The Upper Quaternary of the Cape Flats Area (Cape Province, South Africa)

H. J. W. G. Schalke

Schalke, H. J. W. G. The Upper Quaternary of the Cape Flats Area (Cape Province, South Africa). Scripta Geol., 15: 1-57, 10 figs., 5 pls., 3 tables, 8 appendices (in a separate cover), Leiden, May 1973.

Palynological data and other evidence suggest that the Upper Quaternary of the Cape Flats area can be subdivided chronostratigraphically into units that may be correlated with those of the Northern Hemisphere. Five intervals have been identified in the Middle Pleniglacial and formal names are introduced for these intervals. During three of them, the MILNERTON, KILLARNEY and BLOUBERG intervals, the vegetation had a xerophytic character and is comparable with that of the Holocene. During the intermediate periods, the SALTRIVER and DIEPRIVER intervals, an extension of the mixed *Podocarpus* (Knysna) forest to the Cape Flats area took place. These changes in vegetation can be explained by differences of effective precipitation.

Two periods of sedimentation, corresponding with periods of marine transgression, can be distinguished, viz., a Middle Pleniglacial and a Holocene one. During the Middle Pleniglacial the relative sea-level lay between 24 and 18 m below the present one; a later rise of the continent probably influenced the sea-level, so that the real position of the sea-level was even lower. During the Upper Pleniglacial, when the sea-level was very low, erosion was active in the Rietvlei basin. However, there are indications that inland dunes were formed on the Cape Flats area during that period.

Sea-level fluctuations and sedimentation changed the drainage pattern of the Diepriver basin and evidence of two former outlets have been found. The paralic sediments that have now been dated as Last Glacial and Holocene, are named herein the CAPE FLATS FORMATION. This formation lies unconformably on the Praecambrian and Palaeozoic basement.

Henk J. W. G. Schalke, Rijksmuseum van Geologie en Mineralogie, Hooglandse Kerkgracht 17, Leiden, The Netherlands.

Chapter 1. Introduction

GENERAL SCOPE

Many detailed studies in different disciplines have contributed to the knowledge of the Quaternary of South Africa. The geomorphology of the southwestern coastal region was studied by Gatehouse (1953, 1955) and Mabbutt (1955a, b), mostly in close connection with and as supporting evidence to the archaeology. Hendey (1968, 1969, 1970) treated the vertebrate palaeontology of various localities in the area. Environmental studies and palaeoclimatological information concerning Southern Africa may be found in Cooke (1962, 1967) and van Zinderen Bakker (1966a, 1967c).

Few data are available on the vegetational history and the chronostratigraphy, however, so that a general need exists for more palynological information and ^{14}C data in longer stratigraphical sections, just to extend our knowledge of the South African Quaternary. For this reason a drilling campaign for the Cape Flats area was launched. In the present study six boreholes from this area were analysed pollenanalytically, malacologically and by means of radiocarbon dating. One borehole was used for sedimentary-petrological studies.

The knowledge of the dated sequence of sediments, vegetation, climate and sea-levels, resulting from the study of the seven boreholes, together with stratigraphical data from other boreholes and geophysical data, enabled the reconstruction of the outlines of the Upper Quaternary history of the area.

RESULTS OF SOME EARLIER STUDIES ON THE UPPER QUATERNARY PALAEOECOLOGY OF SOUTHERN AND EASTERN AFRICA

Palynological investigations started in Southern Africa with the publication of the results of the Florisbad excavation by van Zinderen Bakker (1957); initiatives to promote this discipline had already been taken earlier by van Zinderen Bakker (1951) and Martin (1953).

The analysis of the Florisbad samples resulted in indications about a sequence of drier and wetter periods. The oldest deposits (dated $>$ 48 000 B.P.) were thought to express a dry period coeval with an interglacial or interstadial period of the Northern Hemisphere. Younger sediments covering the period from 29 000 $\pm$ 2 000 B.P. to 19 600 $\pm$ 700 B.P. demonstrate a shift from a dry semidesert Karroo vegetation to a less dry grassveld.

A palynological analysis of peat deposits formed near a thermal spring at Aliwal North was made by Coetzee (1967). These sediments have been dated from 12 600 $\pm$ 110 B.P. to 9 650 $\pm$ 150 B.P. Inferred into climatic evidence the palynological data revealed the following changes: from slightly before 12 600 B.P. to about 12 000 B.P. the climate fluctuated from colder and humid to warm and dry, and then back to cooler and moister; from about 12 000 B.P. to about 11 000 B.P. the climate was very warm and dry again; after that the climate changed back to cooler and moister and then to warm and dry in the period around 9 650 B.P.

Martin (1968) who studied samples of the Knysna region from an interval that covered a period from about 8 000 B.P. until present, also found an alternation of wetter and drier periods, whereas a marine transgression, starting at 6 780 $\pm$

160 B.P., seems to have ended at approximately 4 000 B.P., after which a slight extension of the forest, attributable to more effective humidity, can be observed.

To the north of South Africa a sequence of sediments from the Kalambo Falls location, belonging to the Middle and Upper Pleniglacial, was studied by Clark & van Zinderen Bakker (1964). They found that after a warm period at around 58 000 B.P. the climate became cooler at around 50 000 B.P.; then a warmer period at about 45 000 B.P. was followed by a cooler period at around 39 000 B.P.; this was followed again by a warmer phase at around 28 000 B.P. and around 17 000 B.P. a cooler climate prevailed.

From East Africa palynological data were published by Coetzee (1967), Livingstone (1967) and Kendall (1969). There is a consensus of opinion concerning the presence of glaciers on the East African mountains in the Pleniglacial, and the occurrence of glacial oscillations similar to those of the Northern Hemisphere. There is general agreement on the climatic interpretation of the pollen diagrams. Coetzee (1967) considers variations in temperature the controlling factor, whereas Livingstone (1967) and Kendall (1969) suggest humidity as another determining factor. From both studies it is evident, however, that climatic fluctuations indeed exhibit a close resemblance to those found in Europe.

In a recent publication by Butzer & Isaac (1972) the data concerning Quaternary fluctuations of the levels of East and Central African lakes have been compiled. Maximum lake extensions are recorded from Lake Rudolf, Lake Victoria and Lake Chad from the period prior to 20 000 B.P., and from the period between 12 000 and 8 000 B.P. These maxima are thought to have been determined by a relative increase in effective precipitation. Extremely low lake levels occurred in the period between 20 000 B.P. and 12 000 B.P.

For a complete review of literature we may refer here to the series 'Palaeoecology of Africa' vols 1-5 edited by van Zinderen Bakker (1966b, 1967a, b, 1969a, b) and to the latest volumes 6 and 7 (van Zinderen Bakker, 1972a, b) just published, which include such relevant new data from studies by Servant and Servant, Hamilton and Klein.

ACKNOWLEDGEMENTS

A Research Fellowship of the Anglo-American Corporation of South Africa, Ltd., obtained by Professor E. M. van Zinderen Bakker, enabled me to stay in South Africa for three years. I feel greatly indebted to the Anglo-American Corporation of South Africa, Ltd., for their financial support.

The Palynological Research Unit of the C.S.I.R., University of the Orange Free State, Bloemfontein, South Africa has rendered warm hospitality during those years. I am most grateful to the Director, Professor E. M. van Zinderen Bakker, for sponsoring this project.

During my stay in South Africa from 1965-1968 several areas have been explored in a search for sediments suitable for pollenanalytical studies and for analysis by other techniques to elucidate the Upper Quaternary history of southernmost Africa. Thanks to the interest of Fisheries Development Corporation of South Africa, Ltd. (Fiscor), the attention was drawn to the Cape Flats area and to the Rietvlei basin in particular. The generous cooperation of Mr V. C. Roy, of Cementation (Africa Contracts) (Pty), Ltd. and of the Fiscor staff rendered the executed drilling campaign very successful.

The advice and assistance of Dr A. V. Hall, Bolus Herbarium, University of Cape Town, South Africa, who also offered me hospitality at the Herbarium, is gratefully acknowledged.

I wish to thank the Director of the Rijksmuseum van Geologie en Mineralogie (National Museum of Geology and Mineralogy), Dr C. Beets, for his substantial interest in this study and his stimulating discussions during the laboratory analysis of the material.

The author was introduced to the study of palynology by Dr Th. van der Hammen, to whom I want to express my high esteem for his excellent guidance into this discipline and his most encouraging support during the present study.

I was most fortunate in receiving advice and assistance from Dr T. A. Wijmstra, and I am greatly indebted for his stimulating discussions.

I also wish to express my gratitude to Professor A. D. J. Meeuse for his advice concerning South African vegetation types, and for the critical reading and correction of the English manuscript.

Several colleagues I wish to thank for their cooperation and fruitful discussions, especially Dr W. G. Mook for the radiocarbon datings, Dr A. C. van Bruggen and Messrs R. N. Kilburn and A. W. Janssen for identifying the shell collection, Dr C. Downie for analysing the marine plankton, Dr W. H. Zagwijn and Dr W. Punt for discussions and pollen identification, Miss E. van der Wilk for the sedimentary-petrological preparation and for our discussion of the results, and Dr C. E. S. Arps for the heavy-mineral analysis.

Finally I owe thanks to the staff of the National Museum of Geology and Mineralogy, especially to Miss M. Fit, Miss N. Blom and Mrs R. L. Boers-da Silva for the skilful preparation of the sediments and the recent pollen collection, Mrs R. P. L. Bremer for the laboratory assistance, to Messrs J. Timmers, B. F. M. Collet and T. Veldhuyzen for the preparation of the illustrations, maps and diagrams, to Mr J. van der Linden who prepared the models basic to Figs. 7a and b, and to Miss L. Rührwiem for typing the manuscript.

Chapter 2. Physical Environment

This chapter deals with several aspects of climate, vegetation and geology. The principal ocean currents and their influences on the coastal region are also discussed.

CLIMATE

South Africa (see Fig. 1) is situated almost completely within the high pressure belt of the Southern Hemisphere, which at sea-level is located around 30° S. lat. This is the reason why the South African climate is largely arid to semi-arid. The high pressure belt is subject to a seasonal displacement of 4° latitude, its centre being located further south in February. Due to the unequal heating of the land in summer and in winter, this high pressure belt is split up into two cells, one at the Atlantic side and the other above the Indian Ocean. Another important element of the air circulation influencing the climate of South Africa is the presence

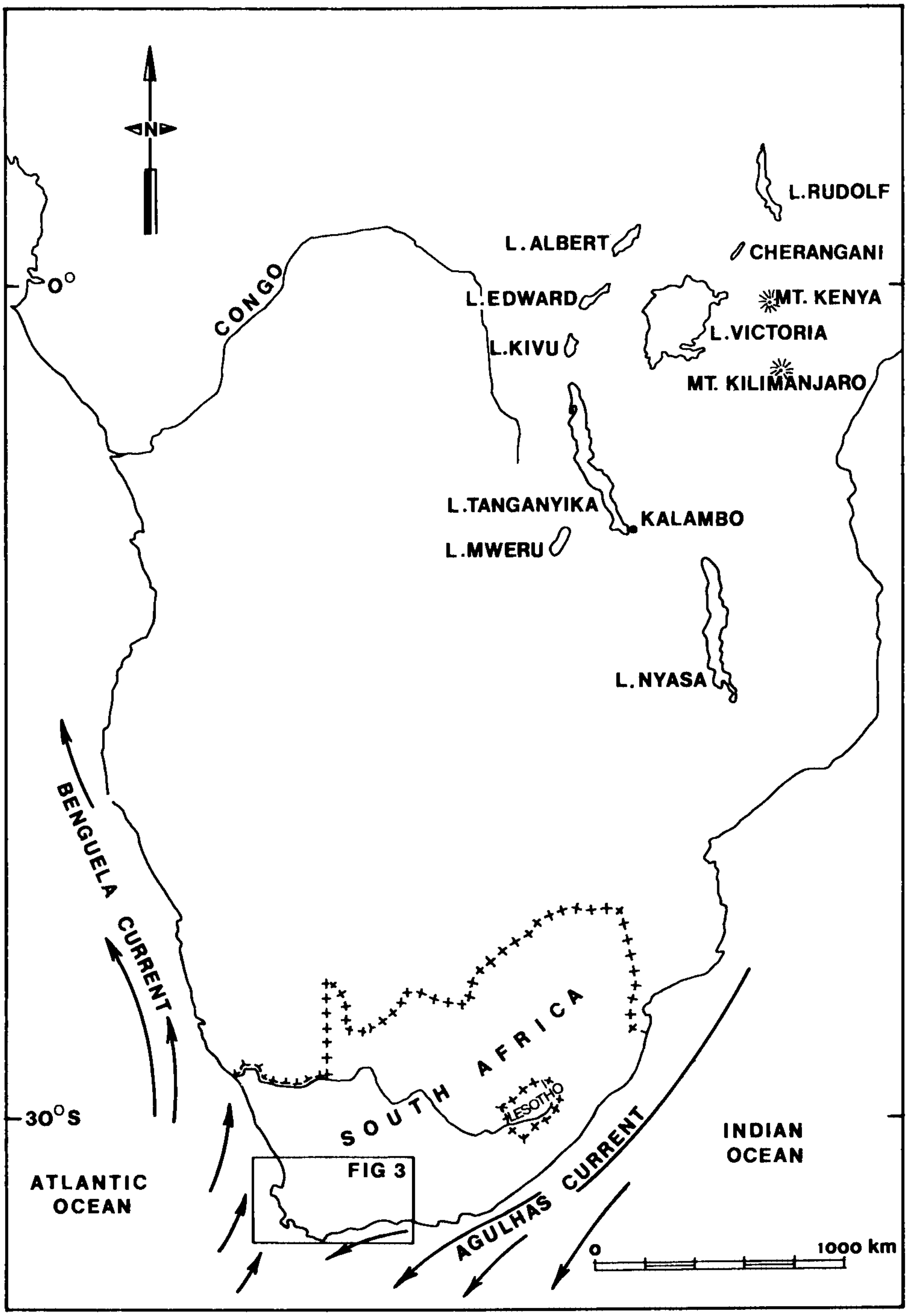


Fig. 1. Map of southern Africa, showing principal ocean currents and important lakes.

of the circumpolar Westerly Winds to the south of the high pressure belt. These Westerly Winds, which at sea-level occur at 35 °S. lat., are found at much lower latitudes in the upper atmosphere. Consequently the weather changes in South Africa are largely determined by perturbations in the westerly circulation of the Southern Hemisphere, though in summer to a lesser extent than in winter. These phenomena may explain the Mediteranean type of climate prevailing in the south-western coastal region (Schulze, 1972).

For general information the climate diagrams of several stations in South Africa are given in Fig. 2 (Walter & Leith, 1960). Diagrams of two climatically related areas in other parts of the world are shown in juxtaposition for easy comparison. In these diagrams the vertical coordinate at the left gives the temperature scale, each interval representing 10 °C. The vertical coordinate at the right shows the precipitation values, each interval corresponding with 20 mm rainfall. On the abscissa the months are indicated, for the Northern Hemisphere starting at the left side with January, whereas the diagrams of the Southern Hemisphere begin with July. According to Walter & Leith (1960), a period is to be called arid when the precipitation curve stays below the temperature curve; these areas are dotted. Hatched areas represent the periods with a relatively higher amount of precipitation. Cross-hatching at the base of the diagram indicates the months with an absolute temperature minimum below zero. Besides the name of the station, height above sea-level (between brackets) and the years of observation of temperature and precipitation (between square brackets) are given, as well as mean annual temperature and mean annual precipitation, whereas at the left side the mean daily minimum of the coldest month and the absolute minimum are indicated. To the diagrams from South Africa the name of corresponding actual vegetation type has been added.

The climate diagram for Cape Town, which is situated at the border of the Cape Flats, reveals that the annual precipitation of the Cape Flats area varies between 400 and 500 mm, with an arid period from November to April, and that the mean annual temperature is approximately 17 °C. The prevailing SE trade winds in summer are replaced by NW anti-trade winds in winter, the latter spelling rainy weather. Very strong winds are frequent (see the climate diagram of Cape Town, Fig. 2).

The Cape Flats area is bordered to the north by a region characterised by an extremely low amount of annual precipitation, decreasing from 250 mm in

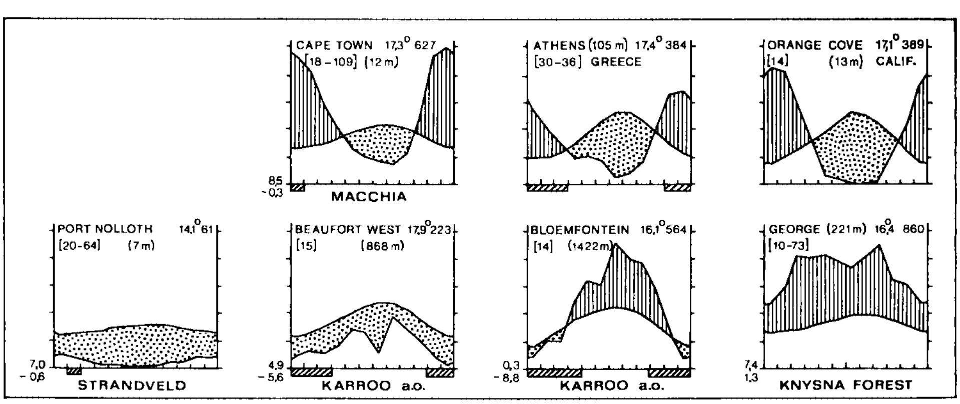


Fig. 2. Climate diagrams of South Africa (with the corresponding vegetation-type), and of two climatically related areas (Greece and California).

the interior towards 50 mm or less along the coast, and by rainfall during the cold season. Owing to the influence of the Benguela current with its upwelling of cold Antarctic bottom water, this region is known by its fog with a diurnal movement. This fog advances 30-50 km landwards across the coastal flats by night, receding seawards in early morning. The moisture of this fog is of paramount importance for the survival of the semi-succulent vegetation in this region (see the climate diagram of Port Nolloth, Fig. 2).

To the NE of the Cape Flats area lies a semi-arid to arid climatic region with an annual precipitation of less than 250 mm. Large temperature fluctuations occur both diurnally and seasonally with a period of frost from June to September (see the climate diagram of Beaufort West, Fig. 2).

A steppe-like climate prevails in the Orange Free State, north of this semi-arid to arid climate region, with an annual precipitation of 564 mm and with frequent dust storms (see the climate diagram of Bloemfontein, Fig. 2).

The climate in the coastal region east of the Cape Flats area is rather uniform, having a higher annual precipitation (about 1100 mm in the mountains and 400 mm on the plains) evenly distributed over the year. Frost is unknown here and the summer heat is tempered by cool sea breezes due to the cold ocean current along the coast (see the climate diagram of George, Fig. 2).

OCEAN CURRENTS

The continental margin of South Africa causes the deviation of the westerly cold ocean current towards and along the western coast of Africa (see Fig. 1). This branch is called the Benguela current and has, off the coast near Cape Town, a mean annual temperature of 12 °C with a variation of 2-3 °C. The influence of this Benguela current on the climate of the western coastal region has been mentioned above.

From the Indian Ocean a warm current flows southwards along the south-eastern coastal area which is called the Agulhas current. It is characterised by an mean annual temperature of 19 °C and a range of 5-6 °C. The topography of the submerged continental Agulhas bank and the westerly cold ocean current, which meets the Agulhas current off the south coast, are both responsible for the splitting up of the Agulhas current into two branches of which the coastal one still influences the temperature of the coastal waters as far west as Cape Hangklip. The westerly cold acean current approaches the coastal region E of Knysna and may be responsible for the higher precipitation, evenly spread over the year, in this area.

VEGETATIONAL ASPECTS

The vegetation of the Cape Flats area belongs to the Cape Flora Region. The latter one with its peculiar composition is differentiated from the Palaeotropis Region, although the size of this autonomeous region is relatively small (Walter & Straka, 1970).

The Cape Flora Region has been studied intensively (Adamson, 1938 and Marloth, 1913-1932), not only as regards its composition and physiognomy, but also on a phytogeographical base in order to trace its possible origin. According to

Levyns (1964) the xerophytic Cape Flora is antedated by the mesophytic forest flora, now covering a restricted area in the Knysna region. Youngest appears to be the Karroo flora, characterised by the high proportion of succulent forms. Evidence for a previous wider extension of forest vegetation, now restricted to the Knysna region, is not only provided by some outlying forest patches, but also by the occurrence of relicts of this forest in sheltered humid mountain gorges west of its present main habitat, in a few areas along the eastern escarpment of South Africa and even on the East African mountain ranges. Finds of pollen of *Podocarpus,* one of the main constituents of the forest flora, in the Tertiary lignites of Knysna and East London demonstrate an ancient origin of this flora. Climatic changes - particularly in humidity - presumably reduced the area of this forest vegetation once covering the whole southwestern region. The conditions have changed since then and facilitated the invasion of the xerophytic Cape Flora from the north; however, its regional extension remained confined to areas receiving more than 300 mm of precipitation annually. The more arid regions were favourable for the succulent Karroo flora. The Karroo flora exhibits floristic connection with more northerly regions from where it is thought to have originated.

