

**THE STRATIGRAPHY AND SEDIMENTOLOGY
OF THE
BREDASDORP GROUP,
SOUTHERN CAPE PROVINCE**

BY

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Master of Science in Geology

University of Cape Town

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THE STRATIGRAPHY AND SEDIMENTOLOGY OF THE

BREDASDORP GROUP, SOUTHERN CAPE PROVINCE.

BY

Jean Arnaud Malan



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ABSTRACT

The Cainozoic Bredasdorp sediments along the south coast of the Cape Province, South Africa, have come under investigation through a few intermittent studies undertaken since the early part of the century. In this presentation the literature is reviewed and a stratigraphic subdivision, based on both lithostratigraphic and biostratigraphic principles, is applied to the sediments of the **Bredasdorp Group**.

The Bredasdorp deposits can be classified, according to origin, as shallow marine and aeolian. The marine deposits are subdivided into the Pliocene **De Hoopvlei** and the Middle to Late Pleistocene **Klein Brak Formations**. The Late Pliocene to Early Pleistocene **Wankoe Formation**, the Late Pleistocene **Waenhuiskrans Formation** and the Holocene **Strandveld Formation** constitute the coastal aeolian deposits. These marine and marine-related (aeolian) formations, characterised by calcareous clastics have been grouped together in a newly defined **Bredasdorp Group**.

In order to construct a depositional model for the Bredasdorp Group, various facies have been identified on the basis of geometry, lithology, fossil contents, palaeocurrent data, biogenic and sedimentary structures. The facies are related to environments constituting a shoreline setting with offshore, transitional, shoreface, foreshore and backshore zones, followed by back-barrier lagoons, estuaries, backshore dunes and coastal dunefields associated with transgressive/regressive shorelines.

The various deposits, as well as distinctive geomorphological features, are correlated with the relative sea-level movements throughout the Cainozoic, which have shaped the southern Cape coastal plain.

Sea-level curves for Southern Africa, drawn by several authors are compared. A relative sea-level curve is constructed for the south coast of South Africa. Several Early Cainozoic transgression/regression cycles are recognised at places along the South African coast. The earliest cycle started in the Palaeocene and was followed by a less pronounced transgression/regression cycle occurring in the Late Eocene to Early Oligocene. Remnants of surfaces related to these cycles are recognised in the Southern Cape Province, but these are interpreted as products of subaerial processes.

The next cycle, reaching a transgressive maximum of c. 180m, started in the Miocene and terminated in the Early Pliocene. Again no evidence of marine deposits is preserved on this marine-planed surface. The Early Pliocene transgression reached a maximum present-day elevation of c. 120m. Marine planation of the coastal platform took place during the transgression, whereas the De Hoopvlei Formation situated below 120m, was deposited during the subsequent Late Pliocene regression. The Wankoe Formation was deposited during the same regression as backshore dunes and coastal dunefields.

During the Quaternary transgression/regression cycles, of which at least three are indicated, the transgression reaching a maximum of about 50m, in places eroded part of the Neogene Bredasdorp Group. The Klein Brak Formation (preserved below 20m) was deposited during Middle to Late Pleistocene regressions. The Waenhuiskrans Formation, which is extensively developed on the present-day continental shelf, was deposited during this regression with sea-level receding to about -130m below present sea-level. The aeolian Strandveld Formation, which is still being deposited, originated from the Flandrian transgressive maximum at the start of the Holocene.

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"Earth and Ocean seem
 To sleep in one another's arms and dream
 of waves, flowers, clouds, woods, rocks and all that we
 Read in their smiles, and call reality"

(Shelley, Epipsychidion)

CHAPTER 1. INTRODUCTION

1.1 SCOPE OF THESIS

This thesis focusses on the stratigraphy, geographical distribution, lateral variation, lithology, sedimentology and palaeontology of the Cainozoic Bredasdorp Group on the coastal plain of the Southern Cape Province between Hermanus in the west and Plettenberg Bay in the east (Figure 1).

1.2 STUDY MOTIVATION

Regional geological mapping undertaken by the writer for the Geological Survey during 1983 and 1984 on the southern parts of the 1:250 000 scale 3319 Worcester and 3420 Riversdale sheets showed that mapping and differentiation of the Cainozoic coastal deposits were possible (Malan, 1984, 1985). The deposits, known as the Bredasdorp Group, were divided into five separate mappable units (Malan, 1986). In 1985 the Tertiary and Quaternary Working Group of the South African Committee for Stratigraphy (SACS) requested the author to submit formal lithostratigraphical proposals for these units. A research project (Project 85/6 - Stratigraphy and lithology of the Cainozoic deposits along the Cape south coast) was registered with the Geological Survey. Fieldwork started in May 1985 and was completed over a period of two years (Malan, 1988a).

1.3 STUDY AREA

The study area covers the coastal plain along the south coast of the Cape Province, from Hermanus in the west to Plettenberg Bay in the east. This study was concentrated in the area between Hermanus and Groot Brak, 20km east of Mossel Bay, because the bulk of the Bredasdorp sediments occurs west of Mossel Bay (Figure 1).

1.4 AIM OF THE STUDY

The chief aim of this study is the lithostratigraphical subdivision of the Bredasdorp Group sediments by means of sedimentological and palaeontological investigations of the different units. The field data is interpreted to elucidate the depositional history and to erect a depositional model for the Bredasdorp sediments. This leads to a discussion of sea-level fluctuations along the south coast during the Late Tertiary/ Quaternary period. Finally, the relationship and correlation of the Bredasdorp Group with other Cainozoic deposits along the South African coast is evaluated.

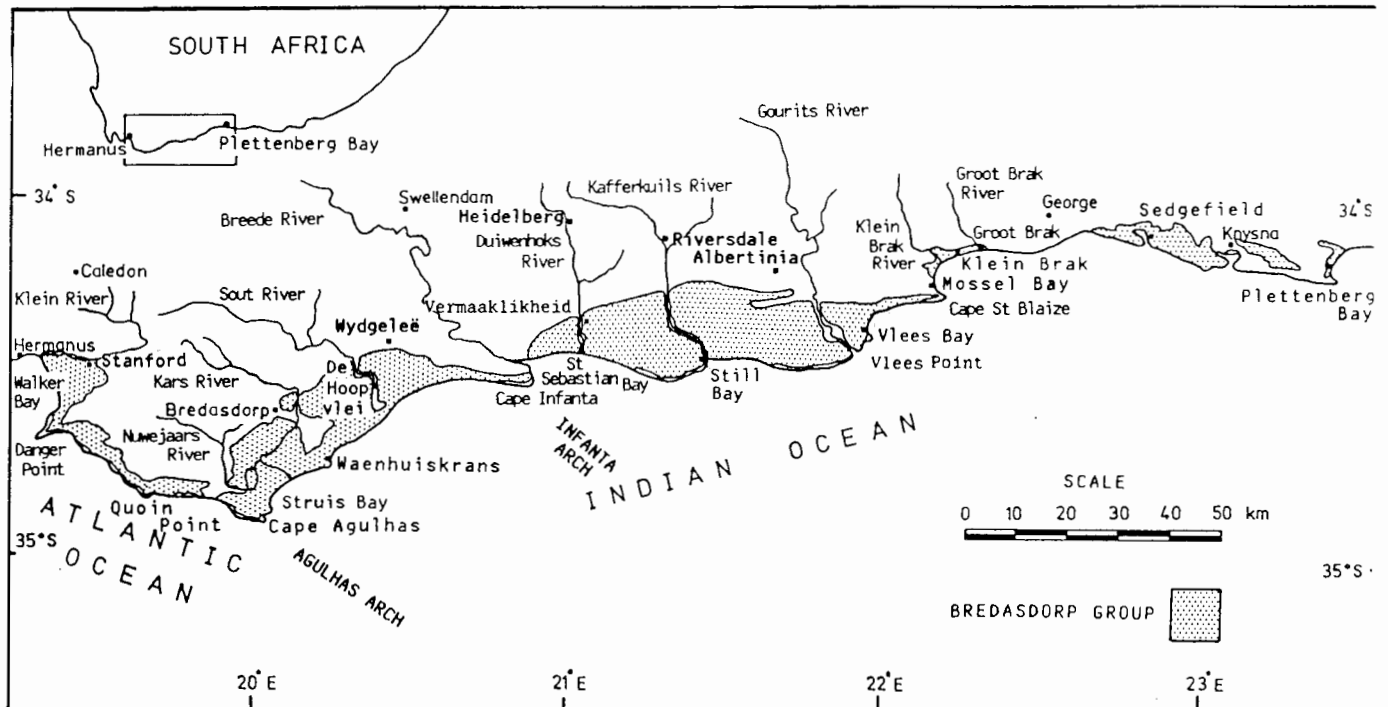


FIGURE 1. Distribution of the Bredasdorp Group along the south coast, Cape Province, South Africa.

CHAPTER 2. LITERATURE REVIEW

The coastal sand dunes and limestones lying between Hermanus and Mossel Bay (Figure 1) were first described by Rogers and Schwarz (1900). They mentioned two limestone ridges of different ages between Cape Agulhas and Cape Infanta and between the mouth of the Breede River and Mossel Bay (Figure 1). These deposits were formed from comminuted marine shells and quartzose beach sands blown into ridges more or less parallel to the present coastline.

In his book "The Geology of Cape Colony", Du Toit (1905) discussed the limestone deposits in the study area. A crossbedded unit "perhaps better developed in windblown accumulations than in sediments deposited under water" (Du Toit, 1905, p. 374) formed the cliffs along the coast between Cape Agulhas and Mossel Bay. A dune snail, Helix sp., from this unit is described. The older dune ridge between Bredasdorp and Cape Infanta (Figure 1) was formed when the sea was at a higher level than at present (Du Toit, 1905).

Wybergh (1919 and 1920) reported extensively on these limestones and in his paper "The coastal limestones of the Cape Province", three earlier references on this topic are mentioned (Wybergh, 1919, p. 47):-

- 1 A.G. Bain in the Transactions of the Geological Society of London (1856).
- 2 Dr. Atherstone in the Cape Monthly Magazine (1858).
- 3 F. von Hochstetter in Reise der Oester, Frig. Novana Geol., Thiel Vienna (1886).

Wybergh (1919, p. 47 and p. 60) gave the names, "Bredasdorp Limestones" and "Bredasdorp Formation" to the limestone deposits between Bredasdorp and the Gourits River (Figure 1). He was the

first to use the general term "Coastal Limestones" for the Tertiary and Quaternary limestones between St Helena Bay and East London (Wybergh, 1919, p. 46). Haughton et al. (1937) referred to the limestones around Mossel Bay as the "Alexandria Series", thereby correlating them with the Alexandria Formation deposits of the Eastern Cape. Maasdorp and Murray (1948) gave a short description of the Bredasdorp deposits in the area east of Hermanus (Figure 1). Spies et al. (1963, p. 15) named these coastal limestones the "Bredasdorp Beds". On their map, 3419C and 3419D-Gansbaai and 3420C-Bredasdorp, the Bredasdorp Beds are described as calcified dunesands of Tertiary to Recent age.

Since the 1960s, detailed work on the Bredasdorp succession has been undertaken by several workers. Siesser (1971) suggested a genetic subdivision for the coastal limestones based on whether the unit was formed as beach or dune deposits. SACS (1980, Fig. 7.9.2) later recognised four members in the "Bredasdorp Formation" (Table 1). The littoral Velddrif and aeolian Langebaan Members, as described in the Saldanha area by Tankard (1975), and the Knysna Member (Haughton, 1969), were included, and the littoral De Hoopvlei Member was proposed as a new member (SACS, 1980, p. 624).

Rogers (1986) divided the Cainozoic succession in the Gourits - Still Bay area into six different members. The status of the Bredasdorp Formation was raised to that of a group subdivided into five mappable units (Table 2) ranked as formations (Malan, 1986, 1989a). The geomorphological aspects of the Bredasdorp limestones were studied by Marker (1981), Russell (1982, 1987) and Rogers (1986, 1988). Mention of the Bredasdorp outcrops along the Cape south coast was also made in textbooks by Tankard et al. (1982) and by Dingle et al. (1983).

TABLE 1. Stratigraphy of the "Bredasdorp Formation", south and southwestern Cape Province (SACS, 1980, Table 7.9.2).

TERTIARY				QUATERNARY	
Eocene	Oligocene	Miocene	Pliocene	Pleistocene	Holocene

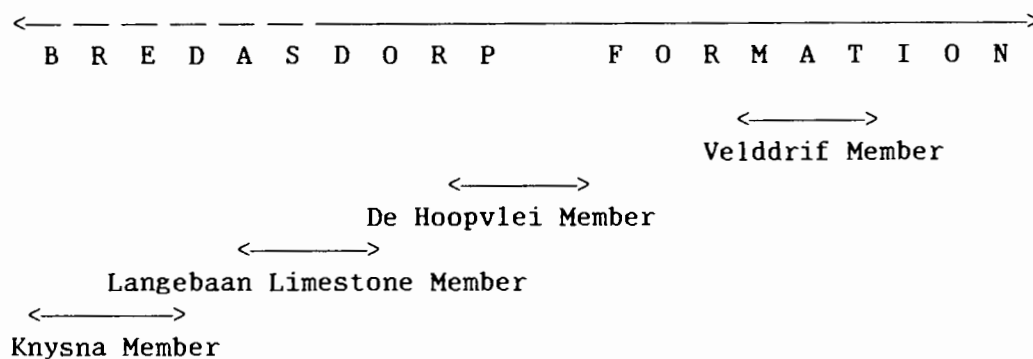
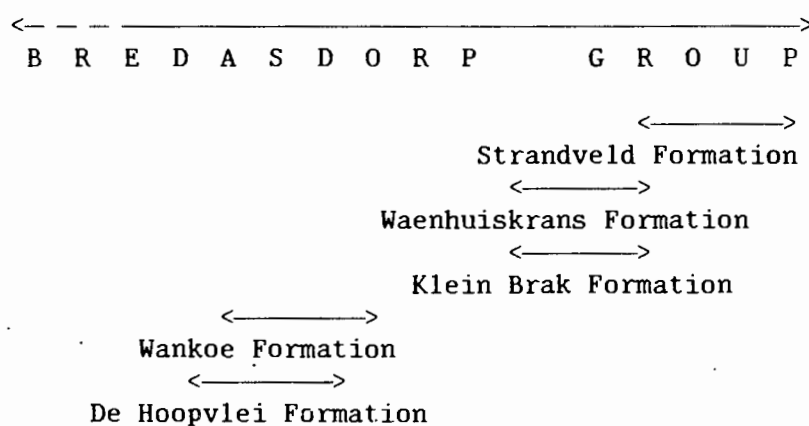


TABLE 2. Stratigraphy of the Bredasdorp Group, Southern Cape Province (Malan, 1986 and 1989a, Table 1).

TERTIARY				QUATERNARY	
Eocene	Oligocene	Miocene	Pliocene	Pleistocene	Holocene



CHAPTER 3. METHODS

3.1 FIELD WORK

Geological mapping of the area south of 34°15'S and to the west of Still Bay was carried out by the writer (Figure 1) in 1983 and 1984 (Malan *et al.*, in preparation). Field mapping was carried out on aerial photographs of Jobs 719 (1973) and 735 (1974). All relevant geological information was transferred onto 1:50 000 topographic sheets. For this detailed study of the Cainozoic deposits the author measured 34 lithostratigraphical profiles with a cumulative length of 825m. Data were evaluated from 500m of core from 40 boreholes drilled between Waenhuiskrans and De Hoopvlei during an engineering-geological site investigation in the Overberg Missile Test Range (Figure 1). Palaeocurrent data were determined with the aid of a Breithaupt structural compass, by measuring dip and dip-directions of foresets in crossbeds and by measuring the orientation of the long axes of pebbles. Observations of sedimentary structures, both primary and secondary, were made to assist in the elucidation of the depositional environments.

3.2 LABORATORY METHODS

The stratigraphic profiles were drawn according to a standard method (Johnson, 1986; Selley, 1990). This simplified comparison between sections. The lithology was determined macroscopically, and a microscopic investigation was performed on selected samples. Grain-size analyses of the leached sand-fractions was performed using a settling tube (Flemming and Thum, 1987). The carbonate content of selected samples was determined with the aid of the Karbonat Bombe method (Müller and Gastner, 1971; Birch, 1981) and through the leaching of some of the calcareous samples. After a comparison of 18 results using both methods, it was decided to use the time-saving and more efficient Bombe method.

3.3 STRATIGRAPHIC PROFILES.

After a detailed study of the lithology, primary structures and fossils in the four older consolidated formations of the Bredasdorp Group a special key was devised for their illustration. The graphic presentation of the profiles follows Selley (1982) and a more expanded format devised by Johnson (1987). Several columns are used (shown from 1 (left) to 9 (right) in Figure 2); the legend of the symbols and abbreviations used in the stratigraphic profiles is shown in Table 3.

- 1) The left-hand column shows lithological types, grain size and the location of plates illustrating field characteristics. The character of the base of each bed (gradational, sharp or eroded) is also shown diagrammatically.
- 2) The next two columns show sedimentary structures (Column 2) and palaeontological information (Column 3) i.e. fossil content and ichnofossils.
- 3) Column 4 describes the lithology in detail, i.e., grain size, sorting, roundness, grain type, clast type, maximum clast size, etc.
- 4) The calcium carbonate percentage, ranging between 0 and 100 percent, is shown graphically by a line diagram linking individual data points; the ornamented area indicates values more than 50 percent (Column 5).
- 5) Column 6 indicates the facies type as described in chapter 10 for that specific interval.
- 6) The next three columns (7 to 9) show interval thickness in metres, interval numbers referred to in the text, and stratigraphic units.

One aspect of this method which is not entirely satisfactory is the grain-size designation. For many samples it was difficult to measure grain size, both in hand specimen and/or in thin section.

Solution and recementation of carbonate grains in particular, led to unreliable grain-size determination in calcarenite (cf. Smuts, 1987). To obtain an indication of grain size in the calcarenite and calcareous sand, small samples were treated with dilute hydrochloric acid. The size distribution of the non-carbonate fraction was initially estimated under a binocular microscope, and grain size was then determined in a settling tube at the Bellville office of the Geological Survey (Brink and Rogers, 1979; 1985).

Clasts can easily be recognised in coquinites and conglomerates: clast type as well as maximum and average clasts size is indicated in profiles in the description column. Grain size is shown where samples of the matrix, i.e. sand size fraction, were available. The profiles are accompanied by a simplified locality map of the area showing profile locality, roads, farm names and boundaries and, where applicable, unit outcrop. For a more detailed location map the reader should refer to the 1:50 000 topographical map of the relevant area.

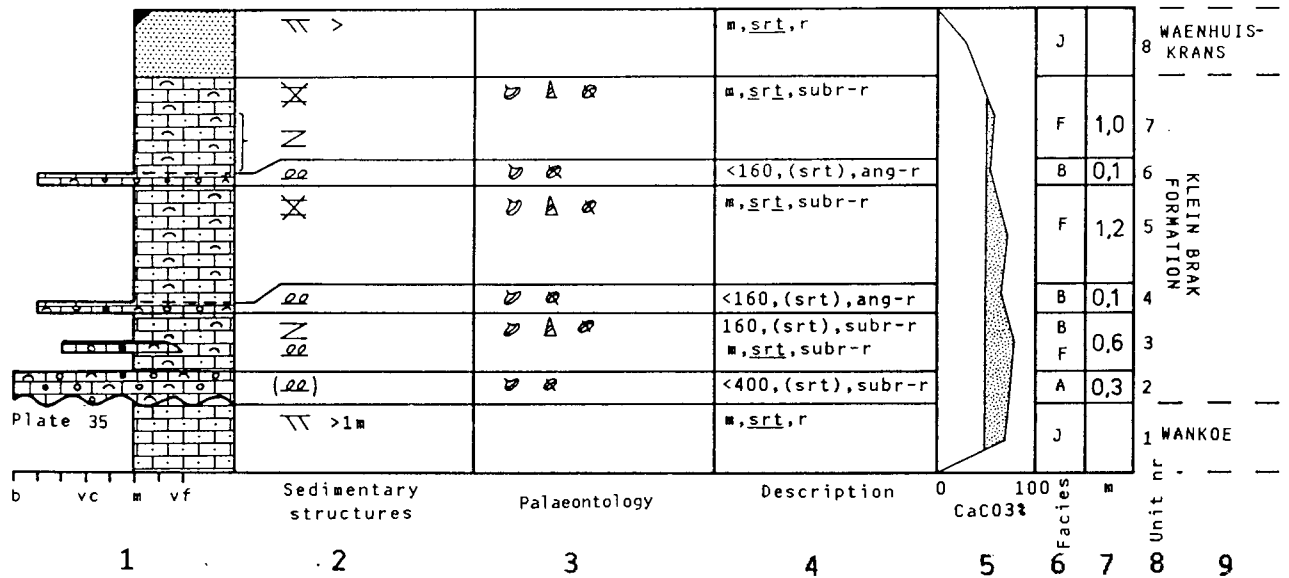


FIGURE 2. Example of the format used for graphic presentation of all the profiles for the different formations of the Bredasdorp Group. (Columns 1 to 9 defined on page 8).

TABLE 3. Legend for the stratigraphic profiles of the Bredasdorp Group.

LITHOLOGY

	Siltstone	
	Sandstone	○ conglomeratic
		● intra-formational
		⊕ shelly
		⊕ calcareous
	Limestone	○ calcirudite
		● intra-formational
		⊕ calcarenite
		⊕ shelly
		⊕ crystalline
	Conglomerate	● intra-formational
		⊕ matrix-supported
		⊕ shelly
	Calcrete	
	Peat	
	Alternating lithologies	
	No outcrop	

SEDIMENTARY STRUCTURES

	No visible structures
	Vague structures
	Massive
	Ripples
	Horizontal lamination
	Graded bedding
	Micro crossbedding
	Inclined bedding
	Reactivation surfaces
	Crossbedding (general)
	Planar crossbedding
	Trough crossbedding
	Herringbone crossbedding
	Imbrication
	Palaeostream directions

CONTACTS

---	Gradational contact
—	Sharp contact
~	Eroded contact

BIOGENIC STRUCTURES

	<u>Ophiomorpha</u>
	<u>Skolithos</u>
	Bioturbation
U	Vertical burrows/tubes
C	Horizontal burrows/tubes
∇	Plant roots

TEXTURE
















b	Boulder
p	Pebble
g	Gravel
vc	Very coarse grained
c	Coarse grained
m	Medium grained
f	Fine grained
vf	Very fine grained
wr	Well rounded
r	Rounded
subr	Subrounded
sub	Subrounded- Subangular
suba	Subangular
ang	Angular
<u>srt</u>	Well sorted
<u>sr</u>	Moderately sorted
(srt)	poorly sorted

TABLE 3 (continued). Legend for the stratigraphic profiles of the Bredasdorp Group.

ABBREVIATIONS

X	Mean size (mm)
<	Maximum size (mm)
200	Size (mm)
200x100x50	Max. clast size (mm)
—	Highly
- -	Moderately
()	Slightly
gln	Glauconite grains
qz	Quartz grains/clasts
qt	Quartzite grains/clasts
ca	Calcarenite clasts
sh	Shale clasts
ssh	Sandy shale clasts
hm	Heavy minerals
m	Thickness in metre
mm	Thickness in mm
Nr	Unit number
340/25	Dip and dip direction
org	Organic material
t	Terrestrial
>1m	Large-scale crossbedding
GRP	Group
FRM	Formation
K	Facies

FOSSILS

	Fish remains
	Shark's teeth
	Bryozoa
	Echinoidea
	Bivalvia
	Gastropoda
	Comminuted shells
	Foraminifera
	Spines
	Terrestrial
	Algae
	Lenticular beds
	Lenticular litho-units
	Semi-consolidated
	Unconsolidated

CHAPTER 4. PRE-BREDASDORP BASEMENT

The terraces on which all Bredasdorp deposits were accumulated consist of Late Precambrian (Pre-Cape rocks), Palaeozoic (Cape Supergroup) and Jurassic/Cretaceous (Lower Uitenhage Group) formations. These rocks reacted differently to the erosional forces imposed on them during Cainozoic transgressive-regressive cycles. As early as the Lower Tertiary, the more resistant Table Mountain Group quartzite of the Cape Supergroup formed highlands, ridges and capes such as Danger Point, Cape Agulhas and Cape Infanta (Figure 1). The highlands and mountain ridges of Soetanyenberg, Potberg and Aasvoëlberg formed islands during the transgressional periods (Figure 3). In the Bredasdorp area and around Aasvoëlberg, the sea reached inland as far as 25km from the present shoreline. The positive-weathering quartzites today form the capes and points of bays such as Walker, Struis, St Sebastian, Still and Vlees Bays (Figure 1), whereas the embayments were carved into more easily eroded Bokkeveld Group shale and Enon Formation conglomerate.

The palaeotopography and resistance of the wave-planed surfaces cut into the pre-Bredasdorp bedrock, together with sea-level fluctuations, controlled the thickness, sediment type and the elevation of the Bredasdorp sediments above present sea-level (Plate 1). At present, the seaward slope of the pre-Bredasdorp bedrock surface can be as much as 11m/km for the more resistant quartzitic Table Mountain Group basement as seen along the Potberg coastline (Section A-A', Figures 3 and 4). Where softer Bokkeveld shale occurs, a gentler seaward slope of 5,6m/km was measured in both the De Hoopvlei (Section B-B', Figures 3 and 5) and Blombos areas (Section C-C', Figures 3 and 6).

This is in agreement with previous workers (Wybergh, 1919; De Bruin, 1971; Whittingham, 1971) showing that the bedrock surface in

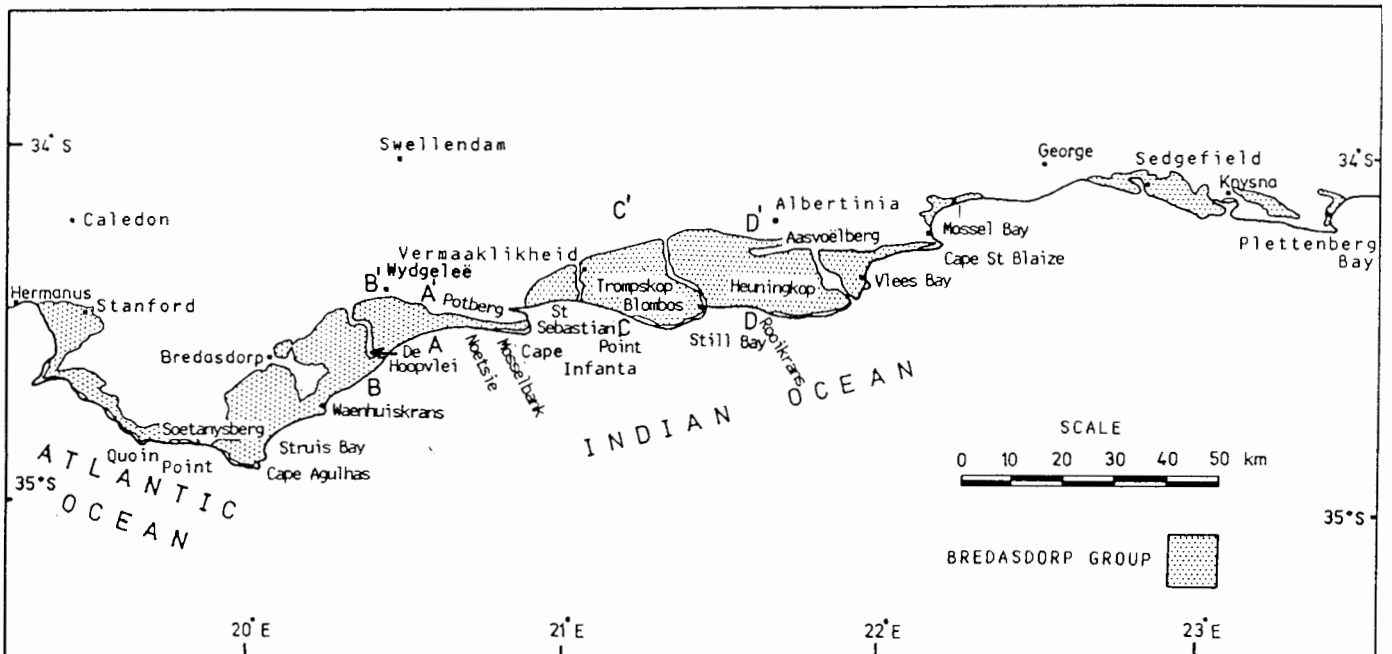


FIGURE 3. Locality diagram for the Bredasdorp Group, southern Cape Province.



PLATE 1. View, looking eastward from Rooikrans (Figure 11a), of the southward-sloping wave-planed surface (arrowed) cut into Bokkeveld shale on the eastern side of the Sout River Valley on the farm Windhoek, north of De Hoopvlei (Figure 3).

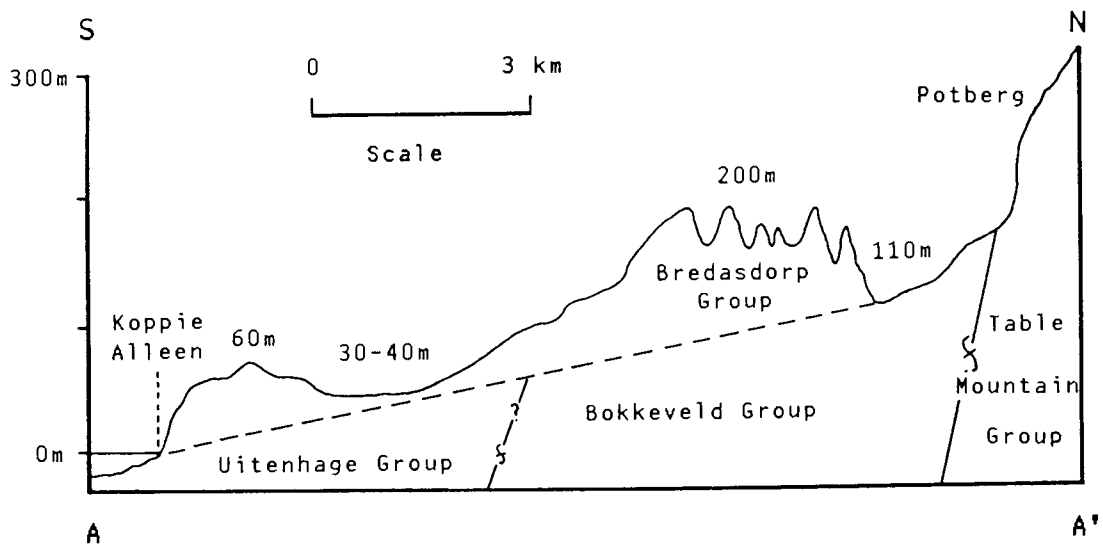


FIGURE 4. Geological section A-A' from Koppie Alleen to Potberg, Potberg coastline (See Figure 3 for section location).

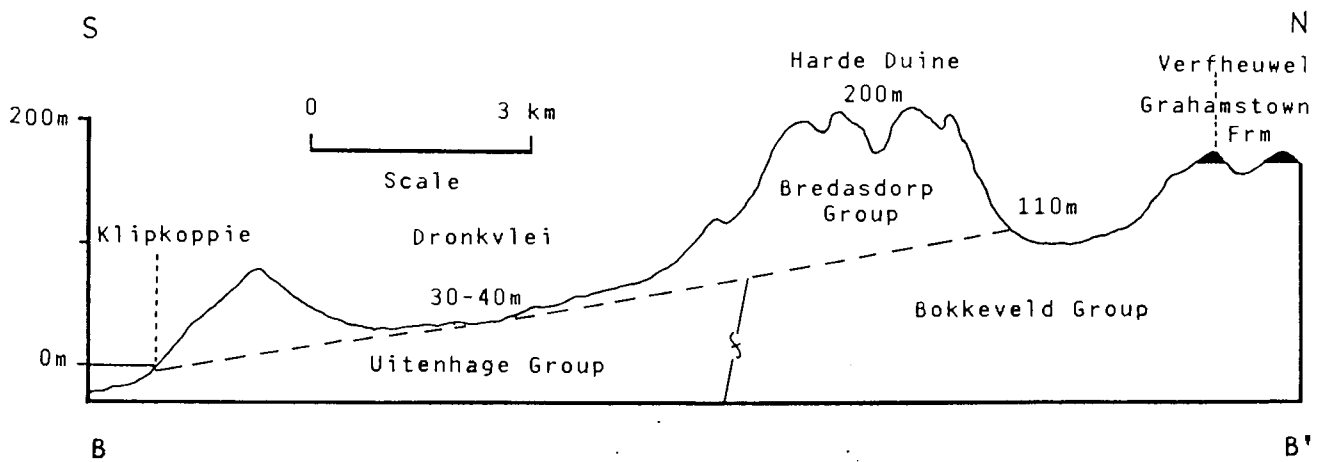


FIGURE 5. Geological section B-B' from Klipkoppie to Verfheuwel in the De Hoopvlei area (See Figure 3 for section location).

