Palaeont. afr., **23**, 197–203 (1980)

TERTIARY ENVIRONMENTAL CHANGES ALONG THE SOUTH-WESTERN AFRICAN COAST

by

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ABSTRACT

Evidence for major vegetation and climatic changes during the Tertiary in the south-western Cape has been obtained from a number of sites. The palynomorph assemblages indicate in general an alternation of relatively cool temperate forests with two periods of subtropical – tropical palm-dominated vegetation from the Late Oligocene/Early Miocene to the Pliocene when many of the taxa became extinct. Subsequently, strong development of macchia vegetation took place. These changes can be correlated with some palaeogeographic data and the major temperature changes of the Southern Ocean indicated in the palaeotemperature curve of Shackleton and Kennett (1975) which reflects the longterm progressive cooling of the earth since the Eocene/Oligocene boundary. The two subtropical – tropical periods can probably be related to the respective Early and Middle Miocene pan-African faunas of Arrisdrift and Lüderitz and could coincide with the two warmest periods of the Miocene at 19 My and 14 My ago. The end of the Miocene witnessed the maximum build-up of the Antarctic ice-sheet and the substantial increase of the upwelling in the Benguela Current. This resulted in the initiation of the aridification of the present Namib desert, the extermination of the palm vegetation and the provincialism of the coastal molluscs. The important drop in temperature which reached its maximum about 3,5 My ago in the Pliocene could have exterminated the surviving elements of the last of the temperate Tertiary forests. The progressive aridity of the continent resulted in the spread of savannas, the evolution of the Alcelaphini and Antelopini and the change to regional vertebrate faunas. The increasing summer aridity in the south-western Cape led to the strong development of the macchia vegetation.

CONTENTS

INTRODUCTION

The Tertiary history of the western margins of southern Africa has received much attention in recent times (Van Zinderen Bakker 1975, Axelrod and Raven 1978, Tankard and Rogers 1978, Coetzee 1978a and b). It will, however, be some time before the intricate problems of climate, oceanography and biogeography can be combined into an overall evolutionary model. The object of this paper is to contribute more information, especially from a palaeobotanical aspect, which will give another dimension to discussions on this subject. At the same time it is envisaged to give a critical review of some of the conclusions drawn so far.

Among the interesting problems of these regions is the evolution of the aridity along the south-western coast. In this connection there have been some contradictions on the question of the age of the Namib desert. On the one hand it has been postulated to be the oldest desert in the world, and on the other it is assumed to be relatively youthful. The first to draw attention to the mechanism which is responsible for the aridity along the Namibia coast was Van Zinderen Bakker (1975) who pointed out that the history of the Antarctic ice-sheet and the changes in the Southern Ocean were closely connected with the aridification.

THE ARIDIFYING MECHANISM

It is generally accepted that the main causes for the present aridity along the south-western coast of Africa are the strong, persistent South Atlantic anticyclone and the oceanic upwelling. The centre of the anticyclone is situated very near the continent and its descending, divergent anticlockwise wind system must be a major aridifying factor. The upwelling is mainly caused by the South East Trades which are directed slightly offshore. This upwelling could also be enhanced by a lifting effect of the Benguela Current which runs parallel to the coast (Currie 1953). The cold upwelled water of 10–14 °C comes from a depth of several hundred metres from the South Atlantic Water which has its origin in the mixing of the northward flowing Antarctic Intermediate Water with Subtropical Surface Water above and the North Atlantic Deep Current below it. Details of the Benguela Current and its upwelling are discussed in Currie (1953), Darbyshire (1963) and Moroshkin, Bubnov and Bulatov (1970).

This aridifying mechanism which has had its origin in the longterm cooling of the earth in the Cenozoic has been registered isotopically and sedimentologically in the Southern Ocean and is expressed in the ^{18}O palaeotemperature curve of Shackleton and Kennett (1975).

