Palynology of Late Quaternary deposits from the Central Plateau, South Africa

BY

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CHAPTER 1

INTRODUCTION

The present study is an investigation of Holocene palaeo-environmental changes in the central plateau, based on pollen analysis. The method of pollen analysis relies on the assumption that long-term climate change affected the vegetation patterns of the region. This study intends to contribute to the proxy data on climatic changes in the interior and to investigate the environmental changes that occurred, especially during the late Holocene, using the pollen data gained in this study together with previously accumulated data.

The palaeo-climatic trends in South Africa, especially for the central plateau is still poorly understood, although some reconstructions have been attempted with variable success. The problem is due to the lack of ideal pollen-preserving sediments that are usually found in permanent water bodies. Therefore, some of the most productive sites have been rare, swampy areas such as permanent springs with peat deposits and pans in the western parts of the plateau (Scott & Vogel, 1999).

During the Holocene many vegetation changes took place in response to climate fluctuations. The Early Holocene, around 10 000 yr BP to 8000 yr BP was a dry and relatively cool period, becoming warmer, as shown by evidence from various sites in the South African interior (Scott, 1993). Pollen data from the grassland region in Aliwal north indicates dryness around 9600 yr BP (Coetzee, 1967), while $\delta^{13}C$ analysis of grazer tooth enamel from Rose Cottage and Tloutle indicate two episodes of cooling around 8500 yr BP and 7500 yr BP (Smith, 1997). Relatively cool, dry conditions were also experienced at Rietvlei between 10 300 yr BP and 8500 yr BP (Scott & Vogel, 1983). The dry and cool climate of the Early Holocene is supported by evidence from the Kalahari, in Wonderwerk Cave where micromammalian faunas from the cave sediments suggest an open and dry vegetation before 9000 yr BP (Avery, 1981). Dry karroid vegetation with little moisture occurred at Equus Cave during the Early Holocene (Scott, 1987). The savanna area at Wonderkrater also showed signs of dryness and gradual warming around 9600 yr BP (Scott, 1982; Scott *et al.,* 1995).

A climatic optimum was reached during the mid-Holocene, between 8000 and 5000 yr BP when conditions were wetter and warmer than present. The increase in temperature which occurred during this time affected the southern hemisphere uniformly, but was not in tandem with moisture changes, which fluctuated on their own (Scott, 1993). A pattern of progressive southward shift in summer rains is thought to have occurred during this period, as it is indicated by evidence that moisture increased in the northern parts (Savanna) first, around 8000-7000 yr BP then spread southwards, reaching the Karoo by 5000 yr BP (Scott, 1993; Scott & Vogel, 1999). But some evidence points to the occurrence of two wet cycles, around 7500 yr BP and around 5000 yr BP (Butzer, 1984a, b; Meadows, 1988; Scott, 1993; Esterhuysen & Mitchell, 1996).

Pollen analyses in the summer rainfall region at Wonderkrater, Rietvlei (Scott, 1982; Scott & Vogel, 1983), Moreletta, Equus Cave (Scott, 1987), Wonderwerk (van Zinderen Bakker, 1982) and Kathu Pan (Beaumont *et al.*, 1984) gave indications of warmer temperatures between 8500 yr BP and 7500 yr BP. During this time, broad-leafed bushveld vegetation with Combretaceae replaced *Tarchonanthus* and other Asteraceae shrubs that occurred to the north of 28°S (Scott, 1993). The interior experienced increased moisture around 7500 yr BP and 5000 yr BP. This was indicated by evidence from Wonderkrater, Alexanderfontein, Wonderwerk, Kathu Pan and Equus Cave (Scott, 1993; Scott, 1982b; Deacon & Lancaster, 1988). Also, at Rose Cottage Cave in the Free State, moisture increase between 8600 and 6800 yr BP was indicated by the occupation of the cave, increased spring activity and increased local rainfall (Avery, 1997). The geomorphology of pans, springs and vleis in the western Free State and north-western Cape suggests increased moisture between 7700 and 6300 yr BP (Butzer, 1984a, b). In the Karoo, in Blydefontein the vegetation comprised of *Stoebe* or *Elytropappus* type and *Artemisia* species around 7790 yr BP, but were later replaced by elements of a more grassy veld (Scott, 1993).

Studies of mid to late Holocene fluctuations in climate gave contradictory interpretations. Geomorphological evidence from pans, springs and vleis in the interior indicate increased moisture around 4500-1300 yr BP (Butzer, 1984a,b) and this is confirmed by pollen data from Deelpan (Scott, 1988; Scott & Brink, 1992) which show the establishment of grassy karoo vegetation by 4000-1000 yr BP. The period between 4000 and 3000 yr BP was generally a wet interval (Tyson, 1986) and evidence of this comes from several sites in southern Africa (Deacon & Lancaster, 1988; Holmgren *et al.*, 1999). There is, however, contradictory evidence from Wonderwerk and Kathu Pan in the southern Kalahari which indicates dryness around 4000-3000 yr BP (van Zinderen Bakker, 1982; Beaumont *et al.*, 1984). Data from nitrogen and oxygen isotopes of ostrich eggshell from Equus Cave do not point to dry conditions (Johnson, *et al.*, 1997), but these data are few. There is also evidence of mid-Holocene dune building in the south-western part of the Kalahari desert (Thomas *et al.,* 1997) and some indications of a dry phase from the Wonderwerk deposits around 6ka (Thackeray & Lee-Thorp, 1992). This evidence from the Kalahari region indicates that a dry period may have occurred in this area some time during the mid-Holocene.

The late Holocene experienced dramatic climatic changes such as, the Neoglacial cooling, the Little Ice Age (LIA) and the Medieval Warm Epoch (Tyson & Lindesay, 1992). The Neoglacial cooling was a cold phase that was felt throughout the world and is assumed to have occurred sometime after 5000 yr BP as indicated by different proxy records (Scott, 1982, 1994; Scott & Thackeray, 1987; Talma & Vogel, 1992). The Little Ice Age was a cool and dry phase that took place around 1300-1800 AD (Holmgren *et al.*, 1998; Tyson & Lindesay, 1992). This phase is indicated by a decline in frost sensitive arboreal species in Wonderkrater, Moreletta and Namibia (Scott, 1982; 1984; 1996,). The Medieval Warm Epoch was less extensive and it occurred shortly after the LIA around 1300-900 AD (Tyson & Lindesay, 1992; Holmgren *et al.* 1999). Evidence of this phase comes from the western Free State pans (Butzer, 1984; Scott, 1988), from pollen in hyrax midden in the karoo and the Namib (Scott & Bousman, 1990; Bousman & Scott, 1994; Scott, 1996) where distinctive changes in climate were recorded. It has been suggested that the warmer conditions may have influenced the movement of the Iron Age people southwards coming into contact with existing Late Stone Age inhabitants (Bousman, 1998).

Palaeoclimates of the Holocene of southern Africa have been simulated by a global climate model (Fig. 1.1) proposed by Wright *et al.*, (1993) and Street-Perrot &

Perrot (1993) which attempts to explain the importance of external forcing, brought about by the earth - sun geometry in controlling climate changes around the globe. Orbital parameters such as, eccentricity, obliquety (angle of tilt of the earth) and precession (distance of earth from the sun), with periodicities of 100 000 years, 41 000 years and 22 000 years, respectively, interact and change from time to time, bringing about changes in climate. This model shows that around 18 000 years BP the season and latitude distribution of solar radiation was similar to that of the present, that is, the time of perihelion (when the earth is closest to the sun) was in January. By then, the climate was very different from that of the present because of the extent of the ice-sheets, land ice, low sea temperatures and low CO_2 concentrations and the greater influence they had on the climate during that time.

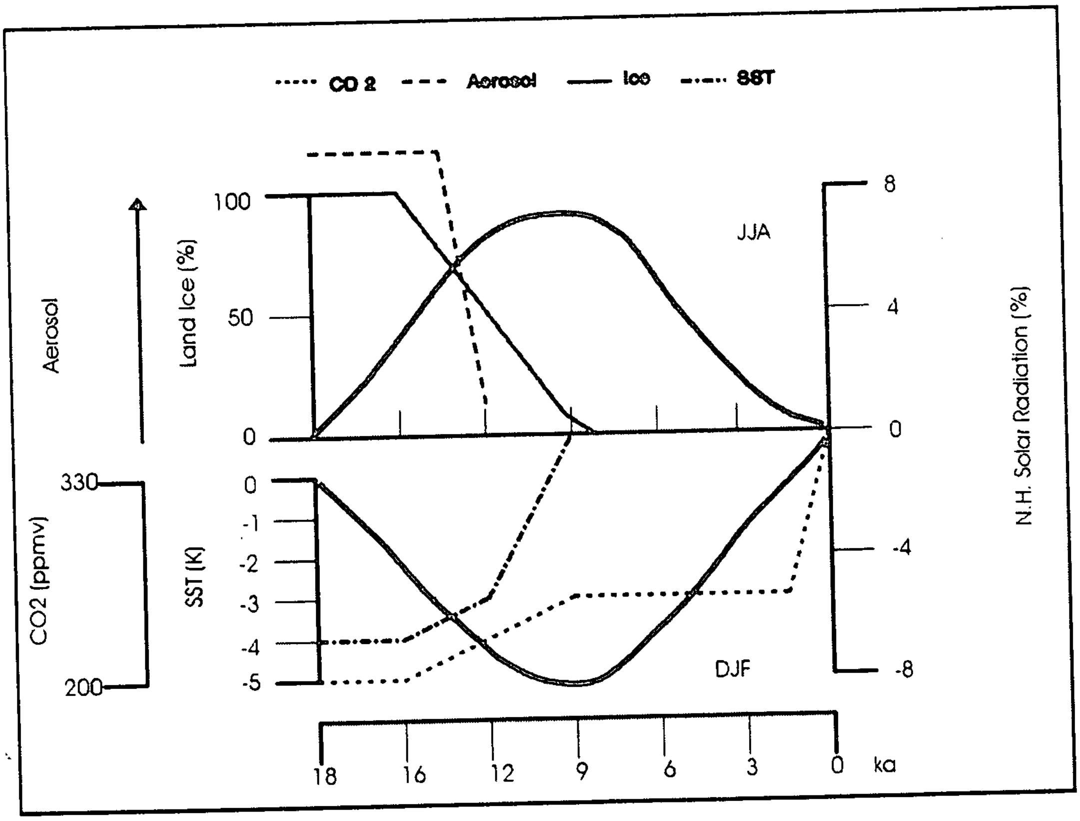

Figure 1.1 The Global Climate Model from Wright *et al.* (1993).

Between 15 000 and 9000 years BP, as the ice-sheets and sea ice retreated, with warming of the oceans, external forcing had more influence on the climate. During this interval, seasonal and latitudinal distributions of solar radiation changed in response to the increased axial tilt and the repositioning of the perihelion in the northern summer. These changes led to an increase in the seasonality of insolation in the northern hemisphere which were accompanied by an increase in precipitation, while the opposite occurred in the southern hemisphere. This model implies relatively cool summers with reduced precipitation and warm winters with increased precipitation for the southern hemisphere around 9000 yr BP, and this agrees with fossil evidence from South Africa for this period (Scott, 1993).

According to the model, climatic conditions began to change slowly from around 6000 years, approaching the present climate regime, with cooler summers and warmer winters in the northern hemisphere and the opposite was simulated for the southern hemisphere (Wright *et al.*, 1993; Street-Perrot *et al.*, 1993). Climatic model simulations for mid to late Holocene agree with palaeo-environmental evidence which indicates that gradual warming was experienced in South Africa from about 8000 (Scott, 1982, 1987 1993; Scott & Vogel, 1983; van Zinderen Bakker, 1982; Beaumont *et al.*, 1984).

The mid to late Holocene climatic changes in southern Africa may be explained by a conceptual model of the modern day wet and dry spells (Fig. 1.2) of Tyson (1986), Cockcroft *et al.*, (1987) and Tyson & Lindesay (1992). These spells are said to be of around nine year's duration and occur with almost an 18-year frequency over southern Africa. This model is based on the proposition that extended wet spells are caused by an invigoration of tropically induced circulation disturbances forced by the tropical easterlies. The dry spells occur with an expansion of the circumpolar vortex and an increased occurrence of westerly disturbances. During these dry spells, the summer-rainfall region becomes drier in summer, the winters are wetter and the net annual precipitation decreases, while the opposite occurs for the wet spells. So, according to this model, climatic conditions during the Holocene optimum and the Medieval Warm Epoch were analogues to the present-day wet spells and the Little Ice Age was similar to the present-day dry spells (Tyson & Lindesay, 1992; Cohen & Tyson, 1995).

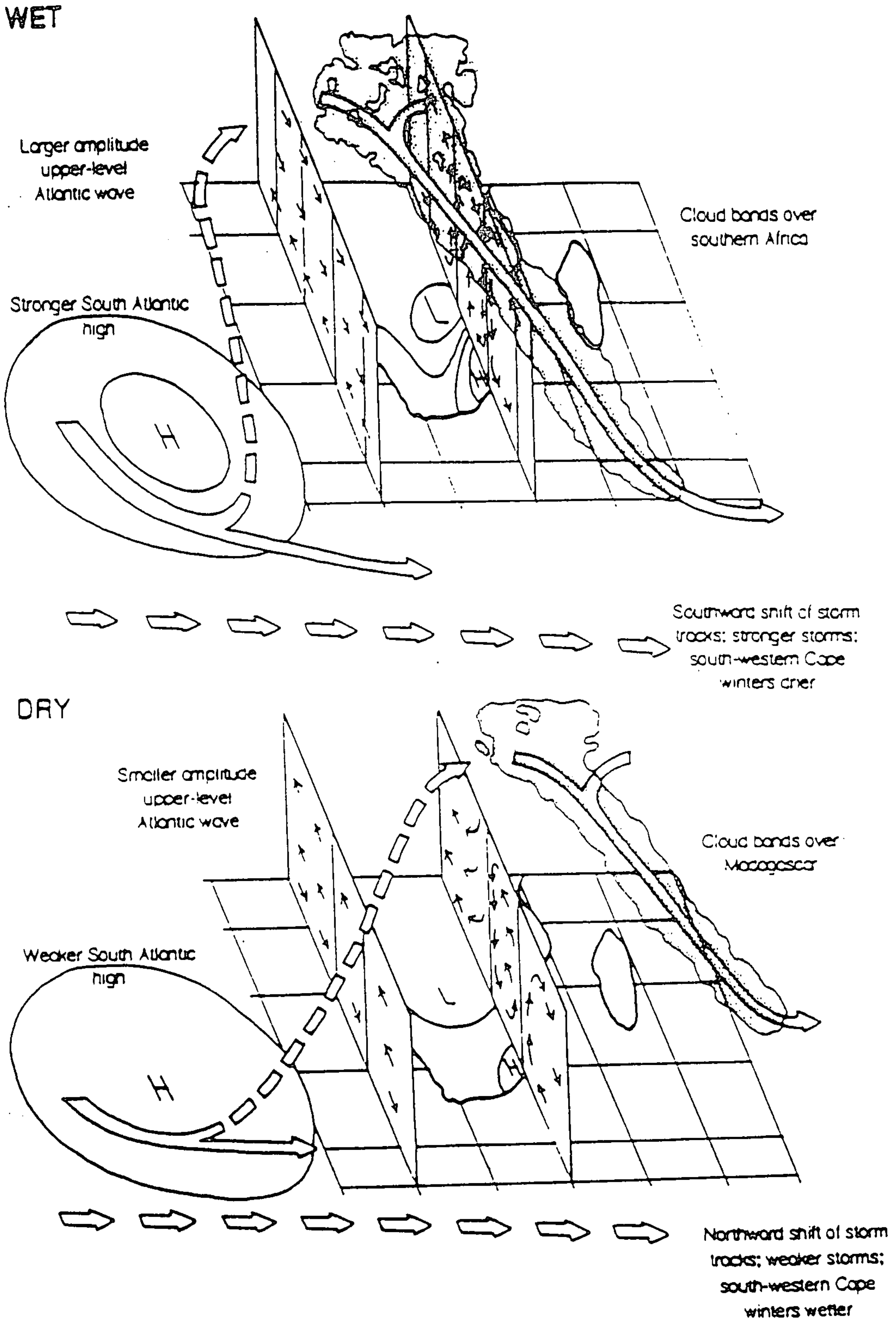

Figure 1.2. Wet and dry climatic conditions and meridonial atmospheric circulation in southern Africa (from Tyson, 1986).

Holocene records for the interior show disparities which may reflect localized differences in the nature and timing of climatic events, problematic dating or individual interpretations of different proxy series. For this research, palaeoenvironmental changes of mid and late Holocene will be described for three sites, Elim, Florisbad and Blydefontein (Fig. 1.3) in the central plateau and the results thereof, be compared with other proxy data of the interior for this period.

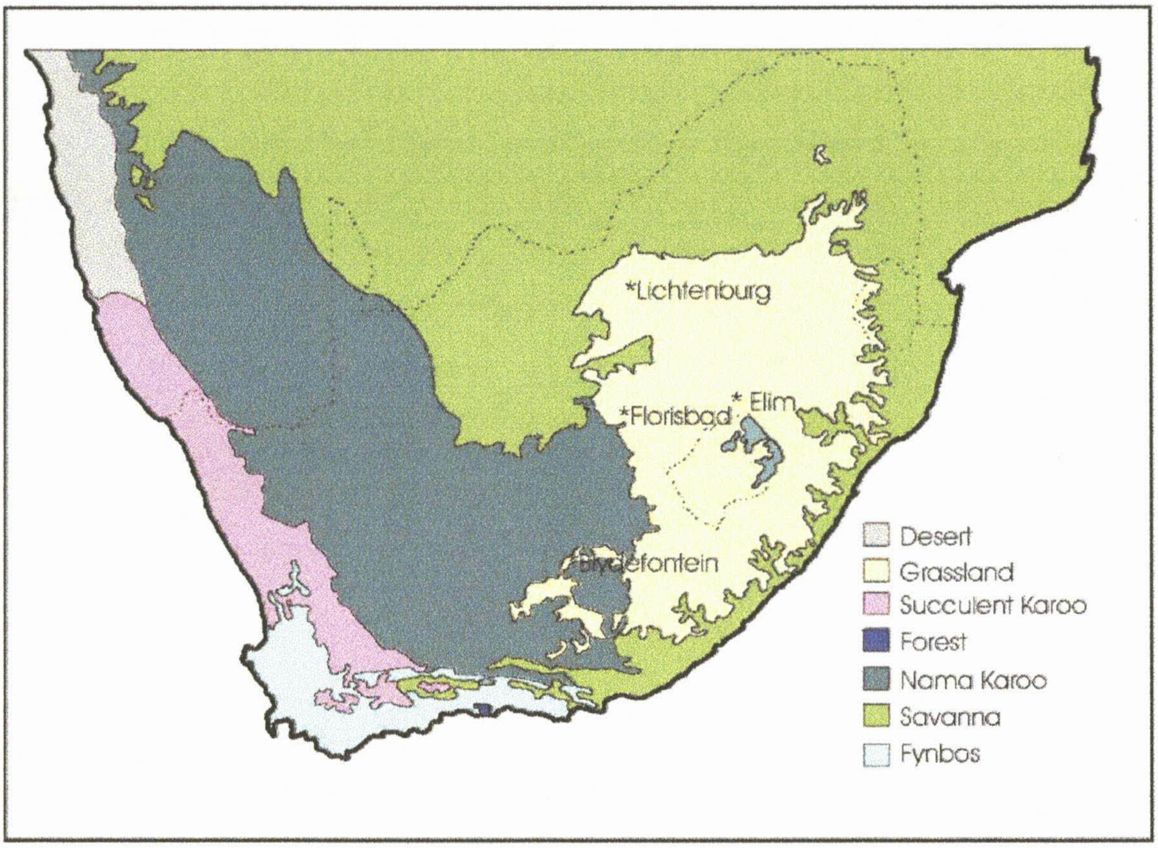

Fig. 1.3. Locality map of pollen sequences in relation to biomes of Southern Africa

In the following chapters, the methods of retrieval and analyses of samples, the climate, geology and vegetation of the study area, and lastly, the analyses of the pollen deposits from the three sites, will be discussed.

CHAPTER 2

PHYSIOGRAPHY, CLIMATE AND VEGETATION OF THE STUDY AREA

In this chapter the importance of several factors that influence and reflect on the vegetation will be looked into.

Physical factors such as, the climate, geology, soil, aspect, evolutionary developments and adaptation of plants, their interaction with microclimate processes, as well as competition, succession, fire, physioecological qualities and many others play a role in determining the nature of a vegetation in an area. These factors control the type, distribution and cover of the vegetation found in a region. Therefore, from the type of vegetation growing in an area, the type of climate can be determined. This concept forms the basis for the reconstruction of past climates by means of pollen analysis. A broader picture of the physiography, climate and vegetation of the study area is given in this chapter, but the local details of each site will be discussed later in the specific chapters.

Physiography

The geology of an area is a basic environmental factor of prime importance because it influences the topography and therefore, has an influence on the climate, parent material, soils and also on the vegetation (Scheepers, 1975 in du Preez, 1991).

The study area is underlain by the Karoo Sequence. The main geological units are the Beaufort, Stormberg and Drakensberg Groups. The Beaufort Group consists of two sub-groups, the Adelaide Sub-group and the Tarkastad Sub-group, while the Stormberg Group is divided into the Molteno, Elliot and Clarens Formations. The Drakensberg basalt is the youngest unit in the sequence and it covers a small part of the eastern Free State (du Preez *et al.*, 1991; du Preez & Bredenkamp, 1991). Numerous dykes and sills of fine-grained dolerite intrude most of the outcrop of the Karoo Sequence.

The type of soil that is found in an area is largely determined by the geology of the particular area, much as the altitude is influenced by the geology. The altitude of the study area varies between 1200m as the lowest point, to about 1800m.

Climate

The Regional Climate of Southern Africa

To understand past climatic changes, the present climate and its influences have to be understood first. The climatic system over southern Africa has been described by many authors such as Schulze (1984) Tyson (1986), and Deacon & Lancaster, (1988). The climate of southern Africa is strongly influenced by the latitudinal position of the subcontinent in relation to the major circulation features of the southern hemisphere. The west coast is influenced by the cold north flowing Benguela current and the warm south flowing Mozambique and the Agulhas current influences the east and south-east coasts. This together with the width of the landmass exerts a moderating effect on the climate.

The description of the interior as discussed below is mainly taken from Tyson (1986).

Rainfall

At present rainfall over southern Africa is mainly a summer phenomenon with over 80% of the annual rainfall occurring between October and March. Over 80% of the winter rainfall occurs in the south-west and this proportion decreases to 40% towards the north, where rainfall is received evenly throughout the year, and to less than 10% further north. Three main forces influence rainfall patterns over the subcontinent, namely,

1. High pressure cells in the Atlantic and Indian oceans and general pressure distribution over the subcontinent
2. The position of the Inter-Tropical Convergence Zone (ITCZ)
3. The influence of the tropical easterlies and the zonal westerlies

Generally, wetter conditions in southern Africa are all associated with lowered pressure over the subcontinent and increased over the Atlantic ocean and the reverse applies during drier conditions. In summer the northeastern parts of the subcontinent receive rains due to the summer position of the ITCZ, which is just to the north of South Africa and the moonsonal inflow from the ocean. The isohyets that are generally aligned north south over the interior plateau, with a mean annual rainfall progressively less from east to west divide southern Africa into wetter eastern and drier western parts. The dryness experienced in the western parts during summer is the result of the south Atlantic high-pressure system and the cold upwelling waters of the Benguela current. The greater distance of the Indian ocean high pressure area from the coast during summer, also leads to higher precipitation in the eastern parts.

South of latitude 20°S the atmospheric controls of climate become more complicated as the temperate disturbances originating in the circumpolar westerlies assume a greater degree of influence and as this occurs, the temperate and tropical disturbances interact to form a major factor affecting rainfall. During summer months the tropical easterlies bring rain to the eastern and interior regions and the zonal westerlies affect the southwestern edge of the subcontinent in winter (Tyson, 1986). Strengthening of the tropical easterlies causes wetter conditions in the interior and correspondingly drier conditions along the western margins, whereas strengthening of the westerlies has the opposite effect (Tyson, 1986; Muller & Tyson, 1988). The Southern Oscillation is also a factor that influences rainfall in summer (about 20%) by increasing the tropical easterly flow and the poleward contraction of the westerlies as they become stronger to the south, during the wet high phase (Tyson, 1986).

In winter the eastern and interior parts are dry and there is anticyclonic control over the interior as a result of cooler landsurfaces while the ITCZ has moved away to the north of the equator. The western parts receive rain during this time as a result of fronts caused by waves of the westerly system, which also carry cold air into the interior.

Temperature

Air temperature in southern Africa depends greatly on the altitude and configuration of the land (Tyson, 1986). Temperature varies from the south to the north and from the east to the west coasts, with a general south-north increases (towards the equator). The temperature of the surrounding seas and the nature of the Benguela and Agulhas currents greatly affect temperatures along the coasts. Thus, the mean annual temperature at sea level in January, on the west coast shows an anomaly of -6 °C due to the cold Benguela current, whilst on the eastern coast an anomaly of 2 °C is recorded, caused by the warm Agulhas current (Schulze, 1984). Temperatures also vary from sea level to plateau, and from plateau to mountain. Generalised isotherms of mean surface temperature tend to follow the contours of the ground and lowest temperatures (Tyson,

1986) with absolute minimum temperatures of below -12.5 °C (Schulze, 1984) occur along the eastern Highveld and escarpment. The highest temperatures are observed in the low altitude valleys of the Orange and Limpopo Rivers and the eastern Transvaal lowveld, with absolute maximum temperature exceeding 45 °C (Schulze, 1972).

Daily fluctuations in temperature may bring about changes in climate. As Schulze (1997) states that temperature changes between day and night-time in summer display a longitudinal trend with temperature increasing from east to west, while in winter a latitudinal trend is displayed with a general decrease from north (ca.18 °C) to south (ca.13 °C).

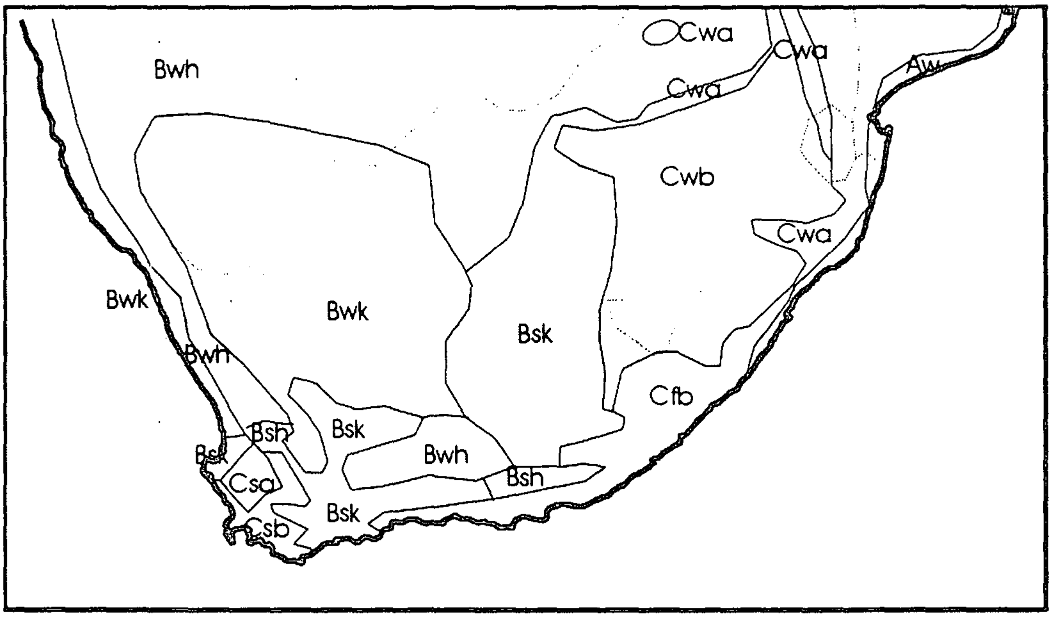

Figure 2.1. Climates according to Köppen from Schulze and Mcgee (1978).

<u>The Interior Plateau</u>

The climate of the study area is typical of the interior summer-rainfall region of South Africa. It is far away from the westerly circulation system, but may be subjected to cold fronts from the southwest, especially in winter.

The climate of the study area may be classified as both the Cwb and the Bsk climates according to the Köppen climate classification map - Figure 2.1 (Schulze & Mcgee, 1978). The Cwb climate occurs in the eastern parts of the Free State and it is temperate (warm) with a dry winter season where the mean temperature of the warmest month is below 18 °C. The Bsk region is in the western parts of the province and has an arid (steppe) climate with a mean annual temperature below 18 °C. The temperature in this region may exceed 18 °C during the hottest month (Schulze 1947 in du Preez, 1991).

Strong precipitation gradients extend across the study area, where the annual precipitation increases from west to east and from south to north (du Preez *et al.*, 1991). These precipitation gradients are caused by the increase in relief from west to east and a decrease of average daily temperatures from east to west (Schulze & Mcgee, 1978).

Vegetation

The studied sites are all found in the grassland biome (Fig. 1.3), although Blydefontein could be said to be in a transitional zone, as it lies between the Grassland and Karoo biomes. The grassland biome occupies 349 174 km^2 and is centrally located in southern Africa. The rainfall gradient varies from about 400mm\yr to 1200mm\yr, while temperature ranges from frost-free to snow bound in winter and the altitude from sea-level to approximately 3300m and occurs on a spectrum of soil types from humic clays to poorly structured sands (O' Connor & Bredenkamp, 1997). The grassland biome is widespread in the interior plateau and includes fynbos-like vegetation in moist higher altitude areas such as Clarens (Scott, 1997). In southern Africa, the present distribution of grasses following isotopically distinct C_3 and C_4 photosynthetic pathways is strongly patterned according to season of rainfall (Vogel, 1978; Lee-Thorp & Beaumont, 1995). C_4 grasses predominate over the interior and eastern regions (the summer rainfall region), while the C_3 grasses are confined to the western Cape (winter rainfall region) and the cool, high altitude areas within the summer rainfall region. The high-lying areas around Clarens and Blydefontein, however, do not exclusively contain C_4 grasses like Florisbad.

A single layer of grasses usually dominates grasslands, but the amount of cover depends on rainfall and the degree of grazing. Trees are absent except in a few localized habitats and geophytes are often abundant (Rutherford & Westfall, 1986). Frosts, fire and grazing maintain the grass dominance and prevents the establishment of trees.

The grassland biome is very important for South Africa as it is utilised for crop production as well as for cattle farming.

Six major floristic regions, comprising 14 vegetation types were identified by O' Connor & Bredenkamp (1997) within the grassland biome, namely the Central Inland plateau, the Dry Western areas, the Northern areas, the Eastern Inland plateau, the Eastern mountains and escarpment and the Eastern lowlands. Within these regions, several plant communities occur and are mapped according to the physical characteristics of their locations.

Prominent species encountered throughout the grassland biome include *Themeda triandra,, Eragrostis curvula, Cymbopogon plurinodis, Setaria sphacelata, Digitaria eriantha, Hyparrhenia hirta and Cynodon dactylon* (O'Connor & Bredenkamp, 1997) and here *Themeda triandra* is the most dominant species.

Some mountain slopes are characterised by woody species where grasses such as *Trachypogon spicatus, Tristachya leucothrix, Panicum natalense, Schizachyrium sanguineum, Loudeta simplex, Monocymbium leresiiforme, Alloteropsis semialata* and *Eulalia villosa* predominate (O'Connor & Bredenkamp, 1997).

Karroid shrubs and forbs may predominate at overgrazed sites and sedges are dominant in wetlands.

CHAPTER 3

METHODS

Sampling

Samples for fossil pollen analyses of the Clarens site (Chapter 6) were collected from a 4.17m high gulley. Here samples were taken from the two cut and fill cycles. Samples were recovered along the length of the cycles at irregular intervals, using a chisel and a hammer and immediately placed in clean plastic bags. Precaution against contamination was taken by cleaning the surface of the gulley wall and again cleaning the surface of the sample once recovered. A surface pollen sample, for comparing the recent pollen spectra with the fossil samples, was recovered by randomly collecting samples a few square metres from the gulley so as to avoid over-representation of some pollen types. Scott (1989) studied other surface samples from the general area. A total of 43 samples, including the surface sample, were collected. Five samples were sent to the Quaternary Dating Research Unit in Pretoria for radiocarbon dating. The sediments are at least 4200 years old, in radiocarbon years.

Sampling in Florisbad (Chapter 7) was carried out at the already excavated spring site. Samples were retrieved from one of the spring eyes in the western half of the site, above where the "Florisbad Man" cranium was found. This section is known as Peat IV (Dreyer, 1938; Kuman & Clarke, 1986; van Zinderen Bakker, 1989) and consists of the Holocene part of an 8 meter sequence of 300,000 years old (Grünn *et al.*, 1996). This sequence of samples was collected from 150cm of sediments, which are overlain by 50cm of modern rubble. The organic-rich sequence consists of alternating grey and black sandy layers. Here again, as in Clarens, a chisel and a hammer were used for the recovering of samples and precautions were taken to avoid contamination. To avoid dating problems caused by root contamination, rootlets were carefully removed by hand from the sediment samples. A total of 39 samples were taken and seven were sent for radiocarbon dating. The oldest sample is about 8170 yr BP.