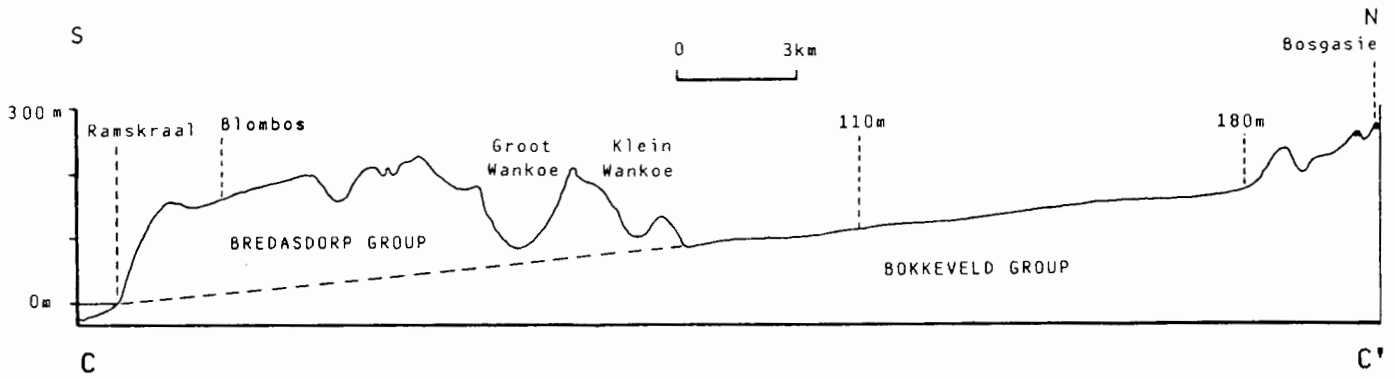


FIGURE 6. Geological section C-C' from Ramskraal to Bosgasiekop, Blombos area, west of Still Bay (See Figure 3 for section location).

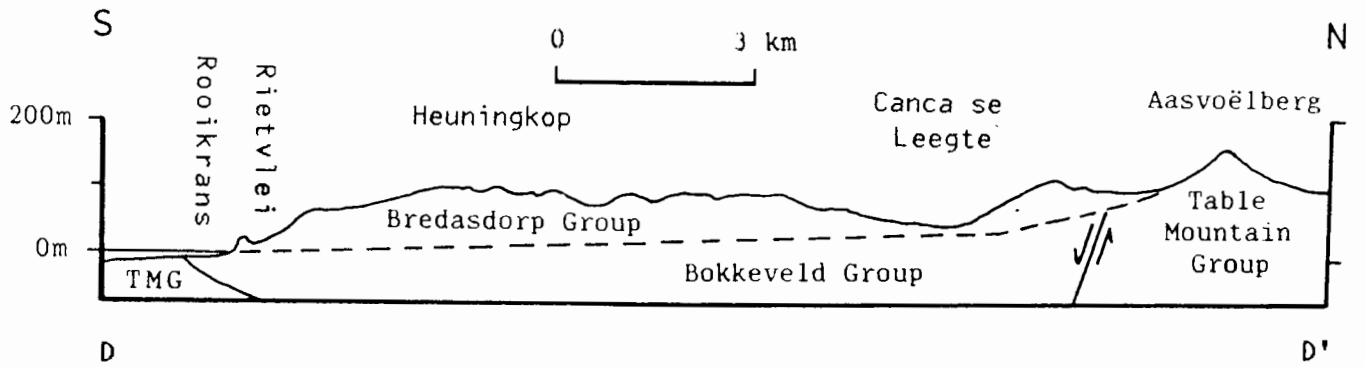


FIGURE 7. Geological section D-D' from Aasvoëlberge across "Die Duine" to the coast (Rogers, 1988, Figure 6) (See Figure 3 for section location).

the Duiwenhoks-Kafferkuils-Gourits River area is a surf-cut plain dipping gently seawards at a rate of 6m/km (33ft/mile, Wybergh, 1919, p. 47) (Section D-D', Figures 3 and 7). Evidence that Bokkeveld rocks are easily planed to a relatively smooth surface can be seen on echograms from the inner shelf between Cape Hangklip and Danger Point, whereas Table Mountain Group sandstone normally produces highly irregular topography (Rogers, 1985, Figure 3).

The total thickness of the Bredasdorp Group seldom exceeds 150m where the unit overlies quartzitic Table Mountain Group bedrock. Where Bredasdorp sediments overlie Table Mountain Group quartzites the basal marine unit (the De Hoopvlei Formation) is restricted to a thickness of only a few metres. Examples have been measured along the Potberg coast at Noetsie (1,8m), Mosselbank (2,1m), St Sebastian Point (0,6m) and along the coastal footpath westwards from Cape St Blaize at Mossel Bay (Figure 3).

The average thickness of the basal marine unit is 8m; this contrasts with a maximum thickness of 17m (measured section at the De Hoopvlei restcamp), where the De Hoopvlei Formation is underlain by the Bokkeveld Group or the Enon Formation. The combined thickness of the marine and aeolian units reaches a maximum thickness of nearly 300m at Heuningkop (west of the mouth of the Gourits River) and 270m at Trompskop (west of Still Bay) where overlying Bokkeveld bedrock (Figure 3).

"Every valley shall be exalted and every mountain
and hill shall be made low: and the crooked shall
be made straight and the rough places plain".

(Isaiah 40: 4)

CHAPTER 5. BREDASDORP GROUP

The Bredasdorp Group includes all the Cainozoic marine and marine-related (aeolian) deposits along the Cape south coast (Malan, 1989a) (Figure 8). The lignitic Knysna Formation, dated by means of palynomorphs as Eocene in age, is confined to a limited area east of Knysna (Thwaites and Jacobs, 1987). This formation is now excluded from the Bredasdorp Group due to its exclusively terrestrial origin. A Mio/Pliocene marine fauna (molluscs and benthic foraminifera) from the basal De Hoopvlei Formation was identified by Spies *et al.* (1963). Silcrete pebbles and cobbles derived from the high-level gravels of the Middle Tertiary Grahamstown Formation (SACS, 1980) are present in the basal conglomerates of the marine De Hoopvlei Formation, confirming a post-Early to Middle Palaeogene age for the latter (Malan, 1988b). The marine unit is overlain by the consolidated aeolian Wankoe Formation (Malan, 1989b).

The Middle to Late Pleistocene marine/estuarine Klein Brak Formation (Malan, in press a) contains extinct species of the Late Pleistocene Swartkops fauna described by Davies (1971, 1972) from various localities along the South African coastline. This unit is conformably overlain by semi-consolidated aeolian sands of the Waenhuiskrans Formation (Malan, 1989c). The unconsolidated aeolian Strandveld Formation of Holocene age forms extensive coastal dunefields (Malan, 1989a).

The Bredasdorp deposits become progressively younger seawards, the marine units lying on terraces of decreasing height above present sea-level close to the modern coastline.

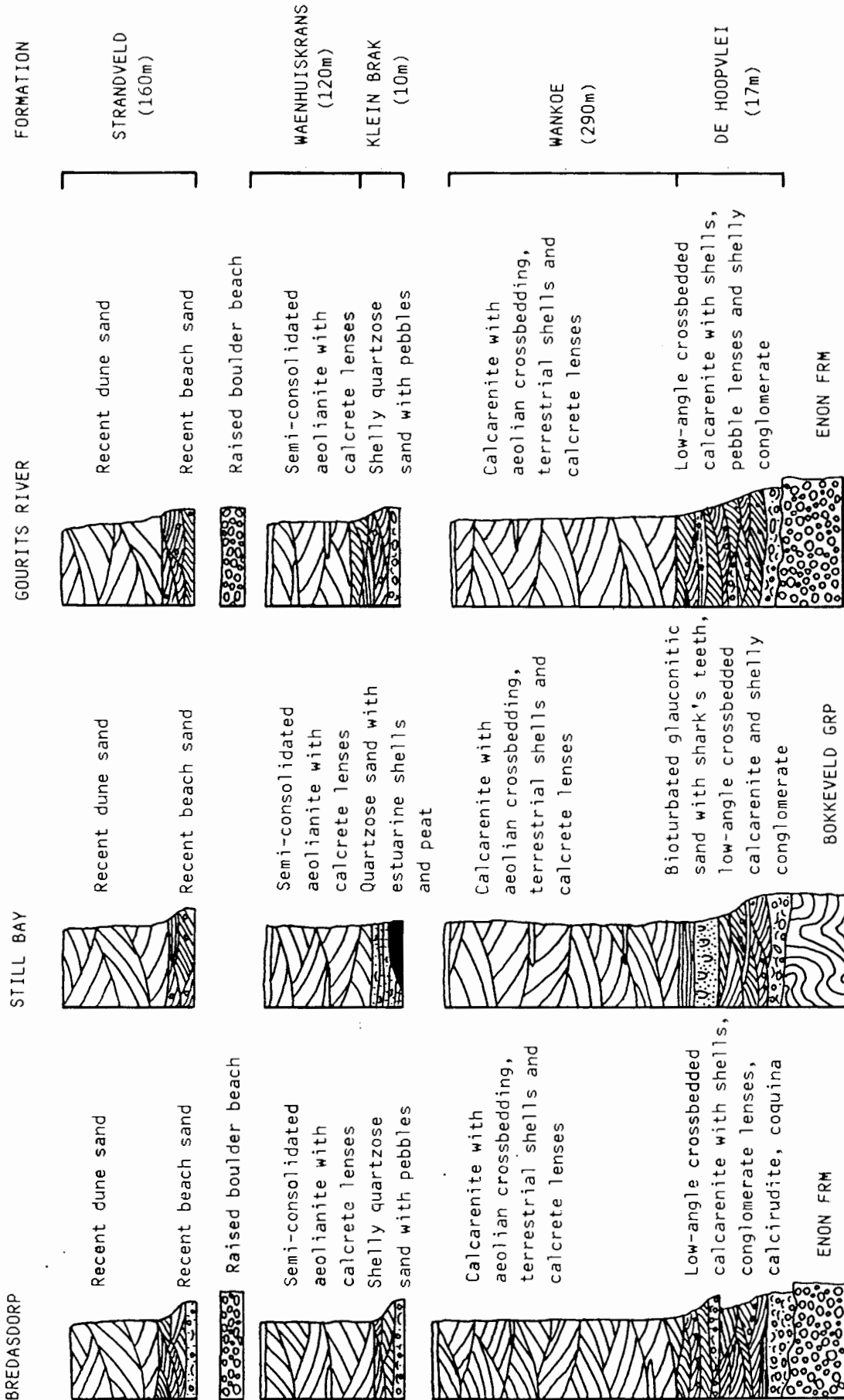


FIGURE 8. Generalised geological sections for the Bredasdorp Group (Maximum thickness of units indicated in metres).

CHAPTER 6. DE HOOPVLEI FORMATION

6.1 INTRODUCTION

The type area of the De Hoopvlei Formation is 35km east of Bredasdorp; excellent exposures occur along the banks of De Hoopvlei and in the Sout River gorge farther upstream (Malan, in press b) (Figures 9, 10a and 11a, Plate 2). The unit rests unconformably on the Cape Supergroup and Lower Uitenhage Group and is in turn conformably overlain by the Late Pliocene aeolian Wankoe Formation. The De Hoopvlei Formation is described with the aid of 22 stratigraphic profiles (Figures 10 to 16); profile abbreviations indicate the measured locality (i.e. DH = De Hoopvlei, RK = Rooikrans, SR = Sout River, BR = Bredasdorp, DR = Duiwenhoks River, KK = Kafferkuils River and GR = Gourits River).

6.2 GEOGRAPHICAL DISTRIBUTION

The De Hoopvlei Formation is limited to a narrow outcrop belt traced for 225km from Bredasdorp in the west to Mossel Bay in the east (Figure 9). The most westerly exposures can be seen along the southern edge of Heuningrug, southwest of Bredasdorp (Figure 9). From here the thin marine unit can be traced eastwards to St Sebastian Point, north of Cape Infanta (Figure 9). The best exposures occur in the Kars and Sout River valleys and along the left (eastern) bank of De Hoopvlei, where river incision has cut through the Bredasdorp Group sediments to expose the underlying Bokkeveld shale and Enon gravels (cf. Malan and Theron, 1987) (Figure 9).

The northern boundary of the deposits is well exposed on the farms Kathoek (Figure 11a), Drie Fontein (Figure 11a) and Renosterfontein (Figure 12a). Between Witsand, at the mouth of the Breede River,

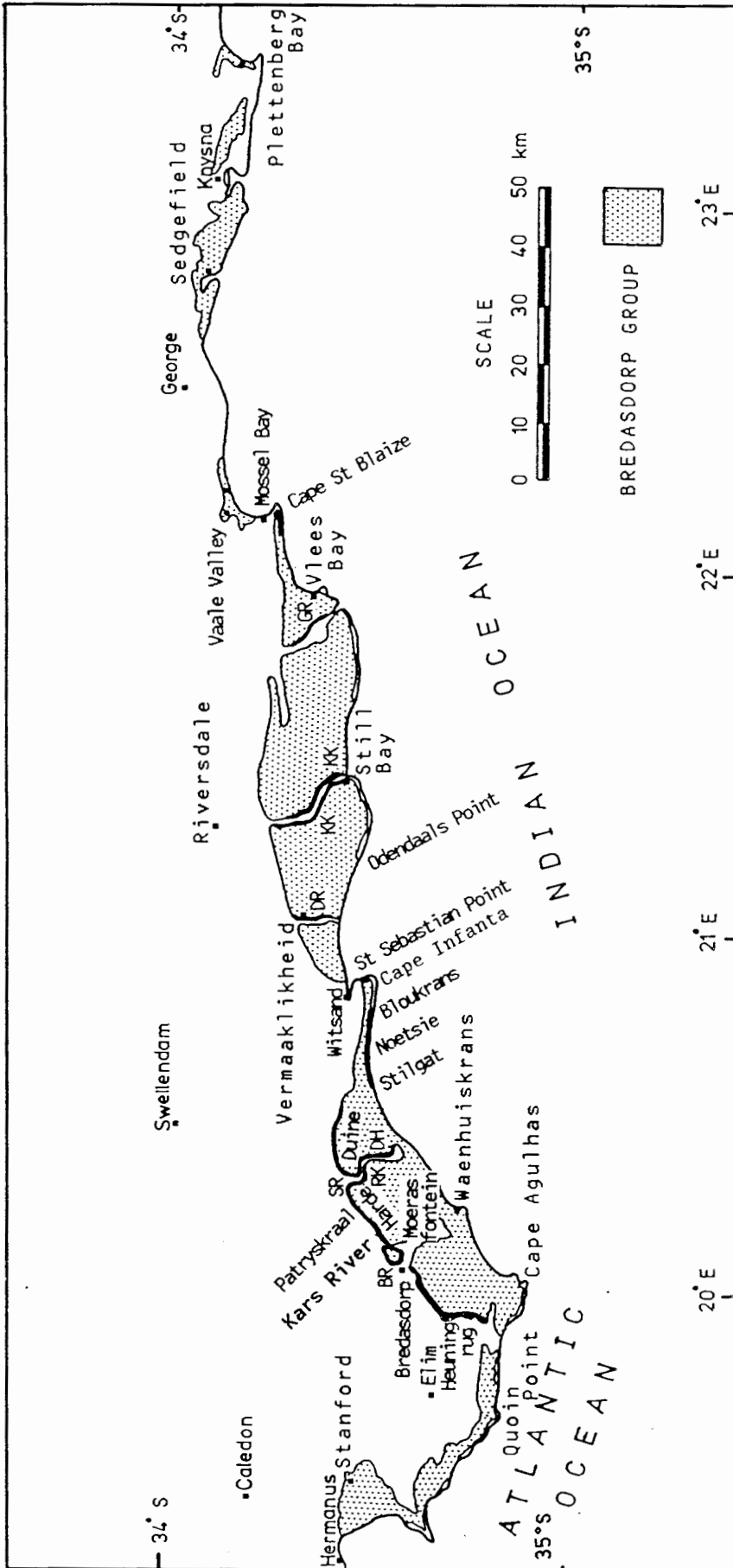


FIGURE 9. Profile localities and locality diagram for the De Hoopvlei Formation, Bredasdorp Group. Outcrops of De Hoopvlei Formation indicated by black colour.

- DH = Profiles DH I to DH VII, De Hoopvlei.
- SR = Profile SR I, Sout River.
- DR = Profile DR I, Duiwenhoks River.
- GR = Profiles GR I and GR II, Gourits River
- RK = Profiles RK I to RK IV at Rooikrans, Sout River.
- BR = Profiles BR I and BR II near Bredasdorp.
- KK = Profiles KK I to KK V, Kafferkuils River.

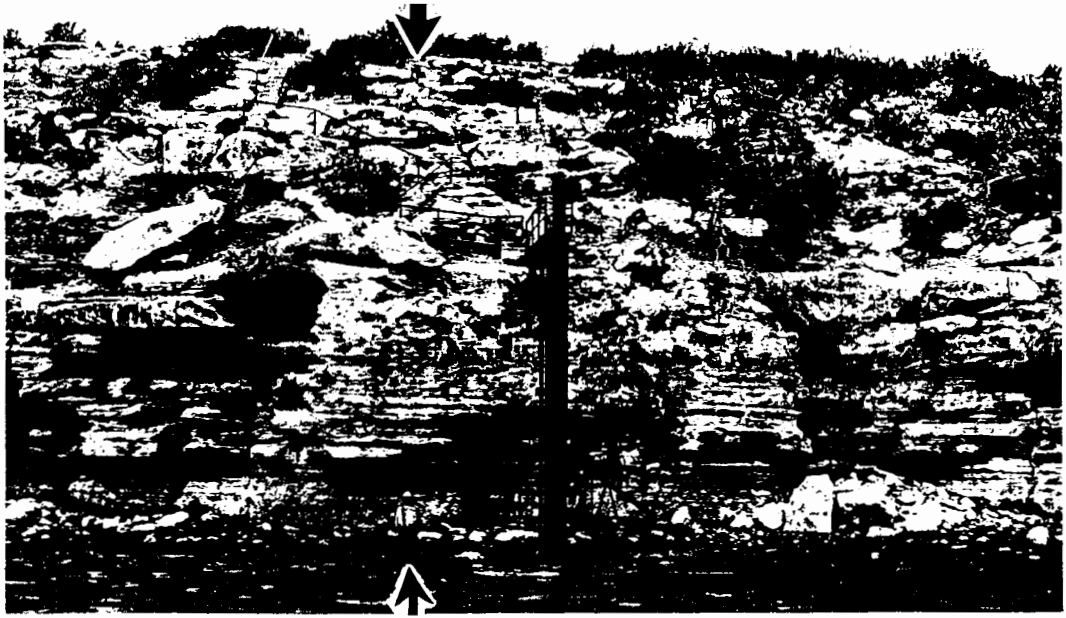


PLATE 2. Stratotype locality (arrowed) of the De Hoopvlei Formation (Profile DH I) along the east bank of De Hoopvlei at the De Hoop Nature Reserve restcamp (Figures 10a and 10b). Person at the base of the cliff for scale.

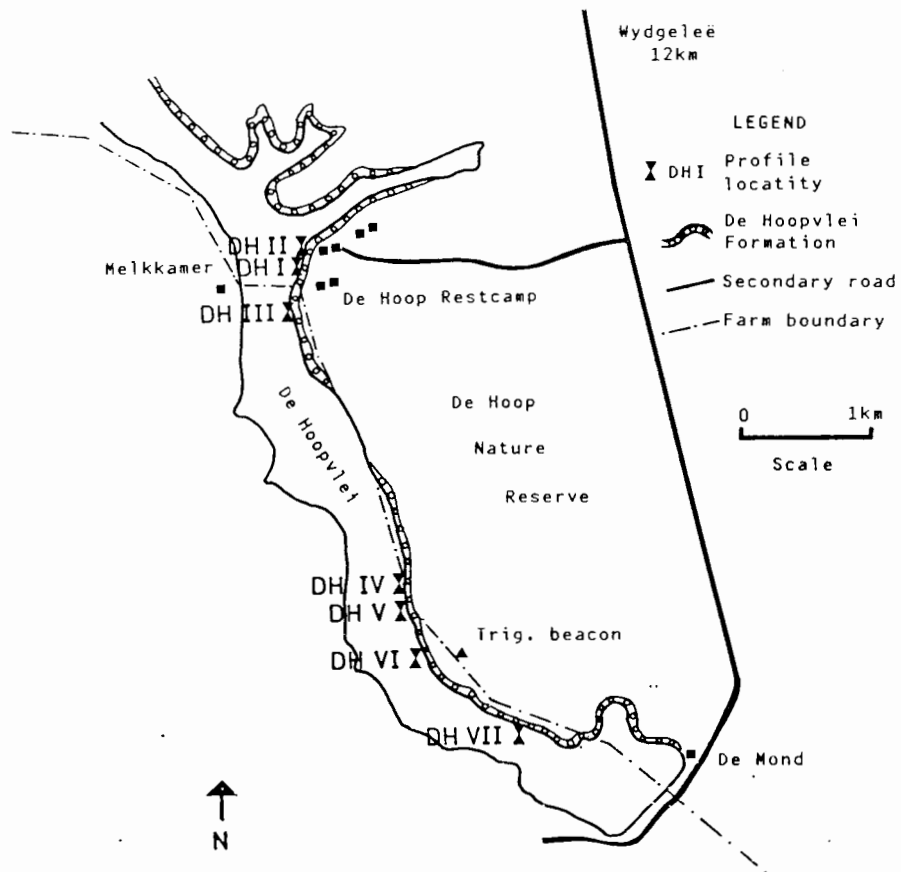


FIGURE 10a. Location diagram for profiles DH I to DH VII along the eastern shore of De Hoopvlei.

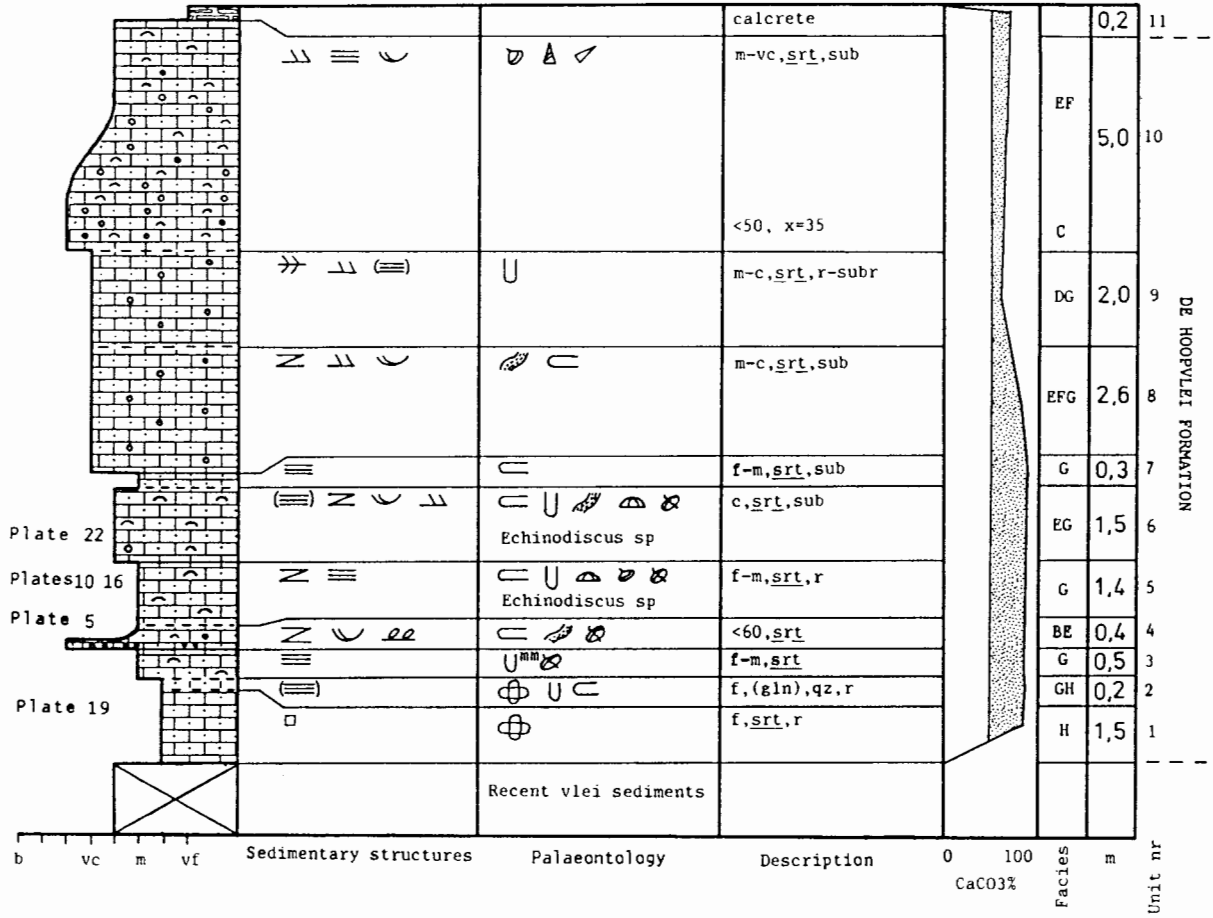


FIGURE 10b. Profile DH I, left bank of De Hoopvlei near the restcamp.

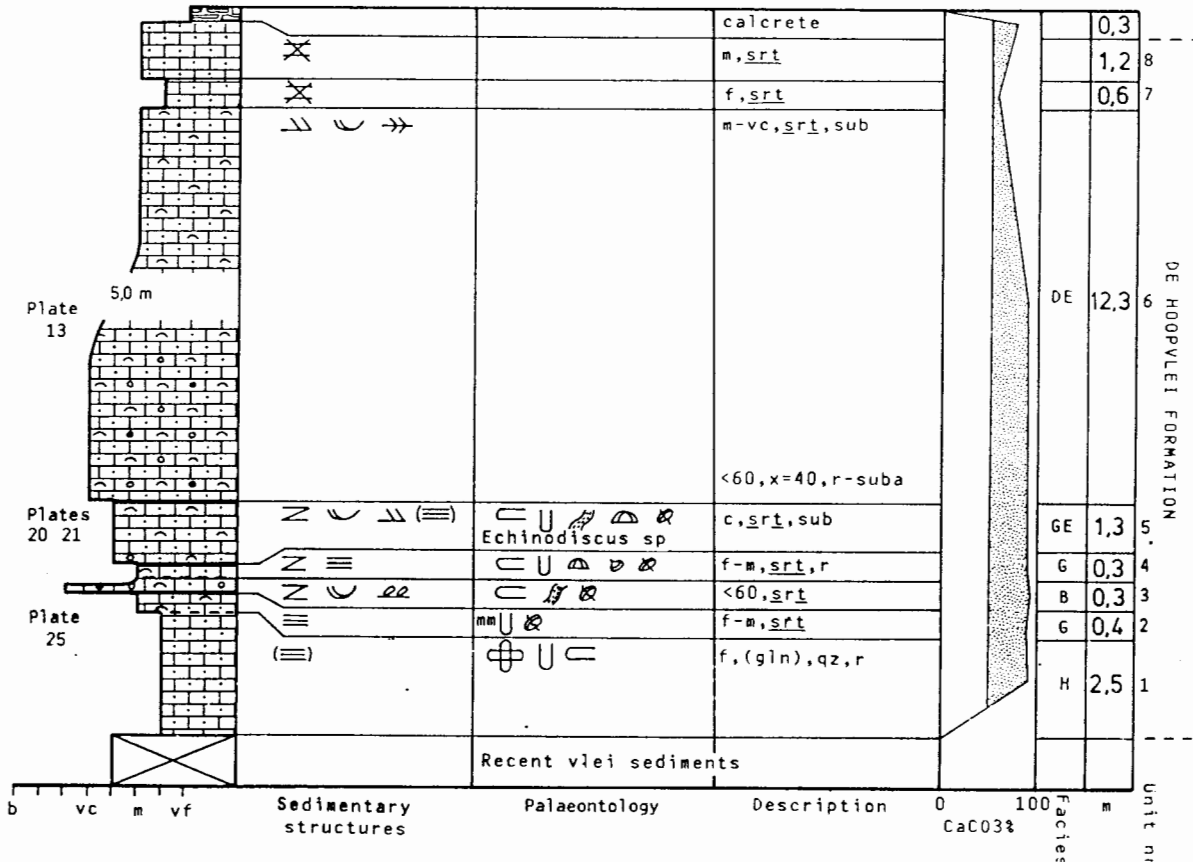


FIGURE 10c. Profile DH II, left bank of De Hoopvlei near restcamp.

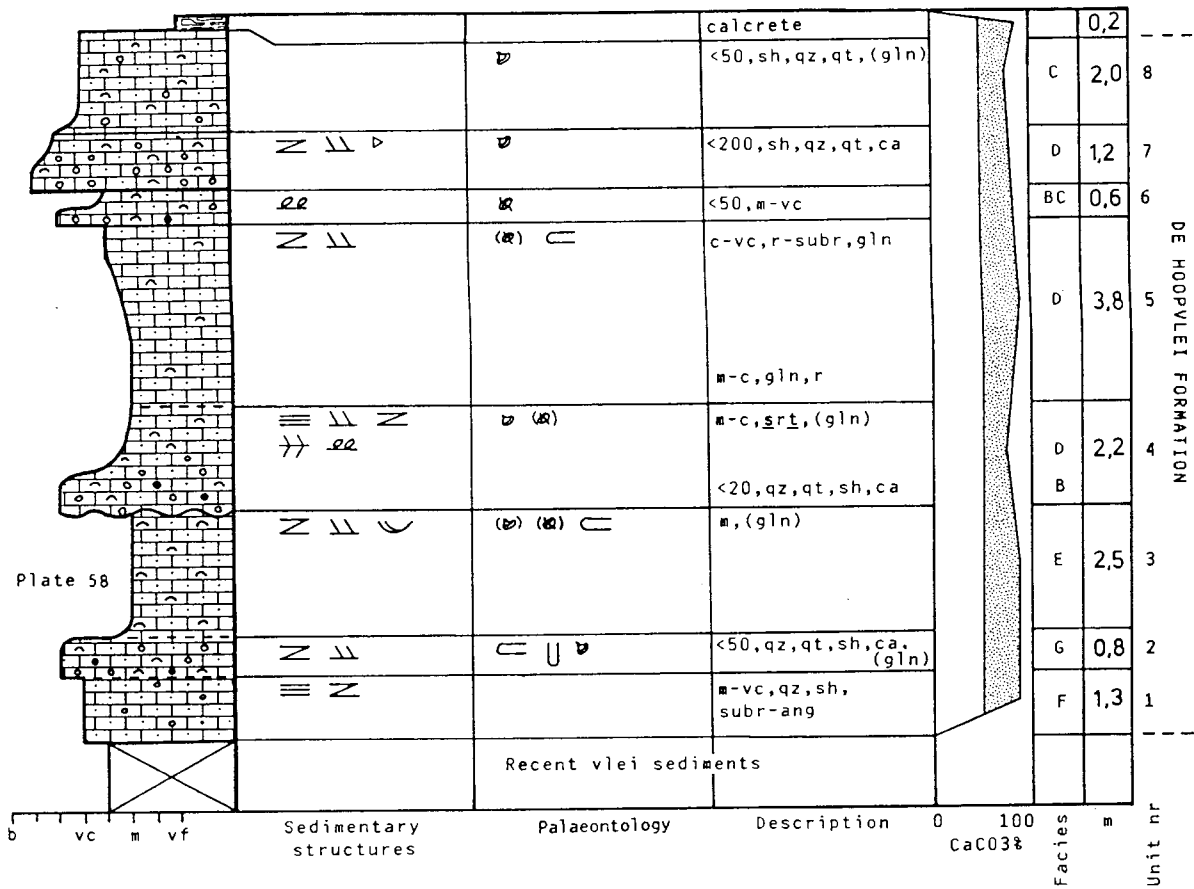


FIGURE 10d. Profile DH III, left bank of De Hoopvlei near restcamp.

