The Palynology of Tertiary sediments from a palaeochannel in Namaqualand

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A Thesis submitted to the Faculty of Science
University of the Witwatersrand, Johannesburg
for the Degree of Doctor of Philosophy

Johannesburg 1997

Abstract

To date, there has been limited palynological study of South Africa's Tertiary sediments. Three sites in Namaqualand, Cape Province have yielded much new palynological information. The sites expose palaeochannels containing fluviatile sands, silts and clays. Palynomorphs were extracted from accompanying peat horizons. The sediments were previously dated as Pliocene and one of the aims of the research project was to establish whether the dating was correct.

A wide variety of palynomorphs was described and fully illustrated, including 87 angiosperm types, 12 gymnosperm types and 27 spore types. They were compared with published descriptions and illustrations to effect identifications. Several new palynomorphs were found: formal names will be given at a later stage. Angiosperms also dominated the assemblages in terms of the numbers of individuals.

The palynoflora provided a Palaeocene-Eocene age bracket for the sediments, estimated from the established ranges of the palynomorphs, confirming that the sediments were older than previously thought.

Botanical affinities were used to reconstruct the palaeoflora. Evidence for the presence of angiosperm trees, shrubs, herbs and vines was found as well as forest trees of gymnosperm origin. The vegetation appeared to belong to the ancient forests dominated by Podocarps which covered much of the southern continents during the early Tertiary. There are some indications that ancient proteas and other evergreen angiosperms existed which may contribute information towards a better understanding of the modern Fynbos biome, unique to the southern Cape. The palaeoclimate was deduced to have been humid and sub-tropical, based on the climatic tolerances of modern plants having affinities with the palaeoflora.

Declaration

I declare that this Thesis is my own, unaided work. It is being submitted for the degree of Doctor of Philosophy at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University.

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Date 25-11-97

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Introduction

"Spores and pollen are marvellous objects for study. Their morphology is infinitely varied, in a package so small that the wonder of their beauty never ceases to fascinate." (Jansonius & McGregor, 1996 p 1.)

The science of palaeopalynology was developed as a geological tool for determining the relative age of sediments of interest to the oil industry. Such information contributed vital data needed for the successful exploration of economically productive oilfields (Traverse 1988). Palaeopalynology is used in other branches of the mining industry in a similar way, that is, to decide whether particular sediments are equivalent in age based on their palynomorph content. It may be possible to indicate the vegetation contemporary with the sediments, adding palaeoenvironmental information.

The research presented here is concerned with fluviatile sediments found along and adjacent to the western coastline of South Africa. To date, there has been limited palynological study of South Africa's Tertiary sediments. The major reason for the paucity of studies is the lack of suitable sites yielding positive results. Recently, however, several closely linked sites on the west coast have been found from which much palynological data is available. The sediments within the sites consist of fluviatile sands, silts and clays with accompanying peat horizons, occurring in a series of palaeochannels. Some preliminary work was completed to establish that the peats were palynologically productive. The age suggested for the sediments was early Tertiary (de Villiers 1994).

The sites are located in the Namaqualand region of the Western Cape (Figure 1.1) lying approximately 100 km south-west of Springbok.

Early Tertiary sediments are of interest for several reasons. The Cretaceous-Tertiary boundary is drawn by a notable world-wide mass extinction, especially of large terrestrial reptiles. At the same time, angiospermous plants were undergoing successful radiation. Palaeopalynological studies of this time may provide indications of the magnitude of evolutionary progress. In southern Africa, changes to the vegetation were induced by climatic change, itself a feature of the initiation and widening of the Atlantic Ocean. As it became larger, currents and climatic systems were developed which produced varied effects on the neighbouring continental masses. The existing vegetation would have had to adapt to the changes in latitude, altitude, rainfall patterns and temperatures. Industrial interest in South Africa's Tertiary sediments on the west coast hinges on the usefulness of dating by palynomorphs and the reconstruction of sedimentary models.

Previous work on South Africa's Tertiary palynology includes work on the Arnot Pipe (Kirchheimer 1934, Scholtz 1985), an analysis of the Knysna lignites (Thiergart *et al.* 1963), studies of coastal sequences from the south-western Cape (Coetzee 1978, 1980) and sampling by the Deep Sea Drilling Project of various offshore sites (McLachlan & Pieterse 1978, Morgan 1978, Partridge 1978).

This study was initiated to establish a date for the sediments. A total of sixty-nine samples were collected from the peat horizons and associated sediments.

1.1 Location of study area

The study area is located in Namaqualand, an informal division of the Western Cape (Figure 1.1). It lies adjacent to the western coastline of South Africa, 490 km north of Cape Town and 95 km south-west of Springbok.

The sites studied are known as Koingnaas, Langklip and Somnaas/Noup. The preliminary study was completed on Koingnaas, which traverses the farms Koingnaas 475 and Zwart Lintjies Rivier 484 (Figure 1.2). The other two sites were added for the main part of the research project. Langklip lies 10km south of Koingnaas, on the farm Langklip 489 (Figure 1.3). Somnaas/Noup lies 5km to the north of Koingnaas and is named after the two farms which it straddles, Somnaas 474 and Noup 473 (Figure 1.4).

1.1.1 Road and air connections

Namaqualand is crossed by national route N7, running from Cape Town to Vioolsdrif, which passes 55 km to the east of the study area (Figure 1.1). Dirt roads connect the main road with the coast.

Small airfields exist close to several of the local towns.

1.1.2 Topography and drainage

The study area is located on the coastal plain, west of the Kamiesberg mountains. This region is characterised by flat-lying ground with dry pans which trend north-south.

Rivers rise in the mountains to the east and flow into the Atlantic Ocean. Their short courses are influenced mainly by the topographical westward slope but partly by the north-south trends found in the basement rocks.

1.1.3 Climate

The Köppen climatic classification has been widely applied in southern Africa because of its simplicity. Under this classification, the western coastline experiences a **Bwk** type climate, where '**B**' represents an arid zone, '**W**' a desert climate and '**k**' indicates dry-hot conditions with a mean annual temperature below 18°C.

The climate is further described according to Schulze (1972). It is greatly modified along the western coastline by the Benguela Current. This current is influenced by the south-easterly trade winds and brings cold water from Antarctica upwelling along the coast. The weather systems in southern Africa are divided into the Atlantic and Indian Ocean cells, of which the Atlantic is more persistent and dominates the region under study. The climate is summarized in Figure 1.5.

The range of daily temperatures is 15-24°C in January and 9-21°C in July. Temperature inversions experienced by most of the subcontinent do not apply here because the coastal belt has a low altitude. Hours of sunshine are rated as 70% of the possible total. Frost is largely unknown.

The annual rainfall for the dry western coastline is ~125mm +/-25%. The rainy season is not well-defined (Schultz & McGee 1978) but rainfall principally occurs in the winter months. The study area lies well north of the southern Cape's winter rainfall region and precipitation caused by frontal systems is less intense here than in the interior. Anticyclones skirt the coast, forcing moist maritime air against the mountains causing orographic rain and drizzle. Rain falls usually in the early morning or at night at which times the humidity ranges from 70-80%. Fog is formed by radiation and advection when warm inshore surface water mixes with upwelling cold water from the Benguela Current.

The wind direction is usually southerly along the coastline and is strongest in mid-summer. Wind speed may reach gale force (65-100 km^{h-1}) and continue for hours, gusting up to 130-160 km^{h-1}. Sandstorms are common.

1.1.4 Vegetation

The regional flora has been described by Acocks (1988) as Karoo and Karroid bushveld type. Specifically, the coastal plain vegetation is known as the Strandveld while inland it becomes the Succulent Karoo.

The Strandveld is an open semi-succulent scrub of Fynbos form, intermediate between the Coastal Fynbos and the Succulent Karoo. Well represented genera include *Salvia, Zygophyllum* and *Ruschia*. Species from Acocks' Dense Scrub which is found nearby occur in bush clumps and on rocky outcrops. Grasses occur on the dunes.

The Succulent Karoo is dominated by succulents, mainly Mesembryanthemaceae. Many species of *Ruschia* are found ranging from dwarfs to 3.5m shrubs. There are few trees or other large shrubs except along the rivers which are lined with *Acacia*. The form of the veld type found in the study area is called the Namaqualand Coast Belt. A feature of this region is the occurrence of mounds called 'heuweltjies', which comprise clumps of bush growing on termite hills.

1.2 Descriptive geology

This section describes the rock types encountered and gives only a basic stratigraphic position, as many of the younger formations have no formal assignation as yet. The geological map of South Africa at 1:1 000 000 scale shows the general surface geology of the region (Dept Mineral & Energy Affairs 1984). Loosely compacted alluvium, sand and calcrete cover ancient gneisses.

1.2.1 Basement

The ancient (Precambrian) gneisses are exposed in river valleys and along the coast where the younger sands and alluvium have been removed. They also crop out to the east as the Bokkeveld mountains, which also existed as high ground during the Cretaceous and Tertiary.

Two rock types broadly similar in age are known in the area.

1. The **Little Namaqualand Suite** is represented by augen gneiss, a highly metamorphosed rock with a distinctive structure.
2. The local **Garies biotite gneiss** has a diagnostic mineralogical composition.

The metamorphic origin of the basement rocks implies that the two rock masses were swirled together by tectonism. Their north-south trending fabric was exploited by rivers in the formation of drainage channels which can be seen on the 1 : 1 000 000 scale geological map (Dept Mineral & Energy Affairs 1984) and on satellite imagery by Landsat. East-west trending weaknesses are probably related to transform faults generated by tectonism associated with the creation of the African plate. These weaknesses were exploited by the rivers to carve out the palaeochannels in this study.

1.2.2 Overlying sediments

The Cenozoic sediments found along southern Africa's western margin comprise coastal dunes which overlie fluviatile, beach and nearshore deposits. The terrestrial sands indicate regressive phases and are frequently capped by calcrete (Truswell 1977). They contain vertebrate remains, plant fossils and palynomorphs of Cretaceous and Tertiary age (Siesser 1982). Marine sediments of similar age are found offshore but are patchy and incomplete due to cycles of transgression and regression (Siesser 1982). They contain marine microfossils such as ostracods and foraminifers.

1.2.3 Local succession

Sandy gravels occur on overlapping marine terraces most of the way along the western coastline from the Olifants River to north of Kleinsee (SACS 1980). They are referred to informally as the Hondeklip Bay sandy gravels and overlie older channel deposits. The gravels were thought to be Pleistocene and the lower sediments Pliocene (SACS 1980).

The channel sediments consist of a suite of sands, silts and clays with accompanying peat horizons. The channel fill is slightly different in each of the palaeochannels studied.

1. **Koingnaas** (Figure 1.6). The palaeochannel is approximately 150 m wide and in excess of 6 km long, trending north-east to south-west. The quarry from which the samples were taken lies relatively close to the mouth of the channel. The basal deposits consist of angular to subrounded quartz rubble lying on the basement rocks. The lowest channel sediments are gritty grey clays, massively bedded with few minor sedimentary structures. Layers of peat are found near the base of many of the channel scours. Occasionally macrofossil debris such as poorly preserved pieces of fossil wood is found.

The later channel sediments comprise well-sorted and medium grained sands and clays with peat layers. Marine incursions may be implied due to the presence of glauconite and foraminifers in some parts of the sediment suite.
The main peat horizon is found at the top of the channel deposits. It has a recognisable seat earth containing rootlets and may represent a major break in the sequence. It has several impersistent layers.
The succeeding deposits show a distinct change in lithology as they are dominated by medium-to-coarse sands, orange in colour and the clay content is much reduced. Parts of the sequence may be aeolian in origin and are unconfined by the channel. Within these thick sands, iron staining is common.
The sands are followed by an unconformity representing time during which sea level changed considerably, as the younger sediments are marine.

2. **Langklip** (Figure 1.7). The palaeochannel measures from 20-70 m wide and is more than 400 m long, trending north-south closely parallel to the coast. The quarry from which the samples were taken lies almost at its mouth.
The basal channel deposits comprise a conglomerate of rubble lying on the basement rocks. Peat and associated clays (10m) are thickly developed immediately above the basal sediments, sometimes lying directly upon the crystalline basement. The peat has several impersistent layers, interspersed with lenses of sandy brown clay up to 8m in thickness. The peat is succeeded by a grey brown clay, 8 - 10m in thickness, which follows the contours of the channel. The highest channel sediments are pale grey, massively bedded clays. Stringers of peat are found near the base of many channel scours.
The later sediments are not seen within the quarry.

3. **Somnaas/Noup** (Figure 1.8). The palaeochannel consists of a main channel trending north-south and several smaller tributaries to the east, trending northeast-southwest or northwest-southeast. The samples were taken from the main part of the palaeochannel where the tributaries converge, possibly close to the mouth.
The channel sediment suite amounts to 30 m in total thickness and is known from borehole drilling. The basal gravels lie on crystalline basement at

approximately 50m depth. They grade upwards into the lower channel sediments, consisting of coarse grits with clay lenses, followed by a layer of clay 1m in thickness and a sand layer 3m thick. The peat horizon has several clay lenses and is found at approximately 35m depth.

The upper channel sediment suite consists of clays and sands from 35m to 22m depth and is succeeded by marine sands.

1.2.4 Peat horizons investigated

Five formations were considered and a palynoflora was derived from each of them. Three came from Koingnaas (channel peats, main peat horizon and stringers above the main peat horizon), one from Langklip and one from Somnaas/Noup.

Figure 1.9 shows the peat horizons that were investigated. The samples which were considered together as a particular palynoflora are shown together on the diagram.

1.3 Geological history

1.3.1 Introduction

This section contains a brief account of the genesis and geological history of southern Africa's western continental margin as established in the literature. Knowledge of the African plate's formation from fragments of the palaeocontinent Pangaea is significant because such events relate to the timing of possible migration routes between Africa and South America (Pitman *et al.* 1993).

The sediments under consideration have not been dated conclusively or assigned a formal stratigraphic position. An examination of the regional geological history, including changes in ocean basin morphology and the development of oceanic and atmospheric currents, will help to confirm their position, as all these factors have an integral effect on the evolution on the west coast's physiography, geology, climate and vegetation.

1.3.2 Disintegration of Gondwana

Pre-drift palaeogeography. In Karoo times (Permo-Triassic) South Africa was part of Gondwana, a supercontinent comprising all the landmasses presently in the southern hemisphere (Truswell 1977). Peninsular India also belonged to Gondwana. Prior to disruption, South America and Antarctica juxtaposed with Africa (Figure 1.10a).

Geological modelling. The South America-Africa refit was the first observation that led eventually to the concept of continental drift and sea-floor spreading (plate tectonics). The fit of the South American coastline into that of Africa attracted attention long before the twentieth century (Kay & Colbert 1963) and is made obvious as both sides of the South Atlantic Ocean have non-destructive continental margins. The ocean between them has a spreading mid-oceanic ridge but no subduction zones.

The South Atlantic Ocean has been the starting point for several, increasingly sophisticated, geological models. Wegener (1912) developed the idea into his Displacement Theory which stated that the present continents are but fragments of a much greater continent which broke apart in the late Palaeozoic. He added geological similarities between the continents such as the Carboniferous and Permian glacial episode which was responsible for similar sediments on both continental fragments to aid the reconstuctions based merely on the goodness of fit. Aeolian deposits of Triassic age again implied that the lands were connected. Palaeontological evidence also supported a terrestrial reconstuction (Truswell 1977). Common fossils were found in South America and southern Africa from sediments Ordovican to Triassic in age, such as the dinosaur *Mesosaurus*, which established that a land connection had existed between two areas now separated by a wide ocean. Initially, it was palaeontological evidence that was used to develop the concept of Continental Drift, but within the last few decades the science of Plate Tectonics has turned the tables; it can now date continental shifts so accurately that it provides a basis for the explanation and understanding of the differences in the world's biota (Goldblatt 1993). Smith & Hallam (1970) produced the first computer-generated fit of the southern continents. The significance of magnetic lineations when related to the dispersal of the continents has permitted the accurate timing of palaeogeographical arrangements (Pitman *et al.* 1993).

Initial rifting. The African plate was initiated during Early Cretaceous times when South America, still connected to Antarctica and Australia, was rifted away. The southern Cape occupied a central position in Gondwana, at palaeolatitude 50 - 55°S, during the late Jurassic - early Cretaceous (McLachlan & McMillan 1979). Most of the development of the continental margin of western southern Africa occurred early in its' history (Bolli 1975). The physiography of the continental margin has a direct bearing on the sedimentary environments and the type of deposits which accumulate. The earliest sediments intersected in boreholes on the west coast date from the Barremian (McLachlan & McMillan 1979).

According to Boillot (1981), the mechanism for Plate Tectonics is provided by large convection cells in the mantle. Where the cells ascend, the process is accompanied by rifting and updoming, forming new sites for terrestrial deposition such as is seen in the eastern African Rift Valley today. The initial opening of the South Atlantic was about 127 Mya (Siesser 1982).

Updoming is seen in southern Africa in the form of the Great Escarpment, formed along the margin of the new continent (Botha *et al.* 1986). Epeirogenic uplift had a characteristic and repeated pattern. Maximum uplift occurred in a zone near the coastal margin seaward of the Great Escarpment resulting in a steep seaward tilting of the outer side and a gentler slope towards the interior of the new plate. Sediments derived from the periodically uplifted areas were transported to offshore and inland basins.

Inactive, rifted continental margins of this 'tensional clean-break' type possess a characteristic bathymetry and geological structure (Scrutton & Dingle 1973). The geological model shows that the migration of sediment depocentres and sedimentary environments is reflected by the rate of sediment accumulation and the degree of marine influence, that is, non-marine, restricted marine or oceanic (Siesser 1982). The early preseparation depocentre lies on continental crust and receives non-marine sediments. The sedimentation rate is high owing to the large topographic differences associated with rifting. The rift-faulting stage of continental disintegration in the case of the Africa-South America rift lasted from 138 - 128 Mya (duration of the early Lower Cretaceous) (Botha *et al.* 1986).

Volcanism. Volcanic activity associated with the opening of the South Atlantic had a long history, from 197 - 105 Mya (early Jurassic to mid Cretaceous) (Botha *et al.* 1986). It is probably represented by the Kaoko Lavas in Namibia, consisting of tholeiitic basalts (Siesser 1982) which had a peak of activity around 125 Mya (mid Lower Cretaceous). Alkaline igneous complexes formed lineaments in Angola, Namibia, Brazil and Uruguay. Each of these lineaments can be correlated with an unique fracture zone/transform fault offsetting the Mid-Atlantic Ridge. Their age range (120 - 135 Mya) suggests that this volcanism developed along the continental extensions of the major transform faults during the initial rifting of the South Atlantic.

Restricted marine phase. As the continents separated, the sea moved into the rift, resulting in a narrow oceanic basin analogous to the Red Sea. However, the geometry of such a narrow basin restricted normal marine circulation. The narrow rift became two enclosed basins between South America and southern Africa (Bolli 1975), the Angola-Brazil Basin in the north and the Cape-Argentine Basin in the south, separated by the Walvis Ridge/Rio Grande Rise (Figure 1.10b).

During this phase, the depocentre prograded across continental crust, reaching oceanic crust late in the restricted phase or early in the oceanic phase. Eventually separation was sufficient enough to connect the basins to the world ocean and true oceanic conditions were established, ending the restricted marine phase.

Major drifting phase. The onset of this phase began at 121 Mya (Barremian - mid Cretaceous). At the northern end of the Angola-Brazil basin, the plates were riding past each other along a series of transform faults. At the southern end of the Cape-Argentine Basin, the Falkland Plateau was hooked under the south and south-east margin of Africa and was finally separated from the Agulhas Bank 104 Mya (Albian, mid-Cretaceous) (Botha *et al.* 1986, Pitman *et al.* 1993). The spreading rate was greater in the case of the Falkland Plateau than in equatorial latitudes. The Walvis Ridge was severed as a continuous land connection probably in the mid-Early Cretaceous and acted as a barrier to oceanic currents until 90 Mya (Turonian; late Lower Cretaceous) when a free connection between the central and southern Atlantic was established (Botha *et al.* 1986). Island-hopping across widening water barriers would have been the only possible dispersal mode for terrestrial organisms across the central South Atlantic after this time (Parrish 1987). Africa and South America were separated for migration by the late Albian - mid-Cenomanian (Pitman *et al.* 1993).

Thus, by the mid-Cretacous, Africa existed as a separate plate. It had non-destructive margins as both the Atlantic and Indian Oceans had spreading mid-oceanic ridges. The circum-Antarctic current was operative in the middle or late Oligocene (Kennett *et al.* 1974, Siesser 1982), implying that all the fragments of Gondwana were separated by this time. Today, the African Rift Valley system marks where the African plate is expanding east to west (Truswell 1977).

1.3.3 Cape-Argentine Basin

The sediments under consideration were formed on the borders of the Cape-Argentine Basin. The basin stretched between the coasts of southern Africa and South America, the Walvis Ridge-Rio Grande Rise in the north and the Falkland Plateau in the south (Bolli 1975), as shown on Figure 1.10b. Alterations to the basin morphology were caused by factors such as variations in the seafloor spreading rate or the volume of the mid-oceanic ridge.