Besides its effect on the upwelling, this progressive cooling has in general had a profound effect on the continents. The lower evaporation of the ocean surface during colder times and the consequent diminished transport of water vapour to the continents will have affected the biomes of the landmasses to differing degrees during this long period. According to varied evidence, temperature changes in the Late Miocene and Early Pliocene had an important influence on the biogeography of the African continent. In Australia a similar strong correlation exists between the climatic events of the Southern Ocean during the Cenozoic and the vegetation history as well as the evolution of the aridity (Kemp 1978).

THE NAMIB DESERT

This coastal desert is a region 2 000 km long with an average width of about 200–300 km and is the most profound manifestation of aridity along the south-western coast. The northern part as far as Mossamedes in Angola is characterised by longitudinal dunes. The central part between the Huab and the Kuiseb rivers consists of a vast gravelly plain with rocky outcrops and the southern part is a sand desert, an erg with longitudinal dunes up to 300 m high.

In the discussion on the causes and age of the desert it appears that attention is focused only on the present configuration of the desert. There is now, however, geological evidence of hyperarid conditions in this same region in Cretaceous times and in the older Tertiary (Besler 1976/1977). It is important to realise that these deserts were not the result of the same mechanism as is responsible for the existence of the present desert. Even the present desert has not always been the same hyperarid inhospitable biome of the present time, since climatic changes have often affected the Namib region. Climatic changes have either ameliorated the environmental conditions or have caused the desert to shift in a meridional direction (Van Zinderen Bakker 1975). Such changes must have affected the "present Namib" since Miocene times. This consideration has been neglected in recent discussions and will be elaborated on at a later stage.

PALAEOGEOGRAPHIC CONSIDERATIONS

The northward migration of continents during the Tertiary and their concurrent positions in relation to the Pole are important considerations in palaeoreconstructions because climate is also affected by latitude. These aspects have recently been demonstrated in the case of Australia (Kemp 1978). According to the Palaeocontinental maps of Smith and Briden (1977), the south-western parts of Africa and Australia may well have shared the same high humidity and circulation pattern of strong westerlies during the early Tertiary. According to Lamb (in Kemp 1978: 179), these westerlies were situated at 60–80 °S during this period. The south-western parts of both continents maintained almost similar latitudinal positions since Late Eocene times when these continents were situated at about 50 °S. Africa, however, had left Gondwanland much earlier, in the Cretaceous. It is interesting that a number of palynomorphs of the forest taxa found in the oldest parts of the Cape deposits also occur in the Early Tertiary of Australia, Ninetyeast Ridge and New Zealand (Coetzee 1978a and b). It is possible, therefore, that the south-western regions of Africa and these other southern continents shared some similar rain forest components in probably a similar type of climate in the Early Tertiary. This evidence could be of considerable phytogeographic interest.

In the Late Eocene (40 My) and by Late Miocene times the northward drift of Africa brought the continent to latitudes 12° and 7° respectively further south than now (Smith and Briden 1977). Conditions along the west coast could have become steadily more arid at the boundary of the Eocene/Oligocene as a result of this northward shift and also as a consequence of the first pronounced temperature drop at this junction as shown in the palaeotemperature curve of Shackleton and Kennett (1975). With regard to this cooling, Siesser (1978) has also provided evidence for the first weak spasmodic introduction of cold water into the Benguela Current from Middle or Late Oligocene times in the region of the Walvis Ridge. In Australia palynological evidence (Kemp 1978) shows that lowered floristic diversity had set in in the Oligocene concomitant with this lowered temperature. It is concluded that precipitation over this continent had become reduced.

TERTIARY VEGETATION AND CLIMATIC CHANGES IN THE S.W. CAPE

Until now very little concrete information on Tertiary vegetation in these regions has been available, and certain speculations have been made on the origin and migrations of the present Cape flora.