Prof. Louis Scott together with Britt Bousman and Paul Goldberg collected the material from Blydefontein. The samples are from three different sections, namely; the Blyde Stream Mouth (BSM97), the Base Section and the Gutter Section. Twenty-eight samples from the BSM97 were recovered in the field. From the Base and the Gutter sections, which were collected as complete sections, 12 and 15 sub-samples were taken, respectively, after cleaning and scraping off the surface with a knife. Three samples from each section were sent for radiocarbon dating, while the rest were used for pollen analyses. The oldest deposit is 5370 ± 70 yr BP and is from the Base section.

In Lichtenburg, samples were collected from a pit dug by the local municipality. The pit is in a vlei near the Blydeville Squatter Camp. A total of 19 samples, together with the surface sample, were collected from a 1,25m long section. Two of the samples were sent for radiocarbon dating. The two bottom samples, taken between 1m and 1,25 meters, were found below the point where the groundwater level was at the time. The rest of the seven samples were also positioned below water, but were recovered from a part that had been dug out. This sequence had a bottom date of 5600 yr BP. Although care was taken not to contaminate the samples, the possibility of contamination was very high due to the presence of dirty water in the pit and the use of the heavy equipment for digging the hole.

All the dating of samples was handled by the CSIR Quaternary Dating Research Unit in Pretoria (QUADRU).

Chemical Treatment

The samples were weighed, and to each sample a known quantity of exotic *Lycopodium* spores were added so as to enable the calculations of pollen concentrations per sample. The samples were then placed in 10% HCl to dissolve carbonates and then boiled in 10% KOH for some minutes to disperse the organic material and dissolve humic substances. This was followed by mineral separation with ZnCl2-solution (S.G+-2). In most instances, the samples were cleared afterwards of finer mineral and unwanted material by washing with 40% HF. The samples were then acetolysed with the acetolysis mixture (9 parts acetic acid anhydride and 1 part sulphuric acid) for 3 minutes at 80 °C. This step removes cellulose and excess organic matter from the sample, concentrates the pollen in the sample and helps to present the exine features more clearly for examination. After each step the samples were centrifuged and washed with distilled water.

Analyses

Slides were mounted on a hotplate with a temperature of about 60 °C using glycerin-jelly as a mountant. Excessive water was allowed to evaporate for 2-3 minutes before fitting the coverslip in order to prevent later drying out and air penetration in the slides which can occur in the dry climate of the Free State.

The pollen analyses were carried out using a Zeiss Photomicroscope. The slides were scanned with a 16x objective along fixed traverses by means of an adjustable stage. After locating the palynomorphs the identifications were made by means of a 100x oil immersion objective. Only reasonably well preserved specimens were counted. Spores and pollen grains that were seriously obscured, corroded, folded or damaged beyond recognition were ignored. Other well preserved specimens which could not be identified positively are indicated in the pollen diagrams as "Unidentified''. To avoid unrealistic over-representations, clumps of the same pollen type, especially those of local elements, were counted as single units. The identifications were performed using the reference collection of the Palynological Laboratory at the University of the Free State.

To obtain statistically reliable percentages of the components of a pollen spectrum it is important that a large number of pollen grains be counted, preferably more than 250 per sample (Faegri & Iversen, 1964; Scott, 1979). Samples or slides that did not have enough pollen grains were not used in the construction of a pollen diagram.

The Construction and Zonation of Pollen Diagrams

After counting the pollen grains, a pollen diagram showing the percentages of the different pollen types in each sample was constructed. A pollen diagram is a diagrammatic representation of the pollen percentages of the different pollen types that are found in a given sedimentary sequence. The Tilia 1.12 and TiliaGraph 1.18 programs were used to make pollen diagrams and to define pollen zones on the computer. The cluster technique, Coniss, a sub-program in TiliaGraph was used to aid in the zonation of the pollen sequences. The zonation process is very important in a pollen diagram as it distinguishes zones or units within the total pollen spectra where spectra with relatively uniform characteristics are grouped together. These units are referred to as pollen assemblage zones (Moore & Webb, 1978).

There are two types of pollen diagrams, the detailed and the condensed. In the detailed diagram, all the pollen of the total pollen spectra are represented individually, this pollen diagram is usually very complex. The condensed diagram is a summary or rather a simplified version of the detailed pollen diagram, which includes the "pollen sum", that is the total on which percentages are based. The concept of the pollen sum was introduced so as to give the results in an understandable way (Faegri & Iversen, 1964). In a pollen sum diagram the elements which are considered to be of wider palaeoecological significance can be presented separately from the local swamp elements. Therefore, the reconstruction of the vegetation of the area surrounding the site and past climatic changes mainly depends on the pollen sum elements rather than the swamp elements.

Data Analysis

Principal component analysis (PCA) of the CSS: Statistica Program was used on the data from the three sites, Clarens, Florisbad and Blydefontein. This analysis was done in order to summarize the complex results, to allow some correlation between the new and old data from the different sites and to aid in the palaeoenvironmental interpretations of these sites. From the data of each site only the prominent pollen types, that is, pollen grains which occurred in 50% of the samples of each sequence were chosen for the analysis. In order to enlarge the size of the data matrix, the data were combined with previously published data from the respective sites For Clarens, the new data from Channel 1 and 2 was analysed together with the old data from Elim, Craigrossie and Cornelia (Scott, 1989). Data from Florisbad was analysed with data from Deelpan (Meriba1, Meriba2 and the South section) from Scott (1988) and Scott and Brink (1991). Old data from Blydefontein (Bousman *et al.*, 1988) was paired with the new data from BSM97, the Base and the Gutter sections. PCA results for the first three factors (PC1, PC2 and PC3), with no rotation were not found to be informative for Clarens and Florisbad and are therefore not discussed further, while those for Blydefontein are elaborated on in Chapter 7.

CHAPTER 4

INDICATOR VALUES OF THE MAIN POLLEN GROUPS

It is essential for the interpretation of pollen diagrams to obtain a picture of the present pollen rain over the type of vegetation found in a region. The available recent pollen data for the study areas are discussed in Chapters (6 to 8). Indicator values for only the main pollen types recorded at the Clarens, Florisbad and Blydefontein sites are given in Table 4.1 and are discussed below. Details of pollen indicator values in southern and East Africa are discussed in Coetzee (1967) and Scott (1982a).

Poaceae

Grasses are found in abundance in grasslands and in the savanna. These are species that require moisture in summer and spring, during their growing season. Therefore, their high numbers in the pollen spectra are usually associated with summer rains. Grasses are wind pollinated and thus produce a lot of pollen grains, so their low numbers in the pollen spectra could indicate their absence in a vegetation. Grasses may occur locally, for example, *Phragmites communis*, and also as part of the regional vegetation, unfortunately it is usually not possible to distinguish between pollen of the different grass genera. This makes it difficult to differentiate between the local and regional elements; when dealing with fossil pollen and therefore other components of the pollen spectra should help in interpreting the composition of the past vegetation. Pollen of this type is found in abundance in the fossil pollen spectra of Clarens, Florisbad and Blydefontein.

Asteraceae (undifferentiated)

This family is an important component of Karoo, grassland and fynbos vegetation, but generally represents a wide variety of habitats. Asteraceae/Poaceae ratio may be used to assess the dryness of the veld as suggested by Coetzee (1967), where values higher than 30% are indicated to mean karroid conditions. Asteraceae abundance in grassland pollen spectra usually indicates even distribution of seasonal moisture or more winter rains. The Asteraceae pollen types dominate the fossil pollen spectra of all of the sites under study.

Artemisia

Artemisia falls within the Asteraceae family. There are only 3 species of *Artemisia* that occur in South Africa, but *A. afra* is the most common and is found in a wide variety of habitats. Coetzee (1967) found that the abundance of *A. afra* in fossil pollen spectra at high altitudes could indicate cold, dry conditions, especially if the rest of the spectrum also points to such conditions. Pollen of this species is prominent in the fossil pollen spectra of Blydefontein. Unlike *Artemisia* species in the northern hemisphere, in South Africa, *A. afra* in fossil sequences is taken to indicate sub-humid local conditions, especially when found in relatively dry surroundings (Scott, 1982a).

Anthospermum

Anthospermum has 25 species that are widespread in South Africa, including ericoid types and herbaceuos perennials (Scott, 1982a). *A. rigidum* is the most widespread species that is found in the grassland. Pollen of *Anthospermum* is prominent in the Blydefontein fossil pollen spectra and according to Coetzee (1967) when found at high altitudes, as in the East African Mountains, could support evidence for cold and dry conditions when it occurs in association with pollen that indicates the same conditions.

Chenopodiaceae and Amaranthaceae (Cheno/Ams)

Cheno/Ams are typical components of the vegetation of dry regions such as the Karoo. They are halophytes and are therefore adapted to saline habitats, like saltpans, where they may dominate the local vegetation during periods of strong evaporation. This pollen type is prominent in some Holocene spectra of Florisbad and Blydefontein.

Cyperaceae

These species are semi-aquatics that are usually part of a swamp, shallow water or damp soil vegetation. Cyperaceae normally occur in the fossil pollen spectra representing relatively humid conditions and this in turn points to the existence of a local swamp, especially when other swamp elements are present. This pollen is an important part of the Holocene pollen spectra of all the 3 sites.

Apiceae

The Apiaceae pollen grains that are encountered in the current sites are assumed to represent semi-aquatics, that is, they occur in similar types of vegetation as the Cyperaceae. These pollen grains occur in abundance in the Florisbad fossil pollen spectra, although Apiaceae are not part of the current vegetation nor are they present in the surface pollen spectra of Florisbad. In the mountainous Clarens area, they may represent the arboreal form *Heteromorpha arborescens*.

Trilete Spores (Anthoceros, Pellaea-type and Pteridophyta)

These ferns represent the Pteridophyta species and liverworts species like *Anthoceros*. The significance of high numbers of these fossil spores in especially the Elim site at Clarens is uncertain as no pteridophytes are noted in the current channels where the samples were taken. They may however, be semi-aquatics that occur in moist soil and shallow water. Some Pteridophyta species are often found between rock crevices. Where these robust spores such as *Pellaea*-type dominate the pollen spectra, together with other large spores or pollen grains like *Mohria*, selective preservation may be considered as a reason for their abundance. The possibility of this kind of selective preservation has been discussed in detail by Scott (1999a, b) in pollen spectra from the Pretoria Saltpan (Tswaing Crater).

Table 4.1. Indicator Values of the Main Pollen Groups.

Pollen Type	Vegetation	Environment
Poaceae	Grassland	Regional humid conditions / summer rains
Asteraceae	Shrubland	Dry, karroid veld / less summer rains
Artemisia	Shrubs on sandy areas	Local sub-humid conditions
Anthospermum		Cold / Dry conditions?
Cheno/Am *	Halophytes	Dry / saline conditions – strong evaporation
Cyperaceae	Semi-aquatics	Local swamp, shallow water / damp soil
Apiaceae		Local swamp?
Trilete spores		Local swamp / selective preservation

Mohria	Montane grassland	Cool, relatively moist highveld conditions

* Chenopodiaceae and Amaranthaceae

Exotic Pollen

Pollen grains of *Cuppressaceae, Callitriche, Platanus, Pinus*, *Eucalyptus* and other species that are not indigenous to South Africa, when found in fossil samples usually indicate some form of contamination of the sediments, as in the case of Lichtenburg.

CHAPTER 5

LICHTENBURG

The sequence from the Blydeville Squatter Camp in Lichtenburg will not be considered in the palaeo-environmental reconstruction that follows due to low pollen counts and apparent contamination of the sequence. A total of 26 samples were recovered, but eventually only 11 were used in the pollen diagram construction (Fig. 5.1).

This peat has a bottom date of 5530 ± 50 yr BP (Pta-7272) and gives negative evidence. It shows that at some stage in the past fossil pollen was destroyed through dessication and aeration or burning. Several cases where peats or sediments were found to be without pollen were reported in the past. For instance, Beaumont *et al.* (1984) describe a peat from Kathu Pan where the older layers were barren of pollen, but the younger ones had pollen. Therefore, it was suspected that either burning or aeration might have caused the disappearance of the older pollen.

In this case though, it seems that low concentrations of pollen of a very young age entered the barren sediments. The presence of pollen of *Cuppressaceae, Callitriche* and *Platanus* in high numbers indicated that the samples were contaminated, as these species are all exotics and only reached South Africa during the last century or so. Other samples that did not contain the exotic pollen had very low pollen counts and therefore could not be used in the construction of a pollen diagram.

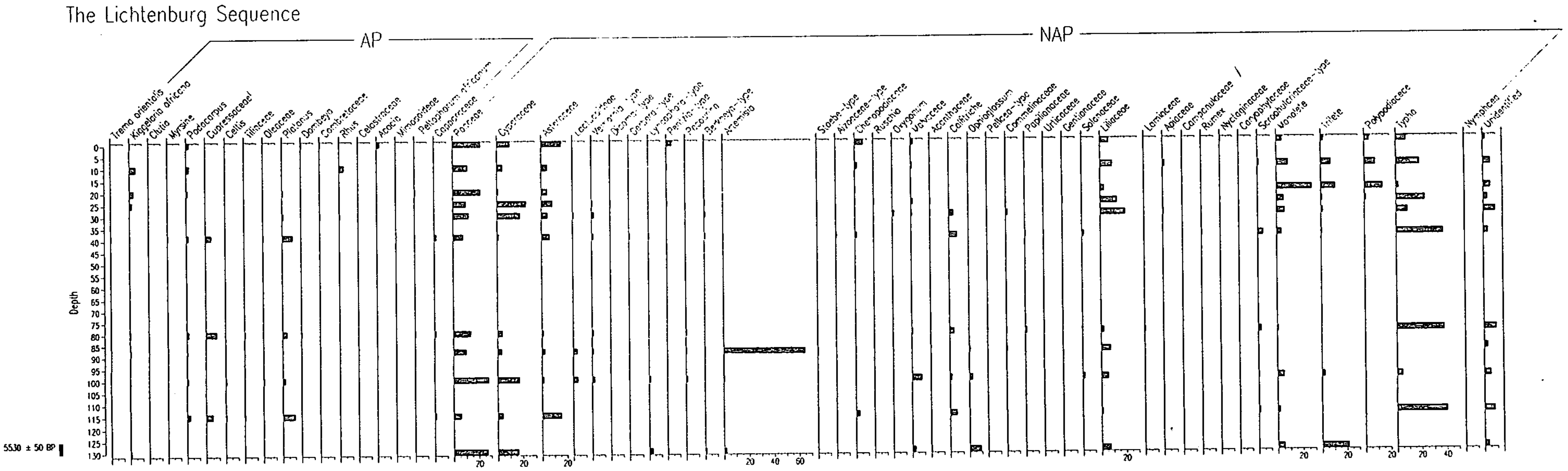

Figure 5.1 Pollen diagram of samples from Lichtenburg

CHAPTER 6

ELIM (CLARENS)

The Physiography of Clarens

The Elim farm near Clarens (Fig. 6.1) is at an altitude of about 1750m (Scott, 1989). The geology is one of a bedrock of sandstone of the Clarens Formation which was formely known as the Cave Sandstone and it represents the youngest sedimentary accumulation in the Karoo basin area (du Preez, 1991). This striking Formation consists of thick layers of yellowish sandstone of aeolian origin. It has characteristic and massive vertical cliffs and consists of fine to medium grained sandstone. Narrow gorges in this formation were formed by the relatively rapid weathering of the dolerite dykes (du Preez, 1992). The Clarens Formation is approximately 195-200 million years old.

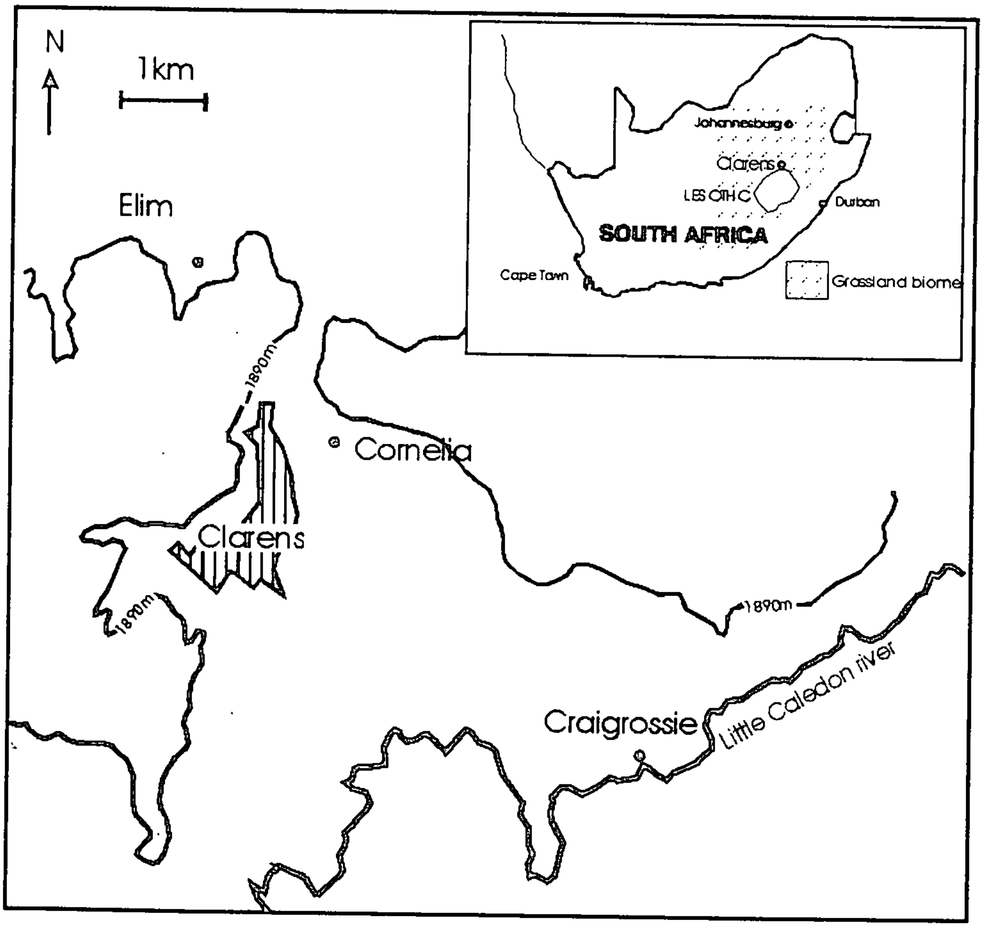

Figure 6.1. Locality map of Clarens showing the studied sites.

In the mountainous eastern parts lithosols with basic rocks are widespread, but lithosols with arenaceous sediments and black montmorrilonitic clays also occur (Harmse, 1978 in du Preeez & Bredenkamp, 1991). Soils of the Clarens Formation are freely drained, yellow and red soils, with a high base status and without water tables (Land Type Survey Staff, 1984). The soil forms which evolved from the Clarens Formation are Mispah, Glenrosa, Hutton, Avalon, Clovelly, Inanda, Maqwa, Griffin, Fernwood and Estcourt (du Preez, 1991).

The Climate of Clarens (Elim)

The topography and more especially, the nearness to the southern mountain ranges (Drakensberg and Maluti Mountains) influence the climate in this region. The region where Clarens occurs is represented within Region H of Schulze's (1984) climates of

In this region the average annual precipitation varies from 900mm in the eastern

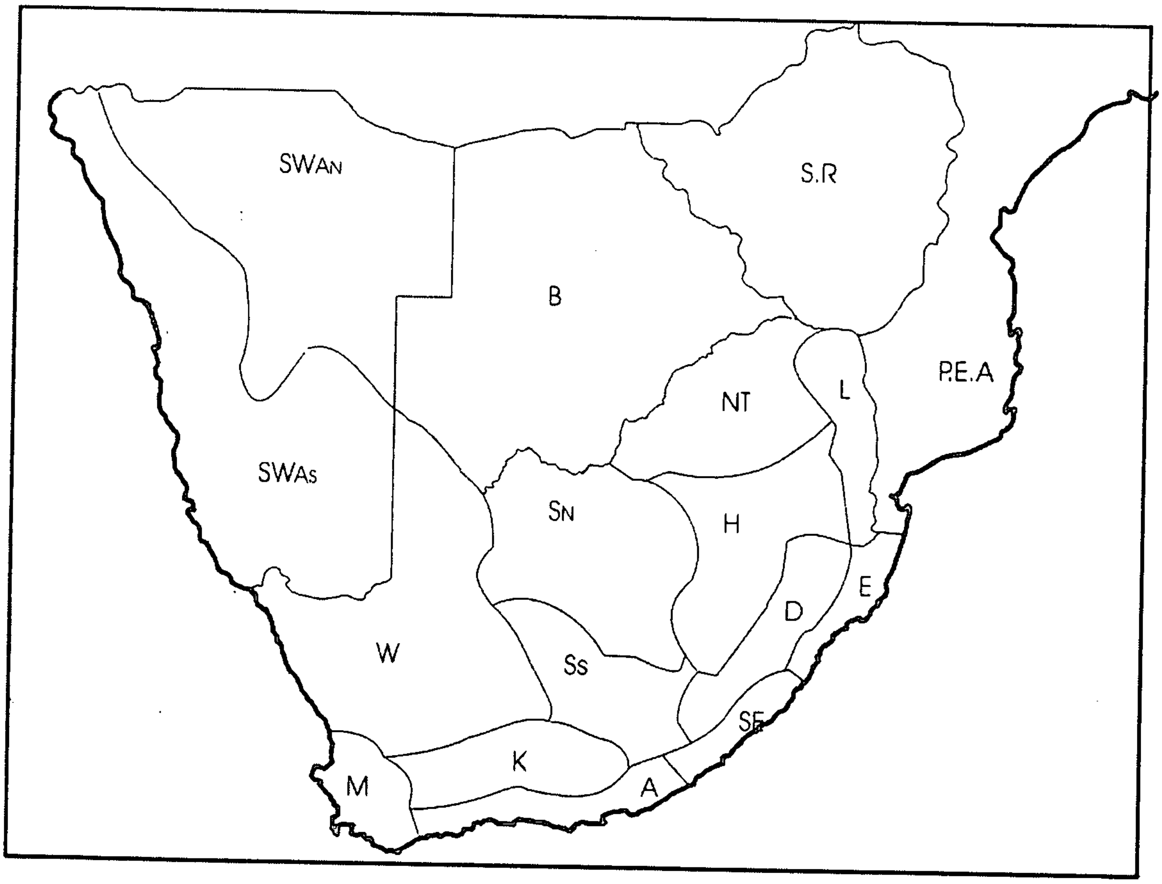

Figure 6.2. Map of Schulze's climatic regions from Schulze (1984).

parts to about 650mm to the west. Precipitation is mainly due to showers and thunderstorms in summer, usually from March to October with maximum rains in January. Thunderstorms are often violent with severe lightning and southwesterly winds and are sometimes accompanied by hail. Winter months are normally dry with less than 15% of rain, while frost may last from May to September. Snow may fall about 8 times during winter months in the Maluti Mountains.

The average daily maximum temperature is 27 °C in January and 17 °C in July, with extremes of 38 °C and 26 °C, respectively. The average daily minimum temperatures are 13 °C in January and 0 °C in July with extremes of 1 °C and -13 °C, respectively.

The Vegetation of Clarens

Clarens is found in the Eastern inland plateau floristic region where land type and soil type have a lesser influence on the vegetation distribution than terrain and associated soil depth, soil moisture, rockiness and grazing (O' Connor & Bredenkamp, 1997).

Within the Eastern Inland Plateau, there are several grasslands and Clarens is found in the *Themeda triandra - Eragrostis plana* moist grassland (du Preez & Bredenkamp, 1991) and the *Aristida junciformis - Eragrostis plana* (O' Connor & Bredenkamp, 1997). Extensive areas of this grassland are ploughed and the natural vegetation is limited to non-arable, shallow soils. *Themeda triandra* is dominant but due to overgrazing, the vegetation has deteriorated to variations where *Elionurus muticus, Aristida junciforms, Eragrostis chloromelas and Eragrostis plana* dominate.

According to Acocks (1988), the vegetation of Clarens belongs to the northeastern Sandy Highveld, which corresponds to the *Cymbopogon - Themeda* Veld to Highland Sourveld Transition and the Highland Sourveld southwards, but has a strong Bankenveld affinity. This vegetation was re-classified as the Moist Cold Highveld Grassland by Bredenkamp *et al.* (1996). This is a dense grassland where *Cymbopogon plurinodis, Themeda triandra, Setaria sphacelata, Elionurus muticus* and *Eragrostis curvula* dominate. Forbs such as *Anthospermum rigidum, Helichrysum rugulosum, Hermannia geniculata, Senecio erubescens, Conyza podocephala* and *Berkheya* species are prominent. Karoo bushes, *Pentzia globosa* and *Felicia muricata* have invaded the grassland in some areas.

The vegetation of Clarens is dominated by grasses, but on south facing slopes and protected ravines, montane woodland with dense growths of shrubs and trees are found (Scott, 1989; Carrion *et al.*, 1999). Woody plants on north facing slopes, like at the Elim farm are scattered, including species such as *Buddleja salviifolia, Leucosidea sericea, Clutia pulchella and Maytenus heterophylla* occur here. On mountain tops and at relatively high altitudes a shrubby ericoid component is found.

Figure 6.3. The modern vegetation around the Elim site.

The Modern Pollen Spectra

Scott (1989) studied the surface pollen rain of Clarens and surrounding areas of Natal and Lesotho. The author also took a surface sample (sample 2331) by scraping soil at different points, from and near the site in order to compare the present pollen spectra with the fossil spectra. Pollen percentages of the most abundant species in sample 2331 are shown in Fig. 6.4, where Poaceae pollen is very prominent and makes up 15% of the total pollen spectra. Scott (1989) also found out that grasses generally make up the most important component of the pollen spectra. This abundance of grasses is to be expected as the study area occurs in a grassland. Although from the recently collected surface sample 2331, (Fig. 6.4) Asteraceae pollen including *Artemisia*, *Pentzia*, *Elytropappus* or *Stoebe* type and others are almost 3% higher than the Poaceae, at 18% of the total pollen spectra. The higher percentage of Asteraceae could be an indication of local overgrazing, coupled with the fact that sampling in this site occurred during Autumn and Winter, when grasses are not in their growing season.

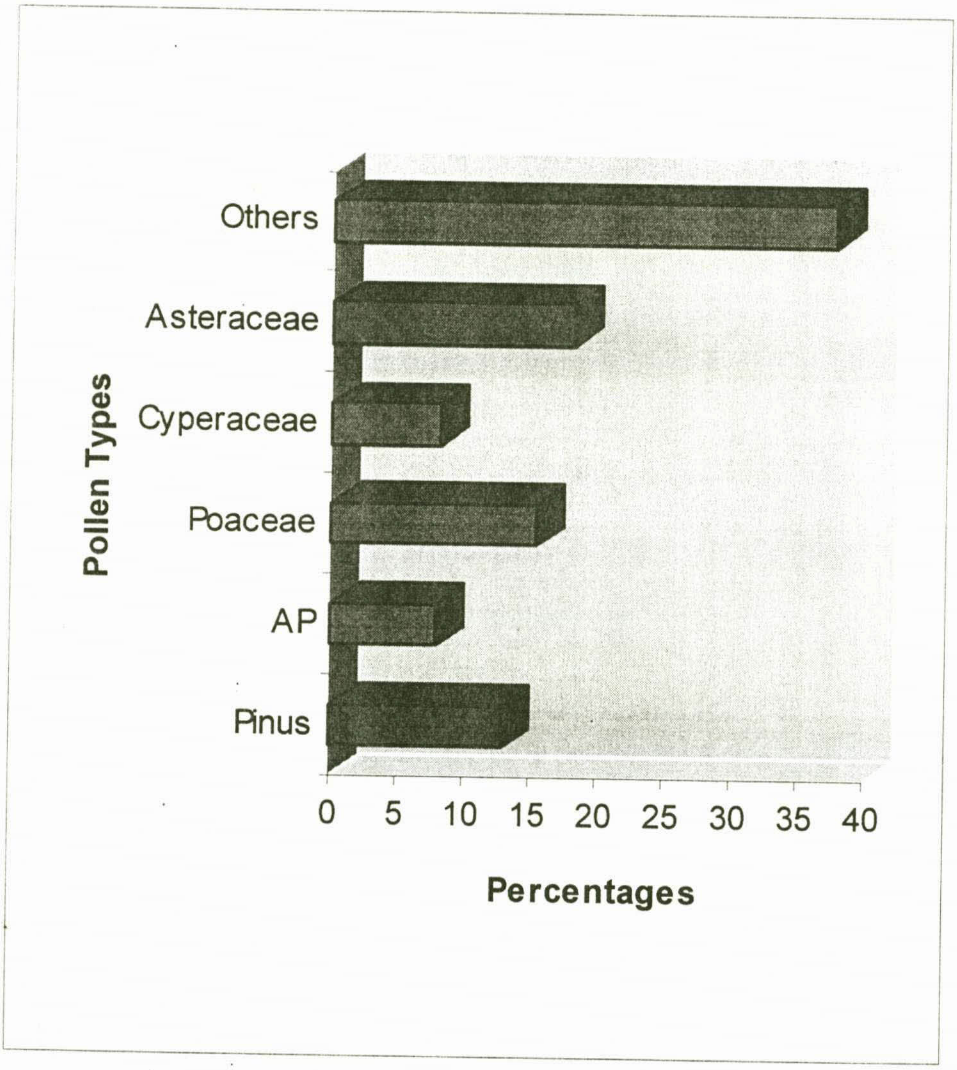

Figure 6.4. The surface pollen sample 2331, showing percentages of the different pollen types.

Arboreal pollen is also present in the sample (2331), at about 6% (excluding the Pinus) of the total pollen spectra, with pollen of *Celtis*, *Grewia*, Celastraceae, *Rhus*, Rhamnaceae, *Acacia* and *Tarchonanthus*. These arboreal species occur on the slopes above and around the site. The *Pinus* and Myrtaceae trees are exotic species that are very common in Clarens and they are found throughout the village. The *Pinus* pollen amounts to about 13% and Myrtaceae 4% of the total spectra. Other species that occur around the site include, the Chenopodiaceae/Amaranthaceae (typical of disturbed areas) at 4%, Ericaceae, Thymeleaceae and *Anthospermum* which are common in cool, high altitude areas such as Clarens, together with Aizoaceae, *Aloe*-type and Malvaceae in low counts. Swamp elements also occur, the ferns and bryophytes being the most prominent at about 22% and the Cyperaceae at 8%.

An interesting observation is the absence of pollen taxa of *Clutia*, *Leucosidea* and *Maytenus* in the surface sample (2331) as these trees, although widely scattered, currently occur near and around the site. The absence of pollen of such taxa from the sample may due to the fact that only one sample was recovered, resulting in a biased selection of pollen or as Carrion *et al.* (1999) note, these species usually have a minor representation in the regional surface spectra. Further the site is on a northern slope, while these plants are more abundant on the southern slopes where Scott's (1989) samples were taken.

The results from Scott's (1989) surface pollen survey of the study area show that generally, from the 12 samples taken in the wider region, including the Drakensberg, Poaceae, Cyperaceae, Ericaceae and *Podocarpus* showed high peaks at different sites and thus reflect the vegetation at these localities. Poaceae is an important factor of the spectra, Ericaceae and other fynbos elements seem reletively important in high-altitude sites. Cyperaceae dominates in swamps and is also found on some slopes above 2000m. Asteraceae pollen was found to be especially prominent at 1920m near Clarens, this is likely a result of overgrazing.

The Deposit

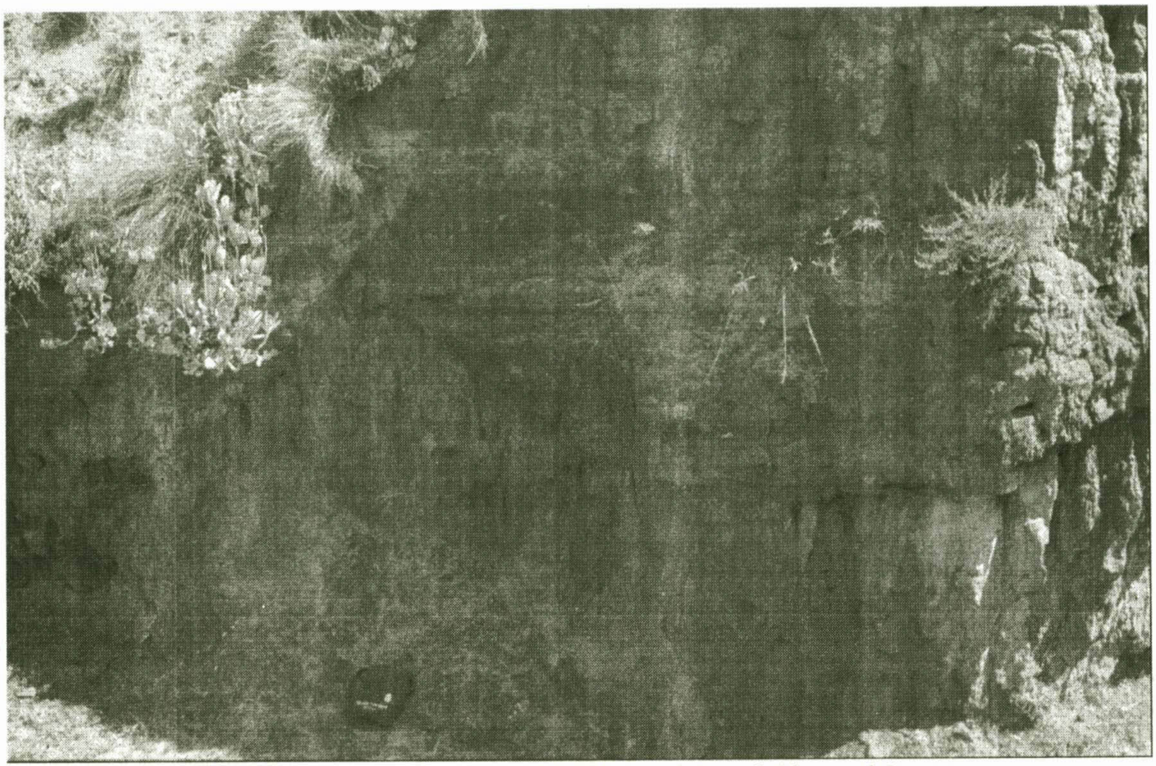

Figure 6.5. The Elim swamp sediments with Channel 1 and Channel 2.

