 63 µm, that is those in the mud (clays and silt) range of the sedimentary spectrum. Grindley (1985) notes the abundance of depositional clays on the coastal platform on which Vankervelsvlei is located. It is, however, unlikely that the clays represented in the Vankervelsvlei cores are depositional in origin since the site is underlain by sandstones and the site is presently surrounded by fossil dune cordons. A more plausible explanation is that the clays have formed in situ through weathering processes.

5.2.5 Organic and pollen content

Considering that organic matter content of sediments is used as an indicator of potential pollen content, results of organic matter analysis have been graphed in conjunction with pollen concentration data and pollen accumulation rates (Figures 5.3 and 5.4). Depths are expressed in cm, organic matter is displayed proportionally in percentages and pollen concentration is measured in thousands of grains per cubic cm.

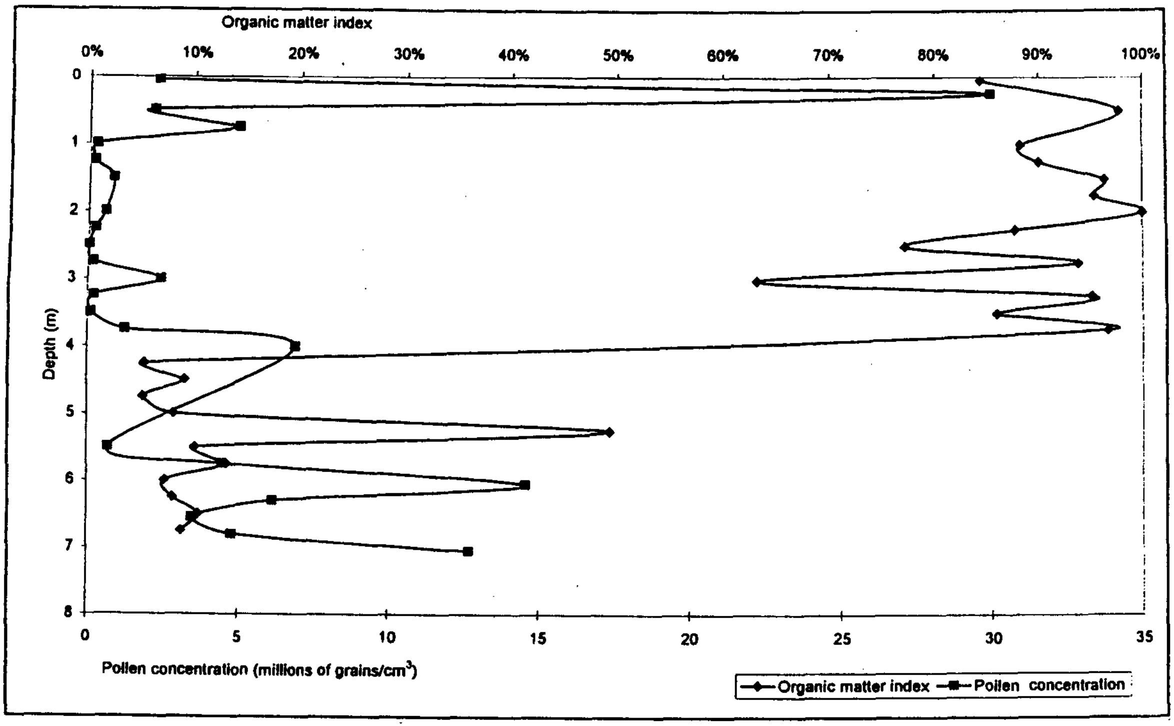


Figure 5.2: Organic matter and pollen concentration data VVVA

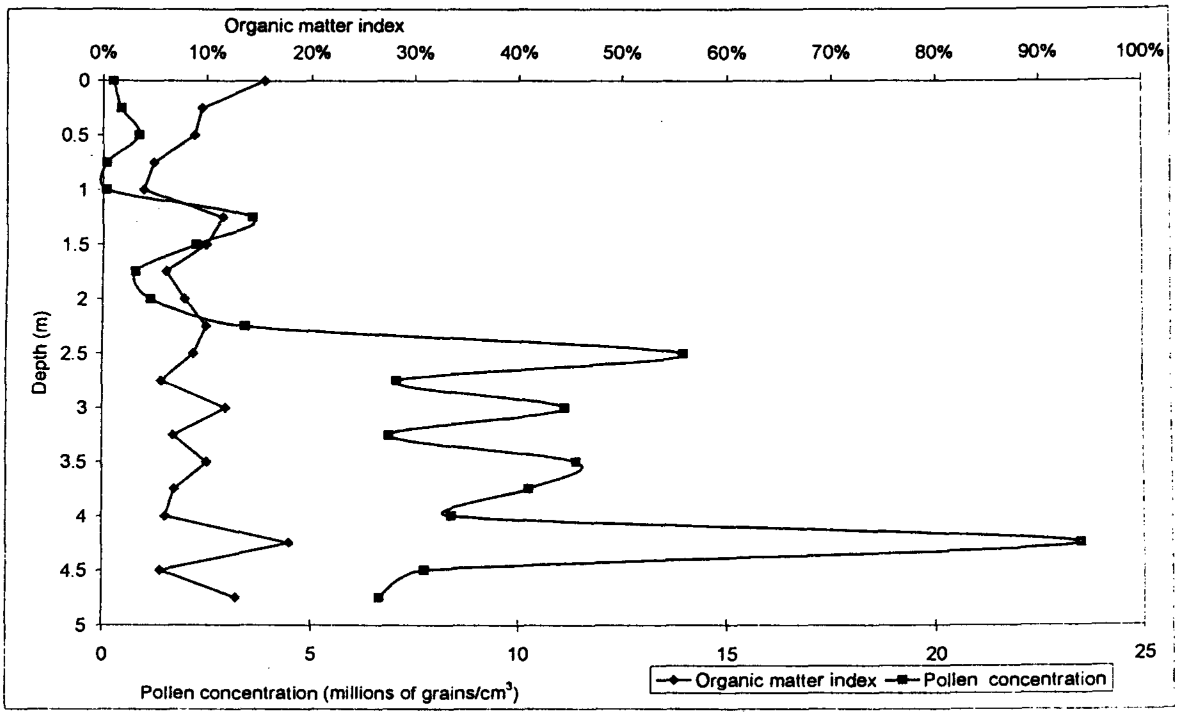


Figure 5.3: Organic matter and pollen concentration data VVVB

5.2.5.1 Organic matter content

5.2.5.1.1 VVVA

Levels of organic matter content for VVVA vary very little in the lower portions. Between 680cm and 550cm few samples reach levels higher than 10%. The sample at 525cm, however, peaks at approximately 50%. Thereafter, levels drop to below 10% once more until 425cm. At this point organic matter levels increase dramatically to over 95%. At 350cm, levels drop slightly to 85% before rising to approximately 95% again at 325cm. At 300cm, the organic matter index drops to 65%, but rises again to approximately 90% at 275cm. By 250cm levels have dropped to about 75% and then rise steadily until 200cm where a peak of 100% organic matter content is achieved. Between 200cm and 100cm organic matter decreases gradually to approximately 85 % before rising to just below 100% at 50cm. In the upper 50cm, organic matter levels drop to just above 80%. Generally speaking, organic matter content below 400cm fluctuates about a mean of 10% with the exception of a peak at 525cm, while levels vary between 65% and 100% in the upper 400cm of the core.

5.2.5.1.2 VVVB

Close to the base of VVVB at 475cm, organic matter comprises approximately 13% of sediment. This drops to just above 5% at 450cm. A peak in organic matter content is evident at 425cm where levels near 20%. By 400cm organic matter content has dropped to approximately 6%, but rises steadily to reach about 10% by 350cm. Between 350cm and 300cm, organic matter content decreases to 6% at 325cm rising again to 12% by 300cm. A decline occurs between 300cm and 275cm to approximately 6% again. Thereafter, levels increase incrementally to rise above 10% by 225cm before dropping to about 7% at 175cm. Levels increase to about 13% by 125cm and decrease to between 6% and 7% at 100cm. From this point, organic matter content increases steadily reaching a peak of approximately 17% at 0cm. In summary, organic matter levels in VVVB fluctuate between 5% and 15%. Generally, a decline is experienced between 475cm and 200cm and an increase is evident between 200cm and 0cm.

5.2.5.2 Pollen concentration

5.2.5.2.1 VVVA

Pollen concentration levels do not accord with expected results insofar as high organic matter did not necessarily reflect high pollen concentration throughout the length of the core. Between 705cm and 655cm pollen concentrations decreases from approximately 1.2 million to about 350 000 grains/cm^3. Between 655cm and 605cm pollen concentrations increase to just over 1.4 million grains/cm^3. From 605cm, concentrations decrease steadily reaching a mere 70 000 grains/cm^3 by 550cm. Data are not available until 400cm where concentrations reach a level of almost 700 000 grains/cm^3. From this point, pollen concentrations decrease once more to below 10 000 grains/cm^3 at 375cm. Similar levels are maintained between 375cm and 100cm with a peak of approximately 250 000 grains/cm^3 occurring at 300cm. Between 100cm and 75cm, concentrations increase again to just over 490 000 grains/cm^3 and drop slightly to 215 000 grains/cm^3 at 50cm. A marked and sudden increase is noted for the sample taken from 25cm where concentrations reach close to 3 million grains/cm^3. Pollen concentrations drop to about 230 000 grains/cm^3 at 0cm.

5.2.5.2.2 VVVB

As is the case with VVVA, pollen concentration data for VVVB are inconsistent. At a depth of 450cm, pollen concentration reaches approximately 700 000 grains/cm^3. This level increases and reaches a peak for VVVB at about 2.3 million grains/cm^3 at 425cm. Levels decrease again to just less than 85000 grains/cm^3 at 400cm. A slight increase is experienced between 400cm and 350cm where levels climb to about one million grains/cm^3. Pollen concentration drops again at 325cm and rises to 1.3 million grains/cm^3 at 250cm. Levels drop below 500 000 grains/cm^3 decreasing steadily until 175cm. Here, levels reach 79 000 grains/cm^3. Between 175cm and 125cm, pollen concentration climbs to approximately 360 000 grains/cm^3 at 125cm. Pollen concentration content between 100cm and 0cm never rises above 90 000 grains/cm^3.

It is worth noting, however, that organic matter and pollen concentration do vary consistently with respect to lithology from core to core. An interpretation of the anomaly in these findings is presented later in this chapter. It appears that rapid sedimentation prohibited accumulation of large quantities of pollen in the upper 400cm of the core.

5.2.5.3 Pollen accumulation rates

Unfortunately, it has not been possible to reconstruct a continuous curve of pollen accumulation rate over time for several reasons. Firstly, pollen data are not available between the depths of 400cm and 550cm in VVVA. Secondly, only eight radiocarbon dates have been acquired for the cores from Vankervelsvlei, and of these, just seven are valid. Consequently, calculation of sedimentation rates has been problematic. Considering that pollen accumulation rates are calculated based on the relationship between sedimentation rate and pollen concentration, it was considered that pollen accumulation rates could not be calculated to the desired degree of accuracy. Nonetheless, it is possible to make certain statements regarding the changes evident in pollen concentration in conjunction with changes in sedimentation rates, thereby providing a possible explanation for the irregular pattern in pollen concentration described in the preceding paragraphs.

5.2.5.3.1 VVVA

Differences in probable pollen accumulation are evident. Between 400cm and 0cm, sediment accumulation is the highest for VVVA while pollen concentrations are low relative to organic matter content (bar one anomalous value). Based on calculated sedimentation rates and pollen concentration data described in previous sections, pollen is likely to have accumulated at a rate of between 30 000 grains/cm^2 and 300 000 grains/cm^2 during this interval. In contrast, the calculated sedimentation rate between 550cm to 760cm is far lower while pollen concentrations are marginally higher producing rough accumulation rates of about 1000 grains/cm2 to 11000 grains/cm^{2}. It is thus evident that pollen would have accumulated more rapidly in the upper 400cm of VVVA than in the lower reaches of the core. In other words, the concentration of pollen in the upper reaches of VVVA seems to have been constrained by the rapidity of sediment accumulation.

5.2.5.3.2 VVVB

Sediment accumulates more rapidly (0.14 mm yr^{-1})for the lower 350cm of VVVB (0.08 mm yr^{-1}) than the upper 100cm, while pollen concentrations are somewhat higher (between about 1 million $grains/cm^3$ and 200 000 $grains/cm^3$ as opposed to between 7000 $grains/cm^3$ and 87 000 grains/cm3). Probable pollen accumulation rates thus range between approximately 3000 and 14000 $grains/cm^2$ in the lower 350cm and 60 - 700 $grains/cm^2$ for the upper 100cm.

5.3 FOSSIL POLLEN EVIDENCE

To enhance palaeoenvironmental interpretation, fossil pollen data have been presented in varying formats. Several types of graphical styles have been adopted. Four continuous curve pollen diagrams lay out detailed particulars of all pollen taxa identified and counted at the site above a certain concentration. Two of the pollen diagrams are based on absolute pollen frequencies, while the other two are based on percentage data and provide a relative comparison in the prominence of the taxa displayed. Two summary pollen diagrams have also been generated providing a useful visual summary of the changing proportions of grouped pollen taxa. Taxa have been grouped according to ecological provenance as explained in Chapter 4. All pollen diagrams are based on absolute pollen counts at each sampled level. Appendix G contains summaries of the raw pollen counts for VVVA and VVVB.

Figures 5.4 - 5.9 detail results of pollen counts of VVVA and VVVB. Depths are recorded in cm allowing for fine resolution description in the fluctuations in community composition over time. Taxa are arranged according to ecological provenance with aquatics plotted to the left of the diagram. Graminoid, heath, woody and forest elements extend towards the right. Both comprehensive pollen diagrams and percentage pollen diagrams have been divided into pollen assemblage zones using cluster analysis as part of the PSIMPOLL program. PSIMPOLL allows for designation of broad pollen assemblage zones but division of these into subzones is left to the discretion of the researcher. Indeed, subzones have been delineated in certain cases according to the principles outlined by Moore *et al.* (1991). The VVVA pollen diagrams have been divided into four major zones while the VVVB diagrams are divided into three zones. Zoning is identical in both comprehensive and pollen diagrams to allow for ease of comparison. Major features of each zone are described and discussed below in terms of ecological significance.

5.3.1 VVVA

5.3.1.1 Comprehensive and percentage pollen diagrams

Zone A

Zone A1a (approx. 39 900 BP - 38 400 BP)

Most taxa from across the spectrum of aquatic, fynbos, woody shrub and forest components are represented. Of these, *Restionaceae, Asteraceae* and *Ericaceae* are the most dominant with pollen concentrations of approximately 150 000 - 250 000 grains/cm^3. Of secondary importance are *Icacinaceae, Celastraceae* and *Lauraceae* ranging in pollen concentration from 54 000 grains/cm^3 in the case of *Icacinaceae* to 81 000 grains/cm^3 in the case of *Lauraceae*.

Zone A1b (approx. 38 450 BP - 25 060 BP)

Again, most taxa are represented. Many taxa peak at around 600cm, the most prominent of which are the families *Restionaceae, Ericaceae and Asteraceae* which maintain high representative pollen concentrations of around 250 000 - 300 000 grains/cm^3. Of the woody shrub taxa present, *Ebenaceae* is the most significant at 55 000 grains/cm^3. This is particularly evident in the percentage pollen diagram (Figure 5.5). The forest trees *Lauraceae* and *Araliaceae* appear in lesser quantities. *Scrophulariaceae* co-varies with these taxa suggesting that they too to represent trees or forest elements in this zone. Aquatics are present, but only in quantities of the order of 13 000 -25 000 grains/cm^3.

Zone A1c (approx. 25 060 BP - 7130 BP)

A break in the pollen sequence occurs between the depths of 550cm and 400cm due to problems during the processing of fossil samples which led to the destruction of grains. Consequently, samples within this range were discarded as uncountable. The resultant hiatus is labelled as zone A1c on the diagram though this is in fact an artificial construct used for ease of explanation.

Zone A2 (approx. 7130 BP - 3570 BP)

This is a particularly large zone spanning 400cm to 140cm depth. Pollen concentration is relatively low as shown in Figure 5.2 in section 2.5. Aquatics appear to dominate especially between 400cm and 280cm in concentrations of approximately 70 - 1400 grains/cm^3. *Poaceae, Juncaeae* and *Restionaceae* make up most of the rest of the pollen complement and these are more abundant towards the top of the zone. Otherwise fynbos elements, woody shrubs and forest elements are also present, but in relatively small quantities (hundreds - several thousands of grains/cm^3), emerging at different periods within the zone. Few taxa appear consistently throughout the time period with the exception of aquatics, grasses and some fynbos taxa.

Zone A3 (approx. 3570 BP - 3370 BP)

Pollen concentration increases again in this narrow zone spanning only 20cm depth of sedimentation. Several taxa peak at approximately 30cm depth. This zone displays similarities to the characteristics of zone A1 in that forest elements reemerge in greater abundance, though different taxa dominate than in zone A1. Of the forest taxa, the most notable influx is in the form of *Oleaceae* (46 000 grains/cm^3*), Flacourtiaceae (*23 500 grains/cm^3*), Podocarpaceae* (17500 grains/cm^3*)* and *Aizoaceae* (12 000 grains/cm^3*)*. Also worthy of note is the absence of woody shrubs with the exception of *Icacinaceae*. Fynbos elements also return though not in as great abundance as in zone A1. Graminoids in the form of *Poaceae and Juncaceae* dominate this zone along with aquatic taxa. These taxa range in concentration from 120 000 to nearly 600 000 grains/cm^3).

Figure 5.4: Comprehensive pollen diagram VVVA.