The oldest date available (magnetic anomaly) in the basin is 130 Mya (L. Valanginian; Early Cretaceous) (Truswell 1977). The sedimentation at this stage was a function of the early stages of ocean formation.

The west coast of the basin is divided into three major morphological provinces (Scrutton & Dingle 1973). The study area falls within the central province, extending from Luderitz in Namibia (300 km north of Port Nolloth) to Saldanha, 100 km north of Cape Town.

During the restricted marine phase (early Cretaceous) the basin was enclosed and stagnant, shown by the black carbonaceous pyritic muds which were laid down (Bolli 1975). Sediment discharged from rivers moved south because of southerly-directed currents or the general absence of currents (Siesser 1982). Deposits accumulated at a very rapid rate, thickening significantly towards the continent. Plant debris found within them suggest that luxuriant plant growth occurred in the source area under humid conditions (Siesser 1982).

By late Aptian times (108 Mya) the South Atlantic was wide enough to allow the oxygenation of bottom waters of the Cape-Argentine Basin by oceanic currents developed during the major drifting phase. Circulation throughout the whole ocean including the Angola-Brazil Basin was only achieved in the late Cretaceous, when the

South Atlantic had reached its full oceanic phase, and sedimentation changed from being a function of Plate Tectonics to being influenced by solely oceanic factors.

These were:-

Currents - The most important was the Benguela Current which flowed and continues to flow northwards from its origin in the cold ocean to the south. It was deflected to the west by the Walvis Ridge and much of the sediment discharge from the rivers began to move in a northerly direction by longshore drift (Siesser 1982) reversing the previously seen trend. The Benguela Current was probably initiated in the mid to late Oligocene with the final separation of South America from Antarctica (Pitman *et al.* 1993) and was fully operational by the Miocene (22 Mya) (Hodell & Kennett 1985). The cold Benguela circulation exerted a progressively stronger influence on the west coast during the Pliocene.

Sea level changes were caused by several interconnected factors. One major cause can be linked to continuing continental drift, that is, an increase in the volume of the oceanic ridges which comprise a significant portion of the volume of the oceans. Vertical movements on ocean ridges thus have a great influence on relative sea levels (Donovan & Jones 1979). During the Cretaceous and Tertiary, changes in the ridge systems may be accounted for by alterations in the length of the spreading axes and the rate at which this occurred. The Cretaceous rise in sea level may in part be accounted for by the expansion of a ridge system into the Indian Ocean (Donovan & Jones 1979). A pulse of rapid spreading in the late Cretaceous produced a sea level rise of 300m which caused an extensive flooding of the continents. Another major factor is the variation of the volume of water which became incorporated in land-based ice sheets. The melting of the modern Antarctic and Greenland ice caps would mean a sea level rise of 65-80m (Donovan & Jones 1979). However, taking into account the isostatic depression of the ocean floor, it might only amount to 40-50m. The formation and dissipation of ice sheets can be three orders of magnitude more rapid than the effects due to changes in the oceanic ridge. Of less general significance is the sedimentary accumulation on the ocean margins which can cause a localised rise in sea level, and the dessication of isolated basins. A very minor rise in sea level may be caused by an increase in the water temperature (Donovan & Jones 1979). The detailed explanation behind the noted transgressions and regressions which are a feature of Tertiary sedimentation in this area is multi-faceted.

Upwelling - The Benguela Current was responsible for the upwelling of nutrient-rich water which promoted rapid sedimentation rates of carbonates at shallow depths (Bolli 1975, Siesser 1982). On the basis of faunal assemblages, the southern tip of Africa has always supported cold-water communities (Bolli 1975).

Carbonate compensation depth (CCD) - The pelagic clays, marly chalks and calcareous oozes known from the Cape-Argentine Basin reflect the water depth with respect to the CCD (Bolli 1975), which is not so much depth dependent as temperature related (Selley 1988). Variations in the level of the CCD are related more to climatic factors than ocean floor subsidence.

1.3.4 Events during the late Cretaceous and Tertiary

The established geological history for the region must be taken into account during this study to determine where the sediments from the palaeochannels best fit in. Events on the west coast are dominated by erosion rather than deposition and relatively few onshore Tertiary outcrops are seen (Scrutton & Dingle 1981). Onshore erosion surfaces appear to correlate well with offshore sediments (Partridge & Maud 1987). Throughout South Africa, a basic pattern can be seen - scant marine Eocene remnants from a transgression, an Oligocene regression, and at least one transgressive-regressive cycle in the Miocene-Pliocene (Truswell 1977, Scrutton & Dingle 1981). The west coast is particularly subject to multiple cycles - three or more are found, some very local, in the Upper Tertiary, while only one unconformity is seen on the south coast (Truswell 1977).

Sedimentary sequences which are formed at passive oceanic margins and are characterized by tectonic, eustatic and sedimentary factors may be modelled by sequence stratigraphy (Steckler *et al.* 1993), which is a methodology for identifying relatively conformable packages of genetically related strata. Tectonics determines the space created for sediment accumulation, sea level modifies the size of that space and sediment transported to the site (clastics) or created within it (carbonates) fill the available space. However, the picture is blurred by other additional processes, such as those provided by climatic factors whereby an increase in rainfall will affect the volume and type of sediment presented at the basin margin.

A summary of the events detailed below appears as Figure 1.11.

Late Cretaceous (prior to 65 Mya) - Epeirogenic uplift of the continent occurred, regenerating erosion of a high continental mass and initiating the so-called "African" erosion cycle (Siesser 1982) which continued until the end of the Oligocene and was widespread throughout southern Africa (Truswell 1977). Any Lower Cretaceous or early Upper Cretaceous sediments that may have been deposited onshore south of the Walvis Ridge would also be susceptible to removal during the regression. The Maastrichtian-Tertiary boundary is paraconformable (McLachlan & McMillan 1979) and easily recognised due to profound changes in the composition of the microfauna.

Palaeocene - (65 - 53.5 Mya. 11.5 My duration) - A regression of the sea from the late Maastrichtian to the late Palaeocene was suggested by Dingle (1973), Dingle & Scrutton (1974), Siesser & Dingle (1981) and Haq *et al.* (1988). The regression is based on seismic records but is not recognised everywhere (McLachlan & McMillan 1979). Local events may mask the effects of world-wide sea-level change. In the Cape Basin, a sudden change in sedimentation occurred coincidentally, as the terrigenous supply was sharply reduced. There is little evidence for Palaeocene rocks occuring onshore today.

Alkali volcanics of this age have been recorded off the southern coast of Africa (Truswell 1977).

Eocene - (53.5 - 37.5 Mya. 11.5 My duration) - Tertiary sedimentation on the continental shelf began with a late Palaeocene - early Eocene transgression (Siesser 1982, Haq *et al.* 1988). Only one outcrop of Eocene rock is known onshore, near East London, but Eocene age sediments are widely distributed offshore. The basinal sediments were hemipelagic, that is, oceanic (shelly debris, foraminifera) with a minor but steady terrigenous (clastic) contribution. The reason for the reduction in terrigenous input may be related to the progressive lowering of the sourceland and the increasing distance which it had to travel or even to dense vegetation supported by high rainfall (Siesser & Dingle 1981).

Truswell (1977) suggested that Eocene sediments elsewhere were possibly reworked into remanie deposits or destroyed during later regressions, as a major period of erosion and regression occurred at the end of the Eocene (Siesser 1982, Haq *et al.* 1988).

Oligocene - (37.5 - 22.5 Mya. 15 My duration) - No Oligocene strata are preserved anywhere on land as the Oligocene was a time of regression (Truswell 1977, Haq *et al.* 1988). The cold, upwelling Benguela Current was initiated in early Oligocene times (van Zinderen Bakker 1984) as the South Atlantic now had sufficient width for the establishment of its circular wind and ocean current systems. The Antarctic ice cap began to expand markedly near the Eocene-Oligocene boundary (Kennett *et al.* 1974) which probably caused the onset of cold bottom water production (Siesser 1982). The Antarctic bottom water essentially controls the CCD in the South Atlantic, and thus the movement of the cold water into the Cape Basin can be traced. The Circum-Antarctic Current also developed in the Oligocene with the final separation of Antarctica and Australia (McLachlan & McMillan 1979, Pitman *et al.* 1993). It circulates completely around the Antarctic and is the only current which mixes the water of all the oceans. The Benguela possibly owes its' existence to the Circum-Antarctic Current.

Much submarine erosion occurred in Oligocene times (Bolli 1975), possibly caused by increased bottom current intensity which may have itself been strengthened by the lowered sea level (Siesser 1982).

Miocene - (22.5 - 5.0 Mya. 15.5 My duration) - At the end of the Oligocene or beginning of the Miocene and again towards the end of this period there was further epeirogenic uplift (Siesser 1982), initiating the "Post-African" erosion surface which is more areally extensive than any other. Between these two regressive phases (during the early or middle Miocene) the sea again transgressed onto the continental shelf (Haq *et al.* 1988), depositing first a shelly conglomerate and limestones, and then thick calcareous aeolian sands informally known as the coastal limestones (Siesser 1972). The marine part of the sequence is Miocene-Pliocene in age (Truswell 1977).

Pliocene - (5.0 - 1.8 Mya. 3.2 My duration) - A further transgression and regression occurred during the Pliocene (Siesser 1982). The regression may well have eroded much of the late Tertiary strata on the shelf. Low sea level with upwelling conditions are ideal for the formation of the phosphate deposits which are widely found.

Pleistocene - (1.8 Mya - 11 000BP. 1.8 My duration) - Cycles of sedimentation in the Pleistocene can be linked to the development of the Ice Ages in the north, based on glacio-eustatic theory (Truswell 1977).

1.3.5 Palaeoclimate of the late Cretaceous and Tertiary

The circulation of the atmosphere and oceans constitutes the mechanism of climate and as a general rule, it tends to be dominated by latitude (Frakes & Kemp 1973). Climatic belts tend to be arranged symmetrically about the Equator (Axelrod & Raven 1978). Circulation patterns are governed largely by the disposition of land and sea areas (Frakes & Kemp 1973). The distribution of palaeoclimates can be predicted by models using the established palaeogeography, and corroborated with palaeontology and lithology (Frakes & Kemp 1973).

In Mesozoic times, the global climate was dominated by the supercontinent Pangaea, consisting of Gondwana and Laurasia combined. The supercontinent straddled the Equator, causing highly seasonal, monsoonal circulation and a dry region that included the equatorial lands as well as the subtropics (Parrish 1987). The monsoon in the southern lands was disrupted during the Early Cretaceous when the Atlantic and Indian Oceans began opening (Parrish 1987). At the close of the Mesozoic, warm global climates had begun a long and irregular slide into the glaciations which characterized the late Cainozoic (Frakes 1979). The continental positions during Palaeocene, Eocene and Oligocene times can be established with reasonable accuracy (Frakes & Kemp 1973) thus predictions can be made for their climate.

Temperature. On a world-wide scale, the climate during the late Cretaceous and Tertiary has often been described as warm and equable (Francis & Frakes 1993). Recent computer simulations which suggest that Cretaceous temperatures were similar to today's are still undergoing validation (Emsley 1994). Estimations of warmth are based on the comparison of modern lifeforms to related ancient ones, extrapolating the known physiological requirements of modern, usually terrestrial, taxa. The effectiveness of the method has, however, been questioned on a number of grounds, as some modern taxa have be shown to have had different climatic requirements earlier in their history (Frances & Frakes 1993).

Conditions during the late Cretaceous and early Tertiary were warmer than at present and according to Frakes (1979) this was possibly the warmest interval in the history of the Earth. The difference is particularly noticable in high palaeolatitudes, due to the contrast with present conditions. The Equator-to-Pole temperature gradient was much less than it is today (Francis & Frakes 1993) at approximately 4-6°C instead of 12°C. During the final part of the Cretaceous there was a distinct cooling trend and both land and ocean temperatures dropped considerably (Francis & Frakes 1993) with freezing conditions at high latitudes. The cool spell was followed by recovery during the Palaeocene, when ocean temperatures in the equatorial regions were 4°C higher than they had been during the Maastrichtian cooling (Coetzee 1993). Warm and humid climates in the early Eocene produced coals and lateritic soil (Frakes & Kemp 1973). A marked drop in temperature occurred at about the Eocene-Oligocene boundary (Parrish 1987) and the first evidence of glaciation in the Antarctic is supplied by ice-rafted late Cainozoic (Frakes 1979). The continental positions during Palaeocene, Eocene and Oligocene times can be established with reasonable accuracy (Frakes & Kemp 1973) thus predictions can be made for their climate.

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A total global temperature drop of about 15 - 20°C may have occurred since the mid-Cretaceous (Parrish 1987).

Rainfall. Predicted global rainfall patterns are based on circulation maps and successfully explain the distribution of evaporites and coals from the Late Cretaceous to Eocene (Parrish 1987). Climatic patterns would have been more nearly zonal when the geographic conditions for a monsoonal circulation were absent and thus rainfall may be predicted for the later Cretaceous and Tertiary based on the zonal model alone (Parrish 1987).

The late Cretaceous and Palaeogene were probably humid (Parrish 1987). The Eocene climate continued to be wet with possibly higher rainfall than now (Frakes & Kemp 1973). By the Oligocene a belt of high rainfall had formed which extended far polewards originating from warm oceanic expanses in mid to high latitudes. In the

Miocene the Namib area was considerably more arid and by the early Pliocene the Cape was also semi-arid (Coetzee 1993).

Regional palaeoclimatology. The Great Escarpment was formed as part of the rifting and breakup of Gondwana (Maud & Partridge 1987). It separated the high standing interior plains from the lower marginal areas to the east, south and west and had a marked effect on local and regional climates.

Abundant rainfall was indicated for southern Africa during the Oligocene (Frakes & Kemp 1973. By the Miocene, palynofloras in the Cape and Angolan Basins indicated cooler, drier conditions associated with the development of the Benguela Current (Maud & Partridge 1987). Subsequently, a general deterioration led to the main Namib erosion surface being cut into a silcreted surface. The current Mediterranean climate of the Cape with dry summers and humid winters is thought to have originated during the early Pliocene (Coetzee 1993).

1.4 Palaeobotany

A brief account of the trends in palaeobotany for the late Cretaceous provides a suitable background for the type of vegetation to be expected from the west coast sediments. By the latest Cretaceous times, the evolution of plants was such that flowering plants comprised the dominant segment of the vegetation. They were geographically widespread (Taylor 1981) especially at low palaeolatitudes (Crane & Lidgard 1989) and had diversified into many forms (Magnoliidae, Hamamelidae, Rosidae and Liliopsidae). Most families of ferns and conifers which survived until then remain extant. The gingkophytes and cycads declined and the cycadeoids died out altogether (Stewart 1983, Spicer 1989).

1.4.1 Anthophyta

Angiospermous plants evolved from uncertain origins during the early Cretaceous (Mildenhall 1980, Taylor 1981) at the end of a time which was characterised by many diverse gymnosperm and pteridophyte flora (Coetzee 1993). Cladistic analyses indicate that angiosperms, Bennettitales, Gnetales and *Pentoxylon* together form a monophyletic group and imply that the angiospermous stock may have diverged from related taxa as early as the late Triassic (Crane & Lidgard 1990, Doyle & Donoghue 1993). Widespread macrofossil evidence indicates that the earliest undoubted angiosperms were coastal plants. They originated at low palaeolatitudes and spread polewards, being found subsequently at higher palaeolatitudes in both hemispheres (Brenner 1986, Axelrod 1976, Crane & Lidgard 1989). Both macrofossils (leaves) and microfossils (pollen) confirm that angiosperms were absent from high latitude sites well after they were diverse in the tropics (Crane & Lidgard 1989). According to Axelrod (1976), west

Gondwana was probably the prime centre of early angiosperm evolution as they are mostly adapted to warm climates.

The major early diversification occurred in the mid-Cretaceous (Crane & Lidgard 1989) and they were floristically dominant by the Cenomanian-Campanian. Environmental change has a crucial role in plant evolution, and great changes were occurring in geographically critical areas. If the area comprising the widening break between the South American and African continents was a cradle for the early angiosperms, they were clearly exposed to a range of climatic conditions very early in their radiation, which may have stimulated their subsequent dynamic evolutionary development (Thomas & Spicer 1987).

Crane & Lidgard (1990) discuss various botanical features, peculiar to angiosperms, which may have given them an advantage over other plant groups such as the Gnetales. These features include the presence of specialised water-conducting vessels in the wood and the origin of entomophilous flowers. According to Thomas & Spicer (1987), the early angiosperms adopted the deciduous habit whereby trees abscise their leaves not continuously but synchronously, followed by a dormant period before the growth of new leaves. This habit must have been a distinct advantage as the plants could then survive temporarily adverse conditions, such as periodic drought or cold weather episodes, allowing the colonization of many environments and the spread to high latitudes where light and warmth were seasonally restricted.

The reproductive system of angiosperms is one of their distinguishing features but it is not represented in the fossil record. It is likely that the early angiosperms reproduced in a similar way to modern forms, both rapidly and efficiently, aiding diversification and geographical radiation. Biotic pollination is most highly developed in angiosperms. Flowers are complex, attractively coloured and scented, and often offer a nutritional reward of nectar to the pollinator. The specialization of pollen and flower types was dynamic during the Tertiary (Thomas & Spicer 1987).

The evolution of the angiosperms is well documented by their resilient and abundant pollen. Angiosperm pollen was probably derived from tectate-collumellate monosulcates, such as that known from Hautervian-Barremian times, which is thought to be related to angiosperms. The oldest undoubtedly angiosperm pollen is tricolpate, found in Aptian beds from Brazil (Brenner 1976), Israel and tropical Africa (Axelrod 1976) which were in the equatorial zone of the time.

The major trends are well documented by Doyle & Hickey (1976) who worked on the mid-Cretaceous Potomac Group from the USA. From monosulcates and trichotomosulcates pollen adapted through more elaborate smooth-walled tricolpates to triangular tricolporoidates and triporates (Stewart 1983). The latter steps probably occurred by parallel evolution in many cases. The evolution of triporate pollen is believed to be an adaptation facilitating germination on a stigmatic surface (Stewart 1983). Superimposed on this progressive trend are various divergent (and often reversed) trends in size, shape and sculpture, from small to very small or large, from prolate to oblate and then triangular, from finely reticulate to tectate-psilate, more coarsely reticulate or striato-reticulate (Doyle & Hickey 1976). Several particular parallel trends can be seen between the African and South American areas (Herngreen & Chlonova 1981) such as a decrease in polyplicates, an increase in the number and diversity of monocolpate palmate types and the appearance of Proteaceous triporates. These trends are shown in Figure 1.12.

1.4.2 Gymnospermophyta

The gymnosperms (naked seed plants) were the first seed and pollen producers. They include conifers, cycads and cycadeoids, gingkos, gnetaleans and the rare gnetopsida. All were more widespread in the Mesozoic than today (Stewart 1983). Gymnosperm pollen is usually saccate (monosaccate, bisaccate or multisaccate) or inaperturate (Traverse 1988).

The conifers were highly diversified by the early Cretaceous (Taylor 1981). Several families can be recognised, including the Podocarpaceae, Araucariaceae, Taxodiaceae, Cupressaceae and Pinaceae. The podocarps and araucarians are today southern hemisphere families, with only a few fossil forms known from the north. The taxoids were once a diverse and extensive group, represented by numerous fossils but only a few species (which includes *Sequoiadendron* in North America) are extant. The Cupressaceae are the largest group in terms of numbers of extant genera. Today the Pinaceae constitute principally a northern hemisphere family that includes the most common conifers. They probably evolved during the Triassic.

All the conifers except the pines declined in the late Cretaceous. The cycads were reduced in numbers throughout this period and the cycadeoids became extinct in the upper Cretaceous. The gingkos peaked at the Jurassic-Cretaceous boundary and then declined during the upper Cretaceous to today's single species. The gnetopsida produced ephedralean pollen, often found in Cretaceous and Tertiary deposits. The variety of bisaccate pollen decreased through the Jurassic (Herngreen & Chlonova 1981).

1.4.3 Pteridophyta

Leptosporangiate ferns (Filicales) producing trilete and monolete spores diversified during the Mesozoic and may have been the dominant herbs (Thomas &

Spicer 1986) until the evolution of angiosperms provided direct competition. Ferns responded during the Tertiary period by evolving many new species, many belonging to the Polypodiaceae and Schizaeacae (Herngreen & Chlonova 1981). Macrofossils of ferns are not abundant.

1.4.4 Other plants

Primitive plants such as lycophytes (club mosses) and sphenophytes (horsetails) generally remained as successful, widespread members of plant communities until the mid-Cretaceous. Competition with angiosperm shrubs and herbs eventually restricted suitable habitats (Thomas & Spicer 1986), thus very few representatives of these formerly important groups remained towards the end of the Tertiary. They commonly produce trilete spores (Traverse 1988).