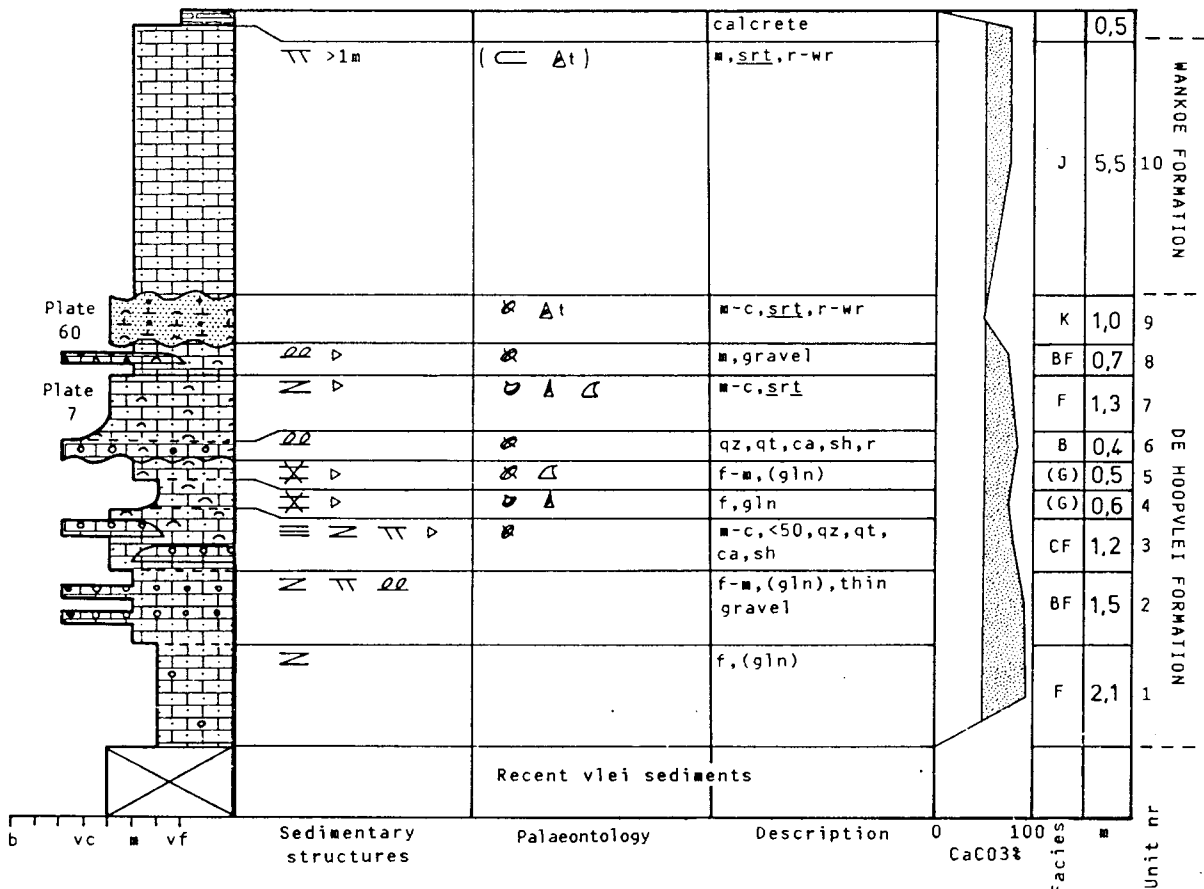


FIGURE 10e. Profile DH IV, left bank of De Hoopvlei north of trig. beacon.

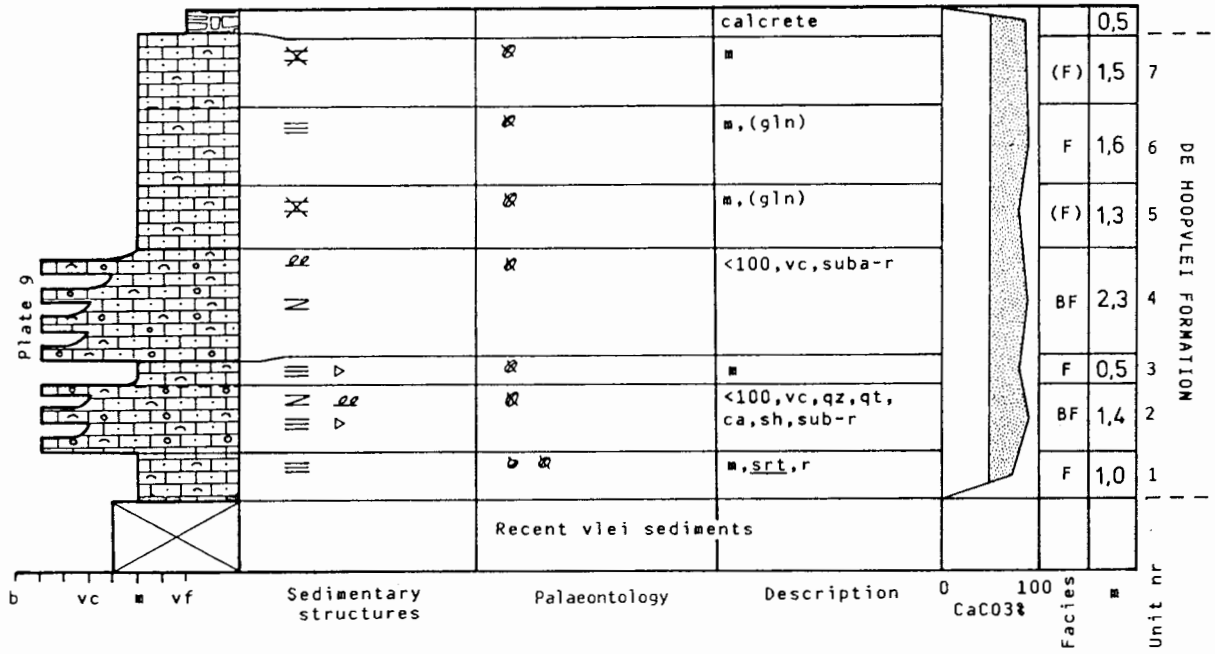


FIGURE 10f. Profile DH V, left bank of De Hoopvlei north of trig. beacon.

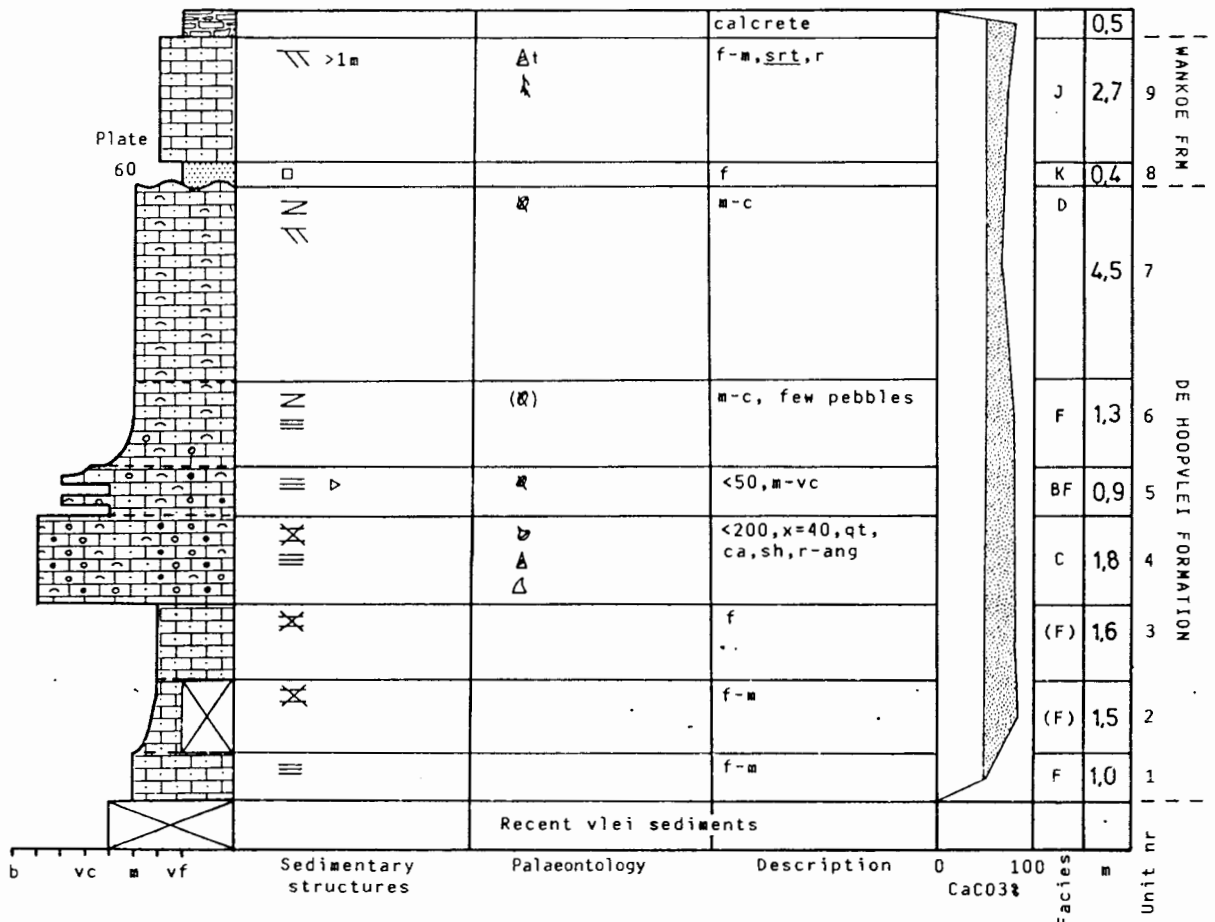


FIGURE 10g. Profile DH VI, left bank of De Hoopvlei west of trig. beacon.

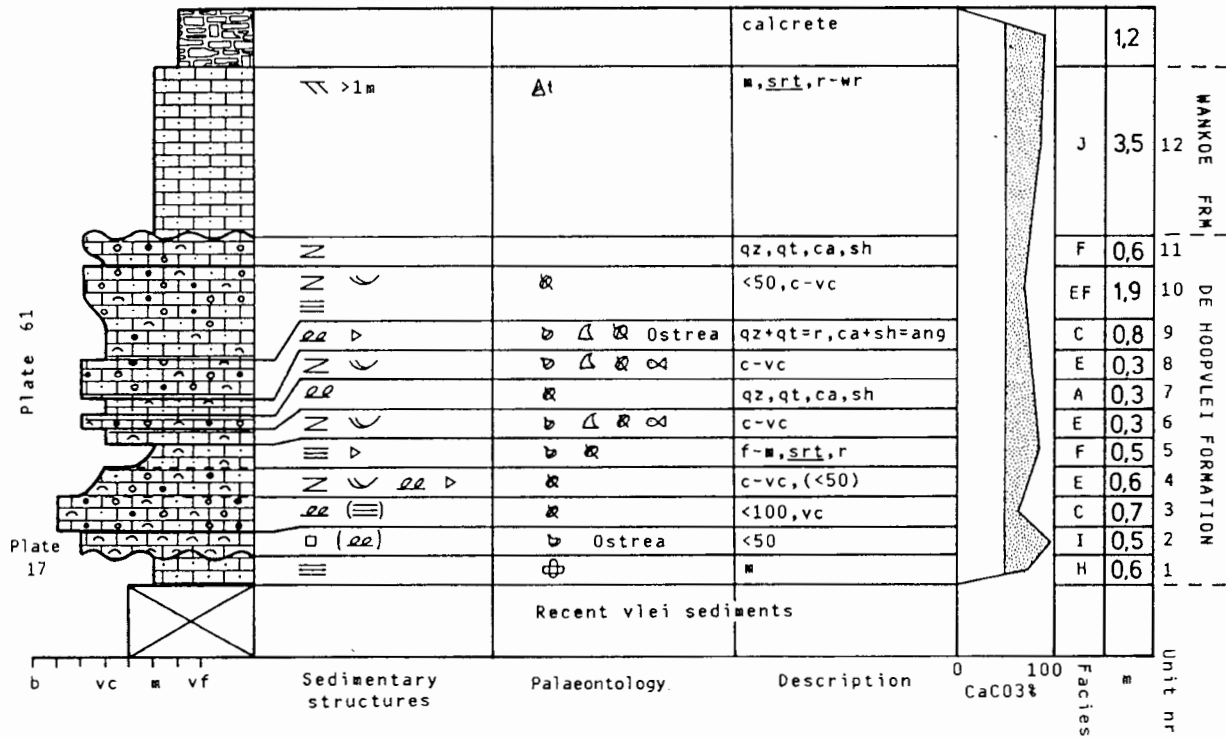


FIGURE 10h. Profile DH VII, left bank of De Hoopvlei west of De Mond.

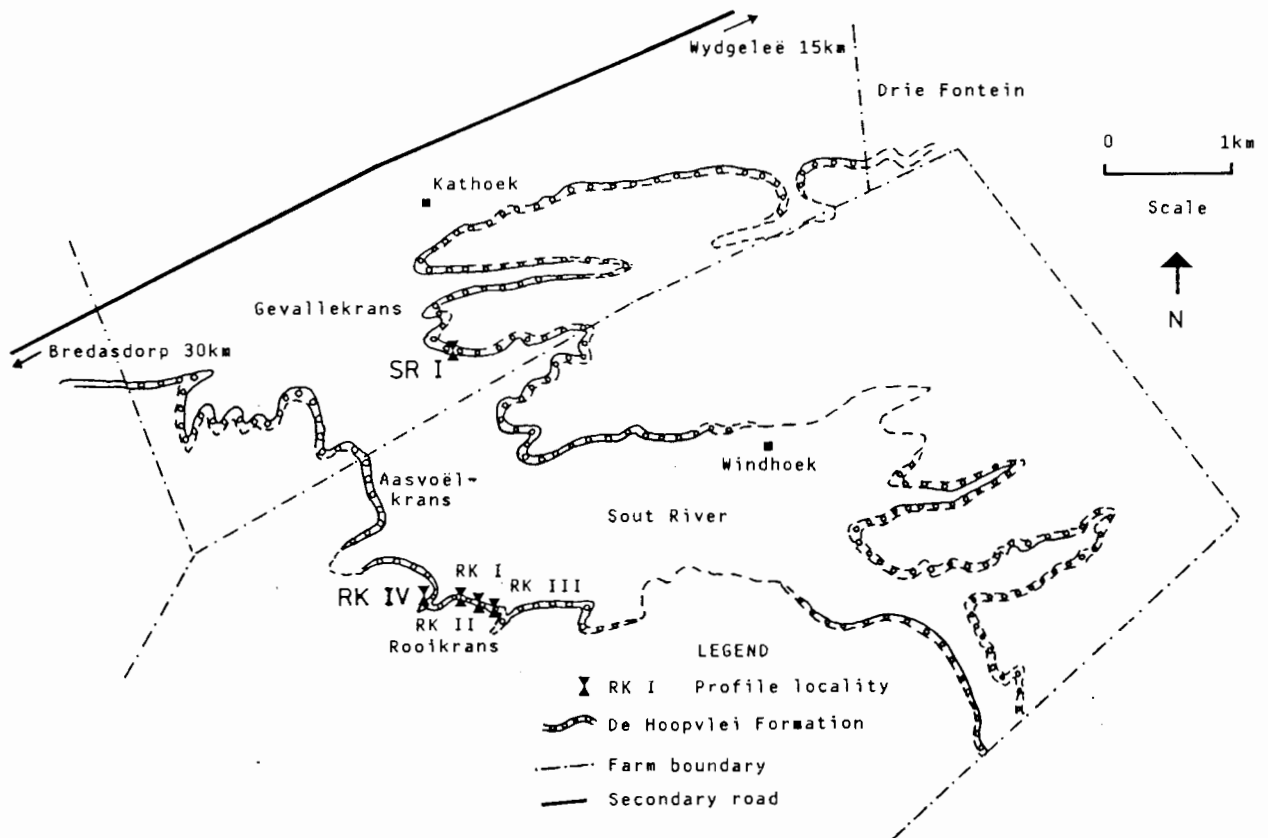


FIGURE 11a. Location diagram for profiles RK I to RK IV and SR I on Windhoek and Kathoek along Sout River.

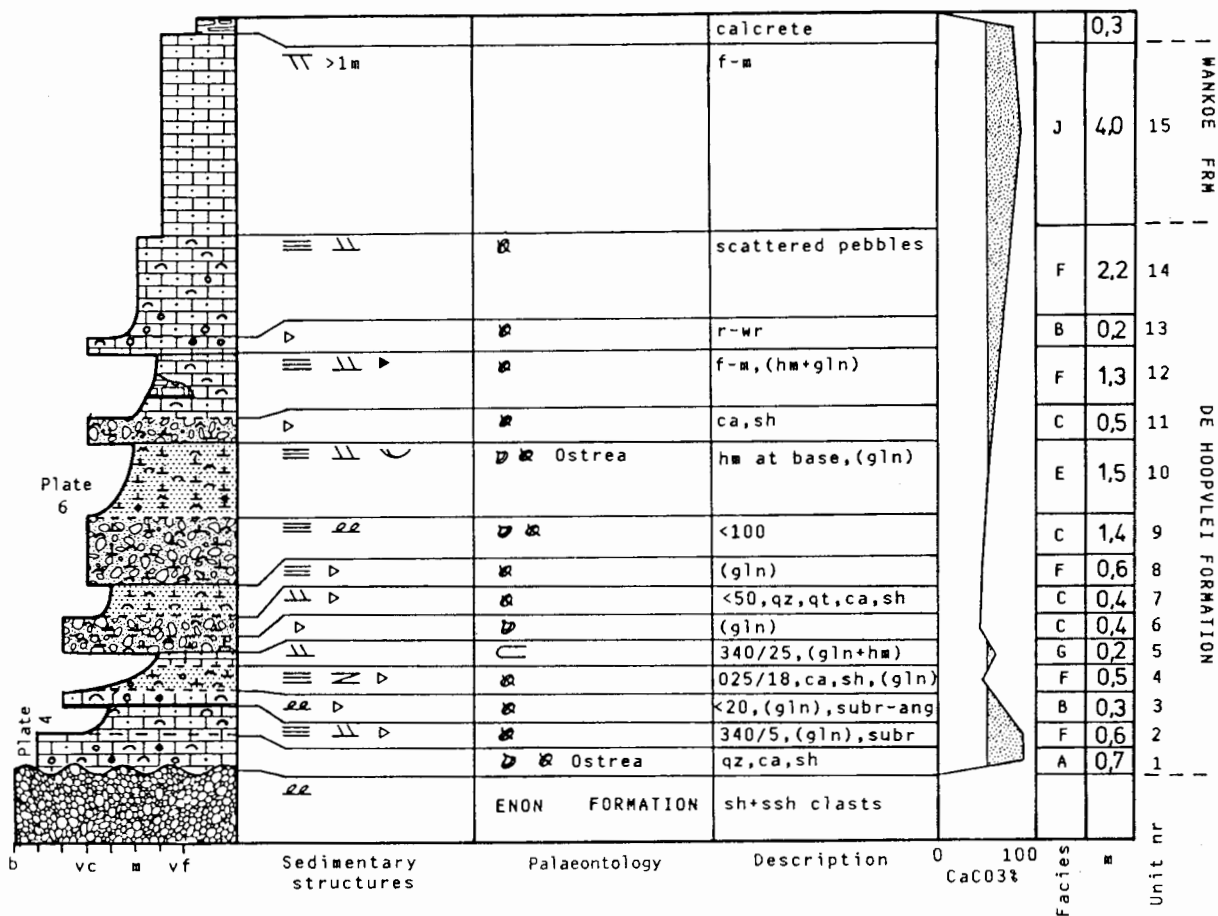


FIGURE 11b. Profile RK I, right bank of Sout River at Rooikrans.

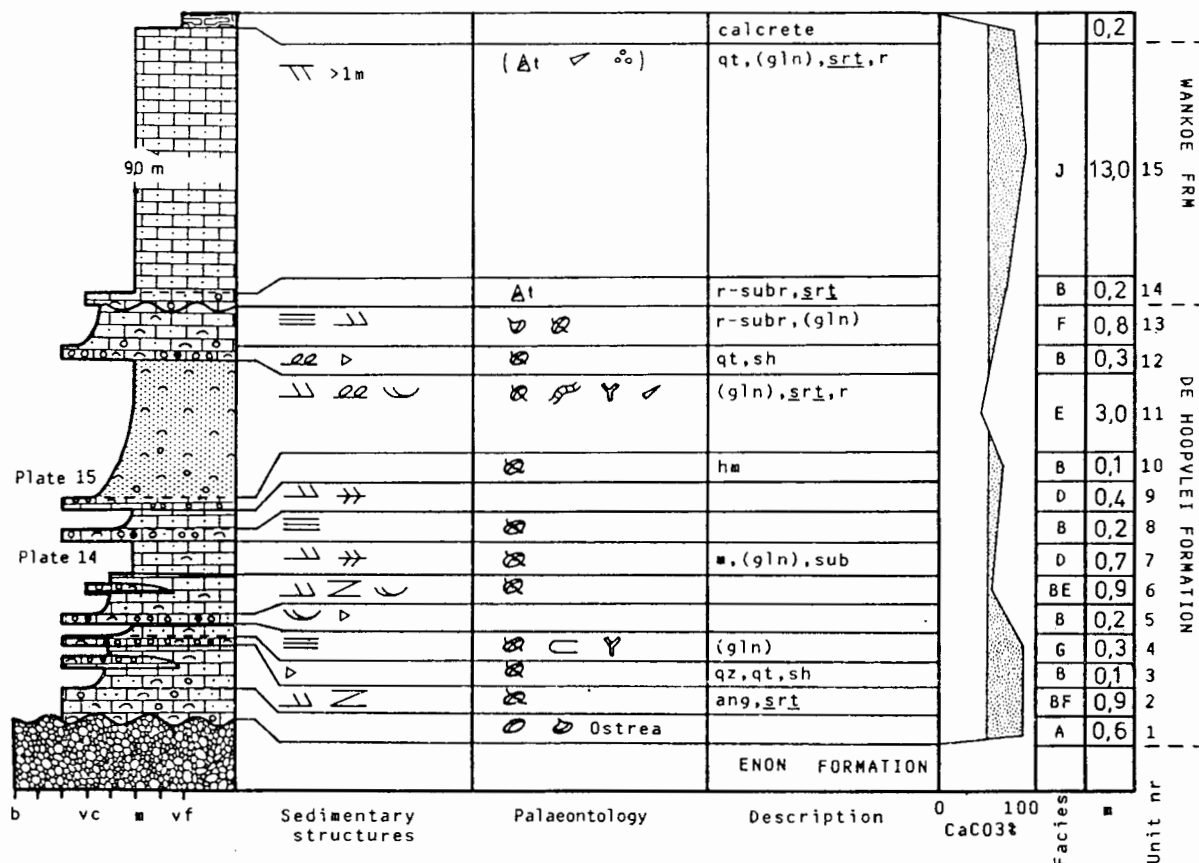


FIGURE 11c. Profile RK II, right bank of Sout River at Rooikrans.

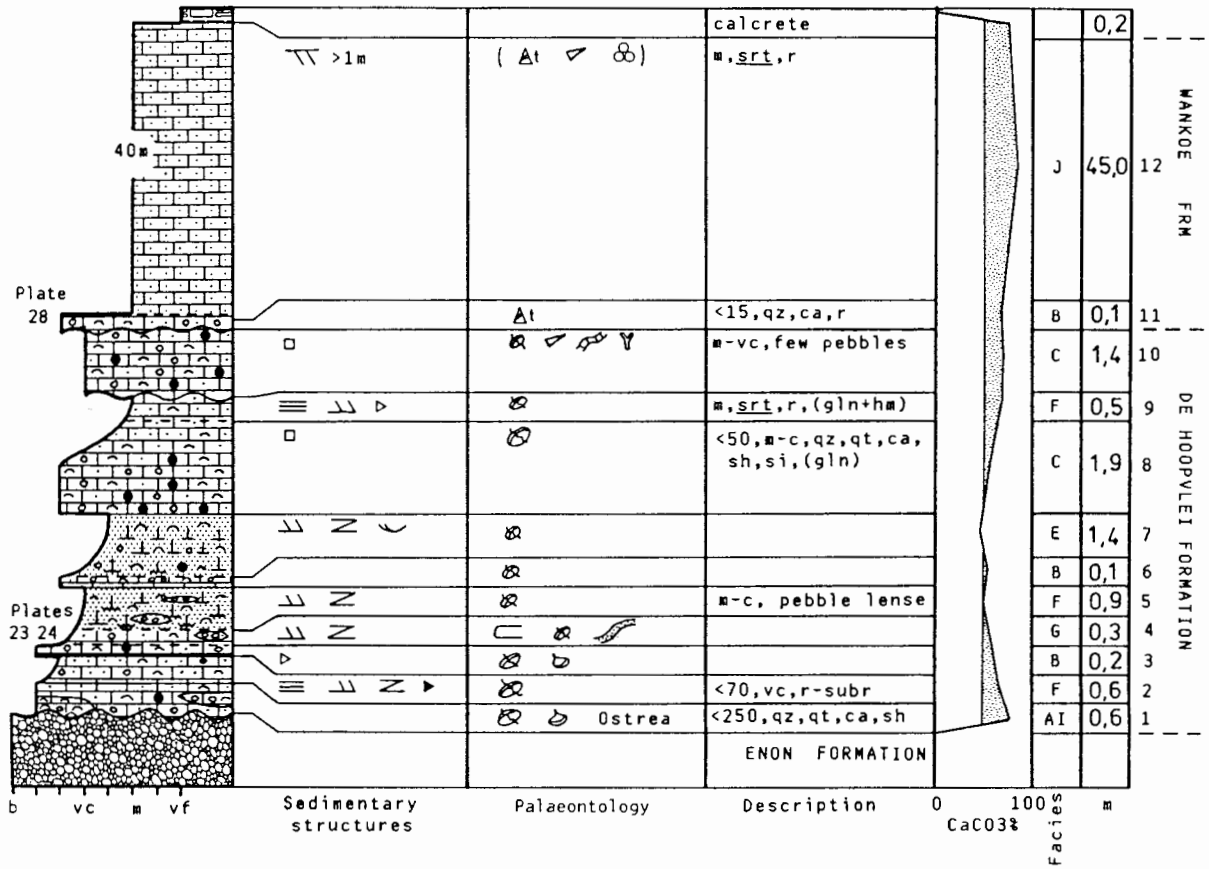


FIGURE 11d. Profile RK III, right bank of Sout River at Rooikrans.

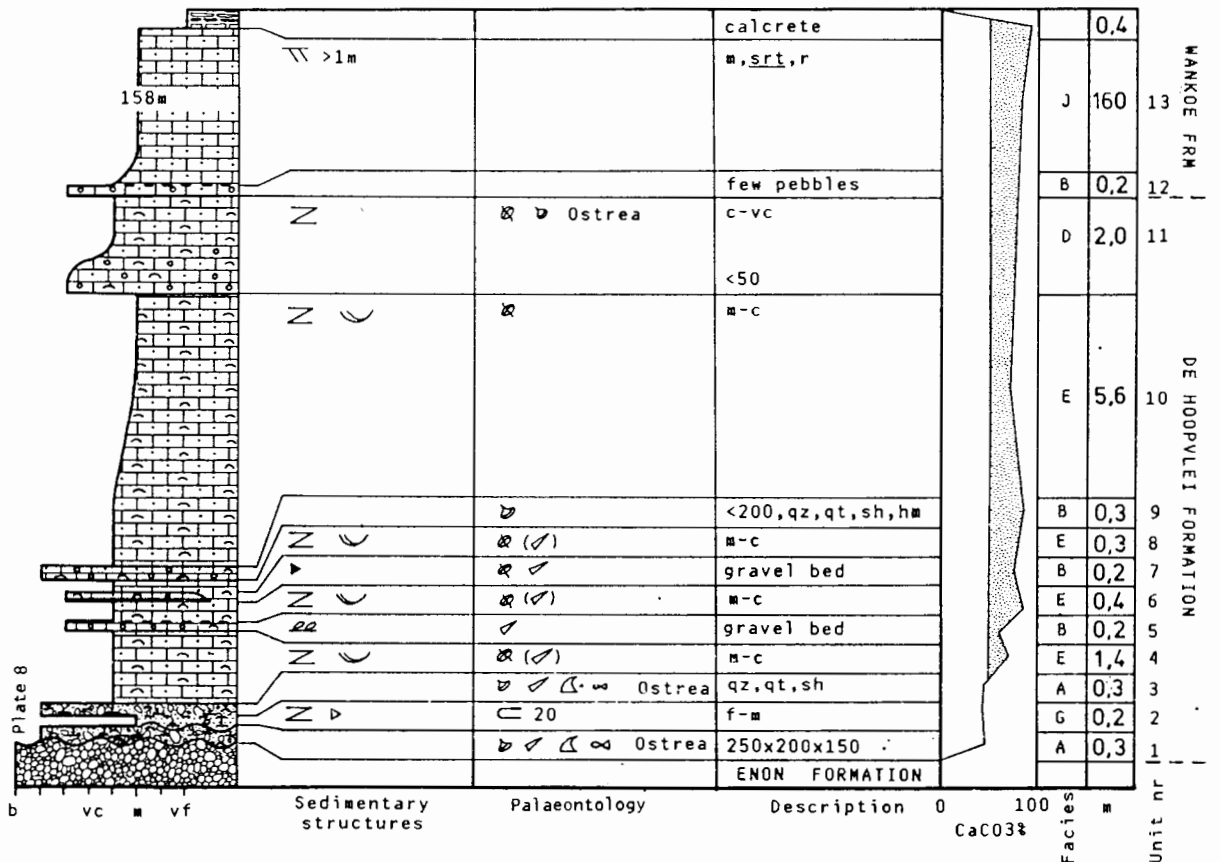


FIGURE 11e. Profile RK IV, right bank of Sout River at Rooikrans.

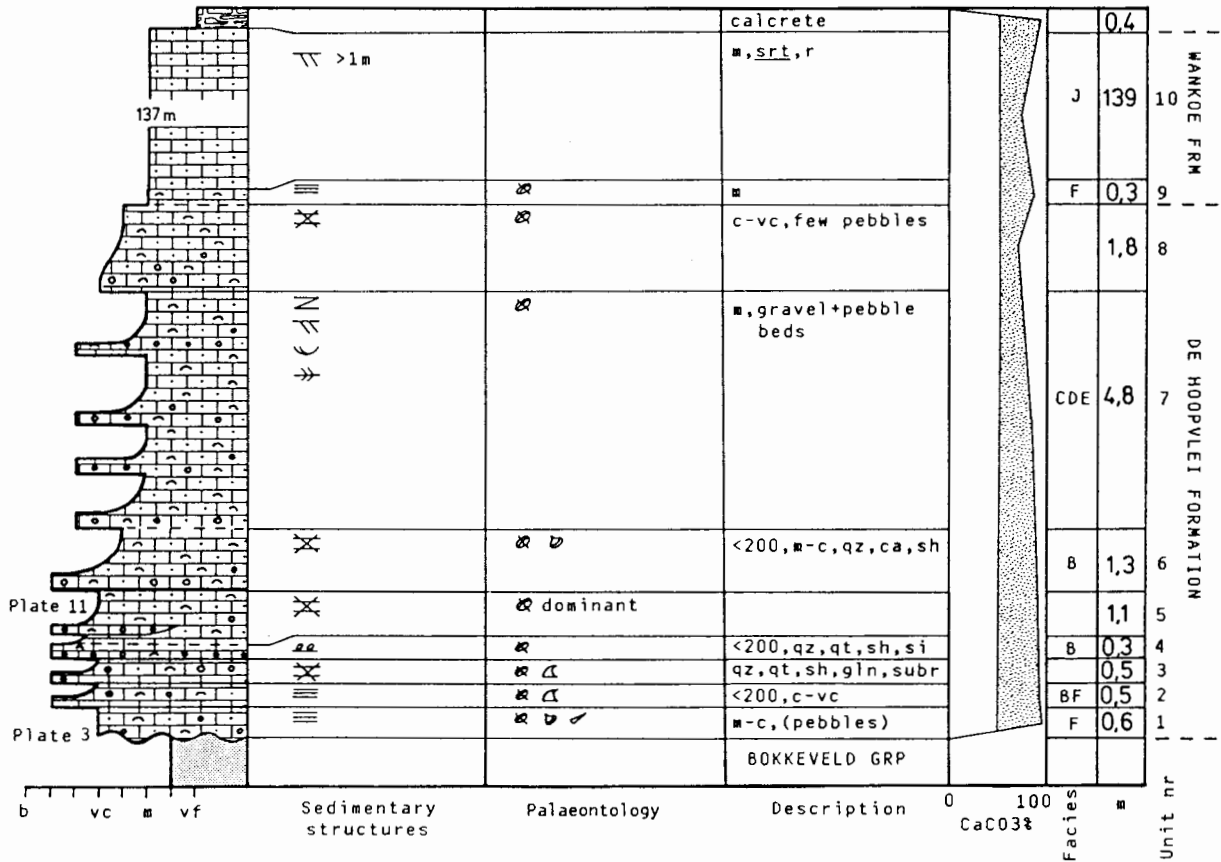


FIGURE 11f. Profile SR I, left bank of Sout River at Gevallekrans.