At present the Cape Flora is bordered to the north by the Karroo flora, and to the east by the flora of the Knysna forest. On the extensive, sandy areas along the west coast a Karroo-like flora occurs. The distribution of the vegetational units of the SW coastal region is shown in Fig. 3, a simplification of the vegetation map of South Africa by Acocks (1953). On our map the Cape Flora consists of the macchia (Fijnbos), the coastal macchia and the false macchia. As mentioned before, humidity is the determining factor in the distribution of these units.

For the present study the vegetation of five areas will be dealt with, viz.: 1. the Cape Flora, 2. the evergreen forest flora of the Knysna region, 3. the Karroo flora and 4. and 5. the vegetation types surrounding the areas of Rietvlei and Cape Hangklip.

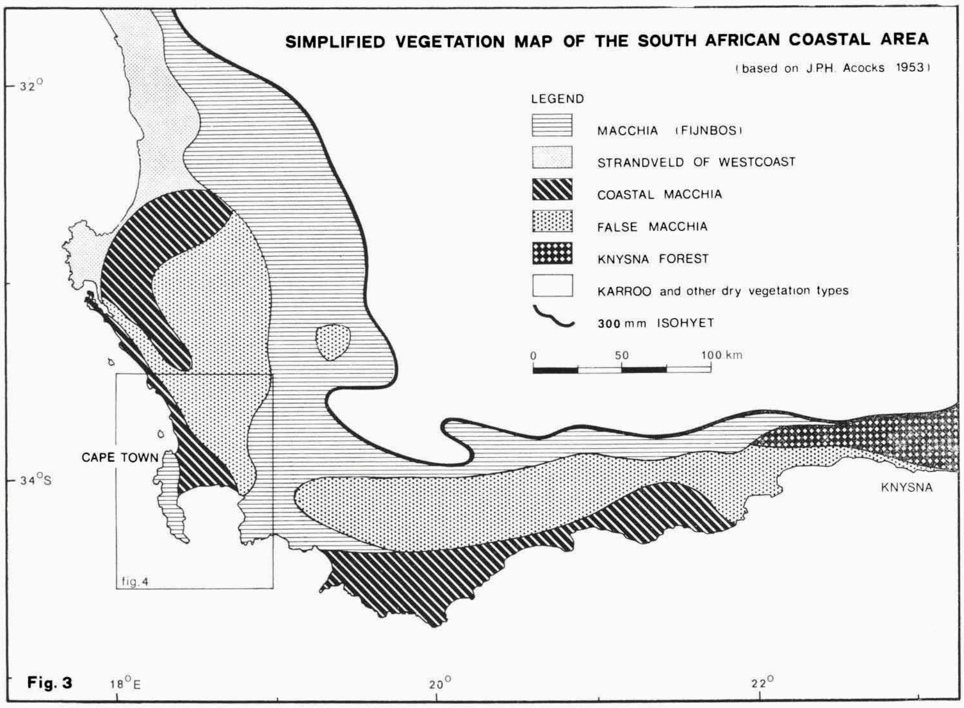


Fig. 3

The Cape Flora

Its essential features are, apart from its xerophytic character: the plant cover consists mainly of low shrubs and geophytes, whereas trees are rare; there is little species dominance and many of the important genera are rich in species.

The most characteristic genera belong to the following families: Proteaceae, Crassulaceae, Geraniaceae (*Pelargonium*), Aizoaceae (*Mesembryanthemum* s.l.), Restionaceae, Ericaceae, Penaeaceae, Amaryllidaceae, Iridaceae, Grubbiaceae, Roridulaceae, Geissolomataceae, Polygalaceae and Bruniaceae (Adamson, 1959, Acocks, 1953 and Walter & Straka, 1970). The leaves of most plants are small and coriaceous (of the ericoid type), and the plants are known to have a wide ecological amplitude. Taylor (1972) describes the Cape Flats vegetation in detail, differentiating it into an inland vegetation and a coastal one, each group in turn consisting of several communities.

Inland Vegetation Communities – a. the inland dune scrub, typical of the more elevated parts of the dunes, is 2-3 m tall, *Euclea racemosa* and *Rhus lucida* are dominant shrubs; b. the inland dune macchia, which covers the undulating country, is about 1 m tall, its composition is complex but *Metalasia* is characteristic in association with *Psoralea fruticans* and *Ehrharta villosa;* c. the Grass-Rush community grows in the low-lying parts of the inland depressions and it comprises Gramineae, Cyperaceae, Restionaceae and Juncaceae, of which a single-species dominance in local stands is often conspicuous.
Coastal vegetation communities – a. the coastal dune scrub contains *Pterocelastrus* and *Cassine maritima,* whereas *Rhus lucida* is absent; b. the coastal dune macchia closely resembles the inland dune macchia except for the presence of *Myrica cordifolia, Mesembryantemum* s.l. and *Euphorbia caput-medusae;* c. in the coastal depressions the vlei-vegetation comprises mostly halophytes, *Plantago carnosa, Scirpus nodosus, Sporobolus virginicus, Chironia decumbens and Cnidium suffruticosum.*

The evergreen forest

This flora has been studied and described in extenso by Weimarck (1941) and by Philips (1931). The forest has a manifestly mixed nature. The most important species – *Olea laurifolia, Podocarpus falcatus, P. elongatus, Ocotea bullata,* and *Apodytes dimidiata* – are large trees, co-dominant throughout the forest. *Podocarpus* and *Olea laurifolia* are the most abundant of the large trees and are very sensitive to environmental changes, e.g. to changes in soil moisture and light intensity. The part of the Knysna forest in which *Podocarpus falcatus* and *P. elongatus* are locally dominant grows on a soil type which contains a moderate amount of humus and has a moist character. The pH of the soil varies from 4.8-5.5. The soil is moderately deep to deeply developed and consists of a sandy or clayey loam. In this semi-humid variant of the Knysna forest, seedlings of *Podocarpus elongata* are frequently found. Phillips (1931) mentioned the following agents for the dispersal of fruits and seeds of *Podocarpus:* birds, water, elephants (now practically extinct), and monkeys. A drier type of forest in which *Podocarpus elongata* is found principally differs from the more humid type by the absence of *Ilex, Cunonia, Ocotea,* and *Curtisia.* In this type of forest, only locally propagation of *Podocarpus* has been observed. The soil under this type of forest is of approximately the same character as that of the wet type, but mostly dry humus is present here. In this context it is interesting to note that the germination of *Podocarpus* in South America is also restricted to humid soils (Hueck, 1966).

The vegetation of the Karroo

Nowadays the Karroo vegetation is mainly composed of Compositae-dwarf shrub communities, consisting of *Chrysocoma, Pteronia, Eriocephalus,* etc. Also *Mesembryanthemum* s.l. shrubs are frequently found. On stony slopes the famous succulent vegetation, which is most characteristic of the Karroo, is encountered. According to Acocks (1953), the grass vegetation was more extensive in the past, but as a result of over-grazing its present area became reduced. The transition from Karroo vegetation to the proper Cape vegetation is formed by the so-called renoster bush, in which *Elytropappus rhinocerotis* (Compositae) is dominant.

The vegetation types of the Rietvlei and Hangklip areas (both belonging to the Cape Flora) will be treated in detail.

The vegetation of the Rietvlei area

In the Rietvlei area two types of environments are at present to be distinguished, viz., the proper vlei and the dune-beach zone respectively, each with its particular vegetation type. The vegetation of the vlei can be differentiated into a wet, a marginal and a dry type of vegetation (Carser, 1967). The wet type covers most of the northern part of the vlei and contains the following species: *Scirpus maritimus, Triglochin elongatum, Aponogeton angustifolius, Juncus kraussii,* and *Chondropetalum tectorum.* The marginal type of vegetation is characterised by *Passerina, Cotula turbinata, Dimorphotheca pluvialis, Carpobrotus, Salsola, Geranium molle, Homeria ochroleuca, Sparaxis grandiflora* and *Chondropetalum tectorum.* The dry type of vegetation covers the southern part of the vlei and is hardly ever inundated. The principal elements are *Arthrocnemum, Salsola, Lasiochloa,* and *Cynodon dactylon.* Going from the beach landwards, at first a pioneer vegetation is found in which *Sporobolus pungens* and *Sebaea ambigua* play an important role. Also halophytes such as *Cnidium suffruticosum, Carpobrotus edulis,* and *Senecio maritimus* are found. Approaching the dune area, a transitional zone is found between beach and dunes. Several plants from the dunes - such as *Cliffortia hirta, Euphorbia mauritanica, Zygophyllum flexuosum,* and *Mesembryanthemum* sp. - and from the beach zone - like *Cnidium suffruticosum* and *Sporobolus virginicus* - intrude into this transitional zone (Cowan, 1963).

The dunes in general are covered with a dense scrub layer in which *Myrica cordifolia, Chymococca empetroides* and *Rhus glauca* are found. In sites where this vegetation is damaged by wind action, *Euphorbia mauritanica* is growing.

The Rietvlei types of vegetation are generally comparable with the Strandveld vegetation of the West coast (see Fig. 3).

The vegetation of the Hangklip area

The natural vegetation around the Hangklip site has been disturbed intensively by human activities. At present the wetter part of the site is a peat bog with Restionaceae and *Berzelia* vegetation, whereas on the drier parts a shrubby ericoid vegetation consisting of *Erica perspicua* and *Brunia alopecuroides* is present (Boucher, personal communication).

GEOLOGICAL SETTING

The large undulating sandy area connecting the hardrock of the Cape Peninsula with the mainland is known in the literature as the Cape Flats (Fig. 4). It is a component of the 'Tertiary and Recent sands' unit of the geological map edited by Haughton (1969) The present study points to an Upper Quaternary age of the deposits in the Cape Flats area. The Cape Flats sediments consist of sands intercalated with clay and gravel beds of various thicknesses. Small basement rock outcrops are known from several localities.

The basement of the Cape Flats is composed of Praecambrian and Palaeozoic rocks belonging to the Cape Granite, the Malmesbury Formation, and the Table Mountain Sandstone.

The Cape Flats are assumed to have developped after the closure of the 'Cape Strait', which at one time united False Bay with Table Bay, by the lowering of the sea-level and a probable rise of the basement (Walker, 1952). Along the coast of the Cape Peninsula and on sites where a cliff - coast is present, raised beaches have been found as evidence of former fluctuations in sea level. The ancient beaches at the levels 18-27 m and 5-6 m are the best known; they are supposed to be of Eemian age and correlated with the mediteranean Monasterian levels (Krige, 1927). The highest of these beaches exhibits evidence of a fossil warm water fauna, whereas the lower one contains a cool water fauna similar to the recent one. According to Krige (1927), the explanation of this phenomenon can be found in the ancient 'Cape Strait', which at that time was a passage for the warm Agulhas current with its accompanying fauna but became closed later on in the Eemian. The elevated position of these raised beaches seems to be in good correspondence with elevated beaches in other parts of the world. Haughton (1969), warning against dating deposits apparently related to these beaches, states that 'a process of intermittent and irregular uplift of the coastal belt . . . began in early Tertiary and continued intermittently into the Quaternary until the present day'.

Evidence of submerged deposits also comes from Krige (1927), who mentioned the occurrence of shell deposits at –18 m near Milnerton, and from Amdurer (1956) who reported blackened wood at –15 m in the central part of the Cape Flats. The minimum age of this wood is 38 000 B.P.

The Cape Flats area, covering about 400 square km, has an average elevation of 30 m. In several depressions flat marshy sites – locally named 'vleis' – are present which sometimes contain open water and are connected by a river with the sea (Stephens, 1929). The drainage towards the S takes place by the Eersteriver and by the Seekoevlei into False Bay, whereas to the N the Saltriver and Diepriver flow into Table Bay (see Fig. 4). On the Cape Flats sand dunes are frequent with a prevalent southeasterly orientation.

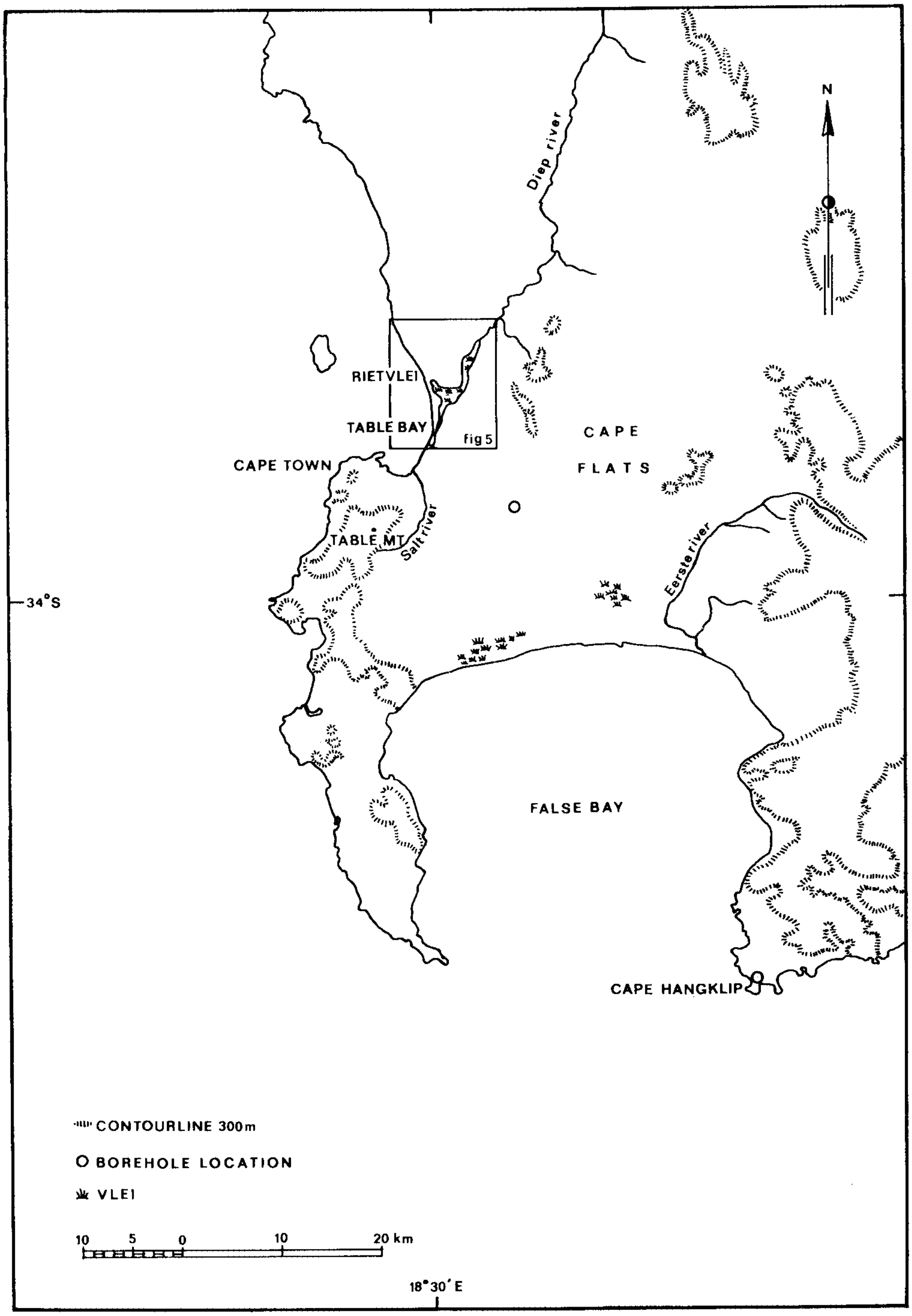


Fig. 4. Map of the Cape Flats area with the main topographical features, showing the localities.

Chapter 3. Analysis of the boreholes

MATERIAL AND LOCATIONS

Boreholes were drilled at three different sites in the southwestern coastal region: at the Rietvlei, at the central part of the Cape Flats just south of Langa, and at Hangklip (see Figs. 4 and 5). The borings are indicated by these names (Rietvlei, Cape Flats and Hangklip, respectively), and sometimes a number is added. The exact geographical locations of the boreholes are indicated on the diagrams (see the Appendices 1-8).

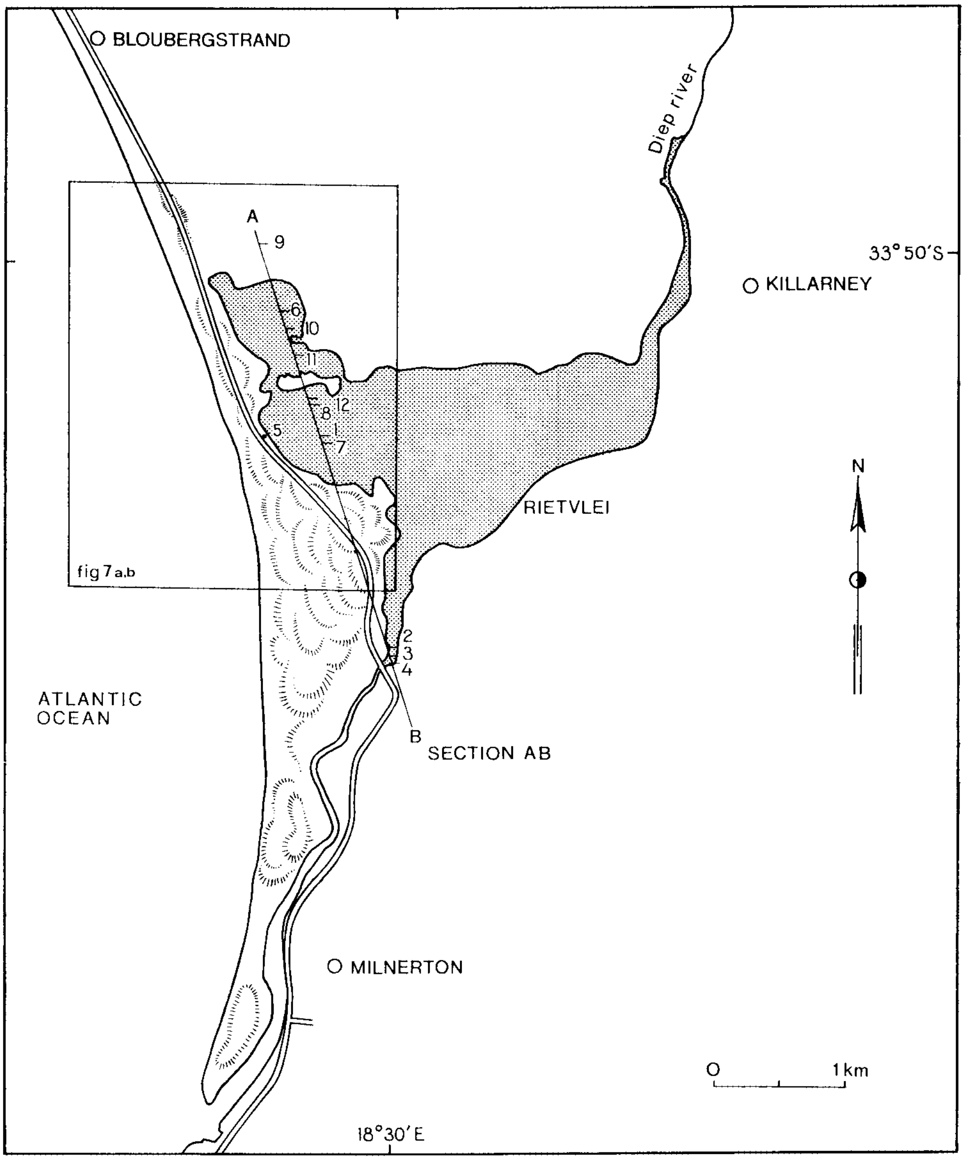


Fig. 5. Localities in the Rietvlei area and drainage pattern of the Diepriver (for section AB see also Appendix 8).

The recovery of continuous cores is rather difficult in this area due to the sandy and gravelly character of the greater part of the sediments. Apart form the core samples, much information has been gleaned from borehole descriptions of several drilling companies active in this area. A study of Amdurer (1956) drew our attention towards the central part of the Cape Flats. The site at Cape Hangklip had been sampled before by Hall and Inskeep, but no pollenanalytical results were published, although several radiocarbon data were given by Vogel (1970). The extensive survey which had been carried out under supervision of the Fisheries Development Company of South Africa, Ltd. drew the attention to the Rietvlei area. This survey supplied much detailed information used in the present study.

All samples are stored at the Rijksmuseum van Geologie en Mineralogie (National Museum of Geology and Mineralogy), Leiden, The Netherlands, and registered under the numbers RGM 158 501 - 159 564.

LITHOLOGICAL DESCRIPTIONS

In the following part a short description of the main lithological characteristics of the layers found in the boreholes is given. Information about the depth of the basement can be found in section AB of Appendix 8.

Rietvlei 1 - see Appendix 1. This borehole is characterised by an alternation of sand layers with clay lenses, and sandy clays. The intervals from 0.20-5.00 m and 14.00-19.60 m were studied pollenanalytically. At the depths of 7.90 m, 9.90 m, 11.00 m, 13.60-13.90 m, and 21 m (the base), gravel layers have been encountered. Shell-bearing deposits extended from 0.20-5.00 m.

Rietvlei 2 - see Appendix 2. The total depth of this borehole is 24.20 m. The sediments consist of clay, sandy clay and sand. At the levels of 2.10 m and 4.00 m dark brown layers have been found, and it is assumed that they represent 'palaeosols'. The exact character of these layers is doubtful and no pollen was recovered from them. At the top of the 4.00 m layer a gravelly sand layer of 0.05 m thickness was found. Several zones of shell-bearing deposits were encountered.