The present intensive palynological studies of deposits from a large number of sites in the south-western regions, such as the Cape Peninsula, the Cape Flats and the Saldanha area (fig. 1), are now shedding new light on the history of the vegetation in this part of the continent since Tertiary times (Coetzee 1978a, b). Most of these deposits contain extremely rich and diverse palynomorphs which

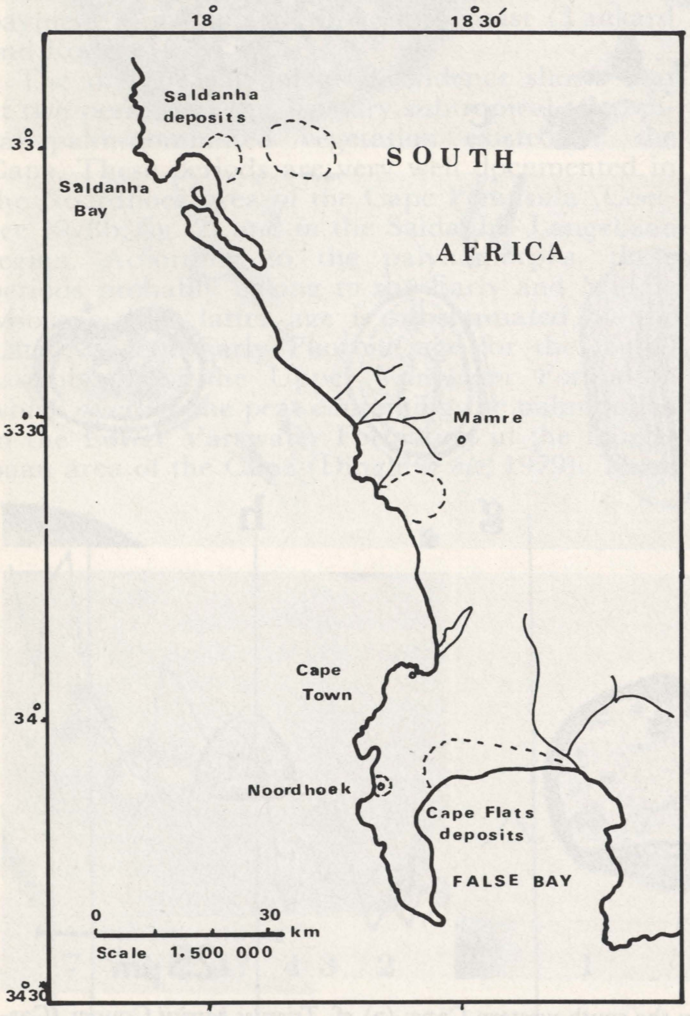

Figure 1. Locality map of Tertiary deposits investigated in the south-western Cape.

are very well preserved (fig. 2). The assemblages indicate the existence at different periods in the Tertiary of very interesting vegetation types from at least the Late Oligocene/Early Miocene to the present. The age of the deposits is based on certain world-wide accepted palynological stratigraphic markers (Leopold 1969) and substantiated by certain associated faunal remains (Dingle *et al.*, 1979). The time ranges of similar fossil taxa in other Southern Hemisphere continents such as Australia and New Zealand and the now submerged Ninetyeast Ridge have also been used as general guidelines for time-spans of taxa on this continent (Coetzee 1978a). However, it must be borne in mind that these time ranges need not necessarily be the same in Africa as in the other southern landmasses. Comparisons at the scanning electron microscope level of fossil taxa from these different southern continents indicate phytogeographical aspects of considerable interest.

The pollen and spore assemblages of the present studies indicate that through most of the Tertiary an overall warmer climate than at present existed with cool oscillations. The pollen spectra show that the relatively cool periods were characterised by Podocarpaceous temperate forests of varying composition. These periods seem to have alternated with relatively warmer phases dominated by palm vegetation. These vegetation changes for which no absolute dating exists are so marked, especially in the Cape Peninsula deposits, that it may be possible to correlate them with pronounced changes in the palaeotemperature curve of the Southern Ocean of Shackleton and Kennett (1975). Finer details of the vegetation succession during the Tertiary will be available when analyses at very much closer intervals in the sequence of the deposit are made in due course. In the following discussion an attempt is made to correlate some of these Tertiary vegetation changes and other on- and off-shore data with the palaeoclimatic evolution of the Southern Ocean and the ultimate aridification of the south-western regions.