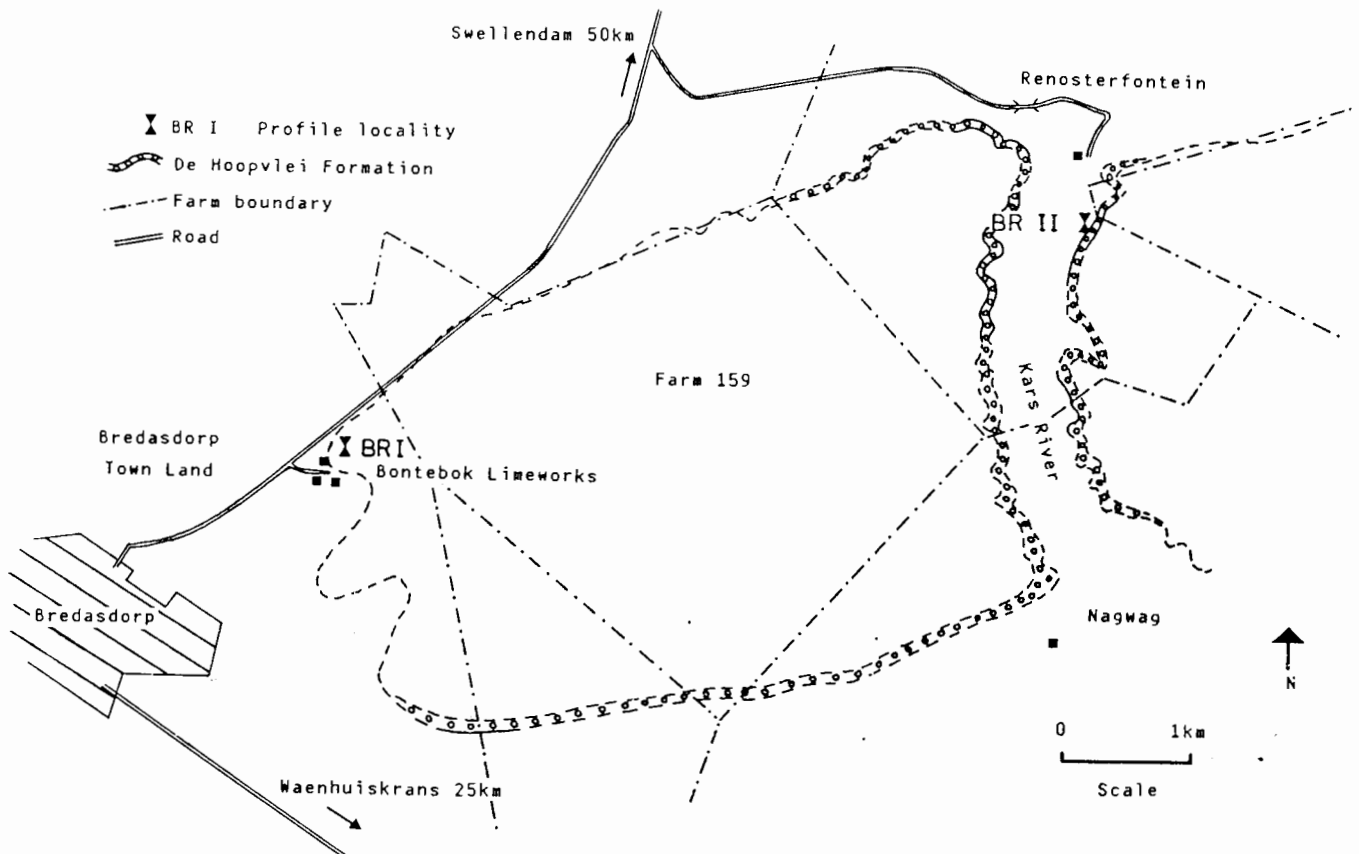


FIGURE 12a. Location diagram for profiles BR I and BR II near Bredasdorp.

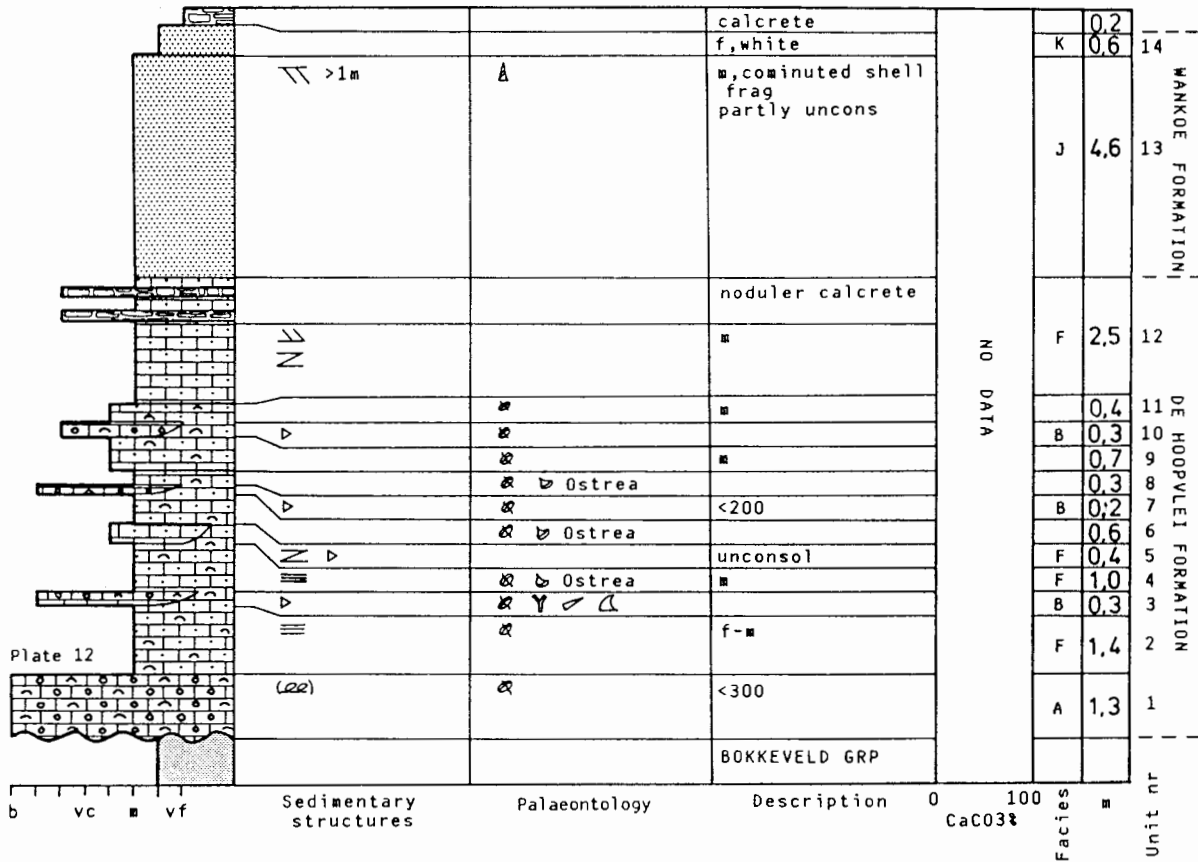


FIGURE 12b. Profile BR I, Bontebok Limeworks northeast of Bredasdorp.

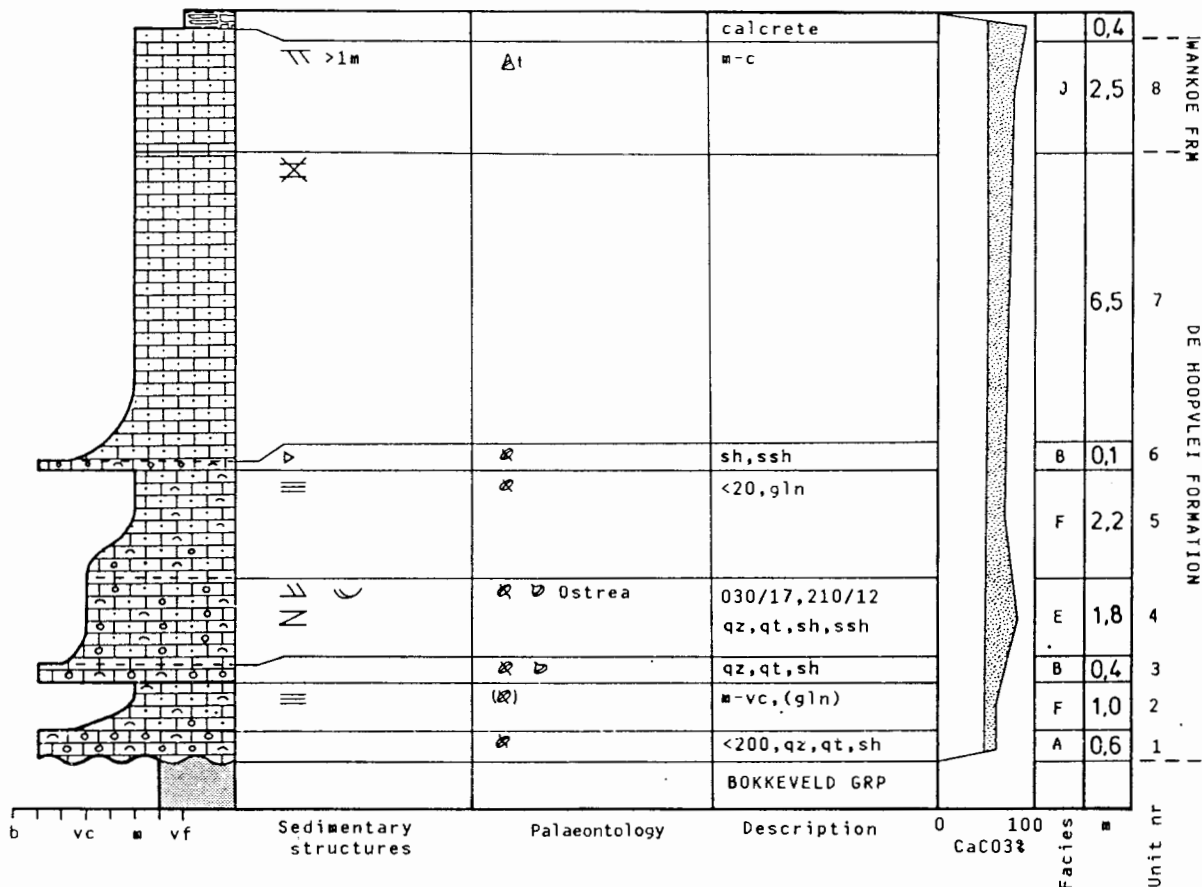


FIGURE 12c. Profile BR II, south of Renosterfontein farmhouse, left bank of Kars River.

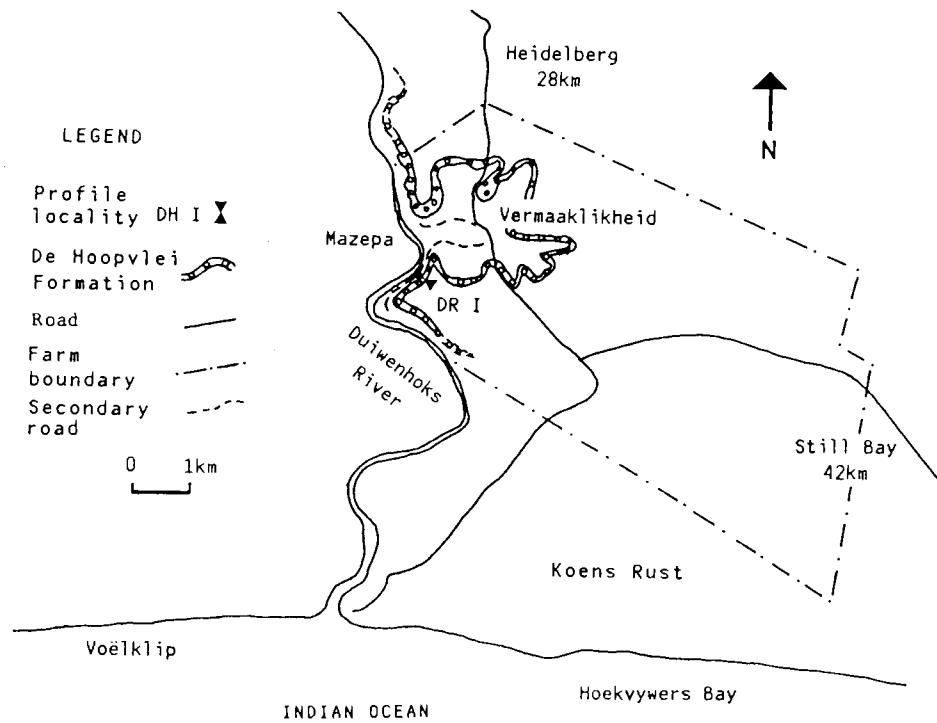


FIGURE 13a. Location diagram for profile DR I near Vermaaklikheid.

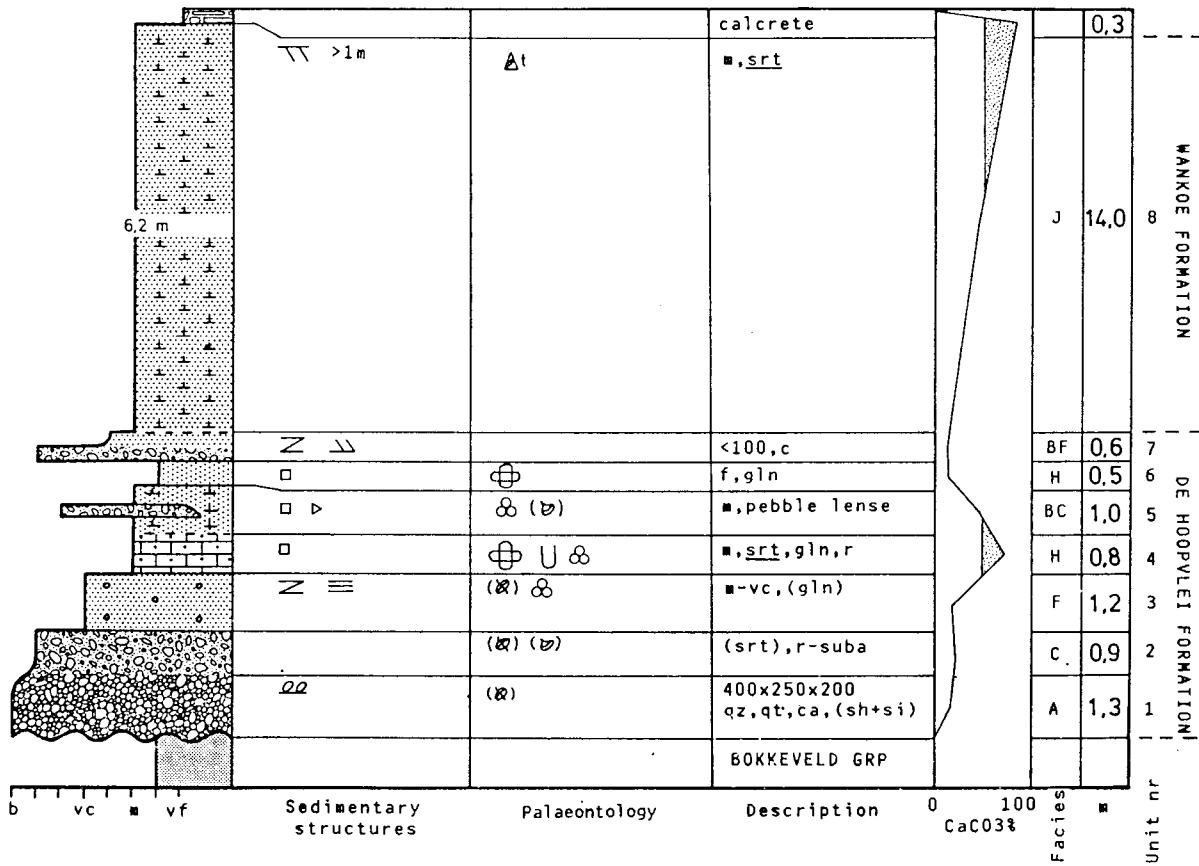


FIGURE 13b. Profile DR I south of Vermaaklikheid, left bank of Duiwenhoks River.

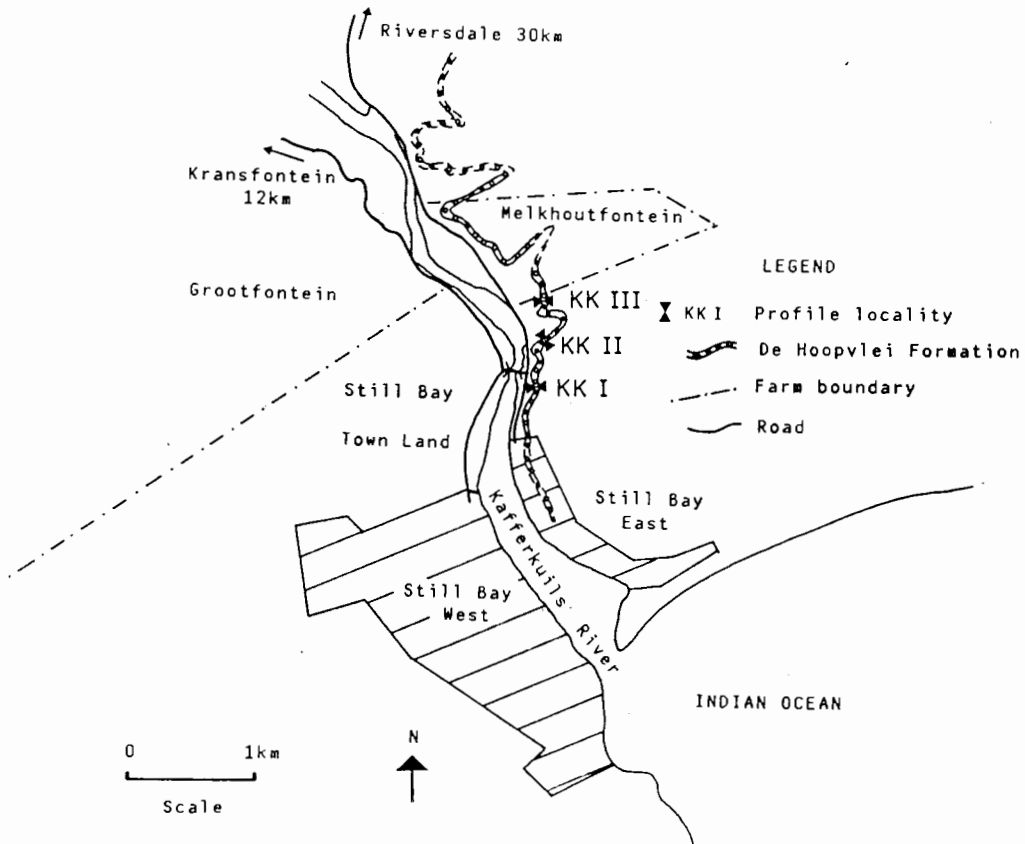


FIGURE 14a. Location diagram for profiles KK I to KK III at Still Bay.

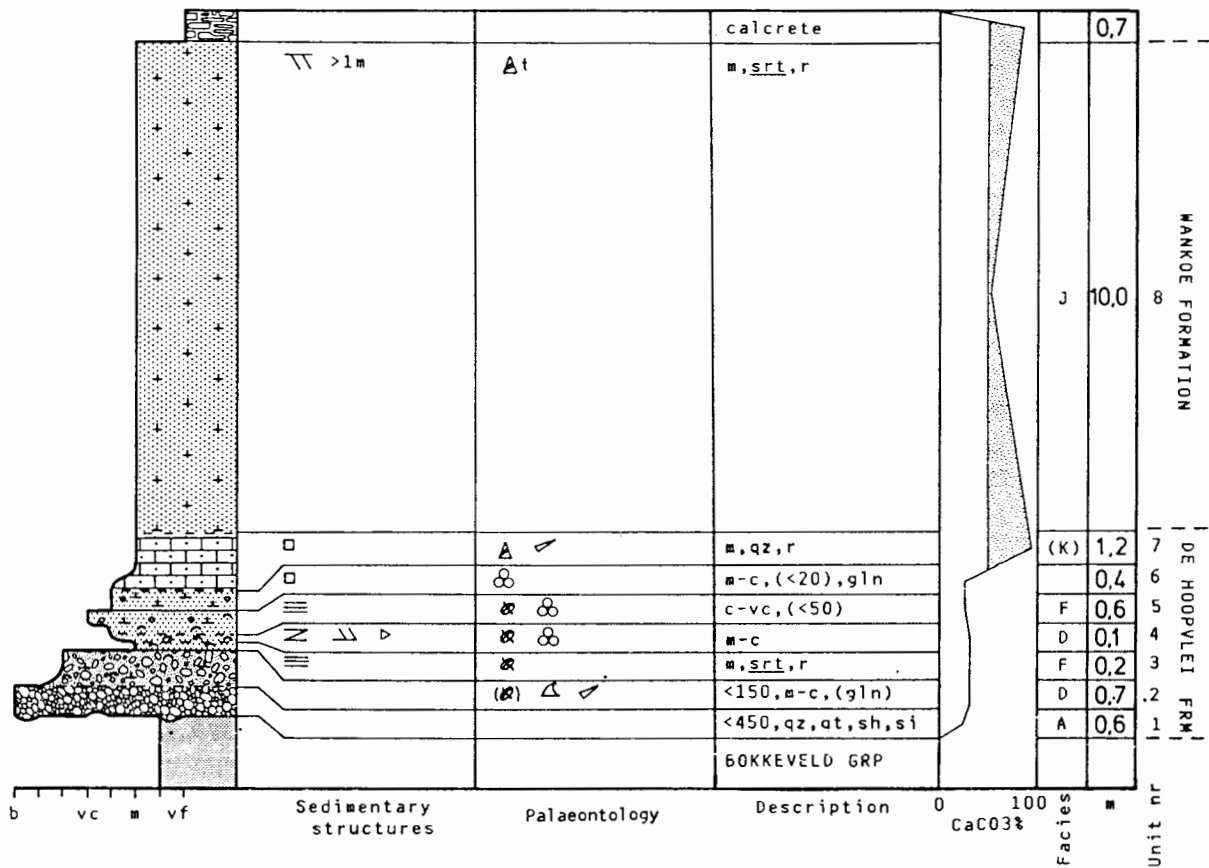


FIGURE 14b. Profile KK I, left bank of Kafferkuils River, just south of Still Bay bridge.

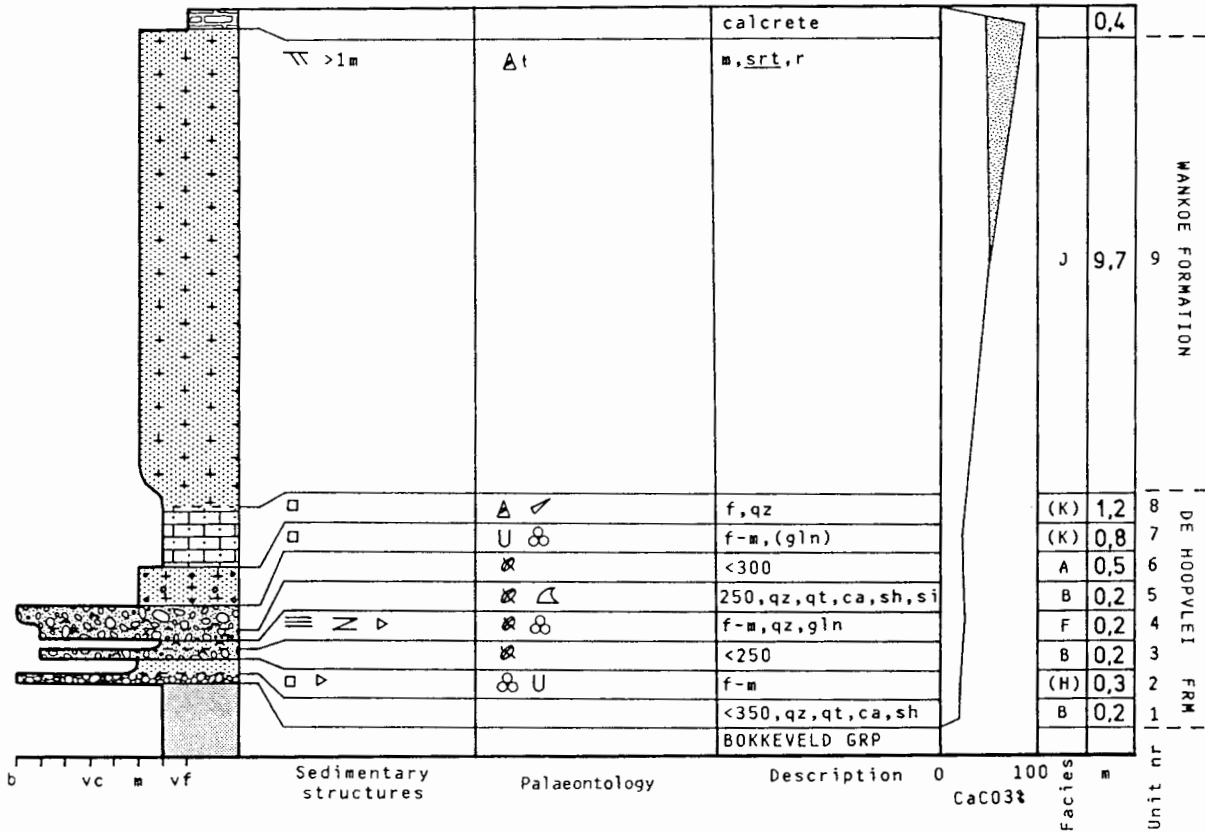


FIGURE 14c. Profile KK II, left bank of Kafferkuils River, just north of Still Bay bridge.

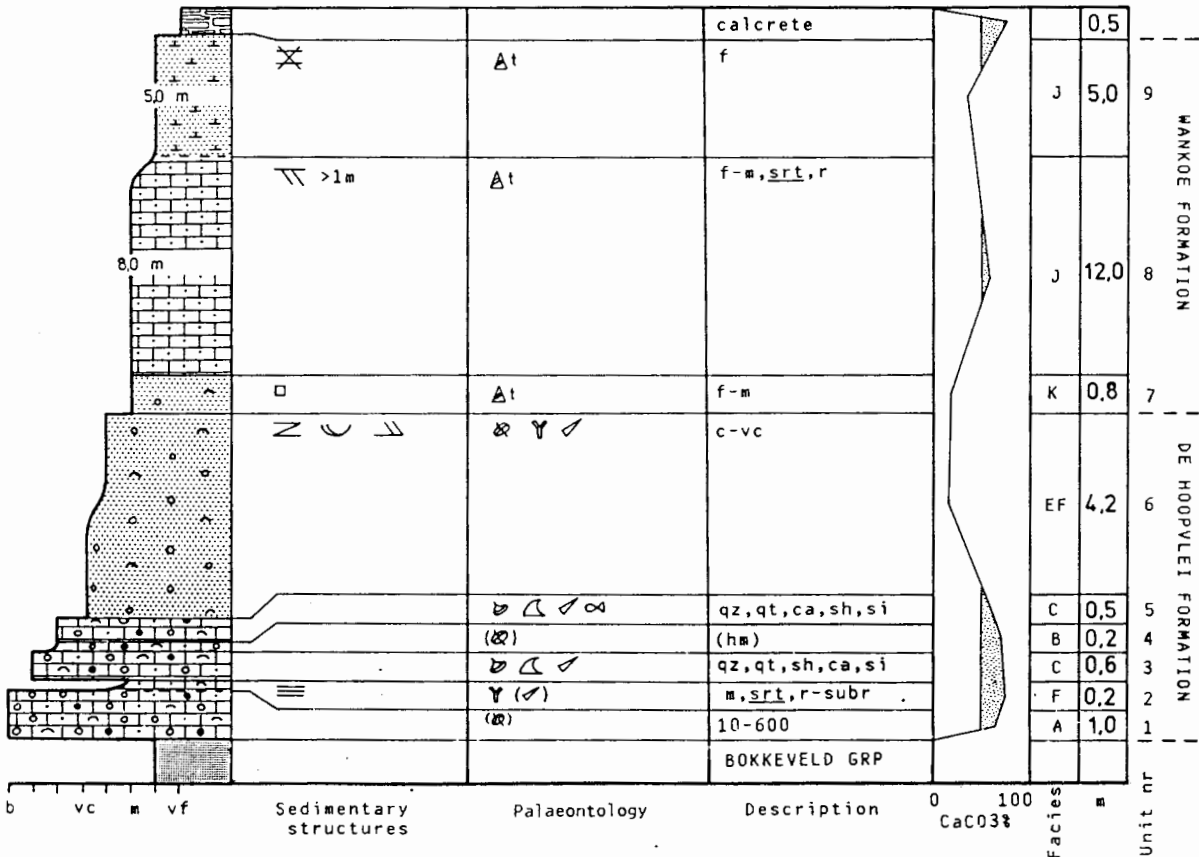


FIGURE 14d. Profile KK III, left bank of Kafferkuils River, just north of Still Bay bridge.

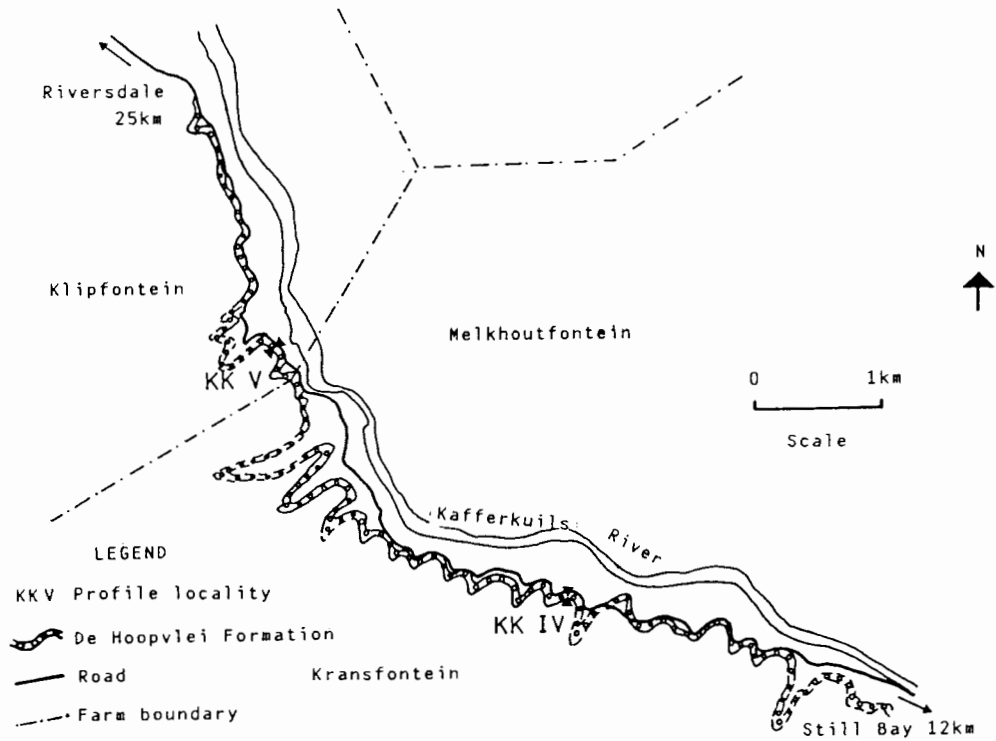


FIGURE 15a. Location diagram for profile KK IV and KK V on the right bank of Kafferkuils River, northwest of Still Bay.