Rietvlei 3 - see Appendix 3. Only sediments from 22.80-24.35 m were recovered from this borehole, due to technical difficulties encountered while drilling. The deposits of this interval consist of clay with one zone of shell-bearing deposits (23.10-23.40 m).

Rietvlei 4 - see Appendix 4. Only the sediments lying between 22.10-25.00 m were recovered, for the same reason as mentioned above. These deposits consist of an alternation of clays and sandy clays. The interval from 22.70-23.00 m and two samples at 23.90 m and 24.80 m were studied pollenanalytically. Two shell-bearing zones were found (at 22.15-22.50 and 23.50-23.75 m).

Rietvlei 5 - see Appendix 7. The sediments of 0.00-15.00 m consist of sand, with gravels in the lowermost part. From 0.80-13.70 m these deposits were sedimentary-petrologically analysed.

Cape Flats - see Appendix 5. From a depth of 3.80-8.40 m sediments were recovered, consisting of sand and sandy clay. At 4.50 m a 'palaeosol' horizon was found, containing plant debris and root layers. The intervals from 4.10-6.20 m and from 7.90-8.00 m were studied pollenanalytically.

Hangklip - see Appendix 6. The sediments from 0.05-3.50 m consisting of peat, sandy peat and sand were recovered and studied palynologically.

SHELL-BEARING DEPOSITS

Levels with shells and other marine fossils were found in most boreholes of Rietvlei, and samples were selected from all these levels (see table 1). Identifications of these fossils were made by Dr A. C. van Bruggen (Department of Systematic Zoology, University of Leiden, The Netherlands), by R. N. Kilburn (Natal Museum, Pietermaritzburg, South Africa) and by A. W. Janssen (National Museum of Geology and Mineralogy, Leiden, The Netherlands). The molluscs are indicative of a shallow water environment. The following species do not occur in 'The revised list of South Africa Late Tertiary and Pleistocene marine Mollusca' by Barnard (1961): *Monia squama, Kellia rubra, Tellimya trigona, Tricolia capensis, Littorina saxatilis, cf. Alvania alfredensis, Assiminea isosceles, Vitrinella cifara, Turritella sanguinea, Epitonium kraussi,* and *'Guraleus' eucosmia.* These species have not previously been recorded from fossil deposits in South Africa. All species are listed in Table 1 (page 46) and denoted with borehole number (Rietvlei 1, 2, 3 and 4) and level. By means of the radiocarbon datings and pollen diagrams four shell-bearing deposits of different age could be recognised, and a chronological sequence of levels has been established (numbered I to IV). Level I antedates 45 000 B.P., level II has an age of 40 500 B.P. – 36 500 B.P., level III of 33 000 B.P. to approximately 28 500 B.P., whereas level IV appears to be of Holocene age.

SEEDS

Nearly all samples from the shell bearing deposits contain seeds of *Ruppia maritima* L. (Potamogetonaceae), a species which at present is typical of the littoral environment (Phillips, 1951). Seeds of *Ruppia* were found in Rietvlei 1 level IV (1.50 and 6.00 m), Rietvlei 2 level II and IV (22.10 and 1.80 m), Rietvlei 3 level I (23.30 m) and Rietvlei 4 level I (23.70 m).

They confirm the littoral depositional environment of level I-IV as already indicated by the associations of Mollusca.

MARINE PHYTOPLANKTON

Large numbers of planktonic cysts and algae were found in levels II and III of the borehole Rietvlei 2, and identified by Dr C. Downie (Geology Department, University of Sheffield, England). The following species were recognised: *Operculodinium centrocarpon, Lingulodinium machaerophorum, Spiriferites, Pterosperma, Pachytheca,* and *Concentricystites circulus* (see Table 1 and Plate 5). According to Downie all these species were marine, and at one time ubiquitous and common in the North Atlantic waters. Cool water species seem to predominate. Their fossil occurrence in the South Atlantic has not previously been recorded.

RADIOCARBON DATA

Samples from each borehole were dated by means of the radiocarbon method (see table 2). If optimal conditions are fulfilled, the present method of radiocarbon analysis allows a dating extending backwards to and even beyond 50 000 years B.P. However, if deficiency in radiocarbon content of the sample is encountered, a younger minimum age results. In our case, according to an international convention, two samples (GrN 6516 and GrN 6524) should be quoted as $>$ 35 950 B.P. and $>$ 39 740 B.P., although ages of 44 000 B.P. and 46 000 B.P., respectively, are quite probable for these two samples (personal communication of Dr W. G. Mook, Physical Laboratory. University of Groningen, The Netherlands).

Rietvlei 1 - Two samples, from 15.50 m and 17.50 m depth, were dated revealing an age of 34 660 $\pm$ 900 B.P. (GrN 6519) and 43 360 $^{+2240}_{-1750}$ B.P. (GrN 6523) respectively.

Rietvlei 2 - The sample from a depth of 17.10 m has been mixed erroneously in the laboratory in equal quantities with material from 20.10 m, which mixture was dated as 32 770 $^{+1110}_{-890}$ B.P. (GrN 6362). At a depth of 21.50 m an age of 40 100 $^{+3630}_{-2490}$ B.P. (GrN 6515) was found. In view of the fact that sample 20.10 m can not be older than 40 100 B.P. and the samples of 17.10 m and 20.10 m have been mixed in equal parts, the date for level 17.10 m can not be younger than 29 000 B.P. and not older than 32 770 B.P.: a date close to 29 000 B.P. seems to be the most probable.

At the depth of 24.10 m an age of 39 780 $^{+1750}_{-1430}$ B.P. (GrN 6522) resulted. The younger radiocarbon date at a lower depth (see sample GrN 6522 and GrN 6515) is possible in this case, if the standard deviation is taken into account.

Rietvlei 3 - Only one sample (GrN 6516) from a depth of 22.80 m could be dated, as $>$ 35 950 B.P., which may be regarded as representing 44 000 B.P. for the reason stated in the introduction of this paragraph.

Rietvlei 4 - From a depth of 22.15 m a sample was dated as 33 830 $^{+1940}_{-1560}$ B.P. (GrN 6614), and for the level at 23.35 m an age of 47 960 $^{+2850}_{-2100}$ B.P. (GrN 6525) was calculated. As stated above already, the age of the sample from the depth of 23.15 m estimated as $>$ 39 740 B.P. (GrN 6524) may be read as representing 46 000 B.P.

Cape Flats - The fossil root layer at 4.50 m was dated 41 500 $^{+2100}_{-1800}$ B.P. (GrN 5550). From a duplicate borehole near this site (Cape Flats 2, at ca 10 m distance from borehole Cape Flats), an age of $>$ 43 000 B.P. (GrN 5551) from a depth of 7.00 m was established (peaty clay).

Hangklip - The peaty material from the depths of 0.83 m, 2.73 m and 3.20 m was dated 1 580 ± 50 B.P. (GrN 6359), 6 520 ± 100 B.P. (GrN 6360), and 7 280 ± 130 B.P. (GrN 6361) respectively.

Several unpublished radiocarbon datings of the Rietvlei area supplied by Fiscor are used here, viz., from Rietvlei 6, depth 12.00 m dated as 8 100 B.P. and Rietvlei 7, depth 17.50 m with an age of > 41 160 B.P. The Hangklip site had been sampled before by Hall and Inskeep (see Vogel, 1970) and samples from 0.45 m, 0.75 m, 2.30 m and 3.60 m were dated 360 ± 30 B.P. (GrN 4585), 2 560 ± 35 B.P. (GrN 4649), 6 080 ± 50 B.P. (GrN 4473) and 11 140 ± 65 B.P. (GrN 4586) respectively.

SEDIMENTARY PETROLOGY

Several studies on recent coastal sediments bordering the Cape Flats area have been published by Bowie, Fuller & Siesser (1969), Fuller (1961 and 1962), and Fuller & Lamming (1967). In these studies the following properties of the coastal sediments were reported: the deposits consist predominantly of quartz sands with 20-40% shell debris, the size distribution reflects a clear bimodality of the samples, and the size range lies between 0.06 and 4.00 mm with a dominance of the 0.09-1.50 mm fraction. The deficiency of sand of about 0.25 mm is attributed to a two-stage fractioning process, viz., to the concentration of this component on the beach and to its subsequent removal by onshore winds. A striking difference has been observed between marine and aeolian sediments: in the marine sediments the cumulative distribution curves show a significant break at 105 μ whereas the aeolian sediments are characterised by a nearly log-normal distribution (Fuller, 1962).

In the present study samples from the recent beach and dune sand, and from the core samples of the borehole of Rietvlei 5 were subjected to the calculations of moment measures as described by Koldijk (1968). The classification was made according to Wentworth (1931). The results of Doeglas (1968) and Buller & McManus (1972) were used for the environmental interpretation of the Rietvlei samples. Heavy-mineral analysis was also applied to all samples. The results of these analyses are given in Appendix 7.

The heavy mineral content of the recent coastal dune samples from the Rietvlei area can be characterised as follows: 25% zircon, 66% tourmaline, 2% rutile and 7% other heavy minerals, including 4% epidote. The median value of the grain size (Md) is 233 μ; the moment measures according to Friedmann (1967) are 2.2, 0.9, 5.5 and 47.5 and those according to Folk & Ward (1957) are 2.1, 0.6, 0.01 and 1.0.

The heavy mineral content of the recent beach samples from the Rietvlei area can be characterised as follows: 26% zircon, 51% tourmaline, 6% rutile and 17% other heavy minerals, including 10% epidote. The median value is 188 μ, the moment measures according to Friedman (1967) are 2.7, 0.9, 1.0 and 5.4, and those according to Folk & Ward (1957) are 2.4, 0.5, –0.05 and 1.0. The beach and the dune samples were classified as 'fine sands'.

From the above-mentioned data it is apparent that a distinction can be made between the dune and the beach sediments on the base of heavy-mineral content: the dune samples contain a higher percentage of tourmaline and a lower percentage of epidote.

The samples of Rietvlei 5 (see appendix 7) appear to have a predominance of resistent heavy minerals throughout the section. Two breaks, however, are evident at 11 and 8 m, which are not only conspicuous by changes of heavy-mineral content but which are also revealed by the values of Md and by the moment measures according to Friedman. The environmental analysis tends to indicate towards a more aeolian type of deposition. The heavy-mineral content of the sample at 11 m includes 60% tourmaline and 2.5% epidote. At 8 m tourmaline reached 58% and 1% epidote was present.

The lower part of the section, between 13.75 and 11 m, exhibits low values of the 2° moment (= sorting) and an increase of the 4° moment (= kurtosis) is evident. From 11 to 8 m a decrease in median value and kurtosis is evident. From 8 m onwards no important changes can be found.

These data provide the following interpretation of this section: from 13.75 m to 11 m a fluviatile depositional environment was present. From 11.50 m to 7.50 m aeolian sediments are found, interrupted in the middle by some fluviatile deposits. From 7.50 m to 0.00 m fluviatile conditions prevailed.

For a further interpretation of these data, we refer to the Chapters 5, 6 and 7.

PREPARATION OF THE SAMPLES AND EQUIPMENT USED

The preparation of the samples and the analysis of the pollen content were carried out at the Palynological Laboratory of the National Museum of Geology and Mineralogy, Leiden, The Netherlands.

The following method of preparation was applied: heating with KOH 10%, followed by washing with distilled water and with alcohol 96%, separation by bromoform-alcohol s.g. 2.0 followed by washing with alcohol 96% and distilled water. The residues were mounted in liquid glycerine, which allows positional changes of the sporomorphae during the examination under the microscope.

The number of grains counted per sample was approximately 200, but in poor samples this number could not be reached. In the Hangklip boring samples the average was as high as 300 grains.

Spores of Pteridophyta, remains of algae, and cysts of other marine phytoplankton were found and counted, but they were not included in the pollensum.

The identification and the counting of the sporomorphae were done with a Leitz Orthoplan microscope; the photomicrographs were taken with a Leitz Orthomat.

The samples for sedimentary-petrological analysis were prepared at the Institute of Geology and Mineralogy, University of Leiden, The Netherlands. The statistical calculations were performed at the Central Mathematical Institute, University of Leiden, The Netherlands, with the aid of the PL-1 computer program published by Koldijk (1968). The heavy-mineral analyses were carried out at the Petrological Department of the National Museum of Geology and Mineralogy, Leiden, The Netherlands.

DATA ON THE RECENT AND THE FOSSIL POLLEN FLORA

The description of the recent sporomorphae of South Africa started with the publication of 'South African Pollen Grains and Spores' (van Zinderen Bakker, 1953, 1956; van Zinderen Bakker & Coetzee, 1959; Welman, 1970). Additional information was obtained from a reference collection of pollen grains of the Cape Flora specially made for this study. As the fossil sporomorphae encountered belong to still extant plants, only the pollen morphology of families and/or genera not treated in the above-mentioned publications, is shortly described here. The descriptions are based on fossil sporomorphae.

In the pollen diagrams curves of the families are drawn, but in several cases curves relating to genera or species could be given. Within the families sometimes various different genera could be identified which are not represented by different curves, either because the individual curves were of little statistical value, or because the ecological situation did not make a separate graph worthwhile. All families, genera or species used in the diagrams are mentioned below, with some ecological data (only the main habitats occurring in our area are indicated). The photomicrographs were all made from fossil material of the Cape Flats-Rietvlei area. The following abbreviations have been used: 3P = triporate grains, 3 CP = tricolporate grains, and 4C(P) = tetracolporoid grains, and* means: for the pollen morphology see van Zinderen Bakker, 1953, ** van Zinderen Bakker, 1956 and *** van Zinderen Bakker & Coetzee, 1959.

Aizoaceae** (see Plate 3, Fig. 7)
Pioneers of the dune environment, efficient sand binders.

Amaryllidaceae*
Characteristic of the coastal macchia.

Anacardiaceae (see Plate 1, Figs. 8-10)
3CP, colpi transversales. Intercolpia in equatorial section markedly convex. Polar axis 26-30 μ, equatorial axis 16-27 μ, endopore 3-4 μ, striate.
Shrubs and trees of the coastal area.

Aquifoliaceae (Plate 1, Fig. 5)
Ilex mitis: 3CP, size 30x24 μ, clavate (clavae sometimes fused to a more or less reticulate pattern).
Tree of wet habitats in riverine and moist forest communities.

Araceae*
Zantedeschia
Plant of the marshy environment, typical vlei dweller.

Balsaminaceae
Impatiens: 4C(P), polar axis 19 μ, equatorial axis 30 μ, polar view rectangular, exine 1-2 μ, tectate, reticulate.
Herbs in damp places of the coastal area.

Bruniaceae***
Shrubs or ericoid shrubs of the southwestern coastal macchia.

Campanulaceae (see Plate 4, Fig. 7)
Roëlla: 3P, spherical, 38 μ, echinate with small spinules in between, exine 2 μ, diameter of pore 3-4 μ, costae pori.
Lightfootia: 3P, 18 x 22 μ, microfoveolate?, exine 2-3 μ, diameter pore 1-2 μ, costae pori.
Both are shrubs of the southwestern coastal macchia.

Chenopodiaceae** (see Plate 3, Fig. 8)
Arthrocnemum and *Salicornia* are predominant.
Plants of the saline and sandy environment.

Compositae (see Plate 3, Fig. 15-17)
Artemisia-type: 3CP, spherical, 17-25 μ, microechinate, echinae in rows, pores 2-3 μ.
Non-*Artemisia*-type: exclusively belonging to the Tubiflorae.
Artemisia is common in the coastal area, whereas the non-*Artemisia* Compositae are ubiquitous.

Convolvulaceae
Falkia: 3CP, equatorial axis 35 μ, exine 3-4 μ, reticulate.
Plant of the southeastern coastal area, growing in moist environments.

Cornaceae
Curtisia dentata: (in the diagrams erroneously indicated as *C. faginea)* 3CP, spherical 13 μ, psilate, endopore, diameter of pore $\pm$ 1 μ.
Tree of the evergreen forest.

Crassulaceae**
Succulent herbs, widely distributed.

Cucurbitaceae
Grains 3CP, 45 x 35 μ, endopore, exine 2-3 μ, pore 5-6 μ, costae colpi, reticulate/foveolate.
Climbing herbs (rarely shrubs), widely distributed.

Cyperaceae*
Principally confined to marshy habitats (helophytes).

Ericaceae (see Plate 2, Fig. 34)
Blaeria: 3CP, polar axis 30 μ, equatorial axis 16 μ, exine 1-2 μ, psilate with cracks on the polar area.
Erica: 3CP, united in tetrads, 20-40 μ, psilate/scabrate.
Found both on the more elevated parts of the beach and in more sheltered positions in the dunes.

Euphorbiaceae (see Plate 4, Fig. 13)
Euphorbia: 3CP, with an endopore, polar axis 35 μ, equatorial axis 28 μ, exine 3-4 μ, microreticulate.
A pioneer in the dune vegetation.

Fagaceae (see Plate 2, Fig. 5)
Nothofagus: stephanoporate, 45 μ, pores with annulus, psilate/scabrate.
Trees of this genus are not living in South Africa and the pollen grains found probably came from South America from where they were transported by the westerlies (long-distance transport).

Gentianaceae (see Plate 2, Fig. 8)
Chironia: 3CP, spherical, size 20 μ, exine 1-3 μ, costae colpi, tectate, columellae distinct.
Plants of the vlei and sandy environment.

Geraniaceae (see Plate 2, Figs. 6-7)
Grains 3CP, size 60-70 μ, coarse reticulum, lumina 1-2 μ, 'clavae' of the reticulum 6 μ, exine 1-2 μ.
Plants of the coastal belt, sometimes semi-succulent.

Gramineae*
Pioneers of the sandy sea shore, grasslands etc.

Haloragidaceae (see Plate 3, Fig. 12)
Myriophyllum: (3)4-(6)P, size 24-28 μ, stephanoporate, pore with annulus, pore 2 μ, psilate/scabrate.
Submerged aquatics.

Iridaceae*
Geophytes of the coastal area.

Juncaceae*
Semi-aquatic plants (helophytes) of the coastal belt.

Juncaginaceae*
Herbs found in fresh-water and salt marshes.

Leguminosae*** (see Plate 4, Figs. 4-6)
Plants of various habitats.

Liliaceae*
Plants of the semi-aquatic environment.

Moraceae*
Probably *Ficus,* trees or shrubs of the coastal area.

Myoporaceae
Oftia: 3CP, almost spherical, size 12 μ, polar view triangular, costae colpi, psilate.
Herbs of the coastal area.

Myricaceae* (see Plate 1, Fig. 7)
Only representative: *Myrica.*
Shrubs or trees of the coastal dune area.

Myrtaceae (see Plate 1, Fig. 6)
Eugenia (Syzygium): syncolporate, size 23-27 μ, psilate.
Tree or shrub of the coastal macchia.

Penaeaceae
Penaea: heterocolporate (6)8-10C, (3)4-5P, polar axis 30 μ, equatorial axis 24 μ, exine 1-2 μ, psilate.
Shrub of the coastal macchia.

Plantaginaceae (see Plate 3, Fig. 9)
Plantago: periporate, 6P, size 32 μ, pori (2½ μ) with annulus 5 μ, verrucate.
Herbs widely distributed.

Podocarpaceae* (see Plate 1, Figs. 1-4)
Trees of the humid evergreen forest.

Polygalaceae
Grains stephanocolporate (8-10 CP), size 25-26 μ, costae colpi, colpi transversales, exine 3-4 μ, psilate/scabrate.
Plants widely distributed.

Polygonaceae**
Herbs or shrubs, widely distributed.

Portulacaceae**
Herbs or shrubs of the coastal area.

Potamogetonaceae*
Plants of the aquatic environment.

Proteaceae* (see Plate 2, Figs. 3-4)
Trees or shrubs of the macchia.

Ranunculaceae**
Plants of the semi-aquatic environment.

Restionaceae* (see Plate 3, Figs. 1-2)
Plants mainly confined to the semi-aquatic environment.

Rosaceae*** (see Plate 3, Figs. 5-6)
Cliffortia: (Plate 3, Fig. 5) is easily recognisable; most grains encountered belong to this genus. Plants of the coastal region: *Cliffortia* is a pioneer in the coastal dunes.

Rubiaceae (see Plate 3, Fig. 11)
Nenax: 3CP, spherical, size 20-30 μ, pori 3 μ, reticulate.
Shrubs in the coastal area, in wet places.

Rutaceae (see Plate 2, Figs. 1-2)
Phyllosma: 3CP, polar axis 30 μ, equatorial axis 15 μ, costae colpi diverging towards the equator, scabrate/micro-reticulate.
Toddaliopsis: 3CP, polar axis 23 μ, equatorial axis 18 μ, colpi transversales, reticulate.
Trees or shrubs of the macchia.

Solanaceae
Grains 3CP, polar axis 15 μ, equatorial axis 19 μ, colpi transversales constricted at the pores, protuding pore 3 μ, costae colpi, psilate.
Widely distributed herbs.

Thymelaceae (see Plate 3, Fig. 10)
Passerina: periporate grains, spherical, size 25-30 μ, 20-35 pores, pori 2-3 μ with thin annulus, reticulate.
Open scrub of the coastal area, especially on dunes.

Typhaceae*
Plants in estuaries with brackish water and in inland lakes, vleis and along river banks.

Umbelliferae (see Plate 3, Figs. 13-14)
Grains 3CP, polar axis 22-25 μ, equatorial axis 13-15 μ, psilate (-scabrate).
Widely distributed plants.