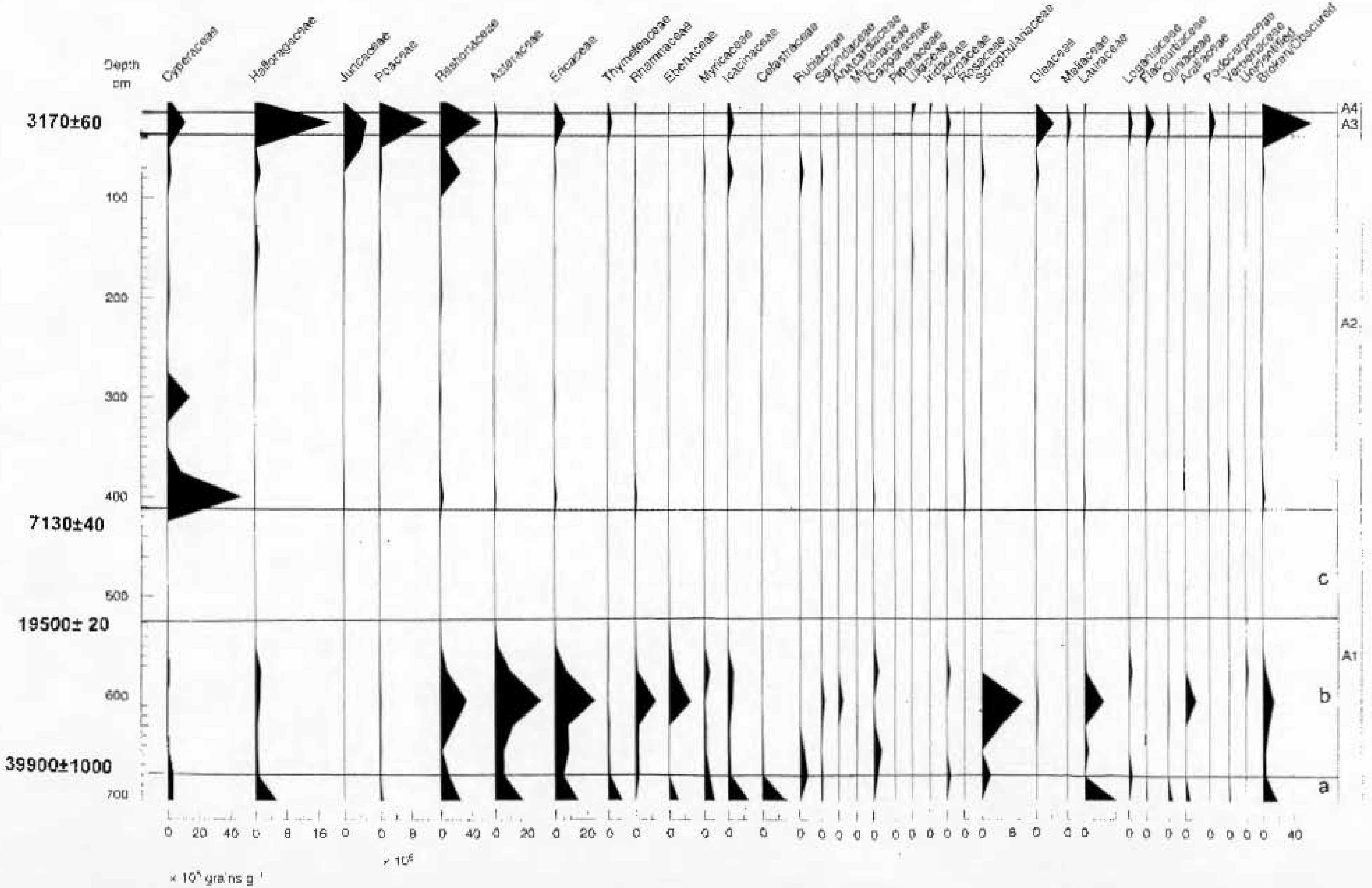
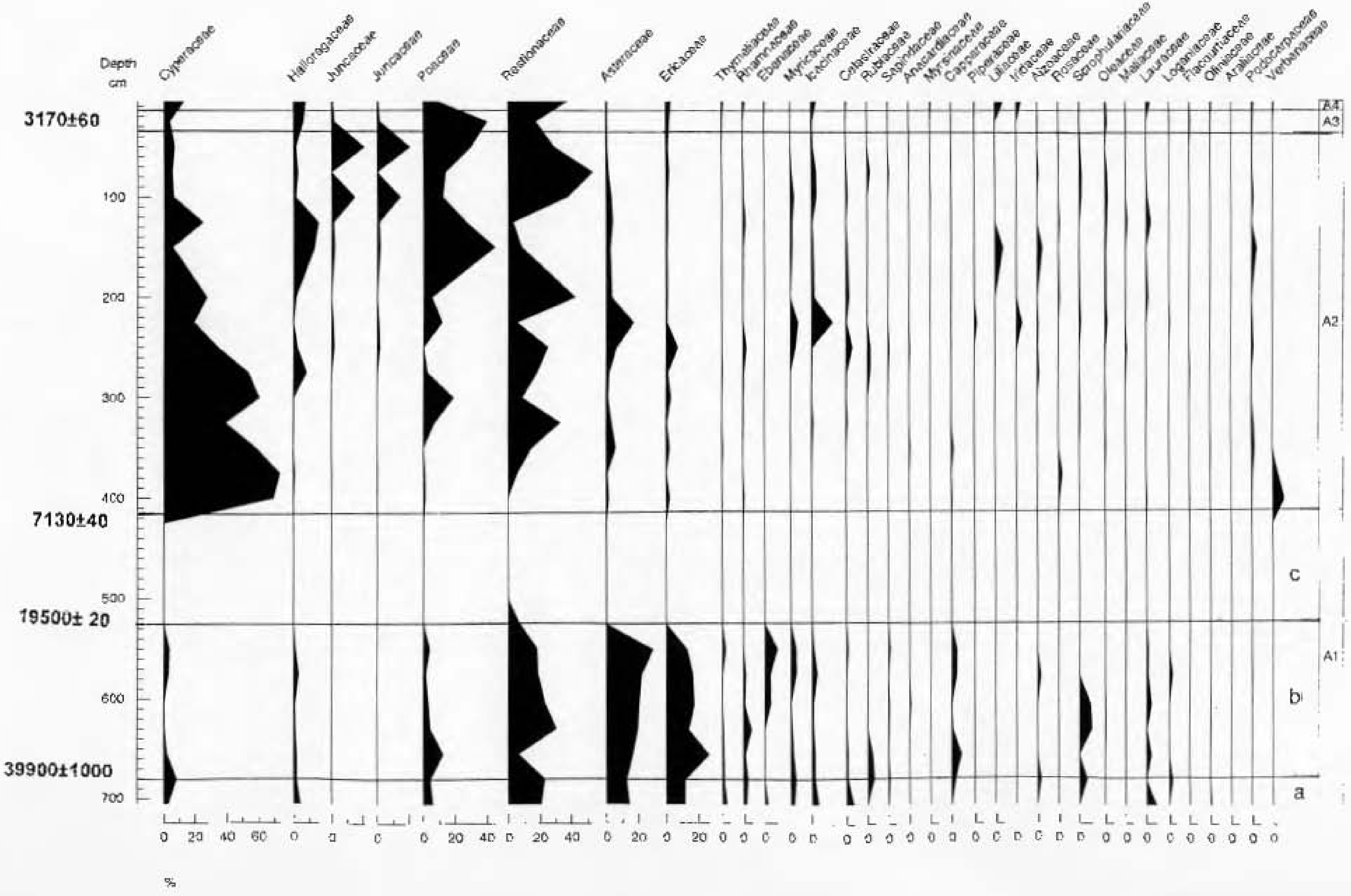


Figure 5.5: Percentage pollen diagram VVVA.



Zone A4 (approx. 3370 BP - 3170 BP)

This zone is extremely narrow and it should be noted that its definition as a distinct zone was based on the characteristics of a single sample. As such, its allocation as a pollen zone is questionable despite the result having been produced by a recognised statistical technique. The decline in many taxa at the top of zone A3 is ameliorated by the reemergence of many of these in zone A4. With the decline of certain forest taxa comes the emergence of others not seen in the sequence previously, for example *Verbenaceae*. Other elements like *Liliaceae* and *Iridaceae*, typically moisture-tolerant taxa, also appear. A notable decline in fynbos and graminoid taxa is noted.

5.3.1.2 Summary pollen diagram

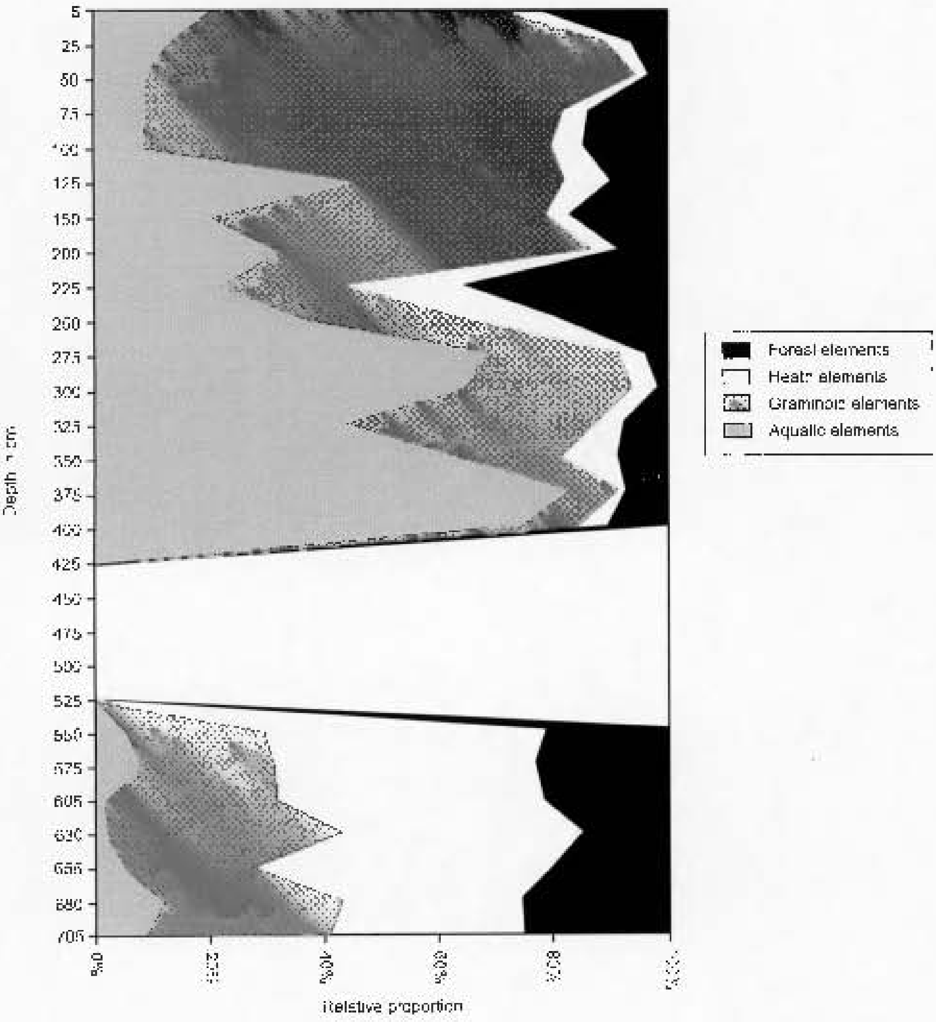


Figure 5.6: Summary pollen diagram VVVA

Aquatics: These decline from just below 10% at the base of the core to approximately 7% at 550cm. In the late Pleistocene aquatics peak at 10% at 680cm and reach lowest proportions at 605cm. From 525cm an obvious influx of aquatics is noted which continues till 250cm. From this point aquatic elements decline once more fluctuating slightly and dropping below 10% between 100cm and 50cm. The late Holocene heralds an increase in aquatic taxa to about 20% of the total pollen complement. Aquatics reach their peak in the sequence at 375cm where they represent 80% of the pollen sum.

Graminoid elements: Almost 30% of the total pollen is graminoid in nature at the base of the core and these elements never represent less than 20% of the pollen sum until 550cm where data becomes unavailable. However, at reemergence at 450cm graminoids appear proportionally less important in relation to the extreme increase in aquatics. With the progressive decline in aquatics with time, graminoids expand more and more and they dominate the sequence from 225cm to the core surface.

Heath elements: These dominate the sequence in the lower 1.5m, increasing in proportion from approximately 35% at the base of the core to 50% at 550cm. A dramatic decrease is noted at 400cm to merely 5% of the total which is maintained throughout the remainder of the record. No doubt, as with graminoids and forest elements to follow, the decline in importance of these elements is affected by the dramatic increase in aquatics.

Forest elements: These comprise almost 30% of the pollen sum at its base but decrease slightly in importance to just over 20% at 550cm. The upper part of the sequence shows a continuing decline reaching a low point at 300cm of less than 5%. Immediately thereafter forest taxa experience increase in proportional importance reaching a peak of about 35% at 225cm. The remainder of the sequence indicates a decrease until 25cm here forest taxa expand in proportion once more to reach a level of 20% at the core surface.

5.3.1.3 Summary of major changes

Late Pleistocene (705cm - 550cm):

I. From 680cm heath and graminoid elements undoubtedly dominate throughout the period from 39 900 BP to 19 500 BP. Forest elements decline in importance heading into the LGM and aquatics become almost negligible;

II. Initially, forest, heath and graminoids appear in relatively similar abundance, with aquatics making up the smallest fraction of the pollen sum.

Terminal Pleistocene - LGM (550cm - 400cm):

No data available.

Early - Mid-Holocene (400cm - 225cm):

I. Massive expansion in the proportional influence of aquatics, dominating all other groups in the early Holocene. Forest elements present in slightly greater amounts than heath or graminoid elements;

II. Decline in aquatics after 375cm filled by graminoid and heath elements at expense of forest taxa till 275cm;

III. Forest influence increases with continuing waning of aquatics. This is accompanied by reduction of graminoids and relative consistency of heath elements.

Mid - late Holocene:

I. Mid-Holocene shows graminoids once again to be dominant at the expense of forest elements and aquatics. Heath or fynbos remains relatively constant.

II. Aquatics stabilise and forest continues to diminish as the Holocene continues. Graminoids continue to increase their dominance in the pollen sum and fynbos decreases slightly in importance.

III. The late Holocene is characterised by rise in aquatic and forest portions of the pollen sum. However, graminoids are still very much predominant and heath elements remain inconsequential.

5.3.2 VVVB

5.3.2.1 Comprehensive and percentage pollen diagrams

Zone B1 (approx. 45 500 BP - 41 000 BP)

Most identified pollen types are present in this zone. Many taxa peak between 430 - 420cm before declining once again. The most important of these include *Cyperaceae, Restionaceae, Asteraceae, Rosaceae and Ericaceae* which are present in concentrations of approximately 170 000 to 350 000 grains/cm^3. Several other taxa peak at this depth as well, but are present in lesser quantities (concentrations in the order of 55 000 - 150 000 grains/cm^3). These include *Oleaceae, Podocarpaceae, Halloragaceae, Rhamnaceae, Ebenaceae, Icacinaceae, Scrophulariaceae, Flacourtiaceae, Oliniaceae and Araliaceae.* Certain taxa present at 475cm decline altogether by 430-420cm; for example *Piperaceae, Meliaceae* and *Myricaceae.*

Zone B2 (approx. 40 700 BP - 28 200 BP)

This zone shows fluctuations in most taxa present in zone B1. Again, most taxa are represented throughout the zone with the exception of several tree taxa which disappear from the sequence altogether. These include *Podocarpaceae, Araliaceae, Flacourtiaceae, Oleaceae* and *Oliniaceae.* *Lauraceae* reemerges and *Meliaceae* appears in the record for the first and only time, peaking at a concentration of about 33 000 grains/cm^3 at approximately 300cm. The zone is also characterised by a strong presence of *Icacinaceae* and *Ebenaceae* ranging in concentration from 15 000 -110 000 grains/cm^3. Fynbos taxa still dominate the sequence in this zone. While maintaining a constant presence, they do fluctuate throughout.

Figure 5.7: Comprehensive pollen diagram VVVB.

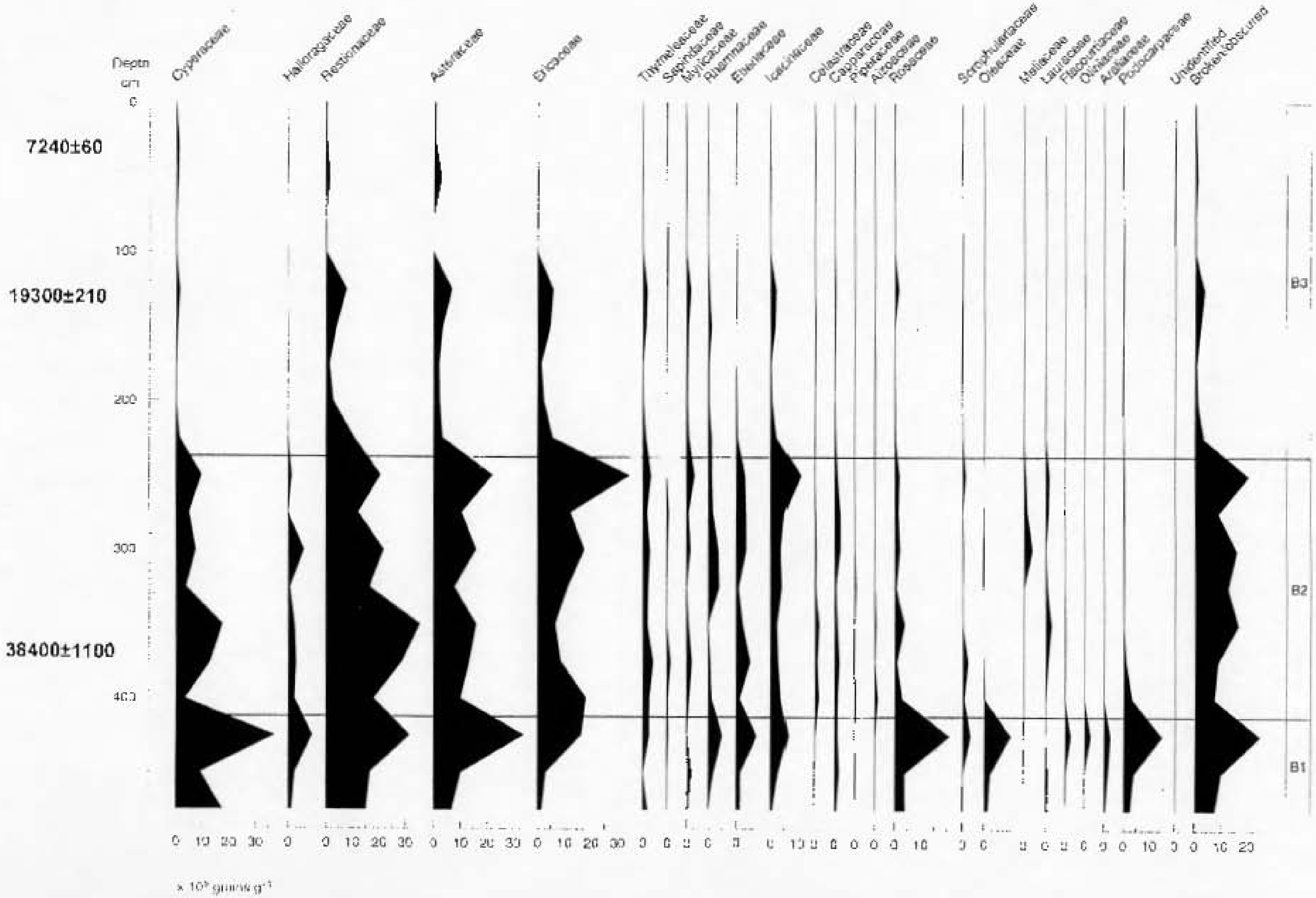
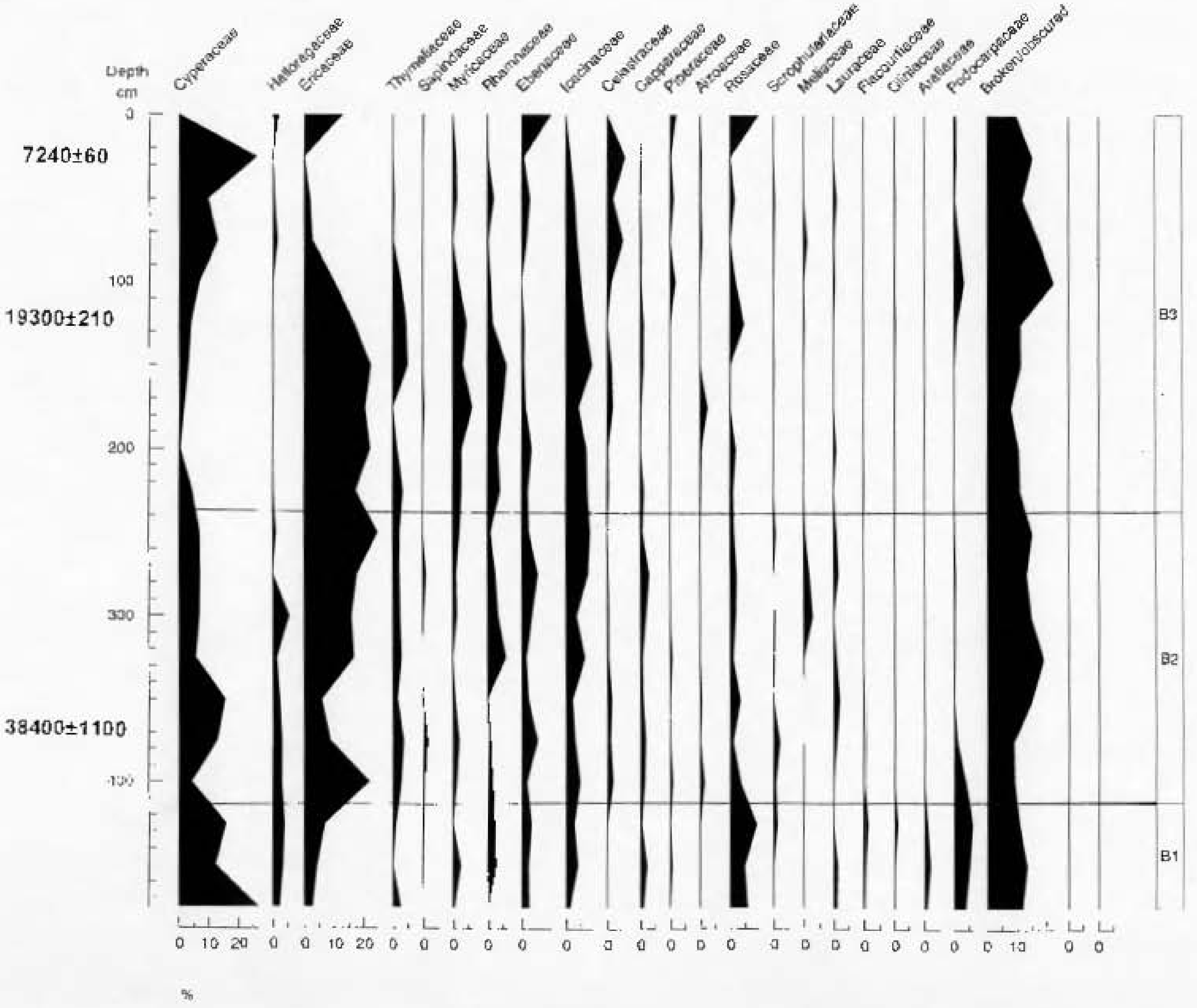


Figure 5.8: Percentage pollen diagram VVVB.



