THE LATE HOLOCENE VEGETATION HISTORY OF LAKE FARM, SOUTH EASTERN CAPE PROVINCE, SOUTH AFRICA.

BY

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SUBMITTED IN FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF ARTS.

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SOUTH AFRICA.

FEBRUARY, 1994

ABSTRACT

THE LATE HOLOCENE VEGETATION HISTORY OF LAKE FARM, SOUTH EASTERN CAPE PROVINCE, SOUTH AFRICA.

Palynological analysis of organic sediments from a freshwater lake near Port Elizabeth (34°S,25°30'E) has provided a high-resolution vegetation history of the area for the last 2200 years. Detailed identification and counting of the fossil pollen resulted in the generation of a pollen diagram. Changing frequencies in fossil pollen over time are represented, and inferences are made regarding environmental conditions which influenced the vegetation.

A detailed narrative of vegetation history in response to environmental change is presented, and this is compared to results from related studies. The significance of the Lake Farm study site has been noted in terms of its location as a 'zone of convergence' for a variety of vegetation types. Results of fossil pollen analysis indicate that environmental conditions prior to 1500BP were drier than at present. Forest and fynbos vegetation were not well-represented in the pollen spectrum at this time, and it is suggested that they were not favoured by these conditions. Environmental conditions ameliorated after 1500BP, becoming more mesic, which favoured the proliferation of both forest and fynbos vegetation types. At present xeric and grassland elements are declining, while shrubs increase, indicating an enhanced human-induced disturbance regime.

It is suggested that the partial decline in forest elements at present is most likely attributable to human-induced disturbance of the environment. The introduction of exotic trees has been noted (approx. 280BP) and is seen to have coincided with the influx of european settlers to the region.

Principal Components Analysis has revealed that the vegetation distribution in the area has been most heavily influenced by human activity and moisture availability. The necessarily subjective interpretation of the statistical results, however, casts some doubt on the validity of the conclusions drawn. The validity of the conclusions drawn from this study becomes apparent not only in terms of what is learned about the history of forests, but also the form any future management should take.

Terence G. Adams February 1994

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ACKNOWLEDGEMENTS

A number of people contributed towards the completion of this thesis, and a few acknowledgements are in order.

Firstly, thanks are due to Associate Professor Mike Meadows, my supervisor, for his interest, professionalism and sense of humour which seem to be limitless. I especially wish to thank Mike for his patience in the face of an apparently infinite sequence of drafts, and for somehow making time available from a hectic schedule to answer my questions, offer advice and criticism, and just be a really nice guy.

Dr. Werner Illenberger, UPE, for taking the core in the first instance, his hospitality, interest and useful suggestions regarding the stratigraphy of the core.

Thanks to Dr Bruce Hewitson, Engeo department, UCT, for his invaluable assistance in performing and interpreting the statistical techniques used in this thesis

Thanks to my parents for their encouragement and support at all times, and for believing in me.

Andy Baxter, my lab partner, for his enthusiasm, great sense of humour, and his enterprise in getting me out of the lab and onto my mountain bike with sufficient regularity to break the monotony of pollen counting and preparation.

Tony George for his frequent visits to the lab for a joke or a chat, and for his friendship.

Thanks and acknowledgement to the FRD, who provided funding for this project.

Thanks to Simone Crantz who introduced me to the perilous world of the Palynology laboratory, helped me learn all there is to know about nasty chemicals, and who kept me in line during sample preparation.

Thanks to Shaada Reddy and Edna Zolin who were of invaluable assistance in the Engeo library.

To staff and students of the Engeo Department UCT.

Last but not least, thanks to Radar, 'Cellus, Marcus, Stanley, Lee, Joe, Dave, Ben and Hardy, all of whom contributed to the completion of this thesis in some way, perhaps in ways they are not even aware of.

I dedicate this work to my parents, without whom I would never have achieved what I did.

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CHAPTER ONE

1.1. Introduction

This thesis examines the vegetation history of an interdunal depression on the South coast of South Africa through high resolution quantitative palynological analysis of fossil pollen extracted from the sediment contained therein. Attention is focused on the inferred environmental changes in the late Holocene which impinged upon the site and the manner in which the vegetation has responded to it. Attention will be devoted to the history of forests, fynbos, grassland and xeric elements. The introduction of exotic vegetation will be noted and all vegetation types will be examined in light of environmental change. Environmental change in this sense is seen to include climatic change and change which has been orchestrated directly by the actions of humans. Studies of environmental change based on Southern hemisphere evidence have only recently gained impetus, and as yet more is known about Northern hemisphere palaeoenvironments. It is suggested that even less is known about Southern African palaeoenvironments but there has recently been an increase in the number of studies examining evidence of Quaternary environmental change. Chapter 2 examines this in some detail.

In order to understand biogeographical patterns and to make meaningful hypotheses about biogeographical history, the nature, amplitude and timing of palaeoenvironmental changes need to be understood. Furthermore, it is not possible effectively to distinguish between the roles of ecological and historical factors in determining biogeographical patterns. Excessive reliance on ecologically-based hypotheses in examining a vegetation history is problematic, since it often obscures the roles played by history or that of humans. In examining this particular study site the probable impact of humans on the environment and more specifically on the vegetation of the area is amplified.

The study is based in a small lake situated approximately 10km west of Port Elizabeth in a late Pliocene fossil dune field, and is unique for its situation within a 'zone of convergence' of a number of vegetation types. See Fig 1.1. for a schematic representation of the various vegetation types represented in the area.

Cowling (1983) notes the phytochorological complexity of the South-Eastern Cape, also making mention of the convergence of various vegetation types. This study should be seen in the context of other studies purporting to examine vegetation history at various sites in Southern Africa (see Chapter 2). By documenting and evaluating vegetation response to inferred environmental change another piece will

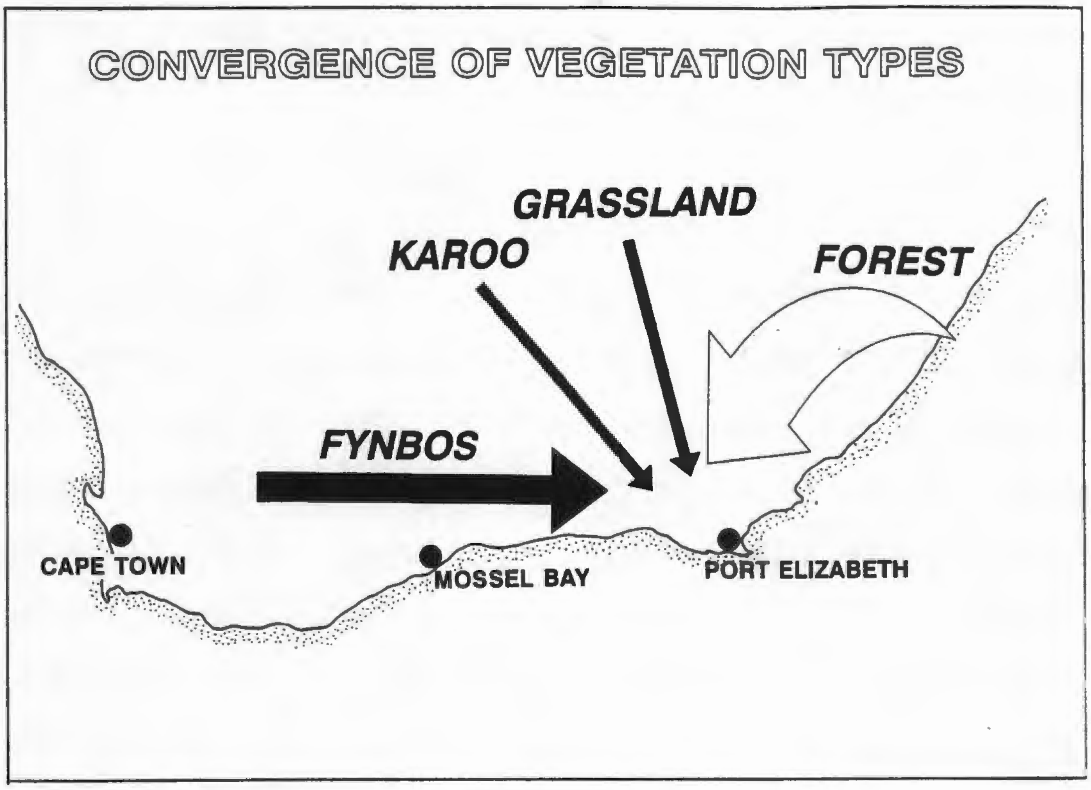

Fig 1.1. Schematic diagram of convergent vegetation types

fall into place in the complex jigsaw puzzle that is environmental change in Southern Africa. We must bear in mind the fact that an attempt to assemble a viable scenario for environmental change should account for various types of proxy fossil evidence, of which pollen is but one.

Fig 1.1. suggests that the origin of Fynbos elements (especially Cape Grassy Fynbos) has been from the West. Grassland and karroid elements essentially originate from the North and West, while Forest elements originate predominantly in the North-East. The rather general term 'forest' has been chosen to describe elements of subtropical Alexandria forest as well as Afromontane forest, both of which are represented in the study site.

Other studies have evaluated vegetation history of the Southern and Eastern coasts of the country (Coetzee, 1967; Martin, 1968) while others have examined contemporary vegetational and ecological patterns (von Breitenbach, 1972; Cowling, 1983; Geldenhuys and Knight, 1989; Meadows and Linder, 1989; 1993). The palynological study of closest proximity to this study site is the account of the vegetation history of Groenvlei in Knysna (Martin, 1968). It is hoped that the results of this study will make some contribution to the body of evidence regarding the late Holocene vegetation history of the Southern Cape coast, and shed further light on that of the South-Eastern Cape in general.

Chapter 2 will examine the nature of environmental change in southern Africa. The various forms of evidence used to support theories of environmental change will be examined. Chapter 3 will evaluate Lake Farm as a palaeoecological data base. The location, geology, climate and existing vegetation of the site will be discussed. Chapter 4 will provide a synopsis of the principles of palynology, the theoretical background to the study and associated problems. Chapter 5 looks at methods employed in the study. Fieldwork, laboratory procedure, generation of the pollen diagram and statistics will be discussed. Chapter 6 will deal with results of the items mentioned under Chapter 5. Chapter 7 will discuss the vegetation history of Lake Farm and relate this to narratives from other sites. Chapter 8 will conclude the thesis, examining the extent to which the objectives have been achieved and making recommendations for future studies.

1.2. Aim

The aim of this thesis is to offer a detailed description of the vegetation history in and around the study site over a period spanning the past 2000 years by examining preliminary pollen counts from a 1.7m sediment core extracted from the site. Given the marked changes in the vegetation composition over the past ten years or so, and the convergence of a number of climax vegetation types in this region (see Cowling, 1983), it is instructive to examine the pollen spectra to determine the extent to which these have been represented. The significance of the site in terms of the convergence of different vegetation types is the primary motivation for carrying out the high-resolution analysis of this core.

1.3. Objectives

The more specific objectives can be outlined as follows:

1). To conduct detailed pollen identification and counting throughout the length of the core

2). To construct a detailed pollen diagram displaying pollen frequencies over time, and allowing comparisons to be made between the relative frequencies of different taxa.

3). To provide a comprehensive vegetation history reconstruction for the study site based on inferences from the relative frequencies of pollen types through time.

4). To evaluate the relative roles of the impact of human settlement and natural environmental change on the vegetation of the area.

5). To examine the usefulness and viability of various Multivariate statistical techniques in zonation of the pollen diagram in detecting environmental parameters responsible for the variance within the data set.

In order that this study may be placed in an appropriate context, Chapter 2 now follows with a detailed discussion of Quaternary palaeoecology in Southern Africa.

CHAPTER TWO
ENVIRONMENTAL CHANGE IN SOUTHERN AFRICA

2.1. Introduction

The earth has been subjected to periods of marked environmental perturbation throughout its 4.5 billion years of existence. Change has been manifested in climate, sea-levels, vegetation belts, animal populations, soils and landforms, and the fluctuations in the planet's climate have necessitated responses within various spheres of its environment.

Global climatic change has emerged as a major scientific and political issue within the past few years. Growing public concern has placed pressure on politicians to take action concerning the envisaged changes, and on scientists to attempt to predict the impacts of rapid climate change (Leggett, 1990a).

Given the frequency and magnitude of the environmental changes over the past 18000 years, the climate and vegetation changes of the last two centuries have been small, and our knowledge of these events has been enhanced by improved investigative techniques. The component of the earth's history covered by radiocarbon (^{14}C) dating is, largely through the benefits to be derived from this technique, relatively well-documented. The next two centuries may experience climatic and vegetational changes unprecedented in the period of instrumental record (Overpeck et al, 1994). Humans have, over the past few million years, gradually diffused over the face of the planet, and have themselves become a powerful agent of environmental change (Goudie, 1992). Increasingly, the over-utilisation of available resources by humans has placed extreme pressure upon the environment. This alone justifies research in climatic change. With an increase in the variability of global climates, unexpected weather events become more probable, and the strain on both society and political systems increases (Bradley, 1985).

Many studies concerning the nature, scale and extent of past climatic changes have focused on the Quaternary period. The Quaternary is unique in earth history as the period characterised by the advent of humans as well as by great climatic fluctuations (Birks and Birks, 1980; Birks and Gordon, 1985). This unique characteristic of the Quaternary and the approach to studies regarding Quaternary environmental history in Southern Africa will be examined later in this chapter.

2.2. The impact of climatic change on ecosystems

The state of the world's ecosystems can be seen as a barometer for the variable nature of the environment. This means that the current state of the ecosystems of the world provides some indication of the nature and rate of environmental change, since they are inextricably linked to this phenomenon. Biological diversity, or biodiversity, is fundamentally an expression of the number of plant and animal species per unit area in any given ecosystem. Biodiversity is concerned with the existence, not only of numbers of species but also with the existence of rare or keystone species as well as their successional and interactive role within the ecosystem. A detailed discussion of the nature of biodiversity as well as the controversy surrounding the definition of the term is beyond the scope of this thesis. It is fair to say that biodiversity represents a potential indicator of environmental change, and if effectively monitored, can provide some indication of future environmental change. As a consequence of environmental change, diversity is being irretrievably lost through extinction perpetrated by the destruction of natural habitats (Wilson, 1988).

Precise estimates regarding species loss through habitat destruction are difficult to obtain, and scientists are in any case hampered by an ignorance of the number of species on the planet. Wilson (1988) suggests that the number of species may lie between 5 and 30 million. The Tropical Rain Forests boast the greatest concentration of species on the planet (Wilson, 1988; Myers, 1988; Raven, 1988), and recourse to the theory of Island biogeography (MacArthur and

Wilson, 1967) suggests that a 90% reduction in the areal extent of the tropical Rain Forests could result in a 50% reduction in species numbers. Gilbert (1980) has subsequently launched a scathing attack on the theory, accusing the authors of oversimplification among other things, but important lessons may still be learned. Common sense suggests that a reduction in the area of an ecosystem implies greater competition for a reduced number of habitats and subsequent extinction (Hartshorn, 1992; Dawson, 1992). It must be remembered that the decay of biological diversity is not necessarily precipitated by direct human malevolence or exploitation of the environment, but the destruction of natural habitats inevitably results from the expansion of human populations and the associated side-effects (Ehrlich, 1988). Human-induced climatic change will present a steadily growing challenge to conservationists, where new and innovative strategies will have to be adopted in the attempt to counter threats such as sea-level rise or changes in rainfall patterns (Rose and Hurst, 1992). This thesis sets out to examine the response of vegetation at a specific site to environmental perturbation. The aim of this is to make predictions about future vegetation response to the environmental changes projected by models or predicted by scientists.

The bulk of the biomass on earth is comprised of vegetation, and if we are to predict how the biosphere may respond to climatic changes such as those predicted for the next century, we must understand how vegetation responds to such changes and how it has done so through the ages (Huntley, 1991). This is important for the South-Eastern Cape, where at least four key vegetation types converge, a number of which are under-conserved (Huntley, 1989).

Before we evaluate vegetational response to climatic change, we must realise how vegetation distribution and soil types coincide with climatic regions (Emanuel et al, 1985). The close link between ecosystem distribution and climatic regions obviates some form of response from vegetation in the face of unprecedented climatic change. Contrary to the belief shared by some that vegetation may display evolutionary adaptation to change (Peters, 1992), the most likely vegetational response appears to be that of migration (Emanuel et al, 1985; Davis 1989a; 1989b; Huntley, 1990a; 1990b; 1991; Overpeck et al, 1994). Rather than ecosystems responding as a unit to environmental change, plants often respond individualistically to changes in physical environmental characteristics (Davis, 1989b; Huntley, 1991; Overpeck et al, 1994). This creates complications for any effort to conserve ecosystems as coherent assemblages of species. Allowance will have to be made for the individualistic responses of various species through the creation of corridors linking a number of smaller reserves. This may be eminently more suitable than one large reserve, which up till now has been the dominant *modus operandi* (Diamond and May, 1976; Higgs, 1981).

Palaeoecological data that provide insight into past vegetational responses to climatic change, are potentially invaluable in the prediction of future rates of response. Data of this nature are used to construct theoretical and diagrammatic representations of vegetation response to a changing environment. Isopoll maps, which essentially depict lines joining points of equivalent pollen concentration over a given area, provide an indication of the response of taxa to major climatic changes in the past, and enable estimates to be made of their rates of response (Huntley, 1990a). Pollen-climate response surfaces, migration rates and palaeovegetation reconstruction may also be determined given accessibility of the appropriate data (Huntley, 1990a; 1991).

Biological response to climatic change often involves some sort of time lag, especially when the rate of environmental change is particularly rapid. Species with long time constraints of change lag decades or centuries behind others (Davis, 1989a; 1989b). Vegetation lag will be a major problem for unmanaged forests, natural areas and reserves (Davis, 1989a). Forests are one of the major components of the vegetation of Lake Farm, and the relatively long inter-generational periods which characterise them could lead to problems of representation in the pollen spectrum. Individualistic migratory response implies that communities and vegetation units emerge as temporary assemblages of species that dissociate and re-associate in different assemblages as the climate changes (Huntley, 1991; Graham, 1992; Peters, 1992). Large trees are likely to be the hardest hit by rapid climatic change, as the migration rates inferred from the fossil record suggest that in the past they migrated at their maximum capability. Huntley (1991) suggests that the discrepancy in migration rates between trees and, for example, aquatic plants such as Typhaceae, can be attributed to these organisms response to different aspects of the climate that changed at different rates and/or at different times. The fact that important climatic changes may have occurred during inter-generational periods could also have contributed to the slow migratory rate of larger trees That future change is envisioned to be at least 1 or 2 orders of magnitude faster than during the last glaciation (Davis, 1989a; 1989b; Huntley, 1990b) does not bode well for these species. Positive steps will have to be taken to ensure the continued survival of these species, even if this implies artificial dispersal.

Migration may occur latitudinally or altitudinally in search of climatic and environmental optima, and invariably this leads to increased competition for available habitat and resources and greater rates of extinction. Species may track their climatic optima, changing their distribution ranges as conditions become more suitable or unsuitable. With global warming, species tend to shift to higher latitudes or altitudes, their ranges contracting away from the equator as conditions become more unsuitable there. Species may shift altitudinally as well as latitudinally in response to climatic change, and a short altitude gain is equivalent to a major latitudinal shift (3°C or 500m vertical shift = 250km in latitude) (Peters, 1992). Because mountain peaks are of lesser area than that normally occupied by species populations, increased environmental and competitive pressure is placed on them (Peters, 1992).

2.3. The nature of climatic change

Climate, then, is a major factor in determining the composition of ecosystems and climate change, and the mechanisms that drive it, has been the topic of a great deal of debate among scientists (Goudie, 1992). Climate, the statistical expression of daily weather events (Bradley, 1985) can essentially be forced externally or internally to the earth-atmosphere system (Tyson, 1986; Lindesay, 1990; Goudie, 1992). External mechanisms of climate change include variations in the relationship between the earth and the sun, and variations in solar output (Lindesay, 1990). Changes in the output of solar radiation (i.e., sunspot cycles) will lead to significant changes in solar radiation receipt at the earth's surface, although it must be remembered that this is a hypothesis that is more difficult to justify over a longer time-scale (Goudie, 1992). The earth geometry theory, more commonly known as the Croll-Milankovitch hypothesis, suggests that as the position and configuration of the earth about the sun changes, so might the receipt of insolation (Lindesay, 1990; Goudie, 1992). As the earth follows an elliptical orbit around the sun, three astronomical factors have been isolated as contributing significantly to this hypothesis. Changes in eccentricity of the earth's orbit, changes in obliquity of the elliptic, and precession of the equinoxes, have been identified as making a contribution to this variation (Lindesay, 1990; Goudie, 1992).

Recent evidence has suggested that the variations in eccentricity of the earth's orbit (which display a cycle of +-100000 years) are largely responsible for the ice ages that punctuate the earth's history (Goudie, 1992).

Other hypotheses of external forcing mechanisms include changes in atmospheric transparency, which suggest that the amount of insolation reaching the earth's surface has been modified by changes in the atmospheric composition (through, for example, volcanic dust) and variations in terrestrial magnetism that seem to be closely linked to climatic variations (Goudie, 1992).

External mechanisms alter the amount of solar energy received by the earth, while internal mechanisms on the other hand, influence what happens to that energy once it is part of the system. Variations in land-sea configuration through continental drift, and changes in the cryosphere (leading to changes in albedo) are factors associated with internal forcing (Lindesay, 1990).

Probably the most important internal mechanism of climatic change concerns variations in heat exchanges through fluctuations in the composition of the atmosphere (Lindesay, 1990). CO_2 levels affect the earth's heat balance, since short-wave radiation of solar origin is allowed to enter the earth-atmosphere system, while the re-radiated long-wave radiation from the earth is trapped, leading to a warming of the system. Fluctuations in atmospheric CO_2 concentration have occurred over time (Leggett, 1990; Goudie, 1992; Peters, 1992; Schneider, 1992). Evidence from the Dome ice core in Antarctica, which documented CO_2 concentrations in preserved layers of ice, suggests that around 20000 years ago (Last Glacial Maximum), CO_2 levels in the atmosphere were approximately 50% lower than present levels (Delmas et al, 1980). Studies of the Vostok ice core have demonstrated an apparent synchroneity between atmospheric CO_2 fluctuations and climate changes in the last 160000 years (Jouzel et al, 1987).

While the aforementioned fluctuations in CO_2 concentration can be classified as "natural", the arrival of humans on the planet has led to a significant increase in CO_2 levels. Scientists have become aware that an absence of an effort to cut greenhouse gas emissions, means that the earth is heading for an increase in global average temperatures. The rate at which these changes will occur will be unprecedented in human history and in fact the last 40 million years (Leggett, 1990).

Schneider (1992) mentions a 25% increase in atmospheric CO_2 concentration since the Industrial Revolution, and Neftel et al (1985) predict that by the end of the 21st century the atmospheric concentration of CO_2 could be double the pre-industrial level. On a shorter time-scale, global atmospheric CO_2 increase in tandem with corresponding increases in other "Greenhouse" gases, would lead to warming of $3^oC+-1.5^oC$ within the next 50-70 years (WMO, 1982; NRC, 1983, IPCC, 1990). While increases in mean annual global temperature of this magnitude are not uncommon in the history of the earth, the factor that distinguishes the present scenario from the past is the *rate* of projected change (Peters, 1992; Schneider, 1990; 1992). Peters (1992) suggests that the rate of warming will possibly be 50 times faster than usual, while Schneider (1990) feels that, given the uncertainty surrounding this issue, change could be as much as 10-100 times faster.

There are many areas of uncertainty, but scientists have attempted to model future climatic change based on emission rates of greenhouse gases in the present and recent past (Manabe and Wetherald, 1986; Rind and Peteet, 1986; Schneider et al, 1987; Washington and Meehl, 1989; Schneider, 1990; 1992). Models are often employed in nature to understand or predict the result of an event, and mathematical models translate conceptual ideas into quantitative statements (Schneider, 1992). At best, models can only really hint at the rate and scale of change due to global warming (Gates, 1985; Hall, 1985; Luther, 1985; Huntley, 1990a; 1990b; Schneider, 1990; 1992).

General Circulation Models (GCM's) run from extremely powerful computers, and generate models of future global climate based upon the input of either empirical or speculative data, see: Gates, (1985); Hall, (1985); Luther, (1985). GCM's need to be verified in order for the predicted climate changes to be meaningful and useful. One way of achieving this is to examine past changes in global climatic patterns. These analogues from the fossil record have been extensively employed as not only a verification of GCM's, but also as an indication of the impact past climatic changes has had on the environment (Roberts, 1989; Huntley, 1990; Delcourt and Delcourt, 1991; Adams and Woodward, 1992; Webb, 1992).

While the exact mechanisms of climatic change may still be open to speculation, there is little doubt that it is taking place. Debate concerning the potential human contribution to the issue of climatic change has recently intensified. We may not be able to isolate the exact impact humans have had on the climate system largely because of its complexity, but we can assume that human activity has contributed in no small way to the current climatic and environmental trends (Goudie, 1992).

2.4. The role of Palaeoecology

Many studies concerning the nature, scale and extent of past climatic changes have concentrated on sites dating to the Quaternary period. The Quaternary is unique in earth history as the period characterised by the arrival of humans, as well as by great climatic fluctuations (Birks and Birks, 1980; Birks and Gordon, 1985).

One of the ways in which scientists have responded to this has been the establishment of the International Geosphere-Biosphere Program (IGBP) in 1986, to address imminent problems anticipated as a result of global climatic change. The study of Quaternary environmental change aims at documenting population, community and ecosystem responses to rapid environmental change that occurred in the past in the hope of providing insight into the rates and directions of biotic changes that may occur in the near future. These changes would be a consequence of Global warming resulting from anthropogenic modification of the levels of CO_2 and other "greenhouse" gases in the atmosphere (Davis, 1988; in Delcourt and Delcourt, 1991).

Regional and global patterns of climatic change inferred from the Quaternary fossil record help:'...identify the primary causes of climatic change and provide specific analogues for future climatic conditions....' (Delcourt and Delcourt, 1991:194).

Species' response to environmental change can be understood and perhaps predicted through an awareness of the way they have responded to past environmental changes. Knowledge of past climates helps in :'.......Judging the severity and uniqueness of potential future changes in climate........' (Webb, 1992:59). It is evident that vital lessons can be learned from studies of environmental history (Huntley, 1990b), while the most useful data, especially with respect to human impact on the global environment, will come from the Quaternary (Adams and Woodward, 1992). By studying records of past climatic change we can obtain insight into a number of aspects of the global climate system including mechanisms of global climate change, rates of change, responses of organisms and ecosystems, and the rate at which these can respond (Huntley, 1990b).

The theories outlined above depend almost entirely on the Principle of Uniformitarianism. The Principle of Uniformitarianism states that physical, chemical and biological processes operative today are those which have obtained throughout the earth's history (Delcourt and Delcourt, 1991). The principle was developed by Charles Lyell in 1830-1833 in response to religious views of divine intervention in the history of the earth. Lyell's 'Principles of Geology' was subtitled 'An attempt to explain the former changes of the earth's surface by reference to causes now in operation', and through this he excluded divine intervention from geological processes, asserting that all features of the earth could be explained by processes still operative in the present day (Birks and Birks, 1980). This is of significance to those examining fossil fauna, flora and landforms which have resulted from these processes.