Early Tertiary

The possible opening up of the early temperate rain forest which as previously mentioned must have existed in the south-western regions of Africa during Eocene/Oligocene times, has been suggested from evidence of fossil pollen and leaves from Banke in Namaqualand (30° 22'S, 18° 31'E) first described by Kirchheimer (1932). The fossiliferous sediments were recovered from a volcanic pipe, and the age for these sediments is assumed from a radiometric data of 38,5 My obtained by Kröner (1973 in Estes 1977) from a nearby geochemically dissimilar volcanic pipe. This age has also been supported by comparison of micrographs and illustrations of the dispersed palynomorphs with microfossil taxa from the Oligocene of Kerguelen (Cranwell 1964). The age for these sediments on these bases, therefore, remains rather speculative. It has been suggested that this pollen assemblage reflects the existence of vegetation which is typical of that occurring in the Cape at present (Axelrod and Raven 1978, Tankard and Rogers 1978). However, on the basis of the present knowledge of the morphology of some of the pollen identified from the Banke sediments more caution should be exercised in drawing conclusions on the type of vegetation which existed in these regions in the Early Tertiary. The pollen identified as that of *Gunnera,* for instance, does not correspond with the pollen morphology of this extant genus, and the fossil pollen accepted as that of *Myrica* is more likely to be that of Casuarinaceae. Thiergart *et al.* (1963) assigned this pollen type from the Knysna lignites to *Triorites harrisii* (Casuarinaceae). *Myrica* is a boreal genus which possibly migrated to South