Urticaceae*
Herbs or shrubs, widely distributed.

Zygophyllaceae (see Plate 4, Fig. 8)
Tribulus: periporate, spherical, size 40-44 μ, 50-60 pores, muri with distinct columellae, lumina 5 μ, pori 2 μ, exine 2 μ, muri 4 μ, reticulate.
Widely distributed plants.

The indeterminable pollen grains have been lumped in three groups, viz. a 3CP group, a 3C group and an Indet. group. The Indet. group represents unindentified grains whose pollen type was unrecognisable. Apart from these groups, three unknown pollen grains have been encountered which have rather distinct morphological features but could not be assigned to any plant taxon.
Type 1: grain 3CP, polar axis 30 μ, equatorial axis 15 μ, colpi constricted at both sides of the operculate pore, psilate.
Type 2: grain 3CP, polar axis 22 μ, equatorial axis 19 μ, psilate/tectate.
Type 3: grain 3CP, spherical, size 20 μ, scabrate with a psilate annulus. They resemble the pollen grains of *Lightfootia,* but are not identical.

Pteridophyta (see Plate 4, Figs. 9-12). For the morphology of the spores see Welman, 1970.

CONSTRUCTION OF THE POLLEN DIAGRAMS

For a better understanding of the vegetational changes in the area investigated, two types of diagrams were designed, indicated with A and B. For the diagrams of type A the pollen sum was determined by calculating the total amount of herb and of arboreal pollen (NAP + AP). The individual curves of the different taxa have been calculated in respect to this sum and shown in part C of the diagrams. In the diagrams of type B the sum of arboreal pollen (AP) was taken as a basis for calculation. The taxa *Myrica,* Myrtaceae, Anacardiaceae, *Podocarpus, Curtisia dentata,* Proteaceae, Rutaceae, and *Ilex mitis* are the constituents of the AP. The total number of AP in this sum is relatively low. Still a reliable basis for interpretation seems available, because the succession of palynological spectra shows a conspicuous consistency in certain intervals. There can be no doubt, therefore, that the major changes from one sequence of coherent spectra to the other are meaningfull. It will, however, be clear that no conclusions can be drawn from the minor changes within each of these sequences of the AP diagram.

RECENT POLLEN SPECTRA AND THE INTERPRETATION OF THE POLLEN DIAGRAMS

For the interpretation of the fossil pollen spectra, it is of course very important to have an adequate knowledge of the relation between recent pollen spectra and the vegetation types in South Africa. Relevant data are still scarce, but those already available are certainly of importance and were fundamental for the interpretation of the diagram.

In Fig. 6 recent pollen spectra are given from a dune vegetation (near Killarney), a treeless heath and bog within the coastal macchia (on Table Mountain), an evergreen forest (Knysna forest) and a coastal estuary vegetation at about 20 km from the Knysna forest. For easy reference these recent spectra have been calcu-

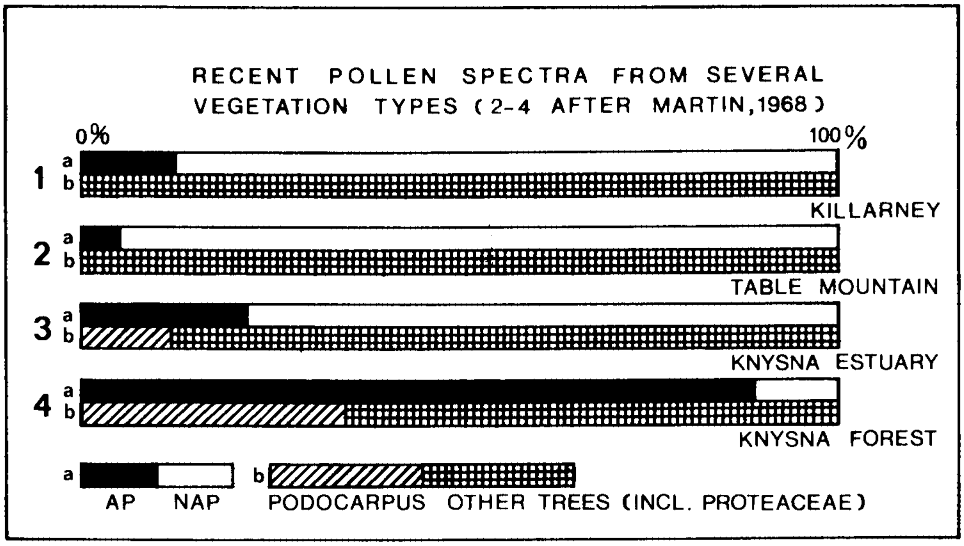


Fig. 6. The upper part (a) of each spectrum gives the relation between arboreal (AP) and non-arboreal (NAP) pollen totals, the lower part (b) gives the relation between *Podocarpus* and other trees (incl. Proteaceae).

lated and represented in a more or less similar way as the fossil ones. In the upper part (a) for each spectrum the non-arboreal (NAP) /arboreal pollen (AP) ratio has been given, in the lower part (b) the ratio of *Podocarpus* pollen in respect of the pollentotal of other trees (including Proteaceae) is given.

In the spectrum of the dune vegetation from Killarney Myrtaceae and *Myrica* are the main constituents of the AP, whereas Compositae (*Artemisia*-type), Chenopodiaceae and Euphorbiaceae are dominant in the NAP.

In the spectrum of the treeless heath and bog within the coastal macchia of Table Mountain only approximately 5% of arboreal pollen is found. The NAP consist of 50% Restionaceae, 20% Compositae and 25% Ericaceae (Martin, 1968).

In the spectrum of the Knysna forest a dominance of 90% of the AP is found. *Podocarpus* is represented by 25% (Martin, 1968).

The spectrum of the Knysna estuary reveals that, although it is located close to the Knysna forest, the AP is relatively low. *Podocarpus* reaches 12% (Martin, 1968). Apparently dispersal by wind is not such an important factor for *Podocarpus* pollen.

If we compare the recent spectra with those of the pollen diagrams, it becomes clear that there are great similarities. Some intervals of the diagrams show a type of spectrum that can be compared with 1 and 2 of Fig. 6, other intervals show spectra that may be compared with 3 and 4 of Fig. 6. Those intervals that belong to the Holocene, show a complete absence of elements from the Knysna forest. In the Middle Pleniglacial, however, there are intervals with NAP to AP relations similar to those now found in the Knysna estuary; the *Podocarpus* percentages in the AP diagrams of these intervals are comparable and may be even higher than in the spectrum from the recent Knysna forest. For further interpretation the following facts are also of great importance: 1. the production of local non-arboreal pollen in the vlei vegetation, leading in this depositionally favourable environment to its over-representation in the NAP/AP ratios, 2. in the sediments that are represented by the Cape Flats diagram, where the highest value of *Podocarpus* and other Knysna-forest elements are found, macro-remains of *Podocarpus* are present: tree trunks (Adamson & Currin, 1951; Amdurer, 1956) and abundant cuticle fragments with stomata.

All these facts lead to the following conclusions: a. in the central part of the Cape Flats Knysna forest vegetation was once growing in situ (see Cape Flats diagram, Appendix 5); b. in the vlei- and shallow marine deposits the diagrams with high NAP values, but with relatively high *Podocarpus* values in the AP diagram, reflect the presence of Knysna forest vegetation in the direct 'hinterland' on the Cape Flats (see lower part of some of the Rietvlei diagrams, Appendix 1-4); c. in the vlei- and shallow marine deposits the diagrams with high NAP values, but without *Podocarpus* and also lacking the other elements of the Knysna forest, and a complete predominance of macchia elements in the AP diagram, indicate the presence of such macchia vegetation in the 'hinterland'.

These data are used for additional interpretations in Chapter 4.

DESCRIPTION OF THE POLLEN DIAGRAMS

Rietvlei 1 - see Appendix 1. In this borehole the intervals between 0.20-5.00 m and 14.00-19.60 m were suitable for pollen analysis. The sample distance is partly determined by the absence of pollen in some types of sediment. The AP to NAP ratios are almost equal throughout the diagram. The following differences between the two intervals may be noted:

a. Absence of *Podocarpus* in the 0.20-5.00 m interval.
b. Generally lower percentages of Ericaceae, Gramineae and Rosaceae in the 0.20-5.00 m interval as compared to the 14.00-19.60 m interval.
c. Generally higher percentages of Cyperaceae, Chenopodiaceae and Potamogetonaceae are found in the upper interval.
d. *Ilex mitis* only occurs in one sample at 3.30 m depth.
e. In the upper part *Isoetes* is well represented, as are the other Pteridophytes.
f. Seeds of Potamogetonaceae, in particular of *Ruppia maritima,* are more frequent in the upper interval.

Rietvlei 2 - see Appendix 2. In this borehole the intervals between 0.25-4.00 m, 8.50-11.90 m and 14.20-24.20 m were palynologically analysed. The ratios of AP to NAP remain almost equal throughout the diagram.

The main differences between the intervals are the following:
a. The 0.00-4.00 m interval differs from the entire lower part in its high percentages of Gramineae and Chenopodiaceae, and its lower percentages of Ericaceae, Proteaceae, *Myrica,* Thymelaceae, Euphorbiaceae and Pteridophyta. Also the consistent absence of *Podocarpus* and the scarcity of marine phytoplankton in the upper part are conspicuous.
b. The interval of 8.50-11.90 m differs from the 14.20-24.20 m interval in its higher percentages of Gramineae, Ericaceae, Proteaceae, Anacardiaceae (*Rhus*), and Typhaceae, whereas its percentages of Cyperaceae, Rutaceae, Crassulaceae and marine phytoplankton are lower. The presence of *Podocarpus* in both intervals is evident.
c. The 14.20-24.20 m interval is characterised by extremely high values of marine phytoplankton in its upper part, and *Podocarpus* is almost exclusively present in the sediment between 18.00-20.20 m.

Rietvlei 3 - see Appendix 3. The 22.80-24.35 m interval contains pollen. The ratios of AP to NAP slightly increase towards the top of the diagram. In this diagram three intervals can be distinguished, from 22.80 to 23.15 m, from 23.15 to 23.95 m and from 23.95 to 24.35 m, respectively. The upper and the lowest interval are characterised by the presence of *Podocarpus* and *Curtisia dentata,* and by higher percentages of Restionaceae and Anacardiaceae, whereas in general the percentages of Chenopodiaceae and Cyperaceae are slightly lower in these intervals than in the middle one. The upper part differs from the lowest interval by the exclusive presence of Crassulaceae in the upper part and of Portulacaceae in the lower part. The percentages of the Restionaceae, Ericaceae and Pteridophyta are slightly higher in the upper part. In the middle interval, between 23.15-23.95 m, only Polygalaceae, Liliaceae, Ranunculaceae and Juncaceae are present.

Rietvlei 4 - see Appendix 4. The 22.70-23.00 m interval has been analysed; in addition, two samples at 23.90 m and 24.80 m also were suitable for pollen analysis. The ratios of AP to NAP are nearly equal throughout this diagram. The diagram may be differentiated into two parts with a boundary at 23.00 m. The upper part is characterised by higher or slightly higher percentages of Ericaceae, Cyperaceae, Aizoaceae, Thymelaceae, *Myriophyllum,* Euphorbiaceae, Anacardiaceae, Crassulaceae, and Pteridophyta. *Podocarpus* and *Curtisia dentata* were only found in this interval. The lower part exhibits higher percentages of Umbelliferae, Myrica, Compositae (non-*Artemisia*-type) and the only occurrences of Potamogetonaceae and Liliaceae.

Cape Flats - see Appendix 5. The 4.10-6.20 m interval and two samples at 7.90 and 8.00 m could be analysed. The ratios of AP to NAP are relatively high (up to 50%), and *Podocarpus* is abundant. A subdivision into intervals, as in the boreholes described above, cannot be made for this section. However, fluctuations of the individual curves are noticeable and will be dealt with in the following chapter. It is noteworthy that abundant cuticle fragments with stomata of *Podocarpus* were found in nearly all the samples from the interval and in the two samples taken at 7.90 and at 8.00 m.

Hangklip - see Appendix 6. The 0.05-0.95 m and 2.35-3.50 m intervals have been analysed. The ratios of AP to NAP are low throughout this diagram. The upper interval, between 0.05-0.95 m, can be distinguished from the lower interval by higher average percentages of Aizoaceae, Ranunculaceae, Type 2 and Type 3, whereas the percentages of Ericaceae, Amaryllidaceae and Bruniaceae are lower.

Chapter 4. The pollenzones, their dating and interpretation

From the description of the diagrams it is evident that a subdivision can be made into zones with *Podocarpus,* sometimes accompanied by *Ilex mitis* and *Curtisia dentata,* and zones in which these taxa are lacking. The radiocarbon datings and shell-bearing levels are used as ancillary support to differentiate and correlate these zones. The vegetational history of the area under discussion may then be reconstructed by using the knowledge of the recent pollen spectra, of the corresponding recent vegetational units, and of the zonation of the pollendiagrams.

The radiocarbon data indicate that our diagrams together represent the time span from about 50 000 B.P. to recent. Each diagram, however, only shows one or several isolated intervals from that time sequence (determined by the local presence of pollen-containing sediments). In each diagram intervals with and without Knysna forest elements can be distinguished. The ^{14}C ages of these intervals were determined, and subsequently the data from all the boreholes were integrated and the dated intervals put into chronological order (for the dating, see Radiocarbon data, and Chapter 7).

Shell-bearing levels found in several intervals may provide additional information for correlation.

In this way the following zone sequence could be established:

zone S preceding 45 000 B.P.,
,, T from 45 000 - 40 500 B.P.,
,, U from 40 500 - 36 500 B.P.,
,, V from 36 500 - 33 000 B.P.,
,, W from 33 000 - 28 500 B.P.,
,, X younger than 28 500 and older than 10 000 B.P.,
,, Z from 10 000 B.P. until the present.

These intervals of pollen-bearing sediments can be subdivided, in the different diagrams, into subzones which are indicated below by the zone letter and by their corresponding depth interval.

The palynological characteristics and the interpretation of the different zones are as follows:

Zone S - This zone, as defined above, is present in the boreholes Rietvlei 3 and 4.

As mentioned in the preceding chapter, the zone in question of Rietvlei 3 can be subdivided into two parts, viz., the subzone from 23.15-23.95 m (= S 23.15-23.95 m) and S 23.95-24.35 m.

The clayey sedimentation in subzone S 23.95-24.35 m points to a vlei-type environment. The presence of *Typha, Myriophyllum,* and Juncaginaceae indicates a slightly brackish to fresh water character of the habitat. The vegetation surrounding the vlei may be described as a scrub vegetation in which Anacardiaceae, Thymelaceae and *Myrica* occurred, possibly with some stands of *Podocarpus* and *Curtisia dentata* in the hinterland.

In the subzone S 23.15-23.95 m the environment had become more brackish as is clear from the presence of the remains of Pisces and of Crustaceae (see Table 1), and the slightly higher percentages of Chenopodiaceae pollen. The macchia vegetation surrounding the vlei during this interval can be described as rather open: there is a slight increase of *Myrica* and a continuation of the relative abundance of Compositae (*Artemisia*-type), whereas forest elements such as *Podocarpus* and *Curtisia dentata* are absent. At the transition from zone S to zone T a lowering of the water-table took place and the vlei area was covered at first by Cyperaceae followed in the succession by Restionaceae, Aizoaceae and Ericaceae.

In Rietvlei 4 only the upper part of zone S is represented (compare the representation of Plantaginaceae and Liliaceae in both Rietvlei 3 and 4).

Zone T - This zone is present in the boreholes of the Cape Flats, Rietvlei 1, 3 and 4. From the differences in the ratios of AP to NAP in the diagrams it may be concluded that different vegetational and depositional environments were present on the Cape Flats and in the Rietvlei area.

During the deposition of zone T on the Cape Flats, an area of swamps and small lakes seems to have been present. This area became intermittently wetter and drier, which may be concluded from the alternation of a vegetation with Potamogetonaceae, *Myriophyllum* and Typhaceae indicating more or less open water, with a vegetation containing Ericaceae and Restionaceae. In the transitional phases Liliaceae, Araceae and Amaryllidaceae are found. From the comparison of the percentage of *Podocarpus* within the AP and from the ratio of AP to NAP of this diagram with the recent pollen spectra of the Knysna forest, the presence of a mixed *Podocarpus* forest in the slightly more elevated surrounding area may be concluded. Within this period of occurrence of a mixed *Podocarpus* forest, three macchia/scrub phases can be noticed, each of them marked by an extension of the percentages of Proteaceae, Euphorbiaceae, Rubiaceae (mainly *Nenax*) and Anacardiaceae, characteristic elements of the coastal macchia. These phases are found at the depth intervals of 6.20-6.00 m, 5.40-5.00 m and 4.60-4.20 m respectively, and seem to be more or less in phase with the lower water table in the lakelets.

The two samples at 7.90 m and 8.00 m also indicate the presence of *Podocarpus* forest. Apparently they belong to zone T.

In zone T of Rietvlei 1, a vlei vegetation within a dune area is reflected in the diagram. From the fact that the common occurence of dune elements, such as *Rosaceae,* Compositae (*Artemisia*-type), and Thymelaceae, is apparent, it may be concluded that aeolian activity was rather low and the dunes were stable. The gradual increase of Euphorbiaceae towards the top level of this zone suggests a breaking up of these dunes. The presence of Potamogetonaceae, Typhaceae, *Myriophyllum* and *Isoetes* points to the local occurrence of a vlei depression containing fresh water.

The maxima of Restionaceae at 17.70 m, 17.10 m and 16.00 m suggest that these depressions dried up frequently. The higher percentages of Typhaceae, *Myriophyllum* and Potamogetonaceae in the middle part of this zone may indicate a higher watertable in the afore-mentoned depressions. The steady increase of Euphorbiaceae in the upper part of this zone is probably due to the increasingly unstable dune environment, a feature that culminates in zone U. The high *Podocarpus* values in the AP diagram indicate the presence of Knysna forest vegetation in the hinterland.

In Rietvlei 3 and 4 zone T is represented by more or less similar vegetation types. The relative abundance of Restionaceae in Rietvlei 1 as compared with the considerably lower values of this taxon in Rietvlei 3 and 4 is indicative for a more swampy environment around Rietvlei 1. It is remarkable that in the Rietvlei samples of this zone Rubiaceae are entirely absent, sharply in contrast with the continuous relatively high values in this zone of the Cape Flats diagram. This may be explained by a higher salinity of the Rietvlei area.

Zone U - This zone occurs in the boreholes Rietvlei 2 and 4, and is well developed in Rietvlei 2. The type of sediment and the intercalated shell-bearing deposits indicate a tidal flat environment of deposition. The littoral character of the mollusc fauna supports this interpretation.

Zone U can be pollenanalytically subdivided into the subzones U 23.00-24.40 m and U 20.20-23.00 m. In the former relatively high percentages of Compositae (*Artemisia*-type), Euphorbiaceae and Rosaceae point to an unstable dune environment. The subzone U 20.20-23.00 m is characterised by a general increase of Restionaceae, Graminae, Ericaceae, and Chenopodiaceae, and by the first appearance of marine phytoplankton. The tidal flat area must have been inundated by the sea more frequently, the dunes remaining unstable as may be concluded from the relatively high percentage of Euphorbiaceae. It is assumed that the diagram of Rietvlei 4 corresponds with the lower part of this zone U.

Zone V - This zone occurs in the boreholes of Rietvlei 1 and 2. As stated above already, the depositional environment of the lower part of Rietvlei 2 may be characterised as a tidal flat.

In Rietvlei 2 zone V exhibits relatively high percentages of Graminae, Compositae (*Artemisia*-type), Chenopodiaceae, *Myrica,* and Thymelaceae. *Podocarpus* is continuously present in this zone. A more stable dune area seems to have been present in this interval, as testified by the higher percentages of Thymelaceae, *Myrica* and Compositae (*Artemisia*-type). The *Podocarpus* pollen suggests the presence of a *Podocarpus* forest in the hinterland (i.e. the central part of the Cape Flats). The general increase of marine phytoplankton can be explained by the assumption that this part of the tidal flat must have become inundated more frequently due to a gully in the vicinity.

In the Rietvlei 1 diagram zone V confirms this interpretation by showing an increase of Restionaceae and Chenopodiaceae and the presence of *Podocarpus*. However, this borehole is situated further away from the marine influence as may be concluded from the absence of marine elements, such as shells and marine phytoplankton. The top level of the sand lens at 15.50 m apparently represents a hiatus, corresponding to zone U.

Zone W - Present in Rietvlei 2 only. The tidal flat environment persists during this zone. The conspicuous increase of marine phytoplankton suggests marine conditions; this assumption is substantiated by the repeated occurrence of shell-bearing deposits and by the slight variation of the percentages of all the sporomorph types, except in the top part of zone W. The great sample distance made the reconstruction of the vegetational history within zone W too speculative to be attempted. A relatively unstable dune vegetation and a macchia vegetation in the 'hinterland' are tentatively suggested.