1.4.5 Microfloral Provinces

By the Mesozoic, different plant communities existed on the now disjunct parts of the supercontinent Pangaea. Separate provinces based on the microfloras (palynofloras) can be recognised (Herngreen & Chlonova 1981) depending upon the position of the continents and the existance of barriers such as epicontinental seas as well as latitudinal climatic control during the late Jurassic/early Cretaceous (Coetzee 1993) whereby an arid zone developed in the equatorial region with warm to cool-temperate conditions beyond the latitudes of 45°N and 55°S. Also, during the Cretaceous, the composition of the microfloras and palaeofloras underwent relatively sudden change coincident with the appearance and rapid evolution of angiospermous pollen grains and profound changes in diversity of non-angiospermous plant groups. Important trends include the decrease in variety of bisaccate pollen types and the appearance of schizaeaceous fern spores, such as *Cicatricosisporites*, with a corresponding decline in previously abundant types, eg *Trilites* (Herngreen & Chlonova 1981). Detailed studies have been completed from sites in the northern hemisphere (Crane & Lidgard 1990) but the findings have yet to be compared with sites from the southern hemisphere.

Several authors have delimited microfloral provinces, such as Brenner (1976), Srivastava (1978), Herngreen & Chlonova (1981) and Herngreen & Duenas Jimenez (1990) as reported by Coetzee (1993).

Four microfloral provinces were identified by Brenner (1976) for the middle Cretaceous:

Northern Laurasian Province - included today's Artic region and had a temperate humid climate. The microfloras were dominated by bisaccate pollen of the Pinaceae and to a lesser extent, of the Podocarpaceae.

Southern Laurasian Province - comprised the middle latitudes of North America and Europe and had a warm temperate to sub-tropical humid climate. Characteristic palynomorphs include bisaccates and other gymnosperm pollen and a diversity of fern spores, with *Classopollis* and inaperturates being found only rarely (Coetzee 1993).

Northern Gondwana Province - consisted of the northern parts of Africa and South America, and was provisionally recognised in the early Cretaceous as the WASA (West African - South American) Province by Herngreen & Chlonova (1981). It was characterised by the predominance of *Classopollis*, *Ephedripites*, and inaperturate gymnosperm pollen. Bisaccate pollen and fern spores were rare or absent. The assemblages suggested a hot and dry climate in contrast to the above. In the middle Cretaceous, the ASA (African-South American) Province recognised by Herngreen & Chlonova (1981) was characterised by elater-bearing genera (Coetzee 1993) and

Ephedripites as well as abundant and varied angiosperm pollen. Saccate pollen was absent and other gymnosperms were rare, as were fern spores.

Southern Gondwana Province (Herngreen & Chlonova's Gondwana Province) consisted of southern Africa, Australia, Antarctica, India, New Zealand and Argentina. A warm temperate to subtropical humid climate was proposed for the early Cretaceous. The Southern Gondwana Province is the one of relevance to this study and will be described further.

1.4.6 Southern Gondwana Province

Most of the information about the Southern Gondwana Province has been obtained from Australia and New Zealand as well as India. Little input has come from South America or southern Africa (Brenner 1976, Herngreen & Chlonova 1981, Coetzee 1993).

A common flora was shared by all the parts of the Southern Gondwana Province during the Cretaceous (Axelrod 1976). By the Senonian, most areas (Australia, New Zealand, Antarctica, Argentina) provided microfloras characterised by *Nothofagities*, the pollen of the rainforest southern beech. However, *Nothofagities* has not been found in the north (southern Africa and India) (Coetzee 1993) and Herngreen & Chlonova (1981) further split the province into the *Nothofagities* and Palmae Provinces. They defined the *Nothofagities* Province by the presence of *Nothofagities* pollen. The Palmae Province in the equatorial regions was characterised by a great diversity of angiosperm pollen and the strong development of Palmae. Srivastava (1978) included southern Africa in the *Nothofagites* province, but as *Nothofagities* has not yet been recorded from southern Africa and it seems that this area was not part of the province. Herngreen and Chlonova (1981) drew no further conclusions as they had insufficient data. Other characteristic palynomorphs such as *Proteacidites, Triorites* and long-ranging austral gymnosperm types have been found (Scholtz 1985), thus southern Africa could represent a transitional area. Even if present at one time in southern Africa, *Nothofagites* may not have survived the general cooling of the climate, or it may not have evolved by the time Africa existed as a separate plate (Axelrod & Raven 1978, Coetzee 1983).

1.4.7 Western Southern African vegetation

Axelrod & Raven (1978) defined major ecosystems based on the principal vegetation belts so far as they could be recognised. Forests rich in gymnospermous Podocarpaceae and Araucariaceae covered southern Africa in the early Cretaceous (Coetzee 1993) in common with other Gondwanan segments. During the late Cretaceous and Palaeocene, the west coast of southern Africa continued to be covered by rainforest, either subtropical or temperate with austral affinities. Saccate gymnosperms found included the trisaccate *Microcachrydites.* Non-saccate gymnosperms were similar to those known from the Northern Gondwana Province, including *Classopollis* and *Araucariacites*. Sporomorphs of bennettitaleans, gingkos, taeniopterids and lycopods were seen. The angiosperm pollen found comprised small, reticulate tricolpates and monocolpate forms such as *Clavatipollenites*.

The time of separation of South America from Africa in West Gondwana is important for angiosperm biogeography as floral exchange was still possible until the final severing of the land bridges of the Walvis Ridge and Agulhas Plateau (Goldblatt 1993). Apparently, the first divergence of microfloras between Africa and South America dates from the uppermost Cenomanian and lowest Turonian, when certain microfossils show a restricted distribution (Coetzee 1993). Some parallel trends continue, such as the decrease in *Ephedripites* pollen during the Senonian and appearance of rich diversity in the upper Senonian, such as is seen in *Proteacidites*, *Cupaniedites* and *Triorites*.

By the Tertiary, a vegetation gradient existed between the more xeric north-western sector of South Africa and the temperate-humid south-western regions, probably due to regional climatic differences (Coetzee 1993). At the Cretaceous-Tertiary boundary, relations between South America and southern Africa were mainly at family level, but by sometime in the Tertiary, most of the floras known had a relatively modern aspect. Palaeogene botanical records for Africa are scarce (Coetzee 1993) due to lack of material, however at Arnot, there is evidence for an open canopied dry subtropical forest with an understorey of Ericaceae, Epacridaceae, Thymelaceae and Restionacae (Scholtz 1985). This group of families may have a direct bearing on the evolution of the present Capensis floral region. By the Oligo-Miocene the flora was beginning the change to sclerophyllous vegetation (Axelrod & Raven 1978), with the rainforest to the south. By the late Miocene, the rainforest had been eliminated except for isolated patches along the south coast from Cape Town to Port Elizabeth.

The modern flora of the southwestern Cape Province is unique in comparison to those from other areas of similar climate as it has been isolated for 100 My. Some modern aspects of the flora were in existence by the Miocene, as the vegetation adapted to the aridifying climate and the elevation of topography, spreading savannah, thorn scrub and grassland at the expense of the rainforests. The temperate forest dominated by *Podocarpus* which exists in the southern Cape today is a relict of the formerly widespread flora (Goldblatt 1978). Local semidesert areas probably existed during the Pliocene, but widespread, regional desert conditions were only created as a function of the ice ages. In late Tertiary times, climatic fluctuations induced extinctions on a large scale.

1.5 Previous Research

The fossil record for plants in southern Africa dating from the Jurassic to the Quaternary is poor (Goldblatt 1978). Only the microfloral (palynological) evidence known from the late Cretaceous and Tertiary is considered in this review of specific studies. The sites in and around southern Africa which yielded palynomorphs are shown in Figure 1.13.

1.5.1 Kirchheimer 1934

Kirchheimer examined some material from the Arnot Pipe near Banke, Namaqualand which was rich in plant fossils and known to be Upper Cretaceous in age. He found pollen from angiosperms and conifers which did not resemble the present day flora of the area.

1.5.2 Thiergart *et al.* 1963

A cursory study was made on lignite found close to Knysna on the south coast (Scholtz 1985). It forms part of the Knysna Formation which has been estimated by various workers to be from Oligocene to Pleistocene in age (Kent 1980) and Miocene by Maud and Partridge (1987).

1.5.3 McLachlan & Pieterse 1978

As part of the Deep Sea Drilling Project, McLachlan & Pieterse examined a core drilled at Site 361, 290 km west-southwest of Cape Town. It intersected a nearly continuous sequence of sediments from Aptian to Eocene. Palynological studies were completed on samples from the Cretaceous interval. They discovered a profound difference between Upper and Lower Cretaceous floras, as the Lower showed little species diversity while the Upper was much richer. The low diversity was interpreted as reflecting a harsh climate of some sort, possibly cold or with scanty rainfall. The higher diversity was thought to indicate a warmer and wetter climate. Mono- and bisaccates, together with *Classopollis,* dominated the Lower Cretaceous sequence. Trisaccates were more important in the Upper Cretaceous. Many of the trilete spores were similar to those known from Australia, however the important species on which the Australian zonations are based, are lacking. Few similarities were noted with described West African floras. The angiosperms appeared very suddenly in the Cenomanian in great numbers, monocolpates appearing earlier than tricolpates. Again, the key palynomorphs used for zoning elsewhere (*Nothofagites*) were not found. Because of the paucity of reliable index fossils, the age boundaries were placed arbitrarily. Site 361 was compared successfully with boreholes drilled close by on the Agulhas bank (unpublished SOEKOR information).

1.5.4 Coetzee 1978

Coetzee presented an overview of several sites of different ages in order to produce a palaeoclimatic picture of the southwestern Cape. The sites from the Cape peninsula were Saldanha Bay, 100 km north of Cape Town; Mamre, 50 km north, inland; Noordhoek, 20 km south; and several separate sites on the Cape Flats, on the north shore of False Bay, southeast of Cape Town.

Two pollen zones were distinguished (Figure 1.14 a). The lower zone (L) represents Tertiary microfloral assemblages containing many extinct forms. It was subdivided into seven sub-zones dated from the late Oligocene to Pliocene, indicating alternations of cool-wet conifer forests with palm-dominated sub-tropical vegetation.

The upper zone (M) contains pollen of the present maccia vegetation and is Quaternary in age.

Coetzee also found that index palynomorphs used elsewhere for zoning were absent and those that were common, had long stratigraphic ranges (*Triorites harrisii*, *Clavatipollenites* cf *hughesii*, *Echiperiporites*, *Sparganaceaepollenites*, and *Cupaniedites orthoteichus*). On the basis of the first occurrence of Compositae pollen, it was assumed that some of the oldest of these deposits were at least late Oligocene-early Miocene in age, as the presence of Compositae is an accepted stratigraphic marker. The time of extinction of Tertiary vegetation in the Cape was taken to be when none of the internationally recognised species continued to be found, at the end of the Pliocene.

In Pollen Zone M, the angiosperm pollen component of the assemblages became much higher, with an increase particularly in the Ericaceae, characteristic of the current unique Cape Flora.

Coetzee noted differences between South African and Australian Proteaceae pollen from sediments of the same age. In Australia, Kemp (1975) found large reticulate and granulate types while in South Africa, the Proteaceae lacked diversity.

Palm pollen was also worthy of note. Although present at all levels, it was dominant (over 30%) during two periods. No palm pollen was recovered after sub-Zone Lvii, and the fossil forms do not resemble any Palmae known in sub-tropical South Africa today, but they do appear similar to Tertiary palm pollen of other continents.

The conifer forests had varying compositions but contained at least 20% Podocarpaceae pollen. The latest (sub-Zone Lvi) was dominated by *Triorites harrisii* (Casuarinaceae) which is well known from the early Tertiary rainforests of Australia. Casuarinaceae do not occur in South Africa at the present day and elsewhere they have become adapted to drier conditions. Coetzee thought that the presence of *Cupaniedites* *orthoteichus* indicated that the last forest phase may have endured wetter conditions than the previous two.

1.5.5 Coetzee 1980

Coetzee related the palaeoclimatic conclusions above to the glacial history of the Antarctic and the aridification of the Namib desert. The last Tertiary temperate forests were eliminated 3.5 Mya during the severe Pliocene drop in temperature following which the macchia vegetation was developed at the Cape.

1.5.6 Coetzee 1981

Coetzee found primitive angiosperm pollen types (*Clavatipollenites* sp cf *hughesii* and *Pseudowinterapollis*) in deposits thought to be late Oligocene/early Miocene. *Clavatipollenites* is well known from the Lower and Upper Cretaceous and Tertiary elsewhere. As the family that it has affinities to, the Chloranthaceae, is not now found in Africa, but does have a markedly discontinuous distribution worldwide, it was considered to be the remnant of an extensive angiosperm flora which has almost disappeared. *Pseudowinterapollis* is similar to pollen of the Winteraceae, confined today mainly to the South Pacific and South America. One genus is known from Madagascar. It was considered to be a very ancient group.

1.5.7 Coetzee & Rogers 1982

Another site close to Cape Town, Langebaanweg, was investigated palynologically. Four geological units occur, the youngest being the Bredasdorp Formation, then the Varswater Formation, the "Saldanha" Formation and the oldest, the Elandsfontyn Formation. The Varswater Formation is economically important because of phosphate deposits and interesting because of the rich fossil fauna. It was assigned a terminal Miocene/early Pliocene age based on the fossils. The "Saldanha" Formation contains late Miocene fossils. Pollen from a peaty horizon occurring near the top of the Elandsfontein Formation indicated a flora entirely different to that known from the area today, but similar to other Tertiary microfloras from New Zealand, Australia and the Ninetyeast Ridge. Again, marker palynomorphs could not be found and the Compositae were used to confirm the Miocene age of these sediments. Two pollen zones, Sa and Sb, were recognised, representing two apparantly distinct vegetation units (Figure 1,14 b). Palm pollen dominated Zone Sa and indicated progressive deterioration of riparian vegetation while in Zone Sb above it a decrease in the palms suggested a freshwater marsh environment.

The sequence of deposits was related to the movements of the Berg River in Miocene times. These pollen zones were not related to those from Noordhoek.

1.5.8 Scholtz 1985

Scholtz re-examined sediments from the Arnot Pipe at Banke. The sediments containing palynomorphs were found as part of the infill of the crater lake which existed shortly after the emplacement of the pipe itself. Other pipes in the area were dated by radiometric means and thus the sediments appear to have an age of 64 - 71 My (late Cretaceous to Palaeocene).

Scholtz found a varied assemblage of spores, conifer and angiosperm pollen which he contrasted with assemblages from tropical Africa and Australia. The assemblage resembled the Australian flora more closely.

1.5.9 Coetzee 1986

Microfossil records from the Cape support the hypothesis that a common flora existed in South America, Antarctica, Africa and Madagascar. The latter was shown to have more in common with southern than eastern African contacts.

1.5.10 Coetzee & Praglowski 1988

The authors illustrate and describe some Winteraceous pollen from Noordhoek. The Winteraceae are one of only two angiosperm families with a fossil record extending back to the Aptian. The discovery of these grains represented the first fossil record of the family in Africa. Currently, they have a relict disjunct distribution between Australasia and Madagascar and also between Australasia and South America. This distribution pattern has generated much speculation about their place of origin and subsequent dispersal. They may have migrated from Australia via Antarctica to South America, or have originated in equatorial Africa and migrated south. The latter theory was adopted as it appeared to fit the facts better.

1.6 Established Systematics

1.6.1 Introduction

Taxonomy combines with nomenclature to produce systematics. There is an important difference between 'taxonomy' and 'nomenclature' (Boulter 1979). The term 'taxonomy' is defined as the scientific recognition and treatment of taxa (Stafleu 1967) which are assemblages of individuals brought together because they are considered to be related in one way or another. Traverse (1988) states that all taxonomic systems found in the literature are informal, ie. not recognised by the ICBN. 'Nomenclature' is defined by Stafleu (1967) as 'a practical system of agreements which enables us to understand and discuss each other's taxonomic concepts' and is concerned with the accepted rules and recommendations of the International Code of Botanical Nomenclature (ICBN) (Boulter 1979).

1.6.2 Taxonomy

Traverse (1996) discusses classificatory schemes and their linkage to nomenclature in palynology. Palaeopalynological genera are typified by dispersed fossil specimens (of a "fragmentary nature" according to the ICBN) which, as they are not 'whole organism' remains, cannot be grouped by ICBN rules under suprageneric names at family level, though they may be referred to taxa at a higher rank, eg class Angiospermae. Thus, fossil pollen and spores cannot be classified according to true taxonomy, ie. the hierarchy of groupings of plants or animals indicative of presumed natural relationships.

Various methods of classifying palynomorphs have been proposed (Traverse 1996), defined as 'parataxonomies' which use the morphological features that the palynomorphs have in common for retrieval purposes. All parataxonomies have the disadvantage that communication between different systems is difficult.

Potonié s turmal system (1950) is the best known format and is described in Traverse (1988). It should not be confused with formal taxonomy; names of the authors for the units and the dates of their establishment should not be cited (Traverse 1996). The turmal system was developed to categorise Palaeozoic sporomorphs and Traverse believes that it is of no use for Tertiary palynomorphs as angiosperm pollen cannot be adequately classified. Batten (1996) commented that much of the taxonomy and nomenclature of Mesozoic and Tertiary dispersed pollen and spores is in an unsatisfactory state, which is a reflection of the difficulties of differentiating taxa from a plexus of morphotypes whose characters overlap.

The parataxonomy used in this research is described under 'Methods' below.

1.6.3 Nomenclature

The naming of genera and species in palaeopalynology has caused much discussion in the literature. Normally, generic and specific names are awarded to the organism as a whole. However, the dispersed, fragmentary nature of pollen grains and spores raises the obvious question of their true botanical affinities. Recognisable connections with modern plants are more and more tenuous as their geological age is increased, until Palaeozoic forms are undoubtedly related to long extinct forms. Palaeobotany as a science is plagued by a multitude of generic names for fossils, such as *Cordaites, Mesoxylon, Artisia, Cordaicarpon, Cordaianthus* or *Florinites* which could have come from the same tree, depending on the plant part and mode of preservation (Traverse 1996). Therefore, botanical names for palynomorphs are possibly not accurate.

However, purely morphological names give no clue as to the botanical origin of the spore or pollen grain.

The Tertiary period encompasses the crux of these issues as relatively little time has passed on a geological scale. Some plant forms which are still extant already existed while others are now extinct, producing a playnflora in which some grains can be related directly to modern forms and others have no obvious botanical affinities. The study of Tertiary palynology is further complicated by the large range of angiosperms and gymnosperms that existed, let alone the uncertainties of plant migration and rates of evolution (Boulter 1979).

The botanical versus morphological debate has raged throughout the development of palynology as a science. The leading workers in the field have periodically published new systems for nomenclature.

The concept of form-genera was first formulated by palaeobotanist Brongniart in the mid 19th century when he stressed the fact that it is better to have an artificial classification based upon a restricted number of characters derived from similar fragments than to speculate too soon on natural relationships, as cited in Stafleu (1967).

Erdtman (1947) proposed a classification system for fossil and recent pollen grains and spores based on morphology. He defined many of the morphological features often seen. No genera were formally designated as the system had not been discussed or ratified by the appropriate international scientific body.

Van der Hammen (1956) introduced an artificial palynological nomenclature which suggested theoretical possibilities as well as formally describing palynomorphs from the Maastrichtian and Palaeocene. However, the system linked fossil forms with modern taxa on the premise that as the system was purely artificial, based on morphological characters only, both fossil and extant pollen and spores belonged to the same genera, and used modern pollen types for fossil species. This practice was not encouraged (Traverse 1996). Pollen grains were recognised by the nature and position of the apertures, following Erdtman. The definitions proposed by Iversen & Troels-Smith (1950) were also adopted. Large genera such as *Tricolpites* were subdivided according to sculpture type producing subgenera such as *Retitricolpites*. Spores were recognised by the presence of laesurae and individual genera erected according to the sculptural elements, eg. *Verrutriletes*.

Between 1956 and 1958, a public debate on the problems of Tertiary palynomorphs was held between Potonie and Traverse, discussed in Boulter (1979). On the one hand, Potonie and European collaborators thought that Tertiary pollen should not be given names based on modern plants if the holotypes are in the form of dispersed fossil material. On the other hand, Traverse and fellow North Americans held the view that dispersed fossil pollen forms belonging to extant genera should be described as organ species. Boulter concluded that it was doubtful whether any direct influence was brought to bear on the methodology of subsequent work. The majority of authors continued to choose to use form-generic names, unassignable to modern or fossil plant families, and attempted to follow the ICBN when new genera or species were described.

Other systems have been proposed in the literature. Boulter & Wilkinson (1977) introduced 'a system a group names for some Tertiary pollen' which assigns pollen to a simply defined grid for identification. The concept was further developed by Boulter (1979) in a second paper. Traverse (1988) mentions the 'Shell Code' which was used in the oil exploration operating companies. More advice on nomenclature was offered by Potonié and Grebe (1974) and Bharadwaj & Venkatachala (1968), among others.

As the ICBN rules of priority apply to generic and specific names, three parallel usages are found in the literature (Traverse 1988):

1. **Natural**, where reference to extant taxa is certain and the modern generic name could be used, eg. *Pinus.*
2. **Semi-natural**, where affinity to an extant taxon is suspected but not proven, eg. *Araucariacites* for forms similar to the pollen of *Araucaria.*
3. **Artificial**, where a form-generic name is given based solely on morphological criteria such as number and structure of apertures and exine features, eg. *Tetracolporites* to describe a grain possessing four colpi and pores.