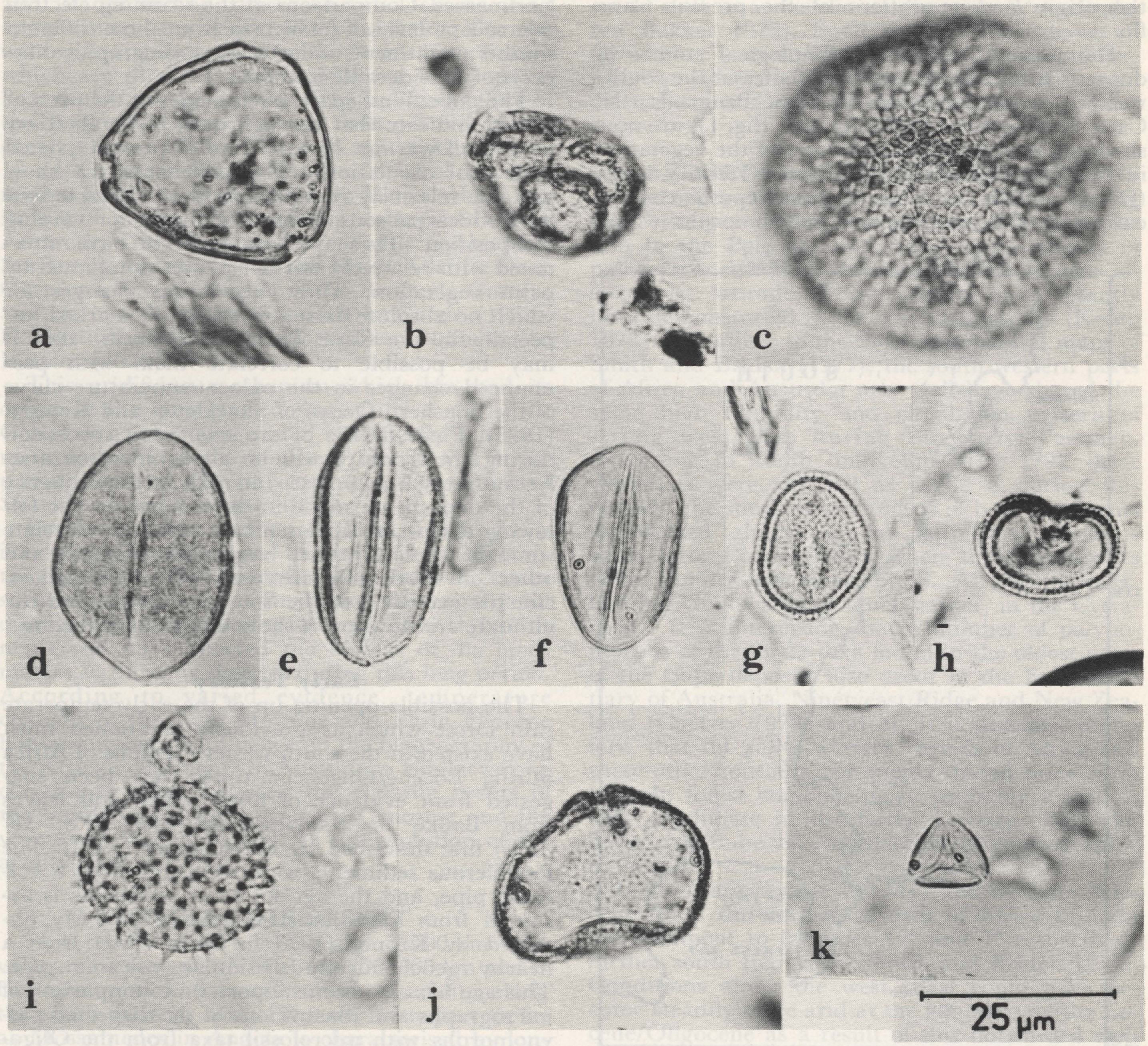

Figure 2. Some Tertiary pollen taxa which have become extinct in the south-western Cape: (a) cf. *Triorites harrisii* Couper (Casuarinaceae); (b) *Microcachrydites* sp. cf. *M. antarcticus;* (c) *Croton*-type; (d)–(f) Palmae; (g) and (h) *Clavatipollenites* sp. cf. *C. hughesii;* (i) *Echiperiporites* v.d. Hamm. and Wijmstra; (j) *Sparganiaceaepollenites* Thiergart; (k) *Cupaniedites* sp. cf. *C. orthoteichus* Cookson and Pike.

Africa in the Pleistocene (Coetzee 1978a), while Casuarinaceae, although not at present indigenous to Africa, was prevalent in the Southern Hemisphere during the Tertiary. If this is accepted, then the frequent occurrence of this pollen type at Banke could suggest that some kind of rain forest dominated by Casuarinaceae was present. It is possible that the pollen assemblage could suggest that an impoverished forest was present because very few taxa were found. The Podocarpaceae pollen types occurred very rarely which suggests that they were blown in from great distances. The occurrence of an impoverished forest could support the suggestion made earlier that, as in Australia, conditions were becoming increasingly arid as a result of the northward shift of the continent and the pronounced drop in temperature at the Eocene/Oligocene boundary. As mentioned above, the age of the Banke sediments is, however, problematical.

Early and Middle Miocene

During the Early and Middle Miocene, the Antarctic ice-sheet continued to expand but the production of cold water was still limited, and the present distribution of cold water masses in the Southern Ocean had not yet come into existence. The upwelling system was not operating continuously (Siesser 1978), and the present atmospheric and oceanic circulation systems dominating Southern Africa had not yet originated. During these times, the subcontinent was probably receiving summer rainfull. East and Central Africa were mainly covered with forests (Andrews and Van Couvering 1975), and open, dry savannas had not yet spread there. Cosmopolitan mollusc faunas with less distinct latitudinal zonation than now indicate warm surface temperatures and much embayment along the south-western coast (Tankard and Rogers 1978).