Zone X - This zone is present in Rietvlei 2 only. The relatively high percentages of marine phytoplankton indicate a tidal flat environment during the deposition of this zone. A subdivision into three subzones, viz. X 11.90-11.00 m, X 11.00-9.70 m and X 9.70-8.50 m, can be made. The subzone X 11.90-11.00 m exhibits relatively high percentages of Gramineae, Chenopodiaceae, Cyperaceae and Anacardiaceae, Typhaceae and *Myriophyllum* also being present. In subzone X 11.00-9.70 m an increase of Euphorbiaceae pollen is noticeable. The occurrence of *Plantago* is restricted to this subzone and Rosaceae reappear. In subzone X 9.70-8.50 m there is an increase of Euphorbiaceae, Thymelaceae, and Gramineae pollen, whereas *Myriophyllum* is absent. *Podocarpus* is found throughout this zone. From the above-mentioned evidence it is obvious that during the deposition of the first two subzones sedimentation took place in a vlei which was surrounded by an unstable dune area; during the formation of subzone X 11.00-9.70 m the vlei became more brackish. The subzone X 9.70-8.50 m reflects a vlei habitat surrounded by more stable dunes, although towards the end of this subzone the vegetation on these dunes became more open.

From the frequency of *Podocarpus* pollen the occurence at that time of a mixed *Podocarpus* forest on the central part of the Cape Flats appears highly probable.

Zone Z - In the Rietvlei basin the upper part of two borehole cores Rietvlei 1 and 2 represent this zone and the whole Hangklip borehole core belongs to this zone. In the Rietvlei basin an alternating series of sand and sandy clay layers is present, intercalated with shell-bearing deposits.

In Rietvlei 1 three subzones can be differentiated, viz., the subzones Z 5.00-4.30 m, Z 4.30-1.90 m and Z 1.90-0.20 m. Subzone Z 5.00-4.30 is characterised by a general increase of *Zostera,* and fluctuations of Chenopodiaceae, Cyperaceae, and Compositae (*Artemisia*-type). A high percentage of Euphorbiaceae pollen throughout this subzone is evident. In subzone Z 4.30-1.90 m the frequencies of the above-mentioned taxa alternate frequently. In subzone Z 1.90-0.20 m the high percentages of Cyperaceae, Restionaceae, Pteridophyta, and *Isoetes* decrease strongly and are replaced by high values of Compositae (*Artemisia*-type), Chenopodiaceae and, towards the end of this subzone, also of Euphorbiaceae. The fluctuations of the different taxa, as described above, suggest the prevalence of a vlei type of vegetation in the area with a succession of *Zostera* → *Cyperaceae* → Chenopodiaceae taking place three times. The site was surrounded by marginal vegetation in which Compositae (*Artemisia*-type) and *Myrica* were present and in many places stands of Restionaceae. The coastal dunes were covered by vegetation in which Thymelaceae, Gramineae and Euphorbiaceae played an important role. The top level of this zone exhibits a vegetation type resembling the present one.

In Rietvlei 2 zone Z can be subdivided into the subzones Z 4.00-2.10 m and Z 2.10-0.25 m. The lower one is characterised by a predominance of Gramineae, the upper one by maxima of Restionaceae, Ericaceae, Compositae (incl. *Artemisia*-type), Chenopodiaceae, and Euphorbiaceae. These differences seem to reflect a gradual replacement of sandy deposits by more clayey sediments in the vlei.

In the Hangklip diagram the lower part of zone Z can be subdivided into the following subzones: Z 3.50-3.25 m, Z 3.25-2.80 m and Z 2.80-2.35 m.

Subzone Z 3.50-3.25 m is characterised by slightly higher percentages of Restionaceae, Gramineae, Cyperaceae, Ranunculaceae, and *Myrica,* whereas the percentages of Ericaceae and Bruniaceae are lower than in the other zones.

In subzone Z 3.25-2.80 m an increase of the percentages of Ericaceae, Proteaceae and Bruniaceae is evident, whereas the percentages of Restionaceae and Ranunculaceae decrease. The relatively high frequency of Proteaceae, *Myrica,* etc. in the surrounding area indicates that a more closed macchia vegetation may have covered the dunes; on the other hand, the abundance of Ericaceae seems to point to a more open and lower type of dune vegetation. This suggests a lowering of the water-table, probably related to slightly drier conditions. This conclusion appears to be supported by simultaneous changes of the bog-vegetation: higher percentages of Restionaceae, Cyperaceae and Ranunculaceae point to wetter conditions, and a better representation of Bruniaceae, Amaryllidaceae and Gramineae to more arid conditions. From these changes it may be concluded that in subzone Z 3.25-2.80 m the prevailing conditions have been more arid than those in subzone Z 3.50-3.25 m.

In subzone Z 2.80-3.25 m the percentages of Restionaceae, Cyperaceae and *Myrica* increase whereas a slight decrease in the percentages of Ericaceae, Gramineae, and Bruniaceae takes place. Wetter conditions seem to have prevailed during the deposition of this subzone.

Sandy (and probably aeolian) sediments have been deposited in the interval 2.35-0.95 m, this may be attributable to drier conditions and prevented a further development of the bog.

In subzone Z 0.95-0.00 m of the Hangklip diagram, the bog had become established again after the sandy interval, apparently as the result of more humid climatic conditions. There is, however, a relatively drier interval in the middle part of this subzone, as indicated by the higher percentages of Aizoaceae and of Restionaceae.

If these conclusions are valid, an attempt can be made to date the slightly drier and wetter intervals with the aid of the ^{14}C analyses.

The deposition of subzone Z 3.50-3.25 m, a relatively wet period was completed shortly before 7 280 B.P.

The deposition of subzone Z 3.25-2.80 m, a slightly drier interval took place between 7 280 B.P. and 6 520 B.P.

The deposition of subzone Z 2.80-2.35 m, a slightly wetter phase proceeded from 6 520 B.P. onward.

If we take into account the rate of sedimentation in subzone Z 3.25-2.80 m (0.6 mm/year), the entire interval 3.50-2.35 m was probably deposited between about 7 700 B.P. and 5 800 B.P. This would correspond fairly well with the Atlantic time interval of the NW European Holocene (a dating of 11 140 B.P. from the base of the bog in another section – see Table 2 – indicates that, at least locally, the forming of peat already started during the Late Glacial).

The deposition of the (probably aeolian) sand between 2.35-0.95 m seems to have started shortly after about 5 800 B.P., and may therefore correlate in time with the drier NW European Subboreal interval.

Subzone Z 0.95-0.00 m, again slightly wetter, was deposited from shortly before 1 580 B.P. to the present, and corresponds in time with the upper part of the wetter NW European Subatlantic.

Chapter 5. Reconstruction of the sedimentary and erosional history of the Rietvlei basin

By means of the data now available from the boreholes and the models of Figs. 7a and 7b the history of the sedimentation and erosion of the Rietvlei basin can be reconstructed.

In Fig. 7b the morphology of the basement-surface is reconstructed from geophysical data provided by the Geological Survey of South Africa. The basement consists of shale, granite and sandstone (see Chapter 2). The morphology of the basement reveals two erosin gullies in the two main directions of the strike and the cleavage pattern of the basement rocks, respectively. The greatest depth of these gullies is –25 m, whereas the top level of the basement rock almost reaches the surface in several places. From the recent topography shown in Fig. 7a it becomes clear that the recent coastal dunes are situated just above the NW oriented ancient gullies. Noteworthy is the position of the northwestern end of the present Rietvlei, which coincides approximately with the northernmost gully. These erosion gullies must have been formed by the Diepriver during the periods of lower sea-levels. The recent stream valley of this river reaches the Atlantic Ocean south of Milnerton (Fig. 5).

In addition to the boreholes drilled in this area, already discussed in Chapter 3, descriptions of seven boreholes drilled by Cementation, Ltd., were used for the construction of section AB, which is nearly parallel to the coastline in a NW direction and chosen in such a way that the most relevant information could be shown (Figs. 5, 7a and b and Appendix 8). The radiocarbon data and the zonation of the pollen diagrams of the analysed boreholes suggest that two cycles of sedimentation have taken place during the process of filling up of this basin (see Chapters 3 and 4).

The morphology of the basement-surface may have been formed in earlier times, but in any case must have at least partly been modelled during the Early Glacial and the beginning of the Lower Pleniglacial when the sea-level was very low. Sandy deposits, assumed to be of Lower Pleniglacial age (see the radiocarbon data of the overlaying sediments), have been found in the boreholes of Rietvlei 7

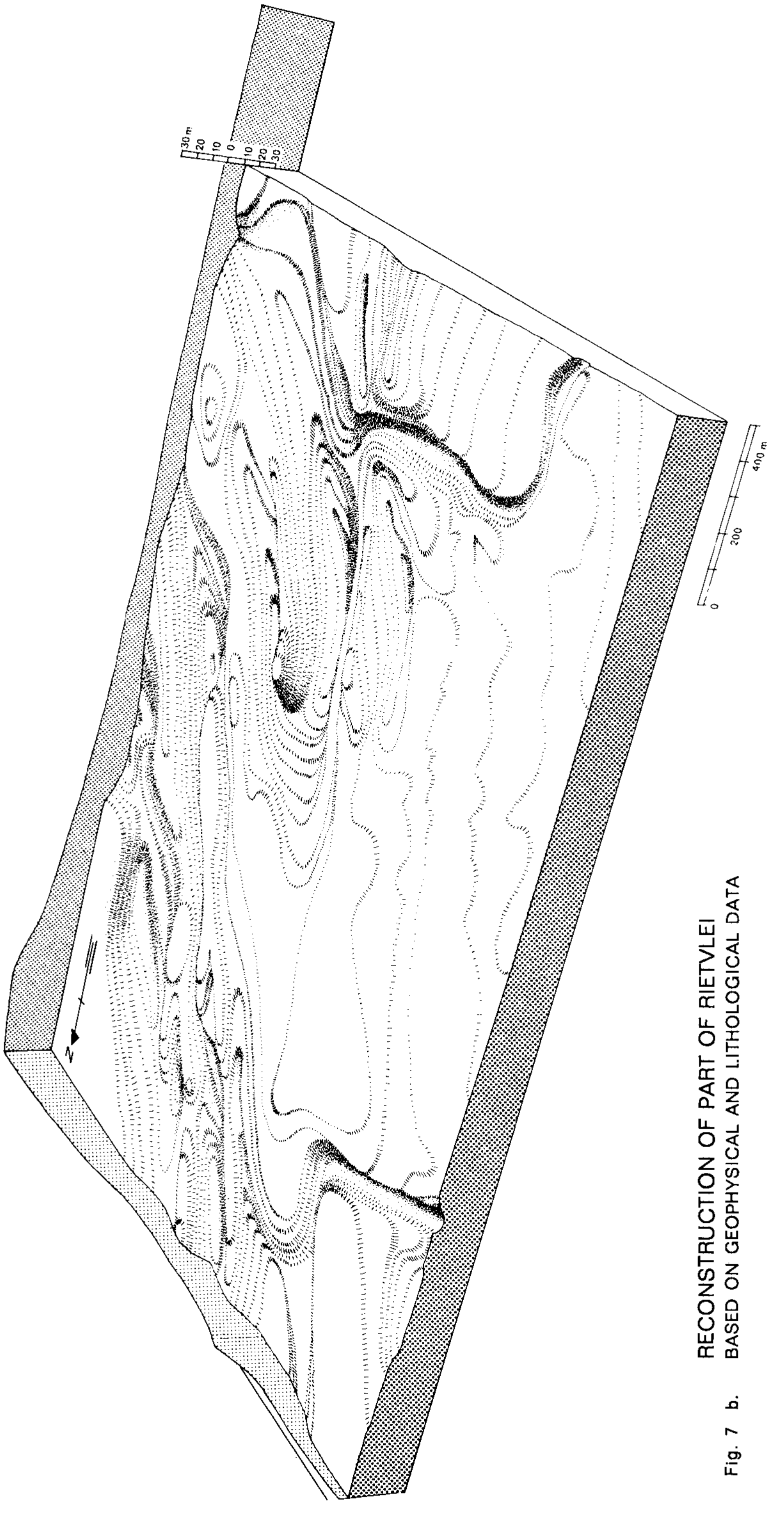


Fig. 7 b. RECONSTRUCTION OF PART OF RIETVLEI BASED ON GEOPHYSICAL AND LITHOLOGICAL DATA and Cape Flats. These sandy deposits are most probably aeolian sediments laid down during the dry and cold conditions prevailing in the Lower Pleniglacial. The southern gully, now buried, was probably in use by the river at that time.

The paralic sedimentation must have started in the beginning of the Middle Pleniglacial and deposits of this age were laid down in the basin. The southern gully – possibly still in use then – gradually filled up, which may be concluded from the tidal flat environment which was found in Rietvlei 2 (a borehole situated close to this gully) whereas in Rietvlei 1 inland vlei deposits were found with their characteristic vegetation. The sea-level was rising in this period after the first severe cold phase of the Lower Pleniglacial. This rise however was interrupted by two intervals (still during the Middle Pleniglacial). By the end of the Middle Pleniglacial the southern gully was loosing its function as a drainage channel of the area and the basin had been filled up to approximately –10 m. This filling up took place in the time span between about 50 000 B.P. and probably 20 000 B.P., and has been indicated as 'sedimentation cycle 1' in Appendix 8.

During the beginning of the Upper Pleniglacial the sea-level dropped again. These sediments of the Middle Pleniglacial, that probably had previously been deposited in the NW area of the basin, apparently disappeared due to the erosional activities as the result of the lowering of the sea-level. The northern gully became the principal drainage channel at that time. The fact that the oldest deposits are only present in the southern part of the basin led to this conclusion. In the meantime aeolian sedimentation apparently took place in the southern part of the Rietvlei basin (and probably also on the central part of the Cape Flats) and a layer of approximately 5 m thick was formed locally, sometimes intercalated with a few bands of very fine gravel. In Appendix 8 this layer is found immediately above the correlation-line between sedimentation cycles 1 and 2, and below the shell-bearing deposits of Holocene level IV. In the boreholes of Rietvlei 1 and 7 this layer is present between 7-11 m and 8-11 m, respectively. In the borehole of Rietvlei 5 (Appendix 7), which is located in the vicinity of Rietvlei 1 and 7 (Fig. 5), this layer is present between 7.50 and 11.50 m. Both the granulometric study and the heavy-mineral analysis indicate the predominantly aeolian character of these sediments (see Chapter 3). The layer was deposited between about 20 000 B.P. and 10 000 B.P. according to the radiocarbon datings. Although a Late Glacial age cannot be excluded completely, an Upper Pleniglacial age seems probable.

From the start of the Holocene onwards (perhaps already in the Late Glacial) paralic sedimentation started anew all over the basin. The Diepriver had to change its bed once more to reach its present outlet south of Milnerton in the later part of the Holocene. The sequence of deposition during the Upper Pleniglacial (and/or Late Glacial) and the Holocene has been marked as 'sedimentation cycle 2' (Appendix 8).

It is proposed herewith to name the complete series of sediments deposited during the sedimentation cycles 1 and 2, which are coeval with a great part of the Last Glacial and the Holocene, the CAPE FLATS FORMATION (see Fig. 10). This formation consits of sand deposits alternating with sandy clay, clay and gravel beds. The depositional environment may be characterised as predominantly paralic with aeolian phases locally developed. The Cape Flats Formation rests unconformably on the Praecambrian and Palaeozoic rocks of the above-mentioned basement. The type-area is the Rietvlei basin, and the type-section is borehole Rietvlei 2, which is the most complete section encountered up to now. The paralic character of the basin is also revealed by the palynological content of the sediments in which coastal, brackish and vlei plant taxa are represented. The presence of seeds of *Ruppia maritima* also substantiates this interpreation. The shell-bearing levels I-IV also support the interpretation of a littoral environment. They are related to the relatively high sea-levels to be discussed in Chapter 6.

Chapter 6. Changes or sea-level

From the evidence brought forward in the preceding chapter, it is clear that sea-level changes took place in the Rietvlei basin. The shell-bearing deposits found in the boreholes could be differentiated into four sequentional levels I-IV by radiocarbon dating and by the palynological zonation. It is evident that the levels correspond with the intervals of low effective precipitation in the Middle Pleniglacial and in the Holocene (see Fig. 10).

The following depths were recorded: level I at –23.50 m, approximate age 45 000 B.P., level II at about –21 m, approximate age 38 000 B.P., level III at about –18 m, approximate age 30 000 B.P., and level IV, beginning at about –12 m, of Holocene age.

Sea-level curves have been drawn from different areas of the world and a general coincidence of their global variances during the last 30 000 years has been demonstrated (Emery, Niino & Sullivan, 1971). Veeh and Chapell (1970) have been able to trace sea-level fluctuations in the area of New Guinea as far back as 200 000 B.P. From both curves it can be deduced that during the Middle Pleniglacial the sea-level lay at –40 m at about 45 000 B.P., –35 m at 38 000 B.P. and at –30 m at 30 000 B.P.

A comparison of the successive Middle Pleniglacial 'global' sea-levels and of our local curve shows a diminishing discrepancy which may be explained primarily by a more or less continuous upheaval of the Cape Flats area as suggested already by Haughton (1969) (see Chapter 2). The early Holocene sea-level (–12 m at about 8 100 B.P.) seems to correlate fairly well with the 'global' curve.

The average level of the raised Eemian beaches in the area is approximately 25 m, which points to an average rate of upheaval (over a period of about 100 000 years) of 0.25 mm/year. According to this figure the levels I, II and III with the ages of 45 000 B.P., 38 000 B.P. and 30 000 B.P. respectively have to be adjusted with the values of –11.25 m, –9.5 m and –7.5 m respectively. The recalculated sea-levels of the Middle Pleniglacial of the Cape Flats thus corrected, viz. –34.75, –30.50, and –28.50 m, appear to be satisfactorily correlatable with the 'absolute' sea-levels of the 'global' curve, especially if one takes into account the spreading of the points on which this global curve is based (Emery, Niino & Sullivan, 1972).

Chapter 7. The history of vegetation and climate

THE BASIC MODEL

From the data of the pollen diagrams with their zonation and interpretation (see Chapter 4) it seems possible to make a tentative to reconstruction of the vegetation for three types of intervals in the Late Quaternary history of the Cape Flats area. In Fig. 8 such a reconstruction is suggested for the Holocene interval, the Middle Pleniglacial wet intervals and the Middle Pleniglacial dry intervals.

By analysing the interval of the Holocene (see zone Z in the diagrams) it becomes evident that the local vegetation during that time was a scrub vegetation which can be differentiated into a dune vegetation and a coastal macchia vegetation. The hydrosere was represented by a vlei vegetation with halophytic elements. During the relatively wet intervals of the Middle Pleniglacial (with slightly lower sea-levels than during the relatively dry intervals) a mixed *Podocarpus* forest, similar to the present-day Knysna forest, was present on the central part of the Cape Flats. In the Rietvlei basin a dune and coastal macchia vegetation was present. In the depressions of this basin, a fresh water hydrosere existed (not indicated in Fig. 8).

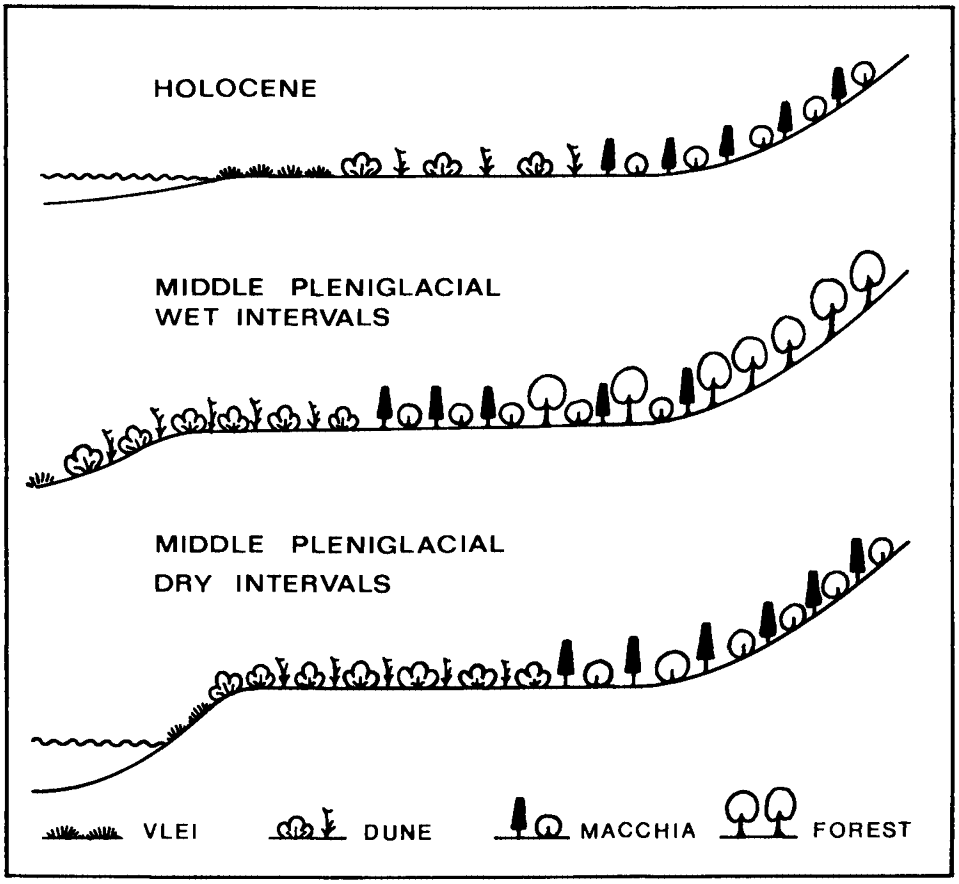


Fig. 8. Diagrammatic vegetation profiles for different time-intervals.