Scott (1989) studied deposits from the Clarens area, from Elim, Cornelia and Craigrossie-see Fig 6.1. The lower, late Pleistocene, unit of the Elim deposit was described by Visser *et al.*, (1986) and Scott (1989). The oldest radiocarbon date of sediments from the three swamp sites is 23 400 yr BP (at Elim), but they all contain samples of Holocene age, although none gave a complete Holocene sequence. The Elim deposit studied by Scott (1989) is some meters away from the current site, which is of Holocene age and shows a completely different statigraphy.

The samples from the Elim site were collected from deposits that seem to represent two adjacent channel-fills (Channel 1 and Channel 2), resulting from cut-and-fill cycles in the sediments (see Figs. 6.5 and 6.6). It appears that Channel 2 is the youngest as it was partly cut into the sediments of Channel 1. The deepest deposit on which the Channel 1 sequence is resting, between 417cm and 381cm is a grey, fine silty sand, with orange mottle. This part of the sequence is barren of pollen and has root channels that may have enhanced oxidation of the sediments. The base of the Channel 1 fill begins with organic, dark-coloured silt with lighter streaks of sandy material occurring between 380cm and 364cm. Overlying the silt are two thin layers between 364cm and 346cm, the first a greyish, fine sand and the other a dark organic silt. Greyish sandy.sediments cover the interval between 346cm and 310cm and these are overlain by a sandier light grey layer up to 250cm. A dark grey sediment with streaks of red and light grey layers appears *ca.* 250cm and 180cm, followed by an orange mottled layer, up till 150cm. The orange and reddish colour of the sequence indicates that the sediments were oxidised and might not contain pollen, as is the case here. Overlying the barren part, a grey layer of compact sand, that is sterile stretches up to the surface of the sequence.

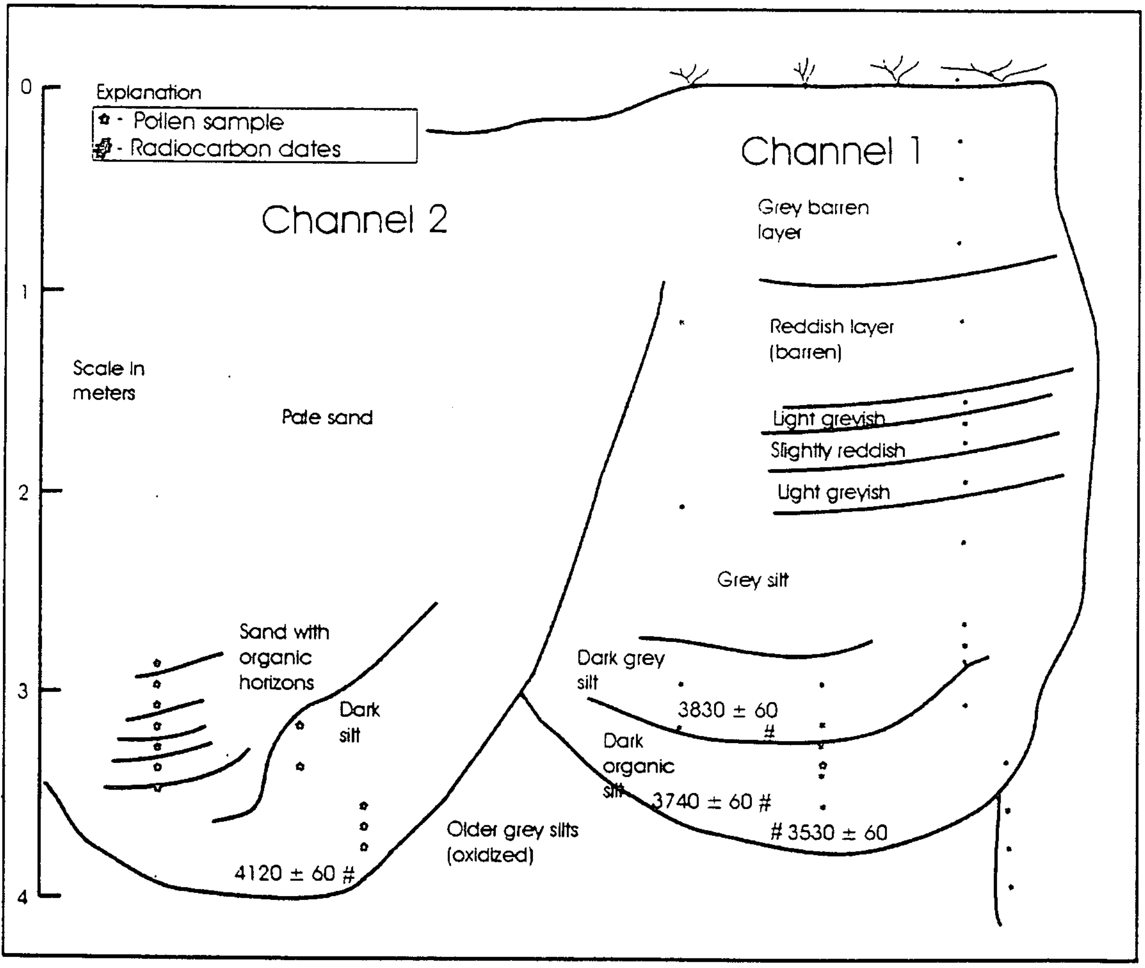

Figure 6.6 Profile of the Elim swamp deposits.

The Channel 2 sequence ranges from 380cm to 255cm. The deepest part of the deposit, between 380cm and 330cm is a dark silty sand, overlain by white stratified sands and above this, grey sand (Fig. 6.6). To the left of the grey sand, *ca.* 310cm, a series of about seven thin layers of dark organic silts occur within light grey sand up to 255cm of the sequence. Above the grey sand with organic horizons, a deposit of pale sand occurs and this was not sampled due to a lack of organic contents.

The basal layers of the sediments from the two sequences were dated between 4120 ± 60 and 3530 ± 60 yr BP, by means of radiocarbon measurements. The rest of the deposits were not rich enough in organics for dating. These dates are problematic, as they are not in chronological order (see Table 6.1, Fig. 6.7). The precise relationship of the lower part of Channel 2 with the lower sediments of Channel 1 could therefore not be clarified. The results of the dating and pollen analyses (Fig. 6.9) suggest that the lower intervals of this sequence were either not dissected and is of the same age as in Channel 1 or the basal channels contain reworked organic material from a similar source higher up in the swampy system. Root contamination of the sediments is another possibility, but no younger rootlets were observed in these levels.

Table 6.1. Radiocarbon dates from the Elim site.

Anal. No Pta-	Sample Designation	Depth (cm)	Radiocarbon Age (yrs BP)
7756	2307 (channel 1)	335-340	3830 ± 60
7754	2306 (channel 1)	371	3740 ± 60
5887	1377 (channel 1)	381	3530 ± 60
7772	2305 (channel 2)	380	4120 ± 66

The Pollen Diagram Descriptions and Interpretations

Pollen diagrams were constructed for the two sequences (Figs. 6.7 - 6.10). The procedure for the construction of pollen diagrams is discussed in Chapter 3.

Elim Channel 1 - Sequence

The pollen diagram (Fig. 6.7) has 63 pollen types, including the unidentified pollen grains. Three pollen assemblage zones, C1, C2 and C3 were distinguished for Channel 1. Prominent pollen in the total spectra are the Poaceae, Cyperaceae, Asteraceae, *Mohria* and the trilete spores. The trilete spores (including spores like the *Pellaea*-type other Pteridophyta and *Anthoceros*) are the most abundant and prominent in the first two zones (C1 and C2). The depth of this channel ranges from 160cm to 390cm. According to available C14 dates the oldest sample is 3830 ± 60 yr BP between 335 and 340cm, followed by 3740 ± 60 yr BP at 371cm and 3530 ± 60 yr BP at 381cm.

The pollen concentration values for each sample in both channels were calculated and are given as grains per gram of sample. Table 6.2. gives the concentration for samples from Channel 1. The pollen concentrations were relatively low, as the maximum content is 7.4 x 10^3 g $^{-1}$ for sample 2321. The low pollen concentrations are consistent with the contention that pollen destruction and selective preservation took place.

Table 6.2. Pollen concentrations values for Channel 1.

Sample no	Depth (cm)	Grains g $^{-1}$
2315	160	8.2 x 10^1
2314	170	1 x 10^1
2312	210	2.3 x 10^2
2291	235	5.4 x 10^2
2311	242	2 x 10^3
2310	256	7.8 x 10^2
2309	270	4.9 x 10^2
2292	305	2.3 x 10^1
2308	310	6 x 10^2
2294	319	3.3 x 10^1
2293	324	3.8 x 10^1

2295	332	1.9×10^3
2296	345	5×10^1
2307	350	4.2×10^1
2297	355	7.6×10^3
2298	364	3.5×10^2
2299	371	2.3×10^3
2306	381	4.8×10^3

ZONE C1

This zone, which is the deepest, covers the interval between 381cm and 315cm in the sequence. All the dates obtained for channel 1 (3830 ± 60 yr BP, 3740 ± 60 yr BP and 3530 ± 60 yr BP) are from this zone.

The Pollen and Spore Composition

The AP (arboreal pollen) is very low in this zone, only about 6% of the pollen sum. The AP consists of pollen of *Podocarpus,* Celastraceae, *Croton, Protea, Olea*, *Rhus,* Rhamnaceae, *Euclea* and *Tarchonanthus.* The other NAP (non arboreal pollen) reaches a total of 77% of the pollen sum and it comprises pollen of the undifferentiated Asteraceae, *Mohria*, S*elaginella* and *Anthospermum* as the prominent types. The other NAP also includes, the fynbos elements (Ericaceae, *Passerina*, *Cliffortia* and Thymeleaceae), *Pacourina*, *Pentzia*-type, *Artemisia* and *Stoebe*-type together with Cheno/Amaranthaceae, Aizoaceae-type, *Oxygonum*, *Aloe*-type and others that occur in smaller numbers. Pollen of the Poaceae makes up only about 16% of the pollen sum.

The local palynomorphs together add up to 57% of the total pollen spectra. The trilete spores are the most abundant, followed by *Ophioglossum* and Cyperaceae pollen Other local elements are present, but hardly reach a fraction of the total spectra.

Interpretation

The low percentage of AP may be an indication that the tree cover was relatively open near the site like at present, and were restricted to the nearby mountain slopes and ravines. It may also be that climatic conditions, may be, the occurrence of frost, were not conducive to the growth of arboreal types. The vegetation near the site was an open karroid grassland with small shrubs and herbs. This vegetation comprised Asteraceae, including *Pentzia*-type, *Artemisia* and others with *Anthospermum*, Thymeleaceae, *Mohria*, Ericaceae, Aizoaceae-type and *Selaginella*. The pollen composition suggests that zone C1 represented a relatively dry period.

Within the swamp environment, ferns and liverworts, such as Pteridophyta, *Anthoceros* and others occurred in abundance, although they are currently not well represented in the vegetation. The reason for the abundance of the trilete spores may be that selective preservation occurred and the large and robust pollen grains and spores, such as *Mohria*, *Selaginella*, *Ophioglossum*, and the Pteridophyta triletes survived, while the others were destroyed (see Figs. 6.7 and 6.8). Cyperaceae must have been common in this vegetation, as it is in the current streambed. The presence of swamp elements indicates local wet conditions in relatively dry surroundings.

ZONE C2

This zone covers the interval between 315cm and 222cm. No radiocarbon dates were obtained for this zone.

The Pollen and Spore Composition

This zone includes a large gap between 300cm and 270cm, where no pollen occurs in the sediments. The AP is still constant at about 6% as in the previous zone. The pollen of *Tarchonanthus* is still the most abundant of the AP (Fig. 6.6). Pollen of *Croton*, *Olea*, and Rhamnaceae disappear completely, while the ones that are still present occur in small numbers. The NAP is constant at about 76% of the pollen sum. Pollen of the undifferentiated Asteraceae, *Artemisia, Stoebe*-type, Thymeleaceae, Ericaceae increase, while that of the *Anthospermum* remains constant. The spores *Selaginella* drop markedly, while *Mohria* and the *Aloe*-type reach their highest peaks (Fig 6.7). Poaceae pollen content is similar to that in zone C1, at 18% of the pollen sum.

The prominent trilete spores and Cyperaceae pollen drop, although all the other local pollen types, including *Ophioglossum* remain constant at very low values.

Interpretation

The type of vegetation that occurs in this zone is similar to that of zone C1. Arboreal pollen still has low percentages, the NAP types are abundant and the grass composition is still low. The vegetation that occurred during this period was a relatively dry grassland with karroid shrubs and herbs. *Tarchonanthus*, which is currently not a prominent species in this vegetation, probably occurred on rocky slopes above the swamp. The fynbos elements, Thymeleaceae (other) and Ericaceae were well developed in the vegetation during this time. The increase in the number of fynbos elements could indicate relatively cooler conditions. The trilete spores were still the most abundant palynomorphs in the swamp deposits.

The presence of a swamp suggests a moist/damp local environment as in the case of zone C1, although the total swamp size might have been smaller.

ZONE C3

This is the topmost zone of channel 1 and it covers samples that occur between the interval 160cm and 222cm. No dates were obtained for this zone.

The Pollen and Spore Composition

There is a general increase in the numbers of pollen that make up the pollen sum. There is a slight increase in the AP in this zone, from about 6% in zone B to 10% of the pollen sum. The most abundant pollen of the AP includes *Tarchonanthus,* Celastraceae, *Podocarpus* and *Protea*. Other pollen types occur in smaller values. The NAP drops slightly from 76% to 69% of the pollen sum. The other NAP consists of increased pollen of the undifferentiated Asteraceae, Cheno/Am and Malvaceae as they reach their highest peaks in this zone (Fig). Also included in the NAP are *Lactucoideae, Artemisia, Pentzia*-type, *Stoebe*-type, Thymeleaceae (other), Ericaceae, *Passerina, Anthospermum, Aloe*-type, *and Oxygonum* with Aizoaceae-type pollen totally absent. The spores *Selaginella* and *Mohria* are also present in this zone. These spores seem to have been following a trend similar to that of the trilete spores from zone C1 up till now, as they fluctuate together. Pollen of the Poaceae increases slightly by 3% to 21% of the pollen sum in this zone.

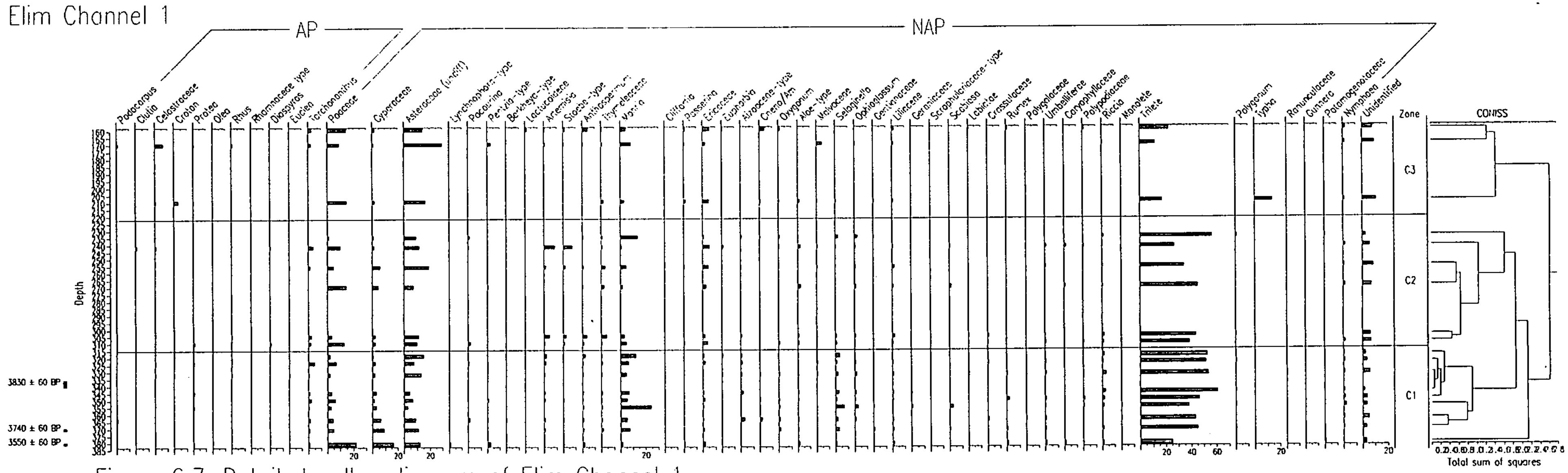

Figure 6.7. Detailed pollen diagram of Elim Channel 1.

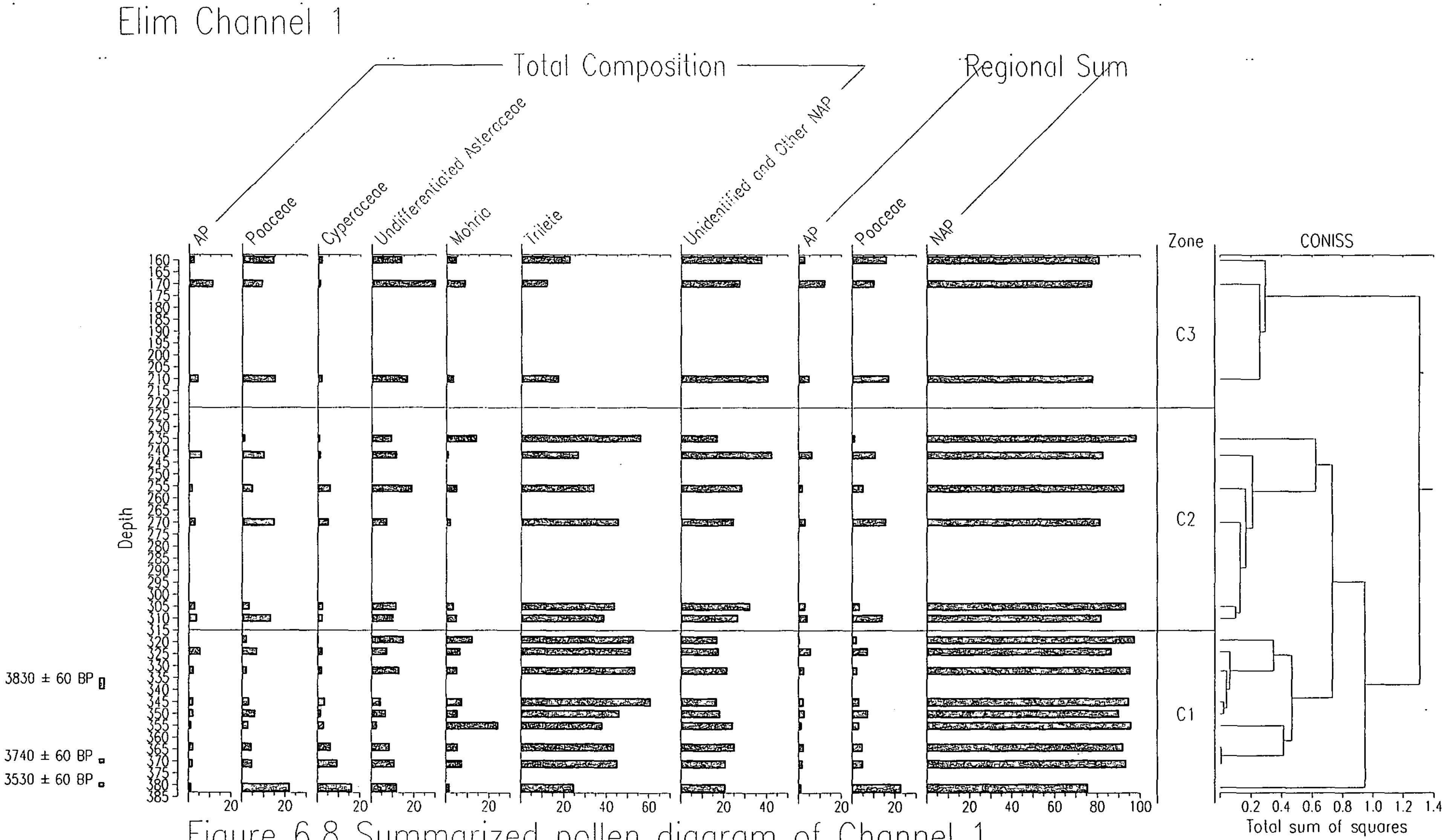

Figure 6.8 Summarized pollen diagram of Channel 1

The local pollen reach their lowest numbers, from 41% to 21%, as the trilete and *Ophiglossum* spores drop markedly, coinciding with the drop in Cyperaceae pollen. The pollen of *Scabiosa*, Polygalaceae, Apiaceae, Labiatae and Polypodiaceae completely disappear. The pollen of *Typha* peaks at 210cm, but is virtually absent in the rest of the sequence. The interval between 210cm and 170cm is barren of pollen.

Interpretation

During the period when this zone was formed, the grass cover was good with some Asteraceae shrubs and herbs, ferns and some fynbos elements in the surroundings. *Typha* species made a brief appearance in the swamp during this period, indicating local humidity or open water. Later, conditions changed as Asteraceae became dominant in the grassveld and the Cheno/Am and Malvaceae appeared. The vegetation changed again, towards the end of the zone to one where there was a balance between the Asteraceae and the grasses.

The beginning of this zone seems to represent wetter conditions, than the upper part that suggests a change to warmer and drier conditions. Later, the climate improved and became slightly humid. This latter period seems to have been relatively cool as indicated by the high numbers of fynbos elements.

Elim Channel 2 - Sequence

The pollen diagram (Fig. 6.8) constitutes 60 pollen types and covers the interval between 381 and 255cm. Four pollen assemblage zones C4, C5, C6 and C7 were distinguished from which interpretations of regional and local vegetation changes can be derived. Only one radiocarbon date of 4120 ± 60 yr BP, at 380cm was obtained for this channel.

Table 6.3. gives the pollen concentration for samples from Channel 2. The pollen content for Channel 2 is almost like that of Channel 1, the maximum concentration per gram is 7.6 x 10^3 for sample 2297.

Table 6.3. Pollen concentration values for Channel 2.

Sample no	Depth (cm)	Grains g $^{-1}$
2331	0	4.6×10^2
2330	257	4.1×10^1
2329	267	1.7×10^3
2327	281	3.9×10^2
2326	289	1.9×10^2
2325	302	3.8×10^2
2323	320	1.5×10^2
2324	330	4.8×10^3
2322	340	3.1×10^1
2321	360	7.4×10^3
2320	370	1.1×10^3
2305	380	2.7×10^1

ZONE C4

This is the deepest zone of Channel 2 and it comprises 3 samples covering the interval between 380cm and 350cm. The date of 4120 ± 60 yr BP was obtained from this zone.

The Pollen and Spore Composition

The AP makes up approximately 7% of the pollen sum. The AP includes *Tarchonanthus*, *Podocarpus* and *Protea*. The other NAP is the most abundant type in the pollen sum, at 65%. The non-arboreal pollen constitutes pollen of the undifferentiated Asteraceae, *Pentzia*-type, *Stoebe*-type, Ericaceae, Thymeleaceae (other), *Passerina*, *Anthospermum*, *Aloe*-type, *Euphorbia* and others that occur in smaller numbers. The spores, *Mohria*, *Selaginella* show an increase in their numbers. Poaceae pollen makes about 28% of the pollen sum.

Pollen of the local flora is quite abundant at nearly 57% of the total spectra. The local pollen includes dominant trilete spores, some Cyperaceae, *Ophioglossum*, *Typha* and a lot of other types that occur in smaller numbers.

Interpretation

The vegetation and conditions that prevailed during this time must have been similar to those of zone C1 as the pollen spectra of these two zones are similar, except for the slight increase in grasses, the Pteridophyta, *Anthoceros* and *Pellaea*-type ferns were still over-represented.

ZONE C5

This zone comprises 3 samples that were lying in between layers of grey sand as dark horizons. It covers the interval between 350cm and 307cm of the sequence and no dates are available for this zone.

The Pollen and Spore Composition

The AP shows a slight drop from 7% in the previous zone to 5% of the pollen sum, in this zone. The AP is now composed of *Celtis*, *Tarchonanthus,* Celastraceae, *Protea* and *Olea*. *Podocarpus* pollen has completely disappeared. The other NAP makes up about 60% of the pollen sum and it is mostly comprised of the undifferentiated Asteraceae. Also included in the NAP (other) are pollen of the *Pentzia*-type, *Artemisia Anthospermum*, *Aloe*-type, Cheno/Am, Thymeleaceae (other), Ericaceae, *Mohria* and *Selaginella*. Poaceae pollen increases from 28% in the last zone, to 34% of the pollen sum in this zone.

The numbers of the local elements drop markedly, from 57% in zone C4 to *ca.* 23% in this zone. All of the locals including the trilete spores seem to have declined, except for the Cyperaceae, which show a huge increase in this zone.

Interpretation

The low AP percentages could indicate that arboreal types such as *Celtis*, *Protea*, *Olea*, Celastraceae, and *Tarchonanthus* did not occur near the site, but occurred some distance away.

This zone was formed during a dry phase, when a karroid vegetation occurred (see Fig. 6.8). Later on, the climate ameliorated, resulting in the spread of grasses at the expense of the Asteraceae shrubs and herbs. During this period, Cyperaceae sedges dominated the swamp vegetation as they replaced the trilete spores. This change in vegetation indicates that climatic conditions changed from relatively dry to sub-humid, during this phase.

ZONE C6

This zone has a high pollen abundance and composition. It covers the interval between 307cm and 272cm.

The Pollen and Spore Composition

The AP constitutes about 6% of the pollen sum and seems to be more diverse in its composition in this zone. The AP is composed of *Podocarpus*, *Celtis*, Celastraceae, *Protea*, *Olea*, *Rhus* and *Tarchonanthus* pollen. The other NAP, reach their lowest peak at about 56% in this zone. The main constituent of the NAP (other) is the undifferentiated Asteraceae with pollen of *Mohria,* Cheno/Am, *Lynchnophora*-type, *Artemisia*, *Euphorbia*, *Aloe*-type and *Selaginella* also represented. The fynbos or macchia elements (*Anthospermum,* other Thymeleaceae, *Passerina* and Ericaceae) are more abundant than in the previous zone. The number of Poaceae pollen has been steadily increasing and now reaches 39% of the pollen sum.

Pollen of the local flora, together makes up 20% of the total pollen spectra. All the swamp elements, including the more prominent types such as, the Cyperaceae and trilete spores decline. The aquatics, Nymphaea and *Typha* each make up a fraction of the total pollen spectra.

Interpretation

The AP values are still low, and may be as suggested earlier, trees could have occurred some distance away from the site. The vegetation of this zone consisted of a dense cover of grasses with some Asteraceae and Cheno/Am shrubs and herbs. Because the fynbos elements, *Anthospermum, Passerina,* Ericaceae and Thymeleaceae were also well developed in this grassy veld, this phase may represent cooler conditions.

Trilete ferns dominated the swamp, as the Cyperaceae had become scarce. The vegetation that occurred during this period points to a relatively wet and cool climate.

ZONE C7

The uppermost zone of Channel 2, consists of only two samples and it covers the interval between 272cm and 255cm of the sequence.

The Pollen and Spore Composition

The AP makes up *ca.* 10% of the pollen sum and it consists of *Tarchonanthus*, Celastraceae, *Diospyros*, *Myrica*, *Podocarpus*, *Grewia*, *Protea, Acacia* and Rhamnaceae. The other NAP reaches 60% of the pollen sum in this zone. The main component of the non arboreal pollen is still pollen of the undifferentiated Asteraceae, as in the previous zones. The pollen types, *Pentzia*-type, *Anthospermum, Oxygonum*, *Aloe*-type, the macchia elements - Thymeleaceae, *Cliffortia* and Ericaceae, and *Selaginella* are also part of the NAP (other). Poaceae pollen makes up 30% of the pollen sum.

The number of the local palynomorphs increases from 20% in the last zone, to about 37% of the total pollen spectra, in this zone. The trilete spores, Cyperaceae, Liliaceae, O*phioglossum* and *Rumex* show a significant increase in this zone. This is the first time in the sequence that the Cyperaceae and trilete spores increase together (see Fig. 6.8), as they have been displacing each other in the previous zones.

Interpretation

The bottom sample of the zone seems to represent a relatively dry phase according to the low species composition in the vegetation and the high Asteraceae to grass pollen ratio, but this is reversed in the top sample.

The increase in AP numbers and composition suggests that conditions were favourable. This was a shrubby, grassy vegetation, in which grasses were dominant. Pteridophyta spores, Cyperaceae and other swamp elements, indicate the presence of a swamp The increase in Cyperaceae coupled with the good grass cover indicates that conditions were relatively wet.

Elim Channel 2

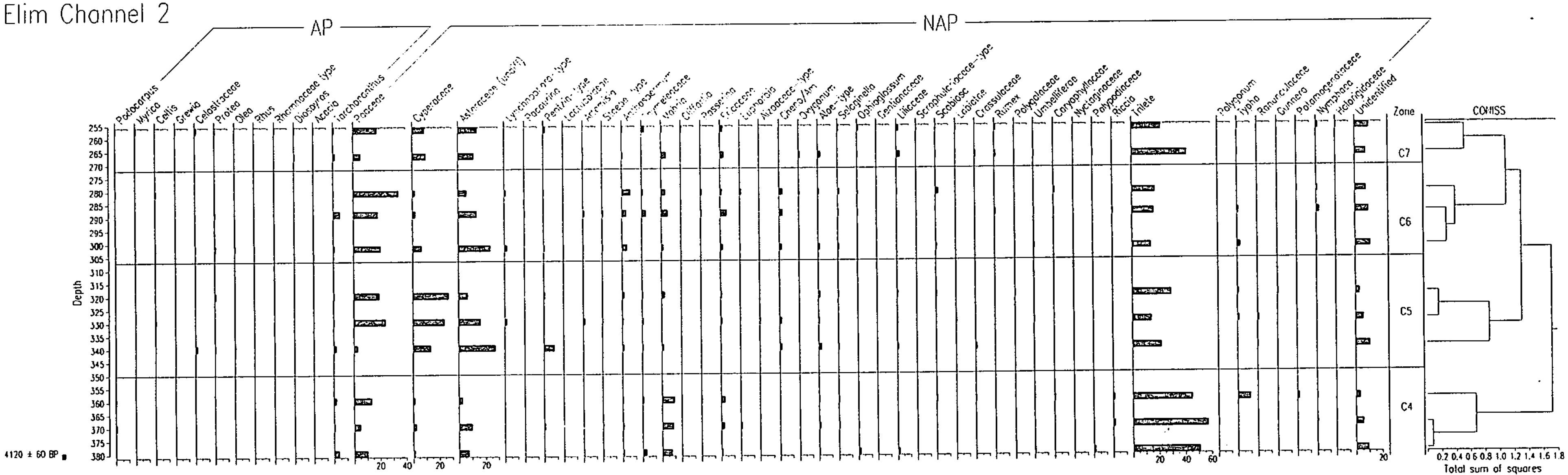

Figure 6.9 Detailed pollen diagram of Elim Channel 2

Elim Channel 2

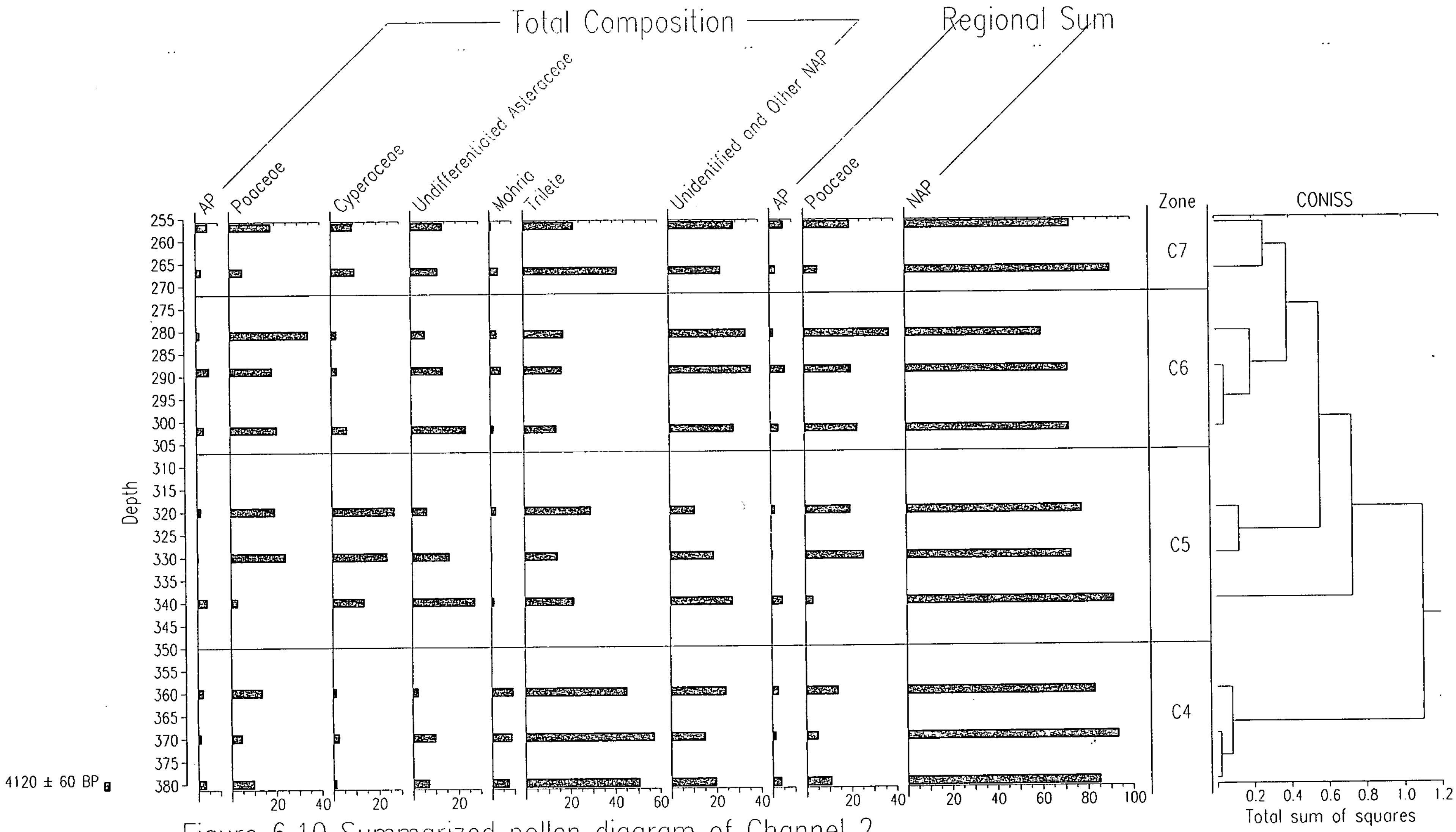

Figure 6.10 Summarized pollen diagram of Channel 2

Summarized Palaeoenvironmental Conclusions

The two channels from Elim show vegetation changes that cannot be well correlated with the dates, as they are chronologically inconsistent. Another problem of interpreting the data from these sequences is the abundance of trilete spores, which either reflects the vegetation at that time or points to harsh environmental conditions especially in the basal zones, that resulted in selective preservation (Scott, 1999a, b). This could have occurred during sediment accumulation or at a later stage. The following Table 6.4 gives a summarized version of the vegetation and climatic changes indicated by the Elim pollen spectra. Provisionally the chronology is based on the available radiocarbon dating, realizing that it is in conflict with the apparent channel morphology.