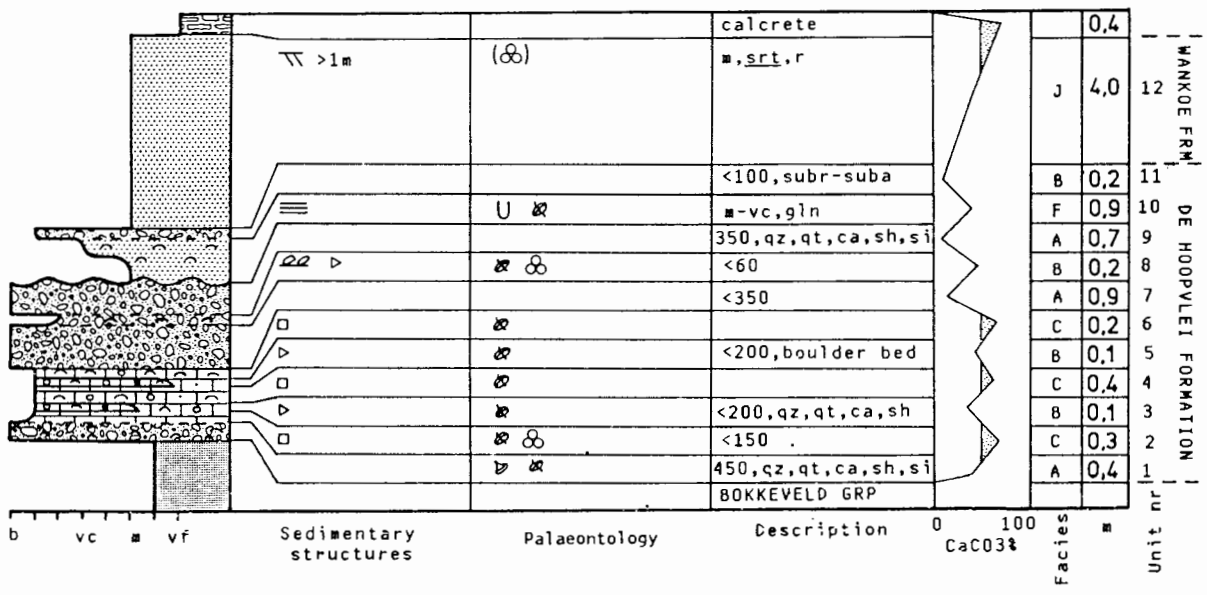


FIGURE 15b. Profile KK IV on Kransfontein, right bank of Kafferkuils River, 15km from Still Bay.

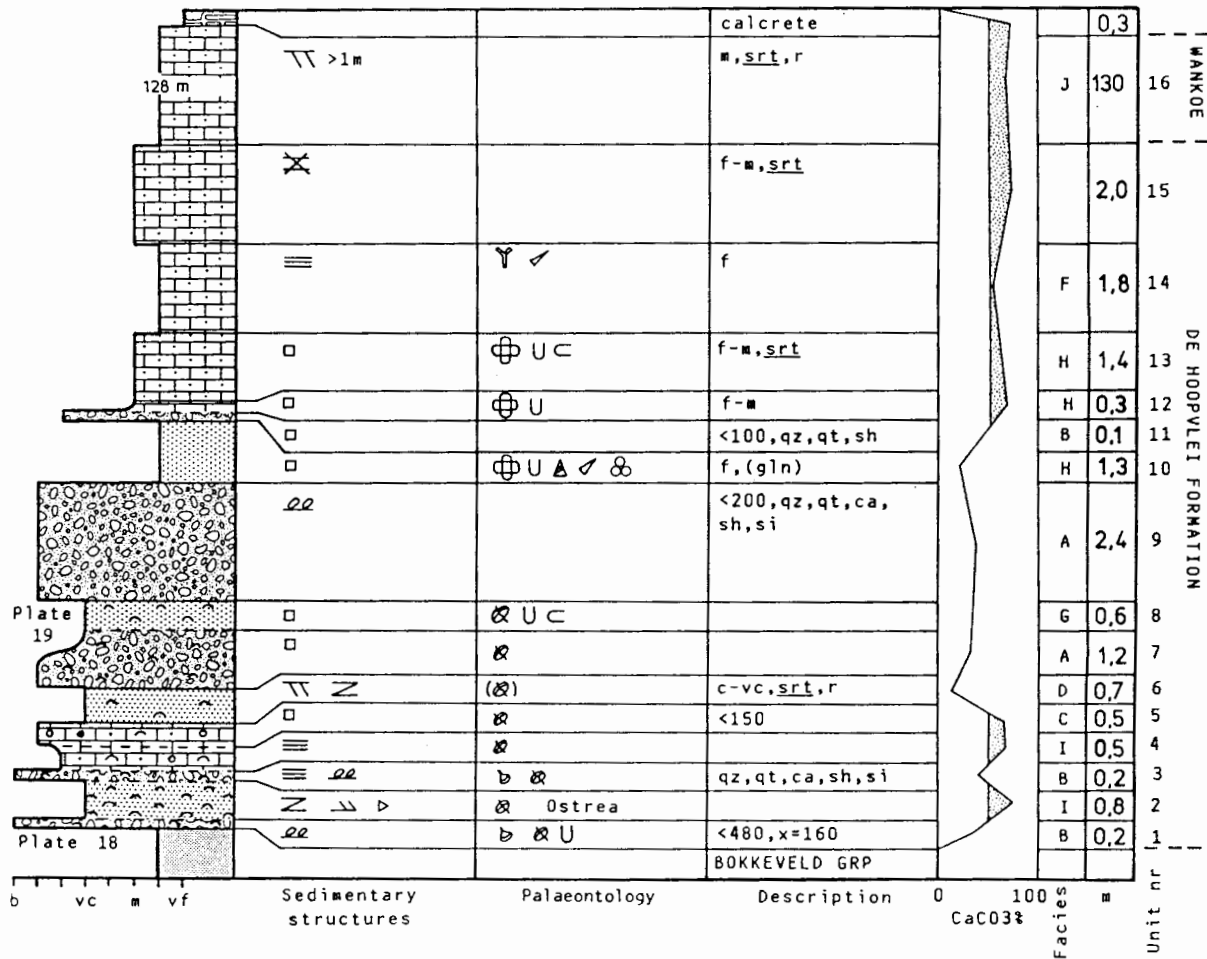


FIGURE 15c. Profile KK V on Klipfontein, right bank of Kafferkuils River, 20km from Still Bay.

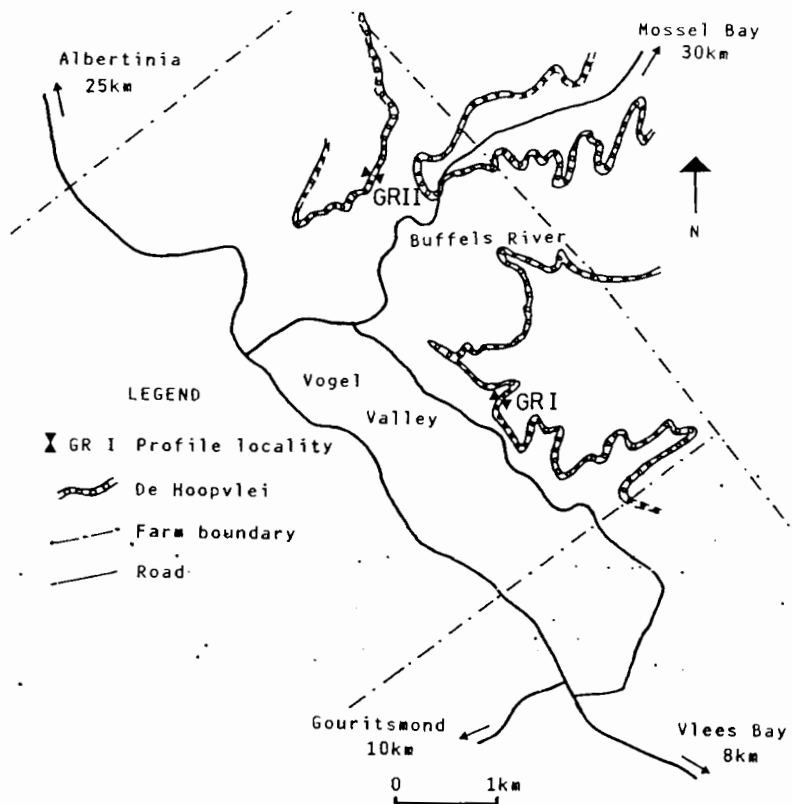


FIGURE 16a. Location diagram for profiles GR I and GR II on Vogelvalley, left bank of Gourits River floodplain.

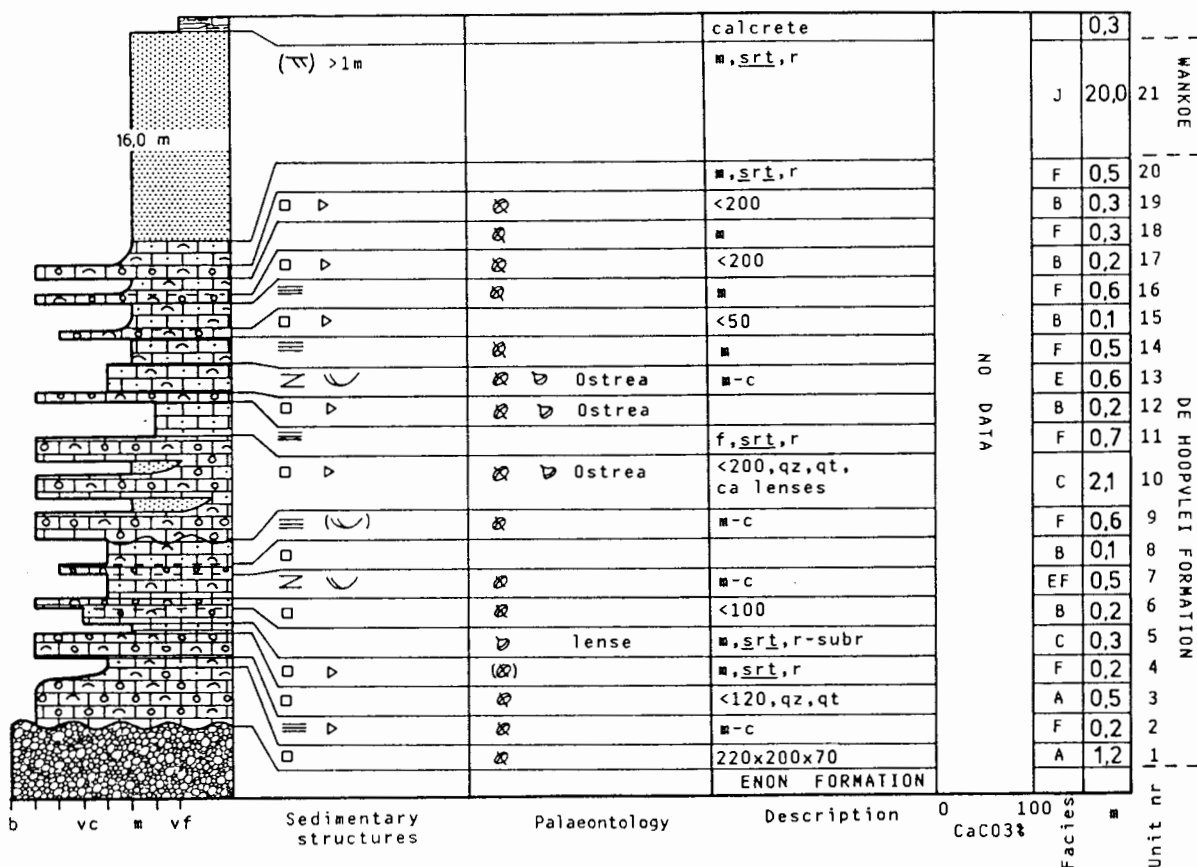


FIGURE 16b. Profile GR I, south of Buffels River, a tributary on the left bank of Gourits River floodplain.

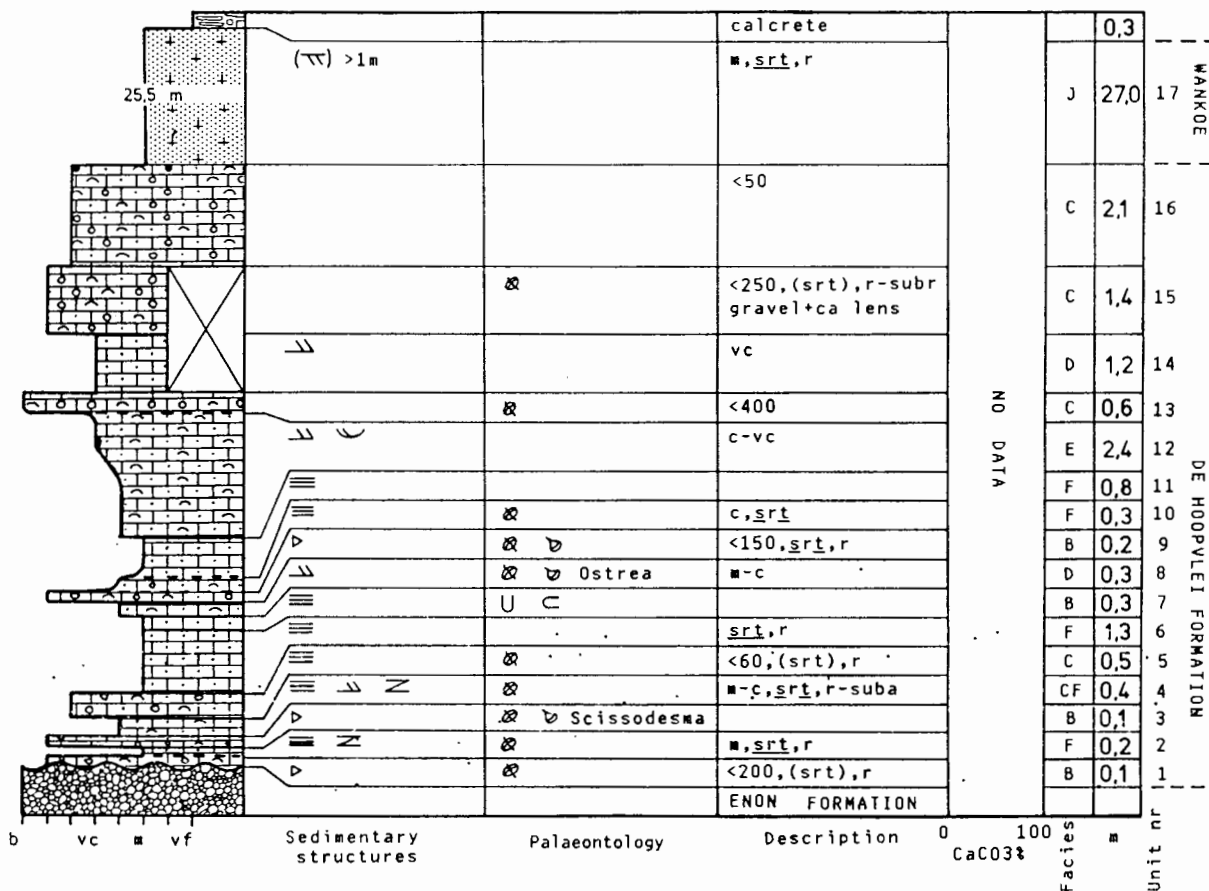


FIGURE 16c. Profile GR II on the right bank of Buffels River, a tributary on the left bank of Gourits River floodplain.

and Mossel Bay the only accessible exposures are along the banks of the Duiwenhoks-, Kafferkuils- and Gourits Rivers (Figure 1) where river incision carved into the underlying bedrock. The most easterly De Hoopvlei exposure is a small deposit on the farm Vaale Valley, west of Klein Brak (Figure 9), where marine gravel with broken Crassostrea margaritacea shells occurs at a height of 110m above present sea-level.

The main criteria for the lateral correlation of the marine De Hoopvlei Formation are i) index macro fossils, ii) index micro fossils, and iii) coherent elevation values for the wave-cut surface underlying the De Hoopvlei Formation. Le Roux (1986) provided a list of eight macrofossils diagnostic of the Late Tertiary Alexandria Formation and the De Hoopvlei Formation. These index species occur in the limestone quarry of Bontebok Limeworks, 2km northeast of Bredasdorp (Figure 12a); in a road cutting on the Elim-Bredasdorp road (Figure 9); along the eastern shores of De Hoopvlei (Figure 10a); on Heuningrug (Figure 9); and at Vogel Valley on a left bank of the Buffels tributary valley of the Gourits River (Figure 16a).

Lateral Correlation is supported by the presence or absence of certain species of benthic foraminifera (McMillan, 1986). De Hoopvlei deposits are preserved at an elevation up to 120m above present sea-level. This maximum height serves as a further indicator of the distribution of this marine unit.

6.3 LATERAL VARIATION

In the Bredasdorp-Cape Infanta area outcrops tend to be much more calcified than those farther to the east along the Duiwenhoks and Kafferkuils Rivers (Figure 1). Lithological variations occur over short distances. In the De Hoop area (Figures 10a to 10h) the unit coarsens southwards, that is, seaward. Facies changes can also be

observed as localised bioturbated sediments south of Vermaaklikheid (Figures 9, 13a and 13b).

6.4 GEOLOGICAL DESCRIPTION

6.4.1 Stratigraphic boundaries

The lower boundary is defined as the erosional unconformity between the De Hoopvlei Formation, and Cape Supergroup and Uitenhage Group. This unconformity is well exposed and contains hollows and channels cut into this surface, e.g. into Bokkeveld shale, north of the boundary fault, at the northern entrance to the Sout River gorge (Plate 3). Palaeo-hollows in the Enon conglomerate surface are filled with pebbles, cobbles, boulders and crushed oyster shells (Crassostrea margaritacea); this is displayed in the basal conglomerate in the Rooikrans section, south of the above mentioned fault (Figures 11a to 11e; Plate 4). The De Hoopvlei Formation is characterised by a carbonate content of more than 60 percent due to a considerable quantity of comminuted shelly material.

The De Hoopvlei Formation is conformably overlain by the Wankoe Formation. In the Rooikrans sections, on the right bank of the Sout River (Figures 11a to 11e), the disconformity is sharp. The transition is defined at the base of the large-scale crossbedded calcarenite and calcareous sandstone (less than 50 percent CaCO_3) of the Wankoe Formation. Pebbles, cobbles, boulders and marine shells in the De Hoopvlei Formation indicate a different depositional environment from the gravel- and shell-free Wankoe Formation.

Near the trigonometrical beacon on the left bank of De Hoopvlei a calcrete horizon (a soil profile) occurs at the top of the De Hoopvlei Formation (Unit 9, profile DH V, Figures 10a and 10f).

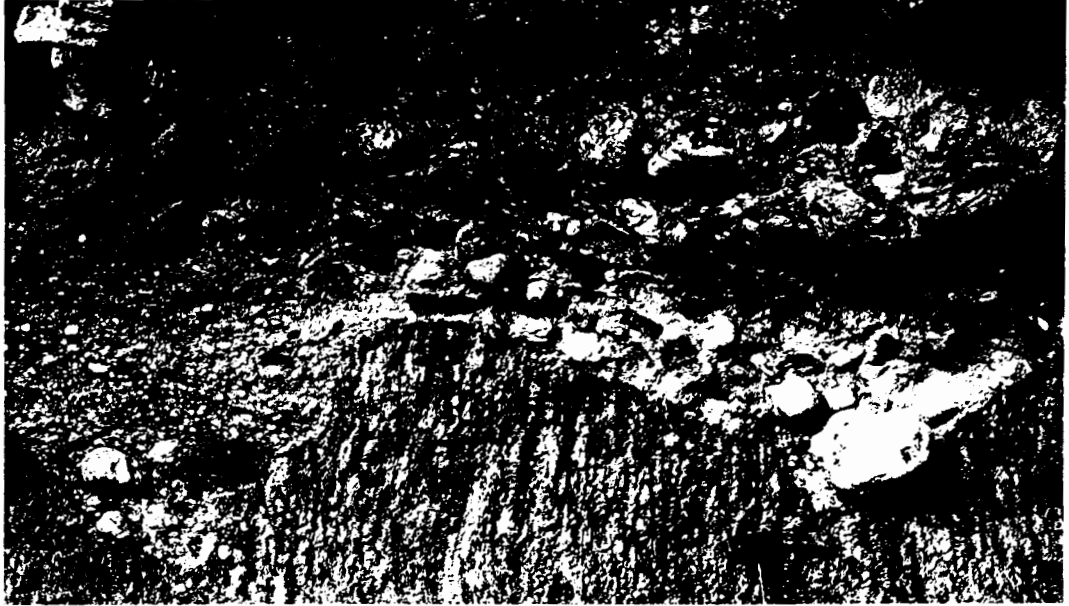


PLATE 3. Well-exposed unconformity between gullied Bokkeveld Group shale (below) and basal marine conglomerates of the De Hoopvlei Formation (above) (Profile SR I on Kathoek)(Figures 11a and 11f).



PLATE 4. Crassostrea margaritacea-filled hollow formed on the unconformity between Enon Formation and overlying De Hoopvlei Formation (Profile RK I, Rooikrans)(Figures 11a and 11b).

Secondary diagenesis in many places has destroyed all the primary structures and characteristics of the units, making the recognition of a boundary very difficult (cf. Siesser, 1971; 1972). In the absence of the Wankoe Formation the upper boundary of the De Hoopvlei Formation is formed by, the top of the terrestrial calcrete and the base of soil and scree deposits, or younger unconsolidated aeolian sands.

6.4.2 Unit thickness

The thickness of the De Hoopvlei Formation varies depending on the lithology of the underlying bedrock. Where the unit overlies Table Mountain Group quartzites, unit thickness varies between 0,2 and 2,1m. Examples can be seen along the Potberg-Infanta coast at Noetsie, Stilgat, Bloukrans and St Sebastian Point (Figure 9). The shelly conglomerate layer is exposed in the coastal trails farther to the east at Odendaals Point, west of Still Bay, and at Cape St Blaize near Mossel Bay (Figure 9). Measured unit thickness for the De Hoopvlei Formation varies between 3,8 and 17,0m (Plate 2) with an average of 8,0m where basement consists of softer Bokkeveld shale or Enon conglomerate. The following values were measured for the De Hoopvlei Formation:-

De Hoopvlei	6.9 to 17,0m	(Figures 10a to 10h)
Sout River	7,9 to 11,2m	(Figures 11a to 11f)
Kafferkuils River	3,8 to 14,1m	(Figs 14a-14d, 15a-15c)
Gourits River	9,9 to 12,2m	(Figsures 16a to 16c)

6.4.3 Lithology

Limestone can be classified by macroscopic features (mostly grain-size) and by its petrography, composition (Folk, 1959) and texture (Dunham, 1962). The basal unit of the Bredasdorp has been described as "sanderige massa skulpgruis tot konglomeratiese gesteentes met heelwat skulpe" (sandy masses of shelly gravel to conglomeratic rocks

with abundant shells) by Spies et al. (1963 p. 15), "coarse sandy-gravel" (Rogers, 1986 p. 3) and "a pebble- or broken-shell bearing fine calcirudite" (Siesser, 1972 p. 177). Outcrops are in many places cemented by secondary calcite derived from dissolution of the shelly material. Diagenesis and/or recrystallisation can also destroy all the primary sedimentary features (Siesser, 1972).

The De Hoopvlei Formation in the Bredasdorp-Infanta area is well calcified; its carbonate content varies between 42,2 percent and 98,5 percent (Figures 10 to 12). Outcrops are formed of calcirudite, calcarenite, coquinite and calcareous sandstone (Siesser, 1970). Farther to the east, between the Breede and Gourits Rivers (Figure 1) outcrops tend to be semiconsolidated to unconsolidated with a carbonate content varying between 8,8 percent and 70,5 percent (Figures 13 to 15). These exposures are formed by conglomerate, calcareous sandstone, calcarenite and calcareous sand. In this study the lithological units of the De Hoopvlei Formation are described in the following separate classes, i.e.:

- 1) calcirudite and conglomerate;
- 2) calcarenite, calcareous sandstone and sand; and
- 3) coquina and coquinite.

6.4.3.1 Calcirudite and conglomerate

The calcirudite and conglomerate fraction represents 35 percent of the cumulative thickness of measured profiles of the De Hoopvlei Formation. Conglomerate with a high shell content are recrystallised; where the combined carbonate content of the matrix and calcareous clasts is more than 50 percent the rock is classified a calcirudite.

The basal shelly conglomerate or calcirudite varies in thickness between 10mm and 2,2m with an average thickness of 0,8m. The clasts include quartzite, shale, siltstone, vein-quartz, silcrete,

calcarenite and calcirudite boulders, cobbles and pebbles (Table 4). The quartzite, vein-quartz and silcrete clasts are spherical and rounded, whereas the shale, siltstone, calcirudite and calcarenite clasts are rod-like, tabular or platy.

The silcrete pebbles were derived from the Palaeogene Grahamstown Silcrete Formation on the "Post- African I" erosional surface (Partridge and Maud, 1987) south of the Langeberg Mountains (Figure 17). Quartzite, silcrete and vein-quartz clasts are well rounded, indicating intense reworking, and transport from a distal source area. The prominent bedding cleavage developed in the Bokkeveld Group shales is the primary reason for the tabular shape of Bokkeveld-derived clasts. The calcarenite and calcirudite intraformational clasts are derived from reworked (cannibalised) De Hoopvlei Formation.

Thin conglomerate layers resting on intraformational erosional surfaces form part of upward-fining calcarenite cycles up to 3m thick (Unit 10 in profile RK II, Figure 11c). Single-clast layers are developed throughout the De Hoopvlei Formation. Angular to subrounded vein-quartz pebbles occur as a single-pebble layer at the base of low-angle crossbedded calcarenite in profile DH I at the De Hoop restcamp (Figures 10a and 10b; Plate 5). These clasts were possibly derived from quartz veins in the nearby Bokkeveld Group. Ilmenite and magnetite grains occur at the base of an upward-fining calcirudite cycle in profiles RK I and RK II at Rooikrans (Unit 10, Figure 11c; Plate 6).

Conglomerate units up to 2,4m thick form as single beds or occur interbedded with calcarenite layers (Unit 9 in profile KK V, Figure 15c). Clast imbrication is well developed in some crossbedded calcarenites, shale and calcarenite clasts, being orientated with their long axes parallel to the dip of the foreset-laminae (Unit 6 in profile DH IV, Figure 10e; Plate 7).

TABLE 4. Clast size, shape and rock type in selected conglomerate units in the De Hoopvlei Formation.

Profile units	n	Clast lithology					Mean Clast measurements (mm)		
		ss	sh	si	qz	ca	Long axis	Intermediate axis	Short axis
DH III unit 6	20	3	10	-	2	5	88	55	25
DH VI unit 4	24	4	12	2	-	6	96	57	24
DH VI unit 3	40	8	14	1	6	11	114	76	33
KK V unit 6	30	21	6	3	-	-	162	114	66
GR I unit 1	25	18	5	1	1	-	216	151	76

n = number of clasts measured
 ss = sandstone
 sh = shale

si = silcrete
 qz = quartz
 ca = calcarenite

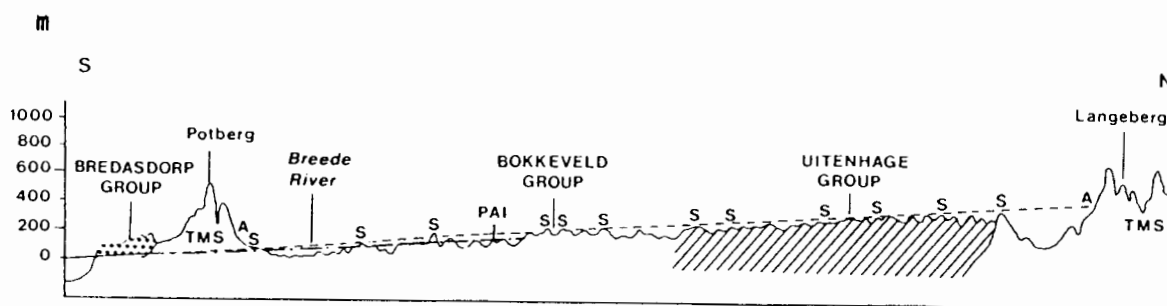


FIGURE 17. Generalised cross-section from the Langeberg Mountain to the coastline at Potberg. TMS: Table Mountain Sandstone S: Grahamstown Silcrete Formation A: African Surface PAI: Post African I Surface (Malan and Viljoen, 1990, Figure 3).



PLATE 5. Angular vein-quartz pebbles lying on an intraformational erosional surface in profile DH I, De Hoopvlei restcamp (Unit 4, Figures 10a and 10b).

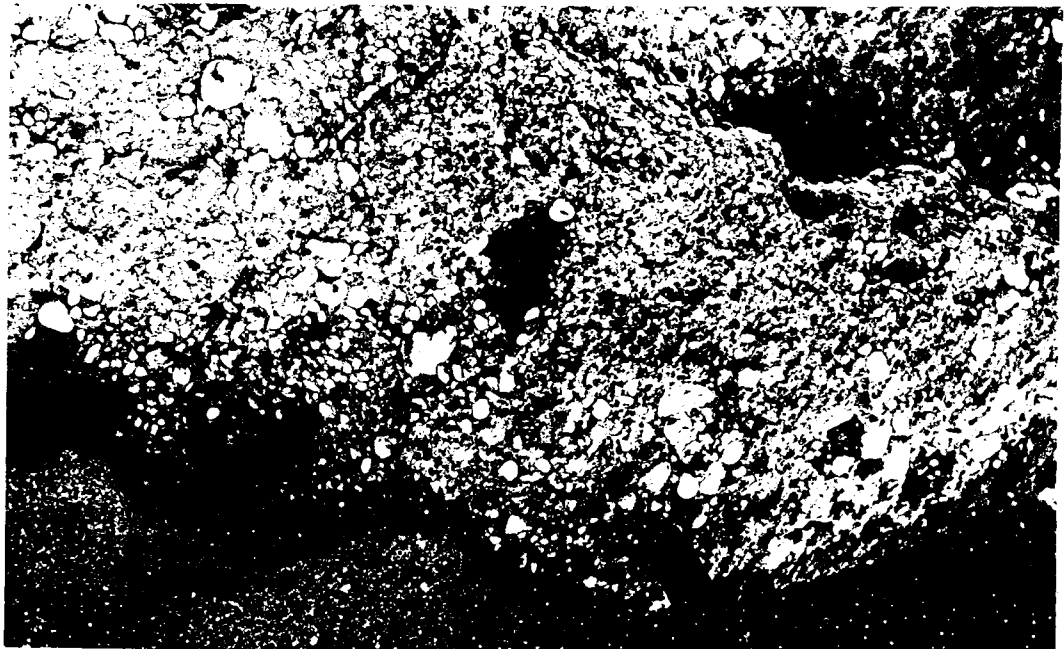


PLATE 6. Basal view of a conglomerate with heavy minerals in profile RK 1, Unit 10, at Rooikrans on Windhoek (Figures 11a and 11b).

A channel (width 1,8m; depth 0,4m), filled with well-rounded cobbles and pebbles, is cut into horizontally bedded calcarenite in profile DH VII (Unit 9, Figure 10h) along the lower shores of De Hoopvlei. Quartzite boulders with percussion marks indicative of a high-energy (shoreline?) environment occur in profile KK IV on Kransfontein (Units 7 to 9, Figure 15b) and GR I on Vogel Valley (Unit 1, Figure 16b; Plate 8).

6.4.3.2 Calcarenite, calcareous sandstone and sand

A calcarenite is defined as a calcareous rock consisting chiefly of sand-size grains with a carbonate content exceeding 50 percent. In the De Hoopvlei Formation calcarenite can occur as recrystallised limestone or as semi-consolidated sand and forms 60 percent of the De Hoopvlei Formation. Calcareous sand and sandstone form the bulk of the eastern De Hoopvlei Formation outcrops in the Duiwenhoks, Kafferkuils and Gourits River areas (Figure 1).