During the dry intervals of the Middle Pleniglacial the vegetation must have been very similar to that pravailing during the Holocene.

THE SEQUENCE OF VEGETATIONAL AND CLIMATIC CHANGES

From the pollen diagrams and the reconstructed models, a recurrent alternation of forest vegetation (or its presence in a nearby 'hinterland') with a macchia vegetation becomes evident (see Fig. 9). Changes of vegetation and the presumed, associated climatic conditions will be dealt with in chronological order (see Fig. 10).

The Lower Pleniglacial

No pollen diagrams are available from this interval to reconstruct the local vegetation. However, from the character of the sandy deposits underlying the palynologically analysed sediments of the Middle Pleniglacial in the Cape Flats borehole,

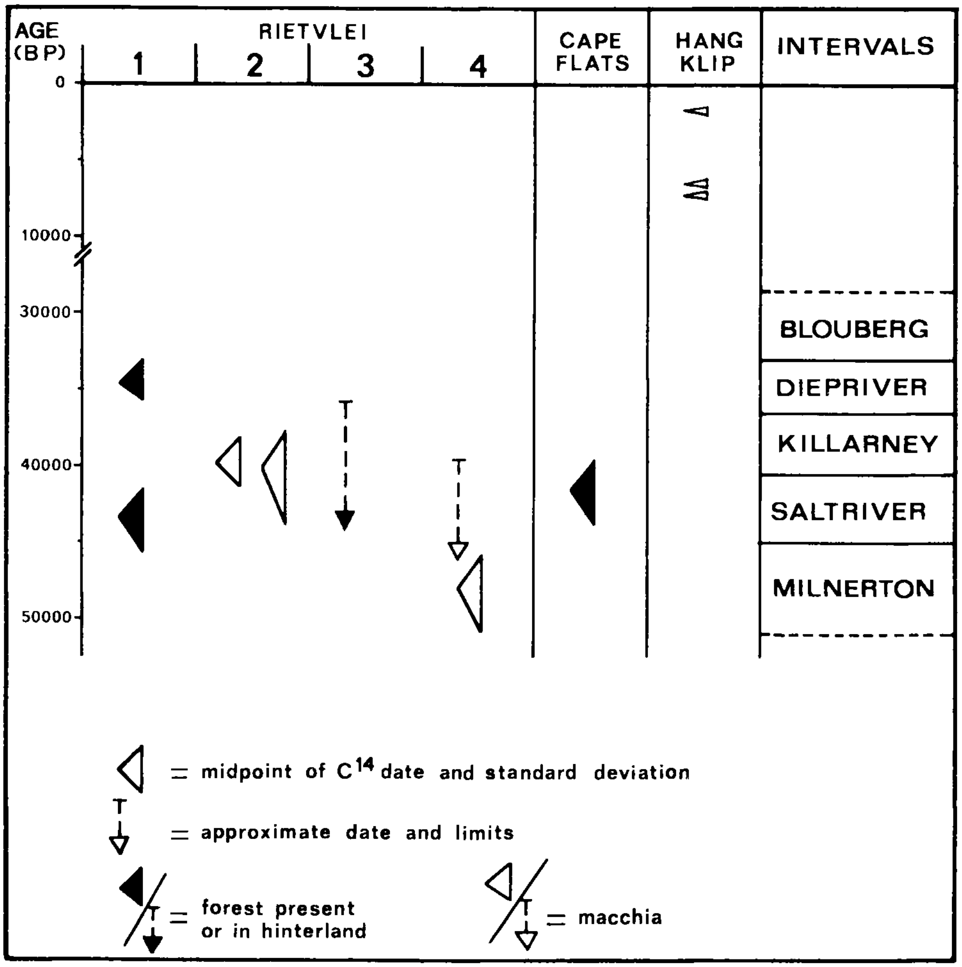


Fig. 9. Middle Pleniglacial vegetation types, their ¹⁴C datings and chronostratigraphical position within the named intervals.

as well as from those found in the southern part of the Rietvlei basin, conceivably fairly dry conditions prevailed which gave rise to probably aeolian deposits.

The Middle Pleniglacial

In the Middle Pleniglacial three dry intervals can be distinguished, alternating with two more humid ones. The radiocarbon data (annotated with their standard deviation) were used to estimate the approximate time limits of the successive dry (macchia) and wet (forest) periods (Fig. 9).

The three dry intervals of the Middle Pleniglacial of the Cape Flats area are proposed here to be named the MILNERTON, KILLARNEY and BLOUBERG intervals, named after the three villages surrounding the Rietvlei basin. These dry intervals approximately cover the following periods:
- the MILNERTON interval precedes the age of 45 000 B.P. whereas the lower limit has been put arbitrarily at 51 000 B.P.
- the KILLARNEY interval may be delimited approximately by the ages of 40 500 B.P. and 36 500 B.P.
- the BLOUBERG interval starts at approximately 33 000 B.P. whereas the upper limit can not be fixed accurately and has been put arbitrarily at 28 000 B.P.

The two wet intervals of the Middle Pleniglacial are proposed to be named the SALTRIVER and DIEPRIVER intervals, after the rivers draining into the Atlantic Ocean in this area. Their ages are approximately between 45 000 B.P. and 40 500 B.P., and between 36 500 B.P. and 33 000 B.P., respectively.

During the Saltriver and Diepriver intervals a mixed *Podocarpus* forest type resembling that of the Knysna region was present on the Cape Flats, or at least in the central part of it. The present Knysna forest in confined to an area with a mean annual precipitation of 860 mm, evenly distributed all over the year. These climatic conditions seem to be the main ecological factors determining its geographical distribution in South Africa. It appears, therefore, likely that during the Saltriver and Diepriver intervals the Cape Flats had a climate in which probably similar conditions of precipitation prevailed as found in the Knysna region to-day. However, the Cape Flats must have been in a critical climatological position, if one takes into account that the Middle Pleniglacial dry intervals of Milnerton, Killarney and Blouberg, with their comparable climatological conditions, were not favourable for forest vegetation but only for the development of macchia.

The Upper Pleniglacial

Although no radiocarbon data are available from this period, pollenzone X is thought to belong to the lower part of the Upper Pleniglacial. The history of the sedimentation and its interpretation, explained in Chapter 5, suggest an Upper Pleniglacial age for this zone. The occurrence of a forest in the 'hinterland' is reflected by the pollen content of this zone, suggesting similar climatic conditions as during the wet intervals of the Middle Pleniglacial. The sand deposits in the upper levels of this zone X (and already to a minor extent in the top part of zone W), may suggest that aeolian sedimentation associated with drier climatic conditions was important in the Upper Pleniglacial.

The Holocene

The pollen diagrams of the Holocene of the Rietvlei basin reveal the presence of a dune vegetation or coastal macchia. The diagram and section of Hangklip give indications of an alternation of slightly drier and more humid conditions that seems to coincide approximately with the NW European sequence of Atlantic, Subboreal, and Subatlantic.

POSSIBLE EXPLANATION OF THE CLIMATIC CHANGES

The phenomena described above may be explained by changes in humidity. A higher humidity may be the result of an absolute increase in precipitation (in time and therefore causally related to the world-wide changes in temperature), or by an increase in effective precipitation (caused by a lower evaporation during a colder climate). Comparison of the humidity curve of the Cape Flats with the temperature curve of NW Europe, seems to suggest that both factors played a role (see Fig. 10).

An explanation of these changes of humidity may be found in the variation of the extension of the glaciated Antarctic area (for further information see van Zinderen Bakker, 1969b) and the consequent north- and southward shifting of the Polar Front depending on changes of temperature as a primary factor. This brings South Africa alternately under direct or less direct influence of the Westerly Winds, and the concomitant shift of the ocean current. The Westerly Winds may either result in an increase in humidity or become dry cool winds due to the extension of the ice-cover in the South Atlantic.

Possibly the apparently very dry climate of the Lower and Upper Pleniglacial intervals (Fig. 10) is causally related to a maximum extension of the glaciation. The alternation of dry and wet periods within the less cold and more humid Middle Pleniglacial may been determined by the alternating higher and lower evaporation during relatively warmer and colder intervals, respectively.

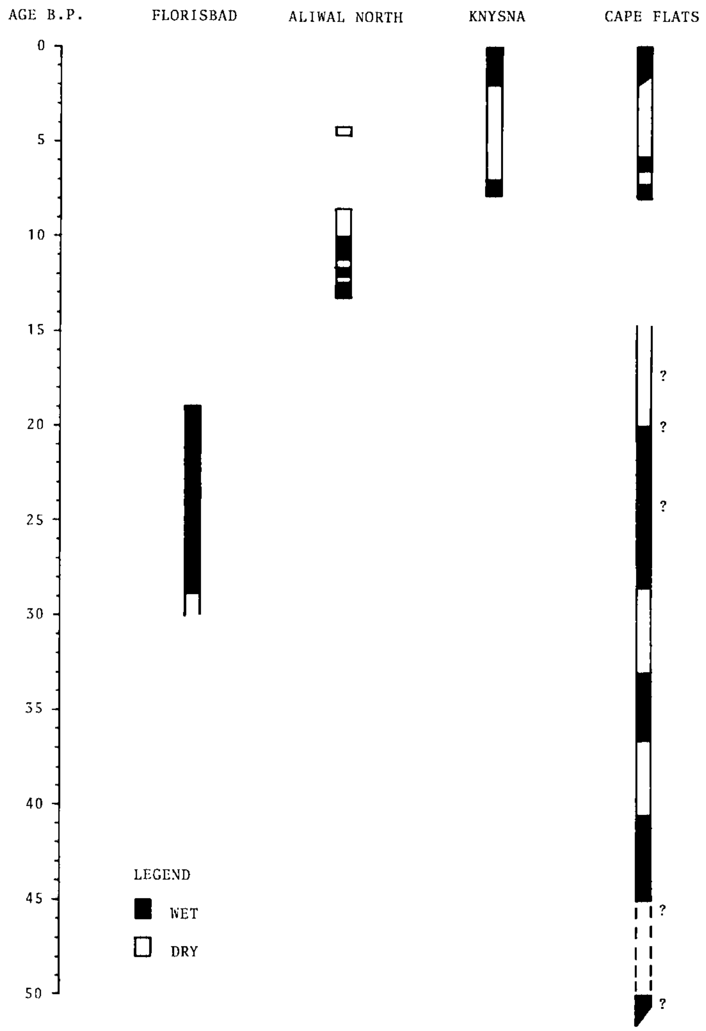
Chapter 8. Correlation with other areas

SOUTH AFRICA

In his interpretation of palynological data from the Knysna region, Martin (1968) concluded that in the Holocene period changes in humidity were responsible for the variation in the extension of the Knysna forest within this area. Martin found a probably wetter period shortly before 6 900 B.P., a probably dry period between about 7 000 B.P. and about 2 000 B.P., and again a wetter period after about 2 000 B.P. This sequence seems to correlate rather well with our data from the Cape Flats – Hangklip (see Table A).

Coetzee (1967) deduced certain changes of humidity and temperature from sections near Aliwal North. She found an alternation of warmer/drier and cooler/moister phases during the Late Glacial. From about 13 000 B.P. to about 10 000 B.P. a cooler/moister climate prevails, only interrupted by relative short warmer/drier phases. After about 10 000 B.P. the climate became warm and dry again (see Table A). There are also indications of a dry climatic period about 4 300 B.P. Although we have no polynological record of the Late Glacial of the Cape Flats, a ^{14}C dating from the basal deposit of the peat at Hangklip of 11 450 $\pm$ 65 B.P. (see Table 2), may indicate the beginning of a wetter phase, that might correspond

TABLE A. UPPER QUATERNARY CLIMATIC CHANGES IN SOUTH AFRICA



to Coetzee's wetter Late Glacial zone Y of Aliwal North.

Van Zinderen Bakker (1957) published the results of pollen and ^{14}C analyses from a section near Florisbad. He concluded that a relatively warm and dry period existed before about 29 000 B.P., and a wetter one between about 29 000 B.P. and about 19 000 ± 700 B.P. No data are available from the period after about 19 000 B.P., but the fact that no pollen is found in the younger sediments might possibly indicate drier conditions. These data are not at variance with those from the Cape Flats, where we found a drier interval prior to 29 000 B.P. followed by a wetter and a drier interval, supposed to date from before and after about 20 000 B.P. respectively.

CENTRAL AND EAST AFRICA

An excellent, recently published, re-appraisal of all the palaeobotanical/climatolo-

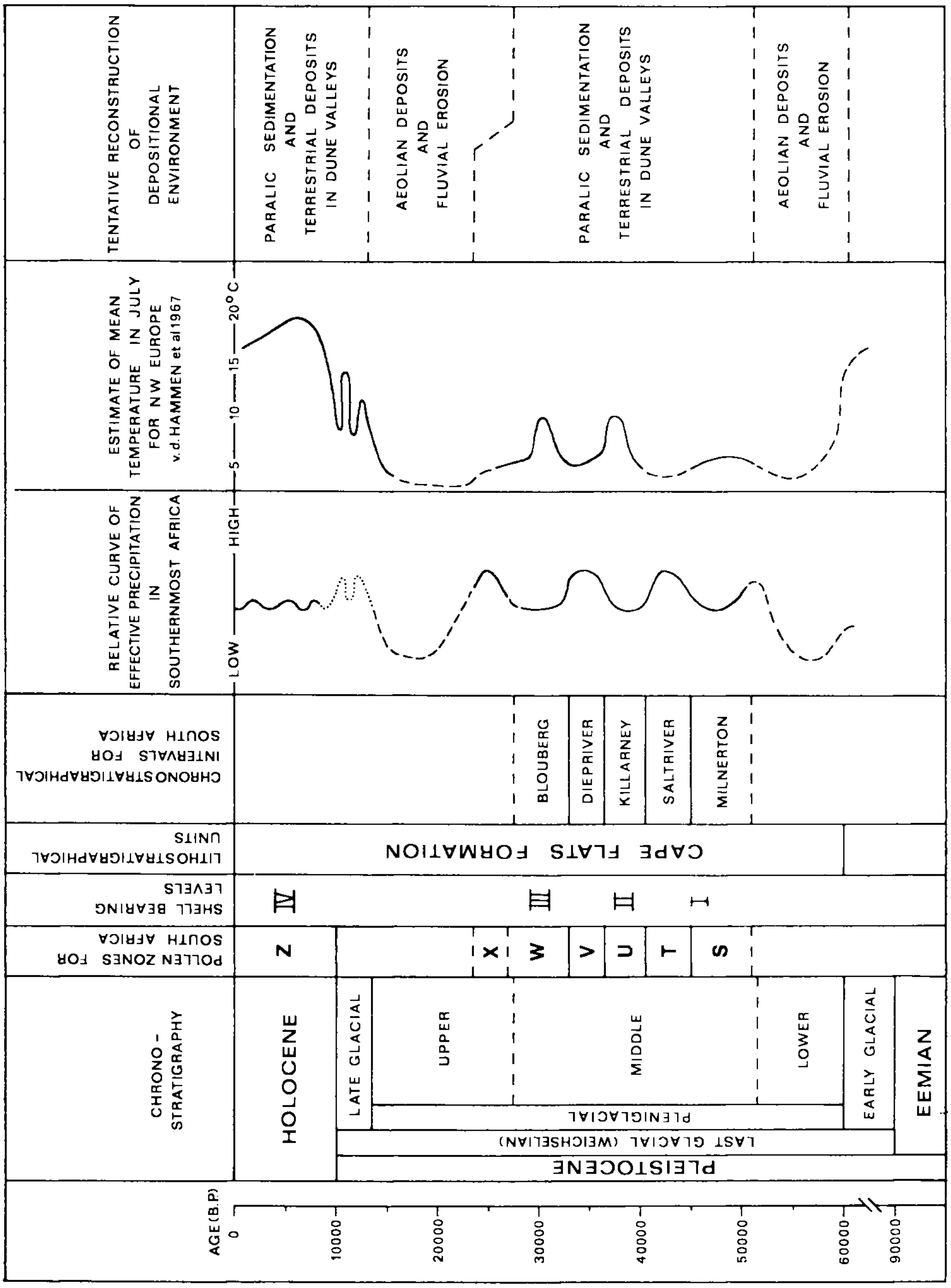


Fig. 10. Tentative curve of changes in effective precipitation, and reconstruction of depositional environment of the Upper Quaternary of the Cape Flats area, compared with the temperature curve of NW Europe (van der Hammen et al., 1967). Dashed line uncertain, dotted line according to data from Aliwal North (Coetzee, 1967).

gical data available from tropical Africa, has been given by van Zinderen Bakker and Coetzee in van Zinderen Bakker (1972b). They came to the following conclusions: temperature changes coeval with those in the Northern Hemisphere also occurred in tropical Africa, and these temperature changes appear to be correlated with changes in humidity. It seems evident from this re-appraisal that the Middle Pleniglacial can be subdivided into relatively wet and drier intervals, and that the Upper Pleniglacial was colder and drier. The Late Glacial was wetter again, interrupted by drier intervals, while the climate in general was ameliorating.

From data collected by Livingstone (1967), Kendall (1969) and Butzer & Isaac (1972), it appears that the Central and East African lakes (such as Lake Rudolf, Lake Victoria and Lake Chad), exhibit evidence of lake expansions in the period prior to about 20 000 B.P. and in the period between about 12 000 B.P. and about 5 000 B.P. Extremely low lake levels occurred in the period between 20 000 B.P. and 12 000 B.P. As far as changes of humidity are concerned, these data are evidently in agreement or at least not contradictory to the data from the Cape Flats.

EUROPE

In Fig. 10 the relative curve of effective precipitation for southernmost Africa is compared with the temperature curve for NW Europe by Van der Hammen et al. (1967). In the Middle Pleniglacial colder phases correspond to wet conditions in southern Africa, and warmer phases to dry conditions. The same relation seems to hold during the lower part of the Upper Pleniglacial (about 28 000 B.P. to about 20 000 B.P.). For the very cold upper part of the Upper Pleniglacial (about 20 000 B.P. to about 13 000 B.P.), corresponding to the period of maximum extension of glaciers, dry conditions may have prevailed in southern Africa, as they did in most parts of Europe.

Chapter 9. Summary of results and conclusions

The Cape Flats (18° 30′ E, 34° S) comprise a low, flat to undulating coastal area N and NE of Cape Town, South Africa. On a basement of Praecambrian and Palaeozoic rocks a series of Upper Quaternary sediments have been found with a maximum thickness of 25 m. These Upper Quaternary sediments were studied from existing data from boreholes and from geophysical research, and in particular by a palynological examination of cores specially drilled for the present investigation. The study of the cores included, apart from palynology, malacology, sedimentary petrology and ^{14}C determinations.

A survey of the recent climate, the vegetation and the outlines of the geological setting has been given in Chapter 2. In Chapter 3 the results of the investigation of the cores are described. In Chapter 4 special attention has been given to the zonation of the pollen diagrams. A reconstruction of the Rietvlei basin is given in Chapter 5, and the changes of sea-level are discussed in Chapter 6. The integral assessment of the results and the conclusions form the subject of Chapter 7 and 8.

Deposits from the Last Interglacial (Eemian) have not been encountered in the area investigated in this study. Probably the bulk of the sediments of this age which may have been deposited in the Cape Flats area was eroded and transported during the subsequent periods with a low sea-level of the Lower Pleniglacial. The outlet of the Diepriver is thought to have been situated N of its present location in the latter period, during which aeolian sediments are assumed to have been deposited in the Rietvlei basin and on the Cape Flats.

During the Middle Pleniglacial a relative rise of the sea-level took place, with maxima from –24 m to –18 m. Probably the positions of the sea-level have to be corrected for the subsequent upheaval of the land. The first sedimentation cycle in this area, predominantly consisting of paralic sediments, dated from this age (approximately 50 000 B.P. - 20 000 B.P.). The Rietvlei basin was filled up during this time, until the level of about –10 m. During this time interval at least two extensions of the forest with *Podocarpus* took place on the Cape Flats, which extensions presumably have been caused by an increase in the effective precipitation. The two main periods of forest extension have been named the SALTRIVER and DIEPRIVER intervals. These wet intervals appeared to have alternated with periods during which a coastal macchia vegetation was present. These more arid periods in the Middle Pleniglacial have been named the MILNERTON, KILLARNEY and BLOUBERG intervals. According to the available radiocarbon datings, the latter intervals seem to correlate satisfactorily with the Moershoofd, Hengelo and Denekamp interstadials of the Middle Pleniglacial of NW Europe.

Aeolian sediments and a subsequent extension of the forest in the 'hinterland', were found in a part of the formation, which probably belongs to the lower part of the Upper Pleniglacial. From the rest of the Upper Pleniglacial (and the Late Glacial) no pollen-bearing sediments have been encountered. Indications of a higher aeolian activity during this period were found. Inland dunes were apparently formed on the central part of the Cape Flats and in the Rietvlei basin. In the Rietvlei basin local erosion and deepening of the riverbeds were associated with the lowering of the sea-level. During the Upper Pleniglacial the outlet of the Diepriver must have been lying even further N than during the Lower Pleniglacial.