Table 6.4. Elim: climatic interpretation.

Age (yr BP)	Elim Channel 1&2 pollen zones	Vegetation Type	Interpretation
?	Channel 2: C7	Grassy, shrubby with swamp elements	Relatively humid, drop in summer rains
?	Channel 2: C6	Grassy with fynbos	Sub-humid and cool
?	Channel 2: C5	Grassy, shrubby with swamp elements	Sub-humid with relatively dry episodes
?	Channel 1:C3	Karroid	Relatively dry
< 3830	Channel 1: C2	Open with some shrubs, fynbos and a swamp?	Relatively dry, possibly cool
ca. 4120-3830	Channel 2: C4; Channel 1: C1	Karroid with swamp elements?	Relatively dry

Around 4120 and 3830 yr BP, the vegetation in Clarens seems to have been an open, arid and cool grassland with a swamp containing ferns and liverworts. These conditions are characteristic of the lower units in both channels and are in contrast with zone C5 (Channel 2) and zone C3 (Channel 1). In the latter, the numbers of ferns declined as grasses, shrubs and sedges expanded. Between zone C5 and C7, conditions were sub-humid with dry episodes and only one phase of increased humidity occurred towards the end of zone C6 when a grassy vegetation was found. The end of the Channel 2 sequence shows a change from wet to a relatively dry climate, as grasses are indicated to have declined.

CHAPTER 7

FLORISBAD

The Physiography of Florisbad

The Florisbad site is found in the central Free State and it is situated on the north-western section of the Karoo basin, at an altitude of about 1270m. This site (Fig. 7.1) is located 45km north-northwest of Bloemfontein at 28 46'S, 26 04'E. It is a by-product of a cluster of springs which come to the surface due to fissures formed by a dolerite intrusion in the shale bedrock, which constitutes the geology (Kuman & Clarke, 1986). The shales that make up the geology belong to the Ecca Group and they were deposited in the inland sea which existed in the basin during Permian times. Fluvial sandstone and mudstones of the Beaufort Group cover the Ecca (van Zinderen Bakker, 1989).

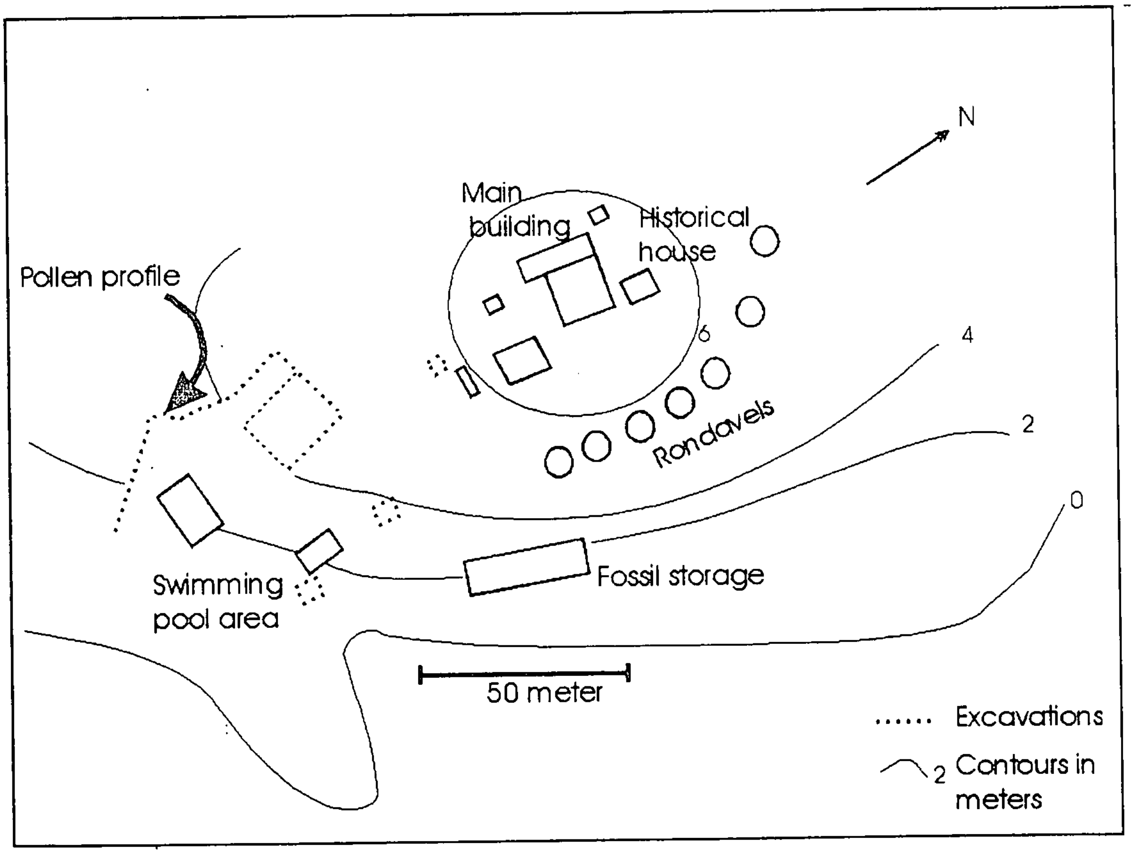

Figure 7.1. Locality of pollen profile in relation to buildings and excavation sites in Florisbad.

The Beaufort Group consists of two sub-groups, where the Tarkastad sub-group has an upper layer - the Bugersdorp Formation that is approximately 220 - 230 million years old. This upper layer consists of red and bluish-grey mudstones with subordinate sandstones and siltstone (Dingle *et al.* in du Preez, 1991). During the Jurassic, dolerite intruded into the superimposed Karoo beds and formed sills and dykes, while subsequent erosion cycles led to the development of pans such as the Soutpan (van Zinderen Bakker, 1989). Lunettes formed on the east-southeastern side of such pans. The Florisbad spring is located in the lunette southeast of the Soutpan (Grobler & Loock, 1988).

Soils in the western Free State are derived from the Upper Beaufort Formation and are typical of areas where the relief varies considerably. The region where Florisbad occurs is of the D-Land Type (Land Type Survey Staff, 1984). The D-Land Type is mostly located in bottomland situations such as in the valleys of the Orange and Vaal Rivers and their tributaries as well as in depressions such as pans (du Preez, 1991). Here duplex soils with gleycutanic, pedocutanic and prismacutanic B -horizons predominate.

The Climate of Florisbad

Florisbad is in Region Sn of Schulze (1984) and this region is hotter and drier than Region H (Fig. 6.2). Region Sn is semi-arid receiving an average of 250mm in the west to 500mm in the east. Rainfall is due to showers and thunderstorms from October to March with the peak of the rainy season in February / March. A maximum of 10 rain days may be expected during the rainy season.

In this region, sunshine hour's amount from 70-80% of the possible duration, even during the cloudy or rainy season. Temperatures are subject to large diurnal and seasonal variations. In January, the average daily maximum temperature lies between 30 °C and 33 °C and in July about 17 °C, whilst extremes of 41 °C and 28 °C, respectively may occur. Average daily minimum temperatures are 15 °C in January and 0 °C in July, while extremes of 3 °C and -11 °C, respectively have occurred.

Winters in Region Sn are cold and dry. When cold fronts from the south affect the area severe frosts occur. The area has about a 100 frost days a year (Schulze, 1984). The prevailing winds are from the northwesterly direction attaining maximum speed in the afternoons.

The Vegetation of Florisbad

Florisbad is situated in the Dry Western Area floristic region, within the *Eragrostis obtusa - Eragrostis lehmaniana* grasslands (O' Connor & Bredenkamp, 1997; du Preez & Bredenkamp, 1991) where differences in geology, topography and associated land type influence plant community distribution. Most of this grassland occurs at 1200 - 1500m, altitude on the flat to gently undulating plains of the high central plateau. Large areas of this grassland have been cultivated, thereby restricting natural vegetation to overgrazed relicts, especially in the northern parts. These grasslands represent the natural climatic climax over most of the Free State (du Preez & Bredenkamp, 1991). The development of woody species is prevented by regular frosts (Acocks, 1988) and fire (du Preez & Bredenkamp, 1991).

The vegetation of Florisbad is part of the Dry *Cymbopogon - Themeda* Veld and is often dominated by the *Themeda triandra* with *Cymbopogon plurinodis* as the tallest, but uncommon grass (Acocks, 1988). This vegetation has been re-classified as the Dry Sandy Highveld Grassland by Bredenkamp and van Rooyen (1996). This grassland merges with the bordering Kalahari Thornveld to the west (Bredenkamp & van Rooyen, 1996) where the *Acacia giraffae* dominates, but the grass cover is about the same composition as that of the Dry *Cymbopogon - Themeda* Veld (Acocks, 1988).

In the Dry Sandy Hghveld Grassland, a few Sweet Thorn *Acacia karroo* trees occur along water courses. Diagnostic grasses include *Eragrostis lehmaniana, E. obtusa, Panicum coloratum* and *Stipagrostis uniplumis* together with the karroid dwarf shrub *Pentzia globosa. Themeda triandra, Eragrostis curvula, E. tricophora, Aristida congesta* and dicotyledonous forbs such as *Dicoma anomala, Anthospermum hispidulum, Acalypha angustata* are also prominent species in this grassland.

The vegetation around the spring site presently includes exotic trees such as *Prosopis juliflora, Pinus* and *Eucalyptus* trees. Some halophytic plants and weeds such as *Salsola glaberescens* may be found with grasses in the vicinity of the spring site

The Modern Pollen Spectra

Modern pollen samples were collected by Coetzee & van Zinderen Bakker (1952) in the southern middle-veld of the Free State and by van Zinderen Bakker (1989) and Cooremans (1989) from areas surrounding Florisbad, in the grassveld, from the vegetation of the adjacent Soutpan and from the aquatic and swamp vegetation. Samples recovered from the surrounding grassveld indicate that grasses dominate (Coetzee & van Zinderen Bakker, 1952), while Asteraceae pollen reaches only ± 12.7%. Arboreal pollen of indigenous species such as *Acacia*, Celastraceae, *Ziziphus, Grewia*, *Diospyros* type, *Euclea, Celtis* and *Olea* reached 0.55 to 7.2%. Samples taken from nearby koppies (low hills) showed *Rhus* species like *R. ciliata* and *R. lancea* to be abundant, reaching about 27.4% (van Zinderen Bakker, 1989) to about 32.6% (Cooremans, 1989), this could be explained by their occurrence on the rocky hills in the grassveld.

The vegetation of the pan consists of a dense cover of *Salsola glabrescens*, as this vegetation is often in a disturbed state because of the exploitation of salt, but it may change to a grassveld with *Diplachne fusca*, during periods when the pan is moist. In the saltbush, Chenopodiaceae/Amaranthaceae pollen may range between 62.3% and 94% (van Zinderen Bakker, 1989; Cooremans, 1989), while Asteraceae reach less than 14% and Poaceae, 19.7%. Arboreal pollen is very rare or totally absent in this type of vegetation (van Zinderen Bakker, 1989), but some pollen of *Tarchonathus*, *Ziziphus* and *Acacia karroo* were found near the pan (Cooremans, 1989).

Pollen from the swampy and aquatic areas includes mainly Cyperaceae, a few grains of *Typha*, *Potamogenotaceae*, *Oxygonum* and *Polygonum*.

Modern samples from Deelpan in the western Free State, show strong variations in the composition of pollen among the different localities within a single pan (Scott, 1988). From the pan floor near the spring, Scott (1988) found that the pollen consisted mainly of Cyperaceae, while the pan shore was composed of Cheno/Am pollen and the karroid vegetation with the undifferentiated Asteraceae and *Artemisia*. Grasses were found to be dominant in the grassveld.

The composition of pollen in the two pans (Zoutpan and Deelpan) is similar, in that the different areas within a pan have more or less the same type of vegetation.

Therefore, pollen from the pans can be used to determine past changes in vegetation on a regional basis.

The Deposit

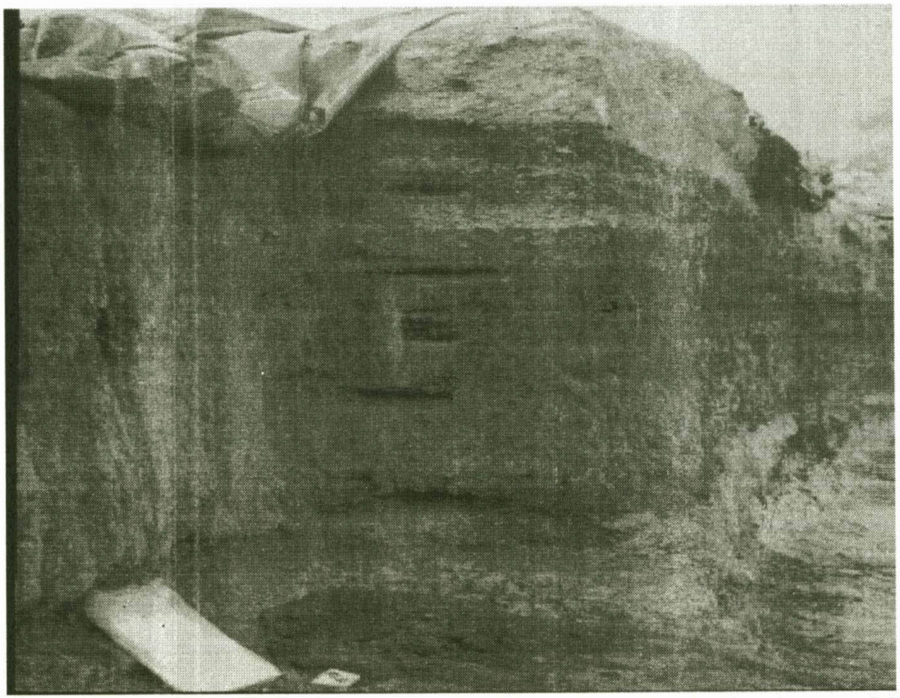

Figure 7.2. The Florisbad swamp deposits with holes indicating position of samples.

As mentioned in Chapter 3, sediments from the Florisbad spring have been studied before, because of their archaeological, paleontological and palynological importance (Dreyer, 1938; Brink, 1987; van Zinderen Bakker, 1957). The section from the western eye of the spring was described by Kuman & Clarke (1986), van Zinderen Bakker (1989), Joubert & Visser (1991) and Visser & Joubert (1991). This sequence consists of four organic-rich layers (Peat I-IV), that are separated by arenaceous and argillaceous units. The different units are thought to represent events of spring aeolian and lake deposits (Scott & Brink, 1992). Van Zinderen Bakker (1989) carried out fossil pollen studies on 660cm of this organic-rich sequence, dated between 300 000 to 3550 yr BP.

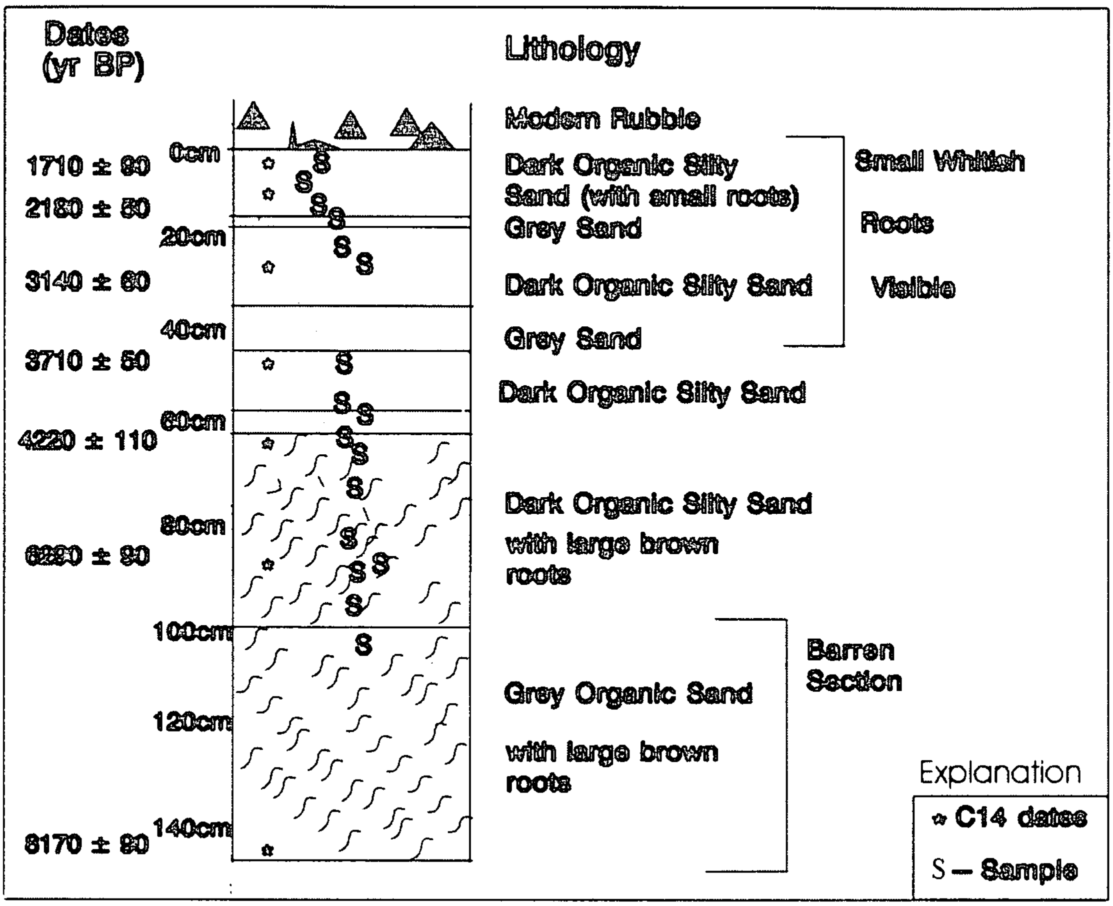

Figure 7.3. The Florisbad Sequence Profile.

According to Kuman & Clarke (1986) and van Zinderen Bakker (1989), Peat IV was dated between 3550 ± 60 yr BP and 5530 ± 80 yr BP. Therefore, van Zinderen Bakker's samples from Peat IV are likely to correspond with the layers between 40cm and 70cm of the sequence in this study where the dates seem to fit.

For this study a detailed set of 17 samples were collected from a 150cm long sequence from peat IV, in nearly the same place where van Zinderen Bakker (1989) had recovered his 3 samples. The sequence contains pollen up to 102cm and the rest of the bottom 48cm is barren. The sediments have alternating layers of grey and black sand (Fig. 7.3) and the deepest and oldest layer around 150-100cm, is a dark grey, organic silty sand. This deposit has some layers within, where the grey shade changes from light to dark and has large brown roots that are visible up till 60cm of the sequence. These roots are presumably from fossil swamp plants and are distinct from the small modern rootlets of exotic plants that also penetrated the sediments.

The following 100cm of the sequence are represented in the pollen diagram. From 100cm to 60cm there is a dark, organic layer with large brown roots and a thin layer of slightly grey sand overlies this with no roots between 60cm and 56cm. The dark, organic silty sand layers and the layers of grey sand continue to alternate up until the top of the sequence, where small whitish roots, which are apparently modern, begin to appear from 34cm to 0cm, in the sequence. This whole sequence is overlain by 50cm of modern rubble. Seven radiocarbon dates have been obtained from these sediments, ranging in age between 1700 yr BP to about 8200 yr BP (Figs. 7.2 and 7.3) and Table 7.1.

Table 7.1. Radiocarbon dates from Florisbad.

Anal. No Pta-	Sample Designation	Depth (cm)	Radiocarbon age (yrs BP)
7834	2475	0 – 5	1710 ± 90
7909	2848	9 – 11	2180 ± 50
7914	2849	24 – 28	3140 ± 60
7910	2850	45 – 48	3710 ± 50
7832	2471	59 – 62	4220 ± 110
7830	2468	83 – 87	6290 ± 90
7826	2463	144 –147	8170 ± 90

The Pollen Diagram Descriptions and Interpretations

The procedure for the construction of pollen diagrams (Figs. 7.4 and 7.5) is similar to that of Clarens and is discussed in Chapter 3. The diagram covers the interval between 0cm and 102cm. There is an interval in the sediments between 30 and 45cm where pollen grains were not found. A total of 17 samples were analysed and used in the construction of the pollen diagram. Six pollen assemblage zones (F1-F6) are distinguished and described below.

The pollen concentration values for each sample from Florisbad were calculated and are given as grains per gram of sample and these are shown in Table 7.2. The samples were not rich in pollen grains as the maximum content is only 6.6 x 10^3 g $^{-1}$ for sample 2469 and the lowest is 3.9 x 10^1 g $^{-1}$ for sample 2492.

Table 7.2. Pollen concentration values for Florisbad.

Sample no	Depth (cm)	Grains g $^{-1}$
2476	2	2 x 10^2
2477	7	8.2 x 10^2
2478	11	6.8 x 10^2
2479	15	2.3 x 10^2
2480	21	1.7 x 10^2
2481	27	6.2 x 10^1
2484	47	1.2 x 10^2
2485	55	1.2 x 10^2
2486	58	5.6 x 10^2
2472	61	4.4 x 10^2
2487	64	4.1 x 10^2
2488	70	1.1 x 10^3
2490	81	2.8 x 10^3
2469	87	6.6 x 10^3
2491	89	5.1 x 10^3
2492	97	3.9 x 10^1
2493	102	1.1 x 10^2

ZONE F1

This zone comprises samples between 102cm and 95cm. A radiocarbon date of 8170 ± 90 yr BP was obtained 45cm below this zone, where the sediments are barren of pollen grains. This is the deepest zone of the sequence.

The Pollen and Spore Composition

There is a very low pollen diversity and concentration in this zone. The AP (arboreal pollen) is almost completely absent with *Tarchonanthus* as the only constituent and it reaches only 0.4% of the pollen sum (Fig.). The other NAP (non-arboreal pollen) show a high value of 66% of the pollen sum and mainly constitute the undifferentiated Asteraceae, *Lyncnophora*-type, *Artemisia* and Chenopodiaceae/Amaranthaceae (Cheno/Ams) pollen. The pollen of the Poaceae constitutes about 33% of the pollen sum.

The local elements are also not abundant in this zone, as they constitute only 7% of the total pollen composition in this zone. Cyperaceae pollen is completely absent, while Apiaceae pollen seems to be the most important local palynomorph at 5%. The other elements of the swamp include Ranunculaceae and Geraniaceae.

Interpretation

The arboreal pollen is barely present and this indicates that trees did not grow here during this time, apart from the *Tarchonanthus* shrubs that occurred some distance away from the site. This is understandable as the present vegetation near the site consists of a vast treeless grassland according to Acocks (1988). This zone seems to have had vegetation similar to that of the present at some time in the past. The slightly higher values of Poaceae pollen than Asteraceae in this zone might imply that the regional environment was fairly humid, but the high percentage of Cheno/Am could indicate dryness or high local evaporation rates. The Cheno/Am to Grass ratio is approximately 1, which would indicate that conditions were relatively warm with high evaporation rates during this time.

Cheno/Am pollen is currently produced by the Soutpan vegetation in large numbers representing disturbance, dryness and saline conditions (van Zinderen Bakker, 1989; Cooremans, 1989). Therefore the abundance of Cheno/Am pollen in this zone, could only be a response to local successional changes rather than a regional change in climate.

ZONE F2

This zone covers the interval between 95cm and 79cm in the sequence. A radiocarbon date of 6290 ± 90 yr BP was obtained between 83 - 87cm.

The pollen and Spore Composition

The AP increases slightly reaching 1% of the pollen sum. As in the previous zone, the main constituent of the AP is *Tarchonanthus,* but pollen of *Celtis* is also present, although in small numbers. This zone begins with low values of Poaceae and high values of the other NAP, but ends with a reversed situation where Poaceae are higher than the other NAP. The other NAP shows a decline from 66% to 59% in this zone, where pollen of the undifferentiated Asteraceae and the Cheno/Ams show a decrease. Although there is a general decline in the other NAP numbers, there is an increase in the diversity of pollen contained in the other NAP. Pollen types such as, Aizoaceae-type, *Stoebe*-type and *Euphorbia* appear for the first time, while that of *Artemisia*, *Anthospermum* and *Lyncnophora*-type are still present. Poaceae pollen numbers increase from 33% to almost 40% of the pollen sum.

The local palynomorphs increase significantly, mainly because of an increase in *Ophioglossum,* Apiaceae and Crassulaceae values pollen. The trilete spores and Cyperaceae pollen have very low values.

Interpretation

The beginning of this zone seems like a continuation of zone F1, where conditions were warm resulting in increased evaporation rates. In this zone, the AP are rare, as they might have occurred some distance away from the palaeolake. The vegetation that was found in this zone consisted of grasses, Asteraceae and Cheno/Am herbs and shrubs with a relatively low cover, but later as grasses became abundant, the cover became denser. Towards the end of this zone, moisture increased both locally and regionally as grasses increased in the surrounding area and swamp elements, especially the Apiaceae, increased locally, resulting in a drop in the Cheno/Am. The significance of the high Apiaceae is not clear, but it is likely that it represents a local swamp element not currently present at the site.

ZONE F3

This zone is represented by only one sample at 70cm in the sequence. The pollen spectrum of this zone differs markedly from the others, according to the clustering results. No dating is available for this zone, but by interpolation it could be between 5000 yr BP and 4500 yr BP.

The Pollen and Spore Composition

The AP is almost non-existent at less than 1% of the pollen sum, the only constituent of the AP is the *Podocarpus*, which appears for the first time in this zone. The other NAP have markedly increased to about 86% of the pollen sum and they consist of the undifferentiated Asteraceae, as the major constituent, with *Pentzia*-type, *Lactucoideae* and Cheno/Am occurring in low numbers. The Cheno/Am seem to reach their lowest point in the total pollen spectra. The Poaceae pollen also reaches its lowest point, dropping from nearly 40% to 14% of the pollen sum.

The local elements reach only 1% of the total pollen composition. All the other local palynomorphs, including Cyperaceae are absent except for the Apiaceae pollen.

Interpretation

The vegetation of this zone was treeless, as, only pollen of *Podocarpus*, which is a long distance element (Coetzee, 1967; Scott, 1982a) occurs in the sample. This vegetation appears to represent a dry, karroid veld where Asteraceae had expanded at the expense of grasses and Cheno/Ams were almost absent. The veld seems to have been impoverished as the species composition and abundance was very low, may be due to unfavourable conditions that occurred regionally. The sharp increase in Asteraceae pollen, which seems to have began towards the end of the previous zone and continues into the next one (Fig. 7.4), shows clearly that a significant change in climate occurred. The high Asteraceae values may indicate a slight shift to relatively more winter rains, in this summer-rain region. The low values of Cheno/Am pollen in this zone suggest that the dryness was not accompanied by extreme evaporation, therefore possibly implying cooler conditions.

ZONE F4

This zone comprises of samples between 66cm and 53cm in the sequence. A radiocarbon date of 4220 ± 110 yr BP was obtained for the sample at 59 - 62cm.

The Pollen and Spore Composition

The AP composition increases slightly, including pollen of *Podocarpus*, Rhamnaceae and *Tarchonanthus*, although it accounts for only 1% of the pollen sum. The other NAP undergo a sharp decline from 86% in the previous zone to about 26% of the pollen sum in this zone. The other NAP is composed of the undifferentiated Asteraceae, Cheno/Ams, *Pentzia*-type, *Lactucoideae*, *Artemisia*, *Anthospermum*, Aizoaceae-type and Aloe-type. The Poaceae pollen increases significantly from about 14% to 73% of the pollen sum.

The local vegetation reaches 10% of the total pollen spectra, with Apiaceae pollen showing an increase in numbers. The other elements of the swamp include Crassulaceae, Ranunculaceae, Cyperaceae, Potamogenotaceae, *Typha, Ophioglossum* spores and trilete spores. This is the only zone where *Typha* pollen appears, though at very low values.

Interpretation

There is a definite increase in the diversity of pollen types in this zone as opposed to the previous zone. The increase in the arboreal pollen, especially in *Podocarpus* (although not much), together with the sharp increase in Poaceae pollen signify a change to wetter conditions in the region. The woody species, Rhamnaceae and *Tarchonanthus* might have occurred a distance away from the site on some rocky hills as Cooremans (1989) found out from studying recent pollen spectra near the Soutpan. The increase in Poaceae coincides with the decrease in both the Asteraceae and Cheno/Am, and thus, the vegetation consisted of a dense cover of grasses, with some herbs and shrubs. The low Cheno/Am values, as in the previous zone are indicative, of a cool climate. The increase in swamp elements is an indication that locally, moist conditions were experienced. Swamps with Cyperaceae, Apiaceae, Crassulaceae and trilete spores flourished. The humid conditions are also indicated by the presence of aquatic elements, *Typha* and *Potamogenotaceae.*

ZONE F5

This zone covers the interval between 53cm and 17cm. There is a large gap within this zone, around 45 - 30cm where pollen was not found in the sediments, suggesting unfavourable conditions for pollen preservation. Two radiocarbon dates were obtained from this zone, between 45cm and 47cm - 3710 ± 50 yr BP and between 24 and 28cm - 3140 ± 60 yr BP.

The Pollen and Spore Composition

The AP is composed of *Podocarpus* and *Tarchonanthus* and they show an increase from 1% to 3% of the pollen sum in this zone. The other NAP increase from about 26% to about 37% of the pollen sum and this increase is mainly due to the marked increase in Cheno/Am pollen in this zone. The other components of the NAP (other) include the undifferentiated Asteraceae, *Vernonia*-type, *Lactucoideae,* and *Artemisia.* Pollen of the Poaceae is still the most prominent, although it declined from 73% to 61% of the pollen sum, in this zone.

There is a general drop in the local pollen types, from 10% to 5.5%. All the other local elements show a decline, including Apiaceae, while Crassulaceae pollen and *Ophioglossum* spores remain constant, with Cyperaceae pollen increasing to reach their highest peak.

Interpretation

This vegetation is very similar to that of zone F4, except for the slight increase in the arboreal species, which might indicate that conditions were favourable during this period. The vegetation consisted largely of grasses, with some herbs and shrubs of the Asteraceae, and Cheno/Ams. A slight increase in temperature during this period is signified by the increase in Cheno/Am pollen. Locally, though grasses were gradually replaced by more Cyperaceae indicating expanded swampy conditions. The swamp vegetation was comprised mainly of Cyperaceae and smaller numbers of Crassulaceae, Apiaceae, Geraniaceae, Potamogenotaceae and trilete spores. This was a humid, but relatively warm period.