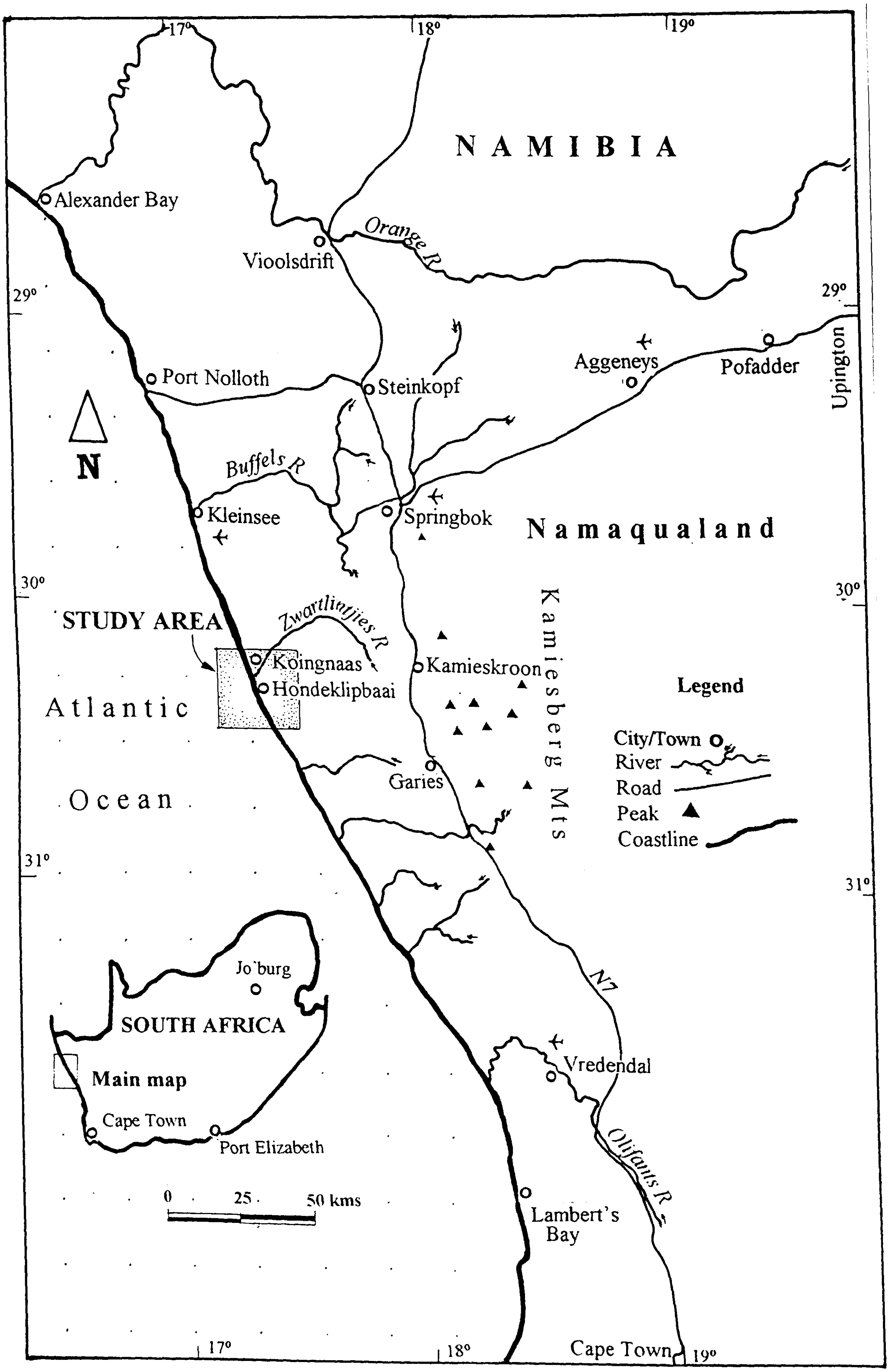
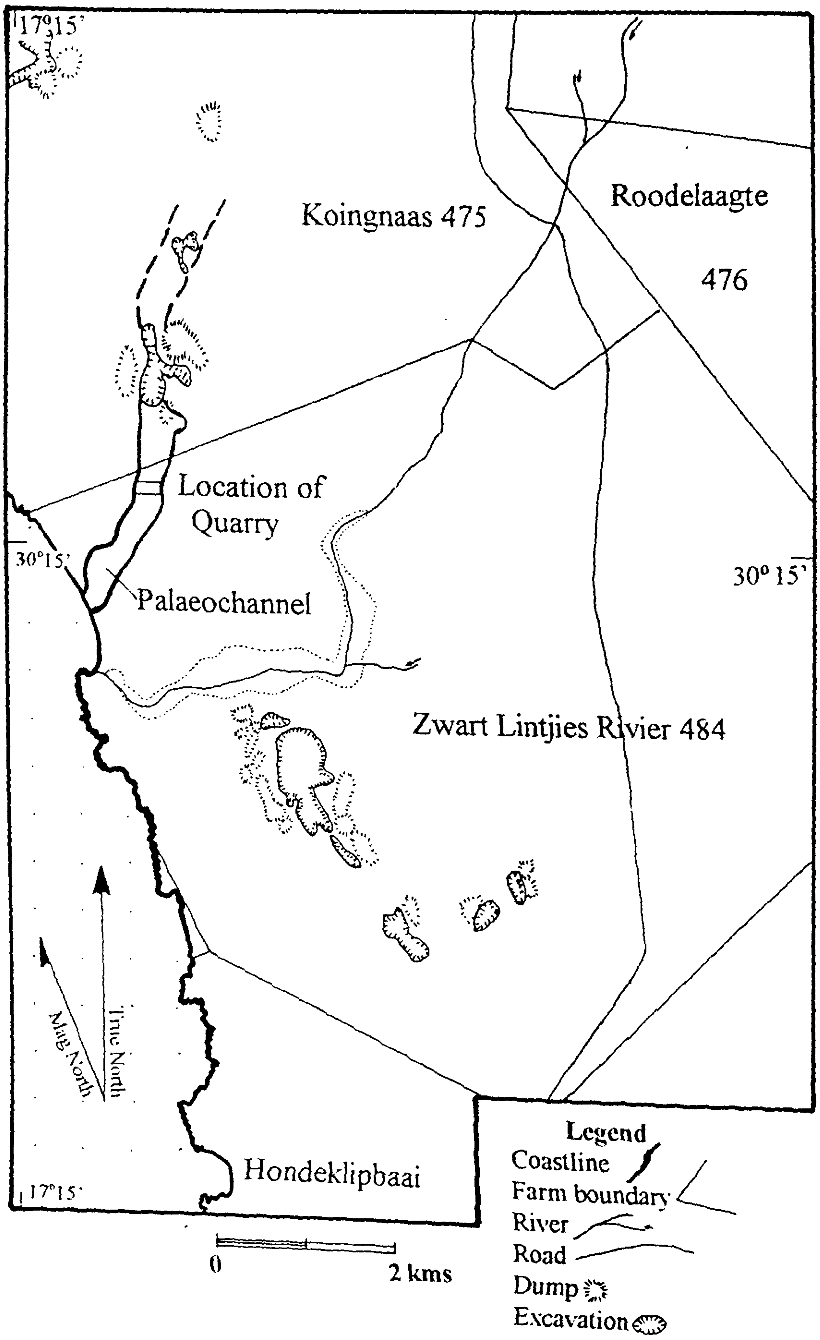


Figure 1.1 **Locality plan**



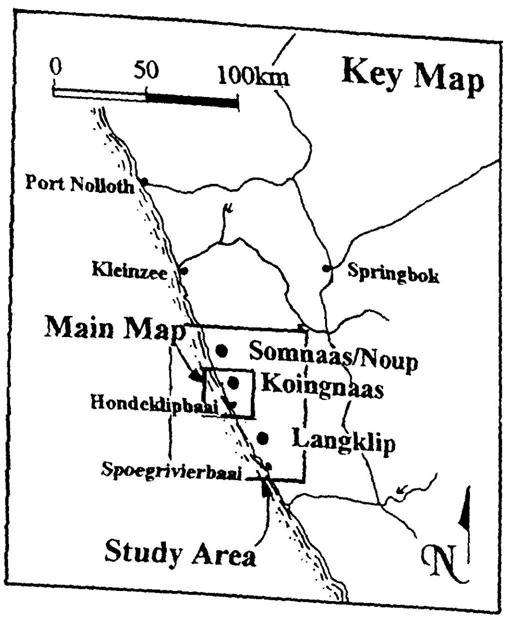
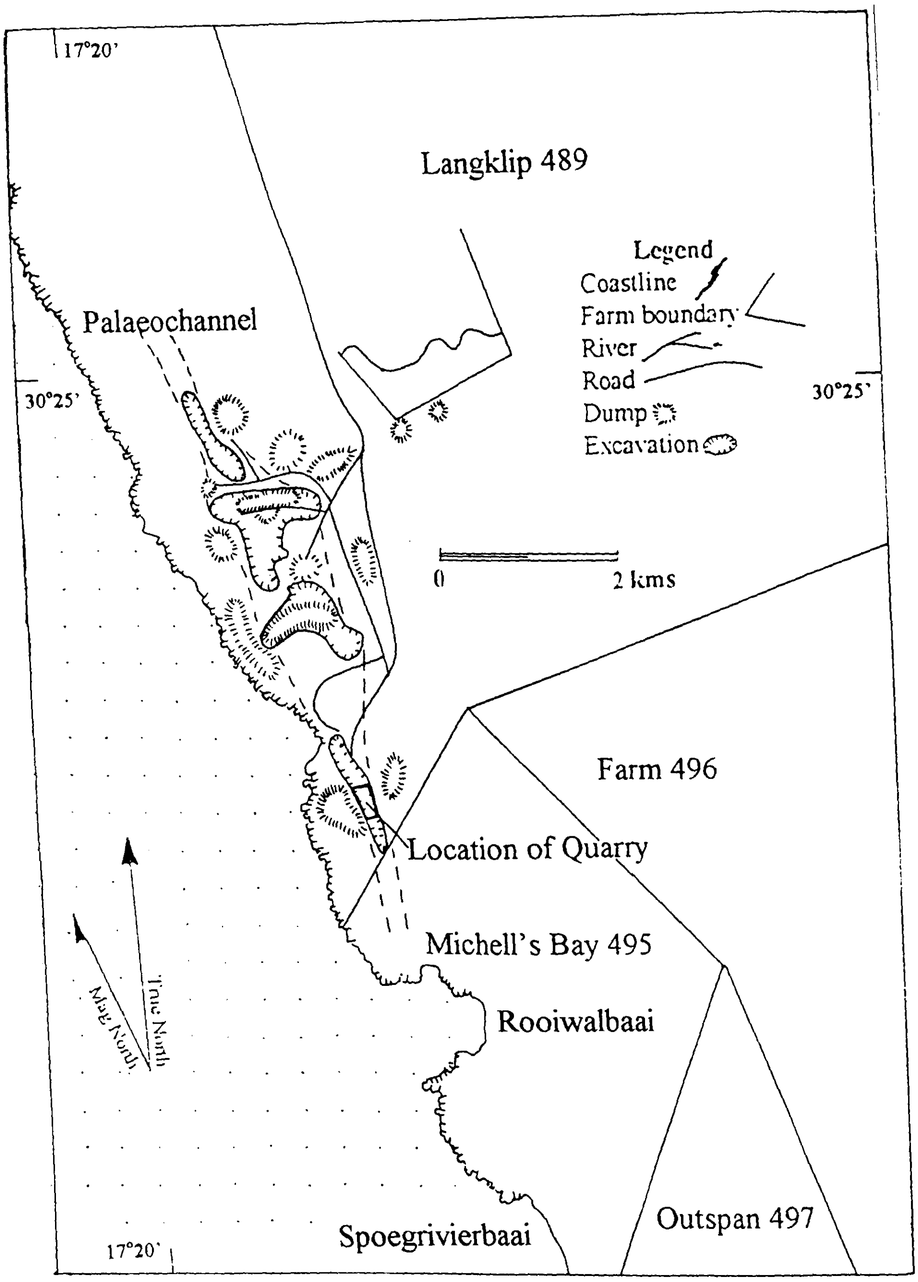


Figure 1.2 **Koingnaas - Locality plan**



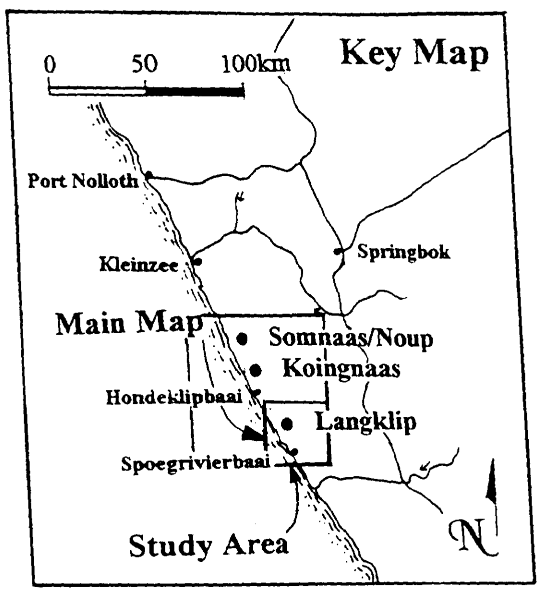


Figure 1.3 **Langklip - Locality plan**

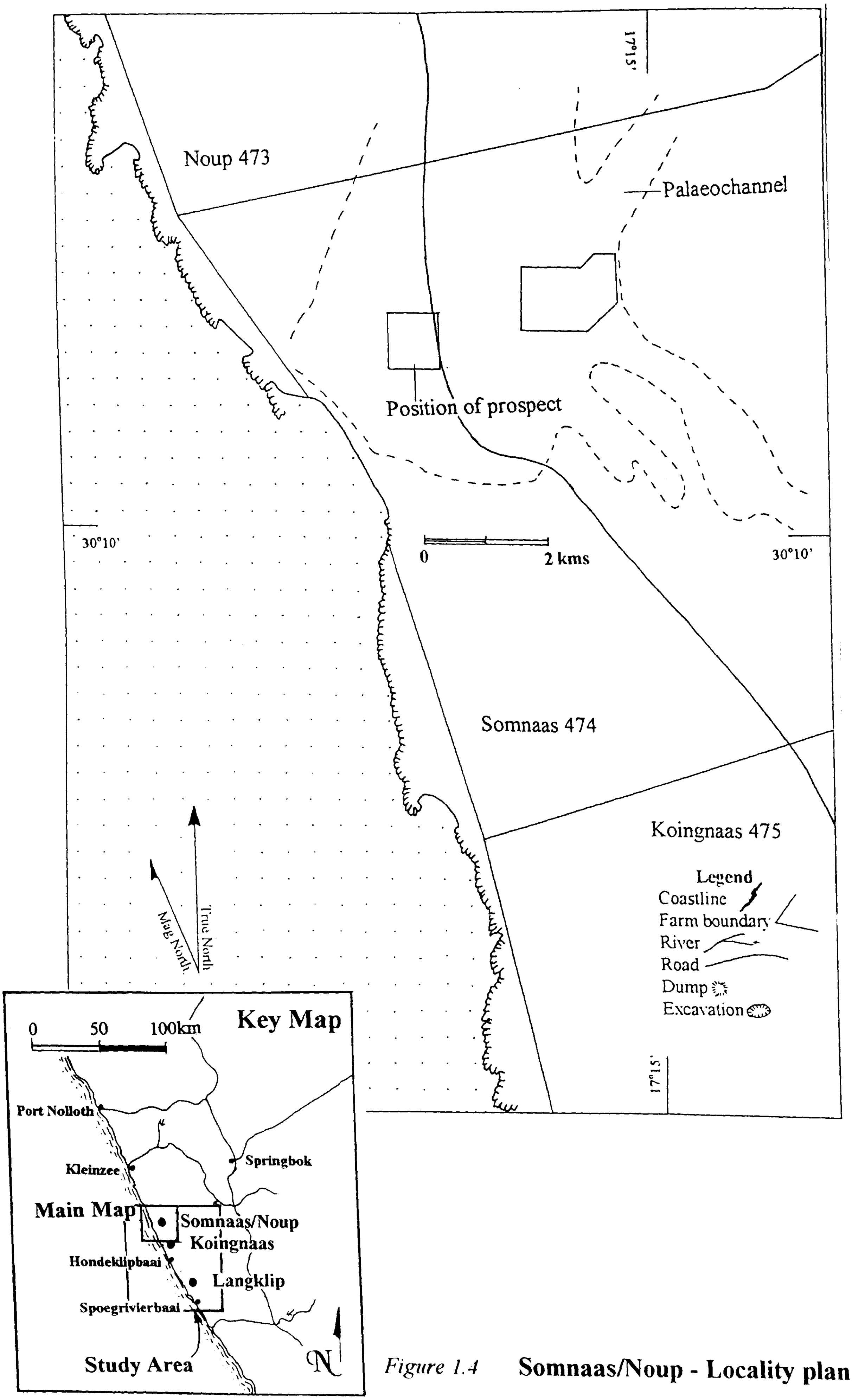
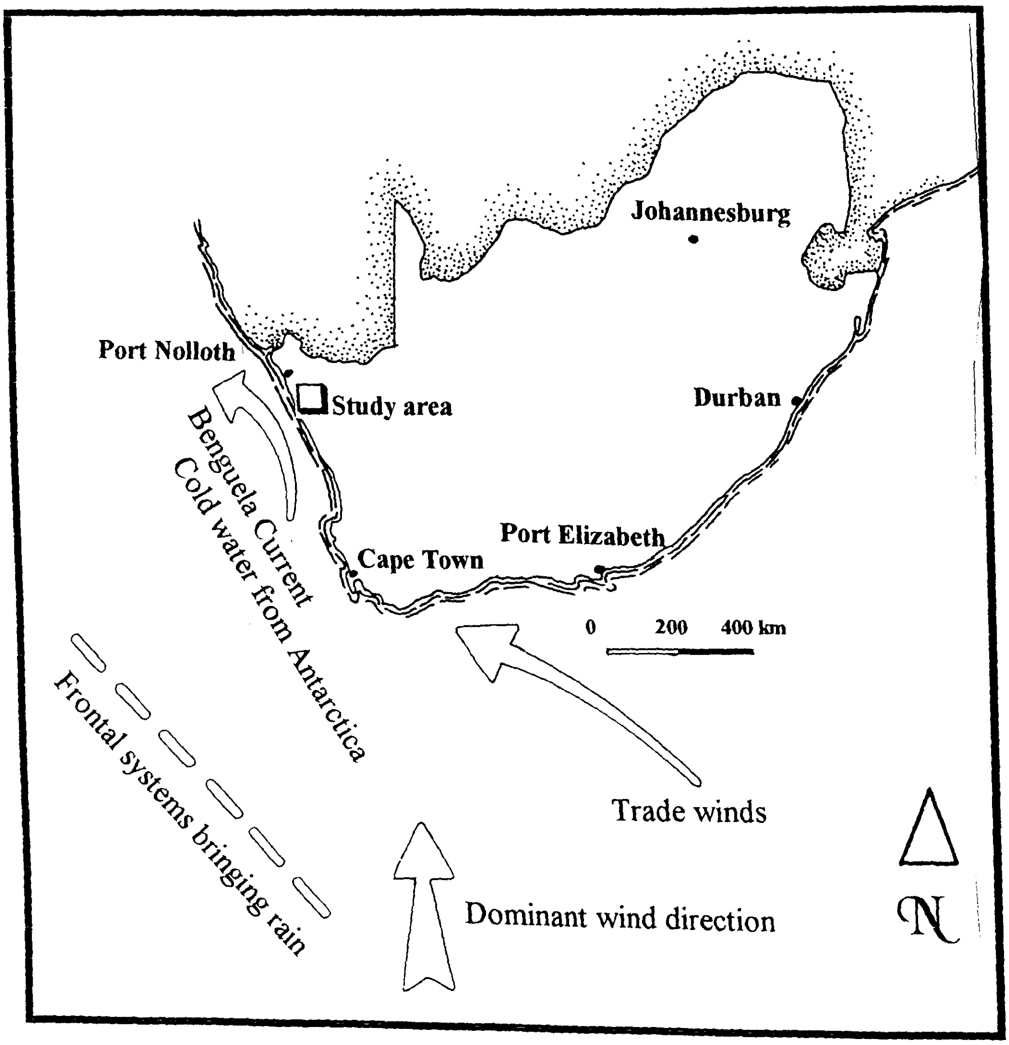
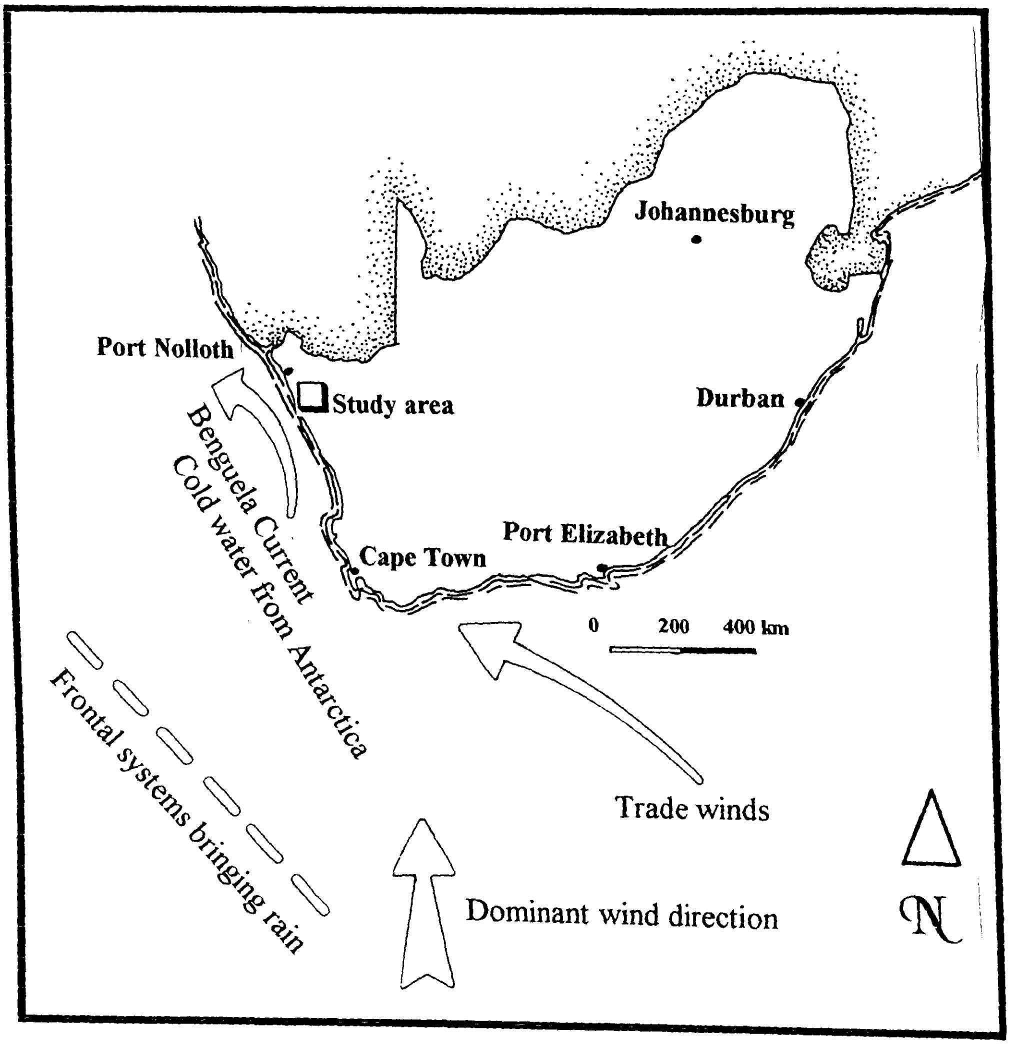