The sand-size fraction in the De Hoopvlei Formation consists of subrounded to rounded grains which are moderately to well sorted (average 0,51 phi) fine to very coarse sand grains (average 1,97 phi i.e. medium sand) composed of quartz, quartzite, shale, glauconite and silcrete-derived grains with comminuted shell fragments, crinoid stems, echinoid fragments and benthic foraminifera. Shell fragments, shark teeth, echinoid fragments and phosphatised fish and seal teeth and scattered pebbles are present in the coarser calcarenite units. The matrix-supported clasts, shell fragments and unbroken shells are in many places orientated with their long axes parallel to the foreset-laminae of the low-angled crossbedded units (Unit 4 in profile DH V, Figure 10f; Plate 9).



PLATE 7. Well-developed imbrication (135 degrees, SE) of tabular Bokkeveld-shale clasts exposed in profile DH IV, near the trig beacon on the left bank of De Hoopvlei (Unit 7, Figures 10a and 10e).

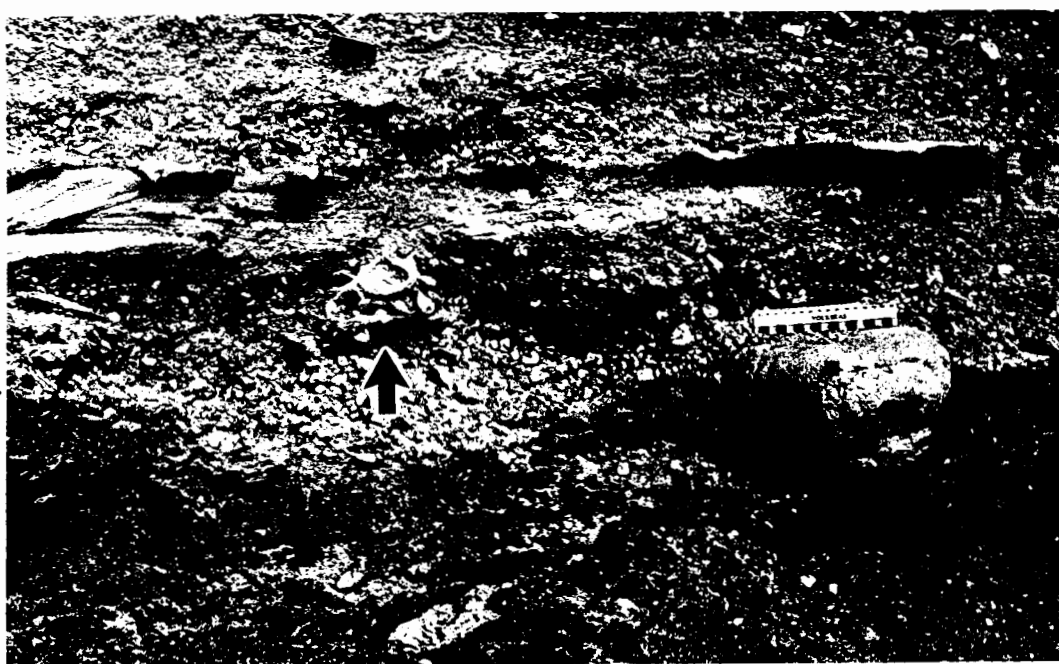


PLATE 8. Basal De Hoopvlei conglomerate with rounded Table Mountain Group cobbles, boulders, and pebbles, Bokkeveld clasts and whole oyster shells (vertical arrow) exposed in profile RK IV on Windhoek, right bank of Sout River, overlying Enon Formation of Bokkeveld clasts. Horizontal arrows indicate the De Hoopvlei-Enon unconformity (Figures 16a and 16b).

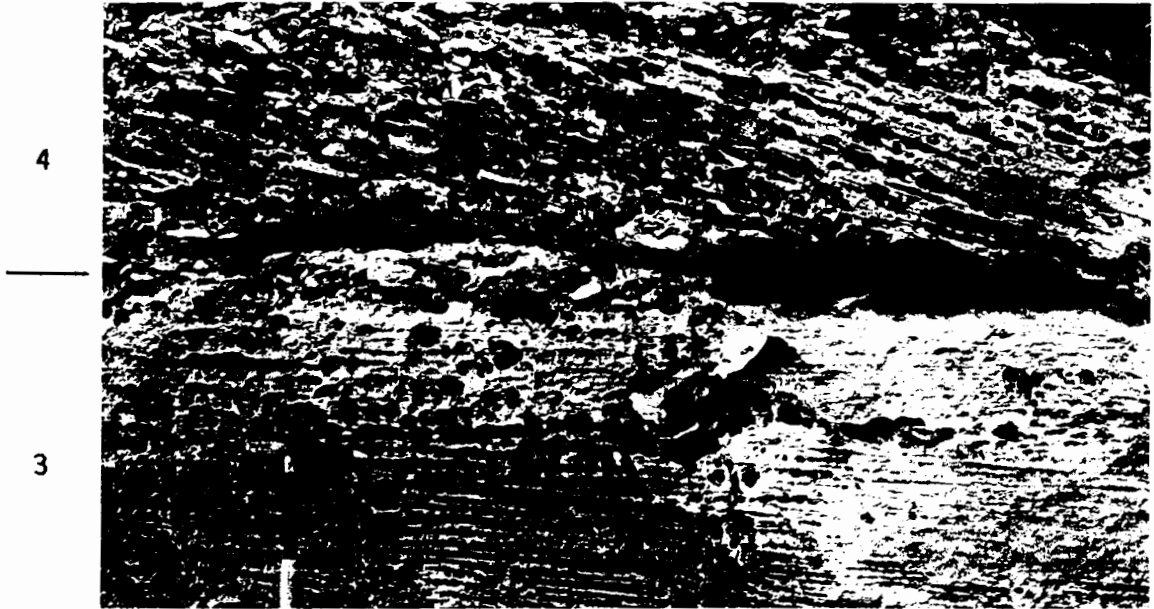


PLATE 9. Matrix-supported Bokkeveld-shale clasts and shell fragments orientated with their long axes parallel to the foreset laminae of the crossbedded Unit 4 overlying a horizontally laminated calcarenite of Unit 3 (Profile DH V north of the trig. beacon on the left bank of De Hoopvlei, Figures 10a and 10f).



PLATE 10. Scattered Ophiomorpha burrows in low-angle crossbedded and horizontally bedded calcarenites overlying a trough-crossbedded unit in profile DH I (Units 4 and 5, Figure 10b).

The calcarenites vary in colour from yellow-orange to orange-pink when fresh, to a light grey colour when weathered. Where the glauconite content increases, as in profiles KK I, KK II and KK IV along the Kafferkuils River (Figures 14 and 15), the colour changes to greenish grey. Bed thickness reach a maximum of 4,2m (average 2,0m) and units are in many places often lenticular. Biogenic structures, vertical and horizontal (Ophiomorpha) burrows as well as unbroken Ostrea (oysters) and Echinodiscus (pansy shells) occur in horizontally bedded and low-angle crossbedded calcarenite in profiles DH I and DH II beside the De Hoop restcamp (Figures 10b and 10c; Plate 10). Trough crossbeds with a thickness of 3 to 50cm and a foreset length of 15cm to 2,5m are also preserved in these sections (Unit 8, Figure 10b and Unit 6, Figure 10c). Herringbone crossbeds with opposing crossbed sets occur in profile RK II at Rooikrans (Units 7 and 9, Figure 10c) and in profiles DH I to DH III at the De Hoop restcamp (Figures 10a to 10d).

6.4.3.3 Coquina

Coquina in the De Hoopvlei Formation can consist of totally recrystallised shell fragments, calcite-cemented shells and uncemented shells and shell fragments. This lithological unit, with a maximum thickness up to 0,8m, forms less than 10 percent of the De Hoopvlei Formation (Unit 7 in profile SR I, Figures 11a and 11f; Plate 11). Coquina lenses filling hollows and channels cut into the basal unconformity are present in a few outcrops. In the section at Rooikrans (Figures 11a to 11e) these coquina lenses are filled mostly by whole and broken Crassostrea margaritacea, with rare Ostrea atherstonei and broken Echinodiscus sp. Here the basal coquina varies in thickness, a maximum of 0,7m being developed in Unit 1 of profile RK I (Figure 11b). It can be recognised all along Rooikrans on the basal unconformity with the Enon Formation. The coarse coquina fraction is formed of unbroken shells, the non-biogenic component consist of quartz, quartzite, shale and

The calcarenites vary in colour from yellow-orange to orange-pink when fresh, to a light grey colour when weathered. Where the glauconite content increases, as in profiles KK I, KK II and KK IV along the Kafferkuils River (Figures 14 and 15), the colour changes to greenish grey. Bed thicknesses vary from a maximum of 4,2m to an average of 2,0m and units are often lenticular. Biogenic structures, vertical (Ophiomorpha) and horizontal burrows as well as unbroken Ostrea (oysters) and Echinodiscus (pansy shells) occur in horizontally bedded and low-angle crossbedded calcarenites in profiles DH I and DH II beside the De Hoop restcamp (Figures 10b and 10c; Plate 10). Trough crossbeds with a thickness of 3 to 50cm and a length of 15cm to 2,5m are also preserved in these sections (Unit 8, Figure 10b and Unit 6, Figure 10c). Herringbone crossbeds with opposing crossbed sets are present in profile RK II at Rooikrans (Units 7 and 9, Figure 10c) and in profiles DH I to DH III at the De Hoop restcamp (Figures 10a to 10d).

6.4.3.3 Coquina

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PLATE 11. Calcite-cemented shells and shell fragments form the prominent Unit 5 in profile SR I on Kathoek on the left bank of the Sout River opposite Rooikrans (Figure 11f).

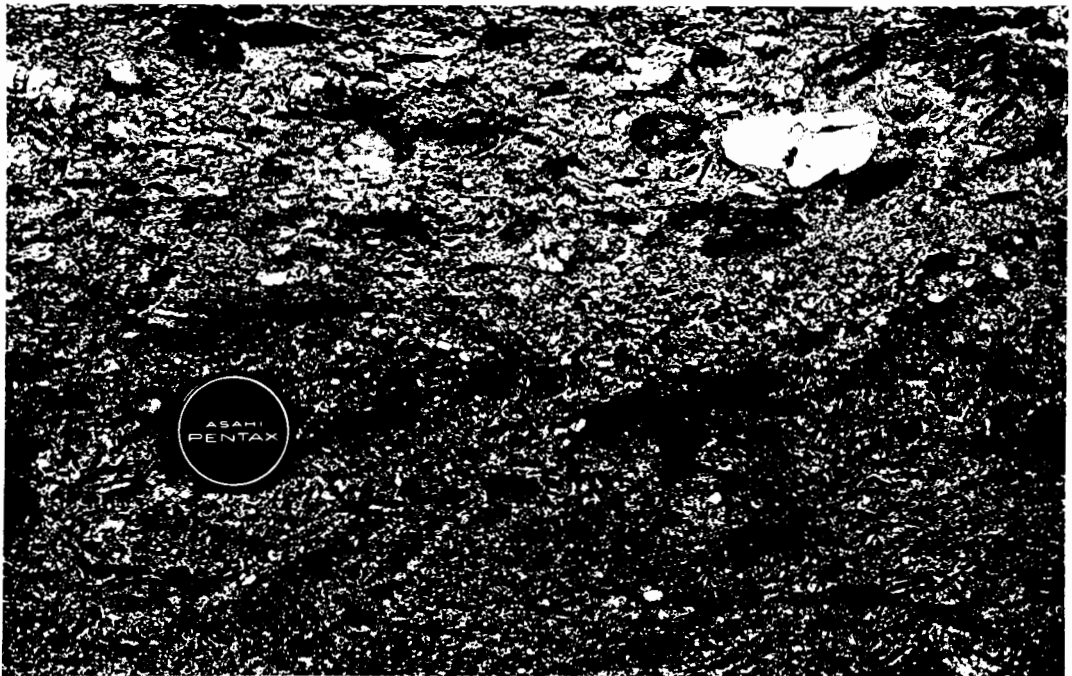


PLATE 12. Coarse coquina formed by unbroken shells, quartzite and shale pebbles with comminuted shell matrix material, basal part of profile BR I (Unit 1, Figures 12a and 12b).

calcarenite pebbles and cobbles with a maximum measured diameter of 25cm. Quartz, finely comminuted shell fragments, glauconite and a few ilmenite and magnetite sand grains, form the matrix (Plate 12).

Two coquina units with a carbonate content of nearly 90 percent occur in profile SR I along the left bank of Sout River (Figures 11a and 11f). A few bivalve shells were articulated, suggesting a short distance of transport before deposition of these shells. In the limestone quarry of Bontebok Limeworks a 0,3m-thick unit, formed exclusively of finely comminuted recrystallised shell fragments, is present 2,7m above the basal unconformity with Bokkeveld shale (Unit 3, Figures 12a and 12b). The coquina units are usually massive or structureless due to their very coarse nature. Crossbedding and low-angle crossbedding are poorly developed in places. Lenticular conglomerate and sandstone lenses up to 30cm thick and 2m in length occur in some of the coquina layers (Unit 1 in profile RK III, Figure 11d).

On the right bank of the Kafferkuils River on Klipfontein (Profiles KK V and KK VI, Figures 15a and 15c) low-angle crossbeds with foreset angles lower than 10 degrees and horizontal, thin laminated beds are preserved in the coquina units. Well-developed casts of the bivalve Scissodesma spengleri are exposed in a coquina lens 10cm thick in profile GR II (Unit 3, Figures 16a and 16c) on Vogel Valley on the right bank of Buffels River, a tributary on the left bank of the Gourits River.

6.4.4 Primary sedimentary structures and palaeocurrents

Primary sedimentary structures and palaeocurrent indicators were studied in order to gain an understanding of the palaeo-environmental setting of the De Hoopvlei Formation.

6.4.4.1 Sedimentary structures

Horizontally laminated, millimetre to centimetre thick, units are present in calcarenites and calcirudites in the De Hoopvlei Formation. These units are lenticular and pinch out over a short distance. Unbroken bivalves oriented parallel to the laminations are present at Rooikrans in Unit 4 of profile RK I (Figures 11a and 11b).

Scattered pebbles occur in laminated, upward-fining, medium to coarse calcareous sandstone (Unit 8 in profile RK II, Figures 11a and 11c). Horizontal laminations and low-angle crossbedding are associated with matrix-supported conglomerates. Measured foreset-laminae on bedding planes in these low-angle crossbedded units resemble sedimentary structures associated with wave-wash action on the upper-foreshore and lower-backshore environments (Hunter *et al.*, 1979). The bedding planes are cut by low-angle discontinuity surfaces. Similar reactivation surfaces were observed in some crossbedded and trough-crossbedded units (Unit 6 in profile DH II, Figures 10a and 10c; Plate 13). These surfaces indicate periodic erosional and depositional cycles (Semeniuk and Johnson, 1982). The presence of pebbles at the base of these cycles indicates high-energy, possibly storm-surge, conditions.

Few ripples were observed in the De Hoopvlei Formation. In a stream cutting on Patryskraal (Figure 9) symmetrical wave ripples with a ripple index between 8,5 and 9,4 occur. These ripples show rounded crests, are fairly continuous and are preserved in a horizontally laminated unit with an overlying low-angle, crossbedded calcarenite, overlain by a similar ripple-laminated unit. In the De Hoopvlei profiles (DH I, DH II and DH III) near the rest camp (Figures 10a to 10d) asymmetric ripples with sharp crests are present near the top of low-angle crossbedded calcarenite units. Ripples with rounded or wavy peaks are formed

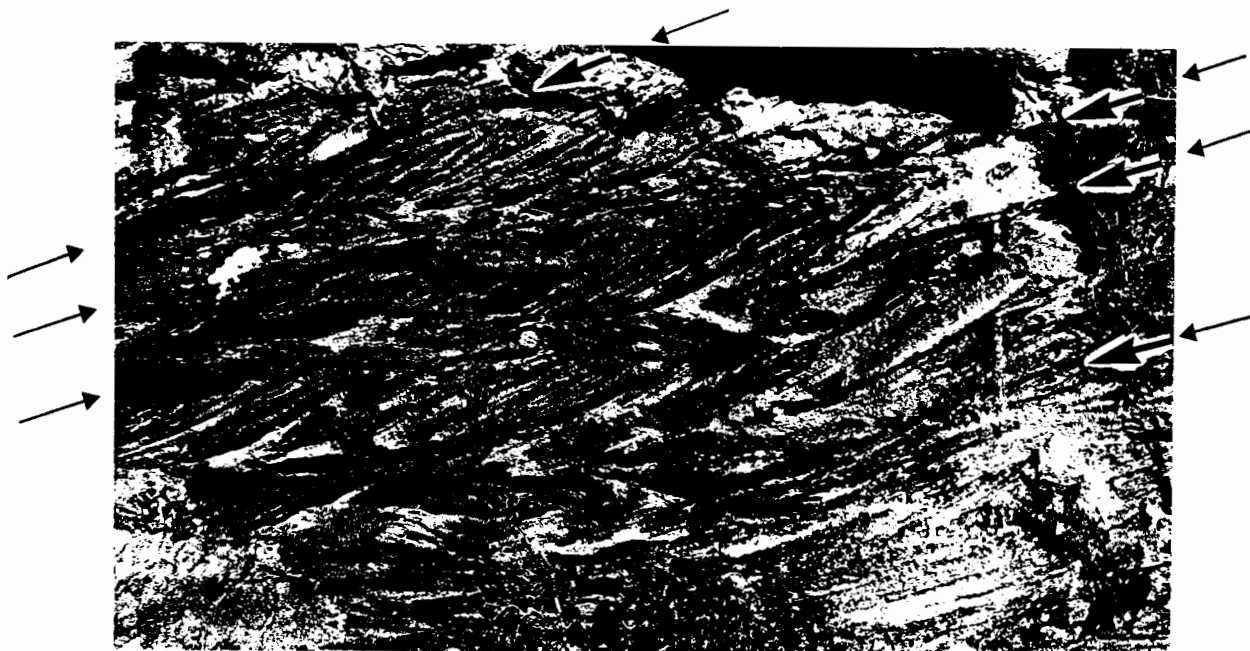


PLATE 13. Reactivation surfaces in crossbedded and trough crossbedded calcarenites in Unit 6, profile DH II on the left bank of De Hoopvlei near the restcamp (Figures 10a and 10c). Hammer for scale on the right-hand side.

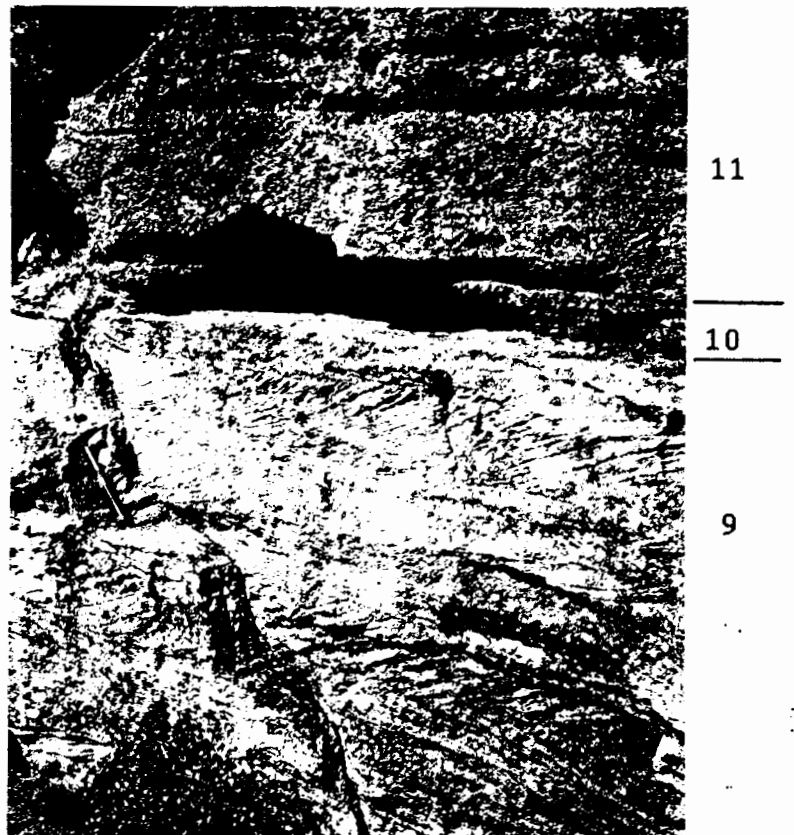
in deeper water, compared to ripples with sharp peaks that are formed in shallow water (Collinson and Thompson, 1982).

Herringbone-crossbedded units, observed in profiles DH I to DH III (Figures 10a to 10d) and at Rooikrans (Profile RK II, Figures 11a and 11c) are indicative of tidal conditions (De Raaf and Boersma, 1971). The crossbedded sets indicate opposing palaeocurrent directions of respectively 075 (ENE) and 255 (WSW) degrees, the latter dominating as the flood-tide (Unit 6 in profile DH II, Figures 10a and 10c). In the Rooikrans profile (RK II) two sets of herringbone crossbeds (Units 7 and 9, Figure 11c) are separated by a thin horizontally laminated upward-fining calcarenite (Unit 8; Figure 11c; Plate 14). These tidalites are overlain by calcirudites deposited during high-energy, possibly stormy, conditions (Plate 15).



PLATE 14. Two herringbone crossbedded sets separated by a thin horizontal laminated calcarenite in profile RK II, Units 7, 8 and 9 at Rooikrans on the right (southern) bank of the Sout River. (Figures 11a and 11c).

PLATE 15. Sets of herringbone crossbedding (Unit 9) overlain by calcirudite (Unit 10) in profile RK II at Rooikrans. (Figure 11c).



6.4.4.2 Palaeocurrents

In the Rooikrans cliff-face foreset laminae in the crossbedded unit (Unit 6, profile RK II; Figures 11a and 11c) indicate a palaeocurrent direction to the southeast, whereas the basal calcarenite (Unit 2) shows transport to the southwest (Figure 18a). A bimodal palaeocurrent pattern (105 and 165 degrees) is present in Unit 4 in profiles RK IV (Figures 11a and 11e); a slight shift in direction (075 and 180 degrees) marks the younger Unit 6 (Figures 18b and 18c). Changes in current directions are to be expected in the dynamic upper shoreface environment (Wright and Short, 1984). Near the restcamp at De Hoopvlei Unit 6 of profile DH I (Figures 10a and 10b) shows crossbedding with a palaeocurrent direction of 315 degrees (NW), but a polymodal distribution occurs in the overlying Unit 7 (Figures 18d and 18e). Crossbedding in the younger Unit 9 shows a bimodal distribution (015 and 285 degrees, NNE and WNW) (Figure 18f). Measurements along the axis of the trough crossbedding indicate directions of 315 and 135 degrees (NW and SE).

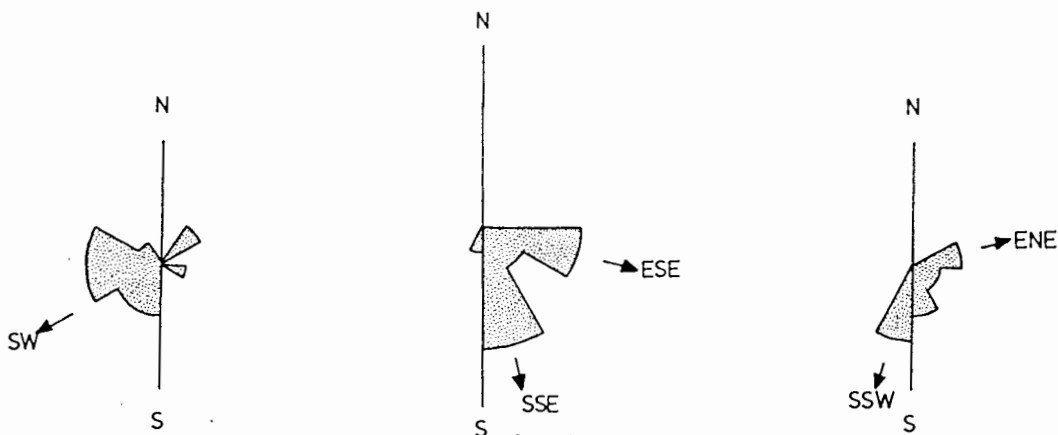


FIG 18a. Unit 2,
Profile RK II
(n = 14)

FIG 18b. Unit 4,
Profile RK IV
(n = 12)

FIG 18c. Unit 6,
Profile RK IV
(n = 9)

FIGURES 18a to 18c. Rose diagrams displaying palaeocurrent data measured at three different localities along Rooikrans, Sout River.

All the palaeocurrent data ($n=190$) from the De Hoopvlei and Rooikrans profiles yield a polymodal pattern with $075/255$ (ENE/WSW) and $165/315$ (SSE/NW) degrees orientations (Figure 18g). This points to a longshore direction as well as a direction perpendicular to the palaeoshoreline. This pattern is confirmed by data from the Bredasdorp area (Figure 18b). The palaeoshoreline followed an orientation similar to that of the present shore (Figure 9).

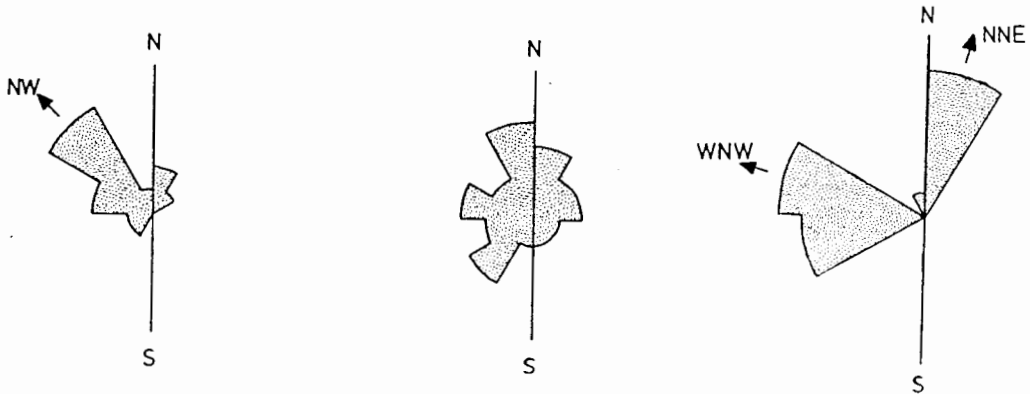
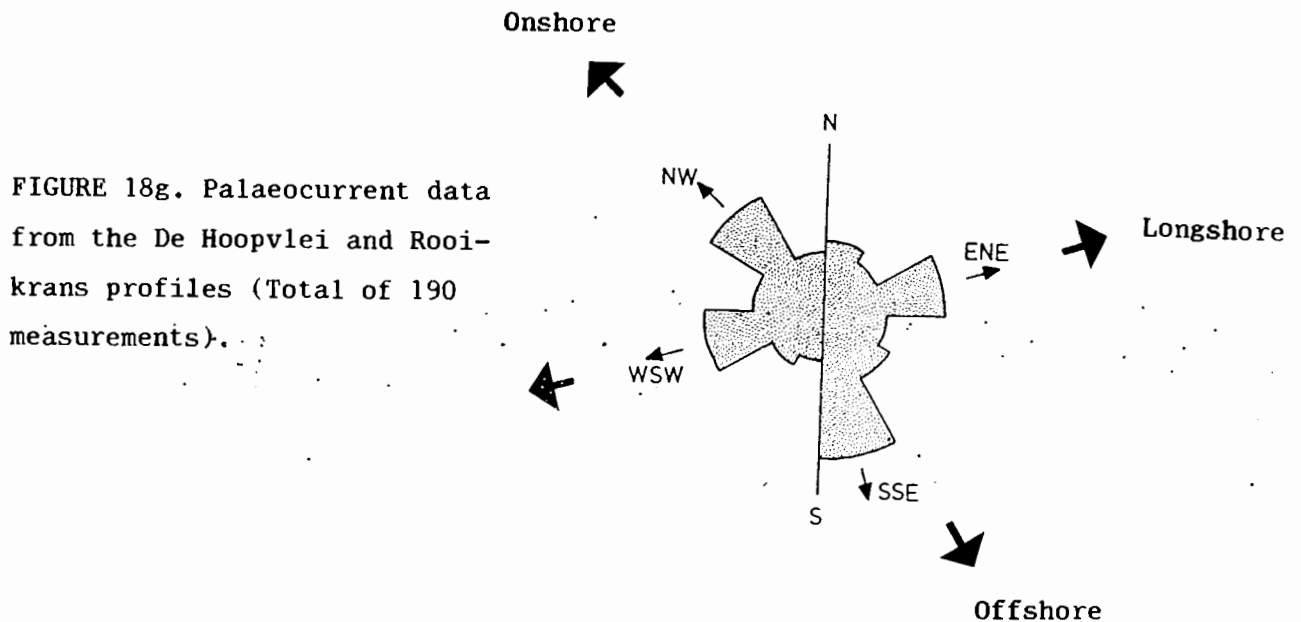


FIG 18d. Unit 6,
($n = 14$)

FIG 18e. Unit 7,
($n = 23$)

FIG 18f. Unit 8,
($n = 18$)

FIGURES 18d to 18f. Rose diagram displaying palaeocurrent data measured in profile DH I at the De Hoopvlei restcamp (Figures 10a and 10b).



6.5 PALAEOLOGY

6.5.1 Introduction

Complete and broken macrofossils, microfossils, fish debris, sharks' teeth, etc., as well as a variety of trace fossils and burrows were used to determine the depositional environment of the De Hoopvlei Formation. Although most body fossils tend to weather out, leaving moulds, the trails and burrows made by epifauna and infauna are better preserved due to lithification and diagenesis.

6.5.2 Macrofossils

Only limited work has been done on the fossil content of the De Hoopvlei Formation due to the lack of good exposures and the difficult terrain. Spies et al. (1963) published a list of macrofossils found in the Bredasdorp succession and this information was added to the present study (Table 5).

Le Roux (1986, 1989) made a list of diagnostic macrofossils from the Alexandria Formation in the Eastern Cape. A combination of two or more of the index species at a locality is indicative of marine deposits of Late Tertiary age. The following extinct species were used to correlate and date the De Hoopvlei sediments:- Echinodiscus sp. (similar to Echinodiscus colchesterensis as described from the Alexandria Formation by Smuts, 1987) and the bivalves Glycymeris borgesii, Tivela baini and Notocallista schwarzi.

The presence or absence of a species is determined by environmental factors and the presence of a species is indicative of certain environmental conditions. Palaeoenvironments are predicted with

more certainty if fossils are preserved in the living position. The extinct Echinodiscus sp ("sand-dollar") is found in living position on foresets of low-angle crossbedding (angles lower than 10 degrees) and horizontally laminated calcarenites in Units 5 of both profiles DH I and DH II near the restcamp along the shores of De Hoopvlei (Figures 10a to 10c, Plate 16).

The modern species, Echinodiscus bisperforatus ("pansy shell"), lives in clean to muddy sands between the intertidal zone and a water depth of 20m in the sublittoral zone along the open coast (Clark and Courtman-Stock, 1976). The extinct Glycymeris borgesii and the extant Scissodesma spengleri are indicative of a lower intertidal to subtidal palaeoenvironment. Glycymeris borgesii lived on a sandy substrate at water depths of 20m to 100m, whereas Scissodesma spengleri lives in the lower intertidal and upper subtidal zone (<3m) (Kilburn and Rippey, 1982, p. 155 and p. 179). A vague orientation of oyster shells in an accumulation of Ostrea atherstonei 0,5m thick can be ascribed to preferential growth of the oyster-bank in a sheltered environment (Plate 17).

Echinodiscus fragments and spines are present in all of the Rooikrans and Sout River profiles (Figures 11a to 11f). Other macrofossil fragments include bryozoans, bivalves and crinoid stems. Sharks' teeth, Odontaspis acutissima, were found in the unconsolidated sand and gravel above the basal conglomerate in several sections along the Kafferkuils River (Figures 14a to 14d). Phosphatized sharks' teeth, fish debris and fish bones are present in the unconsolidated basal conglomerate in profile RK IV at Rooikrans (Units 1 and 3, Figures 11a and 11e). Cemented brown phosphatized calcarenite grains, formed of fine shell fragments and benthic foraminifera, are found in profiles KK II and KK III on the left bank of the Kafferkuils River in Still Bay (Figures 14a, 14c and 14d).