ZONE F6

This is the topmost zone and it is composed of samples that occur between 17cm and 2cm. This zone has two radiocarbon dates of 2180 ± 50 yr BP between 9cm and 11cm and 1710 ± 90 yr BP at 0 - 5cm of the sequence.

The Pollen and Spore Composition

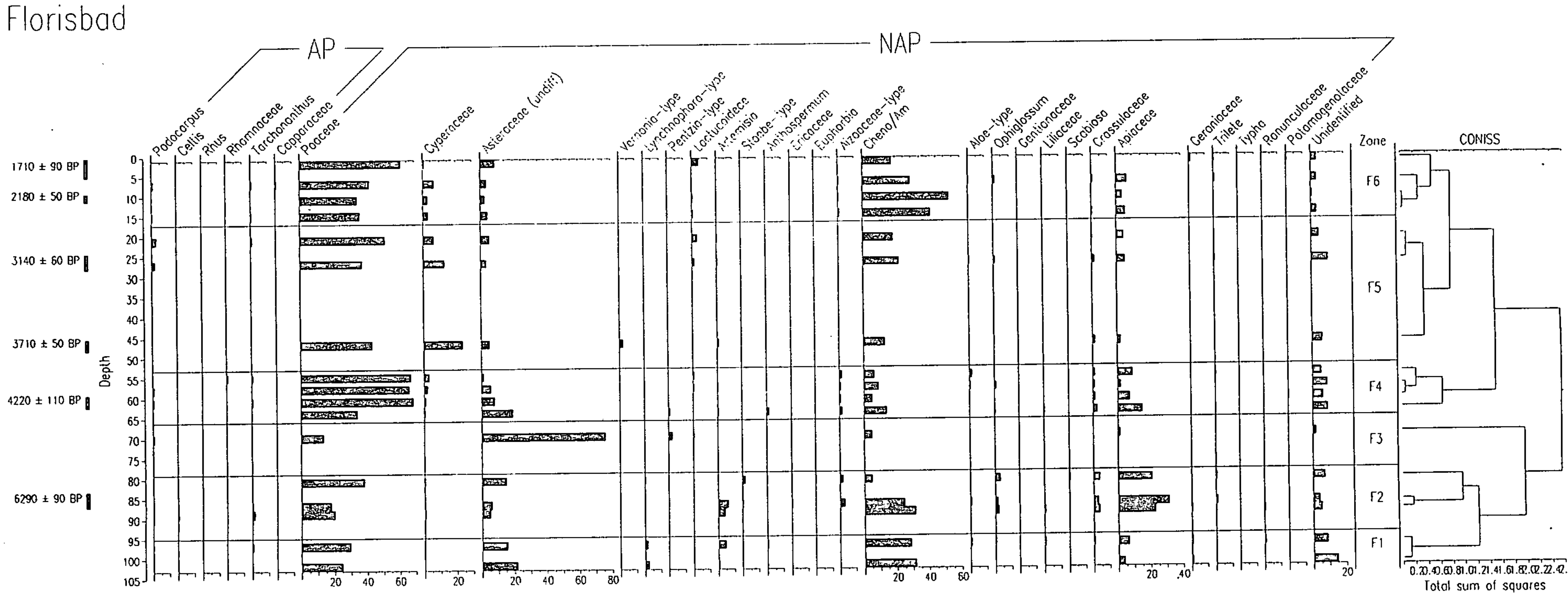

Figure 7.4 Detailed pollen diagram of the Florisbad sequence.

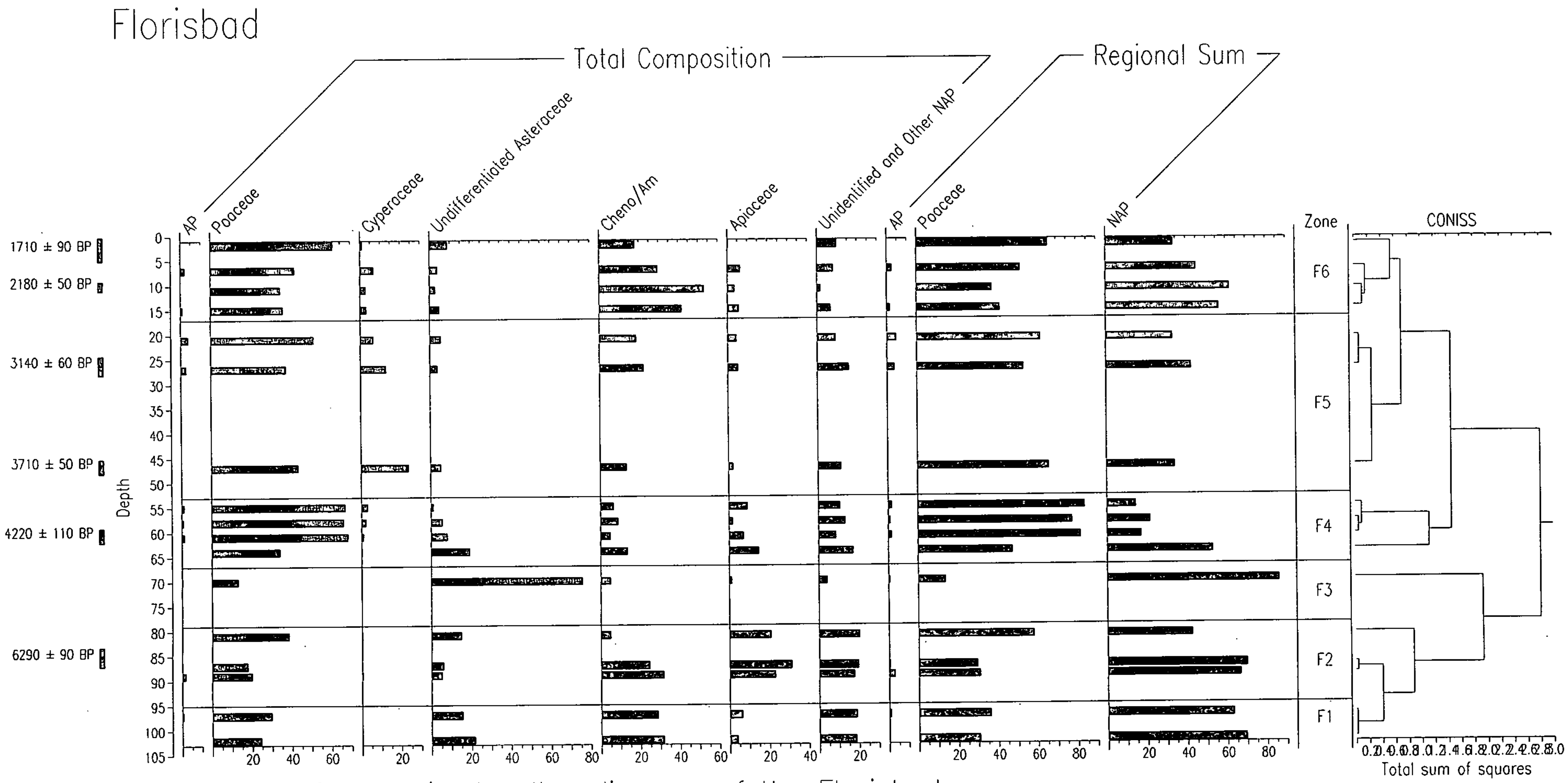

Figure 7.5. Summarized pollen diagram of the Florisbad sequnce.

The AP is composed of *Podocarpus, Rhus, Tarchonanthus* and Capparaceae, but shows a slight decline in comparison with the previous zone. This zone starts with a low Poaceae pollen coinciding with a sharp peak of Cheno/Am pollen (see Fig. 7.4). The other NAP increases to 49% of the pollen sum. The non-arboreal pollen in this zone consists of Cheno/Am, the undifferentiated Asteraceae, *Lactucoideae*, and Aizoaceae-type, with *Aloe*-type, *Artemisia* and *Pentzia*-type pollen occurring in smaller values. The percentage of Poaceae in the pollen sum in this zone is almost equal to that of the NAP, at approximately 50%. The Poaceae have dropped to 50%.

There is a general decline in the local palynomorph composition, as Cyperaceae drops, Apiaceae pollen appears to be constant, while all the other local elements such as Crassulaceae, Geraniaceae, *Ophiglossum,* trilete spores and Potamogenotaceae occur in smaller numbers.

Interpretation

The woody species, *Rhus, Tarchonanthus* and Capparaceae occurred some distance away from the site, but declined slightly in this zone, may be as a response to changes in climate. This increase in the Cheno/Am, early in the zone may indicate either a phase of stronger local evaporation or slightly less rainfall in the area. Towards the end of this zone, the Cheno/Am declined and the Poaceae increased again. Pollen of the Asteraceae remained constant throughout this zone. The vegetation that occurred during this phase was a grassland with some karroid elements, where Cheno/Am were dominant in the local surroundings. At the beginning of this zone, relatively dry conditions with high evaporation rates prevailed, but towards the end of this zone the climate became sub-humid and cooler.

The swamp was still extensive, but smaller than in the previous phase (zone E), as indicated by pollen of the Cyperaceae, Apiaceae, Crassulaceae, Geraniaceae, Potamogenotaceae and trilete spores.

Summarized Palaeoenvironmental Conclusions

The pollen profiles from Florisbad show an interesting sequence of climatic changes that took place between *ca.* 6500 and 1710 yr BP. This sequence begins during a dry phase, but changes around 4220 yr BP, when conditions ameliorate becoming humid all the way, though with some semi-arid episodes, until the end of the sequence. A summarized version of climatic changes is given in Table 7.3.

Table 7.3. Florisbad: interpretations of pollen data.

Age (yr BP)	Florisbad pollen zone	Vegetation Type	Interpretation
ca. 1700	F6 top	Grassy	Sub-humid
ca 2500-2000	F6, bottom	Grassy with Cheno/Ams	Semi-arid to sub-humid, high evaporation
ca. 3140-2500	F5 top	Grassy	Sub-humid
ca. 3710-3140	F5 middle	------	Hiatus
ca. 4000-3710	F5 bottom	Grassy with shrubs	Sub-humid
ca. 4220	F4	Very grassy, low Cheno/Ams	Sub-humid, cool?
ca. 5000	F3	Karroid	Dry, cool?
ca. 6290	F2	Low grass cover with Cheno/Ams	Semi-arid to sub humid
ca. 6500	F1	High Cheno/Ams with some grasses and shrubs	Rel., warm and dry, high evaporation

When this sequence began accumulating around 6500 yr BP, the vegetation was impoverished and open, warm with relatively dry conditions and high local evaporation. The climate changed *ca.* 5000 yr BP, resulting in a karroid shrubland. Less evaporation may be an indication of cooler conditions consistent with regional observations (Lee-Thorp & Talma, 1999). A sudden change in the vegetation is seen around 4220 yr BP when grasses become prominent during a phase of increased moisture, supporting Butzer's (1984) interpretations for the region. Between 3600 and 3200 yr BP, this region experienced unfavourable conditions again as indicated by the pollen hiatus in the sequence. Grasses dominated the vegetation around 3100 yr BP when conditions became favourable and later as the Cheno/Ams increased ca. 2100 yr BP during a warm and sub-humid phase.

CHAPTER 8

BLYDEFONTEIN

The Physiography of Blydefontein

The Blydefontein site is situated about 10km from Noupoort at 31° 09 S, 25° 05 E, at an altitude of 1700m. The topography is such that the basin is flanked by high peaks to the north (e.g., Oppermanskop, 2049m) and others to the south, and has a rolling landscape with a few dolerite ridges (Fig. 8.1). Small gorges occur in the lower reaches where the streams flow and these gorges have valley in valley cross sections with numerous overhangs and shelters (Bousman, 1991).

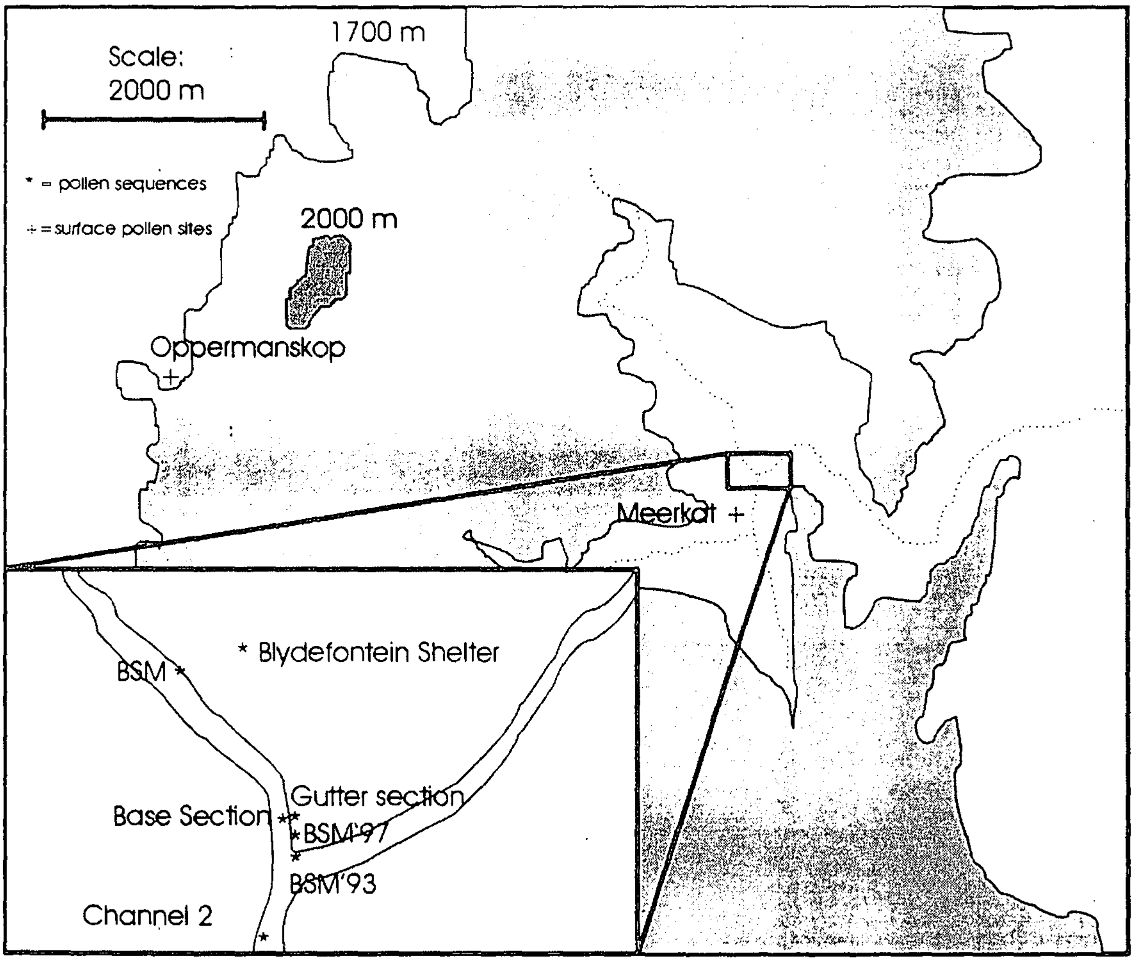

Figure 8.1. Map of Blydefontein basin showing site locations and surface sample collection points.

The Blydefontein landscape was formed by three major processes, plate tectonics, deposition and erosion (Bousman, 1991). The bedrock of the basin consists predominantly of sandstones and subordinate mudrocks of the Tarkastad Formation of the Beaufort Group (Bousman *et al.*, 1988). Numerous dolerite dykes and sills, formed by magma intrude this sequence. The sills tend to form crescent-shaped intrusions which range from a few meters to more than a 100m in thickness (Palmer & Hoffman, 1997), while the dykes usually intrude next to the argillaceous sediments such as shales or mudrocks (Bousman, 1991). Dolerite has metamorphosed adjacent host rocks, from mudstones to hornfels and sandstones to quartzites (Palmer & Hoffman, 1997). Erosion by the small streams led to the formation of rockshelters that are an important feature of the geology of the basin.

Three soil types are mapped for the Blydefontein basin. The lower portion of the basin has highly erosive duplex soils which occur adjacent to major drainage lines (Palmer & Hoffman, 1997) this part of the basin also has soils on alluvium with Melanic A horizons, derived from shales and dolerites (Bousman, 1991). Shallow soils of pedologically young landscapes are found on the relatively flat area of the basin above the gorges and below the koppies (Bousman, 1991).

The Climate of Blydefontein

The climate of Blydefontein which occurs in Region Ss (Fig. 6.2) of Schulze (1984) is very similar to that of Florisbad according to his description of the southern African climates. The climates of Region Ss, which is the southern variation of Region Sn are similar, but with minor differences.

Mainly topographic and orographic effects influence the climate of Blydefontein and resulting in greater rainfalls and cooler temperatures in the area. Precipitation in the Blydefontein basin is due to showers in summer and snow in winter. The mean annual rainfall in Grapevale, which is 200m below Blydefontein, is about 366mm. Blydefontein is said to receive more rain because of the greater orographic effects experienced there (Bousman, 1991). Most rains in this area fall in summer to early autumn.

During winter Blydefontein often remains cold and foggy. Light snows may occur between April and September in the basin, but in the Kikvorsberg and Sneeuwberg, heavy snows occur and these may last up to 10 - 14 days (Bousman, 1991) during winter months. Streams are almost always frozen in winter as frosts also occur most nights from March to September.

The mean annual temperature at Grootfontein, which is 405m below Blydefotein, is approximately 14.6 °C and the mean temperature for January is 20.8 °C and 7.9 °C for June.

The Vegetation of Blydefontein

The Karroid *Mexmuellera* Mountain Veld is the vegetation type mapped for most of the Kikvorsberg Mountains, including the Blydefontein basin (Acocks, 1988). This grassland starts as patches on rocky, dry aspects in the *Festuca-Themeda* Alpine Veld and Stormberg Plateau Sweetveld and it covers mountains of the eastern Karoo and adjacent fringes. It is dominated by the grass *Mexmuellera* with *Themeda* and *Tetrachne* as co-dominants on high mountain tops. Fynbos taxa such as *Elytropappus rhinocerotis*, *Erica caffra, Cliffortia* species, *Restionaceae* species, *Passerina montana, Pentzia cooperi*, *Anthospermum spathulatum, Clutia polifolia* and many others are also present here on higher slopes. Along streams *Cyperus marginatus* and *Phragmites australis* occur. (Acocks, 1988).

The rugged topography of the Blydefontein area, (Fig. 8.2) creates a variety of habitats and as a result many different plant communities similar to those described in the region in general can be recognised (O' Connor & Bredenkamp, 1997). The *Festuca-Themeda* Alpine Veld and the Stormberg Plateau Sweetveld (Acocks, 1988) are said to be part of the Blydefontein vegetation (Bousman, 1991). In these velds *Themeda triandra, Festuca costa, F scabra* and *Elionurus mutica* dominate the vegetation (Acocks, 1988).

According to the classification of O' Connor & Bredenkamp (1997), the vegetation of the Blydefontein area should fall into the *Monocymbium ceresiiforme - Tristachya leucothrix* grassland. The grasses *Ehrharta calycina, Melica decumbens, Karoohloa purpurea, Helictotrichon hirtulum, Pentaschistis* species and *Bromus* *leptoclados* together with forbs such as *Diascia capsularis, Sutera macrosiphon, Dianthus* caespitosus, *Othonna auriculifolia* and *Euphorbia epicyparissias* also occur in Blydefontein. Although the climate in this area is suited for forest or woodland, fire, grazing and frost maintain this grassland.

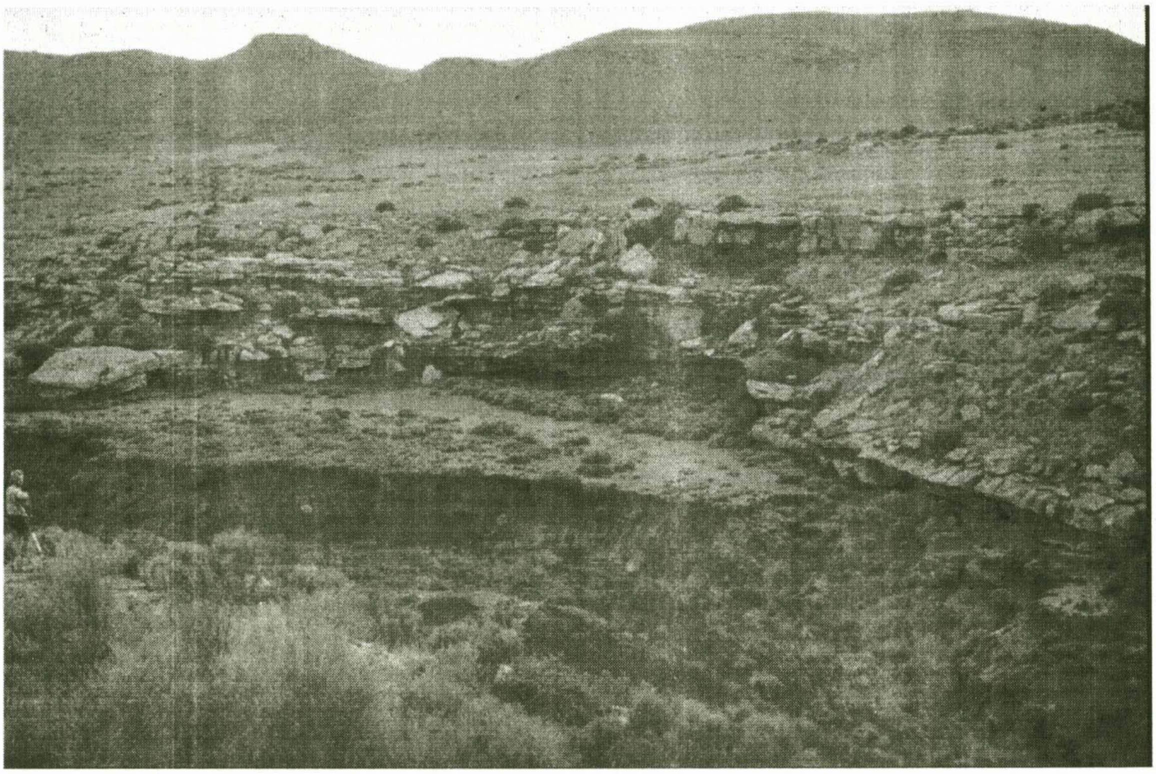

Figure 8.2. The Blydefontein Basin and it's surrounding vegetation.

The Modern Pollen Spectra

The modern pollen spectra of Blydefontein was studied by Scott and Bousman (1990) using six samples recovered from Meerkat and Oppermanskop (see Fig. 8.1) and the following discussion is based on their results. In Meerkat, three samples were obtained, one from hyrax dung, the other from a slope and the last from alluvial mud, whereas for Oppermanskop, samples were taken from hyrax dung and from two different slopes. Pollen spectra from these samples show the undifferentiated Asteraceae to be dominant. Although the combined results of hyrax midden, fossil alluvium together with the surface samples suggest that Asteraceae and Poaceae are the most abundant types. The other NAP includes Scrophulariaceae-type, Cheno/Am, *Artemisia*, *Anthospermum, Stoebe*-type, Ranunculaceae and Cyperaceae. Arboreal pollen is also present, but it is prominent in the slope spectra and not in the alluvium samples and represents forms such as *Tarchonanthus*, *Diospyros*, *Euclea*, *Rhus* and *Lycium*. A north facing valley adjacent to Oppermanskop boasts denser woody vegetation and therefore has higher AP than Meerkat. Pollen of exotics such as *Pinus* and Myrtaceae is also found in the surface pollen in small numbers.

Palynology of a number of Holocene sequences has been described by Bousman *et al.* (1988), Scott & Bousman (1990) and Bousman (1991), including the BSM site that is near the Blydefontein Shelter. In this study, three additional sequences near BSM are investigated in an attempt to improve our understanding of environmental developments during the Holocene and to fill in gaps in the existing records.

The Age of the Studied Sections

The Blydefontein sequence is in three sections as mentioned in Chapter 3 - BSM97, the Base and the Gutter sections. All in all, nine radiocarbon dates were obtained from the three sections and these range between 1980 and 5370 yrs in BP (Table 8.1). The BSM97 section is dated from 1980 to 4850 yrs BP, the base section is the oldest, and ranges between 5130 and 5370 years, while the Gutter section has an anomalous date of 5050 yr BP in between 4460 and 4970 yr BP.

Table 8.1. The Age of the Blyde Stream Mouth deposits

Anal. No Pta-	Sample Designation	Depth (cm)	Radiocarbon age (yrs BP)
7500	BSM97 2122	248	1980 ± 50
7915	BSM97 2133	425	3950 ± 40
7497	BSM97 2143	556	4850 ± 60
7511	Gutter 2152.6	0 – 5	4460 ± 60
7926	Gutter 2152.22	34 – 40	5050 ± 50
7510	Gutter 2152.5	87 – 90	4970 ± 70
7946	Base 2148.8	4.5 - 8.0	5010 ± 50
7509	Base 2148.1	25 – 30	5130 ± 70
7502	Base 2152.1	52 – 56	5370 ± 70

The BSM97 Section

The Deposit

The BSM97 deposit was collected about 10m upstream from the original BSM section of Bousman *et al.* (1988) and Bousman (1991). It was recovered from an exposed slope of 6.04m depth that forms an angle of *ca.* 30°. Sampling commenced from only 1.90m, below the surface (see Fig. 8.3). This sequence has diatomaceous banded layers as those seen in Fig. 8.12 of the Gutter section. Samples below 5.91m were collected below the water level.

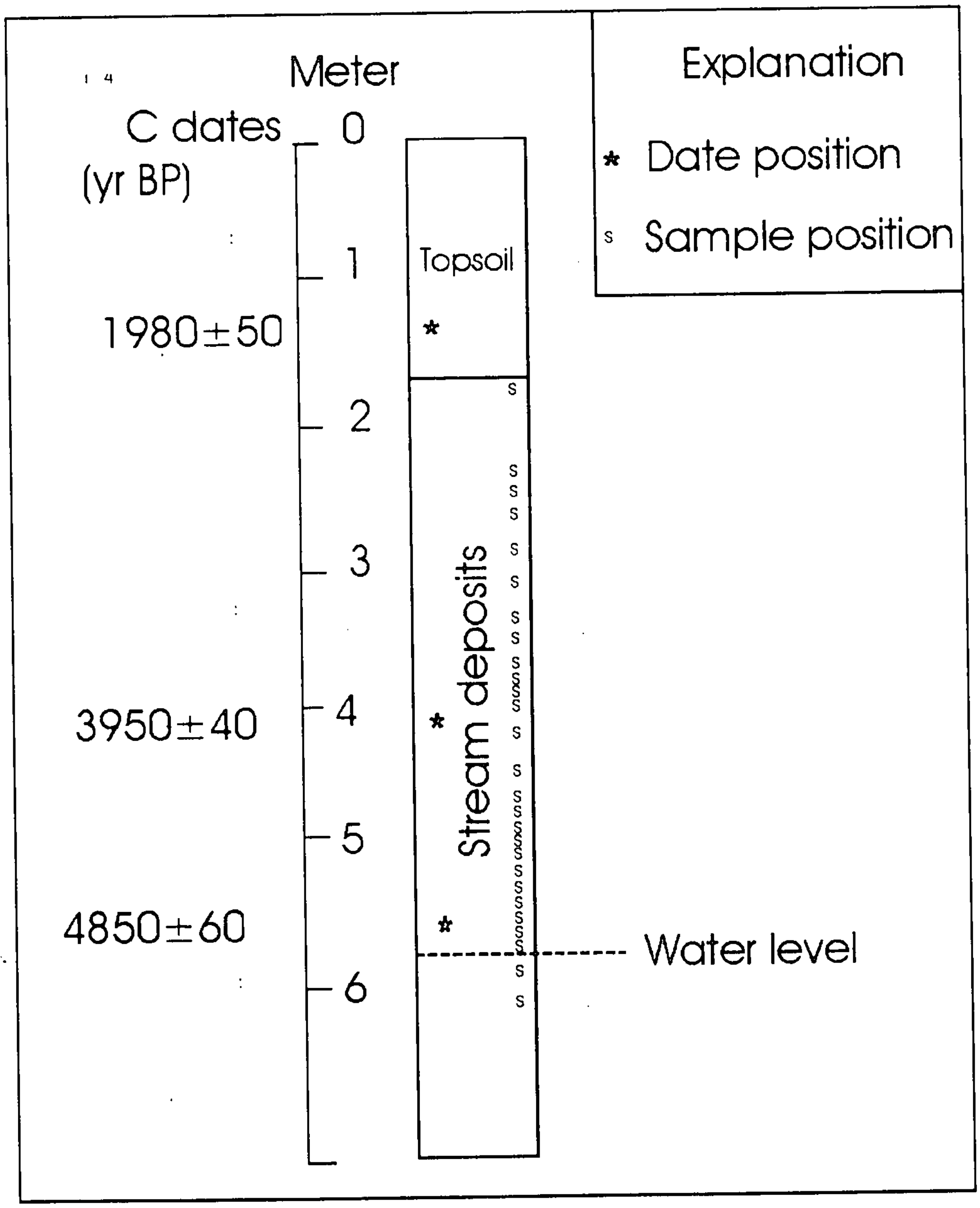

Figure 8.3. BSM97 Section profile

The Pollen Diagram Description and Interpretations

The pollen diagram (Fig. 8.4) contains 57 pollen types, including the unidentified grains. Prominent pollen types are the Poaceae, undifferentiated Asteraceae, *Anthospermum* and Cheno/Am. Five pollen assemblage zones, A, B, C, D and E were distinguished for this pollen diagram. Three radiocarbon dates were obtained - 1980 ± 50 yr BP, 3950 ± 40 yr BP and 4850 ± 60 yr BP.

The pollen concentration value for each sample from the three sections was calculated and is given as grains per gram of sample. Table 7.2 gives the concentration for samples from the BSM97 Section. In general, these samples seem more concentrated than the ones from Elim and Florisbad. The maximum content is 1.5×10^5 g^{-1} for sample 2144. Sample 2120, 2130 and 2133 have the lowest concentration of pollen grain per gram of sample. These are the three topmost samples of the sequence and they have high numbers of trilete spores. The lower concentration of grains in these samples could comfirm the suggestion of selective preservation (Scott, 1999a, b) which might have been caused by drying out of the sediments, in the upper zones.

Table 8.2. Pollen Concentration Values for BSM97

Sample no	Depth (cm)	Grains g^{-1}
2120	190	3×10^1
2130	386	2.7×10^2
2133	425	3×10^2
2134	450	7.6×10^2
2135	470	1×10^3
2136	486	1.2×10^4
2137	498	5.7×10^3
2138	507	2.5×10^3
2139	514	3.9×10^4
2140	524	9.7×10^4

2141	537	5.1 x 10^4
2142	547	1 x 10^5
2143	556	3.5 x 10^2
2144	569	1.5 x 10^5
2145	577	1.5 x 10^4
2146	595	9.1x 10^3
2147	604	3.7 x 10^3

Zone A

This is the deepest zone of the BSM97 section and it covers the interval between 604cm and 572cm of the sequence. No dates are available for this zone.

The Pollen and Spore Composition

Arboreal pollen (AP) reaches about 14% of the pollen sum and is composed of *Tarchonanthus*, which constitutes the bulk of the AP. Other components of the AP include *Podocarpus*, *Clutia*-type and *Rhus*. The other NAP account for almost 57% of the pollen sum, with the Cheno/Am, the undifferentiated Asteraceae and *Anthospermum* as the main constituents. The other components of the NAP are the Aizoaceae-type, *Artemisia*, *Stoebe*-type and others that occur in smaller numbers. The Poaceae are also prominent in this zone at 30% of the pollen sum.

The local elements are very scarce reaching only 5% of the total pollen spectra. Cyperaceae and *Scabiosa* pollen, together with the trilete spores are the prominent locals.

Interpretation

The AP numbers, which constitute mainly *Tarchonanthus*, indicate that this shrub may have occurred near the site during this period, as it is currently scattered around the site, especially up in the slopes. Evidence from modern pollen spectra indicate *Tarchonanthus* to be prominent in the vicinity, for example, at Oppermanskop (Scott & Bousman, (1990). This was a grassy, karroid vegetation with herbs and shrubs of Cheno/Am and Asteraceae. The high number of Cheno/Ams (see Fig 8.4) shows evaporative conditions, while the balance between grasses and shrubs points to an even distribution of moisture seasonally.

Zone B

This zone covers the interval between 572cm and 502cm of the sequence. A date of 4850 ± 60 yr BP was obtained at 556cm in this zone.

The Pollen and Spore Composition

This zone shows a bit more diversity in the pollen types, than the previous zone. The AP drops to about 8% of the pollen sum in this zone and it is composed of *Podocarpus*, *Grewia*, Rhamnaceae, *Diospyros*, *Euclea*, *Clutia*-type, *Acacia*, Mimosoideae, Celastraceae, Capparaceae, *Olea*, *Rhus* and *Tarchonanthus*. The other NAP decline, reaching *ca.* 47% of the pollen sum. Pollen of Cheno/Am, the undifferentiated Asteraceae, *Anthospermum*, *Artemisia*, *Pentzia*-type, *Stoebe*-type and Aizoaceae-type make up the other NAP together with those pollen types that occur in smaller numbers. Poaceae pollen shows a huge increase, reaching nearly 46% of the pollen sum.

The local elements have increased to about 10% of the total pollen spectra and include palynomorphs such as the Cyperaceae, Gentianaceae, *Scabiosa*, trilete and monolete spores.