Figure 1.4 **Somnaas/Noup - Locality plan**



	January	July
Daily max temperature Range (°C)	15 – 24	9 – 21
Sunshine rating	70%	70%
Annual precipitation	125 mm (+/- 25%) (30% in May & June)	
Frost	Largely unknown	
Sea surface temperatures Average (°C)	18	14
Wind speed	Up to Gale force (65-100 km h^{-1}) Gusts (130-160 km h^{-1})	

Figure 1.5 **Climate of the West Coast**



	January	July
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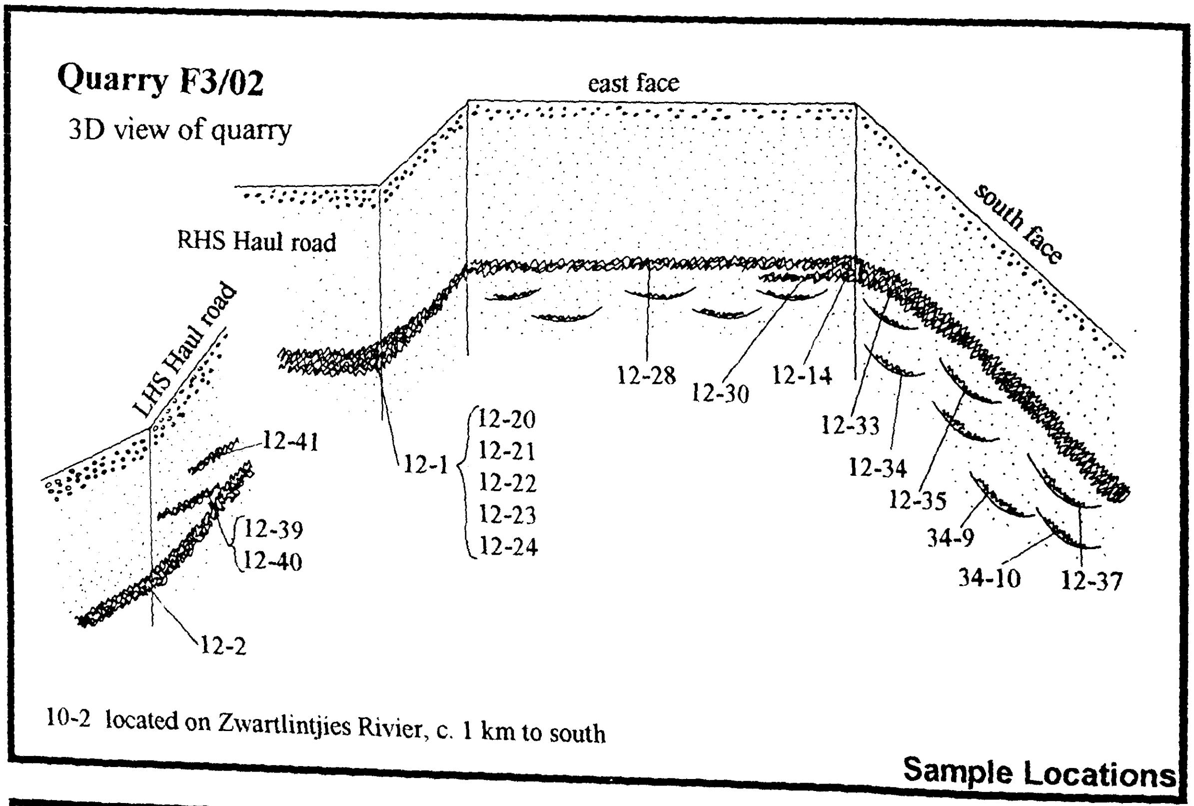
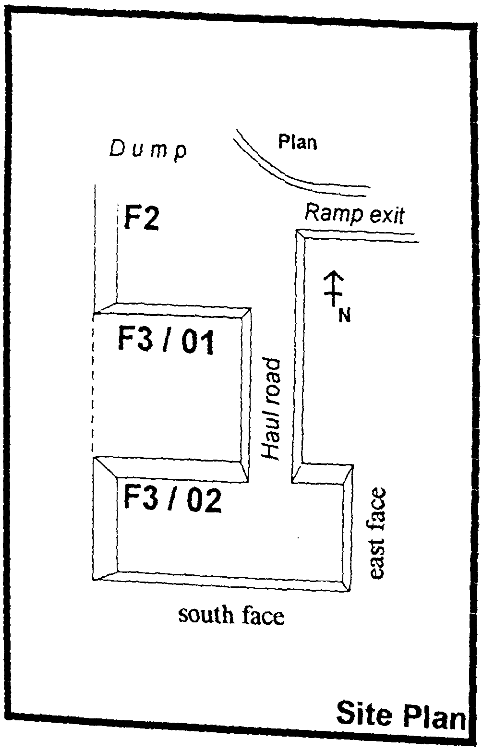




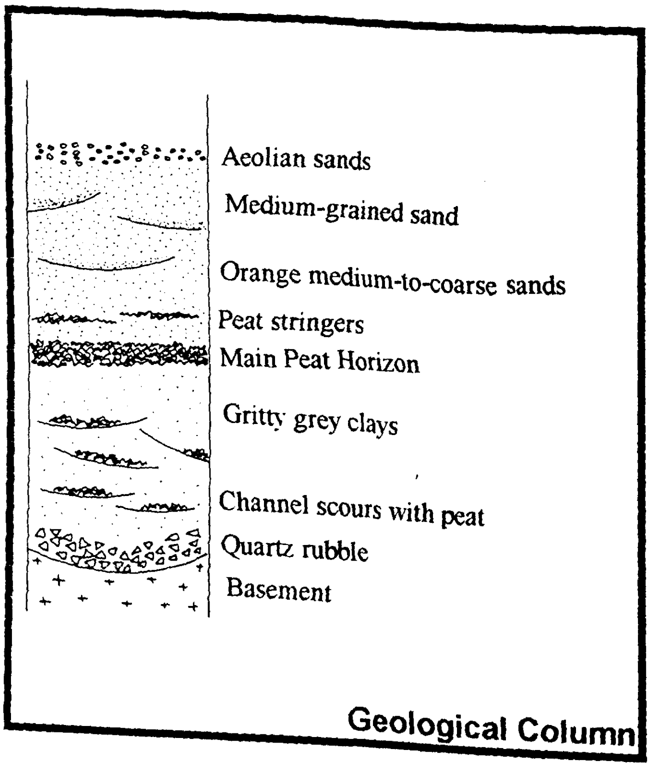


Figure 1.6 **Koingnaas - Site plan and sample locations**

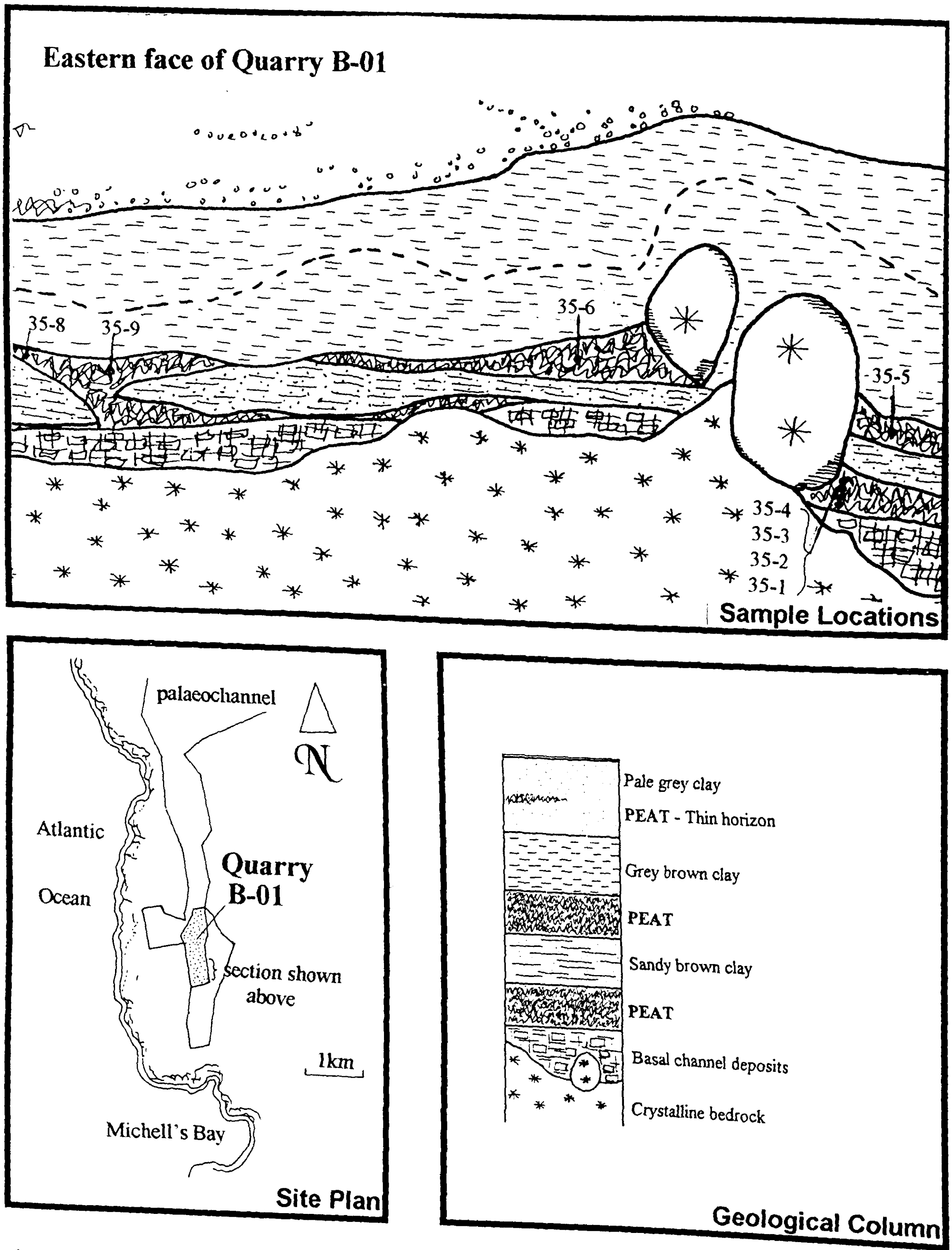


Figure 1.7 **Langklip - Site plan and sample locations**

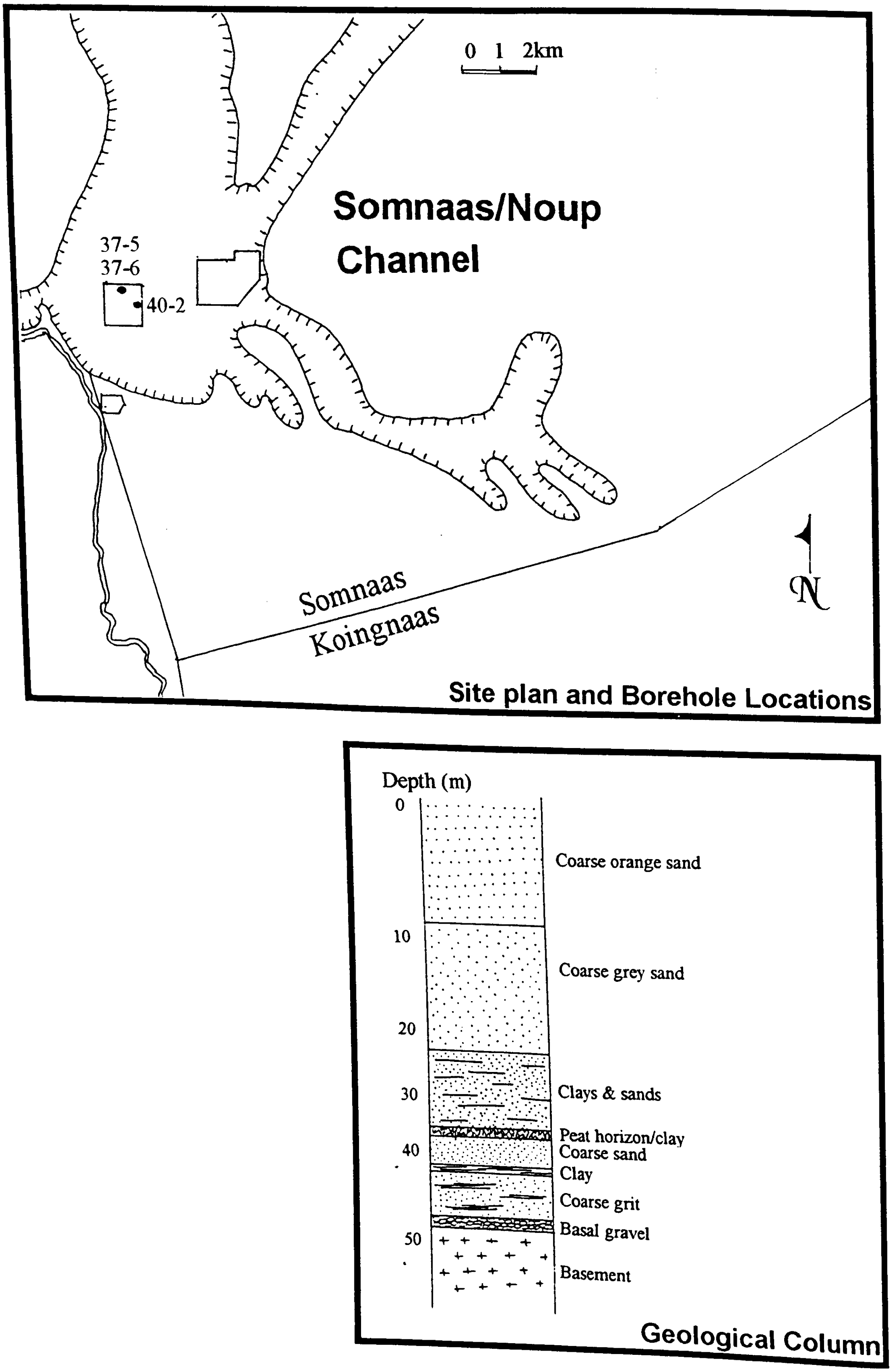


Figure 1.8 Somnaas-Noup - **Site plan and sample locations**

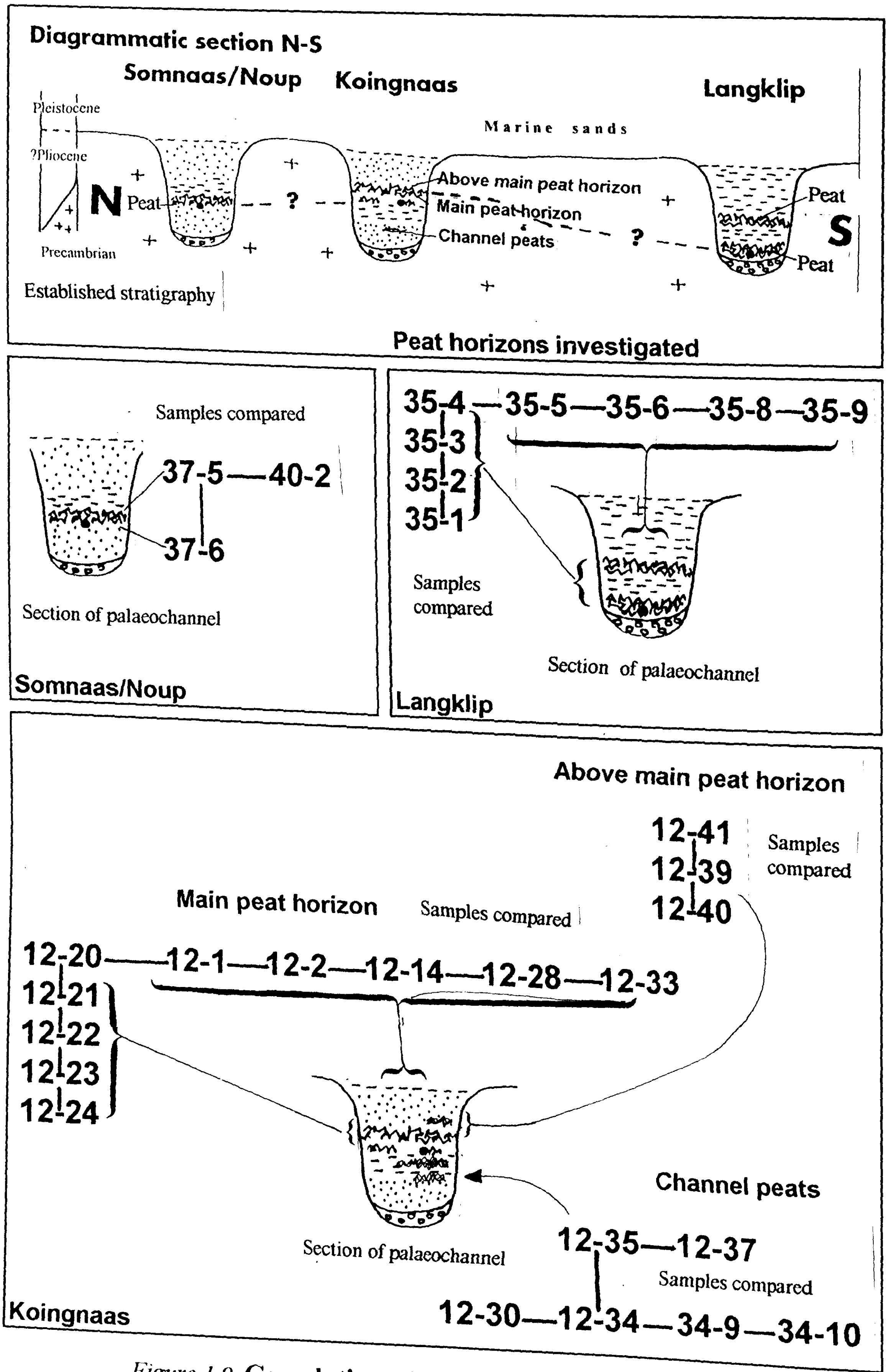
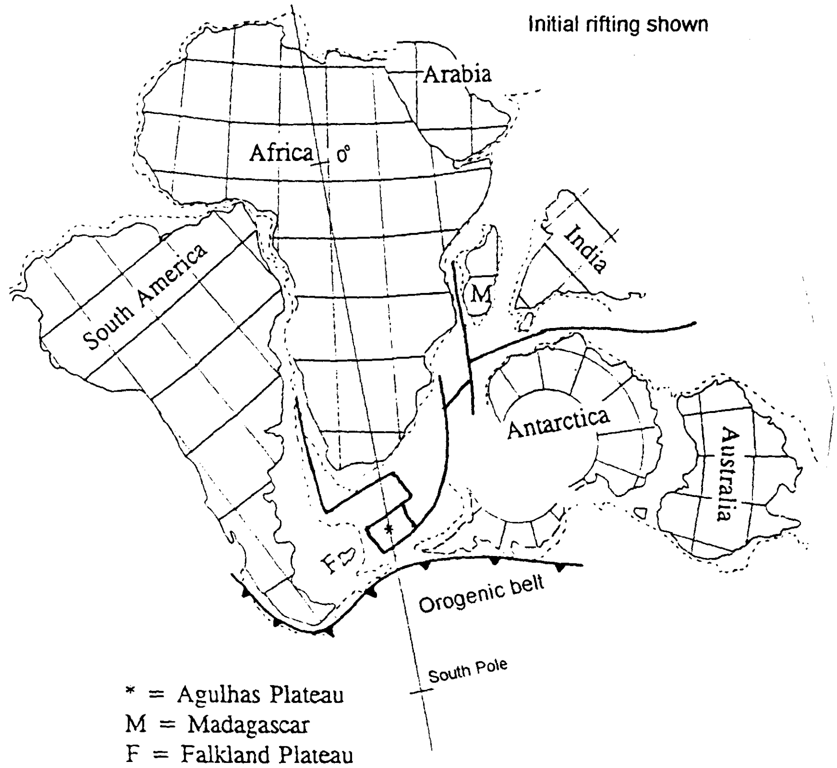