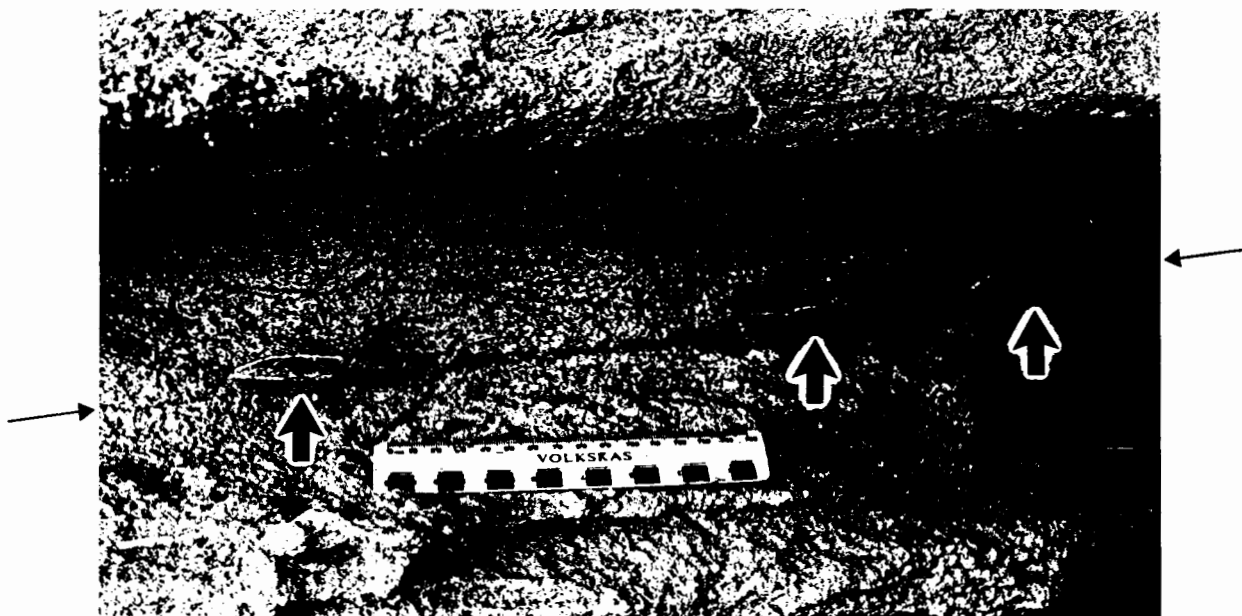


PLATE 16. Several Echinodiscus sp. preserved on a bedding plane (large arrows) in the low-angle crossbedded Unit 5 in profile DH I on the left bank of De Hoopvlei near the restcamp (Figures 10a and 10b).

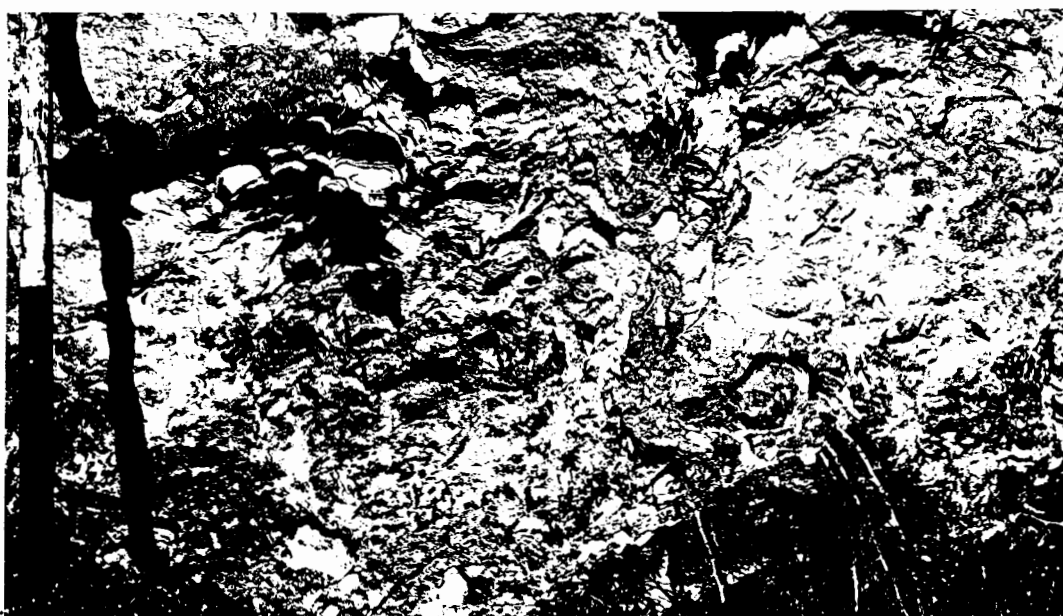


PLATE 17. Preferential growth of Ostrea atherstonei oyster-bank exposed in profiles DH VII along the southern part of De Hoopvlei (Unit 2 in profile DH VII, Figure 10h).

6.5.3 Microfossils

Benthic foraminifera are abundant in the Cainozoic deposits of the south coast and, despite recrystallisation and diagenesis, several species have been identified. C.G. Rümke of the Geological Survey (in Spies et al., 1963) recognised seventeen different benthic species. I.K. McMillan of the Southern Oil Exploration Corporation (Soekor) studied selected samples from the Bredasdorp Group and identified forty-eight species characteristic of a littoral or sub-littoral shallow-marine environment, considered to be of Early to Late Pleistocene age (McMillan, 1986). No planktonic foraminifera occur in the older units, and only rarely in the younger units. The benthic foraminifera Elphidium advenum, Pararotalia nipponica and Cibicides lobatulus are widespread throughout the Bredasdorp Group, and are also known extant from the South African littoral (McMillan, 1986).

Two foraminiferal associations were recognised by McMillan (1986) for the De Hoopvlei Formation. An older association (Unit II, Early Pleistocene) occurs in the sections at Rooikrans along the Sout River (Figures 11a to 11e) and in boreholes penetrating the southernmost edge of Harde Duine on Moerasfontein northwest of Waenhuiskrans (Figure 9). Ostracod fragments were also found in all of the boreholes on Moerasfontein. A younger association (Unit IIA, Middle Pleistocene) occurs in all the sections along De Hoopvlei (profiles DH I to DH VII; Figures 10a to 10h) in all the sections along the Kafferkuils River (profiles KK I to KK V; Figures 14a and 15a). Although abundance is high in many samples, species diversity is everywhere low (McMillan, 1986).

Evidence that the De Hoopvlei sediments were laid down in a regressing sea in which only littoral deposits were preserved is given by McMillan (1986, p.7). He states that "It is clear that sediments which accumulated during the earlier transgressions

(pre-De Hoopvlei Formation in age), and those finer-grained deposits which must have accumulated away from the littoral, on the middle and outer shelf, ...were stripped and reworked as the shoreline regressed and have not been preserved."

6.5.4 Ichnofossils

Ichnofossils (trace fossils) are tracks, trails, burrows, borings and other secondary structures made by organisms on or in a substrate (Frey, 1975). Although a sediment substrate is the most common host for ichnofossils, rocks, wood and shell material also contain ichnofossils such as borings (Warme and McHuron, 1978). Most traces are post-depositional, although some are contemporaneous with deposition and are therefore valuable environmental indicators.

Ichnofossils are an indication of conditions during and shortly after deposition and their presence depends on factors such as sedimentation rate, current strength and substrate type. Ichnofossils are often preserved because of early diagenesis and lithification, whereas the hard parts of body fossils tend to dissolve (Frey, 1975). Seilacher (1967) developed the concept that marine ichnofossils are depth-sensitive and that characteristic assemblages of ichnofossils are representative of various sedimentary facies in ancient marine sequences.

Ichnofossils can be grouped according to the activity of the organism which produced them (Seilacher, 1967) or according to their topology (Martinson, 1970), which describes the relationship of the trace to the adjacent beds. Howard (1978) takes a cautious approach and suggests using traces indicators of general depositional environments rather than as depth indicators. The ethological classification of bioturbated structures describes six categories of lebensspuren (Frey, 1975), i.e. resting traces,

crawling traces, grazing traces, feeding traces, dwelling structures and escape structures, of which the last three types were recognised in the Bredasdorp sediments.

In the classic beach-to-offshore stratigraphic sequence, an energy gradient with higher energy in the nearshore, where shallowing occurs and waves and currents impinge on the bottom and at the shoreline stands in contrast to low energy in the offshore area (Heward, 1981). In the offshore environment, the biogenic record is dominant with limited preservation of primary sedimentary structures, whereas in the transitional zone the physical and biogenic influences are approximately equal.

In the shoreface environment the primary sedimentary structures are more abundant limiting biogenic features to one or two specific forms (Howard and Reineck, 1981). The Cruziana, Skolithos and Scoyenia ichnofacies forming Epichnia, Endichnia and Hypichnia traces (Selley, 1982, Table XXII) are preserved in the Bredasdorp sediments.

6.5.4.1 Cruziana ichnofacies

Poorly-sorted, subtidal sediments deposited under conditions of moderate energy (below storm wave-base) to low energy (deeper water) are characteristic of the Cruziana ichnofacies (Häntzschel, 1975). In this zone, where wave action is less effective, invertebrates crawl over and burrow in the sea-bed. The burrows tend to be shallower, with an oblique or subhorizontal orientation relative to the seafloor (Selley, 1982). These burrows may be three-dimensional branching systems like Thalassinoides, simple U-tubes like Arenicolites or simple, unbranched, horizontal tubes like Planolites (Frey, 1975). Where burrowing is intense the sediment becomes completely bioturbated and all primary sedimentary structures are destroyed.

6.5.4.2 Skolithos ichnofacies

This well-defined ichnofacies occurs in the intertidal zone where the sediment substrate is commonly subjected to scouring action of currents, causing the erosion and reworking of the well-sorted, clean sand. The various invertebrates of the intertidal zone such as worms, bivalves, sandprawns (Callianassa) or crabs tend to live in crawling, dwelling and feeding burrows. These burrows may be simple vertical tubes like Skolithos, vertical U-tubes like Diplocraterion or complex networks of passageways such as Ophiomorpha (Oppelt, 1988). Primary sedimentary structures commonly predominate over biogenic structures, due to the intense physical reworking of the sediments, truncated burrows indicating positions of erosional bedding-plane surfaces (Howard, 1978). Surface traces on bedding planes are scarce or absent, due to higher-energy conditions during the depositional process.

6.5.4.3 Ichnofossils in the De Hoopvlei Formation

Traces from the Skolithos and Cruziana ichnofacies are recognised in the De Hoopvlei sediments. Vertical burrows with a diameter of 2cm occur in Bokkeveld shale below the unconformity in profile KK V along the right bank of the Kafferkuils River on the farm Klipfontein (Figures 15a and 15c). These sand-filled burrows were drilled by bivalves (Pholadidae) to a depth up to 5cm into the Bokkeveld shale (Plate 18). A calcarenite lens with vertical and subhorizontal burrows occurs directly above the upward-fining conglomerate (Unit 7) in profile KK V (Unit 8, Figure 15c). Here Ophiomorpha nodosa burrows, with a diameter of 10 to 15mm and a length of up to 30cm, have an outer, mamillated surface constructed of mud (mucus?) pellets (Plate 19).

Based on modern analogues, Ophiomorpha has been interpreted as the feeding/dwelling structures of a shrimp or shrimp-like animal

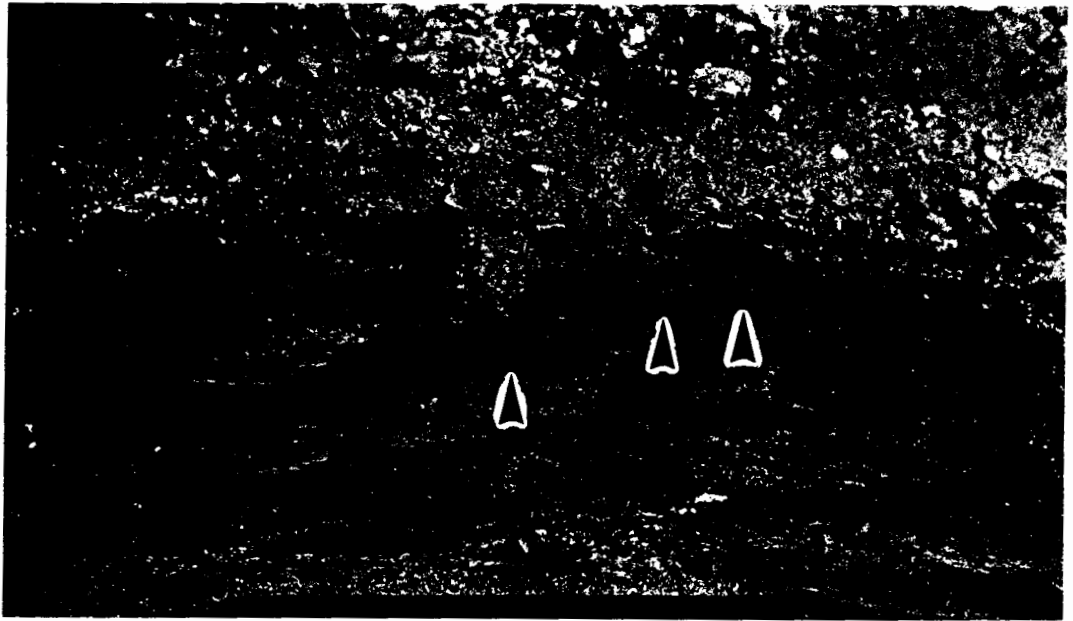


PLATE 18. Pholadidae burrows drilled up to 5cm into Bokkeveld shale in profile KK V on Klipfontein on the right bank of the Kafferkuils River (Figures 15a and 15c). Black bar = 15cm.

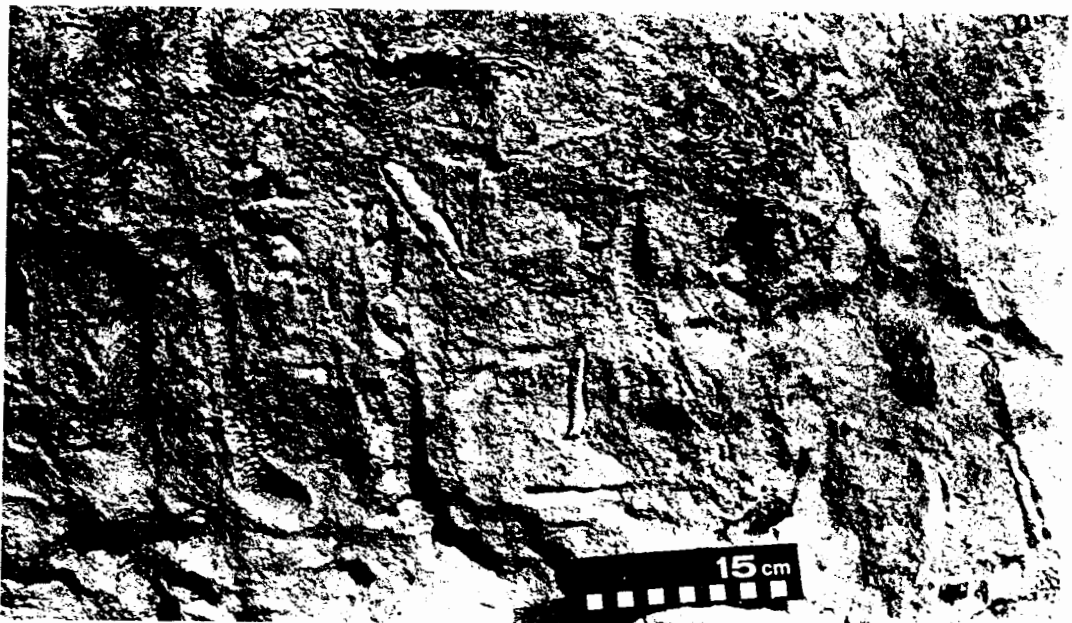


PLATE 19. Mamillated Ophiomorpha nodosa burrows in a calcarenite lens in profile KK V on Klipfontein on the right bank of the Kafferkuils River (Unit 8, Figures 15a and 15c).

(Frey *et al.*, 1978). Branching Ophiomorpha burrows are exposed in low-angle and trough crossbedded, medium- to coarse-grained calcarenite in the cliffs along the left bank of De Hoopvlei (Profiles DH I and DH II, Figures 10a to 10c; Plate 20). These cylindrical, vertical burrows, with a diameter of between 7 and 10cm, have a distinct 3cm thick lining of agglutinated pelletoidal sediments (Unit 5 in profile DH II, Figure 10c; Plate 21). A plan view of these branching tunnels is exposed on a bedding surface (Unit 6 of profile DH I, Figure 10b) with a density of up to 40 Ophiomorpha nodosa burrows per square metre (Plate 22). In the same unit, thin (5 to 10mm thick) sediment-filled horizontal and angled Skolithos type burrows can be seen.

At Rooikrans (Profile RK III, Figures 11a and 11d), a laminated medium-grained calcarenite (Unit 4) is filled with branching horizontal and subhorizontal sediment-filled (possible Planolites burrows) tubes with a diameter of 3 to 5mm (Plate 23). Horizontal Ophiomorpha burrows with a diameter of 5cm and a wall thickness of 15mm occur at the base of the unit. Planolites burrows decrease in abundance higher up in the unit (Plate 24).

At the top of Unit 2, in profile DH I (Figure 10b), Ophiomorpha and Skolithos (vertical and subhorizontal) burrows occur (Plate 25). Unit 3 in profile DH I (Figure 10b), consists of mm-scale vertical Skolithos burrows. Intense bioturbation, which has destroyed all primary sedimentary structures, was observed in fine- to medium-grained calcarenite and calcareous sandstone in profiles DH I and DH II at De Hoopvlei (Units 1 in Figures 10a, 10b and 10c), DR I (Duiwenhoks River) (Figures 13a and 13b) and KK V (Kafferkuils River) (Figures 15a and 15c).

PLATE 20. Branching Ophiomorpha nodosa burrows in low-angle crossbedded calcarenite (Unit 5, Profile DH II). (Figure 10a and 10c).



PLATE 21. Plan view of a vertical Ophiomorpha nodosa burrow, with a diameter of 7cm and a 3cm-thick outer lining of agglutinated pelletoidal sediments (Top of Unit 5 in profile DH II, Figure 10c).

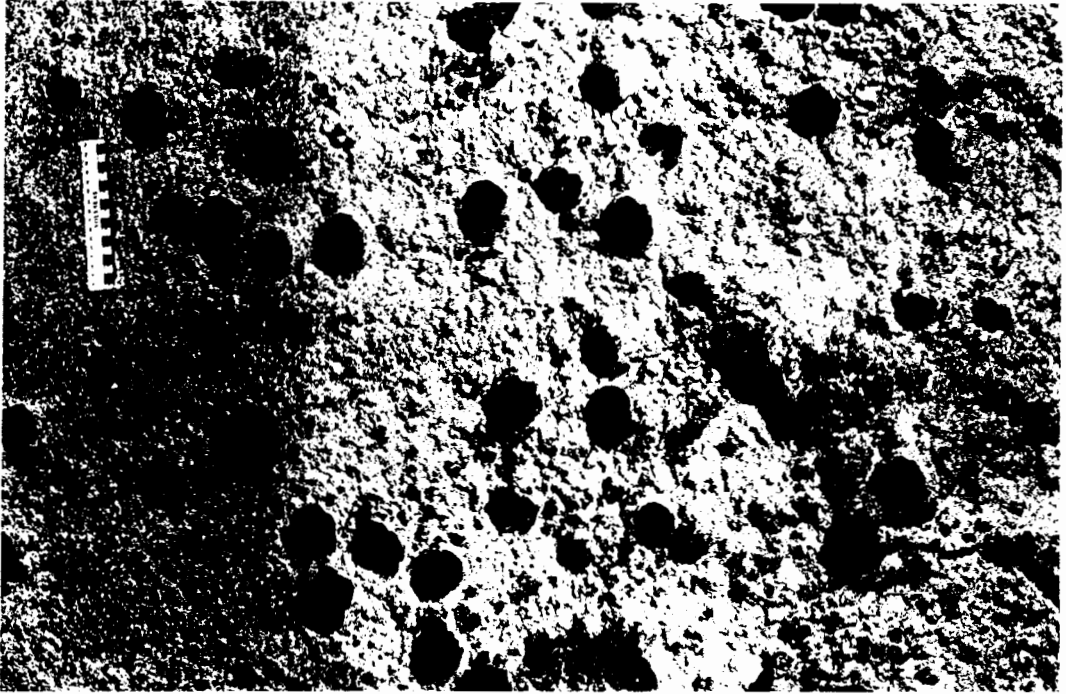


PLATE 22. Plan view of several Ophiomorpha nodosa burrows exposed on a bedding surface at profile DH I, Unit 6, on the left bank of De Hoopvlei near the rest camp (Figures 10a and 10b).

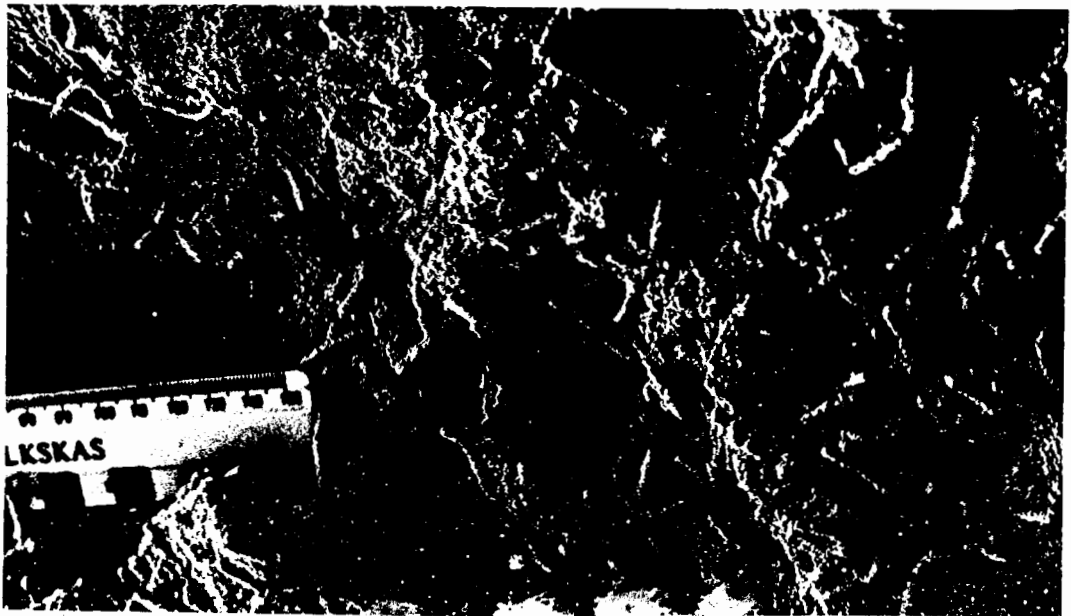


PLATE 23. Branching horizontal and subhorizontal sediment-filled Planolites? tubes with a diameter of 3 to 5mm in profile RK III (Unit 4, Figures 11a and 11d).

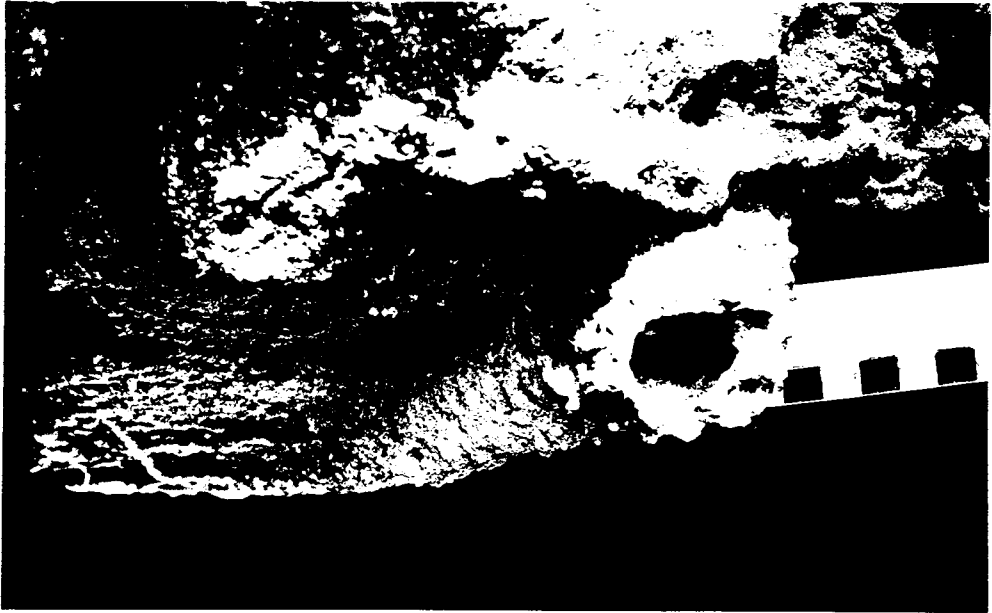


PLATE 24. Horizontal mamillated Ophiomorpha burrow with a diameter of 5cm and a wall thickness of 15mm at the base of Unit 4 in profile RK III (Figures 11a and 11d).



PLATE 25. Ophiomorpha and Skolithos? burrows forming the top of Unit 2 in profile DH I on the left bank of De Hoopvlei near the restcamp (Figures 10a and 10b).

CHAPTER 7. WANKOE FORMATION

7.1 INTRODUCTION

The Wankoe Formation forms the bulk of the Bredasdorp Group. Wybergh (1919, p. 53) described this as the aeolian part of the Bredasdorp limestones. Haughton *et al.* (1937) described fine-grained sandy limestones with large-scale crossbedding in the area to the west of Mossel Bay. Similar windblown deposits were mapped in the Bredasdorp area (Spies *et al.*, 1963). No formal stratigraphic recognition was given to these sediments by SACS (1980).

Well-cemented, calcrete-capped aeolianites exposed in well-developed karst topography between the Kafferkuils and Gourits Rivers were provisionally named the Canca Member of the Bredasdorp succession by Rogers (1986). Malan (1986 and 1987b) subsequently used the name Wankoe Formation to describe the consolidated aeolianites, northwest of Still Bay, the type section being a large polje (solution depression) called Wankoe Valley (Figures 19, 20a and 20b). Since then SACS has given formal lithostratigraphic recognition to the Wankoe Formation (Malan, 1989b). The Wankoe Formation (WAN) will be discussed with the aid of two stratigraphic profiles (WAN I and WAN II, Figures 19 and 20).

7.2 GEOGRAPHICAL DISTRIBUTION

The Wankoe Formation covers extensive areas of the coastal plain along the Southern Cape coast. Exposures occur over a distance of nearly 300km from Stanford in the west to Mossel Bay in the east (Figure 1). Accessible exposures are in the disused building stone quarry on Welgesind, 3km southeast of Stanford (Figure 19). The Dutch Reformed Church and the school buildings in Stanford were built from blocks excavated from this quarry. The Wankoe Formation

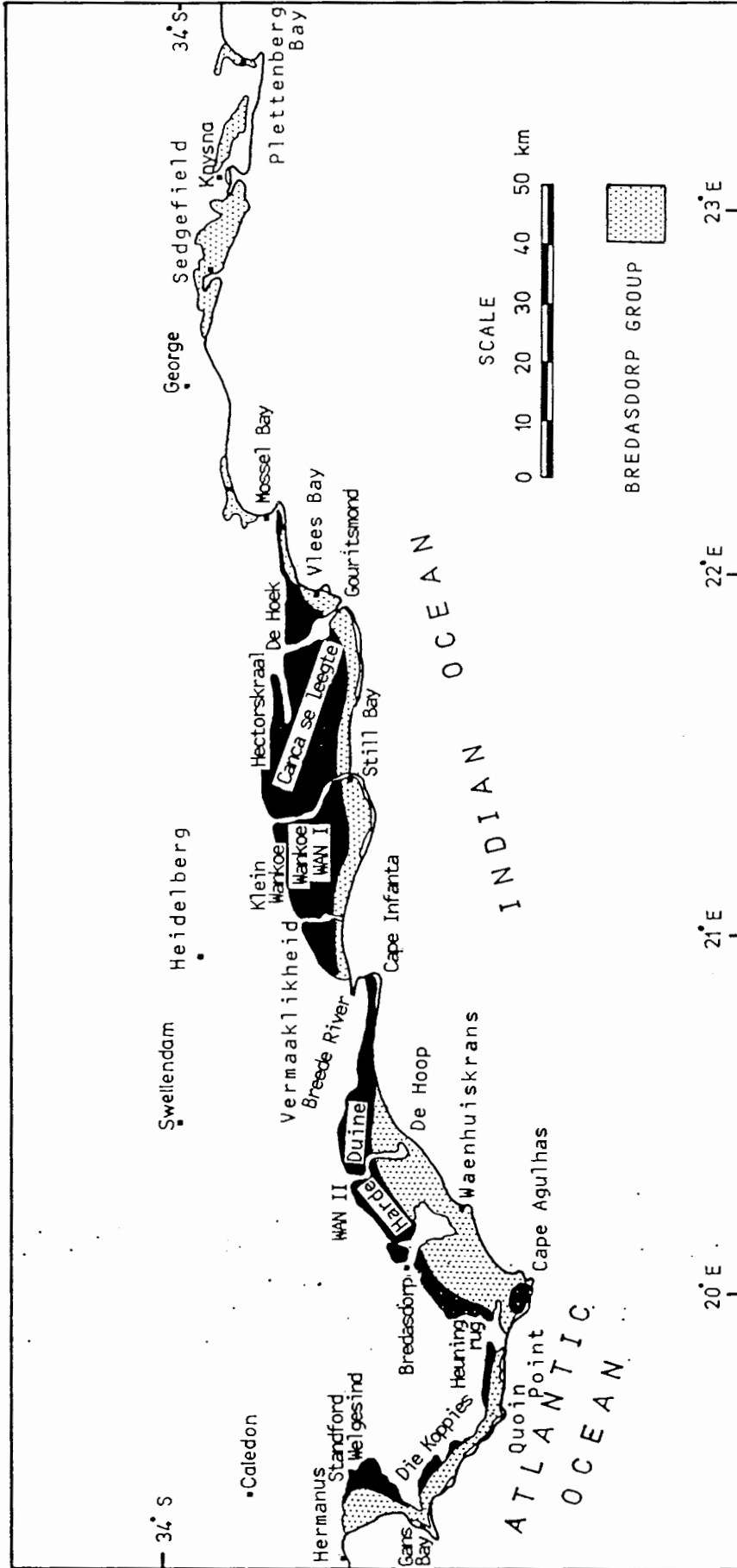
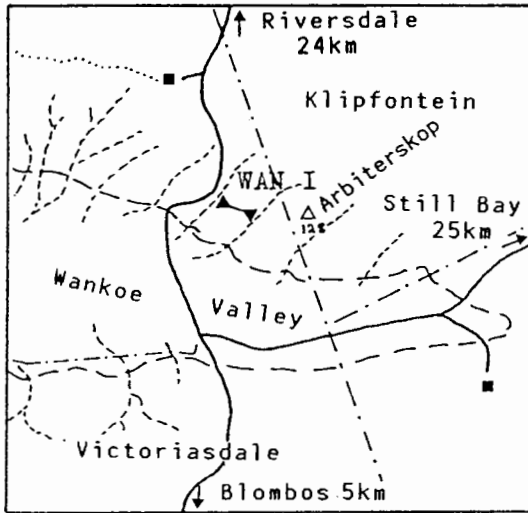
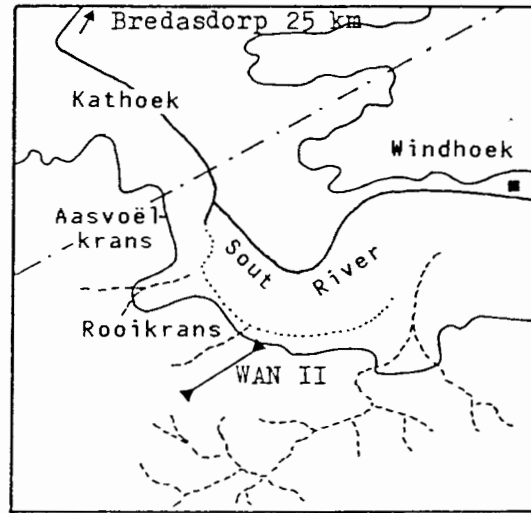


FIGURE 19. Profile localities and locality diagram for the Wankoe Formation, Bredasdorp Group. Outcrops of Wankoe Formation indicated by black colour.