The rate and intensity with which the physical processes occur has varied through time, but the essential nature has remained constant (Delcourt and Delcourt, 1991). The Quaternary does not reveal evidence of glaciation in Southern Africa, although periods of cooler temperatures (5-9°C cooler than present) and changes in rainfall patterns have left their mark on landforms, sediment, and plant and animal fossils

(Deacon and Lancaster, 1988). The Late Quaternary has been marked by fluctuations in temperature and moisture, the Last Glacial Maximum (18 - 20 000BP) displaying temperatures up to 8°C lower than at present. More recently, at 6000BP, the climates of Southern Africa were much moister than they are today, and warming was occurring along the South and East coasts of the subcontinent (Tyson, 1986). The discussion will now shift to a more regional focus and examine palaeoecology within a Southern African context.

2.5. Palaeoecology - the southern African perspective

The southern African landscape reflects the environmental changes which have resulted from climatic change throughout geological time. It can be difficult to determine whether scenarios of past warming during the Quaternary are valid analogues for future warming. This is especially true when the abnormal and unpredictable impacts of modern technology on the global environment are considered (Scott, 1993).

It is fair to say that much of the impetus behind studies examining Quaternary palaeoenvironments has been generated by Northern hemisphere scientists in the past decade. Studies examining Quaternary palaeoenvironments in the Southern hemisphere have only recently become more numerous. One of the major motivations behind an evaluation of climatic and environmental change in southern Africa is undoubtedly the lessons we can learn in predicting the nature and scale of future climatic and environmental perturbations. There is little doubt that the consequences of future climatic change will impact upon all Southern Africans, whether directly or indirectly. Conversely, as suggested in the introduction to this thesis, humans have left an indelible imprint on the environment, and the consequences of their actions are likely to be extensive. We cannot remain blameless, and will have to shoulder part of the responsibility for future climatic changes as we have been directly responsible for some of the factors currently forcing it.

Palaeoecology, as well as other forms of research into Quaternary environmental history, depends upon the availability of suitable sample material. Palynology in particular requires that pollen-bearing sediments adequately preserve the grains. The most suitable environments for the preservation of pollen are acidic, waterlogged environments such as peats, lakes or vleis (Birks and Birks, 1980; Fægri et al, 1989; Deacon and Lancaster, 1988). In view of the aridity of the subcontinent (Tyson, 1986), pollen is not often found preserved, given the paucity of suitable vleis or lakes (Scott and Bousman, 1990). This invariably limits the choice of study site to some extent, and research is dependent upon the availability of suitable sample material. Another problem in Southern African palynology is the lack of sensitive indicator species in the fossil pollen record (especially in certain biomes, e.g. Highveld Grassland), which may have effectively suppressed the signal of warming events in the past (Scott, 1993).

Studies in recent years dealing with Southern African Quaternary climatic change have suffered from over-generalisation, and this points towards detailed case studies as '.......an essential component of the environmental jigsaw puzzle.......' (Meadows and Meadows, 1988:253). Studies concerned with Quaternary palynology in southern Africa, although restricted to sites conducive to pollen preservation, have been reasonably extensive and have examined the vegetation history of all the major biomes of Southern Africa.

A number of geographical areas have been examined. Among the more noteworthy were sites representative of specific floral communities or biomes. These include the Cederberg (Sugden, 1989; Meadows and Sugden, 1989; Meadows and Sugden, 1991; Meadows and Sugden, 1992), the South coast or more specifically, Knysna (Martin, 1968), George (Scholtz, 1986) and Hangklip (Schalke, 1973); Eastern Orange Free State (Scott, 1985; Scott and Cooremans, 1990); the Transvaal (Scott, 1982; Scott and Vogel, 1983); the northern Cape Province (Scott, 1976); the Winterberg (Meadows and Meadows, 1988); Eastern Natal (Scott et al, 1992); and Verlorenvlei (Meadows and Baxter, 1994;

Meadows et al, 1994). More generalised studies, which are not necessarily site-specific include work by Coetzee (1967), Cooremans (1989) and Scott (1993).

Another technique which utilises biological evidence is the analysis of pollen from Hyrax (*Procavia* spp.) middens, see Scott (1990), Scott and Bousman (1990), Scott and Vogel (1992) and Hubbard & Sampson (m.s.). This technique avoids some of the shortfalls of palaeoecology in southern Africa (for example the paucity of suitable sites because of poor preservational environments) and Hyrax middens potentially provide a high resolution of analysis (Scott & Vogel, 1992) because high concentrations of pollen are preserved (Hubbard & Sampson, m.s.). The pollen preserved in Hyrax dung is a sensitive indicator of environmental change (Scott & Vogel, 1992), and the results of the studies in Hyrax middens thus far seem to have justified their existence within the framework of Late Quaternary Southern African environments.

Other forms of biological evidence for environmental change include charcoal, tree-rings and microfauna. Thackeray (1987a; 1987b) and Avery (1990) are two scientists who have achieved notable success in deriving evidence of climatic change from the study of microfauna.

Other sources of palaeoclimatic evidence in Southern Africa include geomorphic studies of palaeo lake-levels, cave deposits (speleothems), karst, periglacial landforms and relict shorelines (Deacon and Lancaster, 1988). A number of studies have examined dunes and aeolian deposits, especially of marine origin, in an attempt to elucidate past climatic change through fluctuations in sea level.

Studies of geomorphic landforms relevant to Quaternary climate change in Southern Africa include Periglacial landforms (Lewis and Dardis, 1985; Dardis and Granger, 1986); Fluvial and colluvial sediments (Helgren, 1979; Stear, 1986; Meadows, 1985; 1987); Lake sediments (Grove, 1969; Crossley et al, 1984; Shaw and Cooke, 1986); Pans (Lancaster, 1978); Dunes (Illenberger, 1986; 1993), fossilised dunes or aeolianite (Smuts, 1986) and Quaternary fluvial deposits (Stear, 1986).

2.6. Climatic change in southern Africa during the Late Quaternary

What follows will take the form of a brief account of climatic change in southern Africa during the Late Quaternary. The scale of climatic perturbations in the Holocene may not, according to some scientists, be as great as during glacial periods, but this does not mean that the Holocene was not the scene of substantial environmental change (Goudie, 1992). Repeated and drastic changes in climate and vegetation characterised the Quaternary in Africa (van Zinderen Bakker, 1978; Lawes, 1990), although in the last 5000-6000BP the climatic changes have not been quite as marked. A few exceptions exist though, and these incidents, which will now be discussed, are indeed associated with marked climatic change.

Following a mid-Holocene warming (peaking at +-5000-6000BP), two extensively-documented climatic events occurred. The Medieval Warm Epoch (1000-700BP) and the Little Ice Age (400-100BP) were globally manifested, although the Little Ice Age was more widespread and the most globally-intensive cool period since the Younger Dryas (10800BP) (Tyson, 1986; Tyson and Lindesay, 1992). Apart from these two events the last 3000 years have seen little by way of significant climatic variation in Southern Africa (Cockroft et al, 1986).

One interpretation asserts that from 10000-6000BP climates influencing the southern cape were markedly moister than they are today (Tyson, 1986; Deacon and Lancaster, 1988). Furthermore it appears as if these conditions prevailed until about 4000BP (Cockroft et al, 1986) and were probably a result of an increase in summer rainfall patterns (Tyson, 1986). As will be displayed in Chapter 7 the evidence from the Lake farm sequence places a question mark on this theory, suggesting that conditions may have become moister in the late Holocene. Meadows (1988) disagrees with this interpretation as well, also suggesting that the latter half of the Holocene was moister than the beginning.

The last 4000 years have been characterised mainly by low-level temperature fluctuations occurring around the present day mean at most sites in Southern Africa (Deacon and Lancaster, 1988; Tyson and Lindesay, 1992).

'The middle and latter part of the Holocene was the period in which the balance of power for the control of nature permanently shifted' (Roberts, 1989:121). Hunter-gathering and fishing were the order of the day, a mode of production which uses and manipulates natural ecosystems without significantly transforming them. By 500BP, many natural ecosystems were replaced by agricultural systems, and many others were altered in their detailed composition through the impact of humans (Roberts, 1989).

This leads to a questioning of the validity of pollen and zoological evidence in elucidating environmental change, as these are inextricably linked to the ecosystems which have, more recently, been altered by humans (Goudie, 1992). Scientists tend to rely more on sources of evidence such as the Cango Cave Speleothem (see Deacon and Lancaster, 1988) in determining environmental change as, theoretically, this form of proxy evidence is not modified by human activity as much as the others may be.

Perhaps this could be part of the reason why evidence for climatic change over the past 2 millennia in general, and the Little Ice Age in particular, has been until recently difficult to assemble (Tyson and Lindesay, 1992). Recently a new and better understanding of Late Holocene climatic change has been sought, especially given the impetus provided by the IGBP.

From proxy data assembled over the past couple of years, the following sequence of events has been determined. From 1000-700BP, variable but generally warmer conditions constituting the Medieval Warm Epoch were experienced. The period 700-150BP included the Little Ice Age, which was characterised by considerable variability and instability of climate. Two major cooler phases, 700-500BP and 325-150BP were experienced, while a sudden warming within the Little Ice Age from 500-325BP was experienced, and appears to have been widespread in Southern Africa. From 150BP to the present day, a period of recovery has been taking place although as yet it has been impossible to distinguish between the effects of anthopogenically-induced atmospheric warming and 'natural' effects (Tyson, 1986; Tyson and Lindesay, 1992).

Climatic changes during the period of meteorological record are the most detailed and reliably established. Temperature records for central England are the longest available (1650 onwards), and indicate quasi-periodic oscillations of apparently global extent. Without the luxury of instrumental records covering any significant time-period in the Southern Cape, we need to revert to other methods of determining past climatic fluctuations.

This study is concerned with deriving evidence of Late Holocene vegetation history in and around the study site by means of palynological investigation of a core sample derived from a representative site. The basal date derived from the sequence is 2200+-45BP, locating the study in the late Holocene. A high-resolution palynological analysis of the sequence will shed light on the history of south coast forest, as well as the other vegetation types evident in the environs of Lake Farm. The study site is discussed in some detail in the following chapter.

CHAPTER THREE
LAKE FARM AS A PALAEOECOLOGICAL DATA BASE

3.1. Introduction

Lake Farm (34ºS, 25º30'E) is situated in an interdunal depression approximately 7km west of Port Elizabeth on the south coast of southern Africa (see Fig. 3.1.). It is a freshwater lake approximately 400m by 140m. Lake Farm is situated approximately 2 km inland of the coast and is bordered by what are most likely late Pliocene fossil dunes (W. Illenberger, pers. comm.), and by a relict raised beach to the south. Immediately to the south of the vlei the narrow coastal band is characterised by active dunes.

Fig. 3.2. reveals the extent to which the vlei is enclosed by the surrounding topography, while it is fed from the north by the Lake Farm stream. Lake Farm is geomorphologically complex, displaying a wide array of features which need to be reconciled before any detailed inferences can be made regarding the palaeo-environment. It is reasonable to assume that the same climatic fluctuations which impinge upon the vegetation of the area, have had an impact upon the other features of the environment. This is in

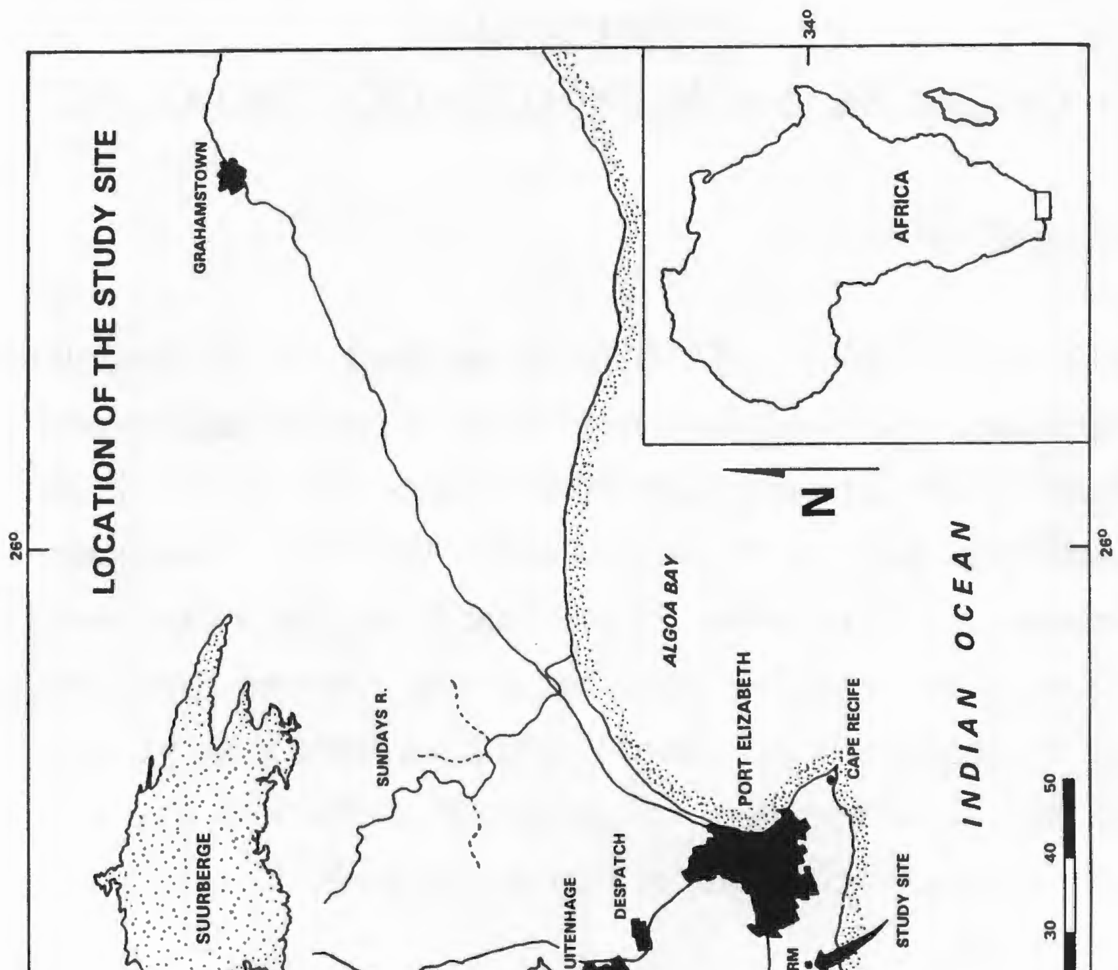

Fig 3.1. Location of Lake Farm (Approx. scale 1:250 000)

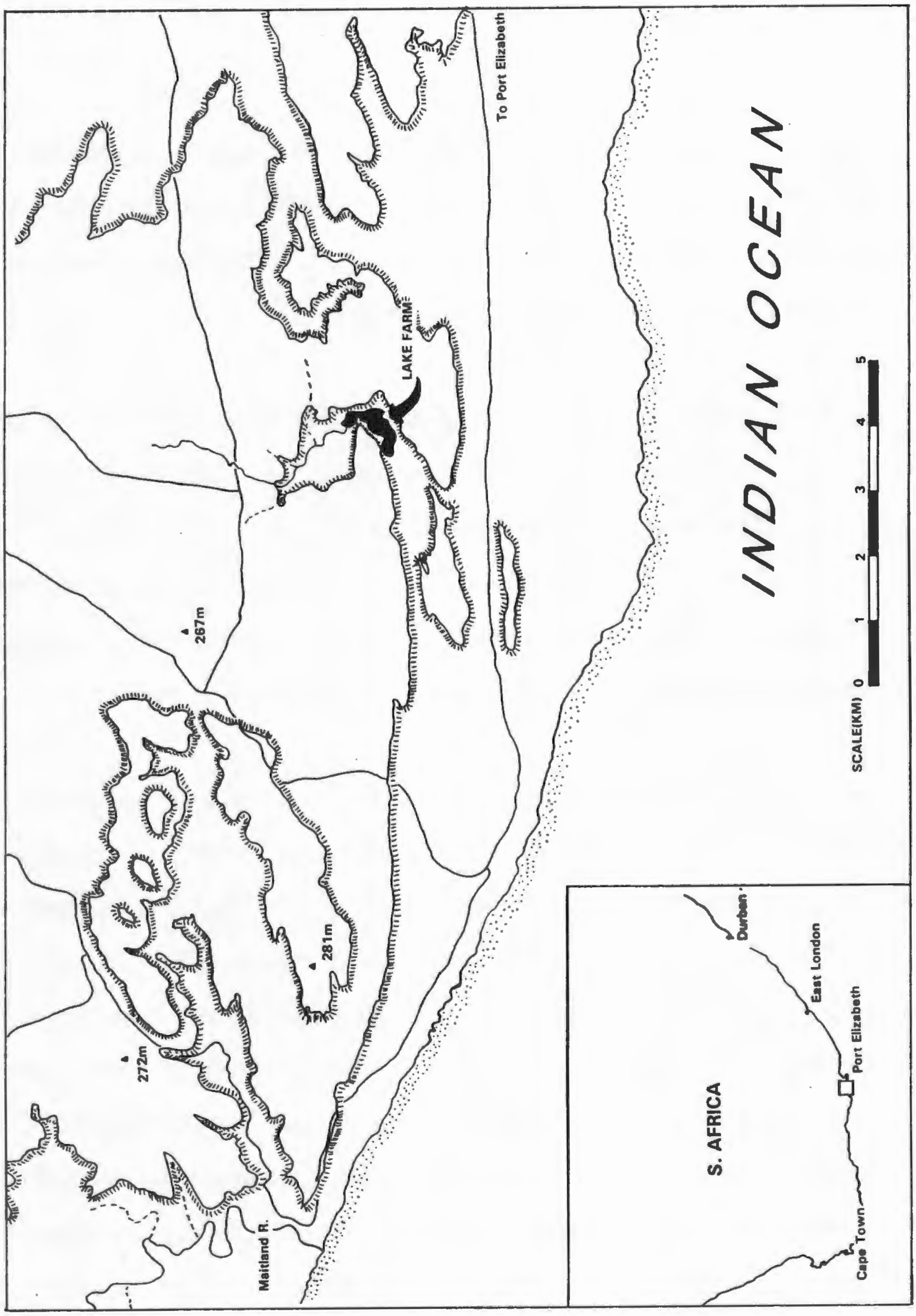

Fig 3.2. Location of Lake Farm (Approx. scale 1: 50 000)

view of the assumption that vegetation is a proxy for 'environment'.

The dunes which border the vlei are quite extensively vegetated, largely Fynbos-type vegetation occupying the South-Eastern dune. The dune to the North-West is covered with a dense stand of forest vegetation.

Fig. 3.3. depicts a plan view of Lake Farm in relation to the bordering dunes and associated vegetation. The South-west section of the lake is the deepest and is thus the site of the LFB core. The immediate borders or banks of the vlei are vegetated predominantly by grasses (Poaceae) with sedges (Cyperaceae) occurring closer to the edge of the water.

The existing water level in Lake Farm is very low as a result of artificial drying. Plate 3.2. illustrates the extent of drying in the vlei, the cracks being approximately 20-25 centimeters in width. The photograph was taken two years after the cores had been derived, and coincided with the lowest lake level in ten years (W. Illenberger, pers comm). Water had been pumped from the vlei to adjacent farmland for irrigation. The bed of the vlei consists primarily of fine peaty mud which is underlain in turn by coarse sand and coarse sand interspersed with small pebbles. In theory the greatest accumulation of sediment in a vlei is in the deepest part (see Chapter 5), and due to its sorting nature, the finer sediment is carried to the deeper part in favour of the coarse material which is deposited sooner. This was the major motivation behind the location of core LFB, and could account for the enhanced fossil pollen preservation relative to LFA, which was taken from a shallower section of the vlei. The vlei deposits are quite organic, leading to good pollen preservation.

Plate 3.1. North-South view of Lake Farm. Note the extensively vegetated dunes which border it.

Plate 3.2. The coring site.

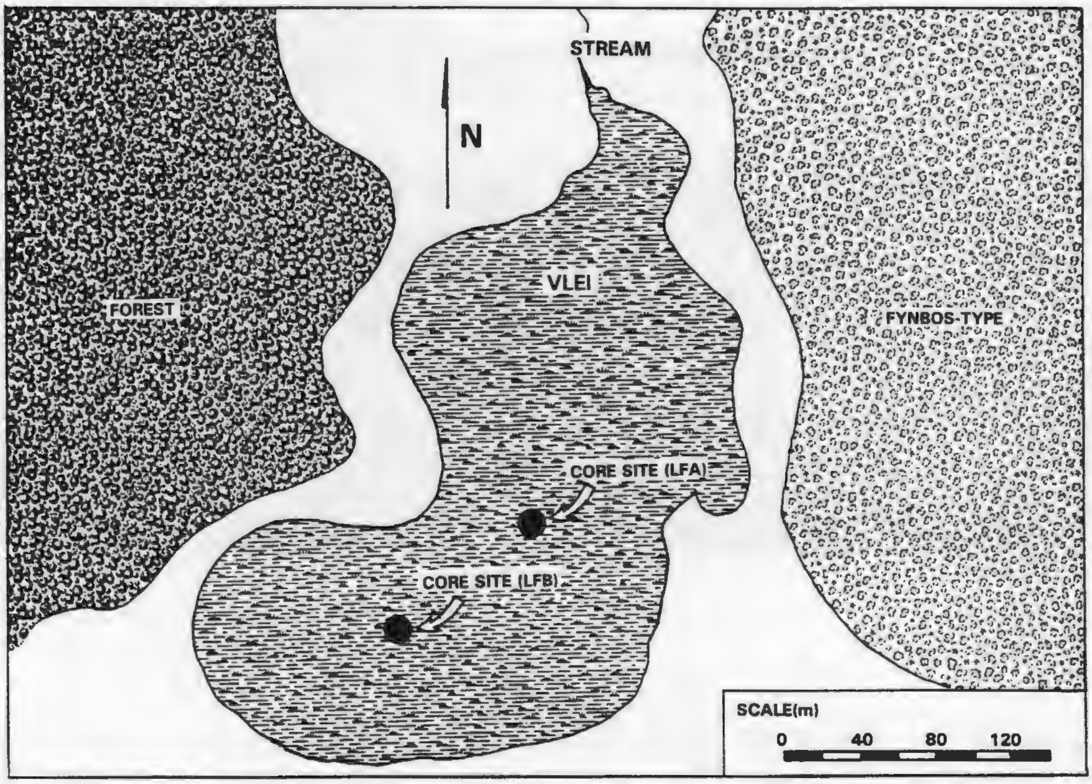

Fig 3.3. Plan view of Lake Farm (Vegetation bordering the lake is largely grasses and sedges).

3.2. GEOLOGY

Landforms are invariably a function of the combined processes of geology and geomorphology. In the Eastern Cape three variables have controlled the present scenery: Geology, including rock type and structure, geomorphological

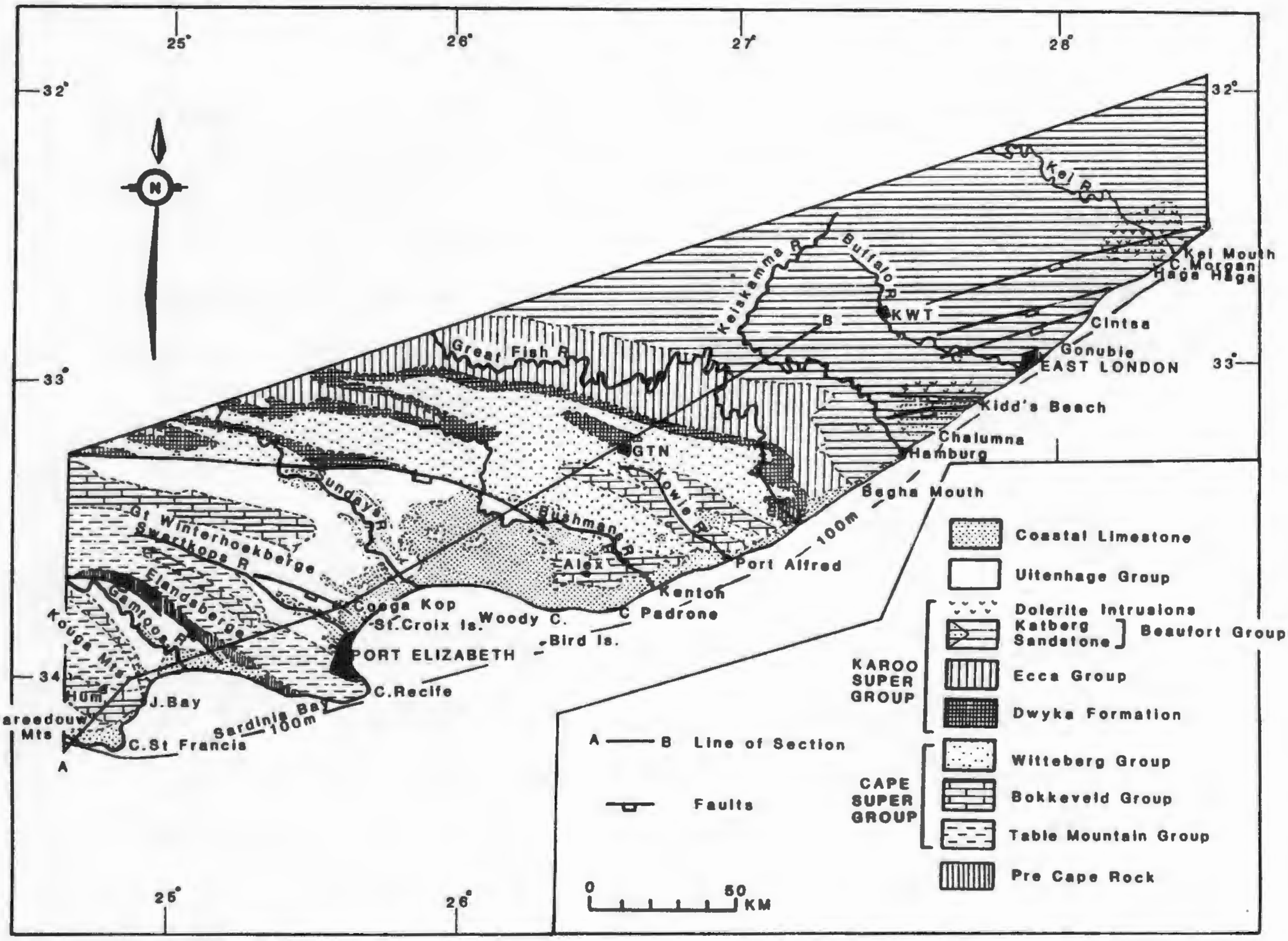

Fig 3.4. Geological map of the area (After Marker, 1988)

processes, such as erosion by rivers, limestone solution and wind and wave action, and relative movements of sea level (Marker, 1988). The fossil dunes bordering the vlei have been cemented by case-hardening, resulting in aeolianite (W. Illenberger, pers. comm.). The aeolianite dunefield is sited on a rocky promontory of quartzitic Cretaceous Sandstone from the Uitenhage group (see fig 3.4.). Late Pleistocene glacial fluctuations led to fluctuations in sea level. During the glacials, low sea levels resulted in the onshore movement of calcareous sands, leading to deposition against any uneven ground. The dunes were then hardened by lime cementation to form the aeolianite ridges which exhibit marked cross-bedding upon examination, confirming their origin (Marker, 1988). To the south of the study site there is an abundance of active dunes driven by the dominant Westerly to South-Westerly winds.