Interpretation

The rare AP indicates that woody elements grew some distance from the site. This was a grassy vegetation with few herbs and shrubs. Hubbard and Sampson (1993) have shown that Asteraceae and Poaceae pollen ratios change seasonally in this region mainly because of the seasonality of rainfall. The sharp peak of Poaceae (see Fig 8.4) suggests an increased summer precipitation and the decline in Cheno/Ams points to a drop in temperature. The increase in swamp elements also shows that conditions were humid even locally. This was a relatively cool phase as *Anthospermum* with some *Artemisia* and *Stoebe*-type herbs had expanded at the expense of Cheno/Ams.

Zone C

This zone covers the interval between 502cm and 427cm. No date was obtained for this zone.

The Pollen and Spore Composition

The AP increases in this zone, reaching *ca.* 12% of the pollen sum. Pollen of *Tarchonanthus* still accounts for a large percentage of the AP. Other AP types include *Podocarpus*, *Celtis*, *Euclea*, *Acacia*, Mimosoideae, Celastraceae, Capparaceae, *Olea*, and *Rhus*. Pollen of *Grewia*, Rhamnaceae, *Clutia*-type and *Diospyros* disappear completely from the pollen spectra. The other NAP, which is dominated by Asteraceae (undifferentiated) show a dramatic increase reaching 66% of the pollen sum. The other prominent types of the other NAP include *Anthospermum*, *Artemisia,* Commelinaceae, Aizoaceae-type and the Cheno/Am pollen. Poaceae pollen drops markedly, from nearly 46% in the previous zone to *ca.* 22% of the pollen sum in this zone.

The local elements are constant at about 9% of the total pollen spectra. These elements include the Cyperaceae, Ranunculaceae, *Scabiosa*, the monolete, trilete spores and others that occur at low values.

Interpretation

The slight increase in AP shows that trees expanded in the mountain slopes and ravines. This zone suggests a completely different vegetation from the one in zone B, as the Asteraceae have expanded at the expense of grasses. This is a shrubby and karroid vegetation. The sharp drop in grasses and increase in shrubs (see Fig. 8.4) signify that summer rains were reduced relative to winter rains or conditions became drier. This zone also shows an increase in Cheno/Ams, which could mean that evaporation rates were high during this phase.

The vegetation of this zone is similar to the one seen from the BSM and Hughdale pollen spectra of Bousman *et al.*, (1988) and Bousman, (1991) where between 4470 ± 70 yr BP and *ca.* 4000 radiocarbon years, Asteraceae and Cheno/Am plants increased at the expense of grasses. Evidence from diatom analysis of the BSM sediments indicates that the waters were shallow around this time, creating stressful conditions for aquatic life.

Zone D

Only 2 samples are part of this zone that occurs between 427cm and 375cm of the sequence. A date of 3950 ± 40 yr BP was obtained at 425cm in this zone.

The Pollen and Spore Composition

This zone has low pollen composition and diversity. The AP shows a 5% decline as compared to the previous zone, reaching 7% of the pollen sum. There is a general decline in the AP composition, as it now comprises only four types of pollen, and that is, *Podocarpus*, *Acacia*, Mimosoideae and *Tarchonanthus*. The other NAP reaches their highest peak at 71% of the pollen sum. The components of the NAP (other) are the undifferentiated Asteraceae, *Anthospermum*, *Artemisia*, *Pentzia*-type, Commelinaceae, and Cheno/Am, while pollen of the Aizoaceae-type completely disappears. Poaceae numbers reach their lowest level at 14% of the pollen sum.

The local palynomorphs show a substantial increase, from *ca.* 9% in zone C they reach almost 30% of the total pollen spectra. The major components of the local elements are the trilete spores that show a marked increase in percentage in this zone. Other locals include Liliaceae, *Scabiosa*, Cyperaceae (which is not very important here), Polypodiaceae, Geraniaceae and the monolete spores.

Interpretation

This was a shrubby and karroid vegetation where Asteraceae shrubs and herbs dominated, while grasses were very scarce. The conditions during this phase must have been relatively arid as suggested by the vegetation that occurred here. An interesting observation is the sudden increase in swamp elements, especially the Pteridophyta ferns, which would indicate moist local conditions in this regionally dry climate. However, the lower pollen concentration numbers above 450cm depth (Table 8.2) suggests that these spores did not become relatively more important. This supports the contention that these spores show up more prominently in this zone due to selective preservation (Scott, 1999a, b) and not through climate change.

Zone E

This is the uppermost zone of BSM97 and it covers between 375cm and 190cm of the sequence with only one sample making up the zone. This zone is barren all the way and only has pollen at the top, around 190cm (see Fig. 8.4 and 8.5). A date of 1980 ± 50 yr BP was obtained in this zone at 248cm.

The Pollen and Spore Composition

This zone has only a few pollen types. The pollen sum is composed of *ca.* 8% AP, 22% other NAP and 70% Poaceae. The AP has only four components - *Podocarpus*, *Rhus*, *Acacia* and *Tarchonanthus*. The other NAP is composed of the undifferentiated Asteraceae, *Pacourina*, *Stoebe*-type, *Anthospermum*, *Artemisia*, *Pentzia*-type, Malvaceae Commelinaceae and Cheno/Am. Pollen of Malvaceae appears for the first time in the pollen spectra, while that of *Ophioglossum*, which was abundant in zone D, has disappeared.

The local elements have dropped markedly, reaching 5% of the total pollen spectra. Only the trilete spores are prominent, the rest of the locals occur in smaller numbers.

Interpretation

The available level seems to show a grassy community. The regional vegetation suggests that conditions were relatively wet. Locally, ferns dominated the swamp and Cyperaceae was absent.

The absence of pollen around 1980 ± 50 yr BP and in the lower levels of the zone may be due to dry conditions that occurred during this period as indicated by an increase in Asteraceae and a decline in Poaceae pollen in the USP pollen spectra (Bousman *et al.*, 1988; Bousman, 1991) around 2000 ± 60 yr BP. From the USP sediments, there is evidence suggesting a temporary change to marshy conditions from a pool environment, this is indicated by an increase in Cyperaceae and the presence of *Succinea*, a mollusc found in marshy areas. The absence of pollen in the zone conforms with a lack of polleniferous sediments in general between about 2000 and 4000 yr BP in the basin. This is probably due to adverse conditions for preservation.

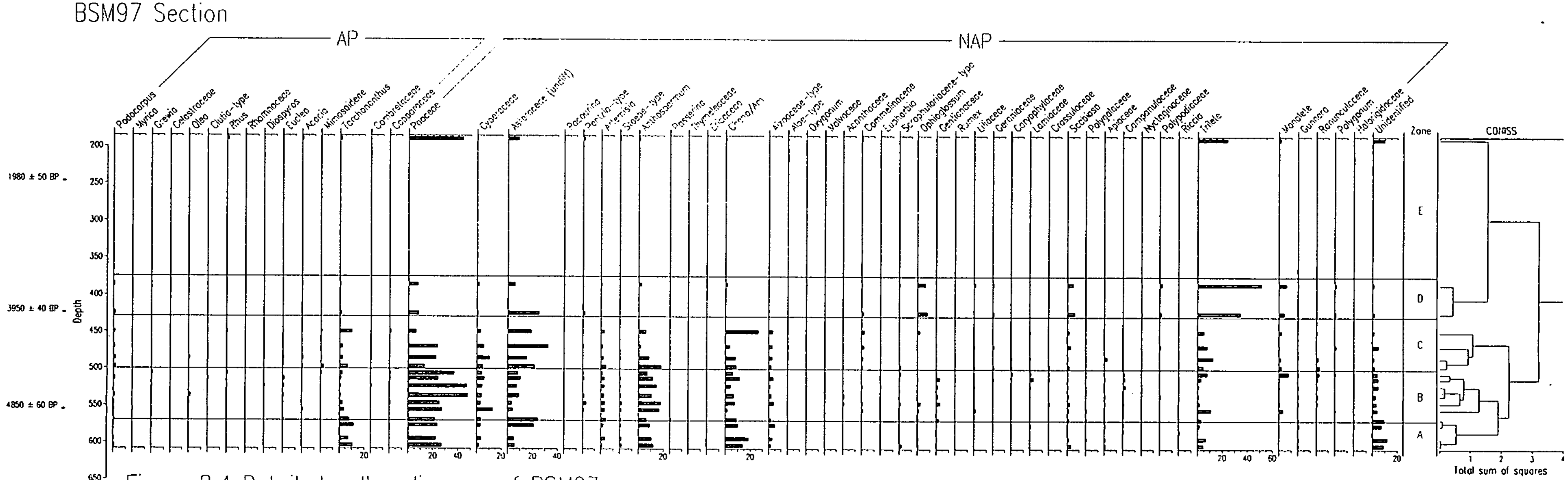

Figure 8.4 Detailed pollen diagram of BSM97.

BSM97 Section

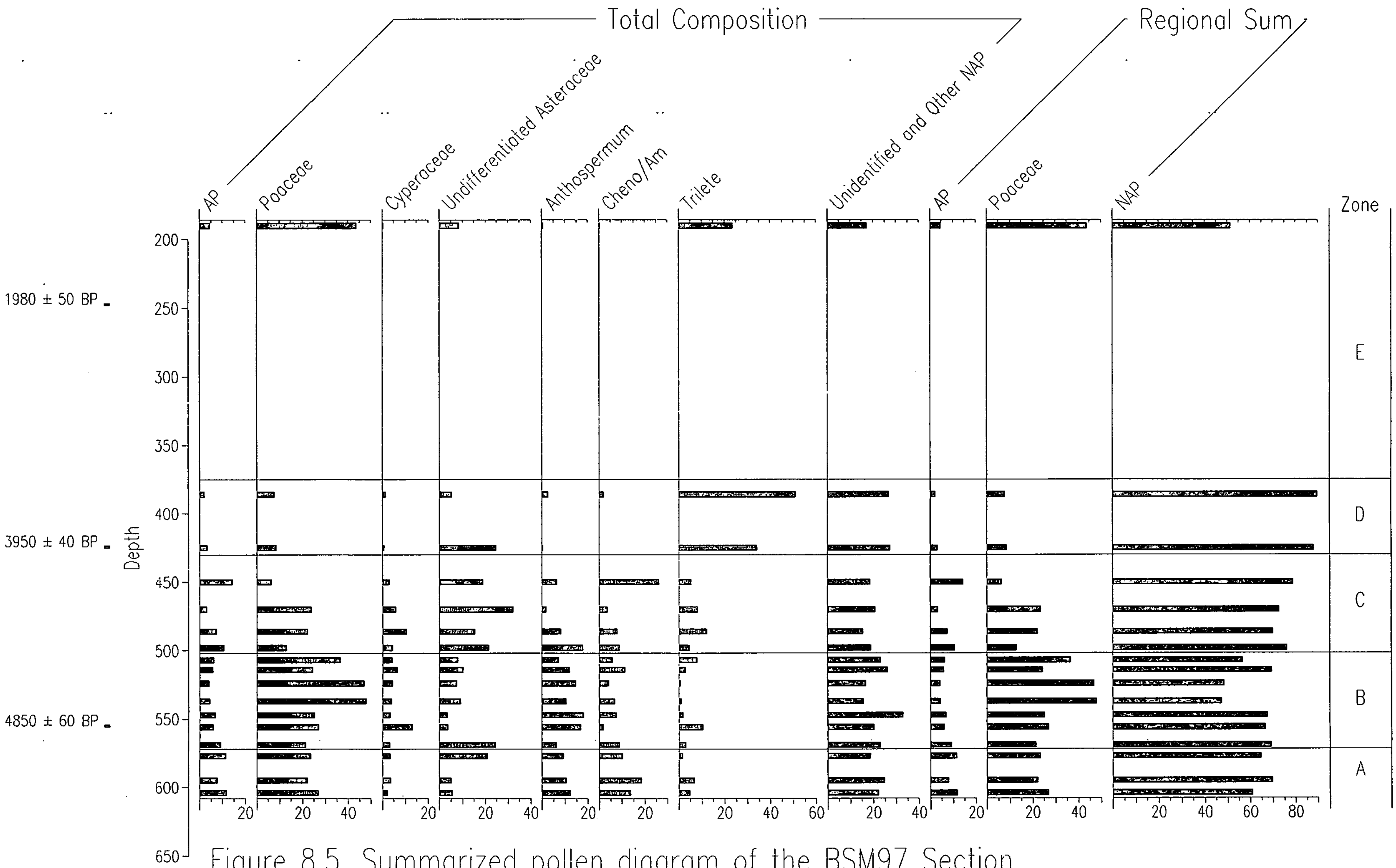

Figure 8.5. Summarized pollen diagram of the BSM97 Section.

The Base Section

The Deposit

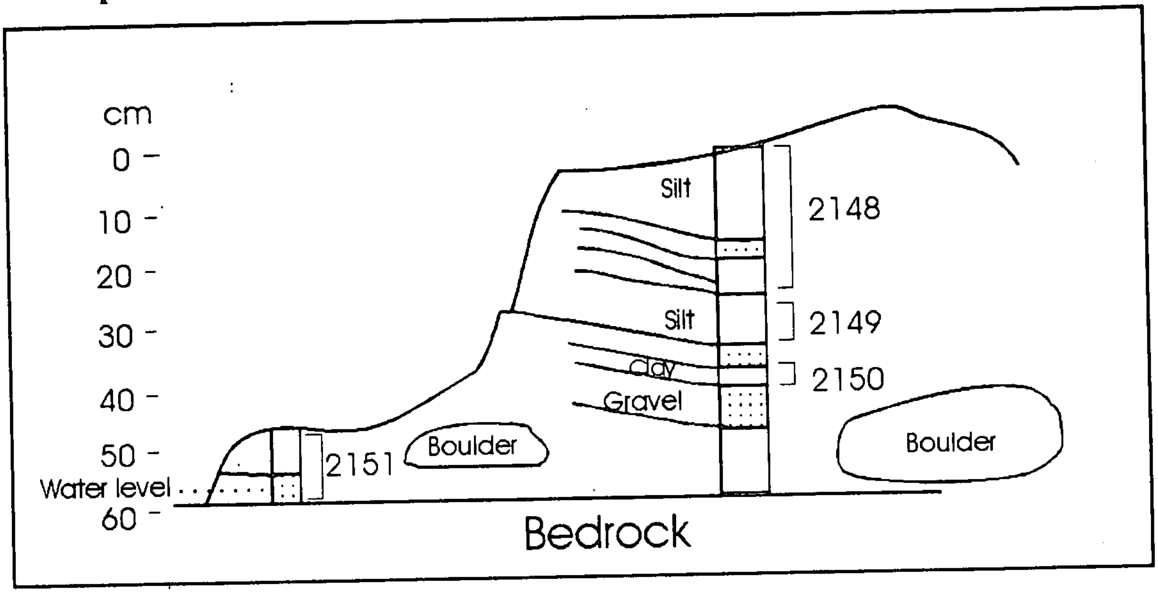

Figure 8.6. Base Section profile showing the position of the samples.

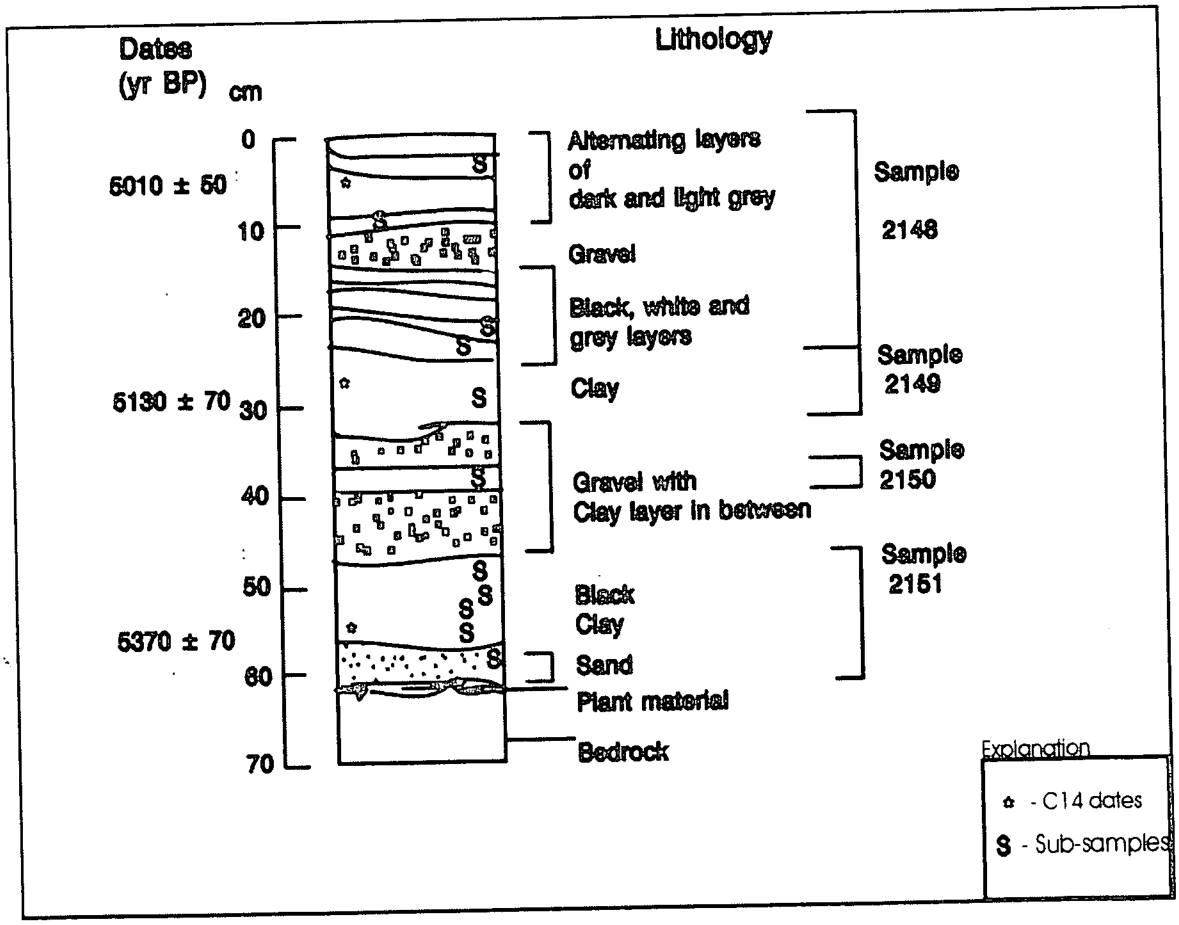

Figure 8.7. Base Section Profile.

The statigraphical profile of this section with its lithology is as seen in Fig. 8.6 and 8.7. Sample 2148, which was collected as a large block of sediment of *ca.* 23cm, consists of black, white and grey layers or banded diatomaceous layers of clay with different shades. This sample was sub-sampled in the lab and includes, two layers of gravel which occur at 12.5 - 15cm, and 19 - 22cm, respectively. Below, between 26 and 33cm, a clay layer is found (sample 2149) overlying 16cm of gravel with a clay lens between 35 and 37cm (sample 2150). Sample 2151 is another block of sediment that is about 12cm long, with a black clay layer lying above a dark greyish sand layer which is on top of the bedrock. Fossil plant material occurred directly above the bedrock.

The Pollen Diagram Descriptions and Interpretations

The pollen diagram (Fig. 8.8) includes 47 pollen types, with pollen of *Tarchonanthus*, Poaceae, undifferentiated Asteraceae, *Anthospermum* and the Cheno/Am more prominent than others. Three radiocarbon dates were obtained: 5370 ± 70 yr BP at *ca.* 52-56cm, 5130 ± 70 yr BP between 25cm and 30cm and 5010 ± 50 yr BP, *ca.* 5-8cm. These dates indicate that this section was accumulated over a short period of time, of not more than 500 years. The pollen diagram is distinguished into four pollen assemblage zones, B1, B2, B3 and B4.

Table 8.3 gives the pollen concentration for samples from Base Section. The maximum pollen content per gram is 1×10^6 for sample 2151.5.

Table 8.3. Pollen concentration values for the Base Section

Sample no	Depth (cm)	Grains g^{-1}
2148.4	1.7	9.9×10^4
2148.5	12	8.8×10^4
2148.6	22	7.1×10^4
2149	25	9.5×10^3
2148.7	30	9.7×10^4
2150	37.5	5.8×10^5

2151.2	49.5	2.4×10^3
2151.5	54.7	1×10^6
2151.3	56.7	1.5×10^3
2151.6	58.7	7.1×10^3
2151.4	60.2	1.1×10^4

Zone B1

This is the deepest zone of the section and it covers from 62cm to 57cm of the sequence. No date was obtained for this zone, but by interpolation the bottom of this zone could be *ca*. 5500 yr BP.

The Pollen and Spore Composition

The composition and diversity of pollen types is very low within this zone. The pollen sum is composed of 4% AP, 52% of the other NAP and *ca*. 44% of Poaceae pollen. The AP is very scarce, but has pollen of *Podocarpus*, Celastraceae, *Olea*, *Diospyros*, *Euclea* and *Tarchonanthus*. The pollen of *Olea* and *Tarchonanthus* dominate the AP. The other NAP is composed of the undifferentiated Asteraceae, *Stoebe*-type, *Anthospermum*, *Artemisia*, Aizoaceae-type, Cheno/Am, Scrophulariaceae-type and others that occur in low values.

The local elements, Cyperaceae, Apiaceae, Ranunculaceae, Crassulaceae and the monolete and trilete spores account for 14% of the total pollen spectra.

Interpretation

The scarcity of AP in the sediments could be due to the absence of woody species near the site during this time. These species might have occurred some distance away from the site in protected ravines on the slopes. The vegetation, judging from the Poaceae pollen numbers had a good grass cover, although herbs and shrubs of undifferentiated Asteraceae, *Stoebe*-type, *Anthospermum*, *Artemisia*, Aizoaceae-type, Cheno/Am and Scrophulariaceae-type also occurred. Modern pollen spectra from Meerkat shelter and Oppermanskop (Scott & Bousman, 1990) show the Asteraceae pollen type as the most dominant followed by the Poaceae. In, comparison with this pattern, the fossil pollen spectra suggests a sub-humid period as indicated by the high values of Poaceae pollen and the presence of swamp elements. The high Cheno/Am values (see Figs. 8.8 and 8.9) signify a period of high evaporation.

Zone B2

This zone covers the interval between 57cm and 45cm. A date of 5370 ± 70 yr BP was obtained between 52-56cm of this zone.

The Pollen and Spore Composition

This zone like the previous zone has a low pollen diversity. The AP shows a remarkable increase, reaching 14% of the pollen sum in this zone. Contents of the AP include *Podocarpus*, Celatraceae, *Olea*, *Rhus*, *Euclea* and the major constituent, *Tarchonanthus*. The other NAP has reached almost 68% of the pollen sum. These non-arboreal pollen are composed of undifferentiated Asteraceae, *Stoebe*-type, *Anthospermum, Artemisia,* Aizoaceae-type, Cheno/Am and others that occur in smaller numbers. The Cheno/Am followed by the undifferentiated Asteraceae are the main components of the other NAP. The Poaceae drop markedly from 44% in the previous zone to *ca.* 18% of the pollen sum in this zone.

The local elements show a slight decrease, reaching 11% of the total pollen spectra. The same elements that were present in zone B1 are present with Cyperaceae pollen prominent.

Interpretation

The increase in numbers of the AP was mainly due to the increase in numbers of *Tarchonanthus* which usually indicates relatively dry conditions. This was a shubby, karroid vegetation, where the Cheno/Ams and *Anthospermum* had expanded at the expense of grasses. This change in vegetation indicates a change to relatively dry conditions. The increase in Cheno/Ams probably suggests high evaporation rates. The lower numbers of swamp elements indicate that although a swamp was present, it was reduced.

Zone B3

This is the longest zone of the base section, ranging from 45cm to 17cm. A date of 5130 ± 70 yr BP was obtained between 25cm and 30cm of the sequence.

The Pollen and Spore Composition

The AP has declined reaching *ca.* 9% of the pollen sum, from 14% in the previous zone. *Tarchonanthus* is still the most abundant AP, while *Podocarpus*, *Grewia*, Celastraceae, *Olea*, *Rhus*, Rhamnaceae, *Diospyros* and *Euclea* are present in the AP. Pollen of *Grewia* appears for the first and only time in this zone. The other NAP declines, reaching 59% of the pollen sum. A significant change occurs in this zone, as the undifferentiated Asteraceae and Cheno/Ams decline and *Anthospermum* become the most abundant pollen type. Pollen of *Artemisia*, *Stoebe*-type, Aizoaceae-type and other inconspicuous types also occur within the other NAP. The Poaceae show an increase, reaching about 32% of the pollen sum.

The local elements make up 16% of the total pollen spectra and they include the Cyperaceae as the most abundant local type. Other local elements include Apiaceae, *Rumex*, *Scabiosa*, Crassulaceae, Gentinaceae, and the trilete spores.

Interpretation

The shrubby species, *Tarchonanthus* still occurred some distance away from the site and its presence could indicate dry conditions. A grassy, karroid vegetation occurred here during this period. This is indicated by the dominance of *Anthospermum*, together with the Cheno/Ams and the other Asteraceae. High concentrations of *Anthospermum* could point to dry conditions, if other indicators of open vegetation are present (Coetzee, 1967). Although in this case, grasses were abundant, so it was probably not the dryness that influenced the growth of shrubs, but a slight decline in the relative proportion of summer to winter rainfall. The type of vegetation that was found here indicates that rainfall was more evenly distributed. Also, the presence of Cyperaceae indicates that a swamp occurred locally.

Zone B4

This is the topmost zone of the base section and it ranges between 17cm and 2cm, and a date of 5010 ± 50 yr BP was obtained between 4.5 and 8cm of this zone.

The Pollen and Spore Composition

This zone has only two samples that are 10cm apart and has a low pollen diversity and composition. The AP has decreased to 7% of the pollen sum and includes *Olea*, Rhamnaceae, *Diospyros*, *Euclea*, Combretaceae, *Acacia* and *Tarchonanthus*. Concentrations of *Olea* and *Diospyros* show an increase, whereas, pollen of *Podocarpus*, *Grewia*, Celastraceae and *Rhus* has completely disappeared from the spectra. The other NAP show a huge increase within the pollen sum, from 59% in the previous zone to 79% in this zone. The NAP (other) is composed of the undifferentiated Asteraceae, Cheno/Am, *Anthospermum*, *Artemisia*, *Stoebe*-type, Aizoaceae-type, *Oxygonum* and those that occur in smaller numbers. Poaceae pollen reaches its lowest peak, at 13% of the pollen sum.

The local elements reach 14% of the total pollen spectra. The locals include pollen of Cyperaceae, Ranunculaceae, Apiaceae, Crassulaceae, Gentinaceae, *Scabiosa* and the trilete spores.

Interpretation

The woody species did not grow near the site, but grew some distance away, as they currently occur on the mountain the slopes. The vegetation that existed during the accumulation of zone B4 was a dry karroid vegetation dominated by herbs and shrubs of Asteraceae, *Anthospermum* and Cheno/Am. This seems to have been a relatively dry period with low summer rains that supported the karroid vegetation. High evaporation rates must have brought about an increase in Cheno/Ams.

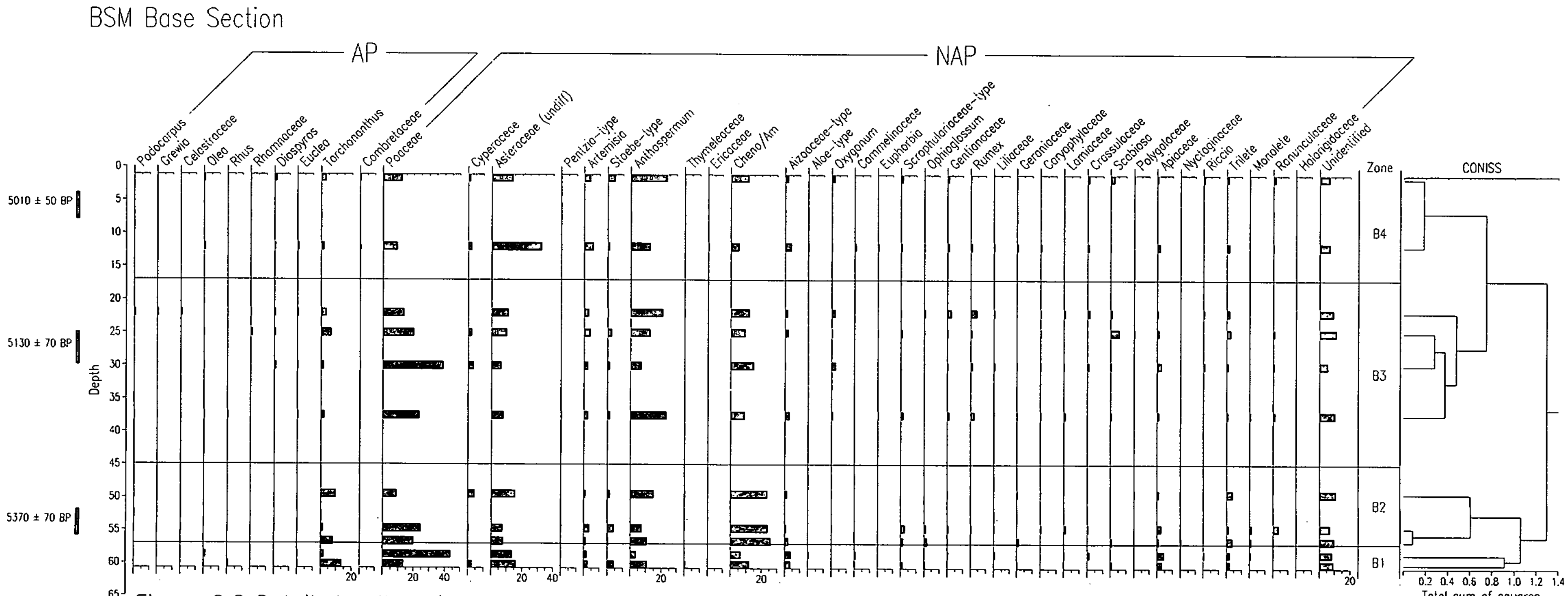

Figure 8.8 Detailed pollen diagram of the Base Section.

Base Section

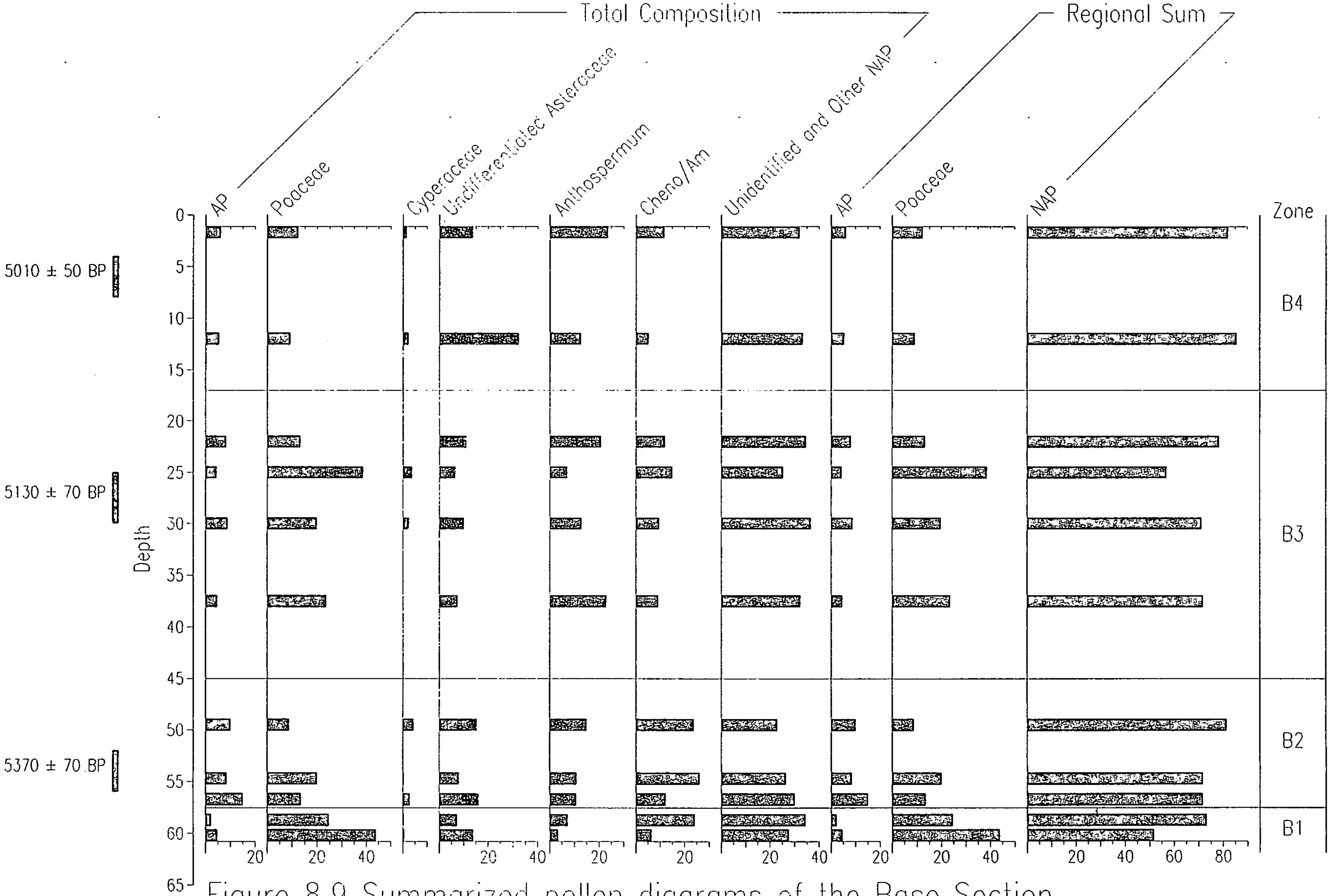

Figure 8.9 Summarized pollen diagrams of the Base Section.