Zone B3 (approx. 28 200 BP - 4700 BP)

The margin of this zone heralds an obvious decrease in the abundance of pollen present in the sedimentary sequence. Dramatic decreases occur in the abundances of most taxa while the number of taxa represented also declines. Tree taxa disappear altogether with the exception of *Rosaceae* which appears in small quantities (about 17 000 grains/cm^3) at approximately 120cm depth. All woody shrubs, fynbos taxa and the family *Cyperaceae* decline on entry to zone B3 at approximately 240cm but reemerge to peak at 120cm at concentrations of approximately 15 000 grains/cm^3. Between 120cm and 0cm graminoid elements emerge for the first time in the sedimentary record albeit in very small concentrations (100 - 3000 grains/cm^3).

5.3.2.2 Summary pollen diagram

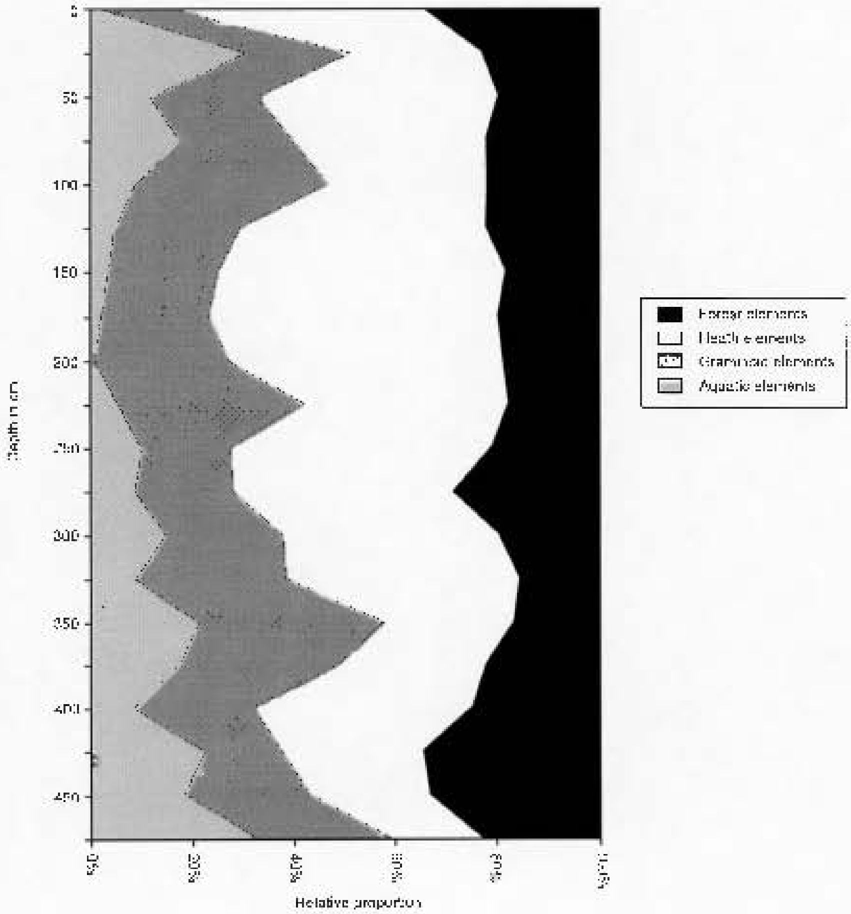


Figure 5.9: Summary pollen diagram VVVB.

Aquatic elements: These elements steadily decrease through time from approximately 30% at 475cm to almost 0% at 200cm. They then increase gradually again to 10% at 100cm reaching over 30% again at 25cm below the core surface. There is a marked decline in the importance of aquatic elements in the upper 25cm of the core.

Graminoid elements: A similar trend is evident in that graminoids experience a decline from 475cm to 350cm though a marked peak of about 30% is evident at 350cm. From 250cm, pollen concentration of graminoids increase to 40% between 250cm and 200cm. Relative stability is then attained before these elements decline in significance from 50 cm till they represent only 15% of the total at 0cm.

Heath elements: This group of taxa dominates throughout the sequence in terms of pollen concentration. At 475cm these elements occupy approximately 20% of the total pollen sum but rapidly increase to representing 50% of the total by 400cm. A brief decline is noted at 350cm, but is followed by massive expansion to 60% of the pollen sum by 175cm. From here, heath elements still occupy the largest proportion of pollen counted, but their dominance begins to drop till levels of 25% are reached at 25cm from the core surface. There are indications of expansion again between 25cm and 0cm. In general, there are indications of dominance of heath over the entire time period represented in the sequence.

Forest elements: These are most abundant in the lower part of the sequence reaching maximum levels of 30% at 425cm. The proportion of forest taxa pollen then drops to a level approaching 15% at 325cm before increasing again to 25% at 275cm. Forest pollen levels then remain relatively constant at around 20% before increasing near the top of the sequence. At 0cm these elements represent just over 30% of the total pollen sum.

5.3.2.3 Summary of major changes

Late Pleistocene (475cm - 250cm):

I. Between 475cm and 450 cm aquatic, graminoid, heath and forest elements comprise relatively similar proportions of the total pollen complement, aquatics and forest elements being slightly more prominent.

II. Between 450 cm and 250 cm a shift from the dominance of aquatics and forest elements to the pre-eminence of heath elements (fynbos shrubs) and graminoids. Graminoids are particularly influential between 400 cm and 300cm with fynbos dominating from 350 cm to 250 cm. A short-lived increase in the proportion of forest taxa occurs around 325cm.

Terminal Pleistocene - LGM (250cm - 150cm):

I. Heading into the LGM aquatic elements continue to decline. Simultaneously, a burgeoning of graminoid taxa occurs reaching a peak at 225cm. Forest elements remain relatively constant with heath elements being the obvious dominant throughout.

II. Heading out of the LGM into the early Holocene, aquatics begin increasing proportionally once more, as do graminoids and forest elements. In turn, fynbos taxa decrease in significance.

Early Holocene (150cm - 0cm):

I. Characterised by steady increase in the proportion of aquatics till around 7000 BP (25 cm depth). Slight proportional increase of forest elements initially which remains constant for most of this period. A decline of heath dominance till approximately 25cm from core surface.

II. Between 25 cm and the core surface, a sudden drop in the proportion of aquatic and graminoid elements occurs and heath and forest elements begin to increase in influence.

5.4 MODERN POLLEN OF THE VANKERVELSVLEI ENVIRONMENT

A good understanding of the composition of modern pollen in depositional environments similar to those of fossil sites is fundamental to valid interpretation of fossil pollen data. Indeed, Moore *et al.* (1991) hold the opinion that interpretation of past assemblages of pollen grains in terms of the vegetation that produced them is to study surface samples from modern vegetation types. Results of analyses of seven contemporary pollen samples from in and around Vankervelsvlei are detailed in this section. Appendix H holds comprehensive details of pollen composition and abundance for each of the seven sites analysed. Table 5.3 lists the locations of the sites in question.

SAMPLE	LOCATION	DESCRIPTION	IMPORTANT TAXA
S1	Coring site of VVVB.	Very moist matted aquatic vegetation. Very little sediment evident.	*Restionaceae, Juncaceae, Cyperaceae, Thymeliaceae, Icacinaceae, Podocarpaceae.*
S2	Between Coring site of VVVB and vlei edge.	Similar characteristics to site 1.	*Restionaceae, Juncaceae, Cyperaceae, Myricaceae, Icacinaceae, Podocarpaceae*
S3	Vlei margin on the verge of the Cyperaceous mat.	Cyperaceous vegetation mixed with terrestrial taxa. Spermatophytes and fynbos taxa present.	*Cyperaceae, Restionaceae, Thymeliaceae, Asteraceae, Rosaceae, Podocarpaceae.*
S4	Approximately 20m from vlei margin.	Transition zone between vlei edge and pine plantation. Scrub forest and fynbos elements present.	*Ericaceae, Thymeliaceae, Icacinaceae, Podocarpaceae.*
S5	Coastal forest.	Dense vegetation. Shrubs dominate with trees of 5-10m in height. Many fynbos taxa present. Evidence of alien invasion.	*Restionaceae, Asteraceae, Ericaceae, Celastraceae, Oleaceae, Podocarpaceae.*
S6	Scrub forest.	Dense vegetation. Trees of 10-12m in height. Fewer shrubs than site 5. Less evidence of fynbos taxa and alien invasion.	*Restionaceae, Poaceae, Cyperaceae, Celastraceae, Oleaceae, Podocarpaceae.*
S7	Fynbos.	Low-growing fynbos of 1-1.5m in height. Predominantly small shrubs. *Erica, Passerina, Leucadendron* dominate.	*Restionaceae, Cyperaceae, Ericaceae, Icacinaceae, Oleaceae, Podocarpaceae.*

Table 5.3: Description of surface sample sites in and around Vankervelsvlei.

S1 to S4 follow a continuum from the centre of the basin extending through a forest transition zone and ending on the margin of the pine forest encircling Vankervelsvlei. S1 - S4 are almost identical in terms of taxonomic composition , but the relative abundances of taxa differ from one sample to the other. S1 and S2 display similar characteristics with *Restionaceae* representing the largest proportion of the pollen sum at 19% in S1 and 16% in S2. This figure declines along the continuum with *Restionaceae* comprising only 2% of S4. *Juncaceae* is found in S1(13%) and S2 (11%), but disappears in S3 and S4. *Cyperaceae* comprises between 15% and 23% of S1 - S3, but quantities decline to only 4% in S4. Asteraceous taxa appear in S3 and S4 in quantities of approximately 10-13%. *Icacinaceae* is found in all samples, ranging between 3% in S2 to 8% in S1 and S4. *Podocarpaceae* is also ubiquitous representing approximately 5% of S1 and S2 and increasing to 12% in S3 and 19% in S4. Interestingly, S3 shows the presence of 9% *Rosaceae* pollen, which is inconsequential in S1 and absent in the other samples.

S5, S6 and S7 are unrelated to the previous four as well as to each other but represent communities common within the Vankervelsvlei surrounds. S5 is representative of a coastal forest community. Although *Asteraceae* dominates at 21% and other fynbos taxa such as *Restionaceae* (16%) and *Ericaceae* (6%) are present, typical forest taxa like *Celastraceae* (13%) and *Scrophulariaceae* (6%) appear. *Podocarpaceae* also feature prominently, making up 18% of the pollen sum.

S6, a scrub forest sample, is fairly similar in composition to S5, yet abundances of taxa vary. Proportionally, *Restionaceae* comprises only 9% while other fynbos taxa comprise less than 5%. *Celastraceae* and *Scrophulariaceae* comprise 7% and 5% respectively, while transitional scrub taxa, *Icacinaceae*, *Rhamnaceae, Sapindaceae* and *Myricaceae* represent between 2% and 5% each of the pollen sum.

Finally, S7, a fynbos community sample, is the most taxonomically rich of the seven. As expected, this sample is dominated by typically fynbos taxa. *Restionaceae* comprises 16% of the total, while *Asteraceae* makes up 14% and *Ericaceae* 8%. *Poaceae* makes up 11% of the pollen sum and *Icacinaceae*, a woody shrub comprises 15%. Interestingly, pollen from several forest tree taxa are also present. *Podocarpaceae* represents 16% while several other taxa are present in quantities less than 2%.

5.4.1 Comparing modern and fossil pollen

The use of statistical methods in the comparison of modern and fossil vegetation communities is a commonly adopted practice as explained in Chapter 4. In this case, Nearest Neighbour Analysis (Baxter, 1997) has been used as the means of comparison. The output of the analysis is summarised below in Figures 5.11 and 5.12. Each bar on the graph reflects a measure of the closeness of relationship between the fossil samples at the depths indicated and their nearest modern analogues as calculated by the Nearest Neighbour algorithm (Appendix I). Values closest to 0.0 indicate closer relationship and thus the existence of good modern analogues for fossil communities. Of the seven modern sites compared with each fossil sample, the nearest are annotated to the right of the appropriate bar. They are labelled according to the surface sample numbers allocated to them in the field and listed in Table 5.3.

5.4.1.1 VVVA

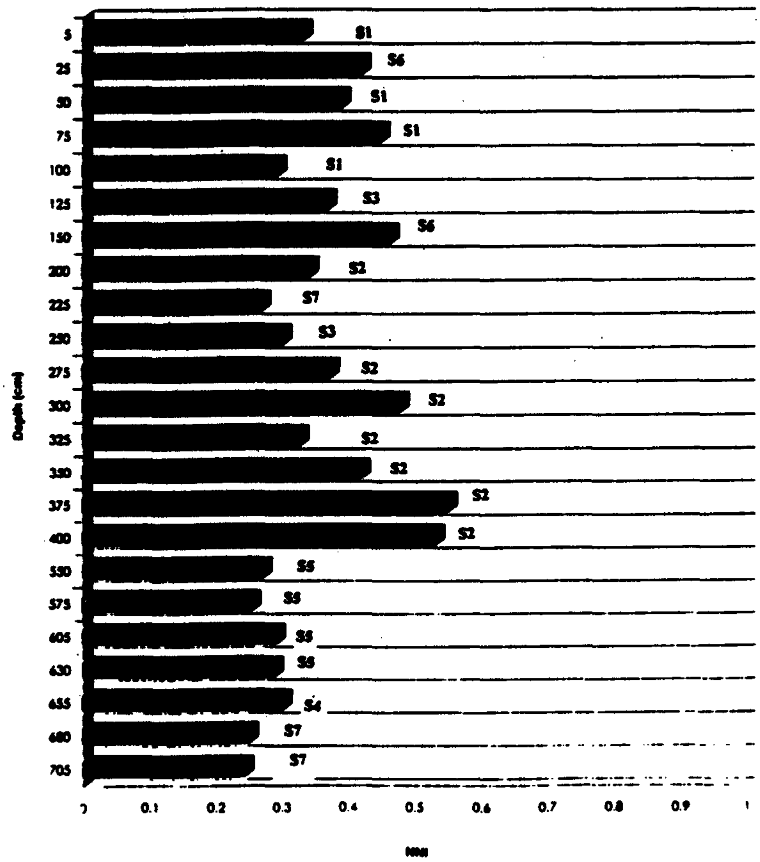


Figure 5.10: Nearest Neighbour Indices for VVVA pollen spectra.

Between 705cm and 680cm site 7 provides the closest modern analogue with a Nearest Neighbour Index (NNI) of 0.25. The sample at 655cm is most analogous to site 4, a transitional community between vlei edge and forest taxa. Between 630cm and 550cm, all samples are most closely related to site 5 with NNI's of between 0.26 - 0.29. Nearest Neighbour Indices have not been calculated for the depths 550cm to 400cm due to a lack of pollen data for this period. From 400cm to 275cm samples are most closely analogous to site 2, though the dissimilarity index varies during this period from 0.3 at 325cm to 0.55 at 375cm. The sample at 350cm is most closely related to site 3. Site 1 provides the closest modern analogue for samples between 100cm and 0cm, with the exception of the sample at 25cm which has its closest analogue at site 6.

5.4.1.2 VVVB

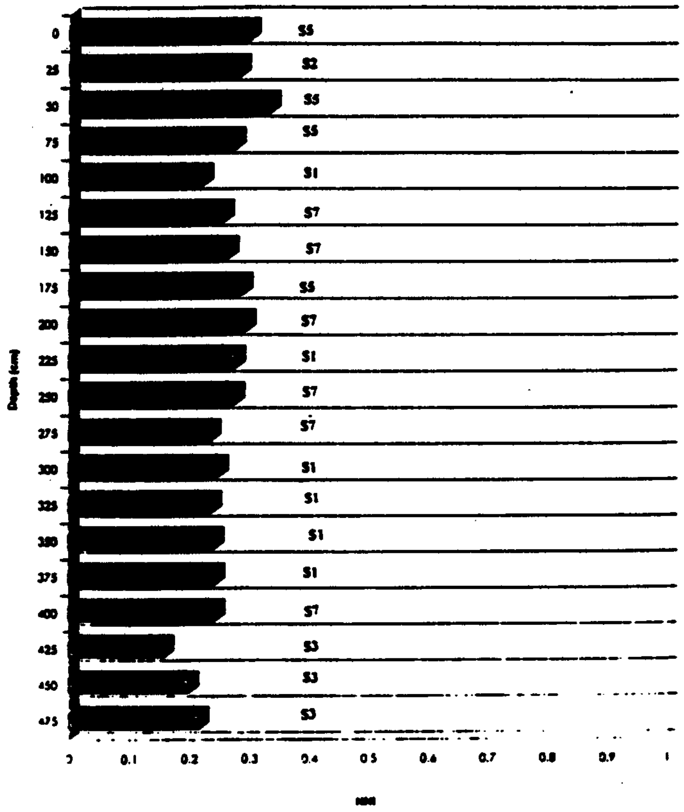


Figure 5.11: Nearest Neighbour Indices for VVVB pollen spectra.