Figure 1.9 **Correlation of Peat Horizons**

1.10a **Gondwana pre-drift (Triassic) palaeogeography**



Taken from Dingle *et al* 1983

1.10b **South Atlantic - Restricted marine phase**

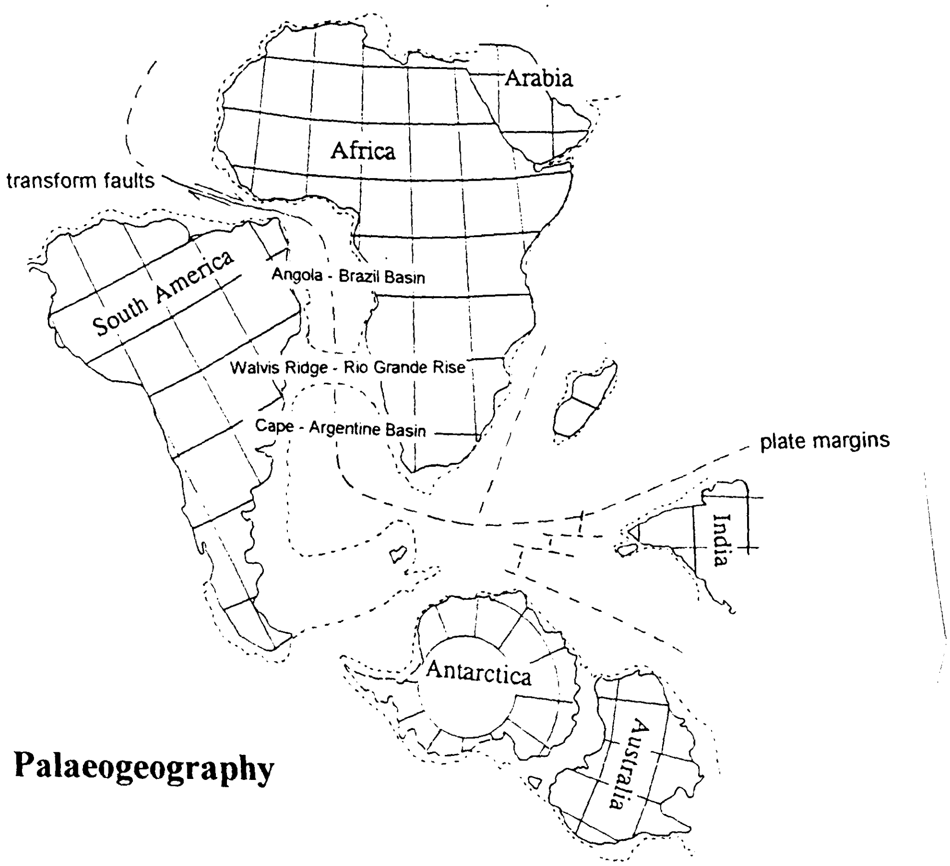
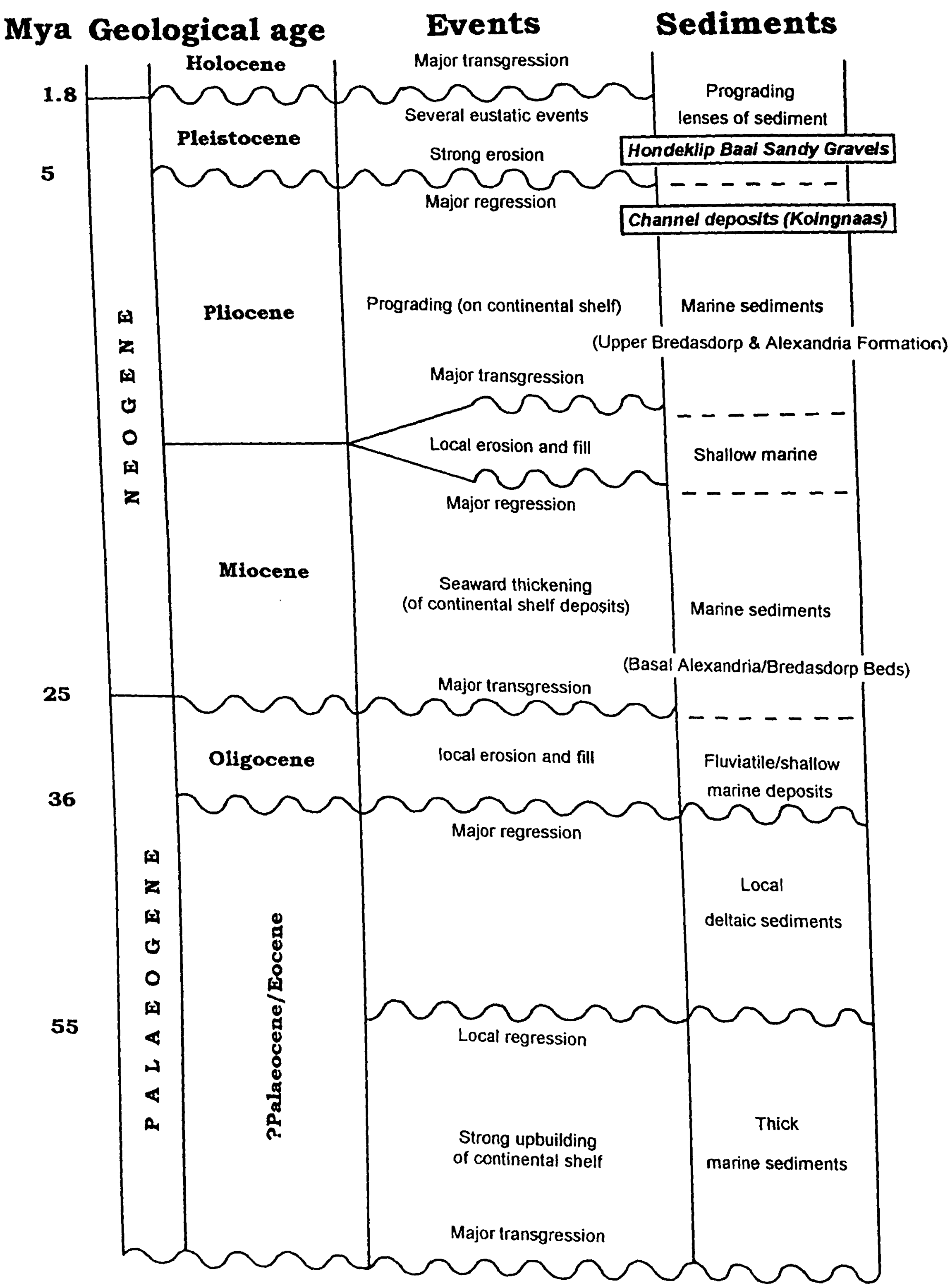


Figure 1.10 **Palaeogeography**

Based on Briden *et al* 1974 and Bolli *et al* (1975)



Information taken from Siesser (1972, 1982), Dingle (1973), Dingle & Scrutton (1974), Kennet *et al* (1974) and Truswell (1977).

Figure 1.11 **Established Stratigraphy**
during the Tertiary of the western coastline of southern Africa

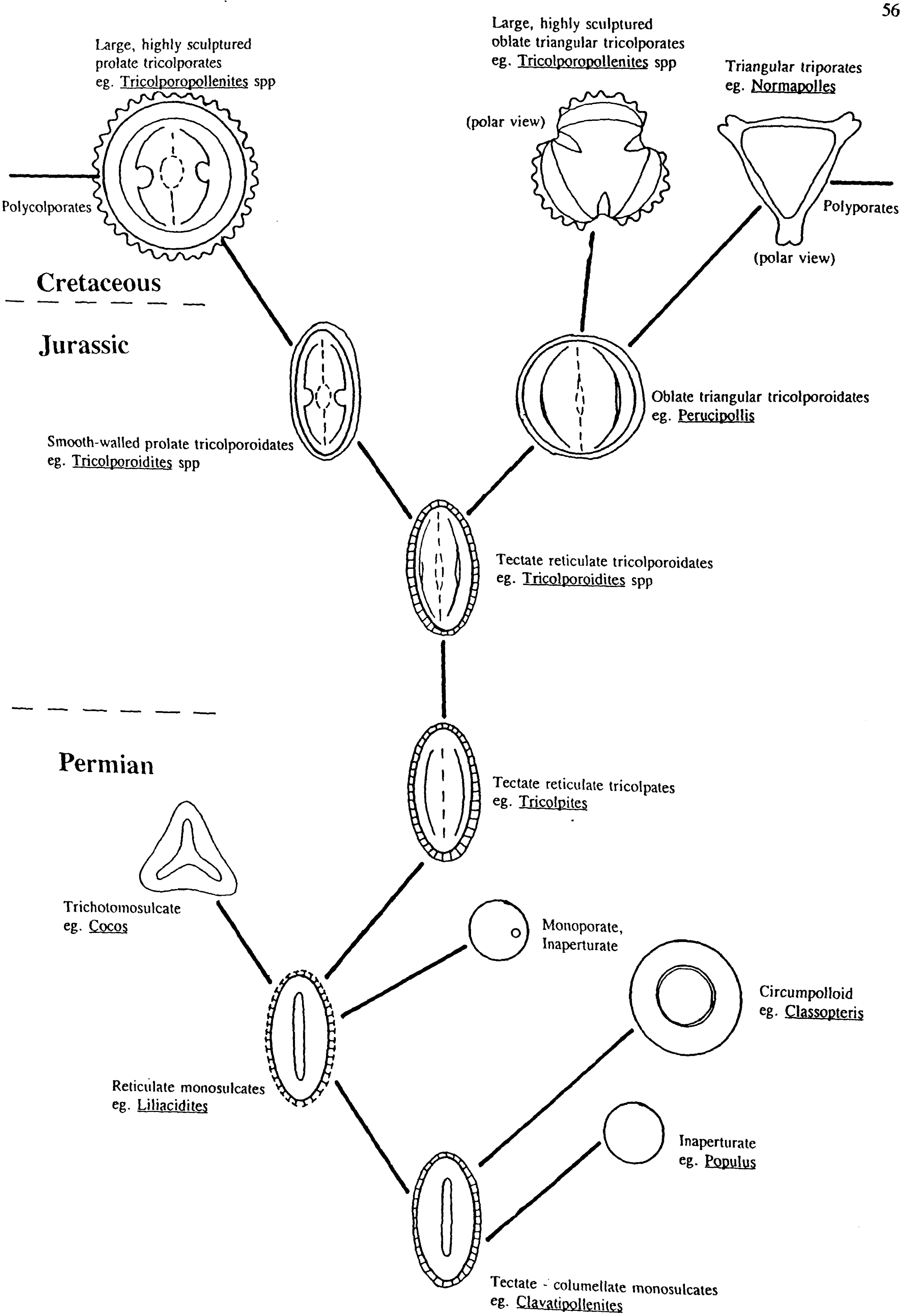


Figure 1.12 **Evolution of angiosperm pollen**

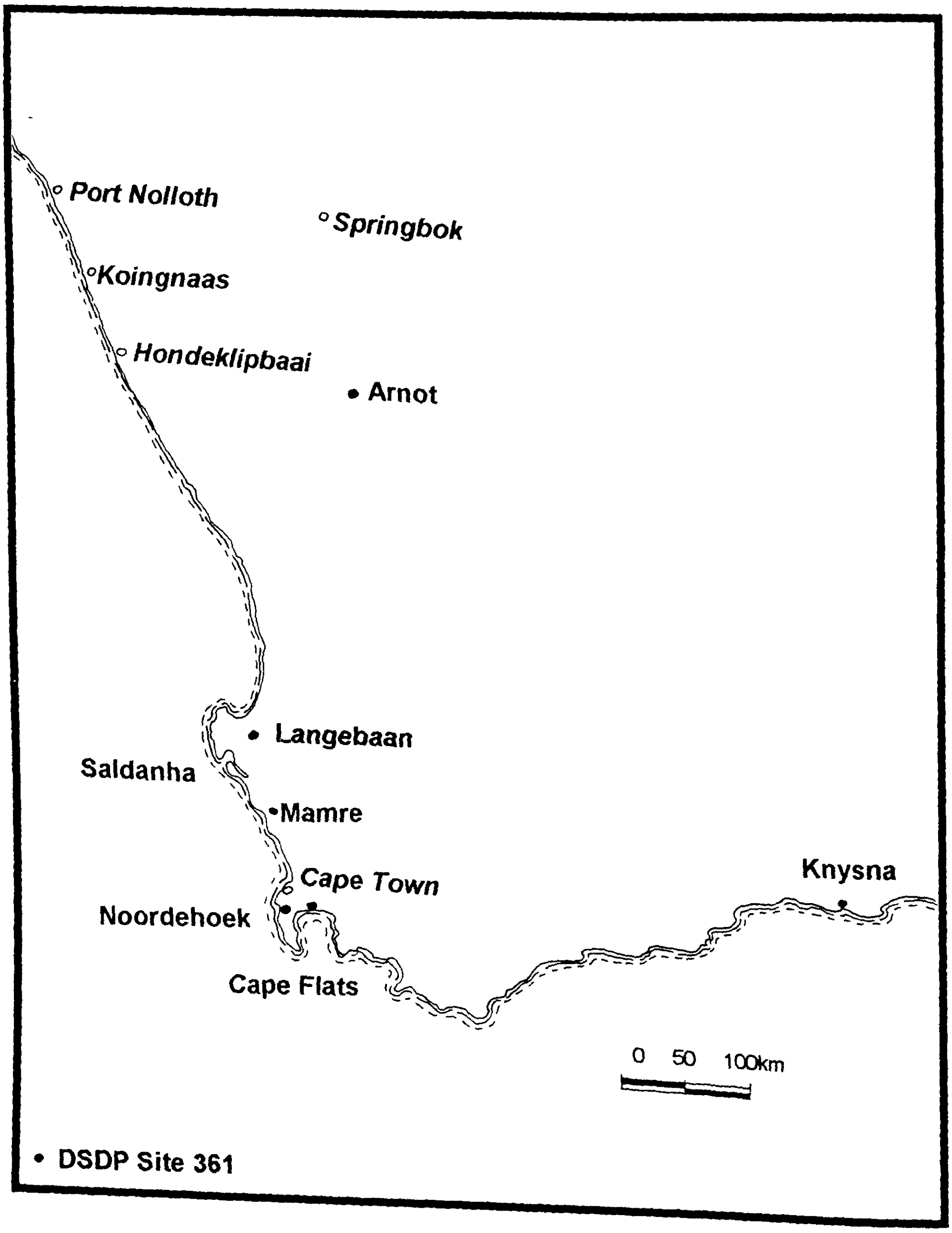


Figure 1.13 **Sites of palynological significance in southern Africa**

Zone	Vegetation	Climate	Suggested Stratigraphy	
M	Present Macchia	Present	Quaternary	
L vii	First strong Macchia devt.	Colder Drier	T	Pliocene
L vi	FOREST Conif, Casuar, Cupan	Cool wet		Late Miocene
L v	Palmae	Sub-tropical Tropical	R	Middle Miocene
L iv	SWAMP Restionaceae	?Temperate Locally wet		Early
L iii	FOREST Conif. 1st Comps	Cool wet	E	
L ii	Palmae	Sub-tropical Tropical		Miocene
L i	FOREST Coniferae	Cool wet	T	Late Oligocene

1.14a Noordhoek Zones (Coetzee 1978)

S b	MARSH	Cool wet	TERT	Middle Miocene
S a	FOREST Palms	Subtropical		

1.14b Saldanha Zones (Coetzee & Rogers 1982)

Figure 1.14 Pollen Zones from the southwestern Cape

Materials & Methods

Chapter 2

Materials and Methods

2.1 Materials

The materials used in this research consisted of core and grab samples from the quarries and boreholes detailed above. The sediments sampled were fine-grained, dark coloured mudrocks and peats. A complete schedule of the sample material is presented as Table 2.1. The sample locations are shown on Figure 1.6, 1.7 and 1.8.

2.2 Field Techniques

Samples were collected in the field according to standard sampling proceedures proposed by Faegri & Iversen (1964), p 54. In order to minimise any contamination, the surface of the exposures was cleaned using a flat-bladed trowel and a small portion (approximately 50g) of the target sediment collected with a plastic scoop. To secure the sample, each plastic scoop and its contents were immediately placed into a sealable plastic packet. The packets were labelled both outside and inside.

Samples previously examined by micropalaeontologists were assumed to be free of contamination. Samples forwarded by geologists were cleaned by removing the outer layers of the sample where possible.

2.3 Laboratory Techniques

The standard extraction techniques used combined those of Gray (1965) and (Doher 1980). A schematic diagram in the form of a pie chart showing the sequence of steps appears as Fig 2.1. The non-routine steps are represented as slices cut from the pie.

Detailed notes were kept on the maceration of the samples. For safety, laboratory work was carried out in a fume cupboard where possible. The procedures are descibed below.

The extraction of palynomorphs followed three basic steps:

1. Disaggregation and dispersal
2. Chemical extraction
3. Density separation

Following the extraction of the palynomorphs from the host material, the residue was cleaned, microscope slides and S E M stubs were prepared and the remainder was stored.

2.3.1 Disaggregation and dispersal

Disaggregation is defined as dividing the sample into smaller pieces by physical means (Gray 1965). The samples were usually pounded in a mortar to reduce the particle size. The required amount for processing (25 g) was weighed out, a further amount was stored (25 g) and any remaining material discarded. Distilled water (100-300 ml) was added to the material undergoing processing to make a slurry. Samples with a high clay content behaved plastically and were initially cut up with a knife before water was added. If the clay remained in pellets, further disaggregation was necessary. Green liquid soap (5 ml) and hot water (500 ml) was found to be an effective deflocculant. Some samples were presented as loose, fine-grained sandy material which needed no pre-treatment.

Dispersal is defined as the state where individual particles are placed in stable suspension in distilled water. Dispersal into a fine slurry was the required end result of the disaggregation processes.

The mortar and pestle, knife and any other items used were thoroughly cleaned after each sample was treated. Any disposable equipment such as plastic bags used to collect the sample material was discarded.

Physical disaggregation and dispersal usually continue during chemical extraction (Gray 1965).

2.3.2 Chemical extraction

Organic and inorganic matter was removed by the addition of various chemicals. Frequent optical checks were performed to determine which procedures could be omitted to avoid overmacerating the material. Strict attention was paid to cleaning the equipment after use to prevent contamination. Samples were centrifuged at 3 500 rpm (except where otherwise stated) in polyethylene tubes to remove the supernatant liquid.

Inorganic material usually comprised the bulk of the sample. Finely divided minerals were partly removed by hydrochloric (HCl) and hydrofluoric (HF) acids. Complete removal of larger particles was later aided by density separation.

Hydrochloric acid (HCl) treatment

The slurry produced by disaggregation and dispersal was centrifuged down to remove the supernatal water. The residue was transferred to a 250 ml capacity beaker and approximately 100 ml HCl (10% solution) added. A water bath was used to speed the reaction. Although most of the samples showed little reaction, this step was routinely included to avoid the precipitation of calcium fluoride during later treatment with hydrofluoric acid. The length of treatment varied from one hour to overnight. The residue was centrifuged and washed with distilled water until neutral.

Sodium pyrophosphate ($Na_2P_2O_7$) treatment

Bates et al (1978) suggested using sodium pyrophosphate as a method of clay removal. This technique was adopted as many of the samples had a high clay content. The chemical deflocculates clays by reducing the binding potential. Ions from the sodium pyrophosphate are adsorbed on the clay mineral particles and the resulting high surface charge means that the clay platelets repel each other instead of aggregating (Bates et al 1978) and are dispersed within the supernate. The treatment lasted not longer than 20 minutes with the samples placed in a water bath. The residue was centrifuged and washed with distilled water until the supernate was neutral and clear.