The Gutter Section

The Deposit

Figure 8.10

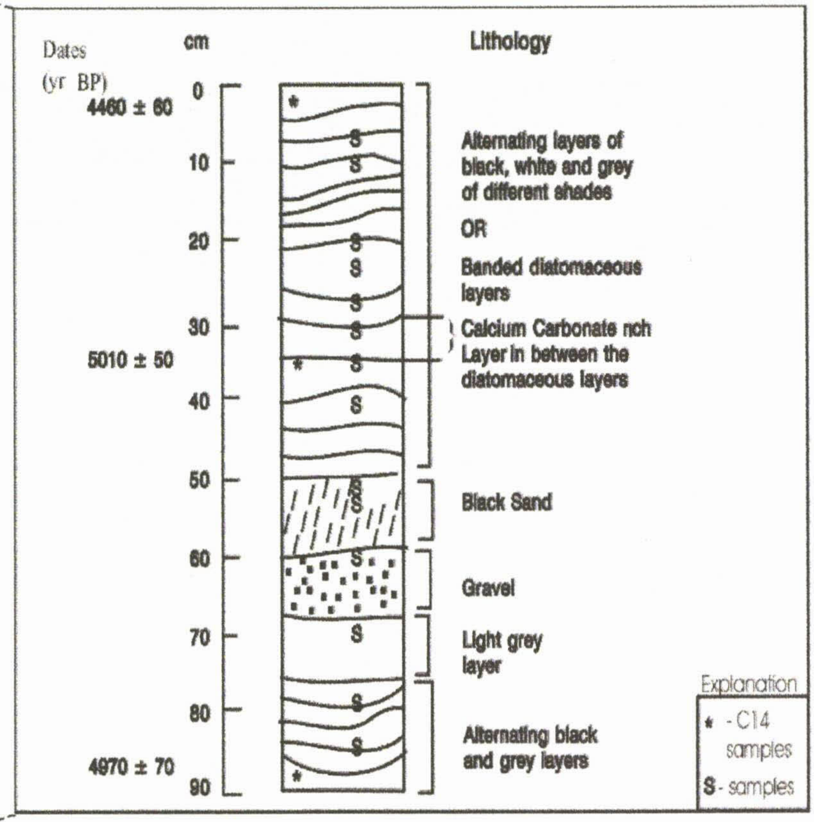

Figure 8.11. Gutter Section Profile.

Figure 8.10 is a photo of the complete Gutter section sequence after it was collected. Figure 8.11 shows the Gutter section profile with lithology, C^{14} dates and analysed samples.

This section was collected some meters to the left and below the BSM97 section (see Fig. 8.1), as a 90cm long sequence of stratified sediments. Like the Base section, it consists of thin layers of interchanging black, white and grey layers of different shades with diatoms. Most of the light banded layers consist of diatoms, (see Fig. 8.11) but between 29 and 35cm, a carbonate rich layer is found (Jansen van Vuuren, unpublished). These layers continue up to 50cm of the sequence where a dark organic sand layer occurs *ca.* 50 - 60cm, above a 9cm-gravel layer. Between 69 and 76cm, a grey layer of clay overlies alternating thin black and grey layers which continue up till the end of the sequence at 90cm (see Fig. 8.11).

These banded diatomaceous layers in the sequence were thought to indicate regional changes in climate, as the diatom concentration increases in the white and grey layers and declines in the black ones. But then, since no significant pollen changes were recognized to suggest this, the layers must be indicative of only local changes (Jansen van Vuuren, unpublished).

The Pollen Diagram Description and Interpretations

The pollen diagram (Fig. 8.12) has 52 pollen types, including the unidentified. Prominent pollen types are the Poaceae, Cyperaceae, Asteraceae, *Artemisia*, *Anthospermum* and the Cheno/Am. Three dates were obtained from this section. They are not in chronological order and this may be an indication of reworking of sediments from high up in the stream. The top of the sequence is dated 4460 ± 60 yr BP, the mid-part 5050 ± 50 yr BP and the bottom 4970 ± 70 yr BP (see Fig). Six pollen assemblage zones, G1, G2, G3, G4, G5 and G6 were distinguished, for the Gutter Section.

Table 8.4 gives the pollen concentration for samples from the Gutter Section. The maximum pollen content per gram is 1.7×10^5 for sample 2152.15, although the concentration is generally lower than for the BSM97 and Base sections.

Table 8.4. Pollen concentration values for the Gutter Section.

Sample no	Depth (cm)	Grains g^{-1}
2152.6	8	7.2×10^1
2152.7	10.5	1×10^4

2152.19	15.5	1.3×10^2
2152.8	21	2.7×10^3
2152.9	23.5	1×10^3
2152.10	28	3.1×10^2
2152.11	31.5	4.8×10^2
2152.13	36	9.7×10^3
2152.14	42.5	1.2×10^3
2152.15	51.5	1.7×10^5
2152.20	54.5	5.7×10^2
2152.21	61	6×10^1
2152.16	70.5	2.4×10^3
2152.17	80	4.9×10^2
2152.18	85	1.5×10^3

Zone G1

This is the deepest zone of the sequence and it covers the interval between 65cm and 90cm. A date of 4970 ± 70 yr BP was obtained between 87 and 90cm of this zone.

The Pollen and Spore Composition

The AP is very scarce in this zone as they only make up 4% of the pollen sum. The AP is composed of *Podocarpus*, *Rhus*, Combretaceae, Celastraceae, *Olea*, *Diospyros*, *Euclea* and *Tarchonanthus*. The other NAP constitute about 59% of the pollen sum, with large numbers of the undifferentiated Asteraceae, followed by Cheno/Ams, *Artemisia*, *Anthospermum*, *Stoebe*-type, Aizoaceae-type and Scrophulariaceae-type. Pollen types such as the *Aloe*-type, *Oxygonum*, *Ophioglossum* and Thymeleaceae are also present, but occur in low numbers. The grasses account for 37% of the pollen sum.

The local elements make up 4% of the total pollen spectra and include pollen of Cyperaceae, Ranunculaceae, Apiaceae, trilete and monolete spores as the major components of the swamp. Other local species such as Campanulaceae, Halorigidaceae, *Rumex*, Gentianaceae, Liliaceae, Caryophyllaceae, *Scabiosa,* Lamiaceae, Crassulaceae and are found at values less than 1% of the total pollen spectra.

Interpretation

The small numbers of AP indicate that trees occurred some distance away from the site, with *Tarchonanthus* as a dominant shrub in the slopes. The pollen spectra points to a grassy vegetation with some herbs and shrubs of Asteraceae, *Artemisia*, *Stoebe*-type, *Anthospermum* and Cheno/Am. Locally, grasses had expanded at the expense of the swamp elements. This vegetation indicates that conditions were relatively humid during this period.

Zone G2

This zone covers the interval between 53cm and 65cm. No radiocarbon dates were obtained for this zone.

The Pollen and Spore Composition

The AP has slightly increased in numbers from the previous zone to 6.4% of the pollen sum. The AP is composed of *Podocarpus, Clutia*-type, *Euclea, Tarchonanthus Olea*, *Diospyros,* Rhamnaceae and Celastraceae. The other NAP shows a remarkable increase to 74% of the pollen sum, although there is a huge drop in the numbers of the undifferentiated Asteraceae in this zone. The Cheno/Am seem to have replaced the undifferentiated Asteraceae as the main components of the other NAP. Pollen of *Anthospermum*, *Artemisia*, Aizoaceae-type and *Stoebe*-type are also part of the NAP (other). The Poaceae show a drop in their numbers from 37% in zone G1 to 20% in this zone.

The local palynomorphs show an increase in composition and they include, Cyperaceae, Ranunculaceae, Apiaceae, trilete and monolete spores with some pollen types that occur in smaller numbers.

Interpretation

There was a slight increase in the number of trees during this phase, although they still occurred some distance away from the site. The vegetation was a karroid one, which mainly consisted of Cheno/Ams, while the composition of grasses and Asteraceae species decreased. The increase in Cheno/Ams could be a local effect that was created by the formation of an evaporative surface in the sediment sequence. The drop in both shrubs and grasses points to a decline in precipitation.

Zone G3

This zone covers the interval between 53cm and 34cm. The anomalous date of 5050 ± 50 yr BP was obtained for this zone.

The Pollen and Spore Composition

The AP accounts for 7% of the pollen sum and it is composed of *Podocarpus*, *Grewia* (which only appears in this zone), Celastraceae, *Olea*, *Diospyros*, *Euclea* and *Tarchonanthus*. The NAP has decreased to 67% from 74% in the last zone. The NAP consists of the undifferentiated Asteraceae, Cheno/Am, Aizoaceae-type, *Artemisia*, *Stoebe*-type, *Anthospermum* and other pollen types that occur at less than 1%. Poaceae pollen increases slightly from 20% to 26% of the pollen sum in this zone.

The local elements include Cyperaceae, Gentianaceae, Campanulaceae and trilete spores, together with pollen types that occur in smaller numbers. These local elements only reach 4% of the total pollen spectra.

Interpretation

There was no change in the numbers of trees, but *Tarchonanthus* shrubs and Ebenaceae species (*Euclea* and *Diospyros*) were prominent in the mountain slopes. The regional vegetation was shrubby with some grasses. The Asteraceae species, Anthospermum and Cheno/Ams were abundant in the vegetation. The increase in shrubs might have been triggered by a decline in summer rains, although grasses were still present.

Zone G4

This zone covers the interval between 22cm and 34cm and no C14 dates were obtained.

The Pollen and Spore Composition

The AP numbers are still constant at about 7% of the pollen sum as in the last zone. The main constituent of the AP is *Tarchonanthus*, followed by Celastraceae, *Podocarpus*, Rhamnaceae, *Euclea*, *Rhus*, *Olea* and *Diospyros*. The other NAP drops from 67% in the previous zone to 58% of the pollen sum in this zone. The NAP (other) is composed of the undifferentiated Asteraceae, Cheno/Am, *Anthospermum*, *Artemisia*, *Stoebe*-type and others with smaller values. There is a 10% increase in Poaceae numbers, from 26% to 36% of the pollen sum in this zone.

The local elements show a general increase, as the Cyperaceae, Apiaceae, trilete and monolete spores all increase in numbers. Other pollen types occur in smaller numbers.

Interpretation

Caution is necessary with the following interpretation as it might contain reworked pollen, as suggested by the anomalous radiocarbon date obtained from this zone. Nevertheless the spectra indicate good grass cover with some herbs and shrubs and relatively humid conditions. The high numbers of Cyperaceae in the swamp (see Figs. 8.11 and 8.12) points to wet local conditions. Local evaporation increased later on in this zone and this led to an increase in Cheno/Ams (see Figs. 8.11 and 8.12).

Zone G5

This zone covers the interval between 13cm and 22cm and no radiocarbon dates were obtained.

The Pollen and Spore Composition

There is a decline in the AP numbers as they drop from 6% to 4% of the pollen sum in this zone. The AP is composed *Tarchonanthus*, *Podocarpus*, Rhamnaceae, Celastraceae, *Euclea* and *Rhus*. Pollen of *Olea* and *Diospyros* has disappeared completely. The NAP reach their highest peak ever at 80% and this is mainly due to a marked increase in Asteraceae pollen (undifferentiated). The other NAP types include, the Cheno/Am, *Anthospermum*, *Artemisia*, *Stoebe*-type, Aizoaceae-type, Scrophulariaceae-type, together with those found in smaller values. Poaceae pollen reaches its lowest peak at 16% from 36% of the pollen sum in the previous zone.

The local flora makes up 7% of the total spectra and is composed of trilete spores and Cyperaceae which show a drop in numbers in this zone. The other local elements occur at less than 1%, each.

Interpretation

The vegetation that occurred during this period was of a dry and karroid nature, where Asteraceae shrubs and herbs had expanded at the expense of grasses and therefore dominated the grassveld. This sharp increase (see Figs. 8.11 and 8.12) in the undifferentiated Asteraceae indicates a change to relatively dry conditions, whereas the drop in Cheno/Ams points to lower evaporation rates.

Zone G6

This is the topmost zone of the Gutter section and covers the interval between 8cm and 13cm. A date of 4460 ± 60 BP was obtained above this zone between 0 and 5cm.

The Pollen and Spore Composition

The arboreal pollen increase slightly reaching about 7% of the pollen sum, while the other NAP decrease to 61% from 80%. The AP consists of *Tarchonanthus*, Celastraceae, *Podocarpus, Olea*, *Rhus*, *Diospyros* and *Euclea*. The other NAP includes the undifferentiated Asteraceae, Cheno/Am and *Anthospermum* as the most important types in this zone. The Aizoaceae-type, *Artemisia, Stoebe*-type, *Pentzia*-type, *Aloe*-type, Restionaceae and *Ophioglossum*, form a small part of the other NAP. Pollen of *Artemisia* drops to its lowest, while the *Aloe*-type reaches their highest peak in this zone. Other types of pollen occur in smaller numbers. Poaceae pollen increases again, reaching about 33% of the pollen sum.

The local elements show a marked increase, as they constitute 12% of the total pollen spectra in this zone from 7% in the previous zone. Pollen of the Cyperaceae, *Scabiosa,* Crassulaceae, Ranunculaceae, trilete and monolete spores show an increase in this zone.

Interpretation

In this vegetation grasses dominated, followed by the Asteraceae and then the Cheno/Ams. Both the grasses and the Cheno/Am show an increase in this zone and this therefore, indicates that conditions were relatively humid with strong evaporation. The marked increase in swamp elements points to an expansion of the swamp which also indicates that conditions were favourable.

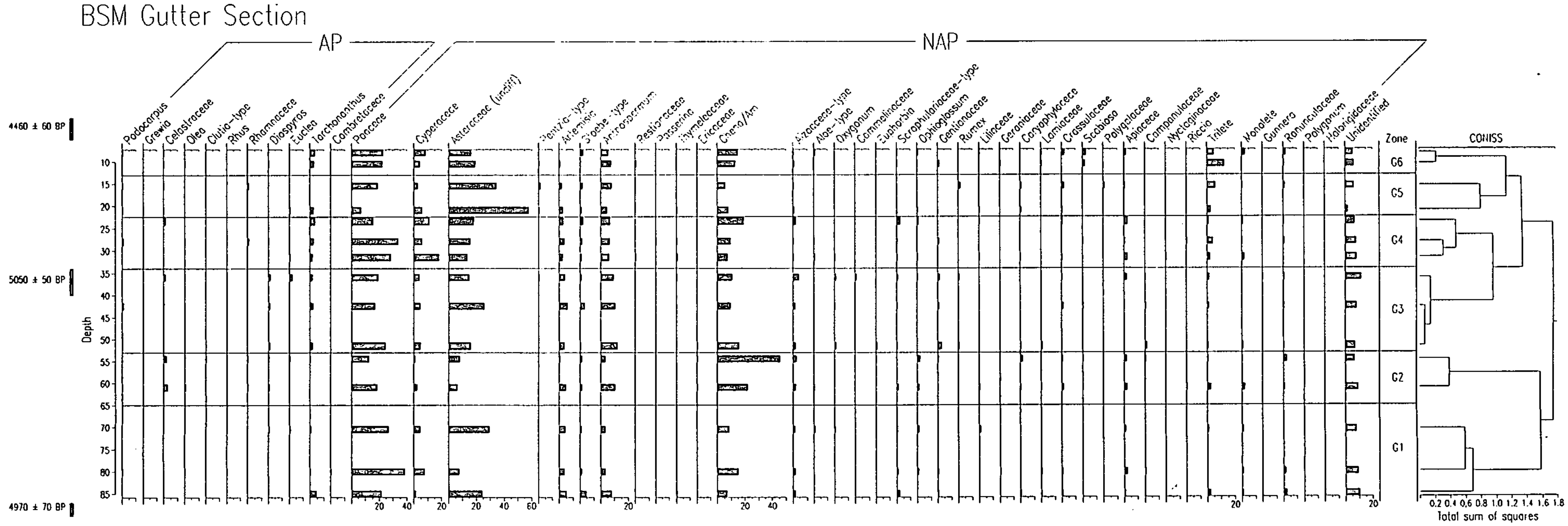

Figure 8.12 Detailed pollen diagram of the Gutter Section

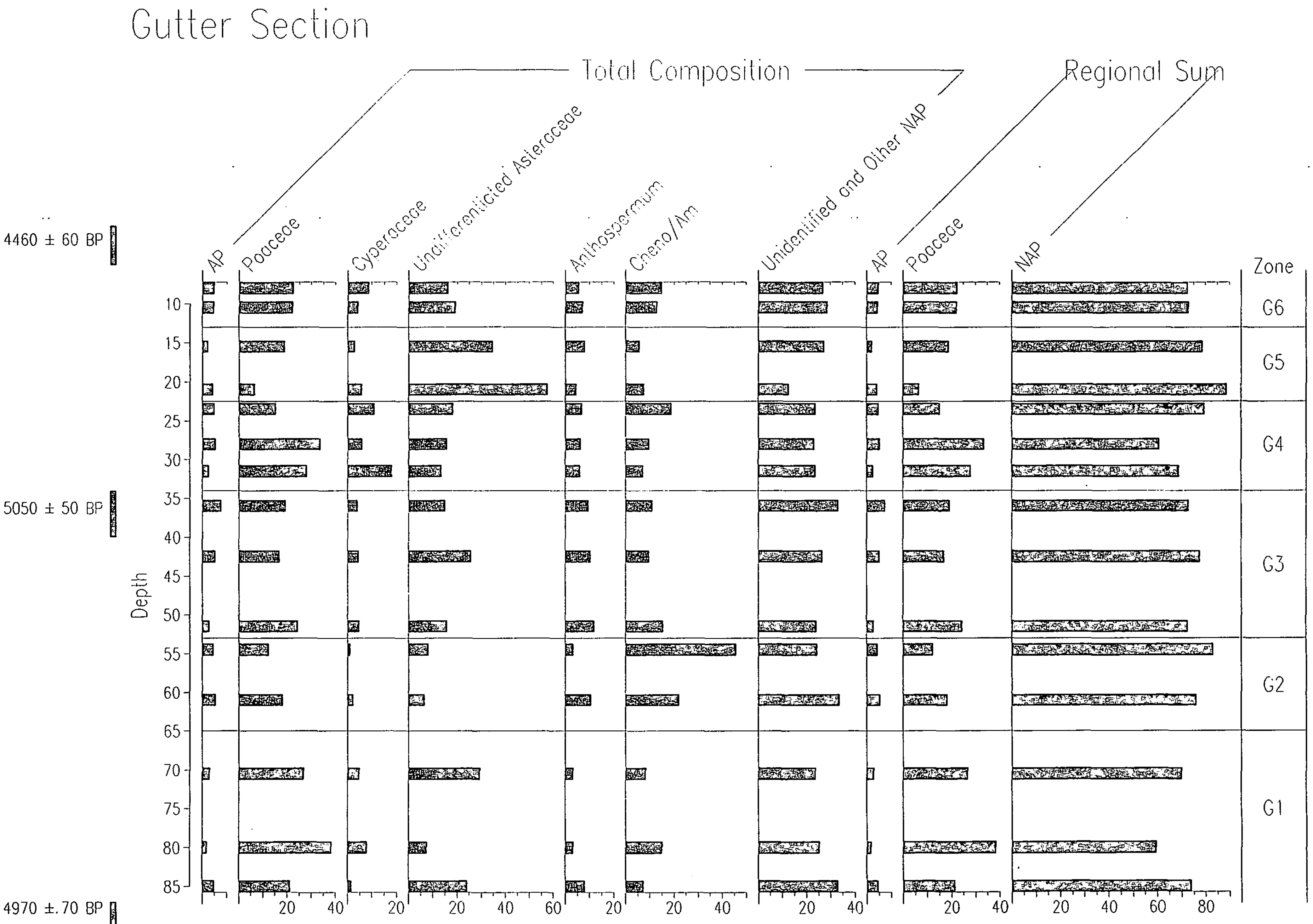

Figure 8.13. Summarized pollen diagram of the Gutter Section.

Principal Components Analysis

As mentioned in Chapter 3, principal component analysis (PCA) was carried out on data from the three sections of Blydefontein, (BSM97, Base and Gutter). This data was lumped together with those of Bousman *et al.* (1988) and Bousman (1991), so as to have a larger database that would give a broader representation of climatic changes that took place in the Blydefontein basin during the Holocene. The PCA results are shown in Fig. 8.14 for PC1 and PC2, and Fig. 8.15 for PC1 and PC3. The significance of the first principal component (PC1) is not clear at this stage from an ecological point of view. PC1 (Fig. 8.14) groupings show negative loadings on Poaceae, Cyperaceae, Aizoaceae and Asteraceae elements and positive loadings on Chenopodiaceae/Amaranthaceae, *Tarchonanthus, Anthospermum, Podocarpus* and Ranunculaceae. The pollen groupings cannot be related to specific environmental conditions. The same conclusion is reached for PC2. PC3 (Fig 8.15) can, however, be related to moisture conditions as it shows positive values on Asteraceae elements, Aizoaceae and others that possibly indicate regional dryness, and negative values on Cyperaceae, Poaceae and *Podocarpus* pollen. Figure 8.16 shows PCA curves of the three principal components only in the case of the BSM97 data, which is the longest sequence, studied here. All three components show the 'marked change' in pollen composition above 450cm of the sequence. If PC3 is taken as a moisture indicator, it however, suggests that this change does not necessarily represent much drier conditions than the levels around 580-590cm. This supports the contention that the change above 450cm is possibly due to post depositional alteration (eg. selective preservation). PC3 also indicates the relatively moist conditions soon after *ca.* 4850 yr BP.

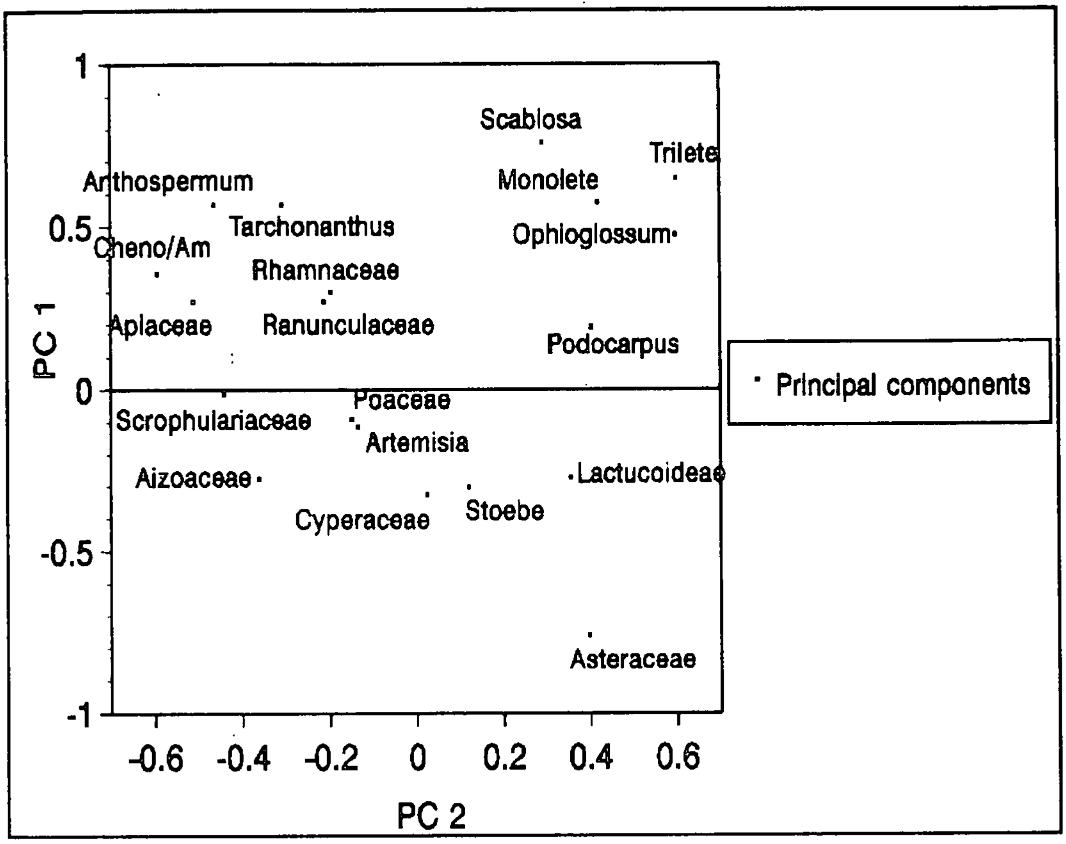

Figure 8.14. PC1 (% variance) and PC2 (% variance) loadings of the most prominent pollen types from Blydefontein.

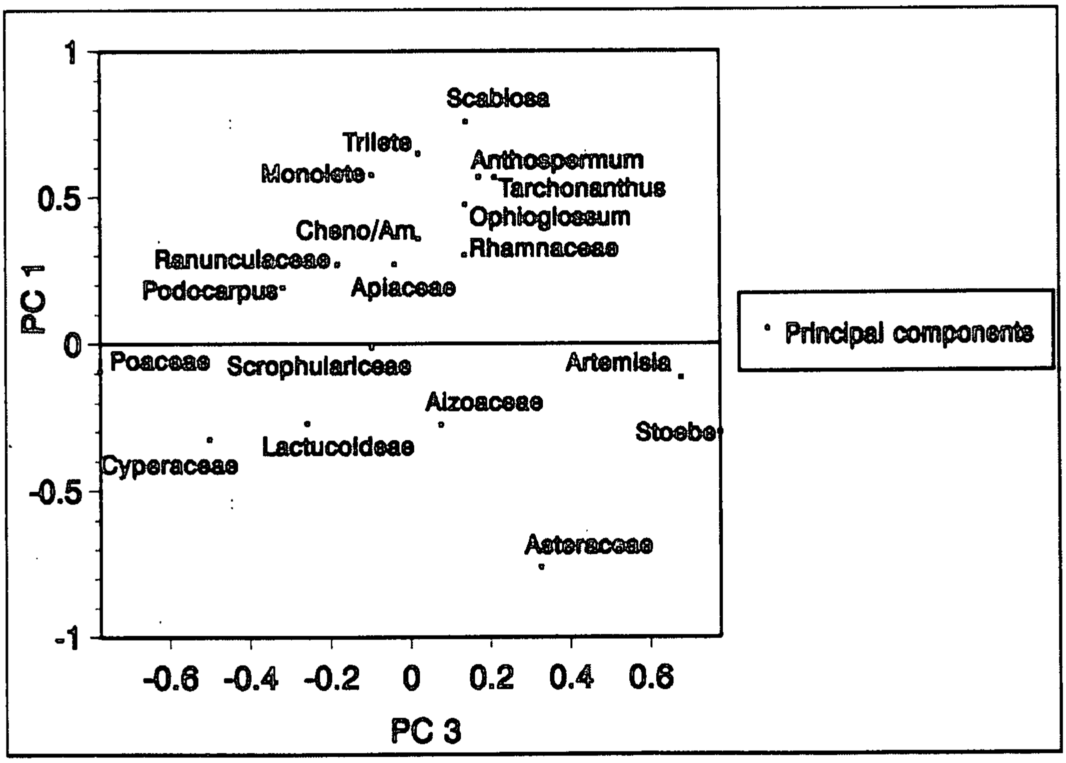

Figure 8.15. PC1 (% variance) and PC3 (% variance) loadings of the most prominent pollen types from Blydefontein.

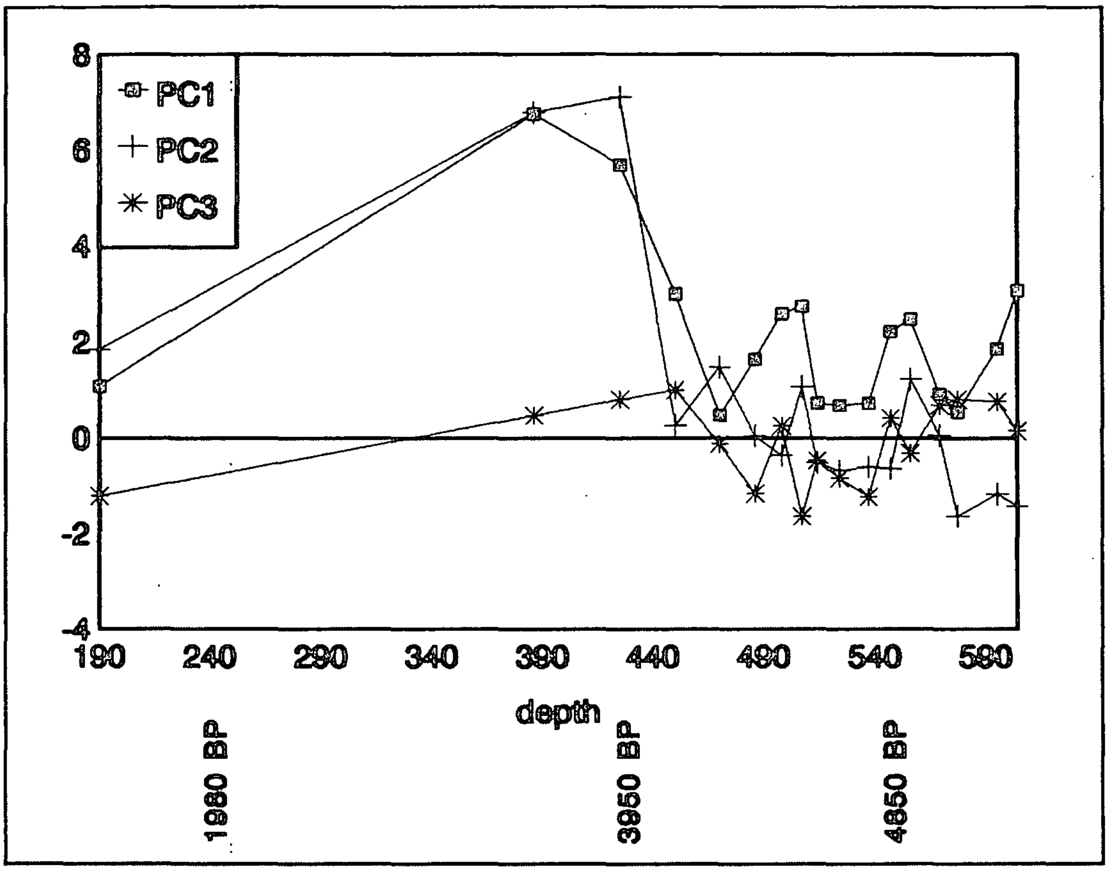

Figure 8.16. PCA curves for BSM97 derived from factor values of the most prominent pollen types.

Summarized Palaeoenvironmental Conclusions of the Blydefontein Sites

The three sections from Blydefontein suggest that changes in vegetation occurred between *ca.* 5500 and *ca.* 1800 yr BP in response to fluctuations in climate, although smaller changes in pollen composition may be due to local sedimentation and succession. Evidence from the Base Section shows that conditions were sub-humid with dry episodes between *ca.* 5400 and *ca.* 5000 yr BP. A sub-humid, warm vegetation with good grass cover and evaporative conditions occurred in this region until the end of zone B3, where Asteraceae shrubs and herbs expanded at the expense of the grasses. This latter period was relatively dry and possibly cooler as *Artemisia* and *Stoebe*-type herbs (see Table 8.5) replaced the Cheno/Ams.

Table 8.5. Blydefontein: Interpretation of the pollen data

Age (yr BP)	Blydefontein sites and Zones	Vegetation Type	Interpretation
< 2000	BSM97	Grassy	Sub-humid
ca. 2000	BSM97	——	Dry event
2000-4000	BSM97	——	Poor pollen preservation
ca. 4400-4000	BSM97	Small shrubs	Relatively dry and warm
ca. 4850-4400	BSM97, Gutter Sect.	Grassy with some shrubs	Sub-humid and cool
ca. 5000	Base Sect, BSM97, Gutter Sect	Shrubby with grasses	Dry
ca. 5100	Base Sect.	Grassy	Sub-humid
ca. 5200-5400	Base Sect.	Grassy with shrubs	Sub-humid to dry and warm

In the Gutter Section anomalous dates makes it impossible to give a clear picture of environmental changes that took place, though if the 5050 yr BP date were true, then the evidence would compare well with that from the Base and BSM97 sections. Zone B4, dated 5010 yr BP and zone G3, dated 5050 yr BP, happen to both show increases in Asteraceae, *Anthospermum*, *Artemisia* and *Stoebe*-type shrubs and herbs and a decrease in grasses and Cheno/Ams. This would therefore, be indicative of less summer rains relative to winter rains with slightly cool conditions in the region. A similar change is seen from the bottom of the BSM97 section, *ca.* 520cm before 4850 ± in zone A (Fig. 8.4).