Good analogues exist for samples between 475cm and 425cm (NNI ranges from 0.16 - 0.22). At 400cm, the sample's closest modern analogue is site 7. The NNI here is also low at 0.24 indicating a close relationship between the fossil and contemporary samples. Between 375cm and 300cm, all samples are most closely related to site 1 with notably consistent NNI's of around 0.25. Samples at depths of 275cm and 250cm display NNI's of less than 0.3 in relation to site 7, while that of 0.28 relates sample at 225cm to site 1. Three of the four samples between 200cm and 125 cm are closely related to site 7 (all NNI's below 0.3) with the sample at 175cm depth being analogous to site 5. Samples from the upper 100cm of the core appear to be closely related to site 5 with the exception of the samples from 100cm and 25cm depth whose closest analogues are site 1 and site 2 respectively.

5.5 GEOCHEMISTRY

Phillips (1931) notes the lack of research undertaken on the geochemical nature of soils in the Knysna afromontane forests. As such, little is known about typical major and minor elemental levels in the area, but is accepted that soils are generally nutrient deficient. Lowe and Walker (1984, 1997) list several indicators of climatic amelioration/deterioration in light of which the sediments of VVVB have been analysed (no geochemical analysis has been carried out on VVVA). Data are presented in a series of line graphs (Figure 5.12 overleaf) showing changes in concentration of several major elements over time. Units of presentation are percentages.

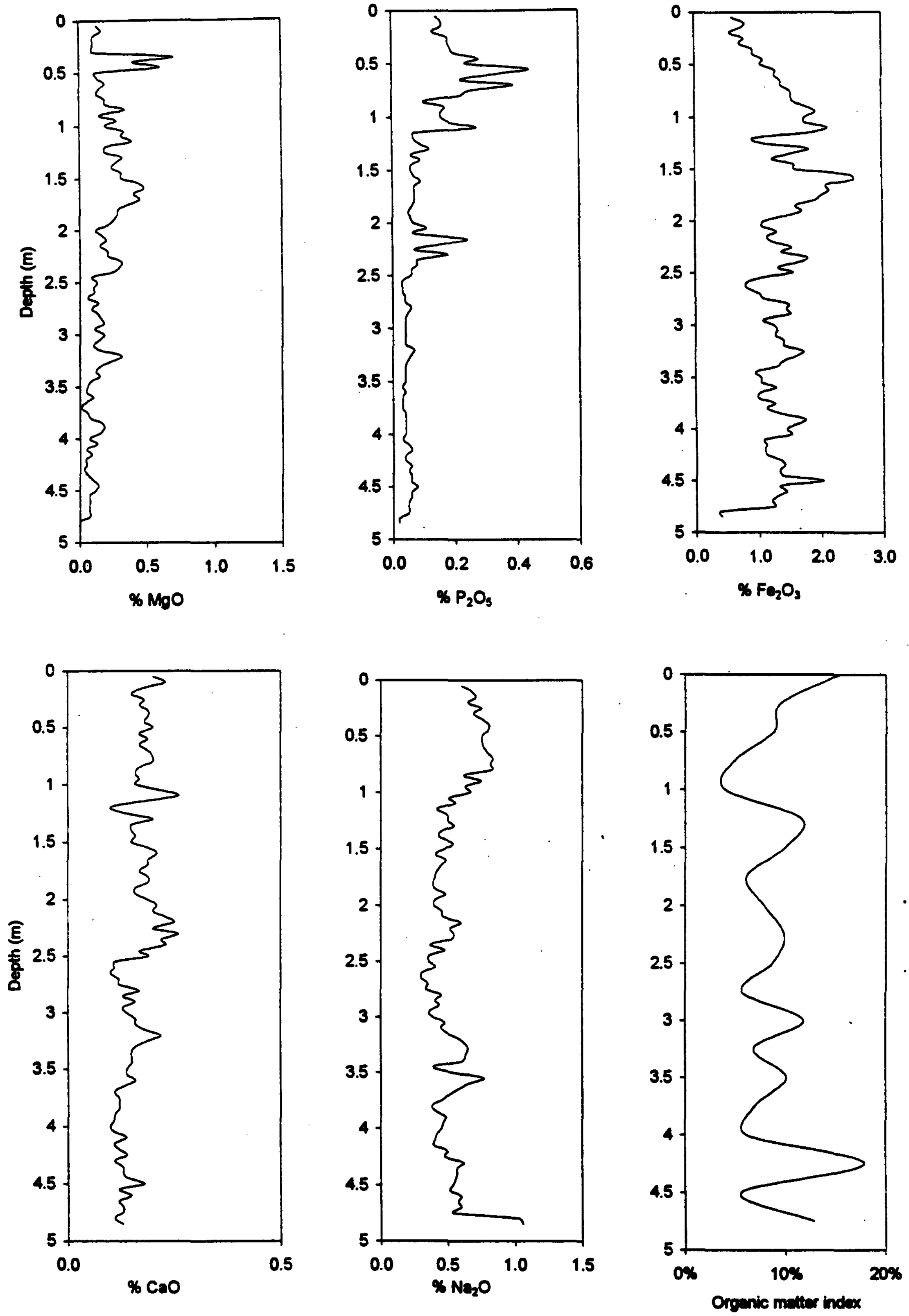


Figure 5.12: Geochemical analysis for VVVB sediments - major element concentrations of selected elements.

According to Lowe and Walker (1984, 1997), increasing levels of organic matter combined with corresponding decreasing measures of Phosphorus (P_2O_5), Sodium (Na_2O), Magnesium (MgO) and sometimes Iron (Fe2O3) and Calcium (CaO) are purported to indicate high vegetation cover and thus favourable environmental conditions. The opposite would be true of comparatively low organic content and high inorganic mineral content. Proportions of major elements relative to organic matter content of sediments are described in terms of changes occurring in the late Pleistocene, terminal Pleistocene and the LGM and the early Holocene are summarised overleaf.

Geochemical element	Late Pleistocene (475cm - 250cm):	Terminal Pleistocene - LGM (250cm -150cm):	Early Holocene (150cm - 0cm):
Organic matter	• levels fluctuate between 5% and 15% with one outlying sample reaching 20% at 425cm. • On the whole levels decrease heading into the LGM.	• Increase from 8.5-10% between 250cm and 225cm. • Decline to 7% by 175cm. • Increase to 10% at 150cm.	• Between 0cm and 150cm concentrations increase to 13%. • By 100cm levels have decreased to 4%. • Between 100cm and 0cm, levels increase steadily to reach 17%.
Sodium	• Decreases from 0.6% at 475cm to 0.4% at 400cm. • Increases to 0.6% by 375cm. • Declines to 0.3% at 275cm.	• Between 250cm and 200cm levels remain constant at about 0.4%. • Levels decrease to around 0.3% by 175cm. • Levels increase to 0.6% heading into the late Holocene.	• Increases from 0.5% to 0.9% between 150cm and 75cm. • Decrease to 0.6% between 75cm and 0cm.
Magnesium	• Fluctuates very little. • Slight increase from 0.1% to 0.25% is noted between 350cm and 250cm.	• Between 250cm and 200cm concentrations decline to 0.15%. • Increase to around 0.5% until about 160cm. • Decrease in concentration heading into Holocene.	• General declining trend throughout 150cm to 0cm period. • Slight decrease in concentration between 150cm and 125cm to 0.15%. • Increase to around 0.3% at 100cm. • Remaining 100cm characterised by declining levels with exception of peak at 50cm of about 0.4%.
Phosphorous	• Fluctuates very little. • Very slight increase from 0.05% to 0.1% between 475cm and 450cm. • Declining trend towards 0.05% at 250cm.	• Increase to approximately 0.18% by 225cm. • Steady decline to about 0.1% by 150cm.	• Slight increase at approximately 125cm to 0.15%. • Decrease to around 0.01% at 100cm. • Marked increase between 100cm and 75cm to 0.3%. • From 75cm to 0cm, levels decline to reach 0.15% at 0cm.
Iron	• Increases from 0.4% to 1.4% between 475cm and 450cm. • Remains relatively constant dropping slightly to 1.2% by 350cm. • Increases to 1.7% at 325cm. • Decreases to 0.9% by 250cm.	• Increase from 0.9% below 250cm to 1.2% at 200cm. • Increase to approximately 1.1% by 175cm. • Decline heading into the late Holocene to around 1.5%.	• Between 150cm and 125cm levels decrease to around 1.1%. • Increase to approximately 0.2% at 100cm. • Uppermost 100cm characterised by steady decline reaching concentrations of about 0.6% at 0cm.
Calcium	• Decreases from 0.15% to 0.1% between 475cm and 400cm. • Increases to 0.2% by 300cm. • Decreases to 0.1% at 250cm.	• Increase between 250cm and 230cm to a peak of 0.25%. • Decrease to 0.18% by 200cm. • Slight increase at 175cm to 0.22%. • Increase heading into late Holocene.	• Little variation • Levels fluctuate around a mean concentration of 0.2%.

Considering the complexity of the results of geochemical analysis on VWB, results have been described in terms of broad trends and three noteworthy tendencies have been highlighted from the analysis. In these three cases, elements appear to co-vary noticeably which may have some significance in the interpretation of pollen zones in Chapter 6. Firstly, a significant peak in organic matter between 450cm and 400cm coincides with decreases in Phosphorus, Sodium, Calcium and Iron at the same levels. Secondly, the overall trend for the terminal Pleistocene and LGM shows low levels of organic matter which correspond to relatively higher levels of Calcium, Magnesium and Iron than the rest of the record. In the Holocene, Iron and Calcium decline steadily in contrast to the significant increase in organic matter at his time.

5.6 CONCLUSION

This chapter has provided detailed description of the results yielded in this investigation. Tabular and graphical formats have been used to aid in describing trends evident in the data. No attempt has been made in this chapter to draw inference from the facts. Chapter 6 goes on to interpret the results presented in Chapter 5.

CHAPTER 6

PALAEOECOLOGICAL RECONSTRUCTION

6.1 INTRODUCTION

This chapter examines palaeoenvironmental evidence from Vankervelsvlei and presents a narrative of environmental history for the site between approximately 45 000 BP and 3000 BP. The first section of the chapter is devoted to detailed interpretation of the pollen zones comprising each of the two cores derived from the study site, namely VVVA and VVVB. Included in this description is a rationale for the exclusion of human impact as a major influence in vegetation change over the period recorded in the Vankervelsvlei record. Every zone is described primarily in terms of its palynological characteristics, although reference is made to sedimentation rates, geochemical content and the nature of modern analogues where applicable. The chapter goes on to link evidence from the two cores by describing environmental changes at the site during the late Pleistocene, LGM and Holocene. Having arrived at a narrative of vegetation history for Vankervelsvlei, comparisons are made with other sites. Results from palaeoecological reconstructions made by Martin (1967) at nearby Groenvlei and Scholtz (1986) at Norga as well as several regional syntheses are compared to the new evidence from Vankervelsvlei. The chapter ends by addressing the issue of forest expansion and contraction at Vankervelsvlei thereby contributing to the body of existing information describing afromontane forest history in southern Africa.

6.1.1 Vegetation reconstruction

Certain principles govern the interpretation of vegetation history from pollen evidence. Faegri *et al.* (1989) and Moore *et al.* (1991) provide insight into the principles governing this inferential procedure. Firstly, the composition of vegetation producing pollen rain should be established. The second step is to draw inference from the vegetation data back to the agents producing them, for example climate, ecology, human interference and so on. This is accomplished through the analysis of fossil pollen and the production of pollen diagrams which the palynologist uses as an indirect indicator of past pollen rain.

When addressing the issue of past vegetation patterns, two approaches may be considered. One involves the identification of indicator taxa with specific environmental tolerances, and whose presence permits certain definitive statements to be made regarding past conditions. However, indicator taxa are often not representative of the whole pollen assemblage and their diagnostic potential is frequently limited to a single environmental parameter. For this reason, Faegri *et al.* (1989) and Moore *et al.* (1991) prefer consideration of the entire fossil pollen complement as a more accurate method. Indeed, it is this technique that has been adopted in the interpretation of fossil pollen evidence from Vankervelsvlei.

6.1.2 Human impact as a causal factor in vegetation change

In terms of humans as agents of vegetation change, Walker and Singh (1993) argue that attributing vegetation shifts to human influence can be problematic. They suggest that palynological change should initially be ascribed to environmental causation because its generality lends itself towards testing more readily than specific causes. Only in cases where positive contrary reasons can be found to support a non-environmental cause, should human influence be considered (Walker and Singh, 1993). This is particularly true when population density is likely to have been relatively low (Roberts, 1989) as is the case with the southern Cape for certain periods of time represented in the Vankervelsvlei record (Deacon, 1995).

Walker and Singh (1993) present several factors to be considered when assigning human impact to a palynological change. These are as follows:

1. The change should reflect ecological processes operating at levels and rates unprecedented under 'natural' conditions but are readily explicable as resulting from human actions of defined kinds;
2. The necessary human activities should be within the technological capacity of pre-historic peoples of the relevant age and region;
3. There should be some acceptable reason why the humans might have taken the hypothesised action (ideally exemplified by the pollen itself, for example crop pollen);

4. There should be strong evidence (ideally artefacts stratified into the pollen analysed deposits) for human occupation at the appropriate time within the pollen catchment.

In the case of the Vankervelsvlei record, human occupation of the landscape is documented throughout the time period covered by VVVA and VVVB. As outlined in Chapter 2, section 2.4.3, human occupation of the landscape continued even through the LGM, the period when conditions were at their worst. This is evidenced by tools and other materials found in dated archaeological assemblages (Deacon, 1984; Volman, 1984; Von den Driesch and Deacon, 1985; Deacon, 1995). In addition, technologies such as fire are documented as being used by the occupants throughout the late Pleistocene and extending into the Holocene. This is evidenced in the discovery of hearths and charred wood and food remains (Deacon, 1995). Fire was not, however, used to clear vegetation for grazing or for the purpose of geophyte bulb farming until after 2 000 BP, a time period not covered in the Vankervelsvlei palynological history (Deacon, 1984; Deacon, 1995).

Thus three of the four criteria appear valid. However, at no point in the Vankervelsvlei palynological record do vegetation changes reflect ecological processes functioning at levels or rates unprecedented under 'natural' conditions. Therefore, it is deemed unlikely that human interference in the landscape could have produced sufficient impact to be considered causal. It is for this reason that human impact is not mentioned directly in the interpretation of pollen zones below. However, reference is made to increasing population densities and changes in social behaviour in section 6.4, a summary of environmental changes at Vankervelsvlei.

6.2 DESCRIPTION OF POLLEN ZONES

Description of pollen zones is based largely on evidence gleaned from the four pollen diagrams produced for VVVA and VVVB. This is corroborated using organic matter content and pollen concentration data as well as grain size information and geochemical content data. Reference is also made to the two summary pollen diagrams generated for VVVA and VVVB. Each of the two cores will be described separately before an attempt is made to integrate the evidence from the two in section 6.4.

6.2.1 VVVA

6.2.1.1 Zone A1a (± 39 900 - 38450)

Both the comprehensive and percentage pollen diagrams (Figures 5.4 and 5.5) show similar trends in pollen fluctuation in this zone. The zone appears to represent a period of high vegetation cover owing to the diversity of taxa represented as well as high pollen concentrations. The presence of several forest tree taxa as well as transitional woody shrub taxa and low growing fynbos and graminoid elements suggest the presence of a range of communities from true forest to scrub forest to heath. Figure 5.6, the summary pollen diagram for VVVA confirms this impression with each of the four designated vegetation communities (aquatics, heath, graminoids and forest elements) occupying similar proportions of the vegetation complement. High moisture availability is indicated in the high concentration of *Lauraceae* (two genera are present in the KAR; *Ocotea bullata*, a canopy tree common in wet forests and found scattered in moist to dry forest and *Cassytha ciliolata*, a parasitic vine) and typically aquatic elements as well as the presence of many tree species. Dessication is indicated towards the top of the zone where moister forest taxa decline in favour of drier forest elements. For example, most high forest tree taxa decline except *Loganiaceae* and *Verbenaceae* which are associated with dryer forest types. Shrub elements such as *Scrophulariaceae (*for example *Teedia lucida, Sutera cordata var. cordata) Capparaceae (*for example *Maerua racemulosa*) and *Rubiaceae* (for example *Gardenia thunbergia*) common in dryer forest and forest margin environments emerge. A significant proportion of the zone is occupied by fynbos taxa, however suggesting a prominent presence of low-growing heath-like vegetation. Nearest Neighbour indices for this period place the fossil communities in closest relationship to modern site 7, a typically low growing fynbos community. It is thus likely, therefore that this zone represents a well vegetated landscape dominated by heath and interrupted by pockets of varying moist to dry forest types.

6.2.1.2 Zone A1b (± 38450 - 21000 BP)

This zone differs little from the previous zone initially, but represents a move towards greater aridity in the landscape. Once again, trends evident in the comprehensive pollen diagram (Figure 5.4) are congruent with those evident in the percentage pollen diagram (Figure 5.5). Although high forest elements such as *Lauraceae* remain prominent in this zone, the influence of dry forest trees and transitional scrub forest trees and shrubs is more dominant than in zone A1a. An increase in abundance and diversity of heath elements and woody shrubs common to drier forest and marginal communities is suggestive of a shift towards slightly drier conditions. A relatively sharp decline in aquatic elements during this time confirms this shift. The summary pollen diagram shows the proportion of forest and aquatic elements decreasing at this time, further verifying the shift. Organic matter content and pollen concentrations are similar in magnitude to those in the previous zone, but decline with depth suggesting less vegetation cover towards the end of the late Pleistocene. It is likely that the landscape retained its appearance of a mosaic of forest patches surrounded by heath, but that the composition of forests varies somewhat in favour of taxa adapted to drier conditions. Site 5, coastal scrub forest, provides a close modern analogue for this time period confirming the dry nature of the forest elements prevalent in the zone.

6.2.1.3 Zone A1c (± 25 060 - 7130)

No pollen evidence is available for this time period although organic matter levels are sufficiently high for pollen to be present. Environmental conditions for this time period have been inferred from VVVB and are described later in this chapter.

6.2.1.4 Zone A2 (± 7130 - 3570 BP)

This zone spans a large portion of core VVVA and gives some indication of environmental amelioration in the landscape. Figure 5.5, based on percentage data, provides a clearer picture of the pollen signal than does Figure 5.4, based on absolute pollen concentrations. However, in both cases it is clear that aquatics are dominant, especially towards the bottom of the zone, as are taxa associated with the moister forest types such as *Lauraceae*, *Meliaceae*, *Flacourtiaceae* and *Podocarpaceae*. Similarly, the summary pollen diagram indicates increased proportions of forest and aquatic elements although graminoids and heath still dominate the landscape. Organic matter levels of 65%-100% during this time period support climatic amelioration as do the corresponding decreases in Iron and Calcium levels. This trend indicates an increase in vegetation cover and thus inferred productivity. Pollen concentrations for this time are surprisingly low, however, but are not an indication of low productivity. Sedimentation rates at this time are faster than at any other time throughout the length of the core, suggesting the presence of an increased amount of organic material for deposition. Moisture availability seems to be highest between 7130 BP and 5500 BP and 4000 to 3570 BP toward the base and top of the zone, with a slightly drier period occurring in-between. Modern sites one and two (S1 and S2) are closely analogous to communities during this time, both of which are largely aquatic in the present day.