3.3. Vegetation

Acocks (1975) defines a veld type as being a unit of vegetation whose range of variation is small enough to permit the whole of it to have the same farming potentials. The existing vegetation on the dunes displays a confusing array of indicators, however the vegetation types on display have been described as a combination of coastal Renosterveld and Alexandria Forest (Acocks, 1988; Lubke, 1988; Lubke and Van Wijk, 1988). The South Coast vegetation occurs on a major climatic, topographic and geological transition zone and is consequently a focus of convergence for four phytochoria (Cowling, 1983). Given the convergent nature of the vegetation in the study site, a pertinent question may be asked regarding the forest elements. It has been suggested that the origins of the South coast forests may lie either in Afromontane Forest or Alexandria dune forest (Cowling, 1983), and one of the objectives of this thesis will be an attempt at documenting the history of forest vegetation over the past 2000 years.

Thicket vegetation is composed of a dense array of woody Fynbos shrubs common along the coastline, and is characterised by shrubs and small trees with a closed canopy, rarely exceeding 3m in height. Grassland elements are also present, and the grasses present at the study site can best be described as Mixed Grassveld, or a transition between sweet and sour grassveld (Lubke and Van Wijk, 1988). The South East Cape is phytogeographically complex, and the flora has a composition which is clearly transitional between a typical Cape Flora and a Subtropical Natal Flora. As mentioned in the introduction, this area is notable for the fact that it is a remnant patch of Alexandria forest. The Alexandria forest is the South-western extension of the coastal forest into the regions of Peddie, Bathurst and Port Elizabeth, with the largest surviving areas in Alexandria. The forests may be seen as a living witness to the great vegetation movements which have taken place on the subcontinent in response to climatic fluctuations over tens or hundreds of thousands of years (Acocks, 1988; von Breitenbach, 1972). The great significance of this study site is borne out by Cowling's (1983) observation that transition zones between phytochoria provide:'.........excellent natural laboratories to study the ecological factors governing biogeographic delimitation......' (p396). There can be little doubt regarding the value of a study of this nature given the possible shifts in ecological tolerance likely to accompany a future climatic change (see Introduction).

3.3.1. THE FORESTS

In Chapter one it was suggested that both Afromontane and Alexandria forest elements are represented at the Lake Farm site. The Alexandria forest is strictly subtropical and its distribution range occurs to the east of Lake Farm (Acocks, 1988). Afromontane forest can be referred to as tropical insofar as its latitudinal distribution is concerned. Conditions in which the forest occurs are essentially temperate though, and the extent of this vegetation type is primarily to the west of Lake Farm (Meadows and Linder, 1991). The forest types occur as a gradient or continuum in the study site and this could be reflected in the palaeoenvironmental signal.

Mixed evergreen forests occur as a series of scattered patches along the Eastern and Southern regions of the Southern African subcontinent. The forests generally occur in areas with an annual rainfall of 500-2000mm per annum, and on a variety of geological formations. The forests of Southern Africa represent the most Southerly forest complex of any significant size in Africa and cover a wide altitudinal range over a very short distance (Goldblatt, 1978; Geldenhuys and Knight, 1989; Geldenhuys, 1993). These forests once covered most of the southern Cape coast, but the action of humans is thought to have reduced them to the patches of refugia evident today (von Breitenbach, 1972; Goldblatt, 1978; Geldenhuys and Knight, 1989). During warmer and more humid periods the tropical forests expanded southwards, more often than not displaying an affinity for river valleys, lakes and the warm-humid coastal plains. Macchia and thornveld veld types retreated in the face of the advancing tropical forests, confined to localities of more extreme climatic and edaphic conditions. When the climate shifted again to a cooler and drier regime the process was reversed, and the tropical elements were forced to retreat towards the equator. This was accompanied by vigorous recolonisation by the southern flora, often forcing the tropical forest elements into a few exceptionally-favoured relict habitats. Conventional wisdom holds that in areas where forest has been reduced to patches within a sea of grassland, the herbaceous communities are 'derived' as a consequence of forest clearance during the relatively recent past (Meadows and Linder, 1989; 1993). Cowling (1983) suggests that grassy Fynbos in the South East Cape bears strong affinities to Afromontane elements. Surviving patches of the forest are found today in island-like refugia, often in sheltered mountain ravines from Soutpansberg to Table Mountain. The existence of refugia of Afromontane forest raises an interesting discussion. Meadows and Linder (1993) argue against the theory that human activity has led to the current fragmented state of the forests, suggesting instead that natural environmental change has been responsible for the current distribution. Large portions of the forest have been replaced by grassveld and thornveld communities or by eastwards moving Fynbos and Karoo vegetation (von Breitenbach, 1972). Afromontane vegetation may be described as a dynamic mosaic of forest and grassland, forest being more widespread in the mountains where precipitation is higher, the dry season shorter and fires less frequent and intense as a result of this (Meadows and Linder, 1993).

Despite their origins the southern Cape indigenous Afromontane forests can no longer accurately be referred to as "tropical". The bulk of the forest is composed of tree species which have been derived from their tropical relatives. Comprising a large proportion of the trees in the forest are members of the extinct western or southern Cape forest in the form of two Yellowwoods, *Podocarpus latifolius* and *P. falcatus*. In the Southern Cape the forest ranges in appearance from open to dense and low to tall woody vegetation i.e., scrub-scrub forest-high forest. This transition of various forest types is environment-dependent, and in accordance with rainfall, air temperatures and humidity, three major climatic zones can be identified on the Southern Cape coast.

The first zone is a **hot and dry** zone which extends from the littoral zone onto the lower plateau, and is typified by very very (v.v.) dry scrub and scrub forest (von Breitenbach, 1972). Following this, a **cold and wet** zone extends from the lower-upper plateau transition up to the lower mountain slopes and is characterised by medium moist scrub forest and moist high forest. The third zone is the **temperate humid zone** which represents the optimum climate for this vegetation type, and occupies the central portions of the plateaux, and tapers out to the west and east (von Breitenbach, 1972). The study site of this thesis lies within the cold wet zone, and the vegetation typical of this climax type will now be discussed in some detail.

The medium moist scrub forest is often encountered in protected ravines or on the landward side of slopes or dunes. The climate favoured by this type of forest is very cool and wet, with shallow peaty and loamy soils. The forest type consists of an open mixture of about 6-10m high stunted and bushy trees, forming an overstorey for shrubs up to 3m in height and a dense ground layer. Abundantly represented trees include *Podocarpus latifolius, Olea capensis, Platylophus trifolatus* and *Virgilia orboides.* Shrubs present include *Hemitelia capensis* and *Laurophyllus capensis.* Appendix G presents a more comprehensive list of vegetation characteristic of the forest.

The moist high forest is found on east and south-facing slopes in medium altitude where a temperate and humid climate dominates. Soils are moderately deep to deep and are waterlogged and moist throughout the year due to low rates of evaporation and bad drainage. The forest consists of three medium-dense and irregular tree strata, a varyingly dense to open undershrub layer and a luxuriant ground flora. The upper storey includes trees usually in excess of 50 meters such as *Olea capensis, Podocarpus falcatus, P. latifolius* and *Maytenus peduncularis.* The intermediate storey (12-20 meters) largely fills the gaps in the upper storey, and includes trees such as *Platylophus trifoliatus* and *Curtisia dentata*. The lower tree storey is usually in the region of 6-12 meters high and consists of sparsely scattered crowns of understorey species. The ground flora is very rich in more open spots and consists of tall and dense ferns and herbs (von Breitenbach, 1972).

3.3.2. FYNBOS

Fynbos elements have entered the area from the west, contributing to the complex mosaic of vegetation types in and around the study area. Fynbos occurs on sand dunes and limestone, and the indications are that the climax of this veld type is a more grassy and open scrub, particularly on the South coast. Altitude ranges from 0-300 meters and rainfall from 300-500mm per annum. Grasses are still quite dominant in the Fynbos of the south coast, and commonly-occurring examples include *Themeda triandra, Eragrostis capensis, Eustachys paspaloides* and *Merxmullera stricta.*

Dominant shrub families include Proteaceae, Aizoaceae, Ericaceae, Fabaceae, Restionaceae, Cyperaceae, Geraniaceae, Rutaceae, Liliaceae and Asteraceae. In wetter, warmer areas, the Fynbos succession leads to *Podocarpus* and *Widdringtonia* forest, and there seems to be little place for grassveld in this succession. It is quite possible that Restionaceae have replaced a lot of the grasses (Acocks, 1988)

3.4. CLIMATE

The eastern Cape coastal zone experiences mild conditions in both summer and winter. Lake Farm experiences what is termed Winter maximum rainfall (see fig 3.5.), and this

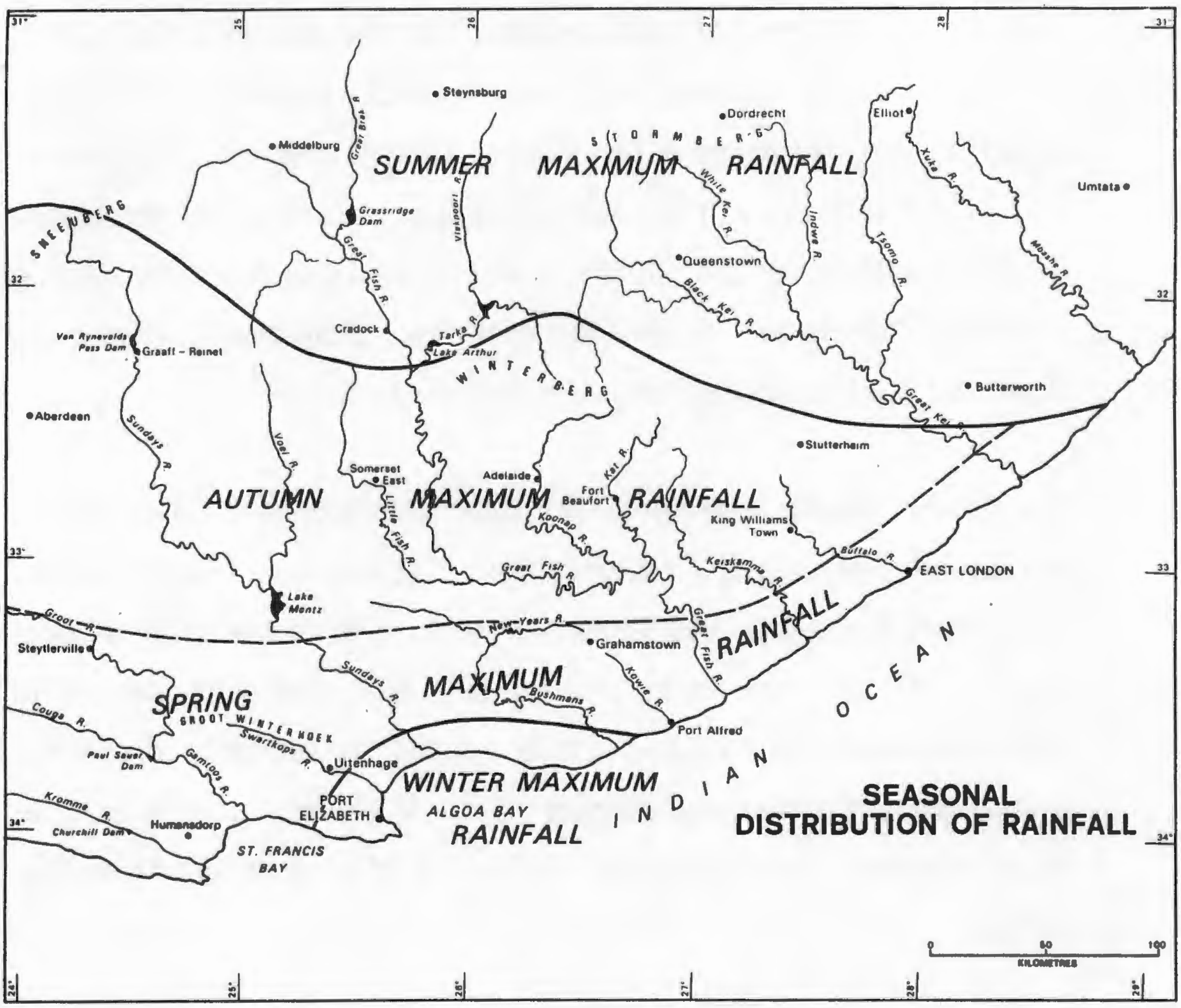

Fig 3.5. Seasonal distribution of rainfall in the eastern Cape. (After Köpke, 1988)

pattern of rainfall can be interpreted as having a more pronounced summer dry period than any other sub-region. Mean annual rainfall is in the order of 500-1000mm p.a., with Spring the wettest period (Rutherford and Westfall, 1986; Köpke, 1988). The prevalence of coastal low pressure systems over the south coast in Spring is largely responsible for this phenomenon. Most of the weather stations in the eastern Cape mark June and July as the driest months with the notable exception of Port Elizabeth. Fig 3.6. provides temperature, rainfall and wind data for Port Elizabeth. The dominant rain-producing system is the mid-latitude cyclone or cold front which dominates the weather over the southern regions of the country in winter and spring. Cold fronts are a regular feature over the southern coast in winter (Preston-Whyte and Tyson, 1988), operating on a frequency of 6-8 days, and Port Elizabeth often receives weather associated with the tail-end of such fronts (Stone, 1988). As can be seen from the graph in fig 3.6. the rainfall is relatively constant from month to month, and the seasonal temperature variation throughout the year does not vary as much as it does at other stations. The biggest temperature variation in the area occurs during summer although areas near the sea benefit from its cooling effect, as well as displaying less diurnal temperature variation (Louw, 1976). Lake Farm falls within a region classified as Cfbl according to a modified Köppen climate classification system (Köpke, 1988)

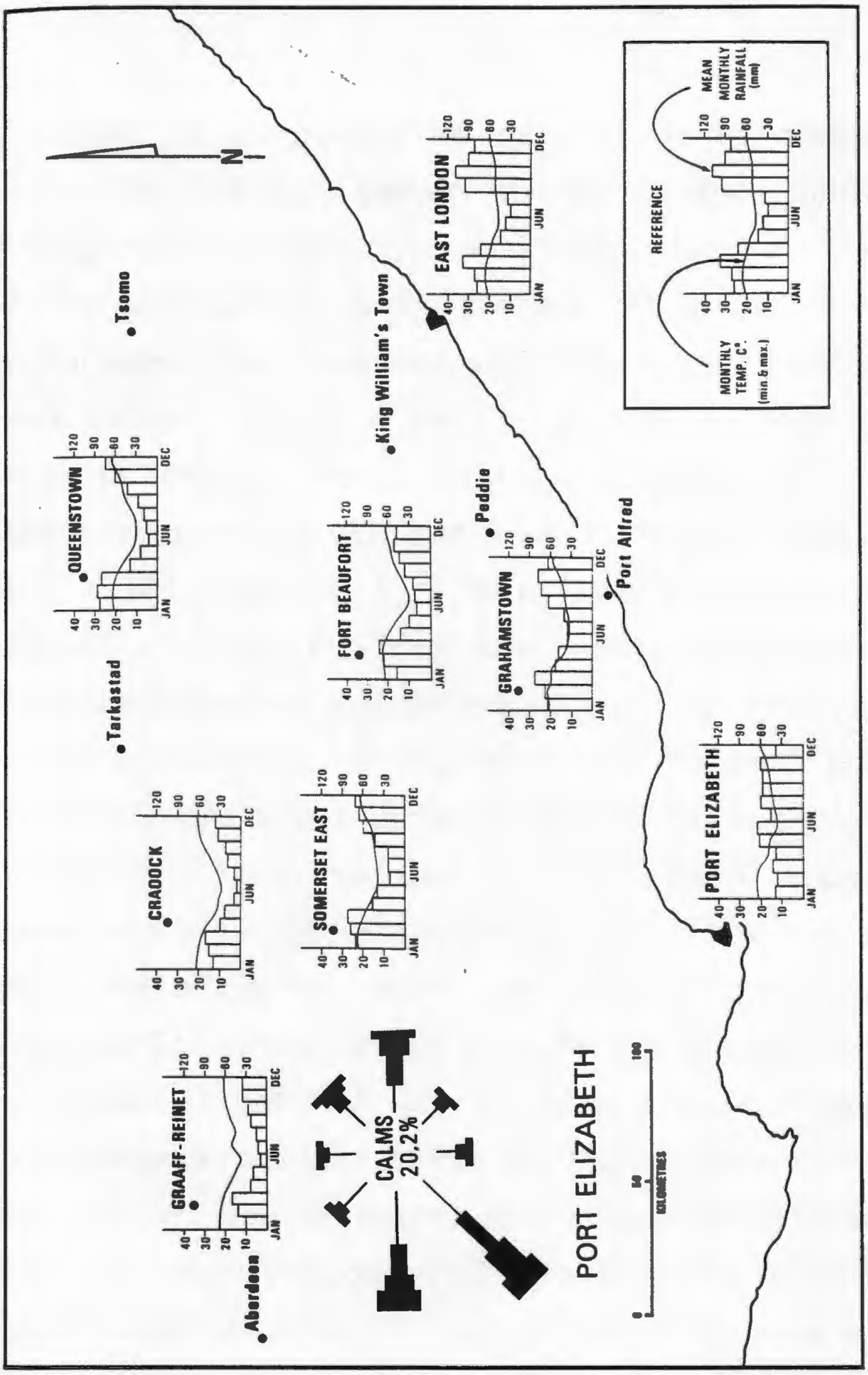

Fig 3.6. Temperature, rainfall and wind in the eastern Cape. (After Stone, 1988)

This indicates that the region is subtropical, the temperature range of all months falls between 10 and 22.2°C, and all months experience at least 60mm of rain.

The dominant winds prevailing in this region are westerly and south-westerly (Stone, 1988). The north-westerly to westerly wind component is prevalent in summer and winter and is generated by the anticyclonic circulation of the continental high-pressure system. When cold fronts pass the region a cooler south-westerly wind replaces the warmer, continental westerly (Köpke, 1988). Records of wind directions in the area over the past twenty years have been recorded by the Airport at Port Elizabeth. These records suggest a dominance of Westerly to South-Westerly winds, contributing approximately 40 % of the wind component in the area. Easterly winds comprise approximately 17 %, while the Northerly and Southerly winds account for less than 10 % each (Louw, 1976). This is illustrated by the wind rose in fig 3.6.

Given the uncertainty surrounding the issue of climatic change and the difficulties associated with its prediction, it is hard to say how weather patterns will be affected by a change in mean global temperature. it is not feasible to speculate on the climatic patterns which could have prevailed around the study site at 2200BP. The current climate is therefore accorded default status, and the discussion on past climatic change which will occur in Chapter 7 will refer to phases which were moister or cooler than the present conditions.

CHAPTER FOUR
PRINCIPLES OF PALAEOECOLOGY

4.1. Introduction

This chapter will examine the principle aims of any palaeoecological study while paying particular attention to the theory of pollen analysis and associated problems. Perhaps the discussion is most effectively initiated by means of a short quotation. Palaeoecology seeks to:

> '....provide a basis for the formulation of ecosystem models in which predictions about future effects of environmental change can be made....'
>
> (Birks & Birks, 1980:6)

Since this thesis deals with palynology, which is effectively a subdivision of palaeoecology, a discussion of palaeoecology, its philosophical principles and variety of approaches need to be reviewed.

Palaeoecology is a descriptive and historical science, and thus depends quite heavily on inductive inferences and reasoning. In palaeoecology the principle of parsimony prevails in that the simplest explanation is often the most accurate (Birks and Birks, 1980), and should be adopted until more evidence is available which will necessitate a more complicated and coherent explanation of the data. The data of palaeoecology are more often than not quantitative and complex, consisting of many observations and variables. Such data may be termed "multivariate", which means that mathematical methods of data analysis need to be employed, and can be of considerable assistance in effectively synthesising the data. These methods deal with large quantities of complex data and can contribute in no small way to critical and meaningful interpretation of the data (Birks and Birks, 1980).

4.2. Reconstruction of Past communities

The reconstruction of past plant communities is a major step towards a reconstruction of the past ecosystems, since the plant community is the most complex part of any ecosystem, and is intrinsically linked to external factors influencing it. It is then possible to make statements regarding 'environmental' conditions in the past, since the factors affecting ecosystems are conceivably 'environmentally' related. Once this has been achieved, inferences can then be made regarding the environment of the palaeosystem, always assuming that the ecological requirements and tolerances of the species and the communities are known (Birks & Birks, 1980; Birks & Gordon, 1985).

Palaeoecological research deals with two main types of fossil evidence; biotic and abiotic material (Birks & Birks, 1980) . The most commonly occurring type of fossil is preserved organic material but in totality there are comparatively few compounds sufficiently stable to be preserved, and consequently the fossil record is biased towards the organisms with preservable parts (Birks & Birks, 1980). The major focus of this discussion will be on pollen. Pollen grains, given suitable depositional conditions, may be preserved very well. This is in no small way attributable to the high resistance of the exine or outer wall of the pollen grain. The exine contains a substance called sporopollenin, which ensures good preservation of grains through time (Fægri et al, 1989). Sporopollenin is one of the most resistant materials known in the organic world (Fægri et al, 1989) and is formed by oxidative polymerisation of carotenes and carotene esters (Brooks and Shaw, 1978). The varying resistance of pollen walls or exines of different taxa has been documented (Fægri et al, 1989; Moore et al, 1991), and this is due not only to variations in wall thickness but also to the percentage of sporopollenin in the wall substance (Fægri et al, 1989).

4.3. Pollen as a form of evidence

Pollen, as primary data, lays the foundation for palaeoclimatic reconstruction . It is essential that the primary sources be carefully assessed before deriving synthesis from them

(Deacon & Lancaster, 1988). The sources have to be evaluated for representativeness in terms of spatial and temporal coverage of the vegetation of the area. There are two very important problems associated with the identification and analysis of primary data : firstly, the method of interpretation has changed over the past century and secondly, the fact that primary data are not spread evenly in space and time (Deacon & Lancaster, 1988) . The changing method of interpretation over time implies that different studies may not be compatible, thus resulting in discrepancies which hinder comparison. This does not appear to be a problem in respect of palynological studies in Southern Africa, where the essential methodology has remained largely intact. The fact that primary data are not spread evenly over space and time however, implies problems of representation. The distribution of biotic fossil data (and abiotic data to a lesser extent) depends on the favourability of the environment to its preservation. Pollen, and particularly the pollen rain generated by stands of vegetation are heavily influenced by factors such as wind speed and direction, topography and rainfall. Often the vlei or bog in which fossil pollen has been preserved is not necessarily the most representative of the vegetation of the area (Fægri et al, 1989; Meadows, 1989).

4.4. Principles of pollen analysis

Today, palynology is regarded as the principal technique in Quaternary palaeoenvironmental reconstruction (Birks and Birks, 1980) . In its most basic form, pollen analysis is a technique for the reconstruction of former vegetation communities by means of the pollen grains that the community produced (Fægri et al, 1989).

Pollen analysis is a technique most widely used to generate historical vegetation data over long periods (Fægri et al, 1989; Prentice, 1988). The information from the pollen assemblages from sediment samples is used to reconstruct plant communities from terrestrial environments. Palynological studies of stratified sediments show sequences of pollen assemblages which represent a broad picture of vegetation change over time. Inferences can then be made regarding the environment of the palaeosystem, assuming that ecological requirements and tolerances of the species and communities are known (Birks and Birks, 1980; Birks and Gordon, 1985). Prentice (1988) suggests that many studies of contemporary (surface) pollen deposition have shown that fossil pollen assemblages are diagnostic for broadly-defined vegetation or veld-types. The relationship between contemporary and fossil material from the same site has been statistically verified, suggesting that fossil pollen data provides a viable representation of past vegetation communities.

What follows are some of the major factors which contribute to the usefulness of fossil pollen in the examination of past vegetation communities.

1). Pollen grains are produced in enormous quantities, thus increasing the likelihood that grains will be present in sediments (Fægri et al, 1989). Pollen analysis depends upon the production of pollen by all flowering plants and spore production by mosses and ferns.

2). Pollen grains are more widely and evenly spread than larger fossils and thus are less reliant on the mother plant being a member of the community forming the deposit (Fægri et al, 1989).

3). Pollen grains can be retrieved in great numbers. With a few exceptions, most flowering plants produce copious quantities of pollen, much of which is preserved in the lake or vlei. Once samples have been retrieved from the site, the preserved pollen will be available for analysis.

4). Pollen grains can be treated statistically. See: Birks and Birks, (1980); Birks and Gordon, (1985); Jacobson, (1988);

Grimm, (1988); Thackeray, (1989); Sugden and Meadows, (1989); Fægri et al, (1989); Adams, (1991).

The graphic representation of the analysis of fossil pollens is the pollen diagram. The pollen diagram can be assumed to reflect vegetation change and spatial maps produced based on adequately time-correlated fossil pollen assemblages can be assumed to reflect vegetation patterns that existed in the past, allowing vegetation to be mapped in space and time (Prentice, 1988). This relies on the assumption that the ecology of a species remains constant through time, otherwise the reconstruction of former vegetation communities would have no palynological significance whatsoever. The changing distribution patterns of a species cannot be construed as being an environmental indicator if the ecology of a species is not seen as constant or at least dynamic about an equilibrium (Sugden, 1989). The pollen diagram and its zonation are discussed in Chapter 6.

Fossil pollen grains were first discovered in pre-Quaternary sediments circa 1836 by Goppert. Lennart Van Post was the first researcher to realise the real potential of pollen analysis (Fægri et al, 1989). Since then the prominence of palynology has increased over time, and a number of guidelines have been stipulated over the years, which the researcher should be aware of when conducting a palynological study. Fægri et al (1989) have outlined the following guidelines, unless otherwise indicated.

1. Pollen and spores are produced in large quantities for reproductive purposes.

2. Apart from relatively few pollen grains which are utilised in reproduction, the rest of the grains fall to the ground or are transported away from the parent plant by various means (Birks and Birks, 1980)

3. Some pollen and spores, under certain environmental conditions, may be fossilised and thus remain identifiable for a long period of time.

4. Atmospheric turbulence produces more or less evenly dispersed pollen 'rain'.

5. The constitution of the pollen rain is an index of the vegetation which produces it (Tauber, 1967; Meadows, 1989).

6. Pollen is specific to the taxon which produces it.

7. If fossil pollen is examined from a sediment of known age, the pollen spectrum is an index of the vegetation.

8. Pollen spectra from stratigraphic samples may provide a picture of the development of the vegetation type through time.

4.5. Problems of pollen analysis

In even the most carefully-planned of studies, a number of problems are likely to occur. In the series of events between the release of pollen to the final pollen diagram, much may happen to distort the record and render the pollen diagram misleading, unless the distortions can be compensated for. The basic assumptions outlined above create difficulties for the palaeoecologist which are compounded to some extent by methodological and statistical problems.

1. Pollen Production

Differential pollen and spore productivity means that it may be difficult to identify the relative abundance of particular elements in a fossil assemblage (Birks & Birks, 1980) . In general, more pollen is produced by wind-pollinated taxa, thus resulting in a bias in the pollen data obtained (Birks & Birks, 1980) . The seasonal and diurnal variation in the dispersal of pollen adds to the complexity of investigating fossil pollen grains . The problem of differential pollen production is apparent in the Fynbos where a large proportion of the taxa are entomophilous (Sugden, 1989).

2. *Pollen Dispersal*

The dispersal of pollen depends principally on atmospheric turbulence, windspeed and direction, weight and shape of pollen grains and the height and strength of the pollen source (Birks & Birks, 1980) . Since most of these parameters are variable in both space and time (some are variable in the short-term) they could and do pose problems for a Palynological study .