Hydrofluoric acid (HF) treatment

Hydrofluoric acid (approx. 40% concentration) was used to remove silicate minerals from the residue. All procedures involving HF were conducted with extreme caution, wearing protective clothing. The acid (100 ml) was added slowly to the damp residue in 250 ml capacity polyethylene beakers to avoid violent reactions. The usual reaction observed was a white gas seen rising from the beaker as a result of some effervesence. Depending on the prejudged silica content, the time allowed for this procedure varied from two hours to several days, some of it in a water bath. Before the sample was removed from the fume cupboard, the acid was diluted well. The residue was centrifuged and washed with distilled water until neutral.

Organic material was present in most samples to some degree. Two methods of removal were used.

Potassium hydroxide (KOH) treatment

Cold potassium hydroxide (5% solution) was used to remove organic material such as broken pieces of cellular matter. The residue was returned to the 250 ml beakers and 50 ml KOH added. Progress was checked after a few minutes, and then at regular short intervals until a satisfactory result was achieved. The total reaction time was less than 30 minutes in order to minimise damage to the palynomorphs. The residue was centrifuged and washed with distilled water until the supernate was neutral and clear.

Treatment with Schultz's solution

In rare cases, enough organic material remained to warrant oxidation with Schultz's solution. A preparation of one part 70% nitric acid and one part aqueous potassium chlorate was made. The samples were treated with 100 ml solution in 250 ml beakers until an optical check revealed a satisfactory result. The total reaction time was less than 30 minutes in order to minimise damage to the palynomorphs. Oxidized humic compounds were removed with 5% KOH as detailed above. The residue was then diluted, centrifuged and washed with distilled water until the supernate was neutral.

2.3.3 Density separation

The process of extracting the palynomorphs from remaining waste material by density separation depended upon the specific gravities of the mineral grains and organic particles, primarily determined by their differential settling velocities (Gray 1965). The pollen grains, spores and other microfossils float on the heavy liquid, leaving the mineral matter as a sediment. The heavy liquid used was zinc chloride ($ZnCl_2$) having a specific gravity of 1,96. Samples were concluded to be positive or negative following this stage of maceration.

Zinc chloride ($ZnCl_2$) treatment

The sample material was placed in 50 ml capacity centrifuge tubes. It was initially acidified with a wash of 10% HCl to prevent the precipitation of white zinc hydroxide. Following this, the zinc chloride (45 ml of aqueous solution) was added and thoroughly mixed, before being centrifuged for 25 minutes at 2 500 rpm. The floating fraction was then checked for palynomorphs. In the case of positive samples, the floating fraction was pipetted off and initially washed with 10% HCl. A distinct interface was often seen. The palynomorphs were found at the interface, and especial care was taken when pipetting off the supernate. After several washes with distilled water, no further zinc chloride remained.

2.3.4 Final cleaning of residue

The residues containing palynomorphs were washed clean of any acid or base chemicals, and prepared for either the relevant mounting medium, or storage.

Alcohol (EtOH) washes

The residue was washed in alcohol of increasing concentrations (30%, 50%, 75% and 97%). Two washes were performed at each concentration. After the final wash, it was assumed that no water was present in the residue. Approximately half was used for microscope preparations and the remainder preserved in distilled water with phenol and placed into storage.

2.3.5 Preparation of material for microscope work

Light and scanning electron microscopy were used in this research. The sample material was prepared differently for each microscopic technique.

For light microscopy, glass slides measuring 75mm x 25mm were used. Drops of the residue in absolute alcohol were placed on a 40mm x 22mm cover slip and allowed to dry thoroughly before being mounted on glass microscope slides. Four slides per sample were routinely prepared. The slide mounting was completed using D.P.X. mountant (supplied by BDH Chemicals UK) and the perimeter of the cover slip sealed with clear nail varnish.

For scanning electron microscopy, 10mm diameter metal stubs were used. Each stub was heated and then dipped into DAG-580 in order to coat it evenly. DAG-580 is a formulation of colloidal graphite in denatured alcohol, supplied by Acheson Colloiden b.v., Holland. When the DAG had cooled a little, sample residue in absolute alcohol was placed on in drops and allowed to evaporate. Subsequent coating of the stubs with gold/palladium was completed in the Electron Microscopy Unit of the University.

2.4 Microscopy

2.4.1 Light microscopy

All work was completed on two Zeiss microscopes. The slides were scanned for palynomorphs from side to side, using x 16 or x 20 objective. Specimens were examined using x 100 objective, under oil. Normaski interference was used to enhance certain features. Routinely, a total of 350 recognisable palynomorphs were counted per sample. Photographic records were kept of representative specimens. The light microscopes were fitted with 35mm film camera attachments and microphotographs were taken using Ilford 50 ASA Pan-F film.

2.4.2 Scanning electron microscopy

The JEOL 840 scanning electron microscope in the Electron Microscope Unit at the University was used to examine the sample material. The stubs were scanned for representative specimens in order to take photographs of important structural details.

2.5 Archiving of material

The microscope slides and SEM stubs were labelled and stored in the BPI's palynology department.

Individual specimens were assigned a specimen number according to the film on which they appear eg. specimen no 264/29A was first photographed on film 264 shot number 29A. Details such as sample and slide number, co-ordinates, size and basic morphology as well as contact prints of microphotographs taken were stored in a card format. An example is given as Figure 2.2. The cards were arranged according to the classification system given below.

2.6 Classification of specimens

2.6.1 Taxonomy

The hierarchical system adopted in this research was erected to suit the major morphologic features of the palynomorphs encountered and is thus a 'parataxonomy' as defined in the introductory chapters (1.6.1). A table representing the hierarchy appears as Table 2.2.

2.6.2 Nomenclature

Individual palynomorph types were identified where possible with published illustrations and descriptions. Dettmann (1973) remarked on the difficulty in comparing new types with previously described taxa, especially those supported by brief descriptions and poor illustrations. The generic and species names may thus be artificial, semi-natural or natural, as defined above. Palynomorphs which could not be so identified were given temporary labels such as `Stephanocolpate pollen A'. New forms will be assigned formal names later.

The palynomorphs were identified with respect to literature focussing on southern hemisphere Tertiary palynology, especially the scarce information originating in southern Africa. As the primary aim of the research was to place the sediments stratigraphically, a 'bottom-up' approach was taken rather than a 'top down' one, because it was the history of the west coast palynofloras which was of immediate interest, not the evolution of the modern vegetation. By comparing the palynomorphs with others of possibly similar age from other regions which previously constituted western Gondwana, an age for the sediments could be achieved. If compared with

Quaternary or Recent southern African vegetation, the botanical affinities could be suggested, but we would still not know how old the sediments might be. The modern vegetation is also known to have changed in response to climatic change in the late Tertiary.

Where possible, illustrations and descriptions of the type specimens were used and comparisons made with as many other examples as were available of the form under consideration.

2.6.3 Chart format used to describe and illustrate palynomorphs

The descriptions and illustrations of each palynomorph type are presented in this thesis in a chart format rather than the usual text and plate method. There are two reasons for adopting this change of style. Firstly, the chart format is clear and easy to refer to as all the details concerned are together, not described in one place and illustrated elsewhere. Secondly, the chart is generated by computer software (Microsoft Windows Excel) and stored as part of a database, facilitating the addition of data from specimens produced by future research. The illustrations have currently been added as hard copy photographs but when image processing becomes available, illustrations of the palynomorphs may be imported directly onto the spreadsheet.

The charts appear at the beginning of the Results section.

An alphabetical listing of the palynomorphs appears as Table 3.1.

Technical terms - Kremp (1965) constructed and encyclopaedia defining all the known technical terms. It has recently been updated by Punt *et al.* (1994). The palynomorphs were described according to both references. Further, a glossary in diagrammatic form was drawn up to clarify the descriptions of the wall structures (Figure

3.1) and sculpturing (Figure 3.2). Such a graphic glossary also appears for each of the main divisions of the classification system.

Orientation - Diagrams (taken from Traverse 1988) appear at the left hand side of the chart for each individual palynomorph, showing its orientation.

Illustration - On the right hand side, the palynomorph is shown in a microphoto. The scale is 1:1 000 unless stated.

The **scale bar** represents 10μ unless otherwise specified.

Illustrated specimen - Particular details are mentioned, such as the microscopic technique used. Light microscopy is abbreviated as 'LM', light microscopy aided by Normaski Interference Contrast as 'NOR-LM' and scanning electron microscopy as 'SEM'.

Quantitative statements - Included as part of the description of each palynomorph type is a quantitative statement concerning the distribution of that type within the sediments. The array of palynomorph types found in each sample was diverse; approximately 30 per sample, with a correspondingly low frequency in the majority of cases. Few samples were found where one palynomorph accounted for more than 25% of the total.

The quantative statements are based on the following format:

- **Very rare** - The number of specimens found is stated
- **Rare** - At least 1% of one sample
- **Little known** - 1 - 5% of one sample
- **Well known** - 5 - 10% of one sample
- **Significant** - 10 - 20% of one sample
- **Common** - 20 - 50% of one sample
- **Dominant** - over 50% of one sample

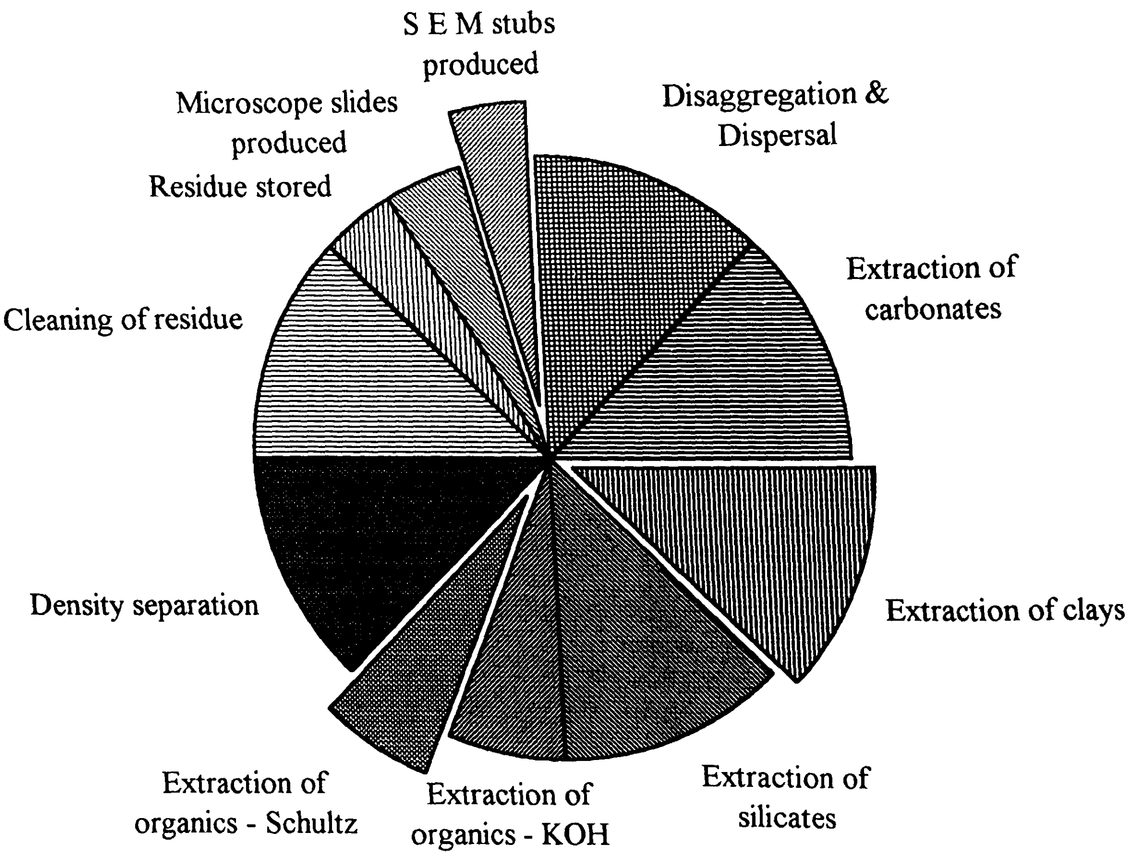


Figure 2.1

Schematic of laboratory techniques

Film no 264			
Shot no	29A	30A	31A
Genus		species	
Sample no	12-14	Slide no	*4
Co-ords	7 x 103	Size (um)	54
SPORE	✓	POLLEN	
Trilete ✓	psilate ✓	Saccate	Mono-
Monolete	rugulate	Porate	Bi-
Alete	foveolate	Colpate	Tri-
	verrucate	Colporate	Poly-
Cingulate	echinate	Inaperturate	x-Peri-
Acingulate	granular		x- Stephano-
	reticulate		
Perinous			
Aperinous			

Figure 2.2 **Specimen card**

Table 2.1

Samples collected from West Coast sites

Lab no	Site	Alternative identification	Lithology	Formation	Collector	Result
10=1	Schulpfontein	SF BH9 91m	Black blocky material	Trib of S/N channel	Andy Allan	☺
10=2	Zwartlintjies	N41 W21	Black, sandy material	S of 68/69 channel	Andy Allan	☺
12=1	Koingnaas	6869 P	Dk grey-brown clayey material	Main peat horizon	Ian Corbett	☺
12=2	Koingnaas	6869 Q	Dk grey soft rock	Main peat horizon	Ian Corbett	☺
12=3	Koingnaas	6869 R	Pale blue-grey sandy clay	Channel clays/grits	Ian Corbett	👎
12=4	Koingnaas	6869 S	Pale buff-grey sandy clay	Channel clays/grits	Ian Corbett	👎
12=5	Koingnaas	6869 X	Pale medium-grey fine sand and clay	Channel clays/grits	Ian Corbett	👎
12=6	Koingnaas	6869 Y	Medium grey fine grained sand & clay	Channel clays/grits	Ian Corbett	👎
12=14	Koingnaas	6869 Peat=P	Black, hard non-friable peat	Main peat horizon	Ian Corbett	☺
12=15	Koingnaas	6869 A	Light & dark sand & clay layers	Upper peat	Ian Corbett	👎
12=16	Koingnaas	6869 B	Light & dark sand & clay layers	Upper peat	Ian Corbett	👎
12=19	Koingnaas	6869 H	Black, hard peaty material	Sands & clays above m p h	Ian Corbett	☺
12=20	Koingnaas	none	Dk grey sandy shaly material	Main peat horizon	S de Villiers	☺
12=21	Koingnaas	none	Dk grey-brown sandy siltstone	Main peat horizon	S de Villiers	☺
12=22	Koingnaas	none	Brown-black sandy siltstone	Main peat horizon	S de Villiers	☺
12=23	Koingnaas	none	Black coloured loose sand	Main peat horizon	S de Villiers	☺
12=24	Koingnaas	none	Black coaly material	Main peat horizon	S de Villiers	☺
12=25B	Koingnaas	none	Dk brown-black clay with sand	Main peat horizon	S de Villiers	👎
12=26	Koingnaas	none	Light brown clay in sand	Main peat horizon	S de Villiers	👎
12=27	Koingnaas	none	Brown-black clay	Main peat horizon	S de Villiers	👎
12=28	Koingnaas	none	Black, friable sandy material	Main peat horizon	S de Villiers	☺
12=29	Koingnaas	none	Black coaly material	Peat stringer below main peat	S de Villiers	☺
12=30	Koingnaas	none	Brown-black sandy peat	Peat stringer below main peat	S de Villiers	☺
12=31	Koingnaas	none	Black coaly sandy material	Main peat horizon	S de Villiers	☺
12=32	Koingnaas	none	Layered sand and peat	Main peat horizon	S de Villiers	☺
12=33	Koingnaas	none	Dk brown-grey sandy clay	Main peat horizon	S de Villiers	☺
12=34	Koingnaas	none	Dk grey-black sandy material	Peat stringer below m p h	S de Villiers	👎
12=35	Koingnaas	none	Grey friable sandy material	Peat stringer below m p h	S de Villiers	☺
12=36	Koingnaas	none	Med grey coarse sand	Peat stringer below m p h	S de Villiers	☺
12=37	Koingnaas	none	Dk brown sandy clay	Peat stringer below m p h	S de Villiers	☺
12=38	Koingnaas	none	Dk grey brown sandy clay	Peat stringer below m p h	S de Villiers	☺
12=39	Koingnaas	none	Black hard peat	Peat stringer above m p h	S de Villiers	☺
12=40	Koingnaas	none	Purple clay with sand	Peat stringer above m p h	S de Villiers	☺
12=41	Koingnaas	none	Dk grey-black friable material	Peat stringer above m p h	S de Villiers	☺
12=42	Koingnaas	none	Dk grey clay with fine sand	Main peat horizon	S de Villiers	👎
34=1	Koingnaas	KN45	Dk brown fine sandy rock	Upper peat	S de Villiers	👎
34=2	Koingnaas	KN46	Dk brown sandy material	Upper peat	S de Villiers	👎
34=3	Koingnaas	KN47	Black dk brown pieces of rock	Upper peat	S de Villiers	👎
34=4	Koingnaas	KN48	Blk-purple-white layers of fine gr rock	Upper peat	S de Villiers	👎
34=5	Koingnaas	KN49	Lt purple-grey clay	Upper peat	S de Villiers	👎
34=6	Koingnaas	KN53	Black blocks of clay with fine sand	Upper peat	S de Villiers	👎
34=7	Koingnaas	KN54	White & brown layers fine gr sand	Upper peat	S de Villiers	👎
34=8	Koingnaas	KN55	Dk brown & light brown layers of clay	Upper peat	S de Villiers	👎
34=9	Koingnaas	KN44	Black friable coaly material	Peat stringer below m p h	S de Villiers	☺
		.....continued....				

Table 2.1 **continued**						
34=10	Koingnaas	KN43	Dk grey-black sandy & friable	Peat stringer below m p h	S de Villiers	☺
35=1	Langklip	LK 1	V dk grey friable coaly material	Main peat	S de Villiers	☺
35=2	Langklip	LK 2	Dk brown dk grey material	Main peat	S de Villiers	☺
35=3	Langklip	LK 3	Dk brown material	Main peat	S de Villiers	☺
35=4	Langklip	LK 4	Dk brown material	Main peat	S de Villiers	☺
35=5	Langklip	LK 5	not described	Main peat	S de Villiers	☺
35=6	Langklip	LK 6	not described	Main peat	S de Villiers	☺
35=7	Langklip	LK 7	White, brown & black sandy material	Main peat	S de Villiers	👎
35=8	Langklip	LK 8	not described	Main peat	S de Villiers	☺
35=9	Langklip	LK 9	Brown sandy disaggragated material	Main peat	S de Villiers	☺
35=10	Langklip	LK 10	Brown clay in yellow brown sand	Peat stringer above m p h	S de Villiers	☺
35=11	Langklip	LK 11	Dk brown peat	Peat stringer above m p h	S de Villiers	☺
37=1	Som/Noup	N40 E0	Black, brown heavy clay with sand		SdeV / AA	👎
37=2	Som/Noup	N44 W4	Black block of silty material		SdeV / AA	👎
37=3	Som/Noup	N40 E0	Light brown clay with sand		SdeV / AA	👎
37=4	Som/Noup	N44 W8	Black clay		SdeV / AA	👎
37=5	Som/Noup	N40 E0	Black friiable coaly material		SdeV / AA	👎
37=6	Som/Noup	N40 E0	Black coal dust		SdeV / AA	☺
37=7	Som/Noup	N48 W4	Dk brown clay with orange sand		SdeV / AA	☺
38=1	Som/Noup	N52 E16	Brown clay little sand	Uncertain	SdeV / AA	👎
38=2	Som/Noup	N22 W9	Black rock with white flecks	Uncertain	Andy Allan	👎
40=1	Som/Noup	N56 E26	Lt brown/dk brown fine grained rock	Uncertain	Andy Allan	☺
40=2	Som/Noup	N56 E24	Black rock with white flecks	Uncertain	Andy Allan	👎
41=1	Som/Noup	N38 E22	Dk brown sandy material	Uncertain	Andy Allan	☺
41=2	Som/Noup	N38 E22	Dk grey/black rock	Uncertain	Andy Allan	👎
					Andy Allan	☺
		69 samples				
		☺	Positive result			
		👎	Negative result			

Table 2.2

Classification System for Palynomorphs

Divisions:

First	Second	Third	Fourth
Spores	**Trilete**	Cingulate	
		Acingulate	Psilate
			Verrucate
			Rugulate
	Monolete	Perinous	
		Aperinous	Psilate
			Verrucate
			Rugulate
Pollen	**Saccate**	Bisaccate	
		Polysaccate	
	Porate	Monoporate	
		Triporate	
		Periporate	
		Stephanoporate	
	Colpate	Monocolpate	
		Trichotomocolpate	
		Tricolpate	
		Stephanocolpate	
	Colporate	Tricolporate	
		Stephanocolporate	
		Syncolporate	
	Inaperturate		
Tetrads & Polyads			
Incertae sedis			

Results

Chapter 3

Results

"A rose by any other name would be very confusing..."

(Traverse 1996, p11)

3.1 Systematic Palynology

The palynomorph types are described according to the parataxonomy (Table 2.2). The charts appear as Figures 3.1 - 3.137. An alphabetical listing of the palynomorphs appears as Table 3.1.