The sea-level rise during the Late Glacial and Holocene, resulted in the renewed deposition of paralic sediments. Only Holocene sediments dated by ^{14}C determinations have been found. The Rietvlei basin was inundated and the sediments filled the northernmost gully and covered the area with Holocene deposits. The formation of coastal dunes started, the vegetation once more resembled the present one, and the river outlet finally took its present position. The sediments in the Rietvlei basin, comprising the sediments now dated as Pleniglacial and Holocene in age, are named the CAPE FLATS FORMATION.

References

Acocks, J. P. H., 1953. Veld types of South Africa. – Bot. Survey S. Africa Mem., 28: 1-192 (with a separate map).

Adamson, R. S., 1938. The vegetation of South Africa. – Mon. British Empire Vegetation, London.

——, 1959. Notes on the phytogeography of the flora of the Cape Peninsula. – Trans. roy. Soc. S. Afr., 35: 443-462.

Adamson, R. S. & M. M. Currin, 1951. Burried trees on the Cape Flats. – Ibidem, 33: 13-23.

Amdurer, S. S., 1956. The engineering geology of the Cape Flats. – Internal report, University of Cape Town, South Africa.

Barnard, K. H., 1961. Revised list of South African Late Tertiary and Pleistocene marine Mollusca. – Trans. roy. Soc. S. Afr., 36: 179-196.

Bowie, D. K., A. O. Fuller & W. G. Siesser, 1969. The marine sediments of False Bay. – Ibidem, 39: 149-161.

Buller, A. T. & J. McManus, 1972. Simple metric sedimentary statistics used to recognize different environments. – Sedimentology, 18: 1-21.

Butzer, K. W. & G. L. Isaac, 1972. Radiocarbon Dating of East African Lake Levels. – Science, 175, 4027: 1069-1076.

Carser, A., 1967. An ecological survey of Rietvlei near Milnerton (South Africa). – Internal report, University of Cape Town, South Africa.

Clark, J. D. & E. M. van Zinderen Bakker, 1964. Prehistoric culture and Pleistocene vegetation at the Kalambo Falls, Northern Rhodesia. – Nature, 201, 4923: 971-975.

Coetzee, J. A., 1967. Pollenanalytical studies in East and Southern Africa. – Palaeoecology of Africa, 3: 1-146, pls. 1-7.

Cooke, H. B. S., 1962. The Pleistocene environment in Southern Africa. – Monogr. Biol., 14: 1-23.

——, 1967. The Pleistocene sequence in South Africa and problems of correlation. In: W. W. Bishop & J. D. Clark (eds.), Background to evolution in Africa. – Univ. Chicago Press, Chicago & London: 175-184.

Cowan, J. A. C., 1963. Report on an ecological survey of the Milnerton sand-dunes (South Africa). – Internal report, University of Cape Town, South Africa.

Doeglas, D. J., 1968. Grain-size indices, classification and environment. – Sedimentology, 10: 83-100.

Emery, K. O., H. Niino & B. Sullivan, 1971. Post-Pleistocene levels of the East China sea. In: K. K. Turekian (ed.), The Late Cenozoic Glacial Ages. – Yale Univ. Press, New Haven & London: 381-390.

Folk, R. L. & W. C. Ward, 1957. Brazos river bar: A study in the significance of grain size parameters. – Jour. Sed. Petrology, 27, 1: 3-26.

Friedman, G. M., 1967. Dynamic processes and statistical parameters compared for size frequency distribution of beach and river sands. – Ibidem, 37: 327-354.

Fuller, A. O., 1961. Size distribution characteristics of shallow marine sands from the Cape of Good Hope, South Africa. – Ibidem, 31: 256-261.

——, 1962. Systemic fractionation of sand in the shallow marine and beach environment of the South African coast. – Ibidem, 32: 602-606.

Fuller, A. O. & P. J. Lamming, 1967. The hydraulic equivalence of Quartz and Zircon in coastal deposits from the South-Western districts of the Cape Province, and its application as an environmental indicator. – S. Afr. Jour. Sci., 63, 10: 521-526.

Gatehouse, R. P., 1953. The origin of the Cape Hangklip shell beds. – Ibidem 50, 1: 2-6.

——, 1955. The prehistoric site at Cape Hangklip. – Trans. roy. Soc. S. Afr., 34: 335-344.

Hammen, Th. van der, G. C. Maarleveld, J. C. Vogel & W. H. Zagwijn, 1967. Stratigraphy, climatic succession and radiocarbon dating of the Last Glacial in the Netherlands. – Geologie Mijnbouw, 46, 3: 79-95.

Haughton, S. H., 1969. Geological history of Southern Africa. – Geol. Soc. S. Africa, Cape Town: 1-529.

Hendey, Q. B., 1968. The Melkbos site: An upper Pleistocene fossil occurrence in the southwestern Cape Province. – Ann. S. Afr. Mus. 52, 4: 89-119.

——, 1969. Quaternary vertebrate fossil sites in the south-western Cape Province. – S. Afr. Archeol. Bull. 24, 3-4: 96-105.

——, 1970. The age of fossiliferous deposits at Langebaanweg, Cape Province. – Ann. S. Afr. Mus. 56, 3: 119-131.

Hueck, K., 1966. Die Vegetation Südamerikas. Band II. – VEB Gustav Fischer Verlag, Jena.

Kendall, R. L., 1969. An ecological history of the Lake Victoria Basin. – Ecol. Monogr., 39: 121-176.

Koldijk, W. S., 1968. On environment-sensitive grain-size parameters. – Sedimentology, 10: 57-69.

Krige, A. V., 1927. An examination of the Tertiary and Quaternary changes of sea level in South Africa, with special stress on the evidence in favour of a recent world wide sinking ocean level. – Annals Univ. Stellenbosch 5, sect. A, 1.

Levyns, M. R., 1964. Migrations and origin of the Cape Flora. – Trans. roy. Soc. S. Afr., 37, 2: 85-107.
Livingstone, D. A., 1967. Postglacial vegetation of the Ruwenzori Mountains in equatorial Africa. – Ecol. Monogr., 37: 25-52.
Mabbutt, J. A., 1955a. Cape Hangklip – A study in coastal geomorphology. – Trans. roy. Soc. S. Afr. 34: 17-24.
——, 1955b. The physiography of an area adjoining Cape Maclear. – Ibidem, 34: 61-67.
Marloth, R., 1913-1932. The flora of South Africa. vols. 1-4. – Darters, Cape Town.
Martin, A. R. H., 1953. Some possible materials for pollen analysis in South Africa. – S. Afr. Jour Sci., 50, 4: 83-88.
——, 1968. Pollenanalysis of Groenvlei Lake sediments, Knysna (South Africa). – Rev. Palaeobotan. Palynol., 7: 107-144.
Philips, E. P., 1951. The genera of South African flowering plants. – Bot. Survey S. Africa Mem., 25: 1-923.
Phillips, J. F. V., 1931. Forest succession and ecology in the Knysna region. – Ibidem, 14: 1-327.
Schulze, B. P., 1972. South Africa. In: J. F. Griffiths (ed.), Climates of Africa. – World Survey Climatology, Elsevier, Amsterdam, London & New York, 10: 501-556.
Stephens, E. L., 1929. Fresh water aquatic vegetation of the South Western Districts: Botanical features of the South Western Cape Province. – Speciality Press, Cape Town.
Taylor, H. C., 1972. Notes on the vegetation of the Cape Flats. – Bothalia, 10, 4: 637-646.
Veeh, H. H. & J. Chappell, 1970. Astronomical theory of climate change; support from New Guinea. – Science, 167: 862-865.
Vogel, J. C., 1970. Groningen radiocarbon dates 9. Radiocarbon, 12, 2: 444-471.
Walker, F., 1952. The geology. In: The Cape Peninsula. – Maskew Miller Ltd., Cape Town: 1-13.
Walter, H. & H. Leith, 1960. Klimadiagram Weltatlas. – VEB Gustav Fischer Verlag, Jena.
Walter, H. & H. Straka, 1970. Arealkunde, Floristisch-historische Geobotanik. – Verlag Eugen Ulmer, Stuttgart: 1-455.
Weimarck, H., 1941. Phytogeographical groups, centres and intervals within the Cape Flora. – Lunds Univ. Årsskr., 37: 1-143.
Welman, W. G., 1970. In: E. M. van Zinderen Bakker (ed.), South African Pollen Grains and Spores, 6. – A. A. Balkema, Cape Town: 1-110.
Wentworth, C. K., 1931. The mechanical composition of sediments in graphic form. – Iowa Univ. Studies Nat. Hist., 14: 1-127.
Zinderen Bakker, E. M. van, 1951. Prospects of palynology in South Africa. S. Afr. Jour Sci., 48: 167-174.
——, 1953. South African Pollen Grains and Spores, 1. – A. A. Balkema, Amsterdam & Cape Town: 1-60.
——, 1956. Idem, 2. – Ibidem: 61-103.
——, 1957. A pollen analytical investigation of the Florisbad deposit. (South Africa). – Proc. 3rd Pan-Afr. Congr. Prehist., Livingstone 1955: 56-67.
——, 1966a. The pluvial theory – an evaluation in the light of new evidence especially for Africa. – Palaeobotanist, 15, 1-2: 128-134.
——, 1966b. Palaeoecology of Africa, vol. 1. – A. A. Balkema, Cape Town & Amsterdam.
——, 1967a, b. Idem, vols. 2 & 3. – Ibidem.
——, 1967c. Upper Pleistocene and Holocene stratigraphy and ecology on the basis of vegetation changes in Sub-Saharan Africa. In: W. W. Bishop & J. D. Clark (eds.), Background to evolution in Africa. – Univ. Chicago Press, Chicago & London: 125-147.
——, 1969a, b. Palaeoecology of Africa, vols. 4 & 5. – A. A. Balkema, Cape Town.
——, 1972a, b. Idem, vols. 6 & 7. – Ibidem.
Zinderen Bakker, E. M. van & J. A. Coetzee, 1959. South African Pollen Grains and Spores, 3. – Ibidem, 104-171.

Manuscript received 15 March 1973.

Table 1.
List of marine fossils from the Rietvlei-basin and their occurrence in the shell-bearing deposits I-IV of the boreholes 1-4. Identifications by R.N. Kilburn, A.C. van Bruggen, A.W. Janssen and C. Downie.

	Rietvlei	1	2	3	4
BIVALVIA					
Mytilidae					
Aulacomya ater (Molina)		IV	II,III,IV		II
Chloromytilus meridionalis (Krauss)		IV	II,III,IV		II
Anomiidae					
Monia squama (Gmelin)		IV			
Psammobiidae					
Psammotellina capensis (Sowerby)		IV	IV		
Lucinidae					
Loripes liratula (Sowerby)			IV		
Erycinidae					
Kellia rubra (Montagu)		IV	II,IV		I
Tellimya trigona Barnard		IV	II		II
Lepton? sp		IV	IV		
Solenidae					
Solen capensis Fischer		IV	IV		
Nuculidae					II.
GASTROPODA (Prosobranchia)					
Fissurellidae					
Fissurella mutabilis Sowerby			IV		
Phasianellidae					
Tricolia capensis (Dunker)		IV			
Littorinidae					
Littorina saxatilis (Olivi)			II,IV		
Rissoidae					
cf. Alvania alfredensis Bartsch			IV		
Assimineidae					
Assiminea isosceles Conolly		IV	II,IV		II
Vitrinellidae					
Vitrinella cifara Bartsch		IV	II,IV		II
Turritellidae					
Turritella capensis Krauss		IV	IV		
Turritella sanguinea Reeve		IV			
Cerithiidae					
Alaba pinnae (Krauss)		IV	IV		
Scalidae					
Epitonium kraussi (Nyst)			IV		
Calyptraeidae					
Crepidula porcellana Lamarck		IV	IV		
Nassariidae					
Nassarius scopularcus Barnard		IV	II,IV		
Bullia laevissima (Gmelin)			IV		
Arcularia kraussiana (Dunker)		IV	IV		
Marginellidae					
Marginella capensis Krauss		IV	IV		II
Mangeliidae					
"Guraleus" eucosmia (Bartsch)		IV			
GASTROPODA (Opisthobranchia)					
Ringiculidae					
Ringicula turtoni Bartsch			II		
Retusidae					
Retusa sp.		IV			
PISCES (otoliths and other fragments)		IV		I	I,II
CRUSTACEA					
Ostracoda					II
Malacostraca		IV	IV		
Balanidae		IV	IV	I	I,II
PROTOZOA					
Foraminifera			IV		
ECHINODERMATA		IV	II,III,IV		II
PHYTOPLANKTON					
Operculodinium centrocarpon			II,III		
Lingulodinium machaerophorum			II,III		
Spi ferites sp.			II,III		
Pterosperma sp.			II,III		
Pachytheca sp.			II,III		
Concentricystites circulus			II,III		

Table 2

Radiocarbon dates of samples from the Cape Flats area.

	^{14}C Age	Laboratory number
Borehole: Rietvlei 1		
Depth 15.50 m	34 660 ± 900 B.P.	GrN 6 519
17.50 m	43 360 ± $^{2\,240}_{1\,750}$ B.P.	GrN 6 523
Rietvlei 2		
Depth 17.10 (20.10) m	32 770 ± $^{1\,110}_{980}$ B.P.	GrN 6 362
24.10 m	39 780 ± $^{1\,750}_{1\,430}$ B.P.	GrN 6 522
21.50 m	40 100 ± $^{3\,630}_{2\,490}$ B.P.	GrN 6 515
Rietvlei 3		
Depth 22.80 m	> 35 950 B.P.	GrN 6 516
Rietvlei 4		
Depth 22.15 m	33 830 ± $^{1\,940}_{1\,560}$ B.P.	GrN 6 614
23.35 m	47 960 ± $^{2\,850}_{2\,100}$ B.P.	GrN 6 525
23.15 m	> 39 740 B.P.	GrN 6 524
Cape Flats 1		
Depth 4.50 m	41 500 ± $^{2\,100}_{1\,800}$ B.P.	GrN 5 550
Cape Flats 2		
Depth 7.00 m	> 43 000 B.P.	GrN 5 551
Hangklip		
Depth 9.83 m	1 580 ± 50 B.P.	GrN 6 359
2.73 m	6 520 ± 100 B.P.	GrN 6 360
3.20 m	7 280 ± 130 B.P.	GrN 6 361

Data, relating to this area, from other sources.

Borehole: Rietvlei 6		
Depth 12.00 m	8 100	(internal report FISCOR)
Rietvlei 7		
Depth 17.50 m	> 41 160	(internal report FISCOR)
Hangklip (Hall-Inskeep 1970, see Vogel 1970).		
Depth 0.45 m	360 ± 30 B.P.	GrN 4 585
0.75 m	2 560 ± 35 B.P.	GrN 4 649
2.30 m	6 080 ± 50 B.P.	GrN 4 473
3.60 m	11 140 ± 65 B.P.	GrN 4 586

PLATE 1

Fossil pollen grains from the Cape Flats Formation (magnification x 1000)

1 - 4 *Podocarpus* (Podocarpaceae): 1 = RGM 159 365, Cape Flats; 2 = RGM 158 770, Rietvlei 2; 3 = RGM 159 362, Cape Flats; 4 = RGM 159 359, Cape Flats.

5 *Ilex mitis* (Aquifoliaceae): RGM 159 364, Cape Flats.

6 Myrtaceae: RGM 159 359, Cape Flats.

7 *Myrica* (Myricaceae): RGM 158 770, Rietvlei 2.

8 - 10 Anacardiaceae: 8 = RGM 159 385, Hangklip; 9 = RGM 158 724, Rietvlei 2: 10 = RGM 158 734, Rietvlei 2.

PLATE 1

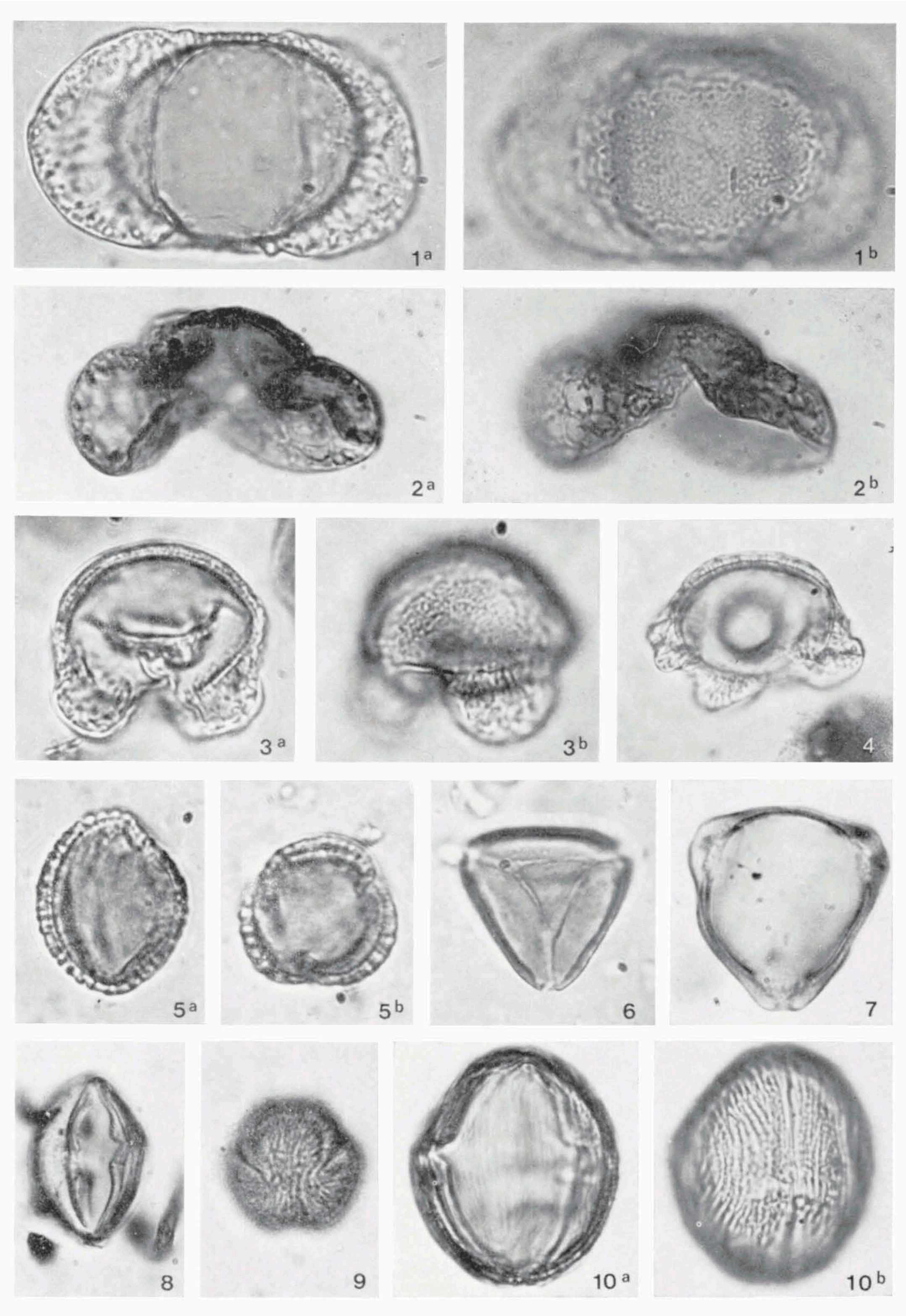


PLATE 2

Fossil pollen grains from the Cape Flats Formation (magnification x 1000)

1 - 2 Rutaceae: 1 = RGM 158 782, Rietvlei 2; 2 = RGM 158 730, Rietvlei 2.

3 - 4 Proteaceae: 3 = RGM 159 397, Hangklip; 4 = RGM 159 384, Hangklip.

5 *Nothofagus* (Fagaceae): RGM 158 737, Rietvlei 2.

6 - 7 Geraniaceae: 6 = RGM 158 744, Rietvlei 2; 7 = RGM 158 766, Rietvlei 2.

8 *Chironia* (Gentianaceae): RGM 158 776, Rietvlei 2.