3. *Pollen Preservation*

Pollen is often differentially preserved, largely due to changes in the availability of suitable preservation media . Pollen grains can be affected and altered by physical, chemical and biological processes from the moment they are liberated from the plant to the time when they are examined (Birks and Birks, 1980). The chances of preservation over time are slim, and not all macrofossils have identical levels of resistance to environmental conditions at the site of accumulation (Birks & Birks, 1980) . Grains can be corroded by bacterial activity as well as being split and further damaged by for example, erosion and physical reworking . This leads to problems of identification which can severely bias the study .

4. *Identification*

As a result of some of the problems outlined above, identification and counting can be problematic . Given the constraints imposed by the limited magnification of the standard light Microscope, some pollen grains can only be identified down to family level at best. Certain pollen grains belonging to families such as Asteraceae, Acacia, Oxalidaceae and Geraniaceae can, more often than not, be identified at genus or even specific level. Pollen morphologists have to some extent overcome this problem by reverting to Scanning Electron Microscopy (SEM) in an attempt to achieve a more specific identification and description. In view of the financial, practical and time constraints associated with SEM, this is not a viable option for the Quaternary palynologist dealing with pollen in sediments. One solution may be the use of an Image Processing unit, which will automatically identify and count pollen grains based on parameters of grain description which have been pre-programmed into the system. This will optimise the speed and accuracy of pollen identification, and possibly allow for identification to specific level in some cases. Financial constraints are again an important consideration in this case. It could be argued that nothing of this nature will replace the experience of a palynologist, and that the Image Processor will not be able to account for grains which have been deformed by the preparation procedure.

Palynologists are likely to remain divided into two camps over this issue, those who favour the advantages of technology and those who favour the traditionalist approach. The method has yet to be tested and its efficiency proven, and no further discussion will be devoted to the topic.

5. *Preparation losses*

The resistance of the exine of pollen grains to acetolysis (See Chapter 5) during slide preparation varies, thus affecting the composition of the fossil pollen sample . Some taxa are more resistant to acetolysis than others, and less-resistant grains may be eliminated from the fossil record during the chemical purification process (Fægri et al, 1989). Another source of pollen loss during preparation is the decanting of supernatent after a particular procedure. Care should be taken while decanting supernatent as pollen grains may be lost as the polleniferous material at the bottom of the container is disturbed. This can be seen as an occupational hazard, as nothing much can be done to avoid the loss of some pollen in this way.

6. Statistical problems

Pollen analysis is subject to the rules that govern all statistical relations . As a consequence, the analysis is affected by any shortcomings or oversimplifications associated with the specific technique (Birks and Gordon, 1985) . The particular statistical problems encountered in this study are discussed in Chapter 8 .

Other problems mentioned earlier have been accounted for and taken into consideration during the preparation and interpretation of data in this thesis.

CHAPTER FIVE

METHODOLOGY

5.1. Techniques of data collection

Fieldwork not only provides a material basis for the work that is to follow it, but the foundation upon which conclusions are built (Fægri et al, 1989). This means that fieldwork in the form of data collection should be as accurate as possible, and result in the least possible risk of disturbing or contaminating the derived sample. Samples may be collected from exposed sections (if these are available), examples of which are peats, lake muds, soil and tufa deposits. Naturally these sections hold the advantage over other sites in that they are more accessible and allow for an assessment of the degree of lateral variation in a deposit and avoid the difficulties of conducting transects of cores. Added advantages of exposed sections include a decrease in risk associated with coring equipment, of sediment distortion, slumping and contamination (Moore et al, 1991).

Unfortunately many sites are not as accessible as exposed sections, and many diverse methods need to be employed to obtain samples from them. Many factors need to be evaluated before sampling can begin. Initial constraints include the accessibility and nature of the site, availability of personnel and suitable equipment. Careful selection of the site from which data is to be collected needs to precede any fieldwork. It must be borne in mind that the site chosen must be representative of the vegetation of the area. An attempt should be made to determine whether any allocthonous influx of sediment or pollen grains is occurring in the form of riverine input to the vlei or lake (Fægri et al, 1989; Moore et al, 1991).

From the moment a pollen grain is deposited, it is subject to the same diagenetic processes as the other organic and inorganic constituents of the deposit (Fægri et al, 1989). Lake sediments containing pollen grains such as Lake Farm contain information regarding the environmental conditions under which they were deposited (Meadows, 1988a). The initiation and subsequent development of peat, a stratified organic deposit, is closely controlled by climate. It has been recognised that certain general climatic and hydrological criteria need to be met in order that peat may accumulate. Peat sediments are usually associated with cool, moist climates where the decomposition of organic debris is retarded and hydrological conditions entail permanent waterlogging and acidity (Meadows, 1988b). Lake Farm is a peat-forming freshwater ecosystem dependent upon rainfall and other sources of fresh water for its nutrient supply. The most efficient peat accumulation is usually in medium to high latitude sites with high precipitation and moderate mean annual temperature, both of which are associated with low primary productivity (Moore, 1989; Thompson and Hamilton, 1981). Lake Farm conforms to these conditions, where mean monthly rainfall does not display much seasonal variation, and mean annual temperature is moderate (see Chapter 3). In these conditions the decomposition of organic detritus is retarded, and hydrological conditions involve permanent waterlogging and acidity (Thompson and Hamilton, 1981).

Sediments are distributed within the vlei in a particular pattern, similar to that seen in the deposition of sediment load from a river into a dam (Weaver, 1979). Common theory holds that as sediment flows into a lake or vlei, the coarser sandy material accumulates along the edge of the lake, while the finer clay sediments (more conducive to pollen preservation) accumulate in the central seepage area. The lake in the study site displays similar sediment dynamics in accordance with this theory. Sediment input into the lake is affected by soil erosion and vegetation cover. This raises an interesting issue which concerns seasonal variation in sediment accumulation. One argument holds that in winter the dense vegetation leads to the entrapment of sediment within the lake, and the corresponding accumulation of organic matter. In Summer by contrast the lower vegetation cover results in greater erosion and runoff and this will also produce a significant sediment influx. Any further discussion concerning the origin of sediment within a lake is beyond the scope of this thesis.

Once the site has been chosen, the decision of where to sample must now be taken. In the case of a lake or vlei, a transect of cores is often desirable in order to obtain a comprehensive record of the cross-sectional stratigraphy. This is often not possible due to inaccessibility of the site (it may be submerged). Often, and under normal circumstances, the sample should be taken where the sediment is deepest, although these may have been contaminated by re-deposited material. Similarly, sites on or near the influx of major water-courses should be avoided as these are prone to erosion and excessive re-working of the sediment (Fægri et al, 1989). Fægri et al (1989) suggest that in small vleis or basins (such as this particular site) a single, central sampling point may suffice as chances of complications in the horizontal plane are small.

Where exposed sections are not present, cores have to be extracted from the surface of the site (Moore et al, 1991). A number of techniques exist which can be used to extract cores, and each of them operate on a similar principle. The sampling tool is pushed down into the sediment and is either filled from the end or the side. The sample is then isolated within the tool and retrieved. Examples of side-filling samplers include the Hiller and Russian samplers (See Fægri et al, 1989; Moore et al, 1991). Examples of end-filling samplers include piston samplers and gouge augers (which technically are a combination of end and side-filling samplers) (Moore et al, 1991). Fægri et al (1989) suggest the use of PVC tubing to extract cores because of the ease of penetration, strength and low friction coefficient associated with them. It has been found however that while PVC tubing possesses all of these characteristics as well as minimal weight (important in transportation), the subsequent splitting procedure in order to analyse the sample leads to excessive disturbance of the sediment, rendering the sample practically useless (Own observation).

5.2. The Vibracorer

The Vibracorer method of core extraction was employed in this study and the core was extracted by Dr. Werner Illenberger in April 1987. The design and construction of the vibracorer was based on guidelines stipulated by Lanesky et al (1979). The assembled vibracorer is shown in Plate 5.1., where a poker vibrator is attached to the aluminium tube and leads to an engine via a pneumatic cable.

Lengths of aluminium tubing were sunk into the sediment in order that a representative core could be derived. The tubing specifications were 6m X 7.62cm X 1.27mm. The edges of the leading end of the tube are filed to a sharp edge to facilitate penetration.

Plate 5.1. The assembled Vibracorer (Note the poker vibrator attached to the aluminium tube by means of pneumatic cable).

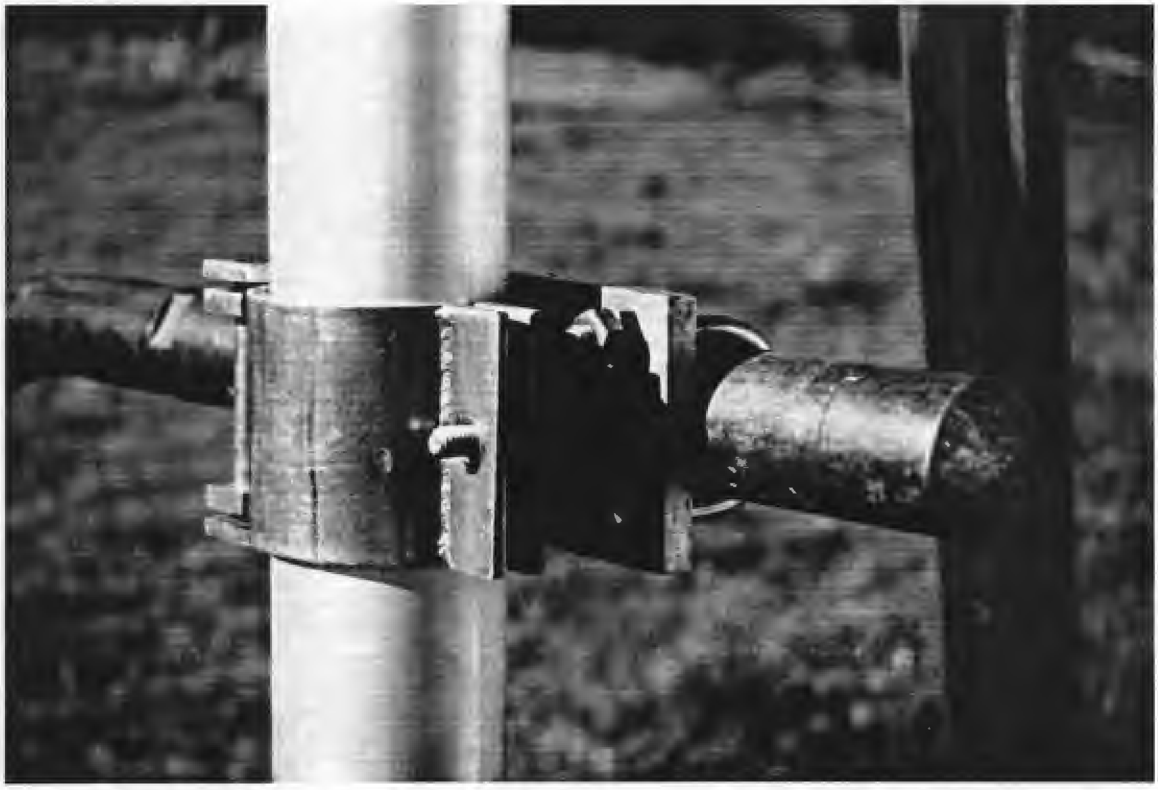

Plate 5.2. The poker vibrator attached to the tube by means of a machined coupling.

A very efficient core catcher was fixed to the leading edge of the tube to prohibit slumping and failure of the core on extraction. The core catcher was constructed of 0.05 inch brass shimstock, and was fixed approx. 1 cm inside the end of the tube with quick-hardening metal glue and 3mm pop rivets. The rivets were subsequently filed down to minimise the risk of disturbing the sediment. A poker vibrator was attached to the tube by means of a machined coupling (see Plate 5.2.), and this in turn led to a four-stroke engine via a pneumatic cable. The pneumatic cable operates on the principle of an unbalanced weight driven by the motor, setting up high frequency vibrations in the poker head. The Vibracorer operates at optimum efficiency in sediments containing a fair degree of moisture, as was the case at Lake Farm (W. Illenberger, pers. comm.). In some cases a reasonable amount of force needs to be applied to the tube to aid penetration. The high frequency vibrations generated by the vibrator created a liquid zone around the tube, thus facilitating penetration. The vibrator coupling was shifted progressively upwards as the tube settled into the sediment.

Extraction of the tube was achieved by means of a winch and pulley system (see Plate 5.4.). A length of sailing rope (13mm diameter) was attached to the tube via a single and a double pulley so as to increase the force exerted on it. The rope was attached by means of a single prissic knot, which could be shifted downwards as progressively more of the tube was extracted.

Plate 5.3. Sinking the core tube

Once the core had been fully extracted it was sawn into lengths of approximately 2 meters and the ends were stoppered for transportation back to the laboratory.

Once in the lab, the cores were opened for inspection. The lengths of tubing were placed in a specially constructed rack and a circular saw was used to cut along the length of the tube. The saw blade was set at 2mm to ensure minimal disturbance of the sediment while ensuring that the aluminium was cut cleanly. The tube was then turned through 180 degrees and the process repeated. A length of wire was pulled along the length of the core between the cuts to effectively split the core in two. In very organic samples containing rootlets and small twigs this can be a delicate and time-consuming procedure. The two halves of the core were then examined for sedimentology and core logs prepared (see Appendix I). Sub-sampling occurred at the interval decided upon (5mm) after a thorough examination of the core. Samples were taken from the centre of the split tube where the chances of disturbance through contact with the walls of the tube were at a minimum. Samples for ^{14}C dating were submitted to the dating laboratory in Pretoria which operates under the auspices of the CSIR. Results of the core logging and dating are provided in Appendix F.

Plate 5.4. Extraction of the core tube by means of a tripod and pulley.

Samples for pollen analysis were placed in labeled plastic sample tubes and refrigerated to minimise the risk of either contamination or drying.

5.3. Laboratory procedure

The laboratory procedure used in the preparation of fossil pollen samples was based largely upon the guidelines stipulated by Fægri et al (1989). There is no definitive procedure for the preparation of fossil pollen due to the almost infinite variation in the composition of different samples. Samples will differ from one another because of discrepancies which range from the nature of the substrate to the extent to which one sample is more organic than another. The laboratory procedure employed in any palynological study should be aimed specifically at the particular sample in question, and should attempt to account for all the characteristics of the sample which render it different to the next.

The samples in this study were very organic, and the soil or substrate in which the pollen grains were preserved was of an extremely fine particle size.

5.3.1. Deflocculation of the sample

The first consideration in the preparation of fossil pollen material is deflocculation. The samples dry quite rapidly once the core has been subsampled, even when placed in the refrigerator for preservation. Some of the samples were hard, and it was often difficult to manually disintegrate it. Fægri et al (1989) suggest a number of procedures which will deflocculate a dry sample, including ultrasonic treatment and physical breakdown with a pestle and mortar. These methods are rejected because even though the high resistance of the pollen wall has been extensively documented (See Fægri et al, 1989; Moore et al, 1991), these methods may still lead to rupturing and subsequent identification problems. Another possibility is to place the sample in a chemical reagent such as ethanol or Sodium Hydroxide (NaOH) (which was favoured in this case) overnight so that the sample may disintegrate on its own accord. The treatment with NaOH was particularly appropriate since a 10% solution was employed in the following procedure, that of the removal of humic acids.

Depending on the coarseness of the sample, a decision should now be taken whether to sieve or not. If a sample is coarse the researcher can foresee a number of problems in later preparation steps. A 150 micrometer sieve is used and the sample is washed through with either ethanol or glacial acetic acid, as both of these reagents have a relatively lower surface tension than water, leading to less retention of sample in the sieve. As with all the procedures in the preparation of fossil material, a certain percentage of the pollen will be lost. This is unavoidable, and most of the pollen is lost when decanting the supernatent after the specific procedures (Jemmett and Owen, 1990). The researcher must remain cognisant of the dangers associated with this stage of the proceedings, and this will minimise the risk of excessive pollen loss.

5.3.2. Removal of Humic acids

Unsaturated organic soil colloids or humic acids were removed from the sample by boiling in 10% NaOH (Fægri et al, 1989). Humic acids, if not correctly or sufficiently removed, can result in a "dirty" sample, where attempts to count and identify pollen grains can be hindered by clouds of opaque matter on the slide. Samples were placed in a boiling water bath for approximately 15 minutes, during which time the reaction of the NaOH was sufficient to dissolve all the humic acid in the sample. Extended periods of exposure to boiling NaOH can damage the pollen wall (Fægri et al, 1989), but exposure for up to 1 hour left no discernible ill-effects. The sample was then removed from the water bath and centrifuged. The supernatent containing the dissolved humic acids was carefully decanted, and the sample was washed with distilled water a number of times (each wash separated by centrifuging) until the supernatent became clear, to remove all the excess acid. On occasion the sample had to be subjected to another treatment of NaOH, indicated by a cloudy supernatant after repeated washes with distilled water. The NaOH treatment was extremely effective and resulted in no discernible distortion of the pollen grain, as long as the concentration did not rise much above 10 percent. Fægri et al (1989) suggest that exposure to higher concentrations of NaOH can severely damage the pollen wall, making identification practically impossible.

5.3.3. Removal of siliceous matter

Subsequent to the removal of humic acids the samples were washed with a solution of 10% Hydrochloric acid (HCl) to remove the last of the humic acids and remove carbonates. The procedures used to remove siliceous matter from a sample will vary according to the nature of the sample and the preference of the researcher. Mineral separation methods involving zinc chloride ($ZnCl_2$) may be used in the case of gritty samples, and sodium pyrophosphate ($Na_4P_2O_7$) can be used in the preparation of clay-rich samples (See: Bates et al, 1978). An alternative is to subject the sample to 40% hydrofluoric acid (HF) to effectively dissolve the coarse soil and clay particles. In this study a combination of procedures was used as some of the samples were more sandy than others, obviating a more effective method of removing the siliceous matter. A combination of mineral separation with zinc chloride and treatment with boiling HF was used.

Hydrofluoric acid is used to dissolve the siliceous matter in the samples, and can be employed as a cold acid or in boiling form (Fægri et al, 1989). The samples may be immersed in a 40% concentration of cold acid for up to four weeks, and this will result in the removal of the siliceous matter with minimal distortion of the exine or outer wall of the pollen grain. This method is not feasible because of the amount of time it takes. The favoured method involved immersing the sample in boiling 40% HF for about three hours in a fume cupboard. This had no discernible effect on the exine of the pollen grain, took a fraction of the time of the cold method, and was comparable in terms of effectiveness. Plastic centrifuge tubes were used in this step as they are not affected by the HF, whereas glass tubes are attacked and vigorously corroded by the reagent. The samples were centrifuged and the excess HF along with the dissolved sand and grit was decanted. At this stage of the proceedings a decision was taken whether or not to employ the mineral separation method, and this was dependent upon the degree of grit or coarse material remaining in the sample.

Zinc Chloride has a high specific gravity, and was added to the sample before centrifuging it at very high speed (+-4500 rpm). All the heavier matter (including the coarse sand and grit) was carried to the bottom of the tube whereas the lighter pollen grains and other organic matter tended to "float" on the surface. The polleniferous material was then poured into a clean plastic centrifuge tube and the process repeated, the supernatent again decanted to the same tube as in the first step. A reagent with a low specific gravity (ethanol in this case) was then added to the supernatent and centrifuged at high speed. The polleniferous material was carried to the bottom of the tube and the rest decanted. The resultant sample was very clean, although it must be remembered that this stage leads to the loss of quite large amounts of pollen, and should only be used when the HF procedure has not sufficiently removed the siliceous matter.

5.3.4. Removal of colloidal silicates

The samples were immersed in a 10% concentration of HCl in order that colloidal silicates may be removed. The samples were immersed in a boiling water bath for 30 minutes and then centrifuged. Glacial Acetic acid was then added to the samples to yield a pH in the region of 3. This step prepares the samples for the acetolysis procedure, which is geared primarily towards the removal of excess organic and cellular matter from the samples.

5.3.5. Removal of excess organic matter

The acetolysis mixture consists of 9 parts acetic anhydride and 1 part concentrated sulphuric acid. The sulphuric acid is added to the acetic anhydride and the mixture is stirred slowly to initiate a chemical reaction. Care should be taken not to stir too vigorously as a violent reaction significantly detracts from the potency of the mixture. Preferably a wide-bottomed flask should be used for the mixing procedure, as narrow receptacles tend to suppress the reaction. The mixture is added to the samples and placed in a water bath for three minutes and then removed. Glacial acetic acid is added to stop the reaction of the acetolysis mixture, and the samples are then centrifuged and the supernatent is decanted.

A neutral pH solution is mixed using 9 parts distilled water and 1 part 10% NaOH. This is added to the sample to derive a neutral pH (or as close as possible) which may be checked periodically with indicator paper. This procedure ensures that the samples are adequately prepared for the staining process which forms the next step in the preparation.

5.3.6. Staining

The samples are washed three times with distilled water, and on the last wash two drops of aqueous safranine stain are added. The samples are stirred and then centrifuged. Tertiary butyl alcohol (TBA) is added, the samples are stirred and centrifuged. The polleniferous material is transferred to labeled vials using TBA. Finally, a known volume (3ml) of TBA is added, and the samples may be stored until counting.

5.4. Counting

Before preparation of the pollen a decision must be taken whether to perform relative or absolute counts. Relative counts involve counting the pollen on a slide until a particular figure is achieved (often a pre-calculated percentage of the average total sum). This method is usually less time consuming than performing absolute counts, but provides no information regarding absolute pollen frequencies over time. Absolute counts involve counting every pollen grain on a slide and can be very time consuming, but the benefits of this technique by far outweigh the drawbacks. In this thesis I decided to employ the absolute counting method. This allowed conclusions to be drawn regarding the frequencies of pollen and their fluctuation over time. One can therefore make conclusions regarding absolute rates of pollen accumulation assuming good dating control and accurate inference of sedimentation rates.

For mounting, a measuring pipette was used to extract a known volume (0.2 ml) from the vial and this was placed on a microscope slide. The slide was then placed on a warming tray to encourage the evaporation of excess TBA from the sample. A cover slip was then carefully lowered onto the polleniferous sample and the slide labeled. Identification and counting were performed by means of a Zeiss light microscope at a magnification of X400. A magnification of X600 was used periodically to aid identification, while the oil-immersion X100 objective was avoided because of the problems this created when attempting to use one of the other objectives afterwards.

Regular traverses of the cover slip were carried out, shifting the cover slip by the width of one field of vision at the end of every traverse. Every pollen grain on the slide was identified and recorded (See Appendix E for total pollen counts per slide).

Glycerol and silicone oil were avoided as mountants because of their high viscosity. TBA was the favoured mountant because of its low viscosity which allowed the orientation of the pollen grains to be manipulated by tapping the cover slip with a dissecting needle. The TBA was problematic at times due to its high rate of evaporation but this was considered less of a drawback than the high viscosity of the alternatives.

5.5. Generation of the pollen diagram

The counts were recorded on sheets from which they were transferred to a spreadsheet. The data were transferred to Quattro Pro™ Ver 3.0, with observations or depth as column labels, and taxa or families as row labels.

The Pollen data manipulation program Tilia™ was used to generate the pollen diagram. The data were exported from Quattro in ASCII format and imported to Tilia. Within this program the data were formatted by editing family names and assigning groups, new cell addresses were given and a dictionary of plant/pollen types was created. A stratigraphically constrained cluster analysis was performed without any data transformation. The results were saved in a separate file and the plot was added to the diagram in the Tilia Graph™ subprogram. The purpose of formatting the data was to put it in a format recognisable to the pollen diagram-generating sub-program. The data were saved as a Tilia file, in a format recognisable to Tilia Graph™. Within Tilia Graph, the file was retrieved and all the necessary parameters such as axis length, taxon order, zonation, titles, shading and so on were performed. The data were saved as a "dump" file with a .tgf extension, and were sent or dumped to a HP Laserjet III printer using an appropriate printer driver. A laser printer was preferred above a plotter because of its speed advantage and greater compatibility with the font chosen for the diagram.

In many studies a pollen diagram is generated manually but this is an incredibly time-consuming process. The ease with which the Tilia program can be manipulated and the speed with which preliminary and experimental pollen diagrams can be generated means that it was a far more feasible method for the graphical representation of the data.

The principles of constructing the pollen diagram as well as a complete discussion of the pollen frequencies through time follow in the next chapter.

5.6. Introduction to Multivariate Statistical techniques

There has recently been a growing awareness of the vital role statistical methodology can play in Quaternary pollen analysis (Birks and Birks, 1980; Birks and Gordon, 1985). Numerous techniques have been employed in an attempt to shed light on the complex problems surrounding Quaternary pollen data. This section examines various techniques employed in the past, drawing attention to their various applications, strengths and weaknesses. Special attention is paid to techniques which have been successfully employed within the Southern African context.

Pollen data are quantitative information governed principally by climatic and environmental factors. The frequency and composition of fossil pollen provides an indication of the relative importance of climatic factors at the time of production/deposition of pollen. Unfortunately the quantitative nature of fossil pollen does not always lend itself to qualitative description, and statistical manipulation offers a more detailed account of the vegetation history of a site. Pollen data have already provided successful quantitative estimates of climatic parameters for regions in North America, India and Europe (Bonnefille et al, 1990). Care should be taken not to base conclusions solely on the results of statistical procedures. Birks and Gordon (1985) caution against excessive reliance on and inappropriate use of these techniques, calling for: '....an inquisitive, but also constructively critical attitude to the methods proposed....' (pg. 27).

One of the key questions asked when applying statistics to fossil pollen is whether and to what extent the sample under analysis is representative of the vegetation at that time. If the pollen rain of the palaeoenvironment had been significantly altered by environmental parameters, the accuracy and predictive power of the sample will have been affected. This would result in a bias towards certain pollen types with better dispersal characteristics or greater rates of production. One way of overcoming this problem and of determining the representativeness of the sample is to compare contemporary pollen rain with contemporary vegetation. The technique used to do this is called Multiple Discriminant Analysis. While this thesis does not employ this particular technique, it has been used in a number of studies to determine the degree of analogy between modern pollen spectra and fossil material. This will be expanded upon in more detail later, for now focus will be concentrated upon a statistical technique employed in this particular study, Principal Components Analysis (PCA). There is a degree of similarity between PCA and a related technique, Common Factor Analysis, and the following discussion will distinguish between the two regarding applications in palaeoenvironmental studies.

5.7. Applications of Principal Components Analysis and Common Factor Analysis

Although clearly-defined differences between Principal Components Analysis and Common Factor Analysis exist, they fall within a category of statistical analysis commonly referred to as Factor Analysis. Factor Analysis refers to all methods of data analysis using matrix factors, including Principal Components Analysis and CFA (SAS/STAT™ User's guide, 1989). In PCA the residuals are usually correlated with each other, while in the case of CFA, the unique factors play the role of residuals and are defined to be uncorrelated both with each other and with the common factors. This does not prevent the estimation of scores however. CFA generally attempts to overcome this problem, defining the components as linear combinations which account for the variance within the data set and which may be traced back to a physical variable which affected it.

Once factors or components have been estimated interpretation becomes a very important consideration. When interpreting components, names are usually assigned to each common component which reflect the importance of the component in predicting each of the observed variables. Given the necessarily subjective nature of interpretation, it is possible to rotate the common components in an attempt to arrive at a less subjective analysis. When rotating common components, a nonsingualr linear transformation is applied. It must be borne in mind that rotation of a set of components does not change the statistical explanatory power of the components (SAS/STAT™ User's guide, 1989). Detailed discussion of the operation of the statistics is beyond the scale of this thesis, and the discussion will pay attention to only the features which relate directly to this study.