WAN I = Profile WAN I in Wankoe Valley. WAN II = Profile WAN II at Rooikrans, Sout River.



Wankoe Valley
(Profile WAN I)



Rooikrans in Sout River
(Profile WAN II)

LEGEND








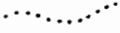
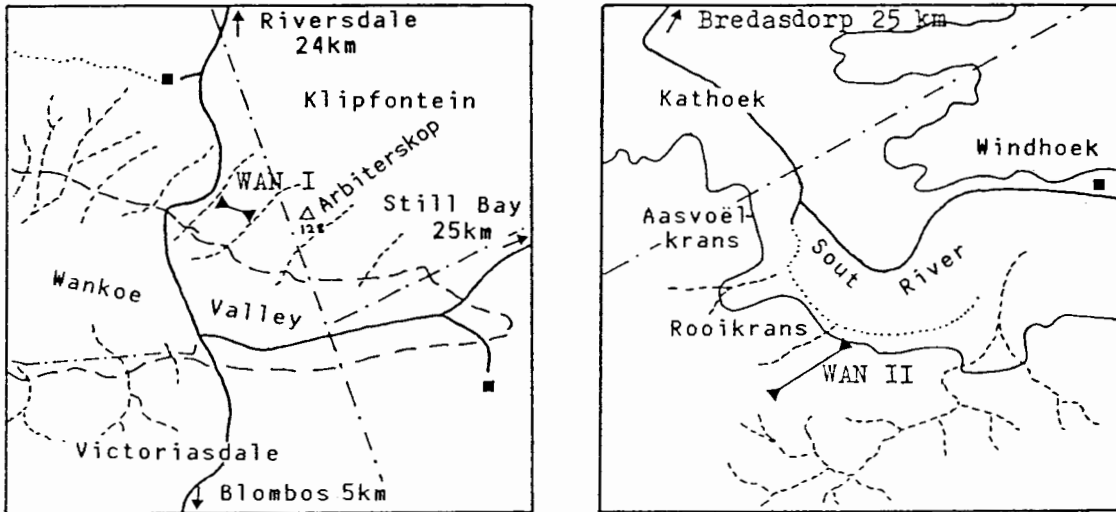
- | | | | |
|---|------------------|---|----------------------|
|  | Wankoe Formation |  | Trigonometric beacon |
| WAN I  | Profile locality |  | Farm boundary |
|  | Dry river bed |  | Building |
|  | Road |  | Jeep track |

FIGURE 20a. Location of profiles WAN I (Wankoe Valley) and WAN II (Rooikrans in Sout River), Wankoe Formation.



Wankoe Valley
(Profile WAN I)

Rooikrans in Sout River
(Profile WAN II)

LEGEND

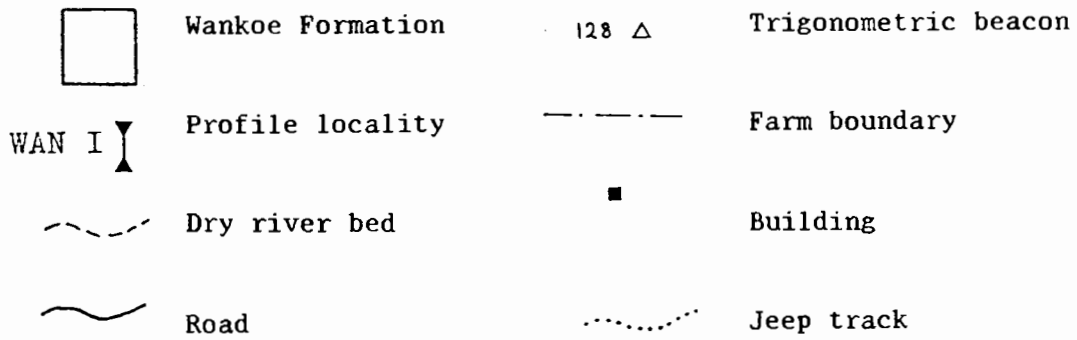


FIGURE 20a. Location of profiles WAN I (Wankoe Valley) and WAN II (Rooikrans in Sout River), Wankoe Formation.

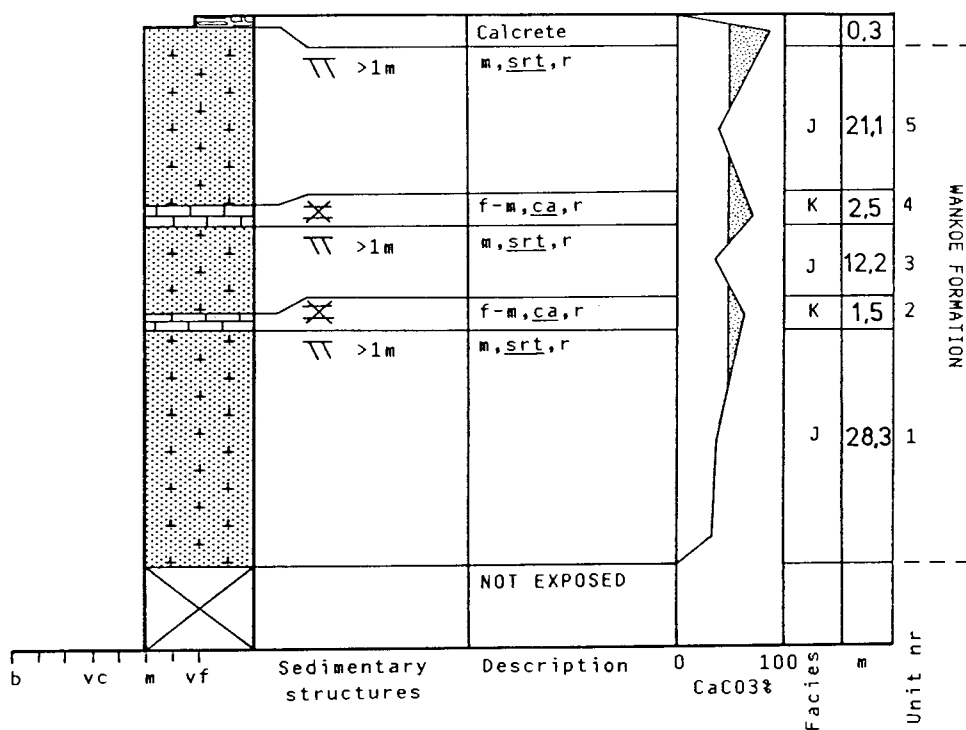
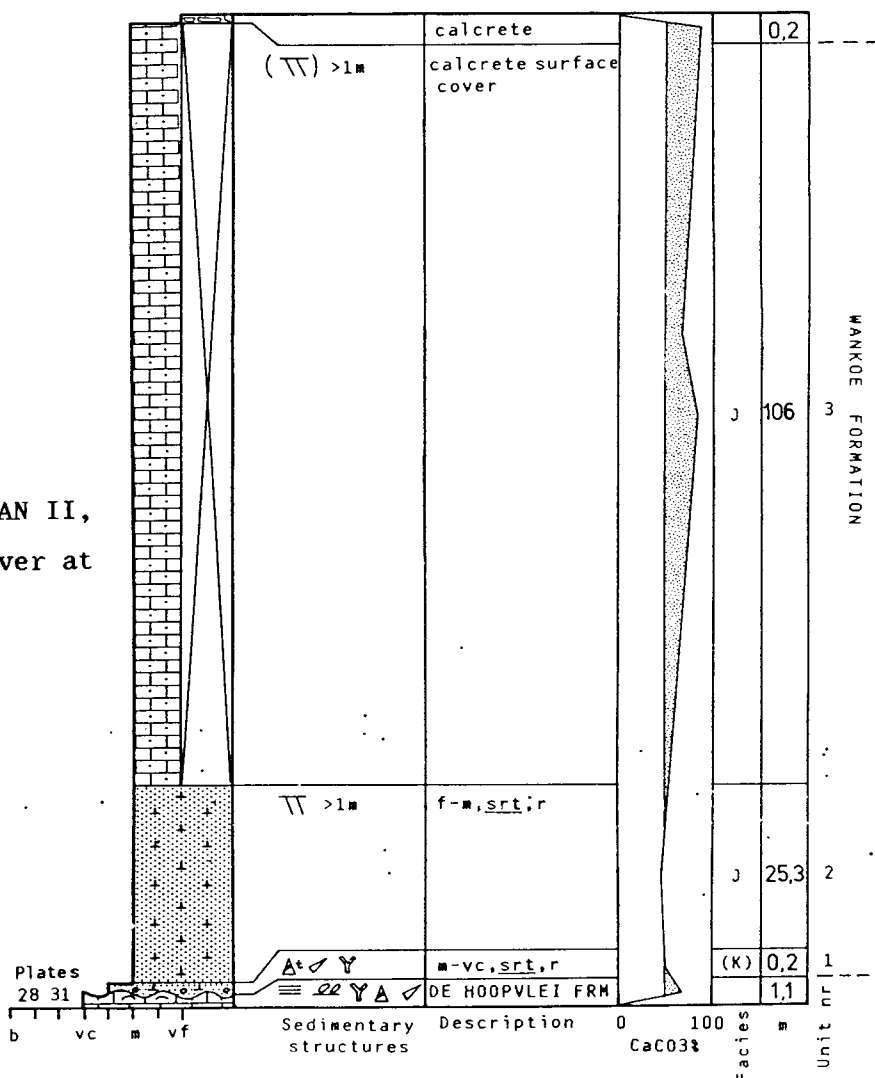


FIGURE 20b. Profile WAN I at the northern side of Wankoe Valley on Victoriasdale, 7km from Blombos.

FIGURE 20c. Profile WAN II, right bank of Sout River at Rooikrans.



can be followed between Gans Bay and Cape Agulhas as conspicuous low ridges, Die Koppies, deposited on a wave-planed surface (Figure 19).

Heuningrug, a prominent ridge south of Bredasdorp, and the series of calcified ridges known as Harde Duine between Bredasdorp and Cape Infanta, are formed by similar deposits (Figure 19); excellent exposures occur in Aasvoëlkrans and Rooikrans on the right bank of the Sout River (Figure 20a, Plates 26 and 27). Between the Breede River and Mossel Bay the Wankoe Formation occurs up to 22km inland from the present shoreline. Numerous dry valleys known as Klein Wankoe, Groot Wankoe and Canca se Leegte, and elevated areas such as Kalkhoogte and Kalkberge form part of the coastal karst landscape (Marker, 1981; 1988 and Russell, 1982; 1987) (Figure 19).

7.3 LATERAL VARIATION

East of the Gourits River the entire thickness of the Wankoe Formation consists of unconsolidated to semi-consolidated calcareous sand and inconspicuous crossbedding. West of the Gourits River this same unit is well consolidated with striking large-scale crossbedding, e.g. at Aasvoëlkrans (Plate 27) and Rooikrans in Sout River gorge (Figure 20a). Nevertheless, the Wankoe Formation shows few, if any, petrographical, mineralogical or geochemical variations (Siesser, 1972).

7.4 GEOLOGICAL DESCRIPTION

7.4.1 Stratigraphic boundaries

The basal contact of the Wankoe Formation with the De Hoopvlei Formation is defined at the top of the uppermost marine shelly gravel unit of the latter formation. This boundary is in general



PLATE 26. The position of profile WAN II (indicated by arrows) along Rooikrans cliff, south bank of Sout River (Figures 20a and 20c).

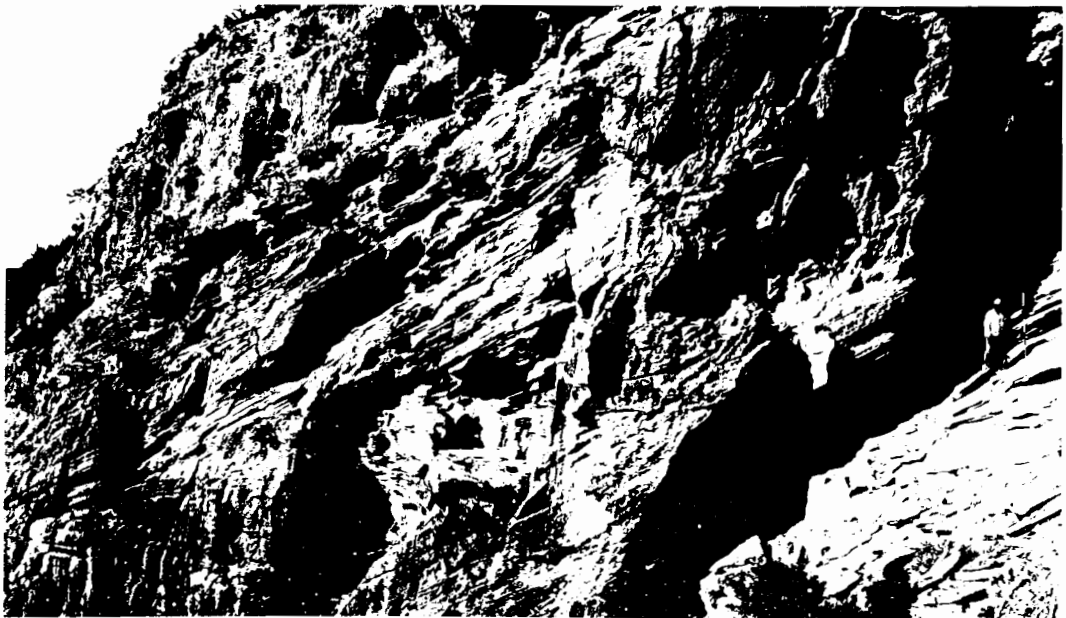


PLATE 27. Large-scale planar crossbedding characterising the Wankoe Formation in the east-facing cliffs of Aasvoëlkrans on Windhoek on the right bank of Sout River (Figure 20a).

sharp with distinctive erosional features developed in places (Plate 28). In the Rooikrans section this unconformity is formed by an undulating surface containig many casts of the terrestrial gastropod Trachycystis sp. (preliminary identification by J. Pether, S.A. Museum), and pebbles filling the hollows (Figures 11c, 11d and 20c). The upper boundary of the Wankoe Formation is defined as the base of the overlying calcrete, soil, scree or unconsolidated aeolian sand.

7.4.2 Unit thickness

The thickness of the Wankoe Formation varies from less than 20m at Stanford and Heuningrug to nearly 300m at Heuningkop, west of Gouritsmond (Figure 19). An unit thickness of 130m was calculated, varying according to the palaeotopography of the

PLATE 28. The sharp basal contact between the De Hoopvlei and Wankoe Formations in the Rooikrans section indicated by arrows. This unconformity is formed by an undulating surface; terrestrial gastropod Trachycystis sp. shells and pebbles fill the hollows. (Figures 11c, 11d and 20c).



original dune crests (cf. profile WAN II, Plate 26). This palaeodune topography is preserved in places along with the palaeo-interdune "streets", forming elongated features like Canca se Leegte, Wankoe, Klein Wankoe and an extensive area northwest of Still Bay (Figure 19). These elongated "dry valleys" form the conspicuous east-west aligned features seen on topographical maps (Rogers, 1986, 1988) and described by Marker (1988, p. 47) as "an aligned karst" landscape. Similar features were described by Stear (1987) in the Algoa Bay hinterland close Nanaga.

7.4.3 Lithology

The Wankoe Formation consists of between 50 and 90 percent calcareous sandstone and between 10 and 50 percent calcarenite. The formation consists of well-rounded, well-sorted, fine- to coarse-grained quartz grains, few glauconite grains and finely comminuted shell fragments. The formation's colour varies from yellowish grey to yellowish orange. Carbonate content ranges from 25 to 45 percent for the calcareous sandstone and from 60 to 95 percent for the calcarenite. Thick-bedded large-scale cross-bedding is the characteristic feature of the Wankoe Formation (Figures 20b and 20c, Plate 27).

The calcarenite in many places appears massive, as most of the primary structure has been destroyed by secondary calcification. Interbedded palaeosols are preserved as conspicuous, fine- to medium-grained calcrete horizons (Units 2 and 4 in profile WAN I, Figure 20b). An aeolianite is a lithified accumulation of wind-blown calcareous grains. These deposits are typically found in coastal dune fields, where the calcareous sediments consist of comminuted marine shell fragments initially thrown up on the beach by waves.

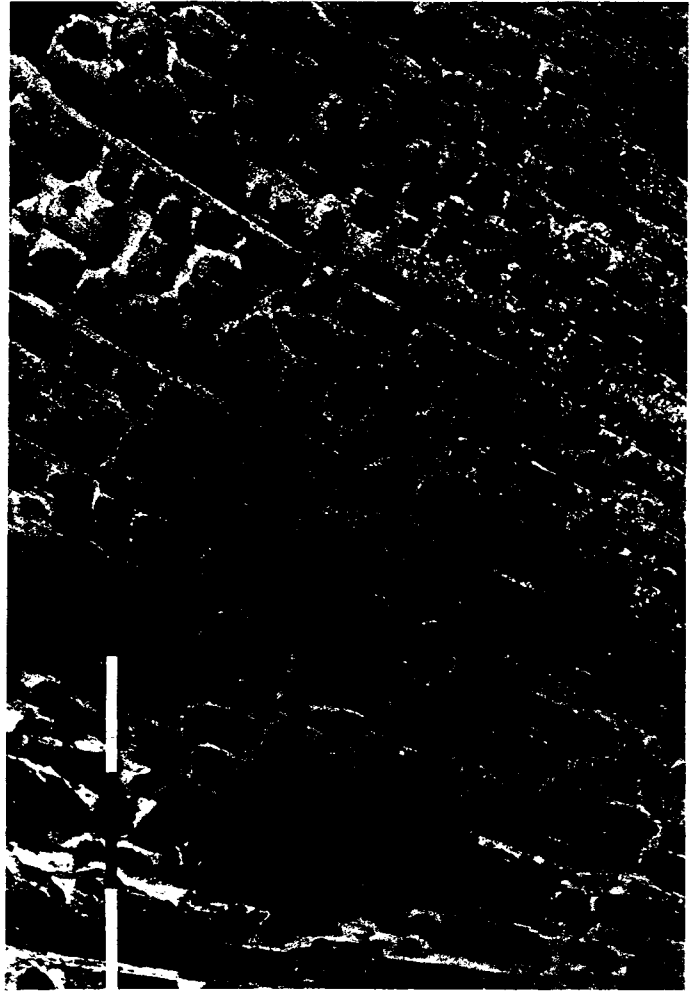
7.4.4 Sedimentary structures

The Wankoe Formation is characterised by large-scale planar crossbedding with a set thickness of more than 1,5m typical of aeolian deposits (Walker and Middleton, 1981) (Plates 27 and 29). Foreset laminae of crossbedding can be as steep as 30 degrees with asymmetrical ripples preserved on some of the exposed surfaces. Abundant erosional unconformities were observed in this crossbedded unit (Plate 30); low-angled or horizontally laminated units are rare.

Cross-sections through the calcified Wankoe Formation on Windhoek (Plate 30) and Kathoek revealed large-scale aeolian crossbedding with excellent examples of first, second and third order Kocurek bounding surfaces (Kocurek, 1981; Brookfield, 1977). The near-horizontal first-order bounding planes were formed during dune migration and wind deflation, exposing the moist sands near the groundwater table. Examples of these surfaces are exposed in the western slopes of Arbiterskop next to the Wankoe Valley, northwest of Still Bay (Figures 20a and 20b). Second-order bounding surfaces occur throughout the Wankoe Formation and mark the migration of individual bedding planes and dune slipfaces responsible for the abundant erosional unconformities. These can be observed in the shallow, wind-deflated caves in Aasvoëlkrans and Rooikrans on Windhoek (Plates 26 and 30). The small-scale third-order bounding planes can be related to small internal changes, including, small-scale deformation features and reactivation surfaces within the aeolian crossbeds (Bigarella, 1972).

Horizontal strata, occurring as interdune deposits, are recognized as palaeosols in sections of the Wankoe Formation in the type section in Wankoe Valley (Figures 20a and 20b) and along the banks of the Kafferkuils River (Profiles KK I, KK II and KK IV,

PLATE 29. Set of large-scale cross-bedding with an upward increase in foreset dip angle, Rooikrans on Windhoek (Figure 20a)(Scale = 0,5m)



Wankoe
Formation

De Hoopvlei
Formation

Bokkeveld
Group



PLATE 30. Wankoe Formation exposure in Aasvoëlkrans on Windhoek revealing examples of Kocurek bounding planes (indicated by thick arrows) (Figure 20a for location on the right bank of the Sout River). (Stratigraphic units shown by thin arrows).

Figures 14b, 14c and 15b). Calcrete layers, seen between some of the crossbedded units, were caused by groundwater effects. The calcrete in the Gourits River cutting, on the farm De Hoek, was possibly formed in stages as pedogenetic calcrete during the deposition of the Wankoe aeolianite.

Angle of dip and dip-direction measurements of randomly selected foreset laminae of crossbedding were taken at several localities in Sout River. These sites were chosen for the well-exposed aeolian cross-bedding preserved in the floor, sides and roof of the wind-deflated caves in Rooikrans and Aasvoëlkrans (Figure 20a, Plates 26 and 30). These measurements were plotted on rose diagrams and show two dominant palaeo-transport directions, with maxima indicating palaeo-wind directions from the northwest and the southwest (Figure 21). This bimodal pattern could be the result of seasonal wind directions, with local changes from onshore- to offshore-blowing winds responsible for the secondary maxima towards the west.

7.4.5 Palaeontology

Terrestrial gastropod shells and comminuted shell fragments are preserved in the Wankoe Formation. Examples of casts of the gastropod Trachycystis sp. (preliminary identification by J. Pether, S.A. Museum) occur on the Wankoe basal unconformity in the Rooikrans section (Figures 20a and 20c, Plate 31), and complete shells and shell imprints of Achatina zebra were found in the quarry on Hectorskraal, southwest of Albertinia (Figure 19, Plate 32). Trachycystis sp. are gastropoda now living on the Cape fynbos vegetation. Weathered and cemented echinoid spines and benthic foraminifera such as Elphidium advenum, Ammonia sp. and Pararotalia nipponica (McMillan, 1986) are preserved in the basal part of the Wankoe Formation in profiles RK II, SR I, DR I, KK II, KK III and KK V (Figures 11c, 11f, 13b, 14c, 14d and 15c). No evidence of trace fossils was found in the Wankoe Formation.

FIG 21a. Rooikrans locality
(Total of 37 measurements).

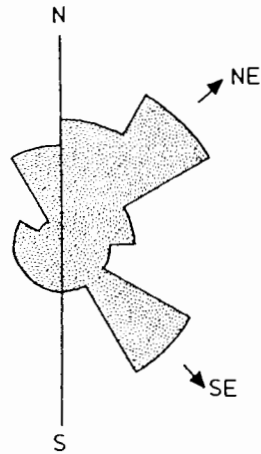


FIG 21b. Aasvoëlkrans locality
(Total of 22 measurements).

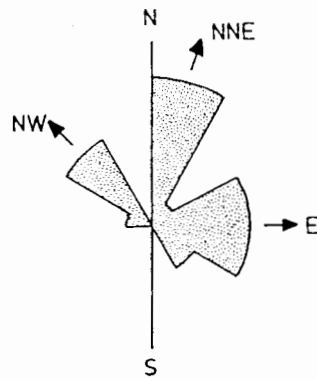
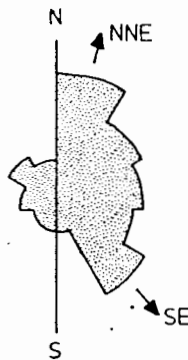


FIG 21c. Combination of data
from both localities
(Total of 59 measurements).



FIGURES 21a to 21c. Rose diagrams showing palaeowind patterns for the Wankoe Formation at Rooikrans and Aasvoëlkrans, Sout River. (Figure 20a).

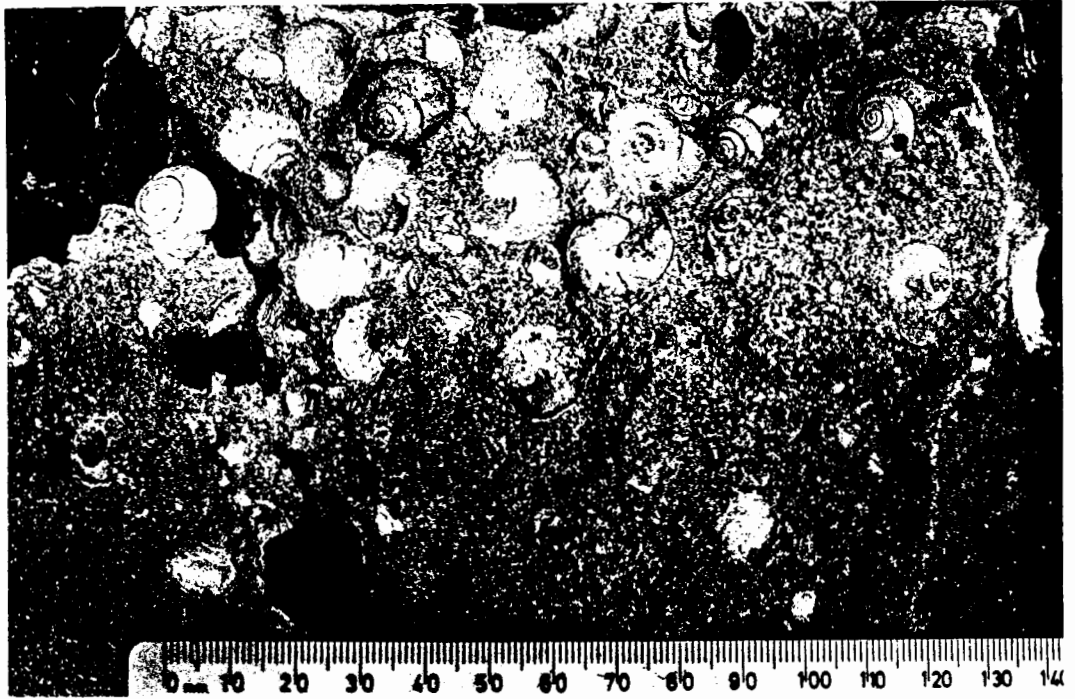


PLATE 31. Casts of the terrestrial gastropod Trachycystis sp. preserved on the basal unconformity of the Wankoe Formation in the Rooikrans section (Unit 1 in profile WAN II, Figures 20a, 20c).



PLATE 32. An Achatina zebra shell imprint found in the quarry on Hectorskraal, southwest of Albertinia (Figure 19).

CHAPTER 8. KLEIN BRAK FORMATION

8.1 INTRODUCTION

Raised-beach deposits in the Klein Brak River estuary were first described by Rogers (1906). Similar deposits were noted by Haughton et al. (1937) in both the Klein Brak and Groot Brak estuaries. Spies et al. (1963) described a conglomeratic unit, up to 2m thick, with abundant shelly material preserved in places on the coastal plain between Bredasdorp and Cape Agulhas. Pleistocene raised-beach deposits at Sedgfield, Knysna, Hartenbos, Vlees Bay, Witsand and Kleinriviersvlei (east of Hermanus) were well documented by Davies (1971, 1972) (Figure 22). These deposits are considered by SACS (1980, p. 607) to be the equivalent of the Salnova Formation in the eastern Cape Province. The shelly and quartz-rich conglomeratic sands of Pleistocene age, preserved on the coastal plain between Cape Agulhas and Mossel Bay, were correlated with the Velddrif Member of the Bredasdorp Formation by Rogers (1986, 1988).

Malan (1986) proposed the name Klein Brak Formation, and nominated a type locality in the Klein Brak Estuary, where extensive exposures with typical Swartkops fauna are preserved on the farms Klipheuwel and Barswell (Profile KB I, Figures 23a and 23e). The Klein Brak Formation was deposited on a wave-cut, seaward-sloping platform cut into Cape Supergroup and Uitenhage Group sediments, except at a locality east of Dana Bay, where the Pleistocene unit possibly overlies the Late Pliocene Wankoe Formation (Profile KB II, Figures 23b and 23f). The Klein Brak Formation (KB) will be discussed in detail with the aid of 7 stratigraphic profiles (Profiles KB I to KB VII, Figures 22 to 24).

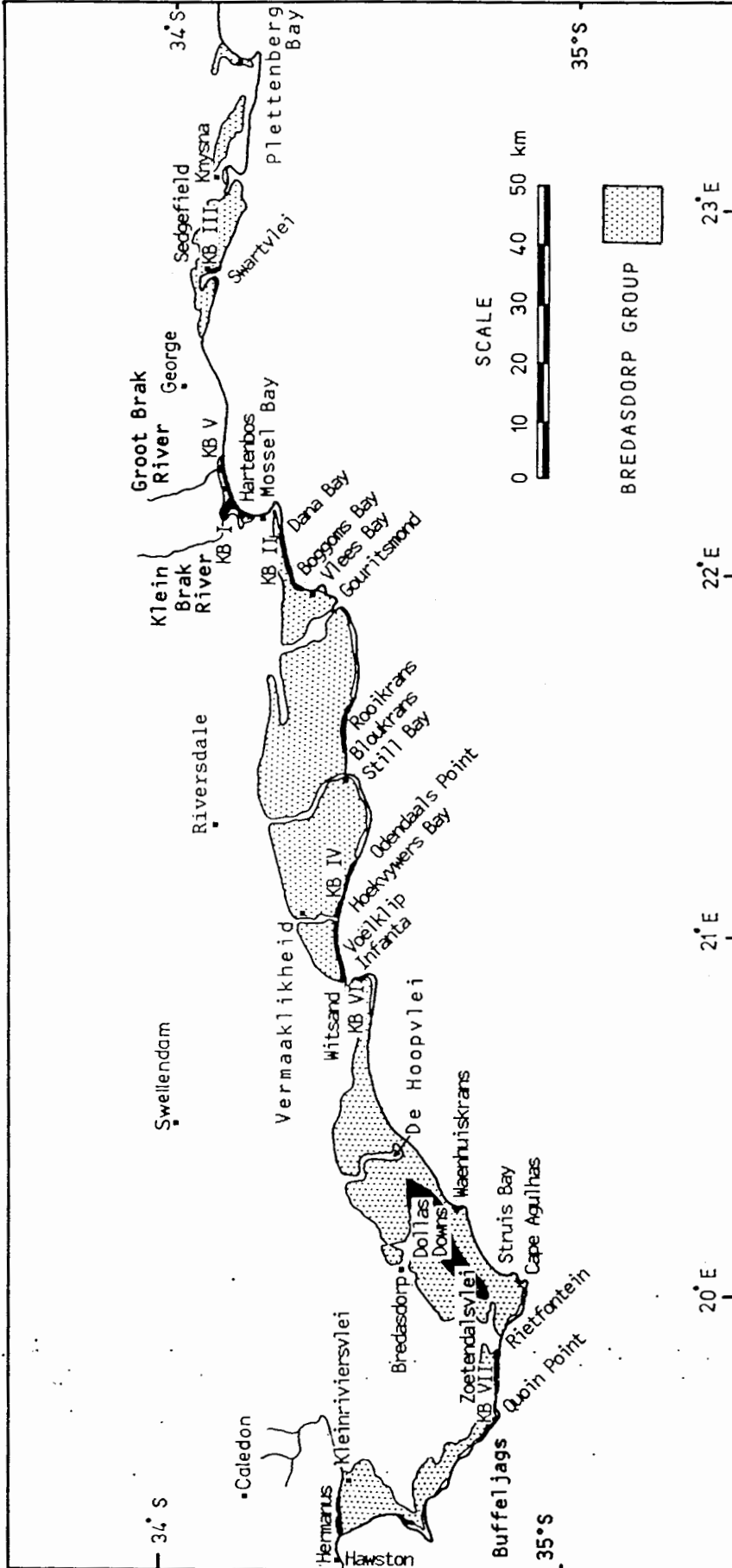


FIGURE 22. Profile localities and locality diagram for the Klein Brak Formation, Bredasdorp Group.

Outcrops of Klein Brak Formation indicated by black colour.

KB I = Profile KB I in Klein Brak Estuary.

KB III = Profile KB III at Swartvlei lagoon.

KB V = Profile KB V in Groot Brak Estuary.

KB VII = Profile KB VII at Hoë Walle, north of Quoin Point.

KB II = Profile KB II at Dana Bay, west of Mossel Bay

KB IV = Profile KB IV in Hoekvuyers Bay.

KB VI = Profile KB VI at Infanta Village.

FIGURE 23a to 23d. Locality diagrams for profiles KB I to KB IV, Klein Brak Formation.