The present palynological evidence shows that at two periods in the Tertiary subtropical to tropical palm-dominated vegetation existed in the Cape. These periods are very well documented in the Noordhoek area of the Cape Peninsula (Coetzee 1978b: fig. 2) and in the Saldanha–Langebaan region. According to the palynomorphs, these periods probably belong to the Early and Middle Miocene. The latter age is substantiated by the Late Miocene/Early Pliocene age for the faunal assemblage of the Upper Varswater Formation which overlies the peat containing the palm pollen in the Lower Varswater Formation in the Langebaan area of the Cape (Dingle *et al.*, 1979). These faunal remains are covered by thick phosphorite deposits which are associated with cold upwelling in an embayed coast line, indicating that the climate had become cooler (Tankard and Rogers 1978).

The palynological evidence for these two warmer periods can probably also be related to the fossil faunas of Lüderitz (Hopwood 1929) and Arrisdrift (Corvinus and Hendey 1978) of Early and Middle Miocene age respectively. These faunas were found in fluvial deposits and testify to warmer and much more humid climates further north along the Namib desert coast. They are related to the present East African faunas and had a pan-African distribution. Hopwood (1929) suggested that the jumping hares and antelopes of the Miocene of the Namib point to open grassland savannas and tragulid remains are indicative of woodland.

The above evidence suggests that there were possibly two periods of greater warmth and humidity in these south-western regions which could be correlated with the two warmest periods of the Miocene at 19 My and 14 My (Mercer 1978) (fig. 3). It is possible that the palm-dominated vegetation was mainly associated with the embayments