Both PCA and CFA are used in exploratory palynological studies directed towards the identification of factors which contributed to regional changes in the abundance and distribution of taxa in palaeoenvironments (Thackeray, 1987a). CFA represents multi-dimensional data in relation to the component axes in such a way that the new distances between individuals reflect the original distances or dissimilarities between the individual specimens (Birks and Birks, 1980).

Attempts may be made to exclude statistical 'noise' by excluding from the data set groups which were rarely represented, or considered to have wider tolerance to environmental change, see: Scott and Thackeray (1987). Whether this should actually be performed or not depends upon the data set under scrutiny as the vegetation composition and environmental conditions would have varied from one site to the next. In the case of the Lake Farm data variables such as Indeterminate, broken and unknown taxa were excluded from the statistical procedure as they would not in any way have contributed to the explanatory power of the results. The crucial part of the statistical analysis is the estimation of loadings for each component. The success of this technique depends on the extent to which taxa with extreme loadings (strongly positive or negative) on the first few factors can be identified. An attempt can then be made to identify ecological and geological requirements of various taxa by isolating those with extreme loadings on the first two or three factors. Variables such as temperature, rainfall and soil pH, which may account for variation within the data, may be identified. This is not always possible (Scott and Thackeray, 1987), and the problems encountered with this particular data set will be discussed in a later section which deals with results and the interpretation thereof.

Multivariate statistics allow the researcher to draw conclusions from a data set which would not otherwise be possible. They also allow comments to be made regarding the representativeness of the contemporary sample and the degree of analogy between observations (i.e. fossil vs. contemporary data). Environmental parameters which influence the nature, composition and distribution of taxa within the study area may be isolated. Depending on the significance and reliability of the results, the data set may be compared to an existing and reliable source of palaeoclimatic fluctuations such as the Vostok Ice Core (Thackeray, 1990).

5.8. Statistical methodology employed in the Lake Farm study

The statistical technique applied in this thesis is based on applications utilised by various authors. The technique has been employed in the study of fossil floral and faunal remains, see: Scott and Thackeray, 1987; Thackeray, 1987a; 1987b; Thackeray and Avery, 1990.

The data or pollen counts were arranged in matrix format, with depths or observations as row labels and taxa or pollen types as columns. In total 46 pollen types were identified and counted throughout the length of the core, while counts were performed at 5mm intervals for the first 300mm of the core, and at 25mm intervals for the rest. The motivation behind this was to attain a high-resolution analysis for the upper part of the core, which was assumed to coincide with the advent of humans in the study site. The hypothesis underlying this decision assumed that the human impact would be reflected both in the composition of the flora as well as in the abundance of the various pollen types. Artificial modification of the vegetation through irrigation, clearing for fuel and building materials, and grazing was expected.

The computer package Systat for Windows™ ver. 5.0 was used for the statistical analysis of the data set. The fossil pollen data had been entered initially on Quattro Pro™ ver. 3.0, and were imported into Systat by means of a text conversion and import facility in the package. Once imported, Principal Components Analysis was performed on the data. The matrix type was specified as a correlation matrix, and a varimax rotation procedure was specified. The Overland and Preisendorfer significance test was employed to determine how many eigenvalues were to be retained (Overland and Preisendorfer, 1982). The test was run at 95% significance level, indicating the confidence limits at which output was not due to noise in the data. Basically the test is run by simulating the exact dimensions of the data rows and columns, and then generating random numbers to occupy the cells of the matrix. The eigenvalues of the correlation matrix are then computed, and the experiment is repeated 100 times (Overland and Preisendorfer, 1982). Appendix I shows the results of the significance test. The eigenvalues generated by the PCA of the Lake Farm data were then compared to the eigenvalues from the 100 times iteration of the Overland and Preisendorfer test. The first eigenvalue of the Lake Farm test is divided by the number of variables (46) and then compared to the test eigenvalue. If the eigenvalue/number of variables figure is greater than the test value, the next eigenvalue is considered and so on. When the test eigenvalue is greater than the value computed from the Lake Farm data, then this is assumed to be the cut-off point in determining the number of eigenvalues to retain. In this case 4 eigenvalues were retained with a 95% confidence that they were not due to noise in the data. Component loadings are given by Appendix A and the significance of these in determining environmental variables of species distribution is evaluated in Chapter 7.

5.9. Introduction to the Pollen diagram

Pollen data in raw, tabular form are not very useful, and some form of graphic representation is necessary in order that the full potential of the data may be realised. The pollen diagram was introduced in 1916 by Lennart Van Post, and can be viewed as the last link in the sequence of technical procedures which started in the field (Fægri et al, 1989). The pollen diagram is a series of graphs of the values for different pollen and spore taxa, plotted against their stratigraphic depth or age (Birks and Birks, 1980). A range of different approaches may be used to produce a pollen diagram, but invariably the choice of technique depends upon the individual preference of the scientist (Moore et al, 1991; Fægri et al, 1989).

The pollen diagram should provide a coherent visual representation of the data matrix in order that the reader may grasp the salient features with the minimum of effort. A danger in the construction of the pollen diagram is attempting to present too much information and :

> '.......losing the salient points in a maze of less relevant data....' (Fægri et al, 1992:91)

Relevance in these terms is to be understood in relation to the objective of the investigation, which involves the identification and discussion of changing trends in the fossil pollen concentrations. The construction of the pollen diagram is often an exercise in balancing the considerations of legibility and documentation. A tradeoff has to be reached which will maximise the amount of information presented without hampering the legibility of the diagram in any way. Apart from summarising pollen counts through time, the diagram should provide information regarding stratigraphy and chronology (Moore et al, 1991; Fægri et al, 1989).

5.10. Features of the Pollen Diagram

Stratigraphical information is displayed in a vertical column usually to the left of the graph, and provides a graphic summary of the sedimentological composition of the deposit as identified in the field and in the laboratory (Fægri et al, 1989). This provides information which could be essential for adequate interpretation of the fluctuating pollen curves (Moore et al, 1991). The chronology should involve the positioning of ^{14}C dates in accordance with the depths from which they were derived.

The pollen curves *per se* are the depiction of proportions of the various pollen types at each level of sampling by a bar or continuous curve. Some researchers may favour the bar or histogram approach because it makes no assumptions about missing data, whereas a curve will interpolate between two points, giving the impression that data exists for the intermediate point. The continuous curve or sawtooth method, apart from the problem just mentioned, is often favoured because it is visually more effective than the histogram.

The pollen types or taxa have traditionally been arranged according to the order of appearance in the core, however more recently the diagrams have broken with tradition and have arranged taxa in ecologically meaningful groups (Moore et al, 1991). Groups comprising Fynbos elements, grasses, karroid, trees and exotic vegetation types are often presented in contemporary diagrams. The precise arrangement of the groups or for that matter, the decision to include groups at all, depends once again on the individual preference of the scientist. Another method of grouping taxa may be based on classification of plant types by taxonomic arrangements, examples of which are arboreal pollen types, shrubs, aquatics, spores and so on. While this may be useful in locating specific taxa on the diagram, it is not necessarily the most instructive in terms of ecological interpretation of events reflected in the vegetation (Moore et al, 1991). As mentioned earlier, the ecological interpretation of the data should be of prime importance, and should not be hindered by poor grouping technique.

In addition to the stratigraphical information and radiocarbon dates alluded to earlier, a variety of other data may be included in the diagram which could assist interpretation.

Data providing an indication of the number of taxa recorded at each level may be of value in interpretation. Fluctuations in the number of taxa may provide some indication of canopy cover, as often the degree of canopy cover over a study site will regulate the number of taxa actually represented in the pollen rain or fallout (Moore et al, 1991). The number of taxa represented in a core is also an index of diversity, and Moore et al (1991) suggest that a statistical index such as the Shannon-Weiner function used in collaboration with the taxa number can be very useful in providing an indication of the level of diversity at various locations in the diagram.

Another feature which may be included in the final diagram is a summary pollen diagram. this is a chart which graphically displays the subdivision of the pollen sum into tree, shrub and herbaceous components at each level. This allows quick and accurate conclusions to be drawn regarding relative shifts in the various components of the total pollen sum over time. Data presented in this manner are often invaluable during the zonation of a diagram. In many cases the summary pollen diagram is totally separate from the main diagram, and the final choice of whether to include it or not lies with the palynologist.

5.11. Zonation of the Pollen Diagram

Pollen analytical data are often so complex in the number of fossil pollen taxa represented and the number of individual fossils counted at each level, that it is usually necessary to divide each stratigraphical sequence into smaller units for ease of description, discussion, comparison, interpretation and correlation in space and time. The most useful unit of subdivision of the time or vertical dimension of a pollen diagram is the pollen zone (Birks and Gordon, 1985).

A pollen zone is a biostratigraphic unit defined purely by its pollen content. Horizontal lines are drawn across a diagram dividing it into a sequence of units. Subdivision of this nature is intended to simplify the information and to construct units which are as internally homogeneous as possible, and display recognisable pollen characteristics which may distinguish one zone from an adjacent zone. The zonation of a pollen diagram may be undertaken without any reference to other information besides the pollen data. It follows that zone boundaries will be placed at the points where change in the pollen spectra is most marked (Moore et al, 1991).

Few guidelines or stipulations exist which define a pollen zone and/or how it is achieved. Fægri et al (1989) suggest that a pollen zone :

> ".......represents the biostratigraphic unit : 'that element of stratigraphy which is concerned with...units based on their fossil contents'.........." (Pg105-106)

Fægri et al (1989) caution against excessive philosophical meanderings or indeed complex statistical techniques in defining pollen zones. They suggest, as do Moore et al (1991), that pollen zones should be defined by presence/absence relations in the pollen sum before anything else. A similar technique has been used in this study, although a brief discussion of some statistical techniques useful in pollen diagram zonation will follow.

The statistical or numerical techniques discussed here refer only to a single stratigraphical sequence, and therefore describe and summarise the basic features of the pollen stratigraphy for that particular local sequence. This differs from the regional pollen assemblage zones which are based upon several sequences. There has been a recent increase in the number of studies which have attempted to employ numerical methods in the zonation of pollen diagrams.

Zonation can occur without reference to any information other than the pollen data. Zones are characterised by a consistent floral composition, while the boundaries are usually defined by a definite change such as an increasing or diminishing composition in the flora. The composition of the flora and consequently the definition of a zone is dependent upon the geographical situation, environmental history and successional stages of the vegetation. Changes in the diagram upon which the zone borders are based should be unequivocal and provide clearly defined borders. If underlying ecological reasons can be deduced which are in some way responsible for the changes observed in the spectrum, it must be remembered that this in no way validates nor invalidates the zonation (Fægri et al, 1989).

The selection of zone boundaries is based on the determination of points of maximum change in the pollen assemblage, and traditionally this has been achieved by subjective means. Since the pollen zone is essentially a unit of convenience, a subjective approach is normally satisfactory (Moore et al, 1991).

A number of basic guidelines need to be considered when undertaking the zonation of a pollen diagram. The following is largely based on the work of Moore et al (1991).

1. A zone boundary should pass between samples, but never through a sample. Every sample must belong to a particular assemblage zone.

2. It is often very useful to select the most distinctive point of change in the assemblage, and subdivide the rest of the diagram from this starting point.

3. A zone boundary should not be based upon a change in only one taxon. The more taxa which display marked changes at a similar depth, the stronger the case for erecting a zone boundary at that point.

4. Zones consisting of a small number of taxa (less than three) should be avoided as far as possible, however this is occasionally indicated by the data, in which case the researcher should consider employing more analytical work or numerical methods in order to clarify matters.

5.12. Statistical zonation of the Pollen diagram

There has recently been much interest in the development and application of statistical procedures in the zonation of pollen diagrams (Birks and Gordon, 1985). In this section a number of techniques will be briefly discussed before a detailed account of the technique in this particular study will be provided. The statistical or numerical techniques to be discussed refer only to a single stratigraphical sequence, and therefore describe and summarise the basic features of the pollen stratigraphy for that particular local sequence. This differs from the regional pollen assemblage zones which are based upon several sequences. There has been a recent increase in the number of studies which have attempted to employ numerical methods in the zonation of pollen diagrams.

One approach has compared pairs of neighbouring levels in the stratigraphical sequence in order that sudden changes in the pollen and spore composition may be detected. The Chi-squared statistic, the product-moment coefficient and Spearman's rank correlation coefficient have been used as measures of between-level differences in pollen composition.

Another approach has been to apply standard scaling procedures such as Principal Components analysis to pollen stratigraphical data. This sort of procedure can also be of assistance in the comparison of several different pollen diagrams. (Birks and Gordon, 1985). A number of other numerical techniques exist, but any detailed description is beyond the scope of this thesis.

Numerical and statistical procedures have recently gained acceptance in palynology largely due to the increased availability and ability of computer systems. These methods provide the researcher with a tool by which personal bias and interpretive preconceptions can largely be avoided, and allow the generation of consistent, repeatable results. A cautionary note however warns against excessive reliance upon numerical techniques in the zonation of pollen diagrams, as they can be invaluable aids in substantiating decisions and zonation, but conclusions should not be based solely on these techniques. There are a number of inherent biases in the statistics which may result in spurious conclusions depending on the nature and origin of the data (Moore at al, 1991).

A procedure called Constrained Incremental Sum of squares Cluster Analysis (CONISS) was employed in an attempt to verify the subjective zonation of the diagram. This procedure was run within the Tilia program and the output plotted against the pollen diagram (See appendix C). The first three levels of the CONISS were chosen as indicative of major trends within the data and the subjectively-inserted zones agree with this to a large extent. The value of this technique will be examined in Chapter 8.

CHAPTER SIX

RESULTS

This chapter examines the stratigraphy and chronology of the core derived from Lake Farm. Following this the results of the statistical analysis will be considered before moving on to the pollen diagram

6.1. Stratigraphy and chronology

Appendix F displays the detailed stratigraphy of core LFB, while Appendix I displays the detailed core log and associated radiocarbon dates. LFB yielded 4285mm of sediment from a 6000mm long core tube with a peat decompaction factor of 2.0149. Pollen counting and identification were performed on the upper 1690mm of the core, while the lower 2595mm consisted of sterile sand of aeolian origin. The section of the core which was analysed consisted largely of fine organic material. The section 785mm to 1010mm consisted of fine organic material mottled with white sand, while the lower 55mm of analysed sediment consisted of fine organic material interspersed with sand pockets. At a depth of 1640mm a ^{14}C age of 2200+-45 years was obtained (Analysis no. Pta-4668). At a depth of 730mm a ^{14}C age of 1310+-50 years (Analysis no. Pta-5035) was obtained.

The core material contained a relatively high proportion of pollen, and the plot of pollen totals through the core is given by Appendix E. The plot suggests an increase in pollen concentration through time. It is not known why this may be so, although inferred moister conditions in the upper half of the sequence (see chapters 7 & 8) may have contributed to more effective pollen preservation as well as greater vegetation abundance.

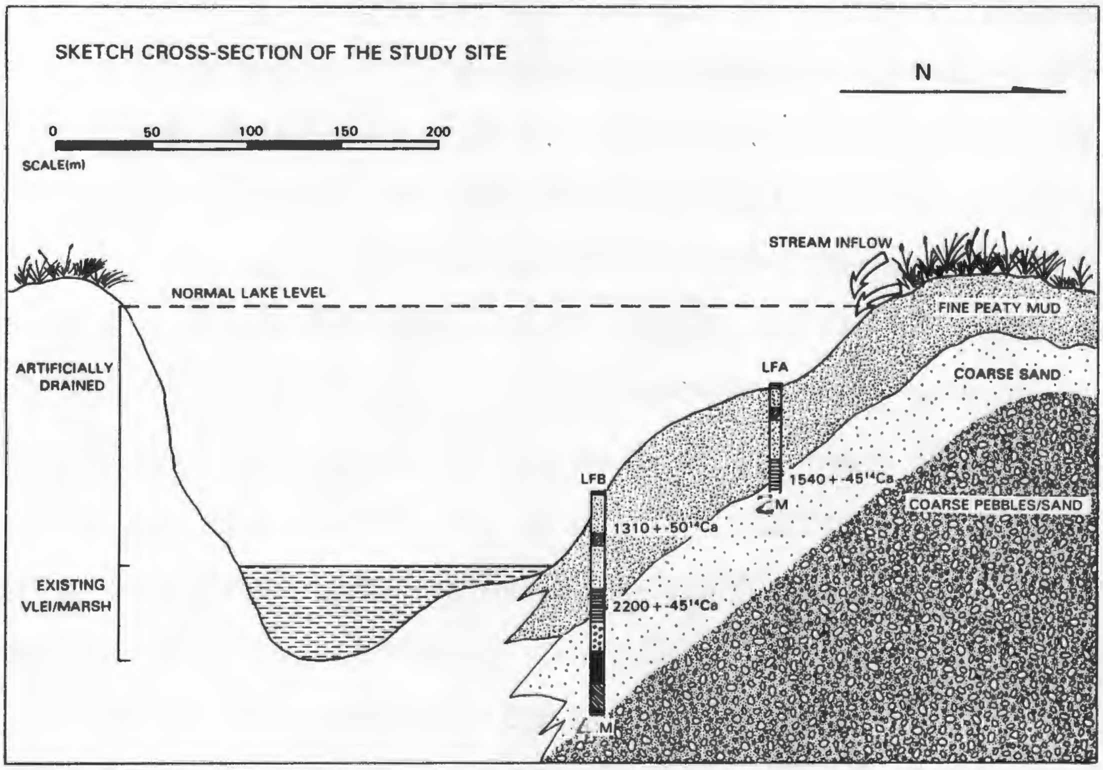

Fig 6.1. Sketch cross-section through the site

Fig 6.1. shows a sketch cross-section through Lake Farm. The discrepancy between the existing lake level and the former level can be attributed to artificial draining of the lake in recent years (subsequent to coring and thus not reflected in the LFB sequence). Water from Lake Farm was pumped to adjacent farmlands for irrigation and this resulted in drying of the local environment (W. Illenberger, pers. comm.). Exploratory drilling prior to the coring procedure revealed three generalised sediment layers which comprise the lake bed, consisting of an upper fine, organic layer underlain by coarse sand. The lower of the three layers consists of pebbles and coarse sand (W. Illenberger, pers comm). Both cores derived from Lake Farm intruded the second layer, LFB being twice as long as another core, LFA. LFA was not examined because it had been subjected to severe disturbance after coring and the results would have been virtually impossible to interpret. LFA did reveal three distinct sandy layers which correspond almost exactly with the stratigraphy of LFB. The sandy layers of LFA were at 100mm, 1000mm and 1215mm. This corresponds to the sandy layers in LFB which are at 100mm, 998mm and 1245mm (see Appendix I). The significance of these layers in terms of possible dry spells will be evaluated in Chapter 7.

Determining the rate of sedimentation through time by examining the sedimentology of a core is always difficult. In the case of LFB there appear to have been two distinct rates of sedimentation before and after 785mm. The ^{14}C age of the sediment at 785mm is 1310+-50 years. This translates to 160 years for every 100mm of sediment. Conversely, for the remaining 890mm of sediment 905 years elapsed. This in turn translates to 101 years for every 100mm of sediment. The discrepancy of 1.6 years per millimeter below 785mm versus 1.01 years per millimeter above 785mm appears to be significant. The marked difference in the sedimentation may be explained by close analysis of the fossil pollen data, and this will be examined in Chapter 7.

6.2. Discussion of Pollen Zones

The Lake Farm pollen diagram was subdivided into 6 assemblage zones, comprising a total of 12 subzones. Major features of each zone will now be discussed in chronological order. The depth (mm) and approximate age of the base of each zone will be given.

LA (1675mm to 1200mm) Approx. age 2200-1710BP

Zone LA occupies approximately 500 years of the sequence, and reveals a presence of most of the pollen types which were identified in the counting. Grassy elements such as Poaceae and Cyperaceae are present, and display largely consistent percentages throughout. Poaceae display a peak at 1300mm and Cyperaceae peak at 1325mm. Juncaceae, Restionaceae and Asteraceae are relatively consistent throughout the zone. Minor incidences of Pelargonium, Stoebe-type and Mesembryanthemaceae are evident, while various other taxa are represented at some stage or another in the zone. The most interesting trend is displayed by Fabaceae, which are present in significant percentages for the duration of the zone, and declines to under 5% at the zone boundary. Fabaceae are present higher up in the diagram but only in very small percentages, and the LA-LB boundary indicates a variable responsible for the sudden decline in the numbers of this pollen type.

LB (1200mm to 1000mm) Approx age 1710-1500BP

Zone LB is characterised by significant fluctuations in the percentage of Cyperaceae pollen. Having dipped at the zone boundary Cyperaceae increase to 1100mm before declining again at the LB-LC boundary. Poaceae dip at 1100mm before recovering to the end of the zone. Asteraceae are largely constant, as are Juncaceae and Restionaceae. Fabaceae, which had been well-represented in LA before declining at the LA-LB boundary, are consistent around 5% for the duration of LB.

LC (1000mm to 800mm) Approx. age 1500-1310BP

Zone LC only encompasses 200mm of the sequence but is significant because of the major changes in pollen frequency occurring here. Poaceae display a steady decline for the duration of the zone. Chenopodiaceae/Amaranthaceae emerged at the LB-LC boundary and are present in significant percentages throughout LC. Asteraceae and Restionaceae display minor fluctuations but are largely consistent throughout. Mesembryanthemaceae, Euphorbiaceae and Fabaceae are present but not in significant percentages. Other pollen types making brief appearances include Proteaceae, Rutaceae, Pelargonium, Liliaceae and Stoebe-type. Cyperaceae again display the most marked fluctuations in this zone, peaking at 875mm before declining to the LC-LD zone boundary.

LD (800mm to 150mm) Approx. age 1310-220BP

This is by far the largest zone in the entire Lake Farm sequence both in terms of core length and time span. Poaceae and Cyperaceae once again dominate the sequence, each displaying some significant fluctuations for the duration of the zone, although Cyperaceae fluctuate quite markedly especially from 600-350mm. Exotic tree pollen makes its first significant appearance in this zone. Both Poaceae and Cyperaceae begin peaking at the zone boundary, while

Podocarpus displays some significant fluctuations prior to the LD-LE boundary. Juncaceae, Restionaceae and Asteraceae are again present in significant percentages, displaying minor fluctuations.

LE (150mm to 75mm) Approx. age 220-120BP

This is a small zone, marked by the presence of tree pollen, particularly that of indigenous trees. Both Poaceae and Cyperaceae decline sharply in this zone, while Restionaceae display a sudden increase. Shrubs and weeds display a general increase, especially Sterculiaceae, while Fynbos elements are also present in significant percentages. Asteraceae in particular attain close to their highest percentage within this zone, increasing towards the zone boundary. Monocots are well-represented.

LF (75mm to 0mm) Approx. age 120BP-present.

Fynbos elements are well-represented at the top of the sequence and Asteraceae are still increasing at present. Restionaceae stabilise, Poaceae decline quite significantly while Cyperaceae decline to zero at the present. Pinaceae, which emerged at the start of LE continue to be well-represented in this zone, and other notable occurrences include Liliaceae, Mesembryanthemaceae and Podocarpus.

Interpretation of the pollen diagram in light of past vegetation fluctuations will follow in Chapter 7.

CHAPTER 7
INTERPRETATION OF THE POLLEN DIAGRAM: VEGETATION HISTORY

7.1. Introduction

This chapter examines the pollen diagram and presents a narrative of the vegetation history of Lake Farm over the last 2000 years. The high resolution of the analysis is emphasised, as the 5mm sampling interval represents 8 years of vegetation history. The narrative is closely linked to the stratigraphy of the sequence, and the significance of various sandy layers is evaluated with respect to changing environmental conditions. The results of the Principal Components analysis are examined and suggestions made regarding environmental determinants of the vegetation distribution. Having arrived at a narrative of vegetation history at Lake Farm, comparisons are made with other related sites. Results from other relevant palaeoecological reconstructions including Martin's (1968) study of Groenvlei and Scholtz's (1986) examination of the palaeoecology of Norga peat near George are compared to those obtained here.

The significance of the inferred environmental changes are evaluated in light of the changes during the Late Holocene as outlined in Chapter 2. The fossil pollen record is examined in an attempt to detect evidence of human activity in and around Lake Farm. Finally, an attempt is made to make conclusions about the current status of forest vegetation and Fynbos in the study site, and the behaviour of these vegetation types over time.

7.2. Principles of vegetation history reconstruction

According to Faegri et al. (1989) the interpretation of a pollen diagram should involve two initial steps:

1). Establishing the composition of the vegetation that produced the pollen rain.

2). Drawing inference from the vegetation data back to the agents behind them i.e., climate, ecology, human interference and so on.

The discussion in this section will adhere to these basic guidelines, with particular attention devoted to agents influencing vegetation as mentioned in point #2.

Earlier in the discussion it was mentioned that pollen rain is a result of the vegetation that produces it. The fundamental aim of pollen diagram interpretation is to reverse this concept. Palynologists attempt to reconstruct the extent of former vegetation through examination of the pollen diagram and, indirectly, pollen rain. Every attempt is made to ensure that the fossil core is representative of pollen rain over time. Numerous pitfalls await careless assumption, however, as the core may have been subjected to re-working, abnormal pollen rain, unusual sedimentation patterns and so on (Fægri et al, 1989). Apart from these problems, the fact that the quantity of pollen produced varies between species, (Moore et al, 1991) has led to numerous difficulties when inferring past vegetation extent. For a detailed account of problems confronting palynologists see Chapter 4.

When addressing the issue of past vegetation patterns (point #1), two approaches may be considered. One approach involves the identification of *Indicator taxa* with specific environmental tolerances, and whose presence permits certain definitive statements to be made regarding past conditions (Fægri et al, 1989; Moore et al, 1991).

The indicator taxa approach may not result in an accurate reconstruction of past vegetation patterns. Indicator species may be dominant in the local vlei environment, in which case they will respond to environmental perturbations which affect the local but not the regional environment. Conversely an indicator species with a more regional extent may not reflect more localised perturbations. Another problem with indicator taxa is that their diagnostic potential is often restricted to one environmental parameter, for example moisture availability.

It is believed that consideration of the entire fossil pollen spectrum through time will result in a more accurate reconstruction of past vegetation. Evaluation and interpretation of combinations of pollen types at various stages in the sequence will be more informative than a single indicator species.

7.3. Reconstruction of past vegetation and environmental conditions

Apart from the sandy layers alluded to earlier, the fine organic sections of the core were uniform in texture, implying that the sedimentation rate at this stage of the sequence was relatively constant. Disregarding the changes in sedimentation rate implied by the sandy layers, a process of interpolation was used to determine the approximate age at various points through the sequence.

7.3.1. LA1 and LA2

Environmental conditions following 2200BP appear to have been relatively stable. The pollen diagram does not reveal any significant fluctuations in pollen concentration in zones LA1 and LA2. Poaceae and Cyperaceae dominate the diagram, with significant percentages of Asteraceae and Fabaceae also evident. Fynbos elements are present but not in large concentrations. Elements associated with the southern coast forest are absent in these zones, suggesting that forest (Fig 7.5.) is not represented at this stage of the sequence.

Near the culmination of LA2 Cyperaceae, which are dominant within the local environment, peak sharply. This occurs at approximately 1325mm (see Fig 7.1.), which coincides with a sharp peak in the total pollen sum (see Fig 7.2.). This along with the relative absence of xeric elements and emergence of a number of aquatic and semi-aquatic elements at this stage of the sequence suggests that a period of greater moisture availability prevailed. This could represent a shift to a wetter climate which seasonally produced waterlogged conditions in the depression. The summary diagram in Fig 7.3. displays a dip in xeric elements above approximately 1300mm.