The BSM97 section shows a period of grassy and cool conditions, immediately after 4850 ± 60 yr BP where *Anthospermum* and not Cheno/Ams were abundant. Zone C points to a change to dry and evaporative conditions as the Asteraceae and Cheno/Am shrubs and herbs dominate in the vegetation. Similar trends in vegetation changes are recognized in the Gutter section - zones G4 and G5. Poor pollen preservation was recorded in sediments dating between *ca.* 4000 and *ca.* 2000 yr BP as the pollen hiatus in the BSM97 sequence, between 375 and 200cm indicates (Fig. 8.4). These harsh conditions may also be evident in zone D, where trilete ferns dominate the pollen spectra probably as a result of selective preservation. Above this level, these robust spores could not survive dessication and oxidation. The negative evidence should, however not be taken as evidence that this whole interval was warm and dry as some pollen might have been destroyed by adverse conditions some time long after their deposition. Around 1800 yr BP, conditions ameliorated and grasses became dominant in the vegetation.

CHAPTER 9

GENERAL PALAEOECOLOGICAL RECONSTRUCTION, CORRELATION AND CONCLUSION

In the previous chapters, interpretations of data and reconstructions of past environments for each site were carried out. In this chapter, a regional palynological interpretation from the three sites of the study area is considered in the light of other relevant palaeoenvironmental investigations in southern Africa. It is assumed that the various radiocarbon dates obtained from different laboratories and different materials are fairly accurate and comparable. The information will then be further evaluated in the context of models for the mechanism of palaeoclimatic changes in southern Africa and elsewhere in the world as proposed by Wright, *et al.* (1993); Street-Perrot & Perrot, (1993); Tyson, (1986); Cockcroft *et al*, (1987) and Tyson & Lindesay, (1992).

ca. 6500 – *ca.* 6000 yr BP

The oldest date obtained from the Florisbad sequence is 8170 ± 90 yr BP and represents a barren section of the sediments. Between 6500 - 6290 yr BP, palynological evidence from this sequence indicates that conditions were relatively dry and warm with high evaporation rates, shown by low grass pollen and Cheno/Am content. Between *ca.* 6000 and 4500 yr BP, Butzer (1984a), notices a dry period marked by a break in deposition and soil stability from sediments in the western Free State and low archaeological visibility in this region during this time. Further support of a dry phase for this period is indicated at the Voigspost site where (Horowitz *et al.*, 1978) sediments deposition occurred under dry conditions, around 6350 yr BP. There is evidence from sediment analyses which suggest that a drier and possibly cool phase occurred from 9000-5000 yr BP at Tlaeeng Pass, in Lesotho (Marker, 1998). Charcoal analyses from Colwinton points to the prominence of *Euryops* species (favour arid climates) over *Leucosidea*, *Cliffortia* and *Passerina* (favour moist environments) at 6270 yr BP and also at Ravenscraig during the mid and early Holocene, but not after 3000 yr BP (Deacon & Lancaster, 1988; Tusenius, 1989; Wadley *et al.*, 1992). There is a break in occupation at

Boomplaas between *ca.* 9000-6400 yr BP and temperature estimates and charcoal analyses (Thackeray, 1987; Scholtz, 1986 in Deacon & Lancaster, 1988) show a sample from 6400 yr BP as the warmest of the sequence with hot and dry summers suggested by the charcoal wood anatomy. Bousman *et al.* (1988) also indicate that conditions were dry before *ca.* 5000 yr BP in Blydefontein (Blydefontein section and Channel 2), as a shrubby karroid vegetation with Asteraceae, including *Stoebe* or *Elytropappus* type occurred there around that time.

There is, however evidence from the Kalahari and Savanna regions that point to increases in temperatures coinciding with high moisture availability. Palaeoenvironmental interpretations from the northern part (Savanna and Kalahari) during *ca.* 7500-5000 yr BP, give a very different picture from what the results of this study suggests. Spring sediments from the Transvaal, in Rietvlei, Wonderkrater, Tate Vondo (Scott, 1982b, 1987, 1989, 1990; Scott & Vogel, 1983) show a more broad-leafed bushveld community with Combretaceae from around 7500 yr BP. This change in vegetation signified the gradual onset of wetter and warmer conditions although indications are that around 6000 yr BP, conditions were still drier than at present (Partridge *et al.*, 1999). An increase in Combretaceae around *ca.* 7200 yr BP is also indicated by pollen from the Pretroria Saltpan Core (Partridge *et* al., 1993). Relatively warm and slightly sub-humid conditions are suggested for Wonderwerk, Kathu Pan and Equus Cave in the Kalahari between *ca.* 7500-5000 yr BP (van Zinderen Bakker, 1982; Beaumont et al., 1984; Scott, 1987). Palynological evidence (Scott, 1993) and a peak in excess air in the Stampriet aquifer (Stute & Talma, 1997) point to an increase in moisture in the Kalahari at *ca.* 6000 yr BP. Temperature (Heaton, *et al.*, 1986) and pollen data (Scott, 1999) from the Uitenhage aquifer show a temperature peak at *ca.* 6000 yr BP, as isotopes, growth and colour banding from the T7 stalagmite in Cold Air Cave suggest warmer, moister conditions between 6600-5500 yr BP (Holmgren, *et al.*, 1999; Holmgren, *et al.*, XV INQUA'99).

ca. 5400 - 5000 yr BP

The Blydefontein BSM97 and Base sections together with the Florisbad sequence indicate changes in vegetation and climate around this period. Pollen analyses from the

Base section deposits at Blydefontein indicate sub-humid conditions with some dry spells. Changes in local evaporation rates are also indicated at the beginning of this period by the prominence of Cheno/Ams, which were later replaced by *Anthospermum.* The BSM97 deposits show that a grassy, karroid vegetation with some *Anthospermum* and Cheno/Ams occurred before 4850 yr BP signalling the beginning of a sub-humid phase. Earlier palynological work from the BSM and Hughdale sites in Blydefontein (Bousman, 1991), show a dry phase from *ca.* 5400 to ca. 5000 yr BP, but the resolution of these are not high enough for detailed comparison with the new sequences from the site. In Florisbad this period in not well documented as no dates are available, but it could fall within zone F3 (Fig. 7.4) which has a barren part and one sample with Asteraceae species in abundance, pointing to very dry conditions with reduced summer rains. Micromammalian evidence from Nkupe in Natal indicates that the grass was more open and shorter between *ca.* 6600-5000 yr BP (Avery, 1990), pointing to drier conditions around this time.

Most of the available evidence from the southern part of South Africa support the results from the studied sites for dry and warm conditions around *ca.* 6500 - 5000 yr BP in the interior plateau regions.

ca. 4800-4000 yr BP

This phase is represented in the Florisbad and BSM97 sequences. The BSM97 pollen spectra shows a marked increase in Poaceae pollen at 4850 ± 60 yr BP and a decline in Asteraceae shrubs, indicating a rise in summer precipitation. Pollen analysis of the Florisbad sediments points to a similar change in vegetation before 4220 yr BP when moisture conditions seem to have increased. Apart from the sub-humid conditions, both sequences indicate this period as a possibly cooler phase, shown by a reduction in Cheno/Ams and an increase in *Anthospermum* in BSM97. Higher numbers of Ericaceae pollen in cave deposits in the Blydefontein shelter, around 4100-4300 yr BP support the indications of cooler conditions (Scott & Bousman, unpublished data). Evidence from the Uitenhage aquifer shows that cooling occurred at 5000 yr BP (Heaton *et al.*, 1986; Scott & Vogel, 1999).

A change to a more grassy veld from a formely shrubby environment is also indicated for Blydefontein at Channel 2, before 4290 yr BP. Such a change is suggested from evidence of the old BSM sequence to have been complete by 5000 yr BP (Bousman *et al.*, 1988, Bousman, 1991). The evidence from the old and the new BSM sequences indicate that a change from vegetation representing an all season rainfall to more grassy vegetation with increased summer rains was gradual. This is in contrast with results from the Base section that has a better resolution, which indicates that the mid-Holocene change to wetter conditions was in fact, abrupt. In Badsfontein, at a thermal spring site 80km from Blydefontein, wetter conditions appeared some time before 4550 yr BP (Scott & Cooremans, 1990). Evidence from spring and lunnette sequences in Deelpan suggests that increased wetness was already present by 4000 yr BP (Scott, 1988; Scott & Brink, 1993). This is supported by Butzer's (1984) evidence for more moisture from pans and springs in the western Free State around 4500-1300 yr BP. Other evidence of wet conditions for this period are indicated by the deposition of organic sediments at the Tlaeeng Pass, from 5000-1000 yr BP (Marker, 1998), while Avery (1990), shows evidence of increased density in grasses between *ca.* 5000-4000 yr BP in Natal. Carbon isotope data from the Cango Cave stalagmite suggests an increase in moisture from *ca.* 5000 yr BP, reaching a peak at 2000 yr BP (Talma & Vogel, 1992). A similar tendency is supported by carbon isotopes in Cold Air Cave and Ficus Cave stalagmites, as they show peaks of C4 grass *ca.* 5000 yr BP (Holmgren *et al.*, 1999, XV INQUA).

ca. 4000-3000 yr BP

This period is represented by sequences from Elim - Channel 1 and 2, Florisbad and BSM97. Although dates from Elim show some discrepancies, the palynological evidence indicates that conditions were not very favourable during this time, as possibly dry vegetation occurred. Fern spore numbers are over-represented, which indicates possible post-depositional drying out or dessication of the sediments. The Florisbad sequence indicates sub-humid and possibly cool conditions up to 3710 ± yr BP, as both grasses and Cyperaceae dominate the spectra (Fig 7.4), and Cheno/Ams are low. Above this level, a gap occurs in the sequence where the sediments are barren of pollen, because of unfavourable conditions for pollen preservation that prevailed during this period. Grassy vegetation is again indicated around 3100 yr BP. A sudden change in vegetation is also seen from the BSM97 sequence shortly before 3950 ± 40 yr BP, where a sharp decline in grasses and an increase in shrubs and ferns occur. Around 3500 yr BP until *ca.* 2000 yr BP this sequence is barren of pollen (Fig 8.4). These vegetation changes at Blydefontein indicate a drier regional climate.

When comparing environmental changes that took place between 4000-3000 yr BP from the three sites, a similar trend is seen. The Elim and BSM97 sites both show an abnormally high number of fern spores probably indicating selective preservation and regionally dry conditions. Also, the BSM97 and Florisbad sites have a gap in the sequence around the same time. These perculiar changes may be interpreted as harsh conditions that were experienced on a regional scale during this period. The Blydefontein Section of Bousman *et al.* (1988) shows that grassy karroid vegetation representing an all-season precipitation occurred shortly before 3290 yr BP. But, because of lack of samples below this point, it is uncertain as to whether or not the same harsh conditions suggested for the BSM97 sequence could also be identified here. Sequences from Moreletta and Rietvlei in the Transvaal (Scott, 1984; Scott & Vogel, 1983) like the BSM97 and Florisbad deposits, show an absence of pollen for some time between *ca.* 5000 and 1000 yr BP. Other palynological results from the Transvaal, in Wonderkrater and Scot show substantial increases in Asteraceae pollen as well as fern spores relative to arboreal pollen (Scott, 1982b, c), pointing to a different rainfall pattern in the region (Scott, *et al.*, XV INQUA'99). Carbon isotopes in a stalagmite at the Cold Air Cave show enriched C^{13} values between *ca.* 4000-2000 yr BP, showing grassy environments around that period (Holmgren *et al.*, 1999). This is supported by pollen data from Scot that indicates two peaks of high swamp forest growth, after *ca.* 3000 yr BP, that might be related to peaks in the Cold Air Cave (Scott, 1982c; Holmgren *et al.*, XV INQUA'99). On the other hand, the nearby Ficus Cave indicates somewhat higher porportions of C_3 vegetation, probably pointing to cooler conditions (Spreckly et al., XV INQUA'99).

Evidence of charcoal analysis from Colwinton and Ravenscraig (Tusenius, 1989) supports the occurrence of drier conditions during this phase. Environmental changes in the Kalahari, in Kathu Pan and Wonderwerk indicate a dry period around 4500 - *ca.* 2000 yr BP, when in both sites a treeless grassland survived during this time (Beaumont *et al.*, 1984; van Zinderen Bakker, 1982). Butzer (1984) also reiterates the occurrence of a dry period in the Kalahari from evidence of the Kathu vlei sediments that show an open vegetation cover between *ca.* 4400-3000 yr BP. Micromammalian evidence from Wonderwerk supports a dry period around 4800 to ca. 4000 yr BP, when grasses were prominent and trees restricted to water courses (Avery, 1981). Scott (1987), from unit 1A in Equus Cave, dated between 7480 ± 80 and 2390 ± 55 yr BP recognized a decline in woodland pollen in the middle section of this unit. This change in vegetation although not dated could support the alleged dry phase that took place in the Kalahari during mid-late Holocene. In the south-western Cape, on the Karoo side of the Cedarberg mountain vegetation changed from more succulent to more karoo shrub, fynbos and renosterbos between *ca.* 4000-3500 yr BP (Scott, 1994), indicating a change in climate. In Natal, shorter and more open grass occurs at *ca.* 4000-3000 yr BP and Avery (1990) suggests this is because of increased dryness during this phase.

Deacon and Lancaster (1988) compiled evidence from different sources indicating that wetter intervals occurred in lake levels and alluvial deposits between *ca.* 4000-3000 yr BP at Makgadikgadi (Helgren, 1984), Drotsky's Cave (Corey & Cooke, 1977) and Alexandersfontein (Butzer *et al*, 1978). Avery, (1997) reports Opperman (1987) as suggesting a wet phase between *ca.* 4000-3000 yr BP in the southern Drakensberg and this supports wet conditions for this period.

To conclude, therefore, evidence from different parts of the interior suggest a marked change in conditions between 4000-3000 yr BP, but interpretations seem somewhat contradictory on whether it was dry or wet. Seasonality changes may have been a major factor, making for conditions that are difficult to reconstruct.

ca. 3000-*ca.* 1700 yr BP

The Florisbad sequence represents the whole of this period, while the BSM97 contains only the later part. Grassy vegetation occurs in Florisbad from *ca.* 3140 to about 2000 yr BP, indicating relatively humid conditions at this time. A possible rise in temperature that is accompanied by an increase in Cheno/Ams and a decline in grasses is seen around 2000 yr BP, but by *ca.* 1710 yr BP, a grassy vegetation develops again showing an improvement in the climate. The absence of pollen at this time in the BSM97 spectra may imply that unfavourable conditions still occurred around 2000 yr BP. Grassy vegetation only appears in the sequence some time after 1980 yr BP, suggesting a change to sub-humid conditions. Bousman's (1991) Hughdale section from near Blydefontein shows that a grassy karroid vegetation occurred around 2520 yr BP, but this is not covered in the BSM97 Section. The USP section from Blydefontein indicates a brief dry phase around 2000 yr BP (Bousman *et al.*, 1988; Bousman, 1991), but later conditions became sub-humid as shown by the grass dominated pollen spectra. There is also isotope and pollen evidence for more grass in the karoo region, which indicate wetter conditions around 2000 yr BP (Talma & Vogel, 1992; Lee-Thorp & Talma, 1999).

This period like the ones before it has been interpreted differently for various regions. Charcoals from East Griqualand sites suggest relatively moist conditions after 3000 yr BP (Deacon & Lancaster, 1988). Similar conditions are reiterated by evidence from Boomplaas which indicates that conditions were warm and mesic (Scholtz, 1986 in Deacon & Lancaster, 1988). Increased spring activity, which suggests wet conditions is indicated for the Gaap Escarpment around *ca.* 3200-2400 yr BP (Butzer, 1984b). Relatively humid conditions are indicated to have occurred between 1950-1450 yr BP at Wonderwerk Cave (Beaumont *et al.*, 1984).

About 2500 yr BP in Bonawe, arboreal species were absent and an open scrub occurred (Avery, 1987), indicating cooler or dry conditions around this time. A short dry interval is detected from pan and spring sediments of the western Free State at *ca.* 1800 yr BP (Butzer, 1984a, b). This dry spell could coincide with the one suggested for Florisbad around 2000 yr BP.

Indications by Climatic Models

The Early Holocene

Worldwide climatic trends between *ca.* 8000 and 5000 yr BP indicate increased moisture and temperatures during this period, referred to as the Holocene altithermal or the climatic optimum. The increase in temperature affected the southern hemisphere uniformly (Scott, 1993), but changes in moisture fluctuated on their own in different areas. Following a dry spell in the early Holocene, the northern sites of South Africa show a gradual rise in species adapted to hot and wet climates, wet conditions only reach the southern parts by mid Holocene. Scott (1993) suggests that a pattern of summer rainfall may have developed in the north first and then spread southwards as may be expected from the effect of precession. Scott's suggestion comes from evidence which indicates that the wet climate was experienced in the Karoo relatively late by *ca.* 5000 yr BP (Bousman *et al.*, 1988) and a peak in C^{13} is reached in the Cango Caves by *ca.* 2000 yr BP (Vogel & Talma, 1992), while the savanna and the Kalahari seem to have enjoyed relatively wet conditions from as early as *ca.*7500 yr BP. Therefore, moisture either spread gradually or as Butzer (1984 a, b), Meadows (1988), Scott (1993) and Esterhuysen & Mitchell (1996) have suggested, distinct wet events occurred.

Tyson (1986), Cockcroft *et al.*, (1987) and Tyson & Lindesay (1992) have suggested a model which conceptualizes the modern day wet and dry spells (Fig. 1.2) and they use it to explain the palaeoclimates of the Holocene. Cohen and Tyson, (1995) using the wet and dry spell model, proposed an ocean-atmosphere conceptual model which predicts that upwelling, higher volume transports of the Agulhas Current and reduced influence of winds from the southwest associated with wet spell conditions are likely to result in lower sea-surface temperatures (SST) in the interior region. The reverse was predicted for dry spells. The measured SSTs from Nelson Bay infers high temperatures and dry conditions in the summer rainfall area for the period between 6000 and 4700 yr BP and lower SSTs with wetter interior climates at ca. 8600-6300 yr BP and 3500-2500 yr BP (Cohen & Tyson, 1995). This model seems to agree with evidence which suggests that a dry period occurred around 6500-5000 yr BP, and explains the wet phase identified from the Kalahari and savanna area beginning around 7500 yr BP, by indicating a wet phase in the interior during this time.

Partridge (1997), uses the dry and wet spell model to suggest that the mid-Holocene altithermal (warm event) coincided with the wet spell scenario in which strengthened Walker circulation would have led to an increase in summer rainfall in the northern areas of the sub-continent. During the same time a weaker westerly circulation would have occurred over the southern regions, resulting in drier conditions there. With a poleward retreat of the westerlies and southward invigoration of the tropical easterlies, warming and increasing rainfall would therefore, occur earlier in the north and later in the south. Partridge's (1997) model gives a possible explanation for the differences indicated by the timing of climatic events in South Africa during the Holocene Altithermal. Then again, there is the possibility of two or a series of wet cycles during the Holocene, which could have occurred and not be clearly reflected in the palynological sequences for that time.

The global climate model of Wright *et al.*, (1993) and Street-Perrot & Perrot (1993) that is discussed in Chapter 1 (Fig. 1.1), simulates that both the summer monsoon and the adjacent oceanic anticyclones in the southern hemisphere were weaker around 9000 yr BP than at present. These changes are assumed to be the result of decreased insolation and a reduced land-sea contrast that would have led to dryness. The palaeoenvironmental evidence from South Africa seems to agree with the simulated picture in that they indicate dryness, or the absence of summer monsoonal rains, for that period. The model predicts lowered but growing insolation in the southern hemisphere for the period between 9000-6000 yr BP. The proxy data indicates it as a warming phase, probably accompanied by a lack of clouds during the dry conditions that were implied.

Mid-Holocene to Late-Holocene

A period of very low temperatures, referred to as Neoglacial Cooling is indicated by palaeoenvironmental evidence from various parts of the world to have occurred some time after 5000 yr BP. Results from this study and evidence from several sites in South Africa show the period around and just after 5000 yr BP to have been wet, until after 4000 yr BP when conditions deteriorated. The data from both Floribad and Blydefontein conform with a lowering of temperature, which coincides with the increase in moisture between 5000 and 4000 yr BP, but then such evidence has been indicated elsewhere. For instance, cooler and wetter intervals prevailed in Elands Bay *ca.* 4200 and again 3000-2000 yr BP, while the same conditions were noticed in the Cape Peninsula ca. 3000 yr BP

(Jerardino, 1995). Between 4000 and 2000 yr BP, the results from the study area and most of the palynological records show gaps in sequences for this period and those that have pollen seem to point to cool conditions that have been interpreted as either dryness or wetness. According to Tyson's (1986) model, climatic conditions during the Neoglacial Cooling were similar to the present-day dry spells.

The Wright *et al.*, (1993) and Street-Perrot & Perrot (1993) global climate model simulates that by 6000 yr BP the insolation anomalies had changed while the interior of South Africa, the Cape region and Madagascar became wetter after 6000 yr BP as summer radiation began to increase. The evidence from the interior region indicates that this area became wet around that time, as the model suggests, but warm conditions already prevailed in these regions before 6000 yr BP. Data from various sources point to reduced rainfall in the Transvaal as compared to the Kalahari during this time. The differences in the amount of rainfall between the two regions is consistent a westward displacement of the quasi-stationery summer lower tropospheric standing wave over the Kalahari which results in the eastern areas becoming drier as the locus of increased rainfall shifts westward (Partridge *et al.*, 1999).

Tyson (1986) suggests that after 3000 yr BP, abrupt cooling set in and temperatures reached a minimum around 2000 yr BP. The lower temperatures suggested for *ca.* 2000 yr BP from the Cango Cave temperature curve (Talma & Vogel, 1992), seem to agree with vegetation changes that are indicated for Florisbad and the Blydefontein area which have been interpreted as aridity. Around 1700 yr BP conditions in the two regions became wetter as signalled by the increase in grasses. Both sequences did not record changes that occurred later than 1700 yr BP until the present.

Conclusion

A summary of the results or interpretations from the study area is given below in Table 9.1. Generally, the period before and around 6500 yr BP was relatively dry with high evaporation rates that signified warmth in these regions, while the northern bushveld was relatively wet and warm. Conditions ameliorated some time before 5000 yr BP when a wet climate enveloped the southern interior sites of South Africa, but a dry spell is indicated around 5000 yr BP. The late Holocene between 4000-2000 yr BP saw some fluctuations in climate that may have resulted in discontinuous sequences, reworking of sediments and or dessication of pollen grains in the sediments. This was apparently the neoglacial cooling period that is said to have occurred soon after 5000 yr BP. From around 4000 yr BP, the sequences from Florisbad and Blydefontein are barren of pollen and this creates problems as knowledge about the environment of this period is one of the main objectives of this research project. Nonetheless, most of the proxy data from South Africa indicates this period as a dry, if not a cool phase, though some evidence of wet conditions has been pointed out for other sites. At this stage there are still unanswered questions concerning the climatic changes that took place during this time, but it seems that the apparent contradictory results from Kathu Pan and Wonderwerk (Beaumont *et al.*, 1984; van Zinderen Bakker, 1982), for dry conditions at 4500 - *ca.* 2000 yr BP can only partly be supported by the data from this project. It must further be pointed out that the present data gives a much better resolution than the few samples studied from Kathu and Wonderwerk.

Table 9.1. Summarized climatic interpretation of the three study sites.

Age (yr BP)	Florisbad	Blydefontein Sites	Clarens
Ca. 1700	+	+	
Ca. 2000	–*	–	
Ca. 2500	+		
Ca. 3000	+		
Ca. 3600 – 3200			
Ca. 4000 – 3700	+	–	–
Ca. 4200	+	+	
Ca. 4900 – 4400		+	
Ca. 5100 – 4900	–	–	
Ca. 5200- 5400		+	
Ca. 6500 – 6290	–*		

\+ Sub-humid, grassy
– Semi-arid, shrubby
* Strong evaporation (Cheno/Ams)
Empty spaces - barren sections / hiatuses

The proxy data that is presently available in South Africa needs to be well correlated and further work is necessary to improve climatic interpretations. It should be interesting to compare the pattern thus obtained for the late Holocene, with that from southern South America and New Zealand. In these areas, three major neoglacial cooling periods accompanied by an increase in moisture occurred after 5000 yr BP and these have been reported, for *ca.* 4500-4200 yr BP, *ca.* 3400-2200 yr BP and the last one, the Little Ice Age (Jerardino, 1995). Jerardino, (1995) seems to think that a similar pattern occurred in South Africa, especially since sea surface temperatures and sea-level measured from Elands Bay were found to be lower during these periods.

Both the Florisbad and Blydefontein sequences, studied in this project, have no record of changes that occurred after 1700 yr BP. Although this was a sub-humid time, conditions were unfavourable around 2000 yr BP, but this could have been only a short dry spell. Fluctuations in climate continued until the present and two phases of marked climate change occurred, namely, the Little Ice Age and the Medieval Warm Epoch (Tyson & Lindesay, 1992; Holmgren *et al.*, 1999) which were recorded at various sites in South Africa, including, Blydefontein (Scott, 1982; 1984; 1996; Scott & Bousman, 1990; Bousman & Scott, 1994). The Little Ice Age was a cool and dry phase that took place around 1300-1800 AD and the Medieval Warm Epoch, around 1300-900 AD (Tyson & Lindesay, 1992; Holmgren *et al.*, 1999).

The Holocene seems to have undergone several climatic changes, which are not yet clearly understood. There is still the problem of moisture differences between the northern and southern sites of South Africa during the Holocene altithermal which climate models have addressed. The evidence is not sufficient enough to eliminate discrepancies that present themselves. For the late Holocene, more data is required for the period of time between 4000-2000 yr BP that produced several barren pollen sequences. The data from this project improves our insight into conditions during this period. The study of better chronologically resolved sequences as well as the refinement of existing ones presents an interesting challenge to provide a more complete climatic picture of the Holocene of South Africa. The collection of this kind of data could contribute towards the understanding of interactions between processes on land, in the atmosphere and oceans that would help towards the development of scenarios for future climate changes.

KEY TERMS

Palynology, Holocene deposits, interior region, vegetation, palaeo-climatic trends, Neoglacial cooling, Holocene Altithermal, palaeoenvironmental reconstruction, evidence, climate models and radiocarbon dating.

SUMMARY

Pollen analyses of organic sediments from Clarens, in the eastern Free State, Florisbad, in the central Free State and Blydefontein, in the Karoo were carried out to investigate the mechanism of vegetation and climatic changes in the South African interior during the Holocene.

The methods of sampling, chemical processing and the construction of pollen diagrams and their zonation are described. In order to assist with the interpretation of past environmental changes, the relationship between physiography, the present climate and vegetation, is addressed. The nature of the different sites, their deposits and the radiocarbon dates obtained, are discussed. Furthemore, each sequence is described and interpreted in terms of past vegetation and climate changes.

According to these reconstructions, the earliest phase recorded for the study area is for Florisbad, around 6500 to 6000 yr BP. This period was relatively dry and warm with high evaporation rates, as indicated by the presence of the local halophytic vegetation. The regional vegetation consisted of some grasses and Asteraceae shrubs and herbs. The period between 6000 and 5500 yr BP is not documented in any of the sequences, but it seems the drier phase continued throughout this time. Between 5400 and 5000 yr BP, conditions were sub-humid with dry episodes in Blydefontein, while Florisbad experienced dry conditions with reduced summer rains.

The next phase between 4800 and 4000 yr BP is characterized by a complete change in the environmental conditions that include increased precipitation and a cooler climate in the interior. This is shown by the sequences from Blydefontein and Florisbad. The vegetation had a good grass cover with indications of cooling characteristic of the "Neoglacial" phase which occurred worldwide some time after 5000 yr BP. Seemingly, harsh conditions prevailed in the interior after *ca.* 4000 yr BP, as poor pollen preservation in sequences from Blydefontein and Florisbad indicate. The Blydefontein sediments show a very high percentage of trilete spores around 3950 yr BP, a possible sign of selective preservation, just below the barren part of the sequence. Although the Clarens sequence (Elim) dates have some discrepancies, it also indicates a high percentage of trilete spores,

especially for the period between 3000 and 4000 yr BP. The vegetation at Elim during this phase was open as a result of cool, dry conditions. The high percentage of trilete spores in Blydefontein and in Elim indicates poor pollen preservation that might be caused by the dessication of the sediments. All of the evidence for the period 3000-4000 yr BP points to dry conditions.

The Florisbad sequence indicates the return of sub-humid conditions from *ca.* 3140 yr BP, while the Blydefontein sediments of this stage are still sterile. A decline in grasses accompanied by a rise in Chenopodiaceae/Amaranthaceae pollen is seen in Florisbad *ca.* 2000 yr BP, possibly indicating a drier phase with increased evaporation. This situation was reversed around 1710 yr BP. Grassy vegetation appears at Blydefontein at *ca.* 1980 yr BP, suggesting a change to sub-humid conditions.

The environmental changes since around 6500 yr BP to 1710 yr BP from Elim, Florisbad and Blydefontein agree with most of the available indications from the interior and with simulation models. Conditions in the interior only became sub-humid later during the Holocene altithermal, *ca.* 6500 yr BP, although the temperature was already high at this time. The period between 4000-2000 yr BP requires further research as most of the available sediments either have a hiatus or show an over-representation of trilete spores. This phase has been interpreted as indicative of harsh conditions for the preservation of pollen.

OPSOMMING

Stuifmeelanaliese van organiese sedimente van Clarens in die Oos-Vrystaat, Florisbad in die sentrale Vrystaat en Blydefontein in die Karoo, is uitgevoer om die meganisme van plantegroei- en klimaatsverandering in die binneland van Suid-Afrika, gedurende die Holoseen te ondersoek.

Die metodes van monsterversameling, chemiese voorbereiding en die konstruksie van stuifmeeldiaframme en hulle sonering word beskryf. Om interpretasies van omgewingsveranderinge in die verlede te ondersteun is die verband tussen die fisiografie, die huidige klimaat en plantegroei ondersoek. Die aard van die verskillende studieplekke, die afsettings en radiokoolstof ouderdomspepalings daarvan word bespreek. Verder is elke opeenvolging beskryf en geïnterpreteer in terme van plantegroei- en klimaatsveranderinge in die verlede.

Volgens hierdie rekonstruksies is die vroegste fase by Florisbad gevind teen ongeveer 6500 – 6000 jaar BP (voor hede). Hierdie periode was relatief droog en warm met 'n hoë verdampingstempo, soos aangedui deur die van lokale halofitiese plantegroei. Die regionale plantegroei het bestaan uit gras en Asteraceae-bossies en kruie. Die periode tussen 6000 en 5500 jaar BP is nie gedokumenteer in enige van die seksies nie, maar die droë fase het waarskynlik aangehou gedurende hierdie tyd. Tussen 5400 en 5000 jaar BP was toestande half-vogtig met droë episodes by Blydefontein, terwyl Florisbad droë toestande met minder somer-reën beleef het.

Die volgende fase tussen 4800 en 4000 jaar BP is gekenmerk deur 'n groot verandering in omgewingstoestande wat verhoogde reënval en koeler toestande in die binneland behels. Dit word aangedui deur die opeenvolgings by Blydefontein en Florisbad. Die plantegroei was gekenmerk deur 'n goeie grassbedekking, met aanduidings dat dit relatif koel was soos gekenmerk deur die "neoglasiale" fase wat wêrelwyd net na 5000 jaar BP voorgekom het. Klaarblyklik het ongunstige toestande in die binneland na ongeveer 4000 jaar BP voorgekom soos aangedui deur swak stuifmeelpreservering.in die opeenvolgings van Blydefontein en Florisbad. In die Blydfontein-sedimente verskyn 'n relatief hoë persentasie van "trilete" spore, 'n aanduiding van selektiewe preservering, om en by teen 3950 jaar BP, net onder die onproduktiewe gedeelde van die opeenvolging. Al bestaan daar ongeruimthede in die datering van die Clarens-opeenvolging (Elim), dui dit ook 'n hoë pesentasie van "trilete" spore aan, veral in die tydperk tussen 3000 en 4000 jaar BP. Die plantegroei by Clarens (Elim) was oop as gevolg van koel, droë toestande. Die hoë persentasies van "trilete" spore in Blydefontein en Elim wys op swak stuifmeelpreservering wat moontlik deur die uitdroging van die sedimente veroorsaak is. Al die gegewens dui op droë toestande vir die periode 3000-4000 jaar BP.

Die Florisbadopeenvolging dui aan dat half-vogtige toestande vannaf ca. 3140 jaar BP weer hulle verskyning gemaak het, terwyl die Blydefontein sedimente van hierdie tyd steriel is. 'n Afname in grasse vergesel deur 'n toename in Chenopodiaceae/Amaranthaceae-stuifmeel word waargeneem by Florisbad teen ca. 2000 jr BP, moontlik as aanduiding van 'n droër fase met meer verdamping, maar die situasie word omgekeer teen 1710 jaar BP. 'n Grasryke plantegroei verskyn by Blydefontein teen ca. 1980 jaar BP, wat half-vogtige toestande aandui.

Die omgewingstoestande vanaf ca. 6500 jaar BP tot 1710 jaar BP by Elim, Florisbad en Blydefontein stem ooreen met meeste van die beskikbare indikasies uit die binneland en met simulasie-modelle. Toestande in die binneland gedurende die klimaatsoptimum van die Holoseen, het eers teen ca. 6500 jaar BP half- vogtig geword. Die periode tussen 4000 en 2000 jaar BP, moet verder nagevors word omdat meeste van die beskikbare sedimente of 'n leemte of oor-verteenwoordiging van "trilete" spore toon. Ongunstige toestande vir stuifmeelpreservering word gedurende hierdie tyd vermoed.

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