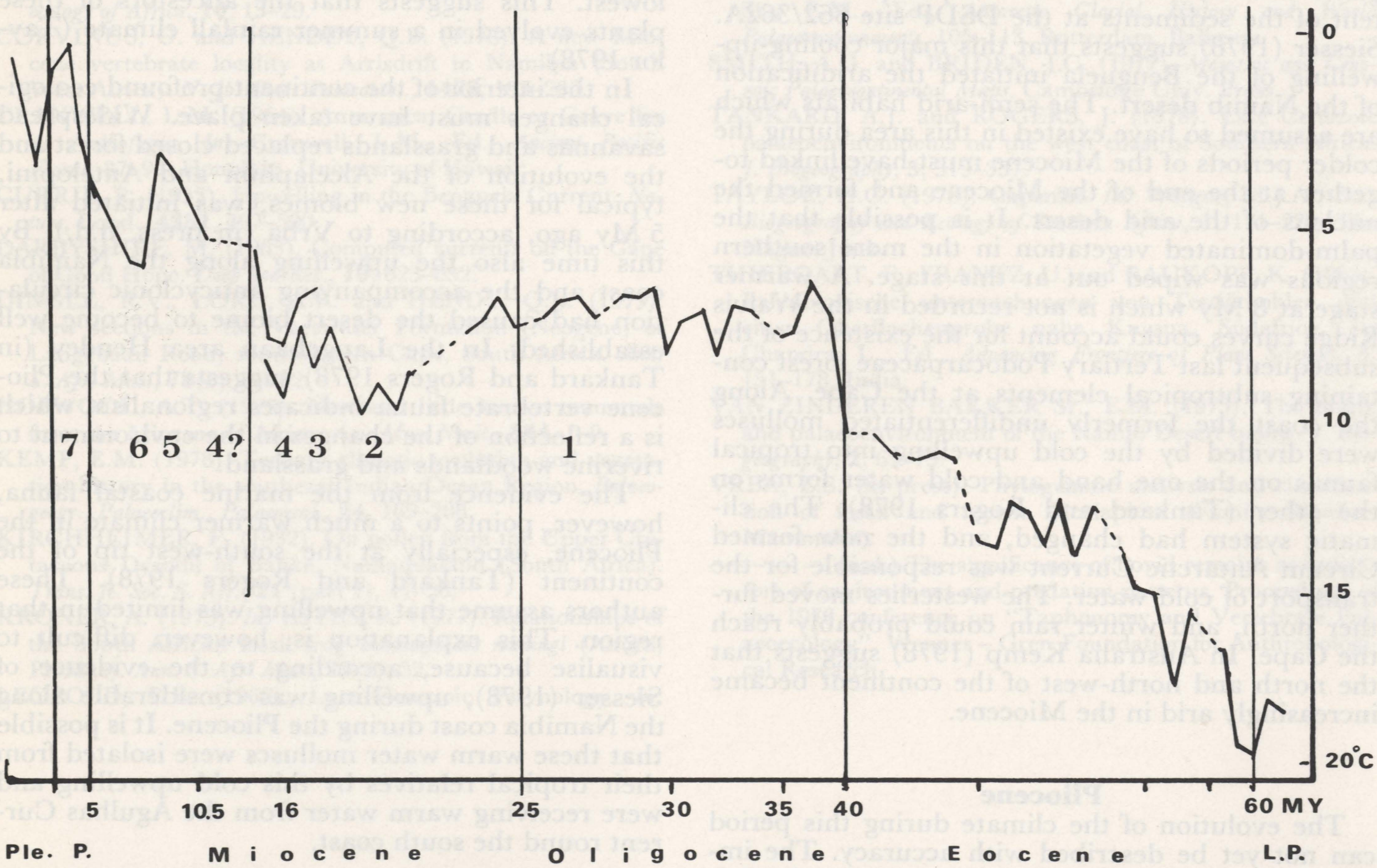

Figure 3. Palaeotemperature curve of the Southern Ocean (after Shackleton and Kennett 1975) with possible correlations of palaeoenvironments in the s.w. parts of S. Africa. 1, *Late Oligocene:* Podocarpaceous forest, spasmodic upwelling at Walvis Ridge, 2, *Early Miocene:* Palmae dominant,? Lüderitz fauna. 3, *Early Miocene:* Podocarpaceae forest. 4, *Early/Middle Miocene:* Palmae, fossil fauna Arrisdrift, Lower Varswater Formation — non phosphatic. 5, *Middle/Late Miocene:* Antarctic ice-sheet build-up, origin of present Namib desert, strong upwelling with phosphates. 6, *Late Miocene:* Podocarpaceous forest. 7, *Pliocene:* summer aridity, S.W. Cape; macchia dominant, Namib desert established, spread of savannas, provincialism of molluscs and vertebrate fauna.

mentioned by Tankard and Rogers (1978) while the areas further north were covered with wooded grassland. According to some of the components of the pollen assemblages of these two periods, such as *Microcachrydites, Echiperiporites Apodytes, Podocarpus* and *Triorites harissii* (Casuarinaceae), it is possible that temperate forest existed in nearby mountain kloofs. This would be in accordance with the wood remains identified as that of *Curtisia,* a temperate forest tree, found in the peat under the phosphorites at Langebaanweg (Tankard and Rogers 1978). As mentioned before, palynological evidence shows that colder periods characterised mainly by Podocarpaceae forests of varying composition existed in the Cape during periods alternating with the subtropical palm-dominated vegetation.

Late Miocene

Considerable changes took place when the Antarctic ice-sheet reached its present size in the Late Miocene between 14–10 My ago (Mercer 1978). By the end of the Miocene the spasmodic upwelling which had occurred along the west coast increased substantially (Siesser 1978). This can be concluded from the increase in the amount of organic carbon, diatoms and the phosphorous content of the sediments at the DSDP site 362/362A. Siesser (1978) suggests that this major cooling-upwelling of the Benguela initiated the aridification of the Namib desert. The semi-arid habitats which are assumed to have existed in this area during the colder periods of the Miocene must have linked together at the end of the Miocene and formed the nucleus of the arid desert. It is possible that the palm-dominated vegetation in the more southern regions was wiped out at this stage. A warmer stage at 8 My which is not recorded in the Walvis Ridge curves could account for the existence of the subsequent last Tertiary Podocarpaceae forest containing subtropical elements at the Cape. Along the coast the formerly undifferentiated molluscs were divided by the cold upwelling into tropical faunas on the one hand and cold water forms on the other (Tankard and Rogers 1978). The climatic system had changed, and the now formed Circum Antarctic Current was responsible for the transport of cold water. The westerlies moved further north, and winter rain could probably reach the Cape. In Australia Kemp (1978) suggests that the north and north-west of the continent became increasingly arid in the Miocene.