7.3.2 LA3

Figs 7.2. and 7.3. reveal the extent to which grasses and fynbos decline after 1300mm. Shrubs display a significant decline after 1300mm (see Fig 7.4.) and the pollen sum declines sharply from 1300mm to 1200mm. LA3 is characterised by significant declines in many of the pollen types, and Fig 7.1. reveals how both Asteraceae and Fabaceae decline to almost zero at the LA3-LB1 boundary, a situation from which Fabaceae never recovers.

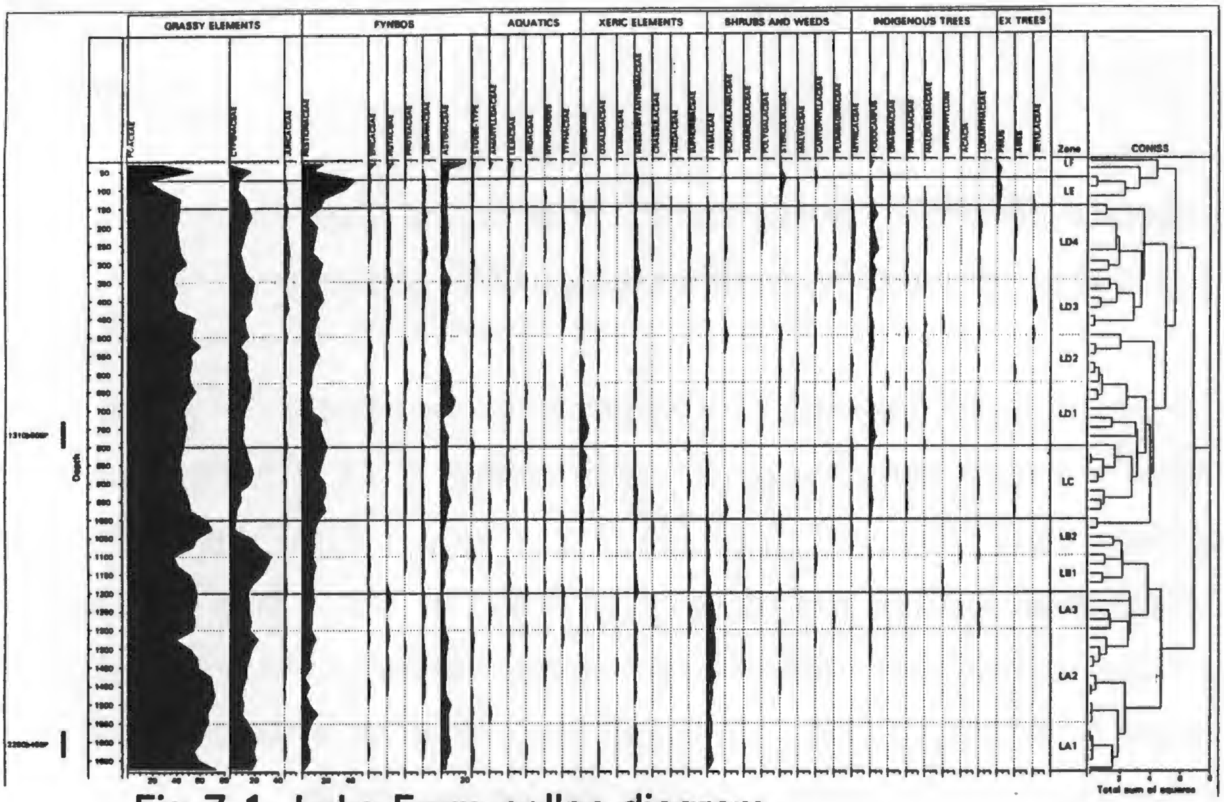

Fig 7.1. Lake Farm pollen diagram

The boundary occurs at 1200mm, and this coincides with a small sandy layer as outlined in Chapter 6. The implication here is that a dry spell was in effect, and that sand was washed or blown into the depression as a result of it drying out. It is suggested that this had a significant impact on the vegetation of the area.

7.3.3. LB1

This zone does not reveal any significant changes in the percentage of shrubs or xerics (see Figs 7.3. and 7.4.). Fig 7.1. shows a steady decline in Poaceae pollen throughout the zone. Cyperaceae by contrast display a sharp increase,

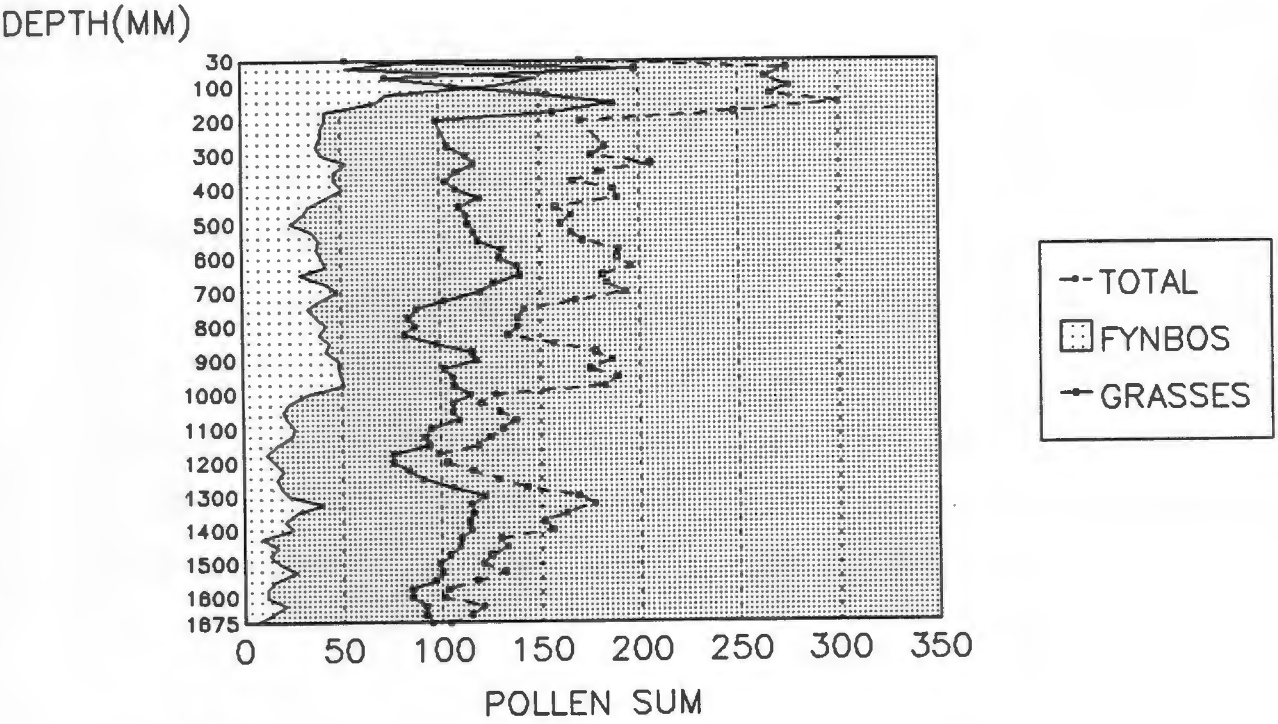
DEPTH(MM)
30
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1675
0
50
100
150
200
250
300
350
POLLEN SUM
TOTAL
FYNBOS
GRASSES

Fig. 7.2.

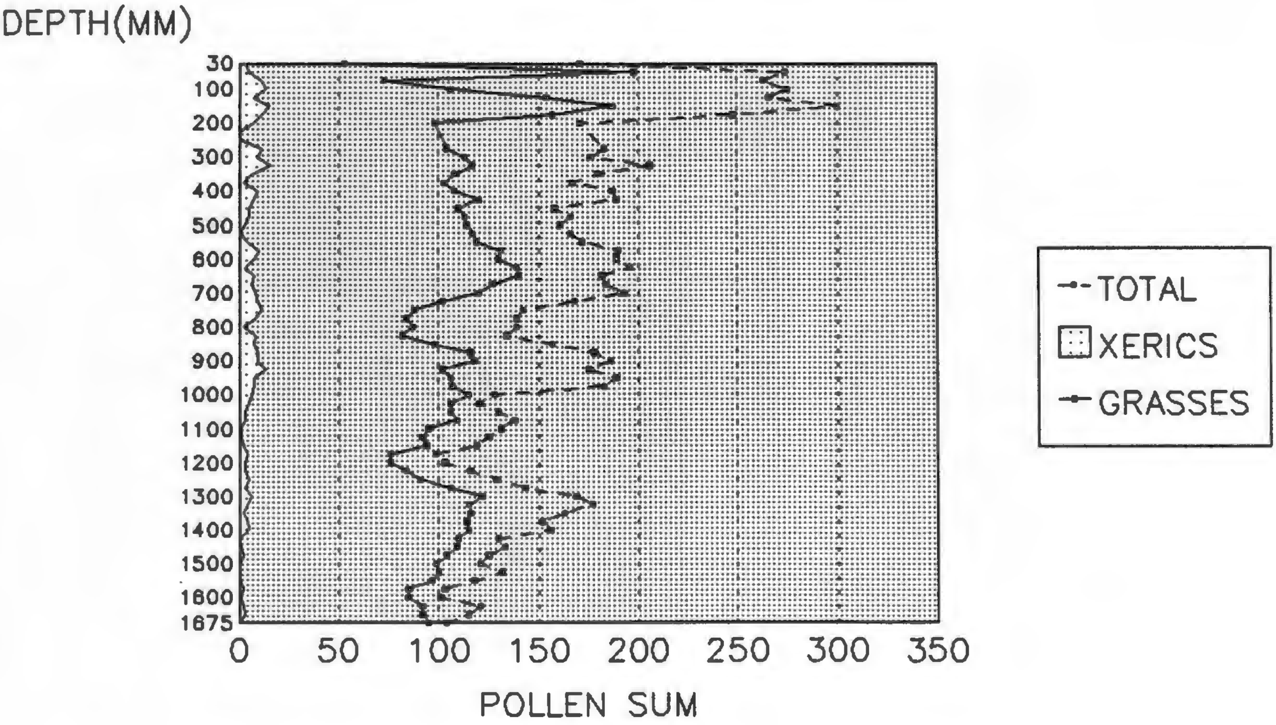
DEPTH(MM)
30
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1675
0
50
100
150
200
250
300
350
POLLEN SUM
TOTAL
XERICS
GRASSES

Fig. 7.3.

suggesting a moister local environment. The consistent nature of the other vegetation groups suggests that any increase in moisture availability was manifested on a local scale, and that there was no significant moisture increase on the regional scale. Appendix E graphically displays the number of pollen grains counted throughout the length of the core. The total pollen sum as given by Appendix E shows a significant increase in the total pollen at 150mm, but this may be attributed to the large increase in Cyperaceae pollen at this stage.

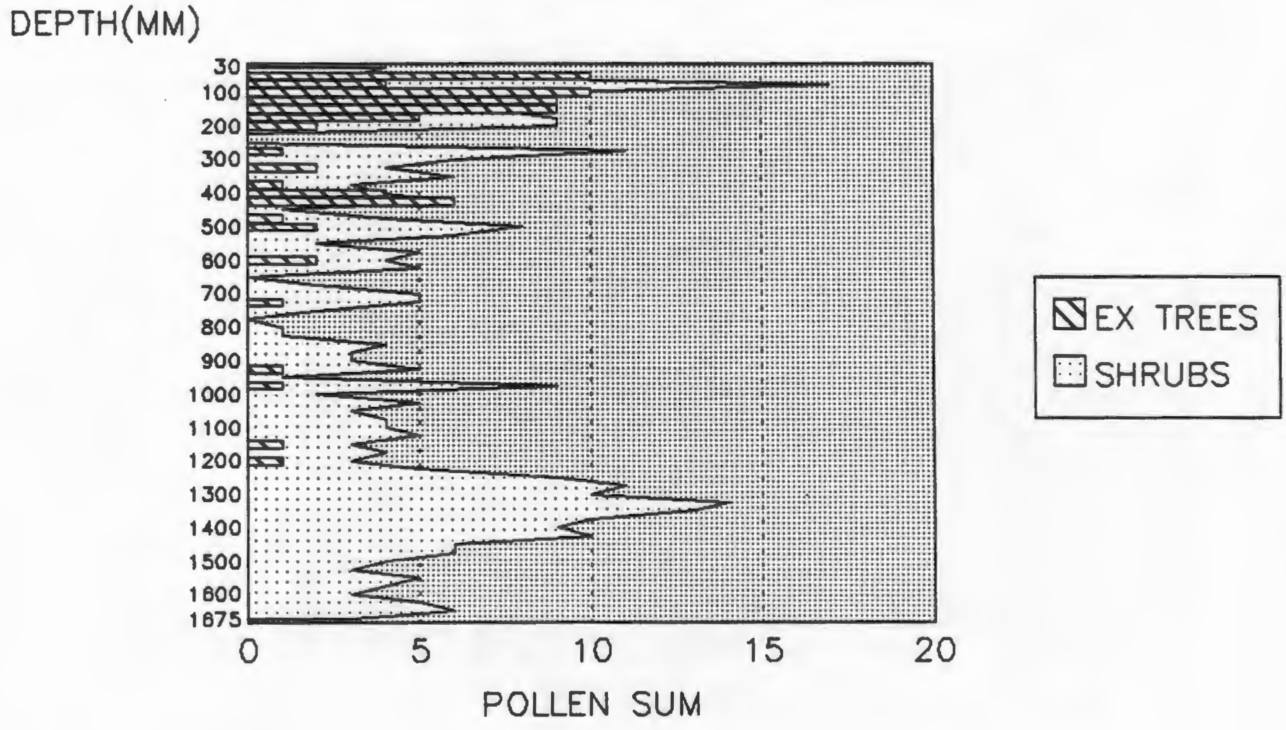

Fig 7.4.

7.3.4. LB2

The total pollen concentration in this zone declines gradually. Shrubs decline quite sharply (Fig 7.4.) xerics display a steady increase and grasses also follow a trend of steady increase. The pollen diagram in Fig 7.1. reveals that Cyperaceae decline very sharply after the peak at the LB1-LB2 boundary. The sedimentological discussion in Chapter 6 suggested that the sand layer at 998mm (1500BP) was indicative of a dry phase, and this is reflected in the pollen spectrum. In this case, as in the previous dry spell at 1710BP, Cyperaceae pollen is largely responsible for the fluctuations in the total

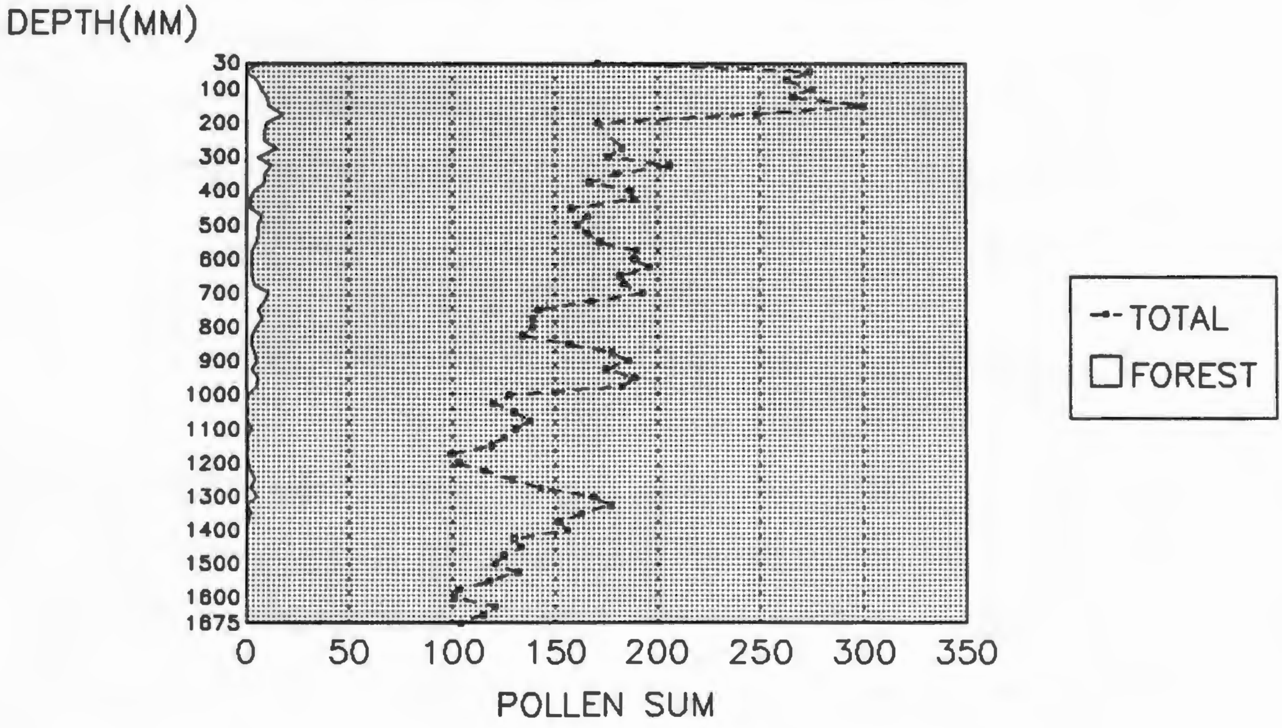

Fig 7.5.

pollen concentration. The implication here again is that the dry spell was very pronounced on the local scale, although in this instance it was also extended to influence the vegetation on the regional scale.

This appears to have been a very important stage in the sequence because the environmental changes were marked. Apart from the fact that 1500BP was characterised by a dry phase, it appears to mark a significant change in the sedimentation rate in the sequence. The sedimentation rate from the top of the sequence to 785mm was 8 years per 5mm. From 785mm to the bottom of the sequence at 1690mm the sedimentation rate was 5 years for every 5mm. The implication of this is that the rate of sedimentation increased after the dry phase which started at 1000mm. Furthermore, the LB2-LC transition is significant because of the increases in various pollen types and groups following the dry period.

7.3.5. LC

Fynbos elements increase significantly from 1000mm (Fig 7.2.), while xeric pollen also displays an increase (Fig 7.3.). The sharp increase in the total pollen concentration points towards a greater availability of moisture and thus a general amelioration in conditions. Increases in individual pollen types are evident in Fig 7.1. Restionaceae display an increase after preceding the dry spell, as do Asteraceae. Chenopodiaceae/Amaranthaceae display a very significant increase, having previously appeared at only 2% in places. Forest elements such as *Podocarpus* and *Moquinella* appear here, and their general increase to the top of the sequence suggests that forest elements were becoming an increasingly significant component of the vegetation. The presence of Haloragidaceae and *Myriophyllum* pollen indicates a much greater moisture availability locally, indeed open water conditions may have prevailed. This is consistent with the idea of a regional increase in precipitation which would encourage forest development.

7.3.6. LD1 and LD2

This period appears to have been characterised by uniform environmental conditions. The total pollen sum remains between 150 and 200 grains per slide for the duration of the two zones, and there is no significant fluctuation in either grasses or fynbos. Fig 7.3. reveals a slight decrease in xeric elements. Two peaks in Asteraceae pollen occur at 700mm and 625mm (1100BP and 960BP respectively). This indicates disturbance of the environment, and Fig 7.4. indicates two peaks in shrub elements at 700mm and 600mm. This is consistent with evidence that Late Stone Age herders and hunter-gatherers were active in the eastern Cape from approximately 1100BP (Hall, 1988).

7.3.7. LD3 and LD4

Environmental conditions during LD3 and much of LD4 appear to have been relatively uniform, but presumably differing from those during LD1 and LD2 because of different frequencies of various pollen types. The total pollen sum hovering around the 180 grain per slide mark. Fig 7.3. suggests an increase in xeric elements while fig 7.2. indicates a steady increase in fynbos pollen. Indigenous trees and forest elements appear to be on the increase. Betulaceae pollen appeared at the LD2-LD3 boundary and attain 4% in LD3. *Podocarpus* and *Moquinella* are consistent throughout the two zones, although *Podocarpus* displays three peaks in LD4.

7.3.8. LE and LF

This period in the sequence has been characterised by a number of significant fluctuations in the pollen frequencies. The total pollen sum increases significantly from 200mm to 150mm by 125 grains per slide, and is between 250 and 300 grains up to 50mm. Fig 7.2. reveals a significant increase in fynbos elements at 90mm, and this is largely due to Restionaceae. Restionaceae, having never exceeded 25% throughout the core, here increase to approximately 90% of the total pollen grains counted. This appears to have been at the expense of grass elements such as Poaceae, Cyperaceae and Juncaceae, all of which dip sharply in the period 70mm to 90mm. Xeric elements had been quite consistent at the start of LE, but decline gradually to the top of the sequence. Shrub elements such as Sterculiaceae and Scrophulariaceae are present, while Asteraceae continue the steady increase manifested in previous zones. These fluctuations in pollen frequencies indicate a significant disturbance of the local environment. The sandy layer at 100mm could be indicative of drier conditions hence the decline in local elements such as Cyperaceae. The presence of shrubs and the strong increase in Asteraceae points towards a disturbance in the environment probably linked to human activity. It is suggested that the fluctuations in pollen in these two zones are linked to human activity in and around Lake Farm.

Fig 7.1. (Appendix C) shows that forest elements such as *Podocarpus* and *Moquinella* decline in LE, although *Podocarpus* emerge again at the top of the sequence. Forest elements appear to be declining at present while Fynbos elements such as Ericaceae, Rutaceae, Proteaceae and Geraniaceae are increasing at the top of the sequence. Restionaceae decrease again after the peak at 90mm and stabilise at the top of the sequence. Both Poaceae and Cyperaceae peak at 50mm and decline to the top of the sequence, suggesting a brief spell of greater local moisture availability followed by an increased disturbance regime, which is presently in effect.

7.4. Discussion

Having performed a zone by zone discussion of the vegetation history of Lake Farm and associated environmental perturbations, palaeoenvironmental implications are evaluated in light of evidence for vegetation change from the closely related studies by Martin (1968), Scholtz (1986) and Cowling (1983).

7.4.1. The Forests

The discussion begins with an evaluation of the presence and distribution of forests at Lake Farm over the past 2200 years. Scholtz (1986) notes the present day marginal status of south coast forest, and suggests that a small decrease in mean annual precipitation will be sufficient to restrict forest elements to more sheltered and mesic ravine-type environments. The dry spell at approximately 1500BP appears to have been followed by some form of climatic amelioration. *Podocarpus* is a very reliable indicator of forest vegetation (Von Breitenbach, 1978; Scholtz, 1986), and this pollen type emerges at 1500BP and occupies a significant proportion of the pollen spectrum up to circa 100BP. The tendancy for *Podocarpus* to be transported over vast distances has been noted. This creates difficulty when attempting to determine whether its distribution was local or regional, as its presence in the pollen spectrum does not implicitly suggest one or the other. The *absence* of *Podocarpus* is a more reliable indicator than its presence. Myricaceae or *Moquinella* also emerge here, lending weight to the conclusion that forest elements were favoured by conditions after 1500BP. This interpretation is strengthened by the relative absence of forest elements before 1500BP, when conditions were ostensibly less favourable for forests. Aquatic elements such as *Nymphoides* and *Myriophyllum* are also present here, indicating greater local moisture availability, some of which was probably in the form of rainfall, which would have favoured the forests.

As was suggested earlier, a number of other pollen types display significant increases after 1500BP, most notable among them are Restionaceae, Asteraceae and Cyperaceae, although the latter is of a more restricted distribution than the others since it is confined mainly to wetlands. This also supports the theory of more mesic conditions after the dry phase at 1500BP. This correlates favourably with conclusions drawn by Scholtz (1986) at George, Schalke (1973) at Hangklip and Martin (1968) at Knysna. All of these papers indicate a synchronous shift to mesic conditions at around 1400BP in the case of George and Hangklip, and 1900BP in the case of Knysna. Scholtz (1986) suggests that Martin's

(1968) conclusions are comparable to his own, and that apparent discrepancies were caused by different ecological settings at the two sites, and the fact that the data from the Knysna site was not derived from the core which had been palynologically examined. The correlation in the results of the various sites suggests that this event constituted a regional shift in climatic patterns towards a regime which was more conducive to the spread of forest vegetation.

Scholtz (1986) also suggests that the shift to mesic conditions would have favoured forests, and this correlates with conclusions drawn from the Lake Farm sequence. Evidence from Lake Farm suggests that conditions prior to 1500BP would not have favoured forests, and although some *Podocarpus* pollen is evident in small percentages, the absence of any other forest indicators implies drier and less-favourable conditions. The absence of aquatics and the presence of shrubs such as Fabaceae lends weight to this theory. Evidence from the Norga sequence at George substantiates this, and the implication here is that environmental conditions prior to 1400BP were drier, and consequently not favourable for the spread of forests. It has been suggested that forests were restricted to protected ravines at this time where a more favourable environment would have been experienced (Scholtz, 1986).

Martin (1968) does not examine the history of forests in great detail, but does suggest that in Knysna the last 800 years have seen an increase in the areal extent of forest vegetation.

To conclude the discussion on forests, the present study indicates that forest elements decline slightly at the present day. This raises an interesting discussion regarding the possible role humans have played in the current state of forest. Meadows and Linder (1993) suggest that the current distribution of south coast forests is fire-maintained, and that expansion is impossible given land-use practises. They also suggest that the impact on forest vegetation by humans has been over-emphasised. The Lake Farm pollen diagram implies that the current distribution of forests has been impacted upon by humans, although the extent to which this has occurred has yet to be established. Fig 7.5. graphically displays the presence of forest elements through the Lake Farm sequence. Forest appears for the first time in the sequence at 1300mm and extends to 1200mm. It emerges again at 1000mm (1500BP) and remains in evidence to the present day. A maximum is reached between 100 and 200mm, and this is concurrent with the overall pollen sum. Environmental conditions at this stage appear to have favoured the vegetation of the area. Fig 7.1. shows how both Cyperaceae and Poaceae also peak at this point in the sequence, suggesting that moister conditions were of regional as well as a local extent.

7.4.2. Fynbos, shrubs and grassland

The increase in fynbos elements towards the present was noted earlier in the discussion. Cowling (1983) suggests that the more fertile soils of the S.E. Cape resulted in an intermingling of fynbos with elements from adjacent phytochoria. In this particular study fynbos elements appear to have increased along with forest elements. Fynbos has been present in significant quantities throughout the sequence, although a sharp increase following the dry spell at 1500BP was also evident.

Cowling (1983) refers to Cape Transitional Shrublands as unstable tension zone communities which have fluctuated dramatically as a result of Pleistocene climatic fluctuations. To draw a distinction between fynbos and the transitional shrubland, it has been suggested that the dominant types within the transitional shrubland are grassland and Asteraceaeous shrubs. Grasses decline significantly at the top of the sequence while a synchronous increase in shrubs is evident. It is suggested that overgrazing by domestic livestock following European colonisation has led to the decline in regional grasses, while shrubs have flourished as a result of the increased disturbance regime. The local vlei environment, which is dominated by Cyperaceae, also reflects disturbance. The sharp decline in Cyperaceae pollen at the top of the sequence may indicate severe disturbance of the local vlei environment.

Cowling (1983) notes that recently the xeric elements which had attained a degree of prominence in the south coast vegetation are being replaced by subtropical and Cape taxa. Fig 7.3. reveals the extent to which xerics have declined in recent times, ostensibly to be replaced by fynbos and shrubs.