3.2 Composition of the palynofloras - Qualitative analysis

The palynofloras' composition was determined by examining the data presented in the systematic charts. The three qualitative aspects are presented below:-

- **Variety** - The variation of palynomorphs found.
- **Age** - An indication of the possible stratigraphic position for each palynoflora is given.
- **Botanical affinities** - An evaluation of the plant types represented by the palynomorphs was made, where possible.

3.2.1 Variety

In order to demonstrate the morphological variety found within the palynoflora of the west coast, the individual palynomorph types were combined into larger groups based on the classification system used, at second division level (triletes, monoletes, saccates, etc). Tetrads and incertae sedis were included as one group (miscellaneous). The grouping reflects the basic botanical separation into angiosperms, gymnosperms and lower plants.

The variety of the palynoflora was plotted in two ways to determine whether significant differences could be found between the two methods of representation, that is, between plotting the number of palynomorph types per taxonomic group or the numbers of individual palynomorphs per taxonomic group. The first method appears as Figure 3.138a and showed that pollen from angiosperms is dominant in the assemblages. The second method appears as Figure 3.138b. Pollen from angiosperms appears even more dominant (75% instead of 64%). No significant difference was seen between the graphs.

3.2.2 Stratigraphic age

The primary aim of the research was to establish a date for the sediments.

The literature consulted focussed on southern hemisphere Tertiary palynology, as discussed in Chapter 2.6.2. A number of zones have been recognised for different areas at different times in the Tertiary, based on different index fossils and palynomorph assemblages. Particular index fossils were either not present at all in the west coast palynofloras or were not seen in sufficient quantities to qualify as an index fossil. As the palynomorph assemblages did not fit well into any of the recognised zones, another approach had to be sought.

The age of the west coast palynofloras was estimated by plotting the stratigraphic range of the palynomorph types as stated on the systematic charts against the stratigraphic column from Lower Cretaceous to Pleistocene, represented with time approximately to scale. Long ranging forms with older records were included in 'earlier sediments'. If a palynomorph was judged to be well known in the literature from a particular geological time division, it was marked with a shaded block. If it was mentioned only vaguely (such as 'early Tertiary') or the identification was not made with confidence (such as *Rhoipites* sp A), a question mark was used. No other bias was included (such as weighting if a large number of palynomorphs of that type was found, or prioritizing those palynomorphs which are known from southern Africa rather than Australia). Those palynomorphs with no known age records were omitted.

Each palynoflora was examined in turn. The number of shaded blocks and question marks was totalled into a graph at the right hand side of the chart. A normal distribution was to be expected, with the main peak indicating the stratigraphic age of the palynoflora. A '50%' highlight was included, as a double vertical line, showing the place at which half of the palynomorphs in that palynoflora were known.

The range charts for each palynoflora appear as Figure 3.139 to 3.143.

Koingnaas - Main Peat Horizon. (Figure 3.139) This is the formation from which the most samples were taken and on which the preliminary analysis was based. Most of the palynomorph types (65%) were recognised from this horizon. The graph on the right hand side of the chart clearly indicates that the age for the Main Peat Horizon falls in the early Tertiary. The 50% marker line is exceeded from the Campanian (76 Mya) to the mid-Miocene (14.5 Mya). The highest point on the graph falls in the mid-Eocene (49 Mya), with the 'break in slope' signifying that the assemblage is comfortably Palaeo-Eocene in age (65-43 Mya).

Koingnaas - Channel Peats. (Figure 3.140) As the Channel Peats are found at a lower level than the Main Peat, their age was expected to be slightly older. A total of 57% of the palynomorph types was seen. The graph on the right hand side of the chart again clearly indicates that the age for the Channel Peats falls in the early Tertiary, with no significant difference in age when compared with the overlying Main Peat. The 50% marker line is exceeded from the Palaeocene (65 Mya) to the late Miocene (11 Mya). The highest point on the graph again falls in the mid-Eocene (49 Mya), with the 'break in slope' signifying a Palaeo-Eocene age (65-43 Mya).

Koingnaas - Above the Main Peat Horizon. (Figure 3.141) The peat stringers which were found closely related to, but slightly above, the Main Peat Horizon were examined to determine whether they would provide a younger age. Approximately half (63) of the palynomorph types were recognised. The graph on the right hand side of the chart again clearly indicates an early Tertiary age with no appreciable difference in age between the underlying two peat horizons. The 50% marker line is exceeded from the Maastrichtian (69 Mya) to the early Miocene (22.5 Mya). The highest point on the graph again falls in the mid-Eocene (49 Mya), with the 'break in slope' again indicating a Palaeo-Eocene age (65-43 Mya).

Langklip. (Figure 3.141) A total of 53% of the palynomorph types was recognised from this site. The graph indicates a Tertiary age for the Langklip sediments. The 50% marker line is exceeded from the Campanian (76 Mya) to the late Miocene (11 Mya) and the highest point on the graph falls in the mid-Eocene (49 Mya). Although the graph has a basically normal distribution, a dip in the early Oligocene produces a small second peak for the Miocene.

Somnaas-Noup. (Figure 3.143) This is the least known of the horizons as only three samples taken proved positive, thus the results may be regarded as premature. Less than half of the palynomorph types were recognised from this site. The graph on the right hand side of the chart again indicates an early Tertiary age. The 50% marker line is exceeded from the Maastrichtian (69 Mya) to the late Miocene (11 Mya). The highest point on the graph falls in the mid-Eocene (49 Mya), with the 'break in slope' indicating a Palaeo-Eocene age (65-43 Mya) for the assemblage.

Comparison of age ranges. When the graphs are compared, it appears that all the palynofloras are virtually the same age.

3.2.3 Botanical affinities

The botanical affinities were taken from the literature and were stated as part of the systematic palynology. The available information was summarised in Table 3.2. Information regarding the habit and morphology of the proposed parent plants was taken from Cronquist (1981), Florin (1963), Schelpe & Anthony (1986) and Scholtz (1985).

The west coast palynofloras were found to be very diverse, with evidence for many different plant groups. Spores representative of nine families of ferns were found, including the Polypodiaceae, Schizaceae, Cyatheaceae, Dicksoniaceae, Gleicheniaceae, Osmundaceae and Blechnoideae. Their modern counterparts are vary from tree ferns to creeping rhizomes.

Saccate and inaperturate pollen was produced by coniferous Podocarpaceae and Araucariaceae, which were probably forest trees.

Porate, colpate and colporate pollen was produced by angiosperms. The majority came from dicotyledenous families, at least twenty-eight being represented. Of special significance are the Compositae and the Proteaceae. Important monocotyledons were Palmae and Liliaceae. These plants vary from trees to shrubs, vines and herbs. Affinities for half the angiosperm pollen could not be further confirmed.

3.3 Composition of the palynofloras - Quantitative analysis

The quantitative analysis considered how frequently each palynomorph type occurred in each sample. The totals of the microscope counts are presented as a spreadsheet, which appears as Table 3.3. The samples constituting each palynoflora are grouped together.

3.3.1 Significant elements within the palynofloras

Small scale trends were difficult to pinpoint because of the great diversity and low frequencies of the palynomorphs. A few palynomorphs had a significant distribution and are mentioned below.

The most important genus was *Rhoipites*, omnipresent and sometimes very abundant (in excess of 25% of some samples). It was not representative of any particular family. *Rhoipites* was differentiated into a number of species, most of which were well represented.

Another palynomorph type which was often significant was *Tricolpites* sp cf. *T. micromunus*, again found in every sample.

Also well represented was *Tricolpopollenites*, found in some numbers in many samples in all the palynofloras except Somnaas/Noup. Its botanical affinities are uncertain.

Proteacidites comprised several percent of every sample except one. It was probably produced by ancient proteaceous plants, possibly rainforest trees according to Scholtz (1985) which is important to the history of today's Cape flora.

Byttneripollis, a spherical periporate form, was represented by a few grains in most samples.

Of the spores, the smooth-walled *Laevigatosporites* was found in every sample (except one) sometimes totalling 10%. Verrucate monolete spores belonging to *Polypodiidites* and *Polypodiisporites* were also common. Trilete spores, such as *Cyathidites australis* and *C. minor*, were numerous.

Several palynomorphs were of interest even though they were not found in great numbers.

The trisaccate *Microcachrydites antarcticus* is noteworthy as it was only found in one sample but comprised 2% of it. It is well known in mid-Cretaceous assemblages (Coetzee 1993).

Only one specimen was found of *Agloreidia* sp, from the Channel Peats. It was the only monoporate found and was identified with similar grains found by Coetzee in localities near Cape Town, which were dated as Miocene.

The Compositae were represented by several species of *Tubulifloridites* but the occurrences were rare (normally less than 1% of few samples).

An unidentified palynomorph, named Incertae sedis A, occurred in small numbers in many samples and dominated three samples from Koingnaas. It may be inaperturate pollen, a dinoflagellate cyst or a fungal spore and will be further investigated in future research.

3.3.2 Trends observed within the data

In order to discover whether any underlying trends on larger scale could be revealed, the data were grouped according to morphological types. Spores were placed into trilete, monolete and alete categories. Saccates and inaperturates were taken as individual categories. Angiosperm pollen was subdivided into monocotyledenous (monoporates and monocolpates) and dicotyledenous (polyporates, polycolpates, polycolporates, syncolporates and Compositae). Compositae were isolated as a group because they are morphologically distinct and known to be stratigraphically sensitive. Tetrads, polyads and incertae sedis were included as miscellaneous.

The data sets were graphed and compared to one another within each palynoflora.

Patterns resulting. Three patterns were seen and are compared in Figure 3.144.

Pattern 1 (eg 35-3). This pattern was the most often seen. Dicot angiosperms produce the highest peak, three times the height of any other; usually but not always the peak is produced by the polycolporates. Spores comprise a relatively small proportion of the graph, and either triletes or monoletes may be more important. The peaks produced by saccates, inaperturates and monocolpates are low.

Pattern 2 (eg 12-30). This pattern shows a much higher spore content. Dicot angiosperms still dominate, but the spore peaks are far higher than before. The other groups produce low peaks by comparison.

Pattern 3 (eg 12-23). The peaks produced by saccates and monocolpates are far higher than before, while dicot angiosperms are still dominant; spores make a contribution equivalent to that seen in pattern 1.

The distribution of the patterns within the palynofloras is examined below

Koingnaas - Main Peat Horizon. (Figure 3.145) A series of samples was taken in a stratigraphic sequence. All three patterns were seen.

Angiosperm pollen, in the form of polyporates, polycolpates and polycolporates, dominated every sample. Only one representative of the Compositae was found, at the top of the sequence (12-20).The spore content, both trilete and monolete, was seen to vary but no distinct trend could be discerned. Gymnosperm pollen was only found in abundance in the middle of the sequence (12-23 - pattern 3), coinciding with a relatively high spore and monocolpate content.

Similar variations were found in an approximately horizontal suite of samples (Figure 3.146) with all three patterns occurring. Angiosperm pollen was usually, but not always, dominant. Compositae were occasionally seen. One sample considered (12-14) was dominated by spores, particularly monoletes. Gymnosperms were represented by saccates rather than inaperturates.

Channel peats. (Figure 3.147) All three patterns occurred in the samples taken. Dicotyledonous angiosperm pollen dominated all the samples, especially the polycolporates. Compositae were occasionally seen. Monocot angiosperm pollen was relatively rare. Saccate gymnosperms were usually present in low numbers, and inaperturate pollen hardly seen at all. Trilete spores were more numerous than monolete.

Above the Main Peat Horizon. (Figure 3.148) An approximately vertical selection of samples was taken and patterns 2 and 3 were seen. Dicot angiosperm pollen dominated the assemblages, polycolpates producing higher peaks than polycolporates, which is unusual. Compositae were seen in every sample. Monocot and gymnosperm pollen was significant only in one sample. The spore content was relatively high, monoletes being more numerous than triletes, which is the opposite trend to that seen in the Channel Peats.

Langklip. (Figure 3.149) A series of samples was taken in a stratigraphic (vertical) sequence. Pattern 1 was produced by all the samples, with little or no variation. Polycolporates produced by far the highest peaks. Polyporates were usually the next highest while polycolpates were often low. The spore content was significant, monoletes being more numerous than triletes. Gymnosperm pollen, saccate and inaperturate, was not well seen.

Samples were taken horizontally at Langklip across the top of the peat horizon (Figure 3.150). The graphed results differed from the lower, stratigraphic sequence as all three patterns were seen. Two of the samples produced a pattern similar to that seen in the stratigraphic sequence.

Dicot angiosperm pollen dominated the samples but Compositae were not found. Monocot pollen was only significant in one sample and gymnosperm pollen was poorly represented. In some samples, spores attained great importance while not in others.

Somnaas-Noup. (Figure 3.151) All the samples from Somnaas-Noup produced pattern 3. Dicot angiosperm pollen was dominant, but relatively less so than at the other two sites. Compositae were seen, occasionally in relative abundance. Monocot and saccate pollen was always significant but inaperturates were unknown. Spores were few.

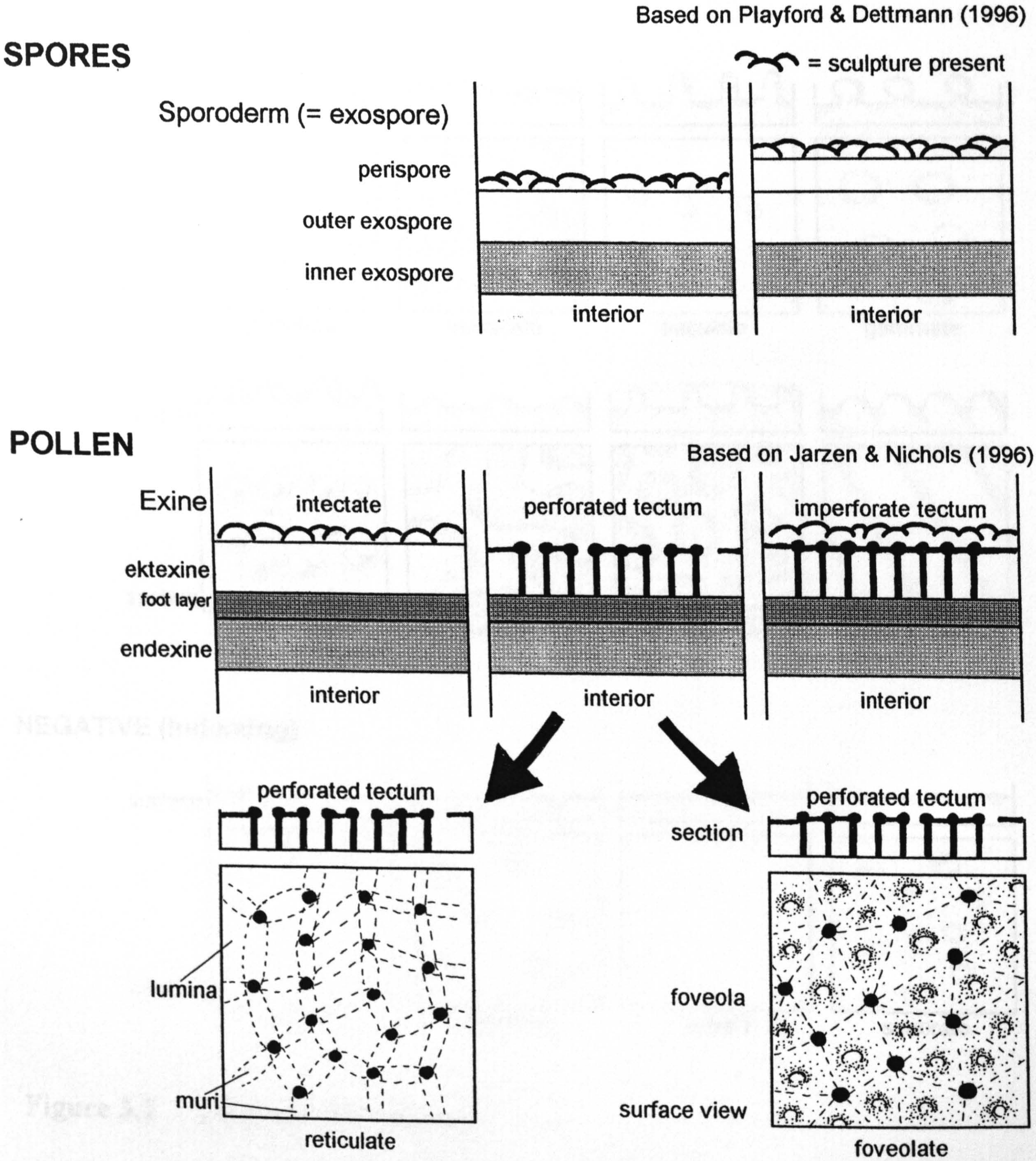
3.4 Summary of results

A diverse assemblage of 125 palynomorphs was described. These comprised trilete and monolete spores and saccate, inaperturate, porate, colpate and colporate pollen. While several palynomorphs could not be identified from the literature consulted, the known types furnished age estimates for the palynofloras, dated as Palaeocene-Eocene. Botanical affinities indicated a vegetation consisting of a variety of ferns, gymnosperm trees and angiospermous trees, shrubs, herbs and vines.

The results were presented in a graphic format and will be discussed below.

Palynomorph wall structure

Graphic glossary of technical terms used in this thesis



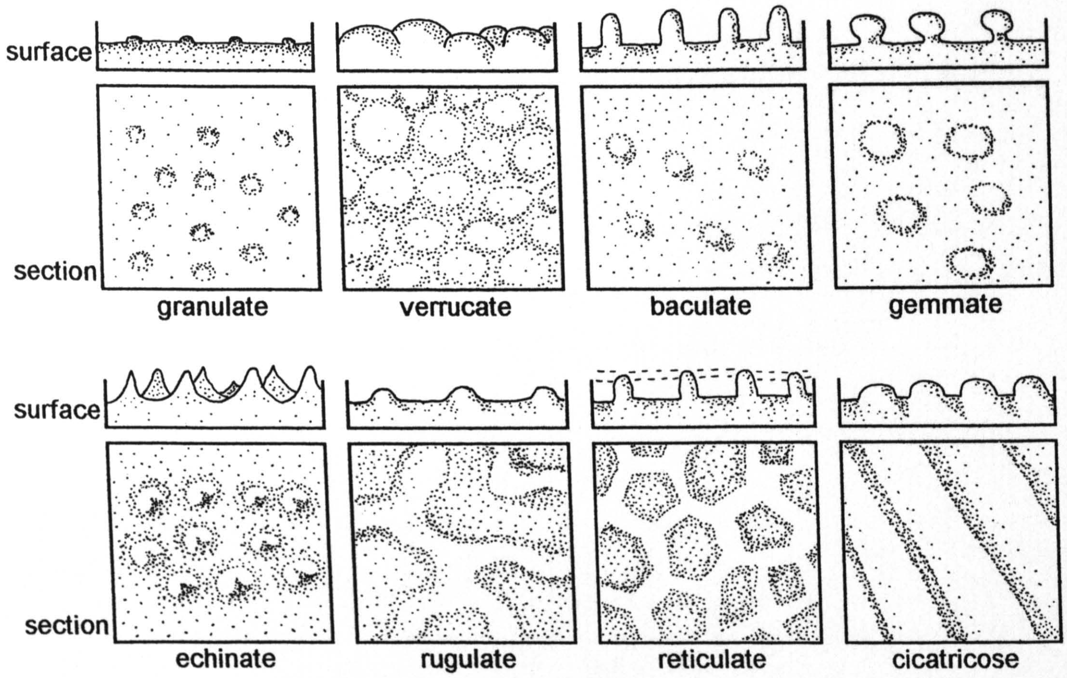
The layers of the sporodermis have been described and variously subdivided by several authors (Fritzsche 1837, Bischoff 1842, Potonié 1934, Erdtman 1943, 48) (Kremp 1965, Traverse 1988)

Figure 3.1 **Internal structure of grain wall**

Surface sculpturing

Graphic glossary of technical terms used in this thesis

POSITIVE (protrusive)



NEGATIVE (indenting)

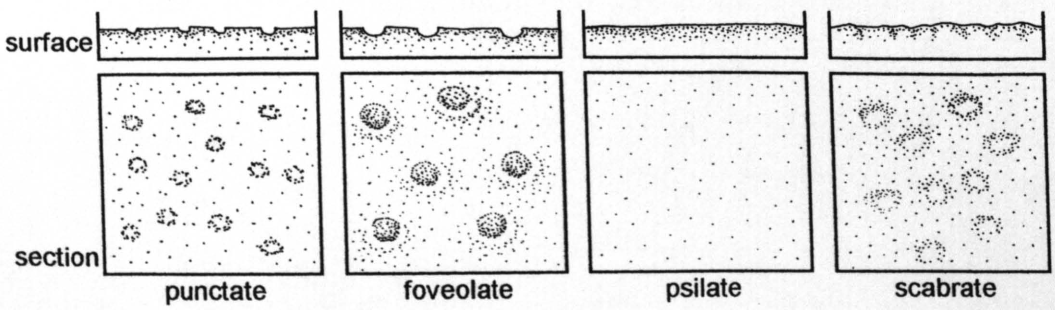


Figure 3.2 Elements of sculpture