Pliocene

The evolution of the climate during this period can not yet be described with accuracy. The important phosphorites and peat deposits in the Saldanha region and the associated faunas are not yet fully understood. The problem of the temperature changes in the Southern Ocean during the Pliocene still has to be solved. The Antarctic ice-sheet reached its maximum Late Cenozoic volume 4,7–4,3 My ago (Mercer 1978) and it is possible that the formation of more ice, especially on West Antarctica, was triggered by the Messinian Salinity Crisis of the Mediterranean (Mercer 1978). In his critical review of the available evidence Mercer (1978) comes to the conclusion that the first cold episode of this epoch in high southern latitudes probably reached its maximum about 3,5 My ago. A sudden northward expansion of cold water over a distance of 300 km may be related to this cool episode (Kemp *et al.,* 1978).

This important drop in temperature with its far-reaching effects on the southern continents must have caused some of the last surviving elements of the typical Tertiary forest (which could not tolerate the accompanying summer aridity) to become extinct in the south-western Cape. This change in the pollen sequence is very abrupt and is followed by a strong increase in pollen percentages of the present macchia vegetation. Some of these types, such as *Cliffortia, Stoebe,* Restionaceae, Proteaceae, Ericaceae, and Compositae, were already sparsely represented in the Tertiary of these regions. A very interesting feature of the growth rhythm of many of the present south-western Cape taxa is the start of very rapid vegetative growth towards the end of the summer when humidity in these regions is at its lowest. This suggests that the ancestors of these plants evolved in a summer rainfall climate (Taylor 1978).

In the interior of the continent profound ecological changes must have taken place. Widespread savannas and grasslands replaced closed forest and the evolution of the Alcelaphini and Antelopini, typical for these new biomes, was initiated after 5 My ago, according to Vrba (in press, n.d.). By this time also the upwelling along the Namibia coast and the accompanying anticyclonic circulation had caused the desert biome to become well established. In the Langebaan area Hendey (in Tankard and Rogers 1978) suggests that the Pliocene vertebrate fauna indicates regionalism which is a reflection of the changes in the environment to riverine woodlands and grassland.

The evidence from the marine coastal fauna, however, points to a much warmer climate in the Pliocene, especially at the south-west tip of the continent (Tankard and Rogers 1978). These authors assume that upwelling was limited in that region. This explanation is, however, difficult to visualise because, according to the evidence of Siesser (1978), upwelling was considerable along the Namibia coast during the Pliocene. It is possible that these warm water molluscs were isolated from their tropical relatives by this cold upwelling and were receiving warm water from the Agulhas Current round the south coast.

CONCLUSIONS

The evolution of the climate of Southern Africa and the history of its biomes could be closely correlated with the glacial history of the Antarctic as studied in the Southern Ocean. The subtropical-tropical vegetation which existed at different times in the south-western Cape until Miocene times was exterminated when the cooling of the Southern Ocean reached its maximum at the end of that epoch. At this time also the aridification of the Namib desert was initiated. The last surviving components of the last of the Tertiary temperate forests must have become extinct during the severe Pliocene drop in temperature about 3,5 My ago. This must have initiated the strong development of the present macchia vegetation at the Cape in the increasingly arid summer climate in these regions and the spread of savannas over vast regions of the subcontinent.

ACKNOWLEDGEMENTS

Grateful thanks are due to the Director of the Geological Survey for initiating this project, for providing substantial financial support and for permission to publish the results. I am especially indebted to Dr. J.N. Theron of the Geological Survey, Cape Town, for the careful collection of the samples.

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