6.2.1.5 Zone A3 (± 3570 - 3370 BP)

This zone represents a continuation of the increasing moisture availability evident in the uppermost part of zone A2. This is evident in the sudden and dramatic increase in aquatic taxa as well as Juncaceae and forest taxa characterising moist to wet forest types, for example *Meliaceae, Loganiaceae* and *Podocarpaceae*. The overall increase in pollen concentration and taxonomic diversity is suggestive of conditions favourable for growth. The case for high vegetation cover is supported by geochemical evidence in that high levels of organic matter and co-varying low levels of Iron and are evident. The increase in abundance and diversity of forest trees is of particular note suggesting the expansion of forest pockets to occupy a greater proportion of the afromontane forest mosaic than previously. It is likely that these forest pockets were more akin to moist or wet forest types. The closest modern analogue for this zone is S6, described as scrub forest, but encompassing a wide range of low growing heath and graminoid elements as well as scrub and high forest trees.

6.2.1.6 Zone A4 (± 3400 - 3100 BP)

This narrow zone characterises the late Holocene, the most recent portion of the palaeoenvironmental record at Vankervelsvlei. The zone covers a brief few hundred years around 3400 BP and 3100 BP. From the decline in pollen concentration, it could be assumed that productivity is decreasing at this time. However, levels of organic matter remain close to 100 % suggesting otherwise. Organic matter levels are at their highest for any time period in the record, while Calcium and Iron levels are correspondingly very low proposing dense vegetation cover. Only one sample can be employed to characterise this zone, making any sound judgments concerning the validity of the apparent deterioration of environmental conditions somewhat dubious. However, it is still possible to comment on certain changes in the taxonomic composition of zone A4. Figures 5.4 and 5.5 differ slightly in their presentation of pollen fluctuation at this time. Figure 5.4, based on pollen concentrations, shows aquatics and major heath elements such as *Restionaceae* and *Ericaceae* to be declining, while these elements are shown to be on the increase in the percentage pollen diagram, Figure 5.5. The same pattern is evident in certain of the forest trees, for example *Podocarpaceae*. The diagrams concur in that *Iridaceae*, *Liliaceae* and *Lauraceae* increase in this zone. It is possible that a shift toward changing environmental conditions to those previous may be occurring, but without further information from younger sediments, concrete conclusions cannot be drawn. Information from Groenvlei (Martin, 1967), a mere 5km from Vankervelsvlei, is suggestive of forest shrinkage in the surrounding region at this time. It is thus likely that deterioration of conditions did in fact occur.

6.2.2 VVVB

6.2.2.1 Zone B1 (± 45500 - 40 100 BP)

In terms of palynological characteristics, both Figures 5.7 and 5.8 show this zone to represent a wide range of communities from high forest through to fynbos elements. Typical heath elements dominate, with *Rosaceae* and *Podocarpaceae* (moisture tolerant taxa) also prominent in the record. Several other moist forest taxa such as *Lauraceae* and *Flacourtiaceae* are also present along with taxa more readily associated with dryer scrub forest communities. It should be noted that *Podocarpus* pollen is often dispersed over long distances and the prominence of this taxon could indicate the presence of moist forest in the broader region and not necessarily locally at Vankervelsvlei. It is likely that the landscape at this time would have epitomised the classic afromontane pattern of pockets of forest surrounded by heath, the forest component comprising moist-dry forest constituents. The most favourable period within this zone appears to have occurred between 450cm and 425cm (estimated to be approximately 40 000 BP) where organic content and pollen concentration peak. Geochemical data for this time show corresponding declines in Phosphorus, Sodium, Calcium and Magnesium indicating high vegetation cover and increased productivity. Interestingly, this portion of Zone B1 coincides with the conditions evident in zone A1a. A productive period appears to have occurred between approximately 43 000 and 40 000 BP. Prior to this, in the latter portion of zone B1, conditions seem to have been slightly less favourable as suggested by reduction in organic matter content and pollen concentrations.

6.2.2.2 Zone B2 (± 40 700 - 28 100 BP)

Although several peaks in pollen productivity are evident in this zone, the most notable environmental shift is gleaned from examining the zone as a whole. Between 40 000 BP and about 30 000 BP a gradual shift in environmental conditions seems to be taking place. This shift is interpreted as documenting the move towards less favourable conditions. It is evident in the general decline in taxonomic diversity as well as even greater dominance of heath and woody shrub/scrub forest elements than in Zone B1. This is evident in both Figures 5.7 and 5.8. There is a marked decline in the volume of high forest trees, many of which associated with moist forest types. The decline in *Podocarpaceae*, traditionally a mature forest indicator, is particularly dramatic. Forest pockets may have contracted making room for greater heath dominance in the landscape and a possible change in the nature of forest composition to greater dominance of dry forest woody elements. Pollen concentrations do not drop dramatically from zone B1 to B2, but dominance of communities does alter, indicating the beginning of the transition toward extreme conditions of the LGM. Nearest Neighbour Indices for this time period are interesting, linking afromontane communities at the base (±42 000 BP - 40 000 BP) and top (± 30 000 BP - 27 500 BP) of the zone to Contemporary site 7 (S7) while the mid-part of the zone (±40 000 BP - 30 000 BP) is most closely linked to site 1 (S1), a largely aquatic community. It is thus evident that the environment at this time was not necessarily dry since sufficient moisture was available for the growth of *Cyperaceae*, *Halloragaceae* and limited quantities of moist forest elements. A gradual decrease in moisture availability is implied, although it does not appear to be extreme at this point. Geochemical content of the sediments is inconclusive, with no clear relationship between organic content and other geochemical elements evident.

6.2.2.3 Zone B3 (± 28 100 - 4700 BP)

This zone marks the continuation of dessication in the environment. Not only do pollen concentrations decline quite markedly, but taxonomic diversity decreases as well. Of particular note is a dramatic decrease in the quantity of pollen from forest trees, and the rapid decline of aquatic elements leaving the impression that the landscape was dominated by low growing heath and woody shrub elements. The presence of forest trees is barely visible in Figure 5.7, indicating low pollen concentrations, however, Figure 5.8, based on percentage data, shows the presence of tree taxa such as *Lauraceae* and *Flacourtiaceae* (as do the pollen counts in Appendix G). Despite indications of dessication in the environment, it appears that a certain level of moisture has been maintained to ensure the survival of these afromontane trees. The possibility that pollen from afromontane tree taxa could have been transported from other localities within the KAR cannot, however, be ruled out.

The obvious decrease in productivity could be a consequence of an extreme temperature drop resulting in a much stunted, yet present local or possibly regional forest flora. In keeping with the afromontane mosaic, heath elements are more abundant than forest, but are also reduced in their abundance in comparison to the obviously more productive late Pleistocene. Geochemical evidence from this zone shows an overall trend of low organic matter content versus higher levels of Calcium, Magnesium and Iron indicating a decrease in vegetation cover and productivity at this time. In addition, Nearest Neighbour Analysis closely links three of four sampled communities in zone B3 to contemporary site 7 and the fourth to S5. Both these modern sites do contain forest taxa, but are dominated by fynbos families. Interestingly, S7 is the most taxonomically diverse.

Figure 5.7, based on pollen concentrations, shows the remainder of zone B3 (early Holocene) to monitor continuing dessication with woody elements having almost disappeared from the pollen record altogether. Taxonomic composition of the upper part of the zone is identical to that of the lower, but quantities of pollen present are far less. It is likely that the landscape at this time would again be dominated by heath elements and somewhat stunted peripheral forest communities. Steady declines in pollen concentration are probably a function of a slower sedimentation rate which in turn is suggestive of greater vegetation cover. Geochemical data from this time period also suggest high vegetation cover in comparison to the lower portion of the zone. The upper half of the zone is thus probably representative of the amelioration of conditions leading into the early Holocene. Indeed, Figure 5.8, based on percentage data, adequately shows the presence of a variety of taxa, dominated by heath elements such as *Ericaceae* and woody shrubs, for example *Ebenaceae*. Moist forest indicators such as *Rosaceae*, *Lauraceae* and *Podocarpaceae* are also evident. Thus, the upper portion of zone B3 probably represents the warming of environmental conditions accounting for increased productivity.

The following section attempts to draw together evidence from VVVA and VVVB into a coherent synthesis of environmental change for the study site. Evidence from pollen zones representing the late Pleistocene, terminal Pleistocene and Holocene from each core are described together. Approximate ages of the three time [periods in question have been calculated by interpolation.

6.3 VEGETATION CHANGE AT VANKERVELSVLEI

This section aims to summarise the major changes in environmental conditions that have been described in sections 6.2 and 6.3. Figure 6.1 provides a summary of vegetation changes at Vankervelsvlei, while Table 6.2 (in section 6.6.1) focuses on the expansion and contraction of the forest component of the landscape in particular. This is an attempt to respond to the proponents of the two schools of thought relating to the history of afromontane vegetation. Obviously, the vegetation history from a single site, as in the case of Vankervelsvlei, cannot in itself dispel the questions surrounding this debate, but the site does provide new evidence extending further back in time than previous palynological studies in the area. It is hoped that this evidence will be used as a basis from which further research can be undertaken.

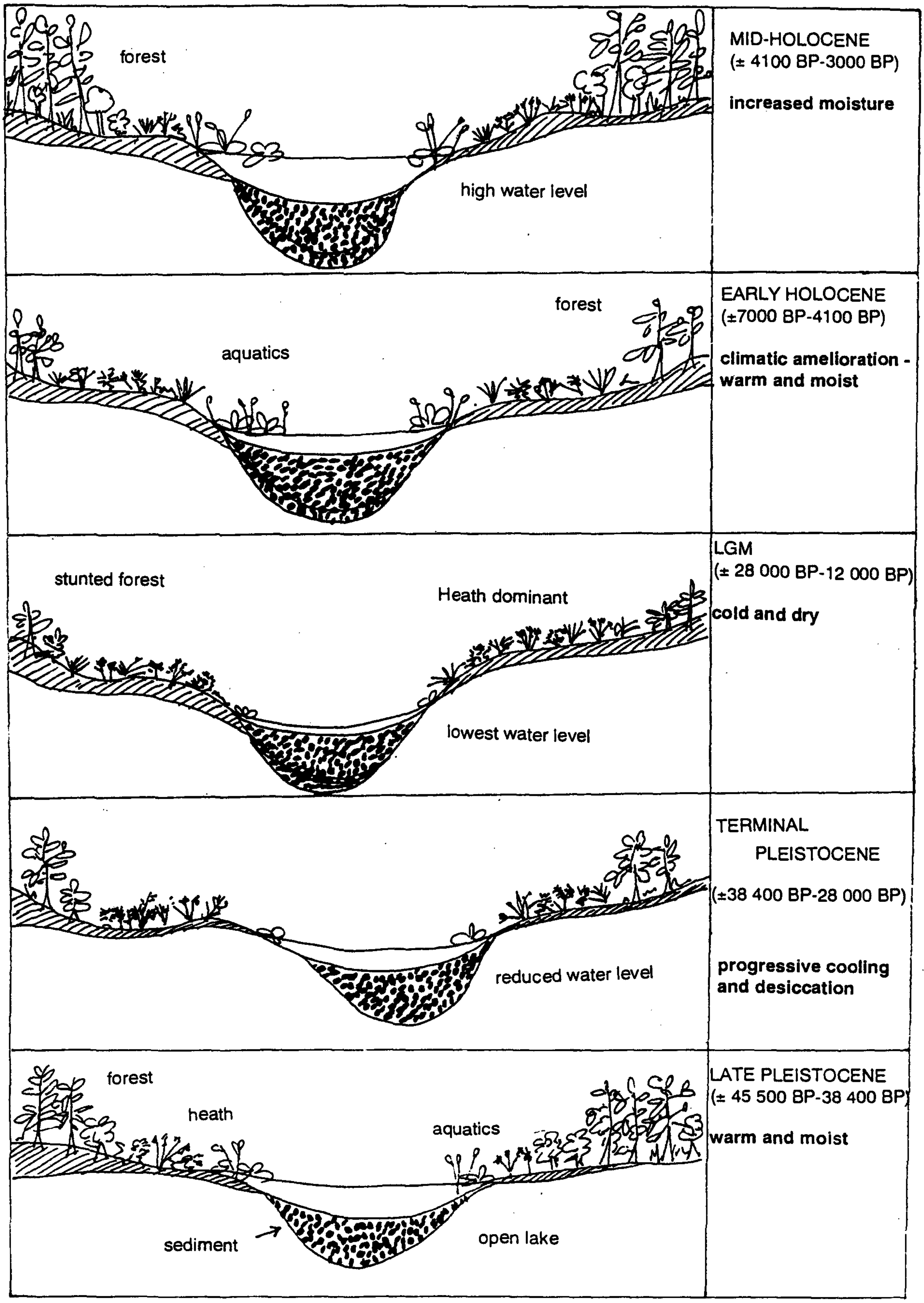


Figure 6.1: Summary of vegetation changes at Vankervelsvlei

6.3.1 Late Pleistocene (approx. 45 500 BP - 28 100 BP)

As stated in sections 5.3.1.3 and 5.3.2 .3. of Chapter 5, the time period known as the late Pleistocene is represented in the cores between 705cm - 550cm in VVVA and 475cm - 250cm in VVVB. The pollen zones within these depth ranges are A1a and A1b in VVVA and B1 and B2 in VVVB. The major trends evident from this time period are listed below:

I. Between around 45 000 BP and approximately 38 400 BP, conditions favourable for forest growth prevail. The system appears highly productive at this time, the full range of afromontane communities (that is, pockets of forest surrounded by heath vegetation) as well as aquatic elements being in evidence. Proportionally, forest and aquatic elements occupy a slightly greater portion of the pollen complement than do heath and graminoid elements. This implies high moisture availability locally as suggested by abundance of aquatic elements and in the surrounds of Vankervelsvlei by the importance of forest elements in the vegetation mosaic. From the abundance of aquatic elements, it is assumed that Vankervelsvlei would have shown characteristics of an open water coastal lake at this time.

II. The remainder of the late Pleistocene, defined in this study as stretching from about 38 400 BP to 28 100 BP, is characterised by gradual drying and cooling of environmental conditions resulting in shifts in the vegetation mosaic. Generally speaking, conditions remain sufficiently moist to support forest elements, but their proportional dominance in the landscape declines in favour of heath (fynbos) and woody shrubs. A notable dry period in the late Pleistocene appears to have occurred between approximately 28 000 BP and 26 000 BP where heath and woody elements dominate the landscape proportionally. A short-lived period of favourable conditions seem to have occurred at approximately 32 000 BP where forest vegetation increase in dominance briefly. Depending on the level of available moisture during this period, the nature of the forest component changes, obviously favouring drought tolerant taxa such as *Ebenaceae* in drier conditions and moisture tolerant taxa like *Podocarpaceae* and *Lauraceae* in comparably moister conditions. Obviously, incremental cooling of temperatures towards the end of the Pleistocene would also have affected forest growth and favoured the hardier scrub forests and low-growing heath. The progressive trend toward cooler and drier conditions suggests that the coastal lake at Vankervelsvlei would have dried out gradually, although not completely.

6.3.2 Terminal Pleistocene and LGM (approx. 28 100 BP -12 100 BP)

Sections 5.3.1.3 and 5.3.2 .3 of Chapter 5 delineate this period between 550cm and 400cm in VVVA and 250cm and 150cm in VVVB. No pollen data are available for this period in VVVA, but it is represented in VVVB by the lower 80cm - 100cm of pollen zone B3. The VVVB core from Vankervelsvlei provides the first evidence linking vegetation to environmental conditions during the LGM in the KAR. Although the evidence pertains only to the localised environment surrounding Vankervelsvlei, these findings are unique and thus of some interest. They are summarised below:

I. Predictably, the latter part of the Pleistocene and specifically the LGM represent the least productive period throughout the palaeoenvironmental record at Vankervelsvlei. From 28 100 BP to approximately 19 000 BP vegetation cover appears to drop to its lowest level and graminoid elements, including the family *Restionaceae* and low-growing heath elements are dominant. Of particular importance though, is the fact that forest and aquatic constituents remain part of the vegetation mosaic, albeit in small quantities. Thus, it is likely that Vankervelsvlei itself reached the lowest water level in the available palaeoenvironmental record during the height of the LGM. The afromontane mosaic, however, appears to have been maintained, but forest pockets are likely to have shrunk dramatically. In addition, forest tracts were probably reduced to a stunted form of their late Pleistocene counterparts, comprising mostly shrubs such as *Myricaceae* and *Sapindaceae* and a few resistant tree taxa.

6.3.3 Holocene (approx. 12 100 BP - 3170 BP)

This time period is represented in a large proportion of VVVA, namely the upper 400cm of the core and to a lesser extent in the uppermost 150cm of VVVB. The relevant pollen zones are A2, A3 and A4 from VVVA and the upper 150cm of B3 in VVVB. The earliest part of the Holocene is missing from the pollen record, but the conditions prevailing between 7500 BP and 3100 BP are detailed below:

I. Between 7130 BP and approximately 5300 BP a return to more productive conditions is evident, that is, an increase in moisture and temperature. The nature of the afromontane mosaic shifts once more to accommodate expanding forest elements and aquatic plants with heath types less prominent. Archaeological records show a reduction in the size and range of social groups at this time suggesting that conditions had improved (Deacon, 1984; Deacon, 1995). The change from terminal Pleistocene conditions is dramatic. This is more than simply the effect of natural environmental amelioration experienced in the early Holocene. The extremity of the change in conditions is also related to the break in the palaeoenvironmental record afforded by the sedimentary hiatus described in Chapter 5. Aquatic elements appear to occupy the greatest proportion of the landscape at this time, suggesting that the basin itself is likely to have filled once more.

II. Between 5300 BP and 4100 BP conditions appear to be slightly drier and less productive. This marks the driest portion of the Holocene in the Vankervelsvlei palaeoenvironmental record. The afromontane mosaic is likely to have reverted to smaller forest pockets and a dominance of Restioid heathland. Close to 4000 BP forest reaches its lowest point in terms of dominance in the landscape with *Restionaceae* dominated heathland predominant. Aquatics are still evident maintaining the presence of open water at the site.

III. The latter part of the Holocene record between approximately 4100 BP and 3170 BP is undoubtedly the most productive period throughout the record. It marks quite a sudden change towards climatic amelioration. Conditions appear extremely moist and warm allowing the burgeoning of aquatics and moist forest elements in the landscape. Forest patches and heath occupy similar proportions of the pollen complement, and aquatics are very prominent. The sudden increase in aquatic elements could herald the onset of growth of the vegetation mat at Vankervelsvlei, but this is uncertain.

IV. Thus it is evident that the early part of the Holocene at Vankervelsvlei was in fact drier than the latter. Sufficient moisture for substantial forest growth is evident early on, but conditions become even more favourable closer to the present day.

To summarise, it is obvious that the afromontane mosaic described in chapter 3 has been present throughout the time period represented by the palaeoecological sequence from Vankervelsvlei. It is apparent that forest pockets have remained a feature in the landscape despite the cooling of temperatures during the late Pleistocene and LGM. During times of climatic deterioration, it would appear that composition of forest pockets changed with hardier taxa replacing moisture tolerant families. It is likely that forest pockets contracted in size and stature as well in favour of lower growing stunted scrub forest vegetation. The maintenance of the forest mosaic would tend to discount the theory put forward by Phillips (1931) and Van Daalen (1980) that the pattern of forest patches evident in the KAR in the present day is a function of human impact. On the other hand, it would appear that forests have, despite fluctuations in accordance with natural climatic perturbation, maintained a consistent presence. It is probable, however, that human interference through land clearance for agriculture, forestry and recreation, have exacerbated natural climatic factors. The palaeoenvironmental record does not cover the interval in which human intervention has become important and this question is thus not pivotal in this study.

6.4 LATE QUATERNARY ENVIRONMENTAL CHANGES AT VANKERVELSVLEI

Therefore, in summary, it is evident that on a broad scale differing conditions have prevailed at different times during the last 45000 years. This section aims to discuss the changes outlined in section 6.4 in comparison to work undertaken by Martin (1967), Klein (1980), Scholtz (1986), Partridge *et al.* (1990) and Partridge (1993) to justify conclusions drawn. In this manner, it is hoped that a valid synthesis of environmental change for the Late Pleistocene, the LGM and the Holocene at Vankervelsvlei can be produced.

6.4.1 Late Pleistocene

Generally it appears as if the Late Pleistocene has been characterised by conditions sufficiently moist to support forest growth. On the other hand, moisture availability does not appear to have been adequate for the development of true high forest as characterised by Werger (1978) (see Chapter 3), but was restricted to moist and dry forest types. With pollen concentrations reaching several millions of grains/cm3, it is obvious that the environment was highly productive and the dominance of clay material, as opposed to sand, in the sedimentary record is suggestive of moist conditions and water retention. As expected, towards the end of the Pleistocene, conditions do appear to change, presumably as a result of lower temperatures and possible dessication. Aridity is somewhat exacerbated towards the end of the Pleistocene epoch heading into the LGM. This is in keeping with conclusions reached by other scientists concerning conditions in the rest of the subcontinent at this time. With specific reference to the southern coast, the work of Martin (1967) and Scholtz (1986) is not applicable due to the limited age range of data analysed at Groenvlei and Norga. Both studies apply only to the Holocene. The work of Klein (1980), however does extend into the late Pleistocene and provides a useful basis for comparison. Evidence from large mammalian remains at Boomplaas Cave from the late Pleistocene show cold and dry conditions at approximately 32 000 BP. What moisture is available is said to be the result of winter rainfall possibly accounting for the abundance of fynbos elements and the dry character of the forest elements present in the Vankervelsvlei pollen diagrams at this time . The Vankervelsvlei evidence, does, however, show the presence of a certain degree of moisture in that moist forest taxa such as *Podocarpaceae* are present.

Evidence from roughly 22 000 BP (Klein, 1980) indicates a climate less harsh than subsequently with increased rainfall facilitating the growth of scrub, karroid vegetation and grassland. It appears that MSA/LSA peoples remained in the area despite the deterioration of conditions suggesting that sufficient moisture was available to them. Archaeological evidence does indicate that there numbers were substantially reduced and the size of social groups and their ranges is likely to have increased to ensure the collection of sufficient resources (Deacon, 1984; Deacon, 1995).

6.4.2 Terminal Pleistocene and LGM

Evidence from large mammalian remains (Klein, 1980) from 17 500 BP shows scrub and grassland to be favoured over other vegetation types. The early part of zone B3 from Vankervelsvlei (which encompasses this portion of Klein's evidence) shows a dramatic decrease in the volume of forest trees in the landscape and the prevalence of low growing heath and woody shrub elements. It is thus apparent that the two accounts of vegetation change concur for the height of the LGM. However, it is vital to note that classic afromontane forest elements are maintained as part of the Vankervelsvlei vegetation mosaic although their proportional significance declines in comparison to late Pleistocene levels.

A drop in productivity during this time is obvious and expected and is evident in the significant decreases in pollen concentration and taxonomic diversity evident at Vankervelsvlei. However, the reason for this decline may be largely function of temperature differences and less so the result of extreme aridity as accepted for the rest of the subcontinent (Partridge *et al,* 1990). VVVB, the core from which pollen evidence has been analysed for this time period, indicates the continued presence of forest elements during the height of the LGM. Thus, it is possible that dessication proved less extreme than elsewhere in southern Africa. Sufficient moisture remains available for the afromontane mosaic to be maintained, although forest pockets were probably smaller and constricted to dry and scrub forest types. Forest communities would probably have been stunted and less complex than their Pleistocene counterparts. Interestingly, no significant fluctuations are noted in organic matter content in the transition from Late Pleistocene to LGM which may further justify a moister LGM on the southern coast of southern Africa.

6.4.3 Holocene

Klein (1980) proposes a very moist late Pleistocene at approximately 14 000 BP through the establishment of all year rainfall at this time and the consequent expansion of mesic vegetation types. Pollen evidence from Vankervelsvlei is unavailable for this time period and thus this evidence cannot be corroborated. By 12 000 BP, Klein (1980), shows the persistence, and even heightening of moist conditions though temperatures remain cooler than later in the Holocene. Evidence from VVVA and VVVB for this time suggests a relatively dry early Holocene (between 12 000 BP and 10 000 BP) which corresponds to the younger Dryas on a global scale and pronounced dessication throughout the interior at this time (Scott, 1993; Partridge *et al.*, 1990).

Evidence from the Vankervelsvlei record continues from approximately 7000 BP and allows for comparison with the Groenvlei (Martin, 1967) and Norga (Scholtz, 1986) accounts of environmental change. Between 7000 BP and 5300 BP conditions appear moister and warmer than during the LGM, but are not as favourable as during the latter portion of the Vankervelsvlei Holocene record. Martin (1967) records a dry period of restricted forest growth between 8000 BP and about 7200 BP followed by a possible period of amelioration lasting until about 6300 BP. The Vankervelsvlei account from both VVVA and VVVB highlights the period of possible increased favourability and forest spread between the depths of 400cm 310cm in VVVA and about 40cm - 0cm in VVVB. However, in both cores heath elements are dominant and in VVVB forest is proportionally less common than previously. This does little to clarify the possibility of moister conditions at this time considering the missing information in VVVA providing no comparison with conditions prior to 7130 BP. Information from VVVB does, however, seem to negate increased moisture. Klein (1980) also documents aridity at 6000 BP supporting Vankervelsvlei evidence. Archaeological evidence from the Mid-Holocene confirms climatic amelioration at this time in comparison to the LGM and terminal Pleistocene. Population densities in the area increase and smaller ranges are required from which to draw resources. It appears that the southern Cape was a preferred region for human occupation at this time (Deacon, 1984; Von den Driesch and Deacon, 1985; Deacon, 1995).

From 6300 BP to 2500 BP two scenarios are provided by Martin (1967). Forest spread is said to be restricted either as a result of dryer conditions or as a consequence of sand cover limiting its movement. Evidence from the Loerie site near Plettenberg Bay (within 30 km of Vankervelsvlei) records the accumulation of littoral dunes and slope and valley fill between 6300 BP and 4300 BP. Palynological evidence from Vankervelsvlei sanctions drier conditions from 5300 BP to 4100 BP, the driest period in the Holocene account from the site. Thus, new evidence gleaned from Vankervelsvlei tends to support the first alternative put forward by Scholtz (1986), that is the restriction of forest growth due to dry conditions. However, evidence for the formation of coastal dunes suggests that sand movement could have further restricted forest spread and it is possible that a combination of the two factors has resulted in the contraction of forest pockets during the mid-Holocene. Vankervelsvlei evidence for the period between 4100 BP and 3170 BP supports conditions favouring forest expansion. Indeed, Scholtz (1986) documents all seasonal rainfall at George with forest more widely distributed at this locality between 4000 BP and 2600 BP. This is in contrast to Martin's (1967) suggestion that the restriction of forest spread due to aridity or sand movement extended until approximately 2500 BP. Evidence from Loerie between 4100 BP and 1500 BP shows the formation of peat once again suggesting the abundance of moisture and conditions suited to forest growth. Archaeological records show humans as hunter-gatherers throughout the Holocene and as such their influence on the environment as minimal before 2 000 BP when evidence of fire management and settled agriculture appears (Deacon, 1984, Von den Driesch and Deacon, 1985).

Thus it is evident that evidence from Vankervelsvlei is largely supportive of findings already in existence regarding environmental change on the south coast of southern Africa. The only possible inconsistency lies in the suggestion that the LGM was in fact drier when the remainder of the CFK, of which the KAR is a part, experienced a wetter LGM. This possibility has been alluded to by the evidence gleaned from the Vankervelsvlei cores, but requires further in depth investigation to ascertain the extent of this phenomenon beyond the locality of Vankervelsvlei itself. Meadows and Baxter (1998, in press), in their revised synthesis of the late Quaternary palaeoenvironments of the southwestern Cape, allude to the probability that the southern Cape has experienced a late Quaternary climatic history different to that of the rest of the CFK region. Building on the regional syntheses compiled by Deacon *et al.* (1983), Deacon and Lancaster (1988) and Partridge *et al.* (1990), new evidence from Eland's Bay Cave and Verlorenvlei on the west coast of South Africa as well as the Cederberg and the Cape Peninsula have been included. Interestingly, it appears that during the LGM, the southern Cape (KAR) has responded to late Quaternary precipitation changes in the same manner as the interior of the subcontinent, that is the summer rainfall region (Meadows and Baxter, 1998 in press).

6.5 THE BURNING QUESTIONS

This final section of Chapter 6 aims to address two important biogeographical questions raised concerning the vegetation history of Vankervelsvlei. Of particular interest is, firstly, the changing status of the forest component of the afromontane forest mosaic at the site over the period represented by the palynological record. The second issue is that of the formation of the unusual floating marsh mat evident at the site in the present day. The length of the palaeoenvironmental sequence at the study site as well as the unique nature of the schwingmoor landform formed the basis of the potential of the site as a landmark palaeoecological research locality. These questions are thus very important in terms of the objectives of this study and specific attention is paid to them in the following sections before more general conclusions are drawn in Chapter 7.

6.5.1 Forest history at Vankervelsvlei

Table 6.2 (overleaf) adequately summarises the fluctuation of afromontane forest elements in the landscape over the time period represented by the Vankervelsvlei palaeoenvironmental record. Although these changes in proportional extent of forest vegetation have already been described in this chapter, this brief summary attempts to draw together evidence specific to the issue of forest history in the KAR laid out in Chapter 1.

TIME PERIOD (yrs BP)	FOREST HISTORY	INFERRED ENVIRONMENTAL CONDITIONS
4000 - 3100	FOREST EXPANSION	wet
5500 - 4000	FOREST DECLINE	dry
7100 - 5500	FOREST EXPANSION	warm and moist
12 000 - 7100	FOREST DECLINE	cool and dry
19 000 - 12 000	POSSIBLE HIATUS	probably cold and dry
28 000 - 21 000	CONSTANT FOREST PRESENCE	cold and dry
32 000 - 28 000	FOREST DECLINE	cool and dry
circa 32 0000	FOREST EXPANSION	cool and moist
40 000 - 32 000	FOREST DECLINE	progressive cooling and dessication
43 000 - 40 000	FOREST EXPANSION	warm and moist

Table 6.1: History of forest spread at Vankervelsvlei between 45 000 BP and 3000 BP.

As Table 6.1 shows, forest expansion occurs between 43 000 BP and 40 000 BP before declining between 40 000 BP and 28 000 BP. During this 12 000 year interval, forest extent remains relatively constant despite a few slight fluctuations. The most notable of these occurs at about 32 000 BP where a brief term of climatic amelioration is experienced. From 28 000 BP to 21 000 BP (the period encompassing the LGM), forest extent appears to vary little, maintaining a constant presence despite the coolest and driest conditions in the palaeoenvironmental record. The proposed hiatus in sedimentation between 19 000 BP and approximately 12 000 BP precludes the formulation of any conclusion regarding the extent of forest at this time. The early Holocene, between 12 000 BP and 7 000 BP shows a proportional decline in relation to LGM forests with expansion evident between 7 100 BP and 5 500 BP. This is presumably in response to the stabilising warmer and moister conditions of the Holocene. A drier period occurs between 5 500 BP and 4 000 BP causing forest to contract. Climatic favourability is once again evidenced in a moister mid to late Holocene with a more dramatic increase in forest extent.

It is thus apparent that forest has been an integral part of the vegetation mosaic throughout the period of vegetation history covered at Vankervelsvlei. This evidence tends to counteract the widely held conviction that afromontane forest along the Cape south coast extended all the way from Knysna to the Cape Peninsula and that human intervention in the past few hundred years has been almost entirely responsible for the forest pockets visible today. Evidence from Vankervelsvlei proves that the mosaic character of the vegetation has been in existence since the late Pleistocene. Obviously, the evidence from Vankervelsvlei is limited in its applicability due to the small size of the basin and the ensuing local nature of the palaeoenvironmental information gleaned from the site. As such, the longevity of the afromontane mosaic cannot necessarily be extrapolated to the remainder of the KAR. It is therefore necessary that further long records of environmental change be synthesised to corroborate these findings. Fortunately, conditions in the KAR are suited to the preservation of reliable proxy indicators of vegetation change such as fossil pollen and suitable sites for palaeoecological research are almost certainly available.

6.5.2 Schwingmoor development at Vankervelsvlei

It is unfortunate that the palaeoenvironmental record at Vankervelsvlei does not shed light on this particular topic. Radiocarbon dates show the earliest part of the sedimentary sequence to date back to 3000 BP, at which point the floating mat does not seem to have developed. A proposed scenario for the formation of the schwingmoor is given below.

Although schwingmoor bogs form for a variety of reasons, the development of a depression in which water collects is the initial step. In the case of Vankervelsvlei, an interdunal lake formed some time after the stabilisation of the Pliocene dunefield and continued to evolve as a doline in response to solution of interstitial calcium carbonate. At some time prior to 45 000 BP, it is assumed that the basin filled with water and consequently organic lacustrine sediments. The water would have provided the necessary stimulus for the growth of aquatic plants as is evident throughout the palaeoenvironmental record at the site. Fluctuations in the dominance of these aquatics are interpreted as indicative of changing water availability over time. The accumulation of organic material in the doline over time would have facilitated a decrease in water depth, gradually driving the succession from marsh to bog-like conditions. The actual growth of the marsh mat over the water surface is, however, not documented in the Vankervelsvlei record. Further investigation of sediments from the site may yield palynological proof of this phenomenon and it is recommended that further cores are acquired for this purpose.

6.6 CONCLUSION

This chapter has endeavoured to reconstruct environmental conditions at Vankervelsvlei from the late Pleistocene to approximately 3000 years BP. Palynological, sedimentological and geochemical evidence from Chapter 5 has been synthesised in an attempt to produce a decisive palaeoecological record for the two cores, VVA and VVB. Evidence from the two cores has in turn been combined with the aid of seven radiocarbon dates acquired from sediments from Vankervelsvlei. Lastly, conclusions drawn from Vankervelsvlei evidence has been compared with results published by other authors for sites close to Vankervelsvlei (Martin, 1967; Scholtz, 1986) as well as regional syntheses of environmental change (Partridge *et al.*, 1990; Scott, 1993). In so doing, an attempt has been made to contextualise consistencies and inconsistencies in the Vankervelsvlei record. Chapter 7 will go on to address the objectives laid out at the outset of this study in Chapter 1 as well as put forward several impending research directives.

CHAPTER 7

THE FINAL WORD

7.1 INTRODUCTION

The previous chapter detailed the palaeoecological reconstruction of environmental conditions at Vankervelsvlei during the late Quaternary. The aim of this concluding chapter is to assess the extent to which the objectives of the study outlined in chapter one have been adhered to. In addition, suggestions are made concerning future research directions into the history of the afromontane forests in the Knysna region.

7.2 REVIEW OF AIMS AND OBJECTIVES

The fundamental aim of this project, as stated in Chapter 1, has been to reconstruct the late Quaternary environmental history of Vankervelsvlei with specific reference to the behaviour of afromontane forest communities. In order to do so, it was necessary to collect data, compile reference material and undertake several types of analyses and necessitated the formulation of various more specific objectives. These are discussed in more detail in the following section.

I. The first objective was to assemble pollen reference material from which fossil pollen taxa could be likened and consequently identified. This objective was successfully carried out and prepared pollen slides of taxa specific to the KAR have been added to the CTCP, thereby increasing its reference base. This collection is housed in the Palaeoecological Research Laboratory of the Department of Environmental and Geographical Science at the University of Cape Town. Furthermore, the collection formed the basis for pollen counting and facilitated the analysis of data used in the two pollen diagrams presented in this thesis. These diagrams, constructed using PSIMPOLL 2.27 (Bennett, 1994) were the key elements used in realising the aim of reconstructing the vegetation history of the site. Thus, the production of a site-specific pollen reference collection successfully allowed for the achievement of a primary goal of this research thesis. Numerous conclusions (expounded in Chapters 5 and

6) were drawn from pollen data regarding the fluctuations in vegetation composition and from these, perturbations in environmental conditions were inferred. Pollen data was also used in the production of two summary pollen diagrams which helped in defining the changing composition of the afromontane mosaic over time. In addition, the reference collection was used to identify contemporary pollen forms in surface collections for use in statistical comparisons between fossil samples and proposed modern analogues. As such, the creation of a pollen reference collection has proved foundational to the rest of the study and to the fulfilment of objectives five, six and eight.

II. The second objective was to extract sedimentary sequences from the site for palaeoecological enquiry. This has been achieved in the form of VVVA and VVVB which have yielded relatively chronologically consistent sediments. A hiatus in sedimentation is, however, obvious during the early Holocene and thus information from this period is missing from the record. However, both cores have been successfully extracted and subsampled allowing for palynological, sedimentological, geochemical and radiocarbon analysis to be carried out.

III. As per objectives three and four, the stratigraphy of the cores VVVA and VVVB has been comprehensively described and a chronology has been produced for each. Sedimentary strata have been described using the 'Munsell Soil Colour Charts' (1975) system and radiocarbon dates were acquired with the assistance of the CSIR in Pretoria. Graphic representation of this information has been detailed in Chapter 5. The achievement of these objectives allowed for greater accuracy of interpretation of palynological data by contributing a temporal element to the analysis. Thus comparison with other studies has become possible.

IV. Objective five called for the reconstruction of the late Quaternary vegetation history of Vankervelsvlei. This has been achieved in the form of a narrative sequence of environmental perturbation based on fluctuations in the relative frequencies of fossil pollen. A degree of subjectivity in this process is unavoidable considering that links between fluctuations in vegetation communities and environmental parameters are made at the discretion of the author. A summary of major events has been outlined at the end of Chapter 6. In the author's opinion, of greatest significance is the presence of forest throughout the palaeoecological sequence. This suggests the relative stability of the afromontane mosaic since the late Pleistocene and implies that human intervention in the landscape has not been the sole cause of forest decline in recent centuries.

V. Objective six involved the correlation of modern and contemporary pollen signals and the identification of modern analogues for fossil communities. The use of Nearest Neighbour Analysis identified several close analogues to contemporary communities. The strength of this technique seems to lie in its use of the entire data set in computing similarities between samples without falling prey to problems of dimensionality (Ter Braak, 1994). For this reason it was chosen above other prominent techniques, notably CA, CANOCO and PCA which are affected by dimensionality. The identification of modern analogous communities may be even more crucial in the context of southern hemisphere palynological enquiry as a result of the greater taxonomic diversity compared to that experienced in the northern hemisphere temperate latitudes. Nearest Neighbour Analysis in particular is useful in this regard owing to the greater precision of analogue identification as explained in Chapter 4. The technique has been successfully proven in the work of Baxter (1997) who applied the procedure to pollen samples from the west coast Sandveld, a similarly complex system comprising several converging phytochoria.

VI. In terms of sedimentological and geochemical analyses mentioned in objective seven, basic grain size and elemental inquiry has been carried out to provide supplementary evidence to pollen data. In effect, these studies have made a somewhat limited contribution to the study, providing information relating to broad scale environmental changes. They have, however, provided valid supportive evidence to the palynological findings of this study.

VII. Finally, objective eight attempted to draw together all the abovementioned elements resulting in a complete palaeoenvironmental reconstruction for the study site. The story of Vankervelsvlei has been described adequately in Chapter 6 and further elucidation will not be attempted here. However, it is important to note the progression of vegetation community changes as depicted in Chapter 6. Chapter 6 epitomises the culmination of this initiative and serve to address the primary research concern of this project, namely the issue of the history of afromontane vegetation in the KAR. The most notable conclusion to be drawn from the vegetation history is that forest elements do not seem to dominate the fossil sequence at any time during the period recorded in the stratigraphical sequence. In other words, it appears that afromontane forest has formed a consistent element in the vegetation complement of the KAR since the late Pleistocene. However, in the opinion of the author, it has not been significantly more widespread than in the latter part of the Holocene as suggested by proponents of the 'conventional wisdom' school of thought (Phillips, 1931; Van Daalen, 1980). Rather, it is proposed that forest has always been only a component of a more complex mosaic of fynbos and coastal dune vegetation, fluctuating in abundance according to the availability of moisture. In terms of the development of the unusual schwingmoor bog at the site, it appears that this landform is likely to have formed in the latter part of the Holocene, but the onset of this event is not recorded in the Vankervelsvlei palynological sequence.

Each of these specific objectives was laid out in order to facilitate the realisation of the primary goal of this study. This section has attempted to illustrate the manner in which each objective has contributed to the palaeoecological reconstruction of environmental conditions at Vankervelsvlei. It is important that the findings of this study be contextualised in a broader framework and it is this directive that forms the premise for recommendations made for future research.

7.3 FUTURE RESEARCH

There are several reasons for pursuing further investigation into the history of the KAR. The first relates to the threat posed to the survival of afromontane vegetation in the face of impending environmental change, while the second focuses on the rarity of lengthy, accurate palaeoecological records in southern Africa. More specifically, the failure to document the development of the floating bog at Vankervelsvlei provides adequate reason to analyse more recent deposits from the site itself. Furthermore, investigation of younger sediments is likely to provide insight into the role of human impact on forest history in the region.

7.3.1 Future research in the KAR

7.3.1.1 Forest management

It is worth noting the value of this study in documenting the history of forests in he KAR. An understanding of the response of forest and other vegetation types to environmental perturbations in the past has important implications for conservation practice and ecosystem management. This is especially significant considering the changes expected to occur in global climatic systems in the future (see Chapter 2) The Vankervelsvlei data has provided indications of the response of forest and fynbos vegetation to fluctuating environmental conditions over a vast period of time, indeed the longest vegetation history yet produced for the KAR. This information could prove fundamental considering that projected CO_2 increases are thought to result in drier conditions which do not favour forest growth. It is thus to be expected that future climatic change will probably lead to a decline in forest extent, so much so that forests may be confined to isolated refugia where conditions remain favourable. Therefore it is imperative that further research be carried out to gain as much insight as possible into the responses of afromontane forest vegetation to environmental change in the hope that careful management will minimise forest loss.

This is particularly true of the afromontane forests of the KAR which occupy the southernmost extension of the afromontane archipelago in Africa (Werger, 1978) and are sensitive to disturbance and predisposed to fluctuations in the area they occupy. Furthermore, it is widely accepted that afromontane vegetation commonly comprises a mosaic of forest 'islands' within a 'sea' of grassland or heath vegetation (Werger, 1978;

Phillips, 1931). This places increased stress on the already pressured forests elements through competition for resources in a constantly shifting tension zone of floras.

7.3.1.2 Southern African Quaternary studies

Several authors address the issue of the paucity of sites suitable for palaeoecological and especially palynological research in the southern African subcontinent (Meadows, 1987; Adams, 1994; Baxter, 1997). With specific reference to the palaeoenvironments of the southern coast of South Africa, it is probable that many sites rich in fossil pollen and other biological indicators exist within close proximity to one another (Adams, 1994). This is a function of the moist all year climate and the abundance of coastal lakes in the area which provide classic conditions for the preservation of polleniferous material. The work of other authors in the areas surrounding Vankervelsvlei has yielded well preserved fossil pollen material (Martin, 1967; Scholtz, 1986), as has the Vankervelsvlei deposit itself, suggesting that other sites are potentially available in the area. Considering the reliable nature of pollen as proxy evidence for environmental change, further contributions to the palaeoecological database for the subcontinent from the area could prove invaluable and it is recommended that new study sites be sought out for investigation.

7.3.2 Additional research at Vankervelsvlei

In terms of Vankervelsvlei, the uniqueness of the schwingmoor bog at the site is in itself sufficient reason to prompt further study. Due to the failure of both cores A and B to provide sufficient information to elucidate environmental change in the recent past, it is proposed that further coring be done at Vankervelsvlei. Attempts to locate evidence spanning the last glacial maximum have been successful allowing for the reconstruction of past environmental conditions to extend beyond present knowledge for the region. However, dating suggests that at least the past 3000 years is unaccounted for in terms of pollen and other geomorphological evidence. In keeping with the research goals of this project, it is vital that this section of the palaeoenvironmental record be retrieved in order to provide a complete environmental history of the site and the surrounding areas. This is of particular concern in attempting to gauge the nature of human impact on the Knysna forests since pre-colonial times. Knowledge of human activity in the last hundred years especially would be useful in determining the development of the unique floating bog landform at Vankervelsvlei in the present day. In addition, the extent of forest spread just prior to colonial human intervention in the landscape remains a mystery and is unlikely to be understood without the procurement of appropriately aged sediments from the area. As such, the aim to understand the behaviour of the forests with respect to climate prior to colonial human impact is at this stage hampered by the lack of applicable information. Of particular interest is the possible role of human interference in initiating the covering of the Vankervelsvlei basin to form a floating bog, a feature apparently unique in the subcontinent. Several indicators have the potential to resolve these questions, the first being the arrival in the pollen record of alien vegetation.

7.4 CONCLUSION

This chapter has attempted to draw together the major findings of this study through assessing the extent to which the objectives laid out in Chapter 1 have been addressed. In addition, an attempt has been made to highlight several possible future research initiatives brought to light in the duration of this project. Indeed, Vankervelsvlei has proved itself a valuable contributor to palaeoecological enquiry in southern Africa and further investigation at the site is likely to yield additional significant information. It is therefore hoped that this study be used as a foundation upon which to base further research work to increase our understanding of the behaviour of forest communities in the face of prospective climate changes.

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APPENDICES

APPENDIX A1

Pollen Reference Collection - background to preparation of samples

Collection of herbarium pollen

Comprehensive plant taxa lists for the South coast have been compiled by Geldenhuys (1988) and Martin (1967). These have been used to identify taxa comprising the forest component of afromontane vegetation that have been missing from the CTCP. A list of required taxa was assembled by the author as a prelude to the gathering of herbarium specimens. Pollen specimens were collected entirely from the Bolus herbarium at the University of Cape Town and acknowledgment of their removal for inclusion in the CTCP was given on each specimen sheet. In accordance with the convention adopted by most South African herbaria, each pollen sample was categorized according to family, genus and species name and allocated with its particular Gibbs-Russell (1984) species number.

Preparation of reference material

The procedure used in the preparation of modern pollen reference material follows a series of steps beginning with the collection of floral specimens described above and ultimately producing a set of microscope slides to be included in a pollen atlas. Before reference slides can be made, each specimen must be subjected to chemical processing whereby the pollen grains are treated to resemble their fossil counterparts as closely as possible. Clearly, fossil grains will have been subject to degradation over time resulting in a varying degrees of decay of the cellulose elements making up their cell contents and part of the exine structure. This clearly exposes the characteristic features of the exine by which grains of different taxa are distinguishable from one another. Chemical treatment of modern specimens allows the natural processes of decay to be reproduced in the laboratory, leaving modern grains in a comparable state to their fossil relatives (Moore *et al.*, 1991). The chemical procedure also allows the removal of any extraneous floral material, concentrating the pollen so that many grains of each taxon may be preserved on a single slide for reference purposes.

Preparation of modern pollen in the laboratory approximates techniques used in treating fossil pollen (Birks and Birks, 1980), although the process is somewhat less complex. The preparation procedure adopted in this case (Appendix A) observes the following basic steps:

I. Removal of anthers from floral parts and release of pollen into ethanol alcohol;

II. Removal of cellulose tissue by acetolysis;

III. Mounting of processed pollen on microscope slide.

In some instances, this procedure needs to be modified to cater for those taxa more prone to decay. In the preparation of South coast contemporary pollen, little modification was required except in the length of time each chemical treatment was applied. In most cases, taxa with delicate grains (for example *Juncaceae*) were already part of the CTCP and duplication was not necessary. Fragile grains of the families *Liliaceae* and *Amaryllidaceae* were subjected to acetolysis treatment for a shorter period than others to prevent excessive deterioration of the pollen grain wall.

The need for reference slides to retain permanence requires that they be mounted carefully. The most effective methods ensure that slides remain airtight preventing oxidation and dessication. Appendix B details a method revised from those evolved by Erdtman (1943, 1969). The method is twofold and relies on the differential chemical properties of glycerol jelly and paraffin wax. A small quantity of glycerine jelly combined with pollen is melted gently onto the centre of a microscope slide. Paraffin wax is then melted to enclose the pollen sample and seal the coverslip. It is important not to heat the slides too vigorously to impede the formation of air bubbles which could encourage oxidation and consequent deterioration of the grains.

APPENDIX A2

Preparation procedure for reference collection pollen.

Source : Revised from Sugden (1989)

Note: -Adhere to laboratory safety procedures at all times. Wear protective clothing.

-Centrifuge at 3000 rpm for approximately 5 minutes, unless otherwise specified.

-Use 20 ml glass Pyrex tubes in a swing-out configuration centrifuge.

-Always discard chemical supernatants into appropriate waste containers.

-Set water bath to 95° C.

1) Place anthers or flower buds into a shallow dissecting dish containing ethanol. Using tweezers and a dissecting needle carefully prize the pollen from the anthers.

2) Remove the flowers and extraneous organic matter from the dissecting dish. Stir vigorously and transfer the pollen suspension to a 20 ml centrifuge tube. Centrifuge and carefully discard the ethanol.

3) Wash with distilled water, centrifuge and decant.

4) Add 10 ml glacial acetic acid, centrifuge and decant.

5) In a fume cupboard, add 10 ml acetolysis mixture (Mix 90 ml acetic anhydride ($[Ch_3\ CO]_2O$) and 10 ml concentrated (0.4M) sulphuric acid (H_2SO_4) measuring cylinder). Stir vigorously and place in boiling water bath for 3 minutes. Centrifuge and decant.

6) Add 10 ml glacial acetic acid. Centrifuge and decant.

7) Wash twice with distilled water, adding a single drop of aqueous safranine to the second wash. Centrifuge and decant.

8) Wash in a mild solution of phenol to prevent spoilage.

9) Invert the tubes onto blotting paper and allow them to drain.

APPENDIX B

Mounting procedure for reference collection slides.

Source: Adapted from Erdtman (1943)

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1) Clean and label the microscope slides.
2) Heat glycerine jelly until hot and melted. Caution - do not allow the glycerine jelly to boil.
3) Gently heat a sterile microscope slide and place a drop of glycerol on the surface using a micropipette.
4) After suspending pollen residue in glycerol phenol solution by stirring vigorously with a mechanical stirrer, withdraw exactly 0.01 ml of solution from graduated storage vial using a pipette.
5) Carefully add the solution to the glycerol on the prewarmed microscope slide drop by drop.
6) Using the tip of the pipette, mix the glycerol-pollen solution to ensure even distribution of pollen grains across the surface of the slide.
7) Gently lower a coverslip onto the surface of the slide taking care not to trap air bubbles under the surface.
8) If necessary, heat the slide gently to ensure that the glycerol-pollen solution spreads to full the entire are beneath the coverslip.
9) Using a micropipette, draw up a small quantity of hot and melted glycerine jelly. Paint a thin line of melted jelly around the edge of the coverslip and leave to set. This seals the coverslip. Sealing the coverslip is important in terms of an absolute counting strategy where pollen accumulation rates will be calculated.

APPENDIX C

Procedure for determining organic matter content by ignition

Source: Adapted from Smith and Atkinson (1975)

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1) Place pre-weighed portions of moist sediment in labelled heat-resistant porcelain crucibles. Oven-dry overnight at a temperature of approximately 105°C to eliminate soil moisture.

2) Allow samples to cool down before recording dry weight measurement in grams (g).

3) Transfer the crucibles to a furnace pre-heated to a temperature of 400° C. Up to 12 samples can be treated in the furnace at a time. Leave samples in furnace for approximately 12 hours to eliminate organic matter by combustion. (Note: it is advisable to make a diagram of the placement of crucibles within the furnace or ensure that the marker used for labelling is heat-resistant.)

4) Allow samples to cool down in a dessicator before recording post-furnace weight in g. This prevents the regaining of hygroscopic moisture prior to reweighing.

5) Calculate organic content of each sample using the following formula:

$$\text{Organic matter index} = \frac{\text{initial weight of sample (g) - final weight of sample (g)}}{\text{initial weight of sample}}$$

APPENDIX D1

Preparation of fossil pollen samples - background

The processing of the Vankervelsvlei cores essentially involved the following:

I. Removal of humic acids and breakdown of sediment through repeated washing with (0.1M) sodium hydroxide (NAOH);

II. Removal of coarse material by sieving;

III. Removal of colloidal silicates by washing with dilute (0.1M) hydrochloric acid (HCl);

IV. Removal of silecious material through prolonged exposure to concentrated (0.4-0.6M) hydrofluoric acid (HF);

V. Removal of organic detritus by means of acetolysis whereby the combination of acetic anhydride ($[Ch_3CO]_2O$) and concentrated (0.4M) sulphuric acid (H_2SO_4) in a ratio of 9:1 produces a reaction resulting in the digestion of cellulose;

VI. Preservation of pollen residue in glycerol-phenol solution to allow for storage over prolonged periods of time.

The final step in preparing fossil pollen for analysis centres around production of microscope slides in a manner most easily facilitating counting and identification of fossil grains. The method adopted is similar to that used for modern pollen except that different mounting media are used. Despite its shortcomings in encouraging grains to swell (Faegri and Duese, 1960); the fluidity of glycerol greatly favours maneuverability of pollen grains under the coverslip. Thus, the ability to turn grains facilitates greater accuracy in identification and was considered to outweigh the problem of size distortion. Following even mixing of a measured proportion of pollen residue (0.01ml) with glycerol on a sterile heated slide, hot melted glycerine jelly is painted in a thin line around the edges of the coverslip. The jelly sets, effectively sealing the slide while still allowing movement of grains under the coverslip. This is particularly useful when trying to identify troublesome grains. A gentle touch of the coverslip with the tip of a dissecting needle permits the researcher to turn the grain and view it from different angles (Baxter, 1997).

APPENDIX D2

A revised method of obtaining absolute pollen frequencies from clay and mineral-rich sediment samples.

Source: Revised from Bates et al. (1978); Berglund and Ralska-Jasieswiczowa (1986); Faegri et al. (1989); Moore et el. (1991) and Horowitz(1992).

Note: -Adhere to laboratory safety procedures at all times. Wear protective clothing.

-Centrifuge at 4000 rpm for 5 minutes, unless otherwise specified.

-Use 50 ml profiled, sealable, polypropylene tubes in a swing-out centrifuge.

-Always discard chemical supernatants into appropriate waste containers.

-Remember to label all samples clearly.

-Set water bath to 95° C.

A REMOVAL OF HUMIC ACIDS

1) Place 4-6 g of sediment in a glass beaker, add 50 - 100 ml of (0.1M) sodium hydroxide (NaOH) and stir vigorously. Leave to stand for approximately 12 hours, stirring occasionally.

2) Wash and strain the sample through a 360 µ sieve using (0,1M) NaOH. Transfer the sample into one (or more) 50 ml polypropylene tubes.

3) Add 30-40 ml NaOH and stir vigorously. Place the sample in a boiling water bath for 10 minutes and stir occasionally.

4) Centrifuge and discard the supernatant. If dirty, add more NaOH and repeat. Recombine the sample into a single polypropylene tube as soon as possible.

5) Wash the sample thoroughly in distilled water, stir centrifuge and decant. Repeat until the supernatant becomes clear.

B REMOVAL OF CLASTIC MATERIAL.

6) Add 20 ml (0.1M) hydrochloric acid (HCl) and place in a boiling water bath for 20 minutes to remove colloidal silicates and silica-fluorides. Centrifuge and decant.

7) In a fume cupboard, treat the sample with 10 ml concentrated (0.4 - 0.6M) hydrofluoric acid (HF) then place the polypropylene centrifuge tube in a boiling water bath for approximately 3 hours, stirring regularly, Thereafter seal the tubes, centrifuge and decant.

8) Wash the sample thoroughly with (0.1M) HCl, centrifuge and decant.

9) Wash thoroughly with distilled water centrifuge and decant.

C ACETOLYSIS DIGESTION OF EXTRANEOUS ORGANIC DETRITUS.

10) Add 10 ml glacial acetic, stir, centrifuge and decant.

11) Add 10 ml of the acetolysis mixture - comprising 9 parts acetic anhydride $(CH_3CO)_2O$ and 1 part concentrated (0.4M) sulphuric acid (H_2SO_4) - and place the samples in a boiling water bath for 3 minutes. Stir with a dry rod, centrifuge and decant.

12) Add 10 ml glacial acetic acid, centrifuge and decant.

13) Transfer the suspension to a 10 ml glass Pyrex centrifuge tube using distilled water. Centrifuge and decant.

14) Wash with distilled water twice.

15) For the last wash add 1 drop of aqueous safranine stain. Centrifuge and decant. Add a few drops glycerol-phenol solution.

D FINAL PREPARATION OF SAMPLES FOR ABSOLUTE COUNTING

16) Use a sterile micropipette to carefully transfer the glycerol-phenol suspension from the centrifuge tube to a graduated 10 ml storage vial. Keep adding glycerol-phenol solution until all pollen residue is successfully transferred.

17) Fill the storage vial with glycerol-phenol solution to the nearest graduation. (NOTE: The ratio of pollen residue to glycerol-phenol solution should be approximately 1.1. If only a small amount of pollen residue is present, centrifuge the vial and extract the excess glycerol-phenol solution using a micropipette till an approximate 1.1 ratio is achieved).

18) Bring pollen residue into suspension by shaking the sealed vial in a vibrator for approximately 30 seconds or until all pollen residue is in suspension.

E MOUNTING

19) Place a single drop of glycerol on a pre-warmed (50° C)sterile glass microscope slide.

20) When the pollen is evenly suspended in the storage vial, use a micropipette to carefully extract 0.01 ml of the glycerol-phenol suspension.

21) Carefully release the contents of the pipette onto the warm glycerol covered slide, leaving the pollen residue suspended in the glycerol mounting medium.

22) Using the tip of the pipette, evenly mix the pollen residue with the glycerol.

23) Place a coverslip over the glycerol suspension and place on a warming table until the mixture has spread to all the edges. Delicate pressure with a dissecting needle can aid this process.

24) Using a micropipette, draw up to 0.5 ml hot, melted glycerine jelly and then apply it, like glue, to the circumference of the coverslip. A steady hand is required to administer the molten jelly in a thin yet consistent line around the edge of the coverslip.

25) Several replica slides should be prepared.

APPENDIX E

A revised procedure for determining grain size data by wet sieving

Source: Revised from Tucker (1988); (Goudie, 1990)

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1) Place approximately 15g of sediment in a sterile glass beaker and oven dry at less than 60 C for roughly 12 hours.

2) Allow sample to cool down and record weight measurement of sediment in g

3) If necessary, add about 20 ml Hydrogen peroxide (H O) to remove organic matter. Return beaker to oven preheated to 30 C for approximately 8 hours or until sample is dry.

4) Add 20 ml Of a deflocculant to the beaker, in this case, Calgon solution. Mix well. Place beaker on shaking table and leave for about 8 hours.

5) Remove sample from shaking table and wash through 63µ sieve using distilled water to differentiate between sands and muds.

6) Collect separated sediments in two pre-weighed beakers and repeat drying process as in step. If after 12 hours the sample has not yet dried out, leave in the oven until all liquid has evaporated.

7) Allow sample to cool and record weight measurements of separated fractions in grams (g).

APPENDIX F

VVVA grain size analysis data

% sand	% muds	Depth (cm)
11.61146	88.09081	450
7.312834	88.20856	470
3.830645	95.56452	500
17.06783	82.78629	525
22.1653	77.76639	545
4.296161	95.33821	570
31.27162	68.68769	600
4.716981	95.07338	600
10.39687	89.32364	630
4.781923	94.95533	655
16.81917	83.00654	680
22.58792	77.27683	700

APPENDIX F

VVVB grain size analysis data

% sand	% muds	Depth (cm)
5.99	91.81	5
8.97	90.9	30
21.45	78.48	55
4.01	95.91	80
5.21	94.66	105
5.78	94.15	130
3.62	96.29	155
3.61	96.32	180
5.93	94.05	205
8.17	91.79	230
7.32	92.61	255
4.32	95.66	280
3.46	96.49	305
14.24	85.7	330
15.76	84.19	355
4.42	95.49	380
4.58	95.33	405
6.02	93.93	430
10.22	89.74	455
6.53	93.39	480

APPENDIX G

VVA total pollen count

FINAL POLLEN COUNT SUMMARY TABLE - CORE A

Depth in cm	5	25	50	75	100	125	150	200	225	250	275	300	325	350	375	400	500	550	575	605	630	655	680	705	760
Radiocarbon years BP	3170															7130	19500								39900
Restionaceae	126	90	117	170	180	14	42	144	26	108	68	31	176	74	32	35		59	69	130	115	30	92	87	
Poaceae	31	206	121	44	58	120	221	18	54		9	66	38		8	8		13	8	18	17	56	18	25	
Juncaceae	3	10	83		70	8	10		6	8	1				2	1									
Cyperaceae	43	20	28	17	30	110	28	93	88	148	199	211	210	290	402	340		12	12	1	2	10	33	12	
Halloragaceae	26	33	7	10	8	70	66	6		12	31	1	2		6	1		4	13	5	4	9	8	18	
Asteraceae (echinate)	3	4	3	1	12	18	12	9	70	28	5	3	14	28	2	2		46	37	25	28	18	23	27	
Asteraceae (sleobe-type)				4	4	2	1	3	10		2	1	4	4	2	8		46	44	88	48	57	27	33	
Ericaceae	11	12	6	7	6	6	5	4	4	32	5	11	4	12	2	12		42	81	97	53	120	47	49	
Thymelaeaceae	4	2									2			4				7	1		3	5	5	12	
Sapindaceae	1			3						4	1							4		4	2		4	1	
Myricaceae	1		1	3	12	6	7		22	14				2				11	13	1	4	8	13	9	
Rhamnaceae	5			1	2	8	2			10	2	1	2			4		8	5	20	8	12	9		
Ebenaceae	2																	28	13	21				8	
Icacinaceae	11	3	4	10	16	2	6	6	62	2	1		8	2				4	13	5	4	9	8	18	
Celastraceae	2			2	6		5	7	2	18	2	1	6					4	1		1	5	4	20	
Rubiaceae				7						20			10	8								15	17		
Anacardiaceae			1							2				4						5					
Myrsinaceae	3				2																1				
Capparaceae														8		3		11	12		3	26	10		
Piperaceae	2								8							1									
Liliaceae	16						28																		
Iridaceae	11								18																
Aizoaceae		2		3			16		4	2	5		2						8				9		
Rosaceae			1			4		3							14	3									
Scrophulariaceae	1		3	6	6			2	8			2	4							41	31		20		
Oleaceae	3	8		5	10	6	4	3	8	2		2	2	4						2	2				
Meliaceae		2				6				4	1														
Lauraceae	9				4	14		5				1				3		4	4	19	1	15		27	
Loganiaceae		2							4										8				9		
Flacourtiaceae		4									2					1								1	
Oliniaceae	3	1												2						1	1			4	
Araliaceae	1								4	6	2									11				4	
Podocarpaceae	4	3	1	1	6		16		4	6			8	10	4	1		1							
Verbenaceae	3														20	37								1	
Tricolp 18	1																		6						
Broken/obscured	7	108	24	22	44	52	22	36	58	2	32	17	46	44	54	32		19	39	58	53	52	37	84	
Pollen counts	335	510	400	316	478	442	489	339	458	428	370	348	534	494	546	486		321	365	552	377	449	393	420	
Spores	1	13	26	61	58	94	21		290	36	20	34	106	132	20			3	4			8	1		
T (traverses)	16	8	18	8	48	32	12	16	48	80	48	6	48	48	16	3		8	3	2.5	5	3	8	3	
V (final suspension)	1	3	1	1	1	1	1	1	4	1.5	1.5	1	2	1	1	1		1	2	3	5	1	6	6.5	
V (aliquot)	0.02	0.01	0.02	0.01	0.02	0.04	0.02	0.02	0.08	0.08	0.03	0.01	0.08	0.06	0.02	0.01		0.01	0.01	0.01	0.01	0.01	0.01	0.001	
M (sample)	0.23	0.32	0.29	0.4	1.1	1.04	1.25	0.95	1.44	1.6	1.15	0.9	0.9	0.95	0.69	1.19		2.84	2.72	2.28	3.08	2.15	3.08	3.8	
V (sample in cm^3)	0.26	0.36	0.33	0.39	1.01	1.00	1.36	1.20	1.30	1.50	0.93	1.00	0.73	0.90	0.59	1.19		2.54	2.62	3.12	4.00	2.36	4.00	5.54	
P (final suspension)	52343.8	956250	62500	2E+05	24896	17266	1E+05	52969	31806	5016	19271	217500	18542	8576.4	85313	8E+05		2E+05	1216667	3E+06	2E+06	748333	1E+06	4.6E+07	
P (concentration g^-1)	227582	2988281	215517	5E+05	22633	16602	81500	55757	22087	3135	16757	241667	20602	9027.8	123641	7E+05		70643	447304	1E+06	812013	348062	478490	1.3E+07	
P (concentration cm^-3)	200272	2629688	189655	5E+05	24670	17266	74980	44048	24451	3354	20779	217500	25546	9569.4	143424	7E+05		76710	389547	828000	797837	187063	266094	#REF!	

APPENDIX G

VVVB total pollen count

FINAL POLLEN COUNT SUMMARY TABLE - CORE B

Depth in cm	0	25	50	75	100	125	150	175	200	225	250	275	300	325	350	375	400	425	450	475
Radiocarbon years BP		7240				19300										38400				
Restionaceae	44	51	66	63	98	70	50	60	98	116	53	62	72	89	121	110	86	52	75	82
Poaceae	9	12		8	6															
Juncaceae							3	8		4										
Cyperaceae		94	34	50	24	13	10	6	2	17	25	26	25	21	60	50	17	61	43	96
Halloragaceae	8		2	6						1	4		20	5	9	12	12	15	12	8
Asteraceae (echinate)	47	73	128	109	19	17	41	38	24	14	21	26	19	19	22	27	21	18	31	25
Asteraceae (stoebe-type)	86	5	6	1	18	46	13	58	60	25	36	28	34	24	33	25	28	36	16	13
Ericaceae	53		7	11	36	54	73	72	89	64	86	64	58	62	23	34	87	27	15	10
Thymelaeaceae			2	1	10	15	17		6	13	8	8	9	11	6	15	12	4		10
Sapindaceae	1							2				4	1			8	2	1		
Myricaceae		4	5		7	15	11	23	12	11	8	4	5		3	8	5		9	2
Rhamnaceae		1	8	1	4	6	21	18	14	16	4	10	13	23		4	7	9	10	
Ebenaceae	41	3	10	7		3	3	5	14	8	9	20	13	6	9	21	7	13	8	9
Icacinaceae		6	11	15	18	21	28	15	28	27	29	27	13	24	9	12	19	11	14	5
Celastraceae		22	7	21	5		5	7	1	2		1	2	2	8	4	8			
Anacardiaceae	14																			
Capparaceae				2	1	4	4	1		5	3	11	7	3	4	7	6	2	8	4
Piperaceae	9	1	5		7									3			4		3	
Aizoaceae		2	1	3				9	2	1					2		6			
Rosaceae	39		6		7	15			8	4	5	8	7	4	13	4	14	34	17	21
Scrophulariaceae			2	1			1				3		1			8	3	5		
Oleaceae																	1	17	11	8
Meliaceae				5		1					2	7	11							
Lauraceae			4	1	2				4		4	6		4	8	4			5	4
Loganiaceae	20	3	1	8				2												
Flacourtiaceae										1					1	1		4	1	
Oliniaceae			1			1												4		
Araliaceae																		4	7	3
Podocarpaceae	3	3	1	7	12	3					1	2	1	1		4	18	24	18	14
Cupressaceae																				4
Tricolp 16		25	7	2	1															
Broken/obscured	40	54	41	67	78	35	36	27	42	40	53	47	53	89	57	34	36	41	46	42
Pollen counts	414	359	353	387	353	319	326	351	402	369	356	362	364	370	386	390	397	384	349	360
Spores	6	21	11	41	7	6	5	16	1		6	9	7	5	4			1	4	8
T (traverses)	24	12	8	29	32	4	8	12	7	4	3	5	3	5	3	6	4	3	7	8
V (final suspension)	2	1	1	1	1	1	2	1	1	1	3	4	4	4	4	6	4	5	6	6
V (aliquot)	0.03	0 02	0.01	0.04	0.04	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0 01	0.01	0 01	0 01	0 01	0.01	0.01
M (sample)	2 459	1.747	2.53	2 342	1.868	1.11	1.819	0.931	2.466	1.353	1.276	2.051	2.185	2.151	2.258	1.903	2.365	1.363	1.933	2 027
V (sample in cm^3)	1.596753	1 065244	1.666667	1.760902	1.745794	0.991071	1.7	0.83125	2.304673	1.353	1.192523	1.614961	1.867521	1.866842	1 213978	0 919324	2 21028	1.376768	2.147778	1 378912
P (final suspension)	57500	74791.67	220625	16681.03	13789.06	398750	407500	73125	267142.9	461250	1780000	1448000	2426667	1480000	2573333	1950000	1965000	3200000	1495714	1350000
P (concentration g^-1)	23383.49	42811.49	87203.56	7122.56	7381.725	359234.2	224024.2	78544.58	116440.7	340909.1	1394984	705997.1	1110603	688052.1	1139652	1024698	839323 5	2347762	773778 7	666006 9
P (concentration cm^-3)	36010 57	70210.84	130805.3	9473.004	7898.446	402342.3	239705.9	87968.92	124581.6	340909.1	1492633	898616.3	1299405	784379.4	2118752	2121125	898076.1	2324285	696400.9	879033.1

APPENDIX H

Surface sample pollen counts

FINAL POLLEN COUNT SUMMARY TABLE - SURFACE SAMPLES

Sample #	1	2	3	4	5	6	7
Site	VVV	VVV	VVV edge	VVV transition			
Restionaceae	69	75	35	6	44	25	72
Poaceae						17	11
Juncaceae	48	54					
Cyperaceae	57	111	55	11	12	25	44
Halloragaceae		15	24				
Caryophyllaceae					5	2	
Asteraceae (echinate)			31	10	35	9	41
Asteraceae (stoebe-type)	9	9	11	16	27	5	22
Ericaceae	15	12	20	65	17	14	36
Thymeleaceae	30	15	29	43		11	1
Sapindaceae		12			4	13	
Myricaceae		24	8	3	2	8	4
Rhamnaceae	21		3	1	10	11	1
Ebenaceae			10		3		
Icacinaceae	30	15	13	22	6	4	64
Celastraceae				2	13	19	5
Anacardiaceae				1	1	5	5
Capparaceae			6	8	8	3	3
Piperaceae							1
Aizoaceae							
Verbenaceae							7
Achariaceae			6			12	3
Rosaceae	3		32			8	8
Scrophulariaceae			1		3		1
Oleaceae			3	2	17	12	17
Meliaceae							
Lauraceae							
Loganiaceae					6		9
Flacourtiaceae							
Oliniaceae							
Araliaceae							
Podocarpaceae	21	21	40	50	53	44	72
Cupressaceae							
Tricolp 16			8		42		
Broken/obscured	69	117	20	29	57	38	24
Pollen counts	372	480	355	269	365	285	451
Spores	35	5	5	11	53	25	14
Pinus	253	210	74	130	26	109	36

APPENDIX I

Nearest Neighbour Algorithm

Source: Professor Les Underhill, Department of Statistical Sciences, University of Cape Town (personal communication) and Baxter (1997).

Let xik be the pollen count for taxon k in modern sample i, and let yjk be the pollen count for taxon k in historical sample j. Counts should first be converted to profiles:

$$p_{ik} = \frac{x_{ik}}{\sum_{k=1}^{K} x_{ik}} \qquad q_{jk} = \frac{y_{jk}}{\sum_{k=1}^{K} y_{jk}}$$

(K is the total number of taxa identified).

Thus, pik is the proportion of taxa k in modern sample i, and qjk is the proportion of taxa k in historical sample j. The Euclidean distance dij between the profiles of modern sample i and historical sample j is then defined as:

$$d_{ij} = \left(\sum (p_{ij} - q_{ij})^2\right)^{\frac{1}{2}}$$

For each historical sample j, the Euclidean distance to all modern samples can be computed. These distances are then sorted from smallest to largest; the modern sample i, for example, with the smallest index, is referred to as the 'nearest neighbour' to historical sample j.

Interpretation of the modern nearest neighbours to an historical sample needs to be done with caution, and in the context of all the Nearest Neighbour Indices (NNI's). The collection of all NNI's to historical samples should be inspected and considered carefully. For those historical samples with NNI's which have relatively small values, the conclusion that historical sample j and modern sample i represent comparable plant communities is likely to be correct. On the other hand, it does not necessarily follow that historical sample j is an appropriate analogue for modern sample i. It is possible that historical sample j is unlike all modern samples, and that modern sample i, although it is the nearest neighbour to historical sample j, consists of a different plant community. Thus historical samples, with NNI's which are relatively large, are likely to represent plant communities unlike any of the modern samples.

A useful guideline for deciding that historical sample j is not similar to any modern sample occurs when all the distances dij to the modern sample are relatively large, and all of similar magnitude. Conversely, a useful guide for deciding that historical sample j is likely to be similar to the modern sample which is its nearest neighbour occurs when the distances dij are variable, with both relatively small and large values. It may sometimes be useful and provide further insight to consider not only the nearest neighbour, but also the second and third nearest neighbours as well.

APPENDIX I

Nearest Neighbour Indices

Sample depth (cm)VVVA	NNI	Closest modern analogue	Sample depth (cm) VVVB	NNI	Closest modern analogue
5	0.33	S1	0	0.30	S5
25	0.42	S6	25	0.28	S2
50	0.39	S1	50	0.33	S5
75	0.45	S1	75	0.28	S5
100	0.29	S1	100	0.22	S1
125	0.37	S3	125	0.26	S7
150	0.46	S6	150	0.26	S7
200	0.34	S2	175	0.29	S5
225	0.27	S7	200	0.29	S7
250	0.31	S3	225	0.28	S1
275	0.37	S2	250	0.27	S7
300	0.48	S2	275	0.24	S7
325	0.33	S2	300	0.25	S1
350	0.42	S2	325	0.24	S1
375	0.55	S2	350	0.24	S1
400	0.53	S2	375	0.24	S1
550	0.27	S5	400	0.24	S7
575	0.26	S5	425	0.16	S3
605	0.29	S5	450	0.20	S3
630	0.29	S5	475	0.22	S3
655	0.31	S4			
680	0.25	S7			
705	0.24	S5			

APPENDIX J

Calculations used to infer pollen concentrations

Source: Revised from Baxter (1997)

Each slide contains a measured aliquot of pollen which is taken to represent an accurate function of the final pollen suspension. Once all the pollen grains on the microscope slide(s) have been counted, the total number of grains in the final suspension may then be extrapolated as follows, viz.:

$P_{\text{final suspension}} = (P_{\text{counted}} \times [\{50/ T_{\text{counted}}\} \times \{V_{\text{final suspension}}\ \text{ml}/ V_{\text{aliquot}}\ \text{ml}\}]$, where

P_{counted} = Pollen counted.
T_{counted} = Traverses counted.
$V_{\text{final suspension}}$ = Volume of final suspension, expressed in ml.
V_{aliquot} = Volume of aliquot, expressed in ml.

Given the total number of pollen grains in the final suspension, it follows that the pollen concentration in grains per unit mass (grains g^{-1}) of each original moist sediment sample may then be calculated as follows:

$P_{\text{concentration}}\ g^{-1} = (P_{\text{final suspension}} / M_{\text{sample}}\ \text{in g})$, where

$P_{\text{final suspension}}$ = Total pollen in final suspension.
M_{sample} = Mass of original sample, expressed in g.

If the relationship between volume and mass of the original sample was established (eg during the loss-on-ignition .procedure, it follows that pollen concentration can be calculated in grains per unit volume (grains cm3) of each original moist sediment sample, calculated as follows:

$P_{\text{concentration}}\ cm^3 = (P_{\text{final suspension}} / V_{\text{sample}}\ \text{in}\ cm^3)$, where

$P_{\text{final suspension}}$ = Total pollen in final suspension.
$P_{\text{final suspension}}$ = Volume of original sample, expressed in cm^3 *

*Calculated on the basis of the relationship between volume and mass, established during the loss-on-ignition procedure described in Appendix C).