The high degree of correlation between this particular study and other studies of vegetation history along the south coast points towards the significance of Lake Farm as a sensitive indicator of vegetation history. The history of south coast forest could be ascertained, as well as the increase in fynbos and shrubs and the decline in grassland and xeric elements. Unfortunately a distinction could not be drawn between Afromontane forest elements and those of the Alexandria forest within the study site. It is suggested that the complexity of the vegetation patterns at Lake Farm make it virtually impossible to distinguish between the two from the fossil record.

7.4.3. Exotics

The Lake farm sequence indicates the emergence of exotic trees such as Pinaceae and Betulaceae at around 200mm, and Abies at approximately 250mm. This implies that the introduction of exotic trees in the region occurred approximately 200 to 280 years before the present. Deacon (1986) and Wells et al (1986) note the introduction of many European plant species in the period 1650 to the present day. Wells et al (1986) note that 9.5% of all current European invasive species entered the country between 1750 and 1799AD, which is approximately synchronous with the Lake Farm data. Betulaceae and Abies occur somewhat lower in the sequence but it is suggested that this is a consequence

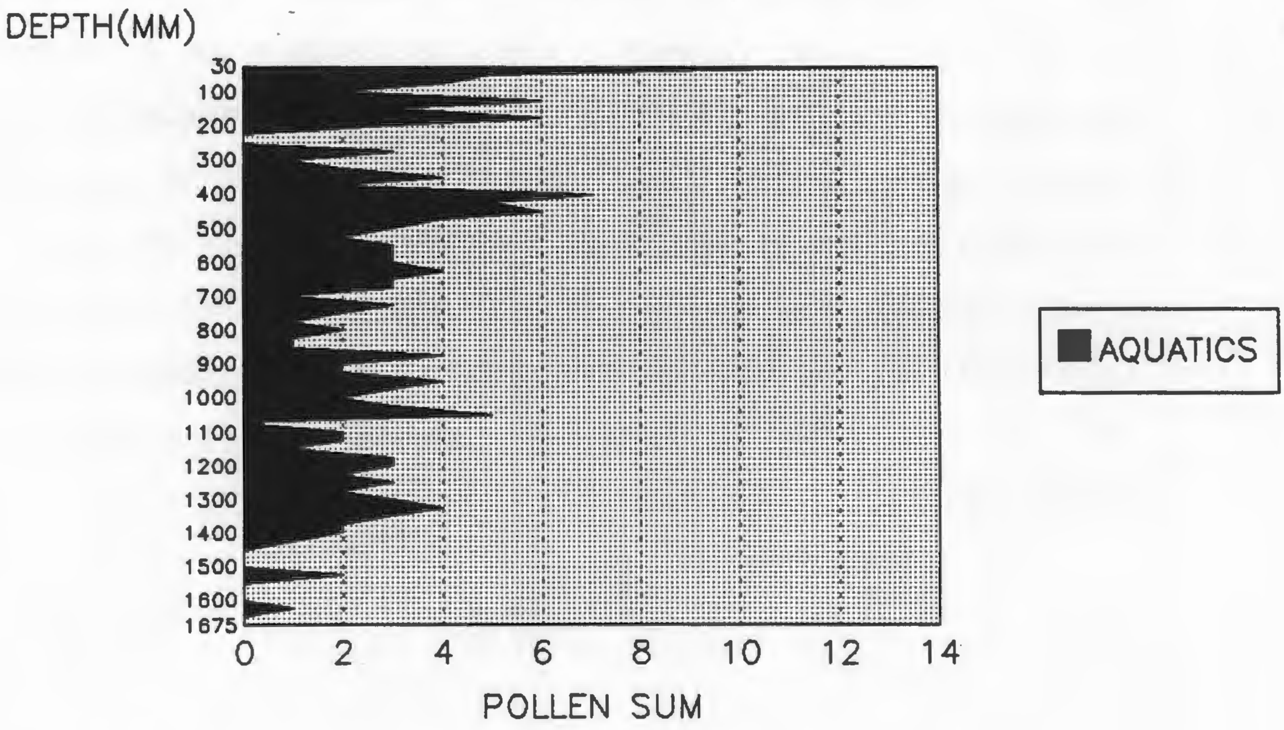

Fig 7.6.

of bioturbation of the sediment rather than a *bona fide* introduction by European settlers. The Lake Farm study site does not provide evidence of exotics, and it is thought that the origin of the exotic pollen is a dense stand of trees approximately 4Km upwind.

7.4.4. Aquatics and Semi-aquatics

Fig 7.6. displays the behaviour of aquatic and semi aquatic elements throughout the sequence. The total number of grains counted belonging to this group at any level never exceeds 16, and no significant inferences can be drawn. In accordance with inferred moister conditions in the upper half of the sequence (see 7.4.1.) the number of aquatics appears to have increased in recent times.

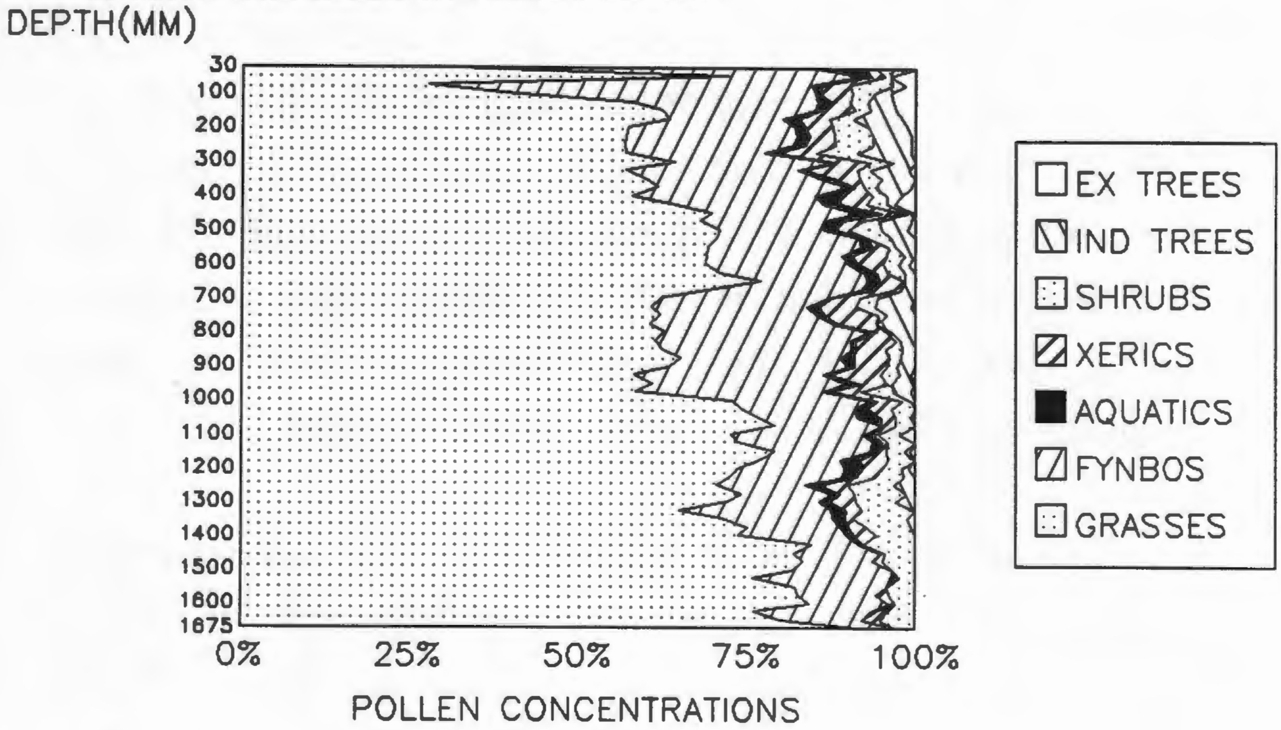

Fig 7.7.

Fig 7.7. presents a composite pollen diagram of the major pollen groupings discussed above. Grasses and xerics are seen to dominate the pollen spectrum, while forest elements are more significantly represented in the upper half.

7.5. Statistical indications

Appendix A displays the results generated by the PCA, details of which are documented in Chapter 5. Eigenvalues of the correlation matrix are presented, followed by the rotated loadings and percent of variance explained by the eigenvalues. Four eigenvalues were retained based on the Overland and Preisendorfer significance test. The percent of total variance explained by the first four components amounts to 37.085%. This is a significant percentage given the large number of factors likely to influence the data, and the remaining 37 components account for approximately 62% of the variance. Component one accounts for just over 11%, while component two accounts for just under 9%. The next two components account for percentages of 9.048% and 7.790% respectively. Interestingly component three accounts for more variance than component two.

The following analysis of loadings on the components is based upon a methodology utilised in a number of papers, see: Scott and Thackeray, 1987; Thackeray, 1987a; 1987b; Bonnefille et al; Thackeray and Avery, 1990.

The analysis is based on the identification of environmental parameters associated with extreme loadings on the first three or four components which account for a significant percentage of the variance. Loadings for the taxa are squared in order to determine a percentage which indicates the variance associated with that particular taxon within that particular component. For example Onagraceae has a loading of 0.864 in component one. Once this has been squared, we can say that Onagraceae accounts for 74.64% of the variance in component one and so on. Other taxa with strongly positive loadings are Restionaceae, Sterculiaceae, and Loranthaceae. It was decided to retain loadings in excess of 0.63, as this can still be viewed as significant (B. Hewitson, pers comm.)

With regard to the strongly-loaded taxa on component one, it is difficult to identify any one parameter influencing these taxa. Onagraceae, most probably *Epilobium hirsutum* or *Epilobium tetragonum* is a perennial, often found on the edges of lakes and vleis, while Sterculiaceae are largely shrubs. Restionaceae are fynbos elements with a wide array of environmental tolerances. Loranthaceae, most probably *Moquinella rubris,* is a hemiparasite. This results in a confusing array of signals, and while component one accounts for more variance than any other it is impossible to identify a parameter, environmental or otherwise, which can be associated with this.

Taxa with strong loadings on component two include Myricaceae, *Pinus* and *Acacia*, all of which are trees. The other pollen type with a strong loading is Polygalaceae, likely to be shrubs. The strong signal from trees, particularly the two exotics *Acacia* and *Pinus*, suggests that this component is associated with human activity of some form. This suggests that human alteration of the landscape in the form of, *inter alia*, the introduction of exotic trees was a significant influence on the vegetation of the Lake Farm region.

Taxa with strong loadings on component three include Poaceae, Aizoaceae and *Oxalis. Aizoaceae* are xeric elements, while *Oxalis* is a weedy element. Poaceae are often associated with drier local conditions, and this suggests that component three is associated with moisture availability.

Ericaceae, Liliaceae and Asteraceae are strongly-loaded on component four. These are representative of fynbos shrubs and as suggested earlier in the discussion (7.4.2.) the recent increase in fynbos elements can be linked to the more recent human alteration of the landscape. Component four can thus be linked to human disturbance.

The implication of these inferences is that the primary influences on vegetation composition and distribution in and around the study site are human disturbance and moisture availability. Even though component three accounts for slightly more variance than components two and four, the fact that human disturbance has been linked to these two suggests that it is a more significant determinant of vegetation distribution than moisture availability. The results of a similar statistical procedure performed on data from the Cederberg suggests that the two environmental parameters responsible for the distribution of the vegetation were geology and moisture (Adams, 1991).

The distribution of the Lake Farm vegetation, especially before the advent of significant human disturbance appears to have been heavily influenced by changes in moisture availability over time. Having reached the above conclusions a cautionary note must be included. The usefulness of techniques such as Principal Components analysis in the study of Quaternary palaeoenvironments is limited. Ambiguity in the loadings on the factors leads to difficulties in assigning environmental variables. Given the plethora of external influences acting upon the data set care must be taken to exclude as much noise as possible when selecting eigenvalues for interpretation. Care must be taken not to place too much emphasis on the conclusions drawn, as they are subjective to some extent, and prone to any shortcomings in the statistical procedure. It is unwise to make any conclusions about the nature and extent of former vegetation at family level. Due to the fact that families consist of a number of species, any analysis performed at family level will obscure inter species variation. The failure to account for intra-family variation is significant, and could result in major oversimplification in the conclusions.

This problem recurs when assigning environmental variables to component one. It is difficult to identify a habitat or environmental niche favoured by a particular family since within the family, different species flourish in different habitats. This suggests that assigning habitats in support of explanatory components is a generalised and partially subjective process. The conclusions outlined above were not based only on species endemic to the Southern Cape, but on all species within the particular family. Scott and Thackeray (1987) suggest the exclusion of some pollen types from the analysis to reduce statistical 'noise'. The rationale behind this is that the excluded taxa have a wide tolerance to environmental change, and their inclusion will in some way bias the sample.

Apart from excluding data like unknown, broken and indeterminate pollen, it was believed that exclusion of any of the other taxa would be to deny that some plant types survive under environmental conditions markedly different to others. The advantages and disadvantages of this particular statistical technique are discussed in Chapter 8.

7.6. Implications for climatic change theories in southern Africa

The region of southern Africa subjected to Winter and all-year rainfall patterns has a more complete record of climatic change than any other. This is partly due to active research programmes over the last 50 years and that conditions for the preservation of various forms of evidence have been favourable (Deacon and Lancaster, 1988). Deacon and Lancaster (1988) suggest that two periods of slightly warmer conditions between 7000BP and 2600BP favoured the increase of forest elements. Furthermore, they suggest that a general decline in forest elements in the last 2000 years has occurred (Deacon and Lancaster, 1988). Evidence from a number of south coast studies such as Groenvlei (Martin, 1968), Norga (Scholtz, 1986) and Lake Farm contests this theory, as the fossil spectrum indicates an increase in forest elements after 1500BP towards the present (see fig. 7.5.). Deacon and Lancaster (1988) also suggest a present day influx of coastal Renosterveld at the espense of grassy elements. The Lake Farm spectrum supports this theory, although it is suggested that the decline in grassy elements near the top of the sequence can also be related to disturbance. Results from Lake Farm correspond favourably with other sites examining south coast vegetation history, and make a significant contribution to the body of evidence concerning the history of forests.

In Chapter 2 mention was made of the Medieval Warm Epoch (MWE) (900BP) and the Little Ice Age (400-100BP). As was suggested earlier, environmental conditions became warmer and moister after 1500BP up to the present and this favoured the spread of forests. The MWE occurred at approximately 650mm to 450mm in the Lake Farm sequence.

The Little Ice Age (LIA) (700-150BP) occurred ostensibly from 450mm to 100mm in the Lake Farm sequence. Tyson and Lindesay (1992) suggest that the LIA was characterised by considerable variability and instability of climate and evidence for this appears to be forthcoming from the Lake Farm sequence. Fig. 7.4. indicates increasing shrubbiness as a consequence of a variable climate leading to an enhanced disturbance regime, while the complete pollen diagram reflects marked fluctuation in all taxa during this period. It is suggested that there is a degree of correlation between the Medieval Warm Epoch and the shift to more mesic climates at Lake Farm.

Chapter 8 presents a synopsis of the vegetation and environmental changes at Lake farm over the past 2200 years. The validity of Multivariate statistics is evaluated, and the extent to which aims and objectives have been addressed is also considered.

CHAPTER EIGHT
CONCLUSIONS

8.1. Introduction

Deacon and Lancaster (1988) suggest that the worldwide cycle of glacial and interglacial events within the late Quaternary must have resulted in a number of significant palaeoenvironmental adjustments, which have been an important influence on the nature and distribution of present day vegetation communities. As a consequence of this, contemporary vegetation patterns must be viewed in light of these environmental changes resulting from shifts in climatic patterns and more recently, from human activity.

The fundamental aim of this thesis as stipulated in Chapter one was to examine the vegetation history of Lake Farm over the past 2200 years. This was to be carried out with a view to making conclusions about the nature, frequency and magnitude of environmental change in and around the study site, and the impacts of this change on the vegetation of the Lake Farm region. The extent to which this was successful is outlined below. The individual objectives are now discussed in detail.

The first objective, although by no means the most significant, was to perform pollen counting and identification throughout the length of the core. This was achieved with relatively few problems, although a number of samples taken near the top of the sequence could not be processed as they had become desiccated through exposure to the atmosphere. Pollen counting was performed as accurately as possible and to as great a level of taxonomic detail as was possible given the constraints imposed by the light microscope. Identification could in most cases only be performed down to family level, although in a number of cases individual genera and even species could be identified. The absolute method of counting was preferred as this at least provides some indication of the fossil pollen influx over time as opposed to the relative method which does not.

Objective two, a logical progression from the first objective, was to construct a pollen diagram. This was performed successfully by means of the software package called Tilia Graph™. The fossil pollen frequencies through the sequence were plotted on a vertical axis and pollen types were grouped to facilitate interpretation and discussion. Numerous conclusions were drawn regarding the fluctuation in the vegetation composition over time. Environmental perturbations were inferred from the vegetation history and the core stratigraphy.

The third objective was to reconstruct a narrative sequence of environmental perturbation based on fluctuations in the relative frequencies in the fossil pollen. Naturally a degree of subjectivity becomes necessary here as an attempt is made to link various vegetation types and groupings to environmental conditions or parameters. Recourse to the stratigraphy of the core supplemented the reconstruction of past environmental perturbations. Conclusions drawn regarding environmental fluctuation suggest an important event at approximately 1500BP. Conditions at Lake Farm appear to have been drier prior to 1500BP, suggested by the relative absence of forest elements. As suggested in Chapter 7.4.1. the relative absence of *Podocarpus* prior to 1500BP is a reliable indication that forest elements were not abundant. Thereafter an amelioration in conditions occurred which favoured the spread of forest and fynbos vegetation. The most recent part of the sequence indicates that grass and xeric elements are declining. The increase in shrub elements indicates disturbance of the environment, while there is evidence of recent influx of coastal Renosterveld. Forest elements appear to be holding their own at present, and evidence of exotic tree introduction by European settlers exists. The local vlei vegetation has proved a sensitive indicator of environmental change, and has to some extent overshadowed the signal of the more regional vegetation. Poaceae and Cyperaceae proved to be important indicators of environmental change or, more specifically, moisture availability, while shrubs and weeds were indicators of disturbance. The disturbance referred to in the previous statement was largely initiated by aridity and changes in the vegetation patterns, although more recently in the sequence the advent of humans has been responsible for major shifts in vegetation patterns.

The fourth objective was to evaluate the roles played by natural environmental change and humans in determining the vegetation composition. The impact of humans can be detected in the more recent sections of the core. The pollen sum dips sharply at the top of the sequence as the local vlei environment is altered, and the number of shrubs and weeds increases along with the increased disturbance regime. Exotic pollen types are also evident in the upper sections of the core, and these are also an indication of the impact humans have had in the area. The lower 1400mm of the core appears to have been governed solely by natural environmental change.

The fifth objective was to evaluate the usefulness of Multivariate statistics in detecting environmental parameters responsible for the distribution of vegetation in and around the study site. Principal Components Analysis was employed in an attempt to account for the distribution of vegetation. The loadings on the first component are ambiguous, and this resulted in difficulties in assigning an environmental parameter of species distribution. Analysis of loadings on component two was more successful, indicating that human disturbance of the landscape is the variable associated with this factor.

Moisture availability is the parameter most likely to be associated with component three, given that the strongest loadings belong to three xeric elements.

Component four appears to be linked to human activity as well as component two (see chapter 7).

The analysis of loadings is subjective. Part of the problem is caused by an inability to identify many pollen grains down to specific level. As a result the subsequent interpretation assumes uniformity within a particular family, taking no account of intra-family variation by species. The ambiguity of the loadings on component one can most probably be attributed to this, as it is practically impossible to account for the environmental preferences of all the species within one family. With respect to the shortcomings of the light microscope this problem will not be overcome within the foreseeable future.

The use of Cluster Analysis in verifying the subjective zonation of the diagram was a useful exercise. Although all zonation was performed subjectively and prior to any statistical analysis, the CONISS procedure verified this to a large extent, and can be useful in drawing attention to trends within the diagram which may have been overlooked by the analyst.

8.2. Recommendations

This thesis has drawn attention to a number of aspects of palynological research which require discussion.

The paucity of suitable study sites in southern Africa has been documented (see Chapter 2) but this is on the mend. The Lake Farm results have made a significant contribution to the evidence of south coast vegetation history, and there is little doubt that other suitable sites exist within a similar location (W. Illenberger, pers. comm.). While the vegetation history of the area over the last 2000 to 4000 years has been well-documented, little is known regarding vegetation history prior to 8000BP. Members of the Palaeoecological Research Group at the department of Environmental and Geographical Science, UCT, have recently extracted a core from another south coast site at Vankervelsvlei (34°S,22°55'E), north of Buffelsbaai. Evidence of south coast forest is in abundance at this site, and the basal ^{14}C date of 39,900+-1000BP (Pta-6361) suggests that the vegetation history of the south coast will be extended further back than it is at present. It is suggested that attempts be made to link the results obtained from different studies in an attempt to generate a more coherent account of Holocene vegetation history. Lake Farm is an extremely significant site because it is a zone of convergence for various vegetation types (see Chapter 1). Any attempt at a follow-up study at another site should take this into account, and attempt to determine the extent to which this complex vegetation signature has changed through time.

Given the difficulty of establishing the representativeness of the fossil pollen, i.e. the extent to which it is an index of the vegetation which produced it, an analysis of the current pollen rain index is desirable. Studies of contemporary pollen rain will help identify the degree of analogy between the existing vegetation and the pollen it produces. This may be supplemented by Multivariate statistics such as Multiple Discriminant Analysis, which has proved to be an effective means of establishing the degree of analogy between fossil and contemporary pollen (Sugden, 1989; Sugden and Meadows, 1989).

Multivariate statistics can assist the identification of environmental determinants of vegetation distribution. It is suggested that this procedure be employed only as a supplement to observed evidence. The irony of this is that while the statistics are intended as a scientific analysis, the interpretation of the results may fall short of objectivity.

It is suggested that high-resolution palynological studies such as this one are a vital component in the attempt to reconstruct palaeoenvironments. As vegetation is a sensitive indicator of environmental change, fluctuations in temperature or moisture availability will be reflected in the fossil pollen. Evidence of the Medieval Warm Epoch and the Little Ice Age has been detected in the Lake Farm pollen spectrum, further emphasising the validity of this method.

8.3. Lessons for the future

The value of this study in documenting the history of forests is noted. An awareness of the response of forest and other vegetation types to environmental changes in the past has important consequences for conservation and ecosystem management, especially in view of the projected changes in global climatic systems (see Chapter 2). The Lake Farm data has provided indications of the response of forest and fynbos vegetation to changing environmental conditions as well as to human-induced disturbance.

Many predictions of future global climatic change suggest that an increase in atmospheric CO_2 conditions is likely to result in drier conditions (see Chapter 2). The pollen record suggests that forest elements were not favoured by dry conditions, as they proliferated in response to a moister environment (Chapter 7). We can therefore expect that future climatic change will result in the retreat of forest elements to the extent where they will be confined to isolated refugia where conditions are favourable. The Lake Farm sequence suggests that fynbos proliferated in response to a moister climate, and thus may not favoured by future climatic change either.

This emphasises the value of palaeoecology as a predictive tool, and it places another piece in the complex jigsaw puzzle that is ecosystem conservation and management.

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APPENDIX A:

LATENT ROOTS (EIGENVALUES)

1	2	3	4	5
6.846	3.922	3.086	2.711	2.225
6	7	8	9	10
2.084	1.958	1.896	1.739	1.482
11	12	13	14	15
1.318	1.135	0.997	0.977	0.922
16	17	18	19	20
0.749	0.720	0.692	0.578	0.547
21	22	23	24	25
0.521	0.478	0.436	0.408	0.359
26	27	28	29	30
0.325	0.315	0.248	0.224	0.207
31	32	33	34	35
0.165	0.144	0.125	0.100	0.080
36	37	38	39	40
0.075	0.054	0.051	0.043	0.036
41				
0.022				

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COMPONENT LOADINGS

                          1           2           3           4

   JUNCACEA             0.737       0.295      -0.132       0.112
   RESTIONA             0.700      -0.467       0.050       0.265
   MESEMBRY             0.645      -0.082      -0.113       0.335
   PODOCARP             0.638       0.388       0.140      -0.135
   RUTACEAE             0.619       0.285       0.357      -0.027
   LORANTHA             0.605      -0.377      -0.466       0.060
   ONAGRACE             0.544      -0.501      -0.064       0.318
   PELARGON             0.543       0.157      -0.103       0.362
     STOEBE             0.542      -0.211       0.089       0.093
   ASTERACE             0.531      -0.260       0.277      -0.335
   MYRICACE             0.504       0.571       0.103      -0.249
   STERCULI             0.479      -0.654       0.098       0.333
     ACACIA             0.183       0.550       0.299      -0.085
   EUPHORBI             0.129       0.523       0.222       0.252
    POACEAE             0.282       0.021      -0.575      -0.352
   AIZOACEA             0.361       0.081      -0.511      -0.253
   CARYOPHY             0.374       0.110       0.352       0.478
   PROTEACE             0.071      -0.334       0.240      -0.447
   IRIDACEA             0.342       0.002      -0.243      -0.431
   MALVACEA             0.361      -0.039      -0.233      -0.383
   TYPHACEA             0.208       0.441       0.068       0.353
       CHEN             0.428       0.147       0.099      -0.313
   PLUMBAGI             0.148       0.293       0.113       0.309
   PINACEAE             0.214       0.276       0.332      -0.294
   FABACEAE            -0.448       0.157      -0.230       0.290
   BETULACE             0.264       0.261      -0.069       0.288
   POLYGALA             0.251       0.472       0.272      -0.254
   ERICACEA             0.452      -0.423       0.464      -0.240
     OXALIS             0.324      -0.009      -0.419      -0.239
   AMARYLLI             0.007      -0.299       0.452      -0.203
   LAMIACEA             0.023       0.270      -0.059       0.195
   MYRIOPHY            -0.136       0.065       0.121       0.189
   SCROPHUL             0.328      -0.193       0.192       0.144
   NYMPHOID             0.065      -0.053      -0.198       0.143
   CRASSULA             0.289      -0.083      -0.385       0.111
   LILIACEA             0.497      -0.336       0.373      -0.105
   PRIMULAC             0.247       0.068      -0.024       0.097
   MOQUINEL             0.459       0.315      -0.082      -0.068
      ABIES             0.374       0.188      -0.379      -0.052
   RANUNCUL            -0.215      -0.056      -0.007      -0.026
   CYPERACE             0.291       0.215      -0.384       0.025

VARIANCE EXPLAINED BY COMPONENTS

                          1           2           3           4

                        6.846       3.922       3.086       2.711

PERCENT OF TOTAL VARIANCE EXPLAINED

                          1           2           3           4

                       16.698       9.566       7.527       6.612
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ROTATED LOADINGS