PLATE 2

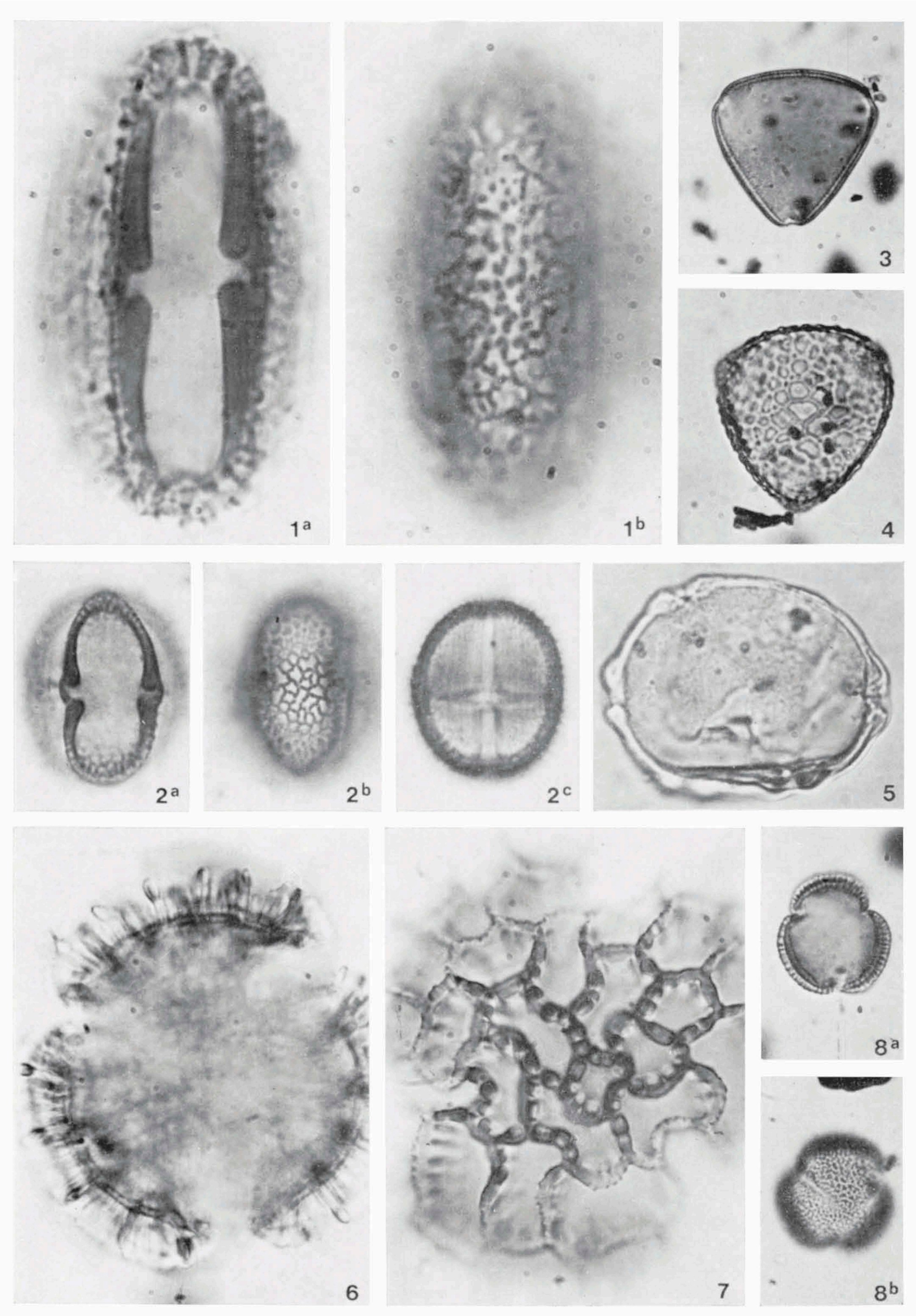


Plate 3

Fossil pollen grains from the Cape Flats Formation (magnification x 1000)

1 - 2 Restionaceae: 1 = RGM 159 384, Hangklip; 2 = RGM 158 732, Rietvlei 2.

3 Ericaceae: RGM 158 732, Rietvlei 2.

4 *Blaeria* (Ericaceae): RGM 159 397, Hangklip.

5 *Cliffortia* (Rosaceae): RGM 159 384, Hangklip.

6 Rosaceae: RGM 158 737, Rietvlei 2.

7 Aizoaceae: RGM 159 385, Hangklip.

8 Chenopodiaceae: RGM 158 732, Rietvlei 2.

9 *Plantago* (Plantaginaceae): RGM 158 732, Rietvlei 2.

10 *Passerina* (Thymelaceae): RGM 159 385, Hangklip.

11 *Nenax* (Rubiaceae): RGM 159 365, Cape Flats.

12 *Myriophyllum* (Haloragidaceae): RGM 158 778, Rietvlei 2.

13 *Annesorhiza* (Umbelliferae): RGM 159 397, Hangklip.

14 Umbelliferae: RGM 158 782, Rietvlei 2.

15 Compositae (*Artemisia*-type): RGM 158 766, Rietvlei 2.

16 - 17 Compositae (non-*Artemisia*-type): 16 = RGM 159 388, Hangklip; 17 = RGM 158 715, Rietvlei 2.

PLATE 3

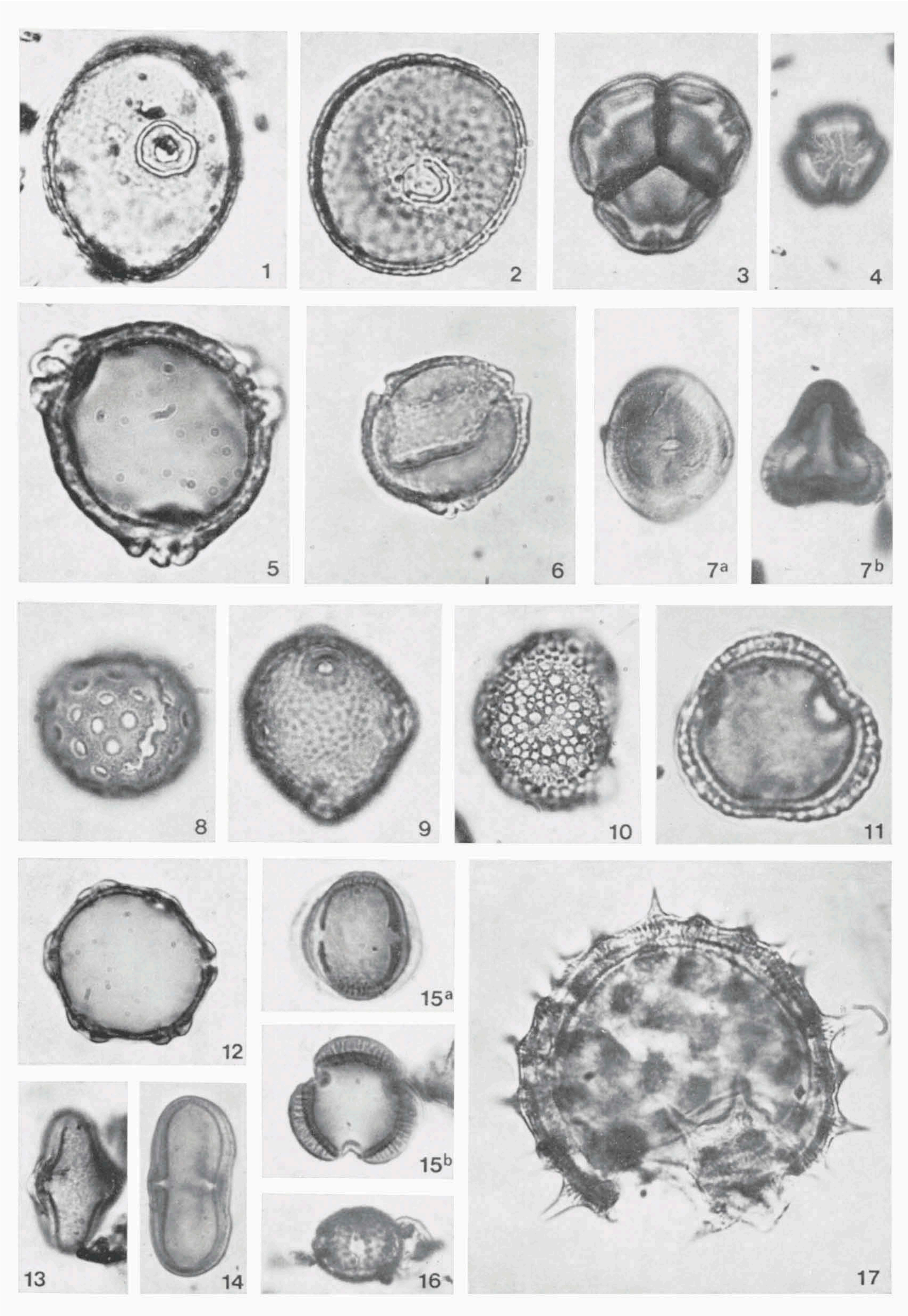


Plate 4

Fossil pollen grains and spores from the Cape Flats Formation (magnification x 1000, unless otherwise indicated)

1 - 3 Euphorbiaceae: 1 = RGM 159 388, Hangklip; 2 = RGM 159 365, Cape Flats; 3 = RGM 158 854, Rietvlei 1.

4 - 5 *Trifolium* (Leguminosae): 4 = RGM 158 994, Rietvlei 1; 5 = RGM 159 350, Cape Flats.

6 Leguminosae: RGM = 158 746, Rietvlei 2.

7 *Roëlla* (Campanulaceae): RGM 158 766, Rietvlei 2.

8 *Tribulus* (Zygophyllaceae): RGM 158 732, Rietvlei 2.

9 *Isoetes* (Isoetaceae): RGM 158 888, Rietvlei 1.

10 *Mohria lepigera* (Schizaceae), x 500: RGM 159 072, Rietvlei 3.

11 *Mohria lepigera* (Schizaceae), x 2000: RGM 158 766, Rietvlei 2.

12 *Ceratopteris thalictroides* (Parkeriaceae), x 500: RGM 158 732, Rietvlei 2.

PLATE 4

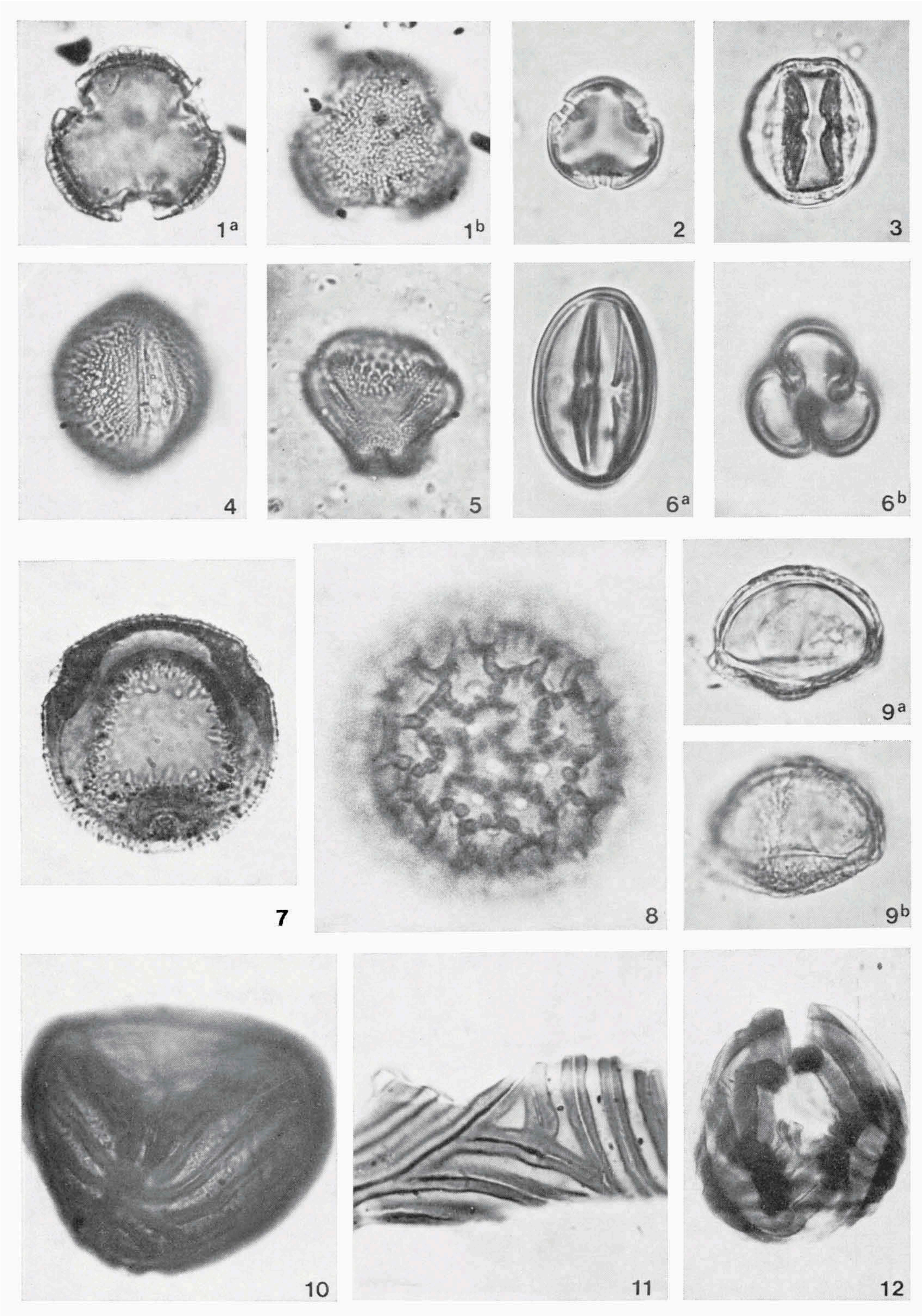


Plate 5

Marine phytoplankton

1 *Spiriferites:* RGM 158 788, Rietvlei 2.

2 *Lingulodinium machaerophorum:* RGM 158 762, Rietvlei 2.

3 - 4 *Operculodinium centrocarpon:* 3 = RGM 158 776, Rietvlei 2; 4 = RGM 158 749, Rietvlei 2.

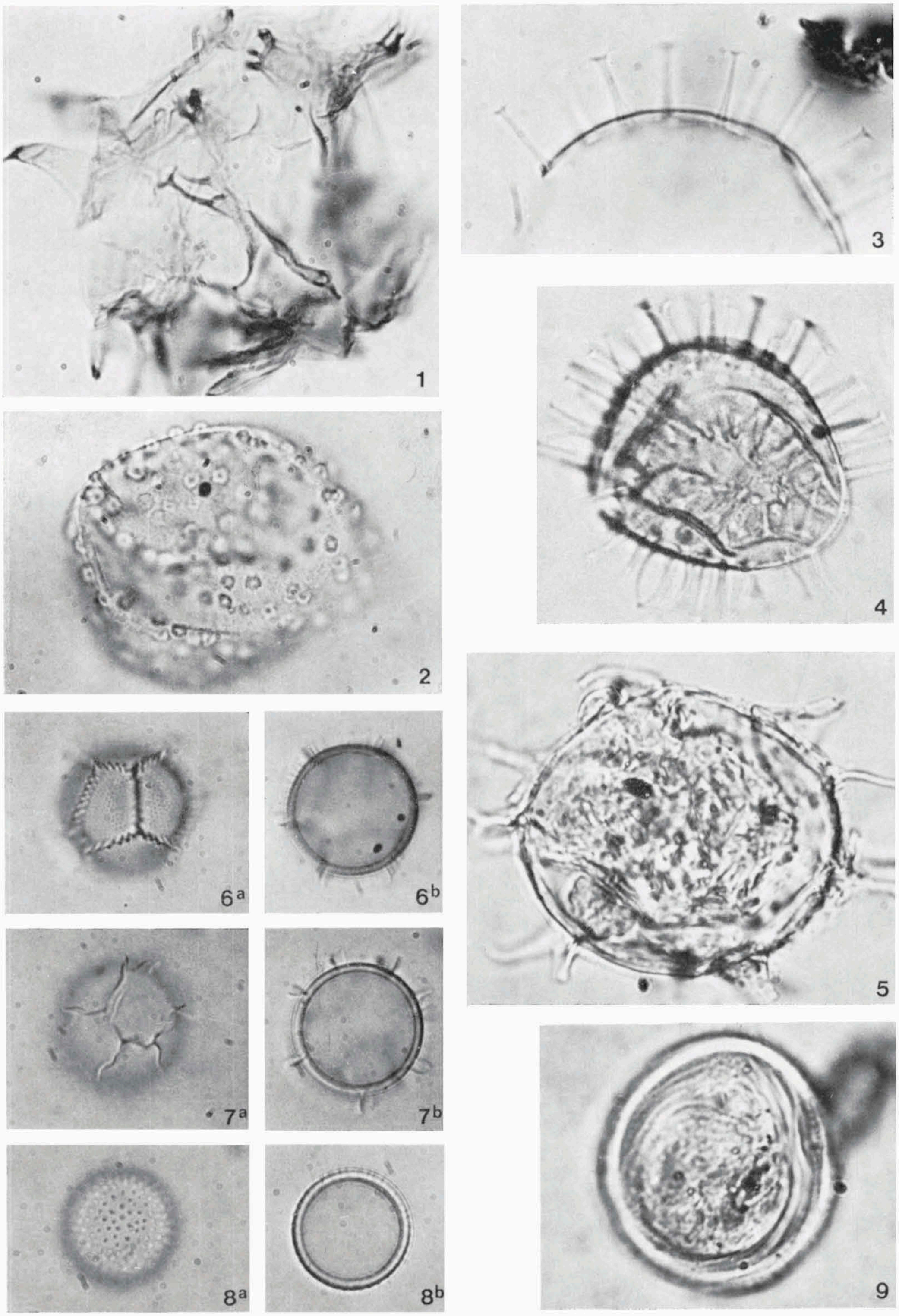
5 *Hystrichosphaera:* RGM 158 754, Rietvlei 2.

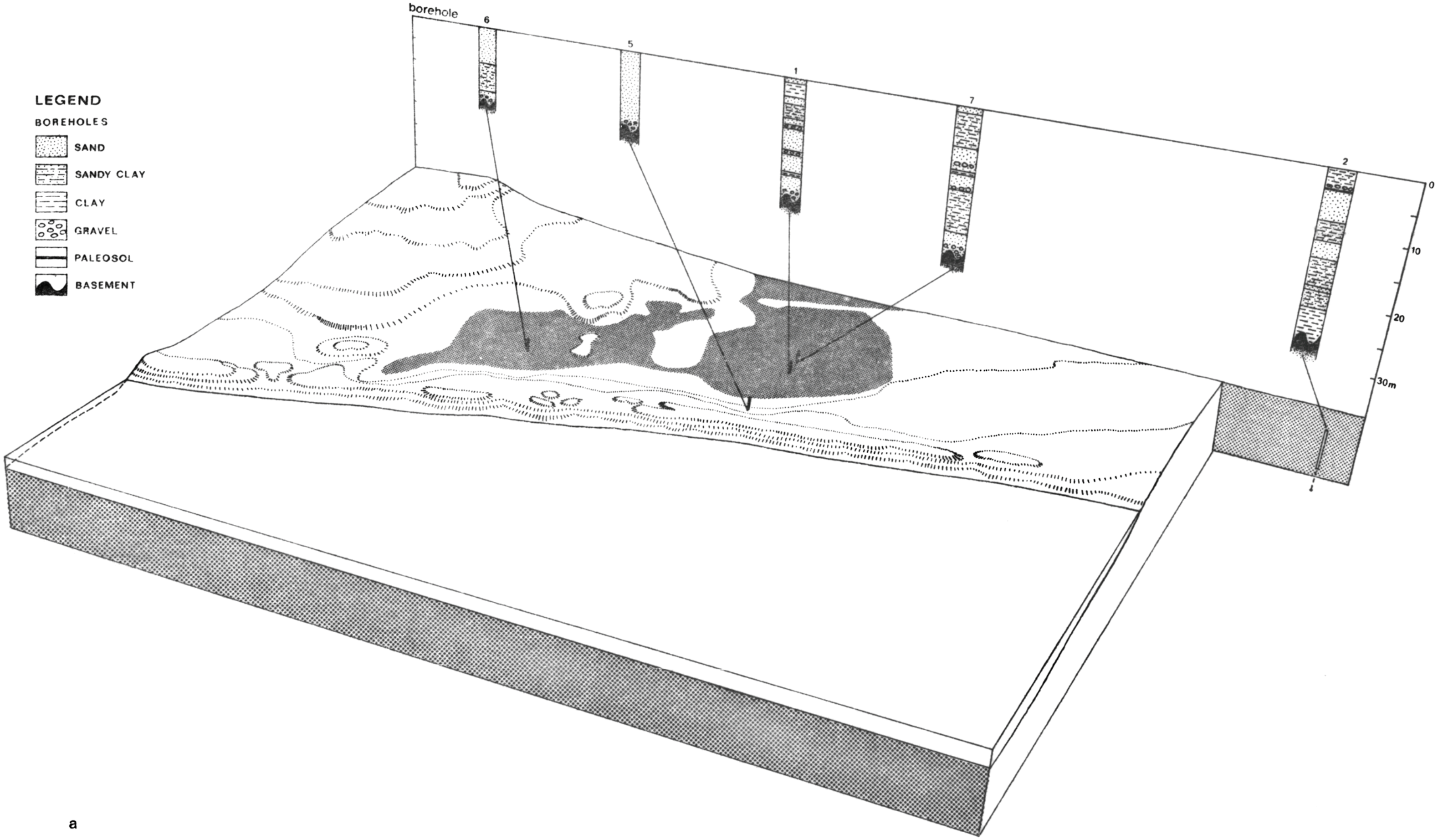
6 - 7 *Pterosperma:* 6 = RGM 158 749, Rietvlei 2; 7 = RGM 158 762, Rietvlei 2.

8 *Pachytheca:* RGM 158 762 Rietvlei 2.

9 *Concentricystites circulus:* RGM 158 750, Rietvlei 2.

PLATE 5




LEGEND
BOREHOLES
SAND
SANDY CLAY
CLAY
GRAVEL
PALEOSOL
BASEMENT
borehole
6
5
1
7
2
0
10
20
30m

a

Errata slip for The Upper Quaternary of the Cape Flats Area (Cape Province, South Africa), H. J. W. G. Schalke.

Table A	Age B.P.	should read	Age B.P. (in thousand years)
Table 2	Hangklip 9.83 m	,, ,,	Hangklip 0.83 m
Appendix 8	Borehole 1 29 000	,, ,,	34 660