                            1          2          3          4

  ONAGRACE              0.864     -0.045      0.057     -0.002
  RESTIONA              0.855      0.008      0.120      0.216
  STERCULI              0.855     -0.181     -0.053      0.184
  LORANTHA              0.621     -0.137      0.555      0.003
  MESEMBRY              0.567      0.036      0.266      0.046
  MYRICACE             -0.013      0.757      0.244      0.026
  PINACEAE              0.075      0.742     -0.083     -0.038
  POLYGALA             -0.106      0.676     -0.003      0.056
    ACACIA             -0.122      0.643     -0.122     -0.042
      CHEN              0.148      0.501      0.176      0.179
   POACEAE              0.050      0.099      0.704     -0.173
  AIZOACEA             -0.012     -0.012      0.691      0.030
    OXALIS              0.063      0.022      0.644     -0.021
  IRIDACEA             -0.080      0.056      0.591      0.305
  ERICACEA              0.355      0.098     -0.015      0.737
  LILIACEA              0.358      0.031     -0.023      0.707
  ASTERACE              0.258      0.176      0.249      0.645
  AMARYLLI             -0.026     -0.088     -0.184      0.597
  RUTACEAE              0.083      0.356      0.128      0.539
  TYPHACEA             -0.027      0.158     -0.027     -0.094
  BETULACE             -0.027     -0.087      0.167      0.087
  CARYOPHY              0.406      0.219     -0.264      0.025
  PLUMBAGI              0.060      0.169     -0.082     -0.135
  LAMIACEA             -0.084     -0.001     -0.142     -0.041
  PELARGON              0.447      0.176      0.038     -0.061
     ABIES              0.082      0.085      0.396     -0.026
  PODOCARP              0.085      0.489      0.228      0.344
  EUPHORBI             -0.059      0.374     -0.270     -0.104
  PROTEACE              0.174      0.256      0.006      0.223
  JUNCACEA              0.279      0.285      0.423      0.137
  MALVACEA              0.150      0.242      0.408      0.097
  FABACEAE             -0.302     -0.351     -0.178     -0.329
  PRIMULAC              0.314      0.317      0.073     -0.269
  CYPERACE              0.057      0.075      0.414     -0.175
  MYRIOPHY             -0.002      0.002     -0.289     -0.102
  RANUNCUL             -0.018      0.008     -0.171     -0.166
  NYMPHOID              0.306      0.118      0.032     -0.412
  CRASSULA              0.307     -0.051      0.349     -0.210
    STOEBE              0.425      0.008      0.191      0.343
  MOQUINEL              0.129      0.420      0.321     -0.049
  SCROPHUL              0.447      0.138     -0.100      0.105


  VARIANCE EXPLAINED BY ROTATED COMPONENTS

                              1          2          3          4

                              4.614      3.663      3.710      3.194


  PERCENT OF TOTAL VARIANCE EXPLAINED

                              1          2          3          4

                             11.254      8.933      9.048      7.790
```

APPENDIX B: FOSSIL POLLEN PREPARATION PROCEDURE

NOTE:
-Preset water bath to +-90°C
-Initially use 50ml plastic centrifuge tubes
-Label samples clearly
-Store samples in the refrigerator when not in use
-All centrifuging to be done at 3600rpm for three minutes unless otherwise stipulated.

1. Place 0.4-0.6g of each sample into plastic centrifuge tubes. NOTE: It may be desirable to pre-grind the sample in the tube using a stirring rod or, alternatively, using a pestle and mortar to facilitate later procedures. Deflocculation may be performed by soaking the sample overnight in a solution of 10% NaOH.

2. Add 10-20ml 10% NaOH and place in a water bath for 25-30 minutes, stirring occasionally.

3. Strain and wash thoroughly through a 150 micrometer sieve using either Glacial Acetic acid or Ethanol, both of which have a lower surface tension than water. This leads to loss of smaller quantities of pollen than would have been the case had distilled water been used.

4. Centrifuge the sieved sample and excess NaOH and decant the supernatent.

5. Wash the sample five times with distilled water or until the supernatent becomes clear (tube should be approx. 2/3 full with each wash).

6. Wash the sample with 10% HCL, stir, centrifuge and decant.

7. In a fume cupboard, treat the sample with 40% HF by immersing tubes in boiling water. Leave for 3 hours, stirring occasionally.

8. Alternative to step #7: Samples may be treated with Zinc Chloride, which has a high specific gravity. This is added to the sample, which is then centrifuged at high speed (4500rpm), where all heavier material is carried to the bottom of the tube in favour of pollen and lighter organic material which float on the surface. The lighter material is decanted along with the supernatent and the process is repeated. A reagent with a very low specific gravity is now added (Ethanol) and the process is repeated, only now the pollen sinks to the bottom of the tube and all excess is decanted. This results in extremely clean samples, and can be used either on its own or as a supplement to the HF procedure.

9. Decant suspension into 10ml glass centrifuge tubes using 10% HCL. PLace in water bath for 30 min to remove colloidal silicates.

10. Stir, centrifuge and decant.

11. Wash with distilled water, stir, centrifuge and decant.

12. Add +-5ml Glacial Acetic acid, stir, centrifuge and decant.

13. Add Acetolysis mixture to each sample. NOTE: For 8 samples 50ml of the mixture is sufficient. 9 Parts (45ml) Acetic Anhydride + 1 part (5ml) concentrated Sulphuric Acid. Measuring cylinder must be dry and stirring must be performed carefully. Add +-6ml of the mixture to each

sample using either a pipette or glass funnel. Place in heated water bath for 5 minutes.

14. Stir, centrifuge and decant.

15. Add Glacial Acetic acid, stir, centrifuge and decant.

16. Add neutral Ph solution (1 part NaOH and 9 parts distilled water). Test with indicator paper until a neutral Ph is obtained.. Stir, centrifuge and decant.

17. Wash three times with distilled water.

18. For the last wash add two drops of Aqueous Safranine stain, stir, centrifuge and decant.

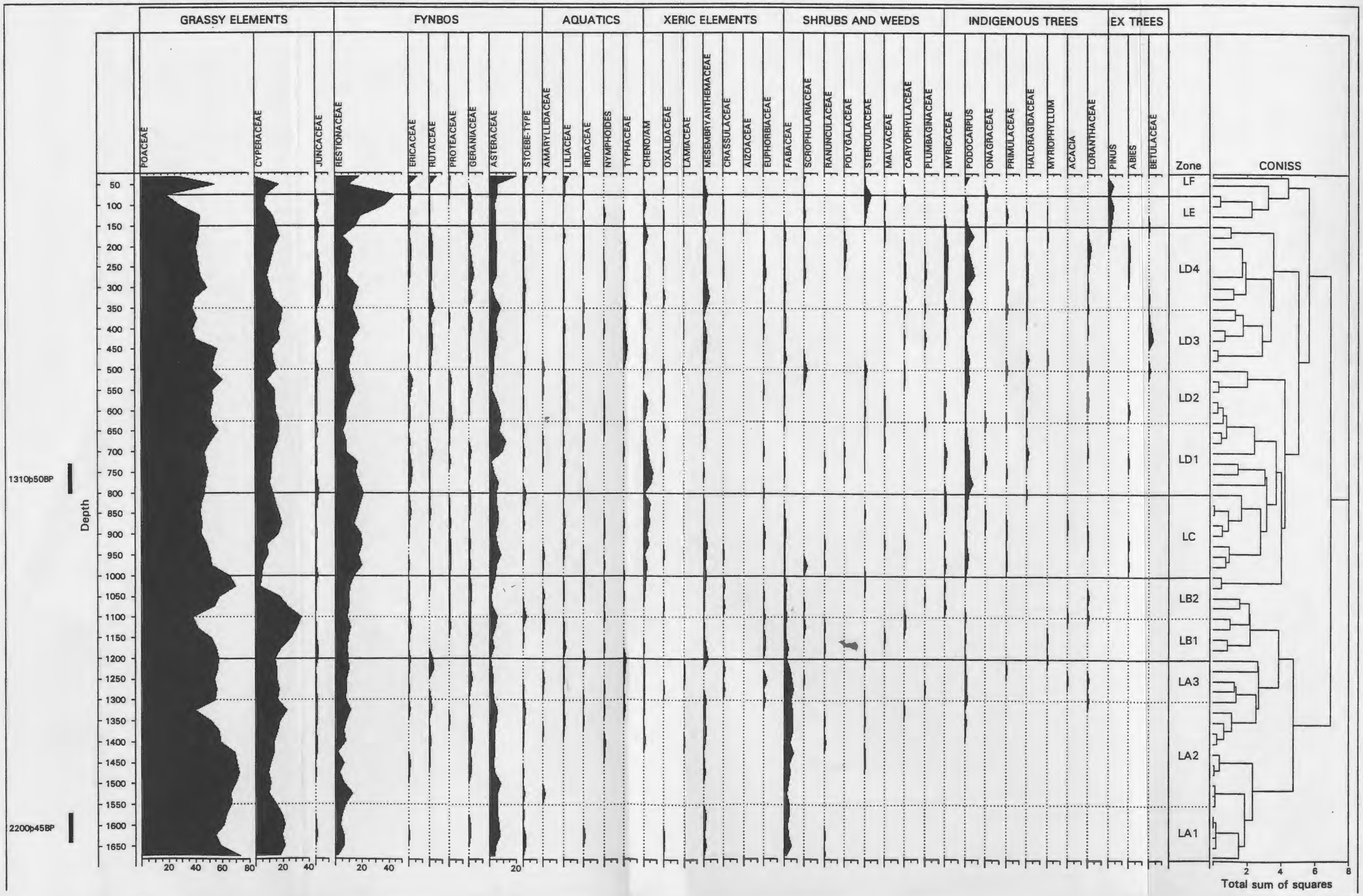
19. Add +-5ml Tertiaryy Butyl Alcohol, stir, centrifuge and decant.

20. Transfer solution into labelled vials using TBA, stir centrifuge and decant.

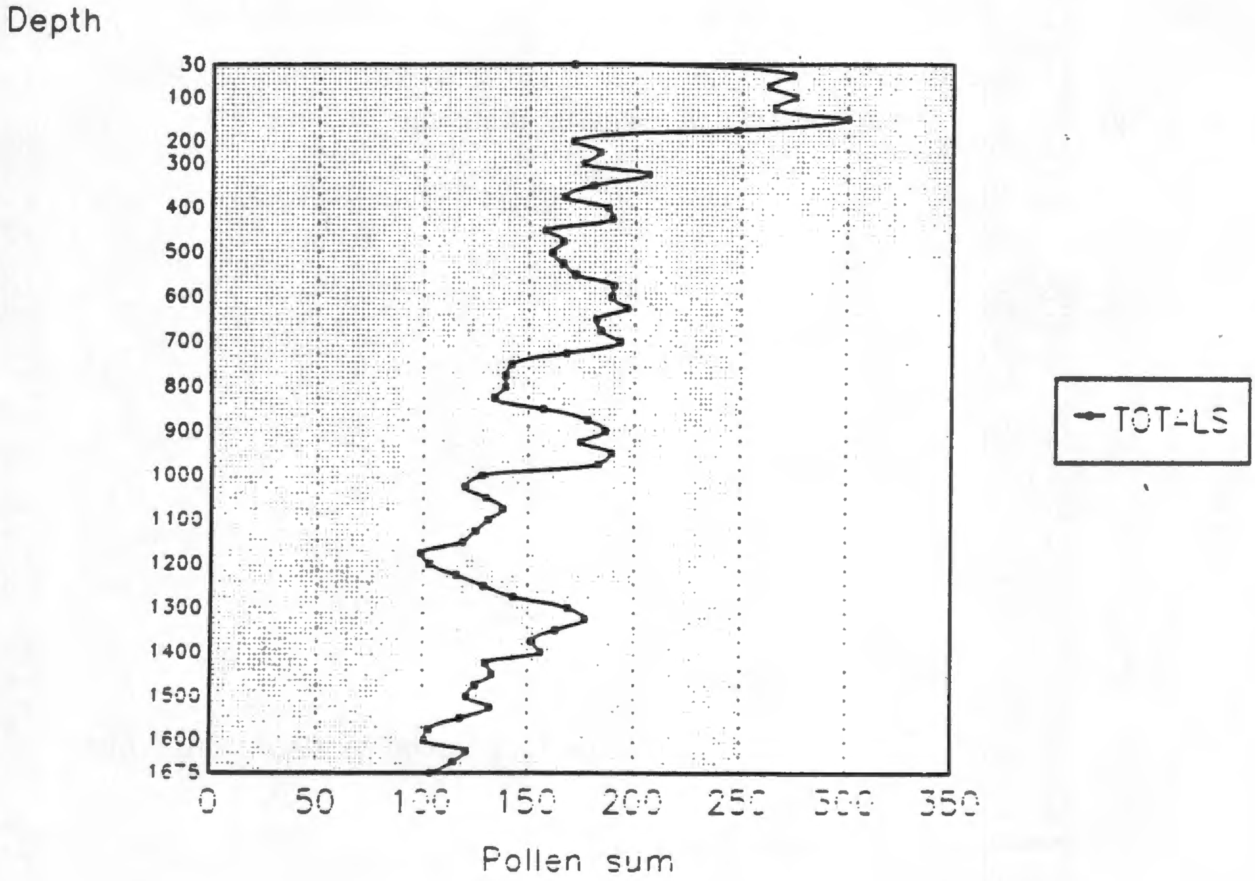
21. Add Silicone oil or Glycerol equal to the amount of sediment in the vial.

22. Store uncapped for 24hrs to allow the excess TBA to evaporate.

APPENDIX C

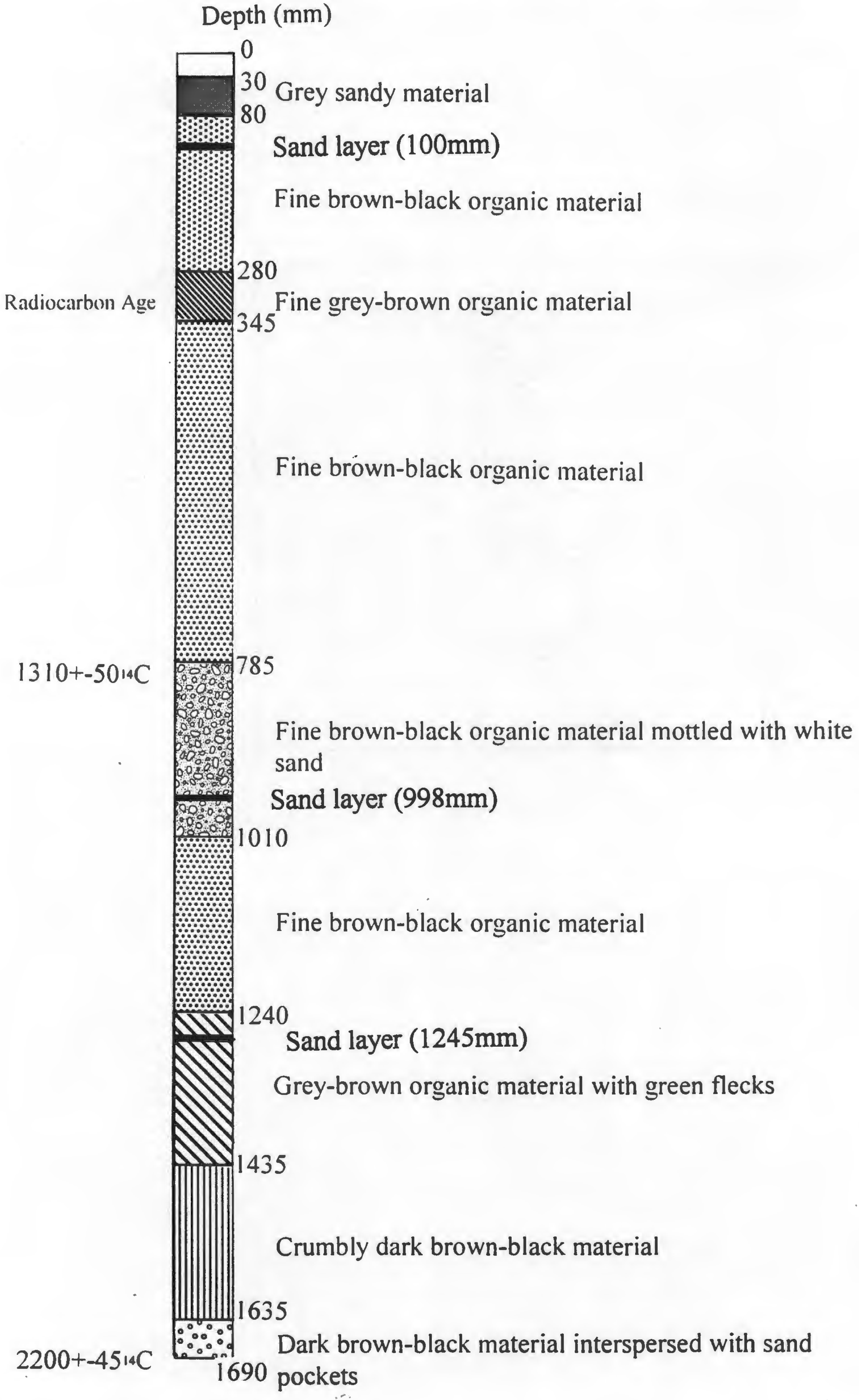

GRASSY ELEMENTS
FYNBOS
AQUATICS
XERIC ELEMENTS
SHRUBS AND WEEDS
INDIGENOUS TREES
EX TREES
POACEAE
CYPERACEAE
JUNCACEAE
RESTIONACEAE
ERICACEAE
RUTACEAE
PROTEACEAE
GERANIACEAE
ASTERACEAE
STOEBE-TYPE
AMARYLLIDACEAE
LILIACEAE
IRIDACEAE
NYMPHOIDES
TYPHACEAE
CHENO/AM
OXALIDACEAE
LAMIACEAE
MESEMBRYANTHEMACEAE
CRASSULACEAE
AIZOACEAE
EUPHORBIACEAE
FABACEAE
SCROPHULARIACEAE
RANUNCULACEAE
POLYGALACEAE
STERCULIACEAE
MALVACEAE
CARYOPHYLLACEAE
PLUMBAGINACEAE
MYRICACEAE
PODOCARPUS
ONAGRACEAE
PRIMULACEAE
HALORAGIDACEAE
MYRIOPHYLLUM
ACACIA
LORANTHACEAE
PINUS
ABIES
BETULACEAE
Zone
CONISS
Depth
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1000
1050
1100
1150
1200
1250
1300
1350
1400
1450
1500
1550
1600
1650
1310þ50BP
2200þ45BP
20 40 60 80
20 40
20 40
20
LF
LE
LD4
LD3
LD2
LD1
LC
LB2
LB1
LA3
LA2
LA1
2 4 6 8
Total sum of squares

APPENDIX D: PLOT OF POLLEN COUNTS



APPENDIX E

CORE STRATIGRAPHY: LFB



APPENDIX F

List of trees and shrubs characteristic of Southern Cape Forests.

FAMILY	**SPECIES AND GENUS**
Podocarpaceae	*Podocarpus latifolius*
Cupressaceae	*Widdringtonia cupressoides*
Musaceae	*Strelitzia alba*
Myricaceae	*Myrica serrata*
	Myrica cordifolia
	Myrica humilis
Moraceae	*Ficus burtt-davyi*
	Ficus capensis
Proteaceae	*Faurea macnaughtonii*
	Leucospermum attenuatum
	Leucadendron salignum
	Leucadendron eucalyptifolium
	Protea cynaroides
	Protea mundii
Santalaceae	*Colpoon compressum*
Bruniaceae	*Brunia nodiflora*
	Berzelia intermedia
Rosaceae	*Prunus africana*
Papilionaceae	*Psoralea pinnata*
	Virgilia oroboides
Rutaceae	*Fagara capensis*
	Fagara davyi
	Calodendrum capense
	Empleurum unicapsularis
	Vepris undulata
	Clausena anisata
Meliaceae	*Ekebergia capensis*
Polygalaceae	*Polygala myrtifolia*

Euphorbiaceae	*Andrachne ovalis*
	Lachnostylis hirta
	Clutia affinis
	Clutia pulchella
Anacardaceae	*Laurophyllus capensis*
	Rhus chirindensis
	Rhus crenata
	Rhus longispina
	Rhus lucida
	Rhus tomentosa
	Rhus undulata
	Rhus glauca
Celastraceae	*Maytenus acuminata*
	Maytenus heterophylla
	Maytenus peduncularis
	Pterocelastrus rostratus
	Pterocelastrus tricuspidatis
	Mystroxylon aethiopicum
	Cassine peragua
	Cassine parvifolia
	Elaeodendron capense
	Hartogia schinoides
Sapindaceae	*Allophylus decipiens*
	Dodonaea viscosa var. *augustifolia*
	Hippobromus pauciflorus
Rhamnaceae	*Scutia myrtina*
	Rhamnus prinoides
Tiliaceae	*Sparrmannia africana*
	Grewia occidentalis
Flacourtiaceae	*Kiggeleria africana*
	Scolopia mundii
	Scolopia zeyheri
	Trimeria grandifolia
	Dovyalis rhamnoides
Thymeleaceae	*Passerina falcifolia*

	Gnidia denudata
Araliaceae	*Cussonia thyrsiflora*
	Schefflera umbellifera
Ericaceae	*Erica floribunda*
Myrsinaceae	*Rapaena melanophloeos*
Sapotaceae	*Sideroxylon inerme*
Ebenaceae	*Euclea recemosa*
	Euclea polyandra
	Euclea schimperi
	Euclea undulata
	Diospyros dichrophylla
	Diospyros whyteana
	Diospyros glabra
	Diospyros pallens
Oleaceae	*Linciera foveolata*
	Olea africana
	Olea capensis
	Olea exasperata
Loganiaceae	*Strychnos decussata*
	Nuxia floribunda
	Buddleia saligna
	Buddleia salviifolia
Scrophulariaceae	*Halleria lucida*
Rubiaceae	*Burchellia bubalina*
	Rothmannia capensis
	Canthium mundianum
	Canthium obovatum
	Canthium pauciflorum
	Canthium ventosum
	Psychotria capensis
Asteraceae	*Brachylaena glabra*
	Brachylaena neriifolia
	Tarchonanthus camphoratus
	Chrysanthemoides monilifera

NOTE: SURVEY CARRIED OUT BY AUTHOR

APPENDIX G

LIST OF PLANT FAMILY GROUPINGS AND POSSIBLE ASSOCIATED SPECIES.

GROUP	FAMILY	SPECIES
Grasses	Poaceae	*Agropyron distichum*
		Agrostis bergiana
		Andropogon appendiculatis
		Andropogon eucomus
		Aristida Diffusa
		Brachypodium distachyum
		Eragrostis bergiana
		Eragrostis capensis
		Lagurus ovatus
		Leersia hexandra
		Phragmites australis
		Spartina maritima
Grasses	Cyperaceae	*Bulbostylis contexta*
		Chrysithrix capensis
		Cyperus denudatis
Grasses	Juncaceae	*Juncus bufonius*
		Juncus oxycarpus
Fynbos	Restionaceae	*Cannomois parvoflora*
		Chondropetalum tectorum
		Elegia capensis
		Elegia asperiflora
Fynbos	Ericaceae	*Anomalanthus discolor*
		Blaeria fuscescens
		Coilostigma zeyherianthum
		Erica abelii
		Erica affinis
Fynbos	Rutaceae	*Acmadenia obtusata*
		Agathosma capensis

Fynbos	Proteaceae	*Leucadendron album*
		Leucadendron eucalyptifolium
		Leucospermum glabrum
		Protea coronata
		Protea humiflora
Fynbos	Geraniaceae	*Pelargonium acetosum*
		Pelargonium althaeoides
Fynbos	Asteraceae	*Amellus strigosis*
		Arctotheca calendula
		Arctotis arctoides
		Athanasia dentata
		Brachylaena elliptica
		Brachylaena glabra
		Cuspidia cernua
		Elytropappus adpressus
		Elytropappus cyathiformis
		Eriocephalus capitellatus
		Haplocarpha nervosa
		Helichrysum anomalum
		Helichrysum argenteum
		Hertia kraussii
		Stoebe alopecuroides
		Stoebe plumosa
Aquatics	Amaryllidaceae	*Ammocharis corianica*
		Apodolirion macowanii
		Crinum lineare
Aquatics	Chironia	*Nymphoides indica*
Aquatics	Typhaceae	*Typha latifolia*
Xerics	Cheno/Am	*Atriplex halimus* (Chen)
		Chenolea diffusa (Chen)
		Chenopodium album (Chen)
		Exomis microphylla (Chen)
		Achyranthes aspera (Amaran)
		Achyropsis leptostachya (Amaran)
Xerics	Oxalidaceae	*Oxalis algoensis*

		Oxalis depressa
		Oxalis fourcadei
		Oxalis imbricata
		Oxalis polyphylla
		Oxalis stellata
Xerics	Mesembryanth	*Carpobrotus acinaciformis*
		Carpobrotus deliciosus
		Conicosia bijlii
		Delosperma algoense
		Disphyma crassifolium
		Drosantheum floribundum
		Drosantheum parvifolium
		Erepsia polita
		Lampranthus Laxifolius
		Mesembryantheum aitonis
		Platythyra haekeliana
Shrubs	Fabaceae	*Amphithalea fourcadei*
		Argyrolobium collinum
		Argyrolobium tuberosum
		Aspalathus
		Crotalaria capensis
		Eriosema zeyheri
		Erythrina caffra
		Indigofera denudata
		Lessertia annularis
		Otholobium candicans
Shrubs	Sterculiaceae	*Hermannia althaeoides*
		Hermannia holosericea
		Sterculia alexandri
Ind trees	Myricaceae	*Myrica cordifolia*
		Myrica humilis
		Myrica quercifolia
Ind trees	Podocarpaceae	*Podocarpus falcatus*
		Podocarpus latifolius
Ind trees	Onagraceae	*Epilobium hirsutum*

		Epilobium tetragonum
Ind trees	Primulaceae	*Anagallis huttonii*
		Lysimachia nutans
		Samolus valerandi
Ind trees	Haloragidaceae	*Laurembergia repens*
		Myriophyllum spicatum
Ind trees	Fabaceae	*Acacia*
Ind trees	Loranthaceae	*Moquinella Rubra*
Ex trees	Pinaceae	*Pinus pinaster*

NOTE: SURVEY CARRIED OUT BY AUTHOR

APPENDIX H

Core Log (LFB)

sampled at 5mm intervals

Undecompacted 'depths' in (mm)

0-30	no sample
30-80	grey sandy material
80-280	fine brown-black organic material Sand lens from 10-100mm
280-345	fine grey-brown organic material
345-785	fine brown-black organic material
#730-800:	1310+-50^{14}C age, analysis no. Pta-5035
785-1010	fine brown-black organic material mottled with white sand, sandy layer at 998mm
1010-1240	fine brown-black organic material
1240-1435	grey-brown organic material with green flecks, sandy layer at 1245mm
#1570-1640:	2200+-45^{14}C age, analysis no. Pta-4668
1435-1635	crumbly dark brown-black material
1635-1690	crumbly dark brown-black material interspersed with sand
1690-4285	white sand with occasional plant fragments
1690-1755	white-grey sand with slight mottling
1755-2630	white sand
2630-2640	brown streak 45 deg. dip
2640-2800	white sand
2800-2930	brown sand with some plant fragments

2930-3290	white sand
3290-3298	brown layer 25 deg. dip
3298-3580	white sand
3580-3590	brown sandy layer, 3/4 way across core only
3590-3652	white sand
3652-3655	brown layer
3655-3720	white sand
3720-3740	brown layer
3740-3845	white sand
3845-3875	brown layer
3875-3882	white sand
3882-3917	brown layer
3917-3995	grey sandy layer
3995-4010	mottled orange
4010-4285	white sand

Compaction: 1690mm peat and 2595mm sand recovered from a vibracore tube 6m long. Assuming that the sand compaction is negligible, average peat compaction = 1690/3405 = 0.4963. Decompaction factor for peat = 2.0149.

NOTE: Core logs supplied by Dr. W.K.Illenberger

APPENDIX I : RESULTS OF OVERLAND AND PREISENDORFER SIGNIFICANCE TEST

41 TAXA 65 OBSERVATIONS

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7.834  6.912  6.336  5.981  5.580  5.290  4.983  4.639
4.420  4.139  3.903  3.648  3.433  3.257  3.026  2.842
2.701  2 0.501  0.407  0.351  0.290  0.233  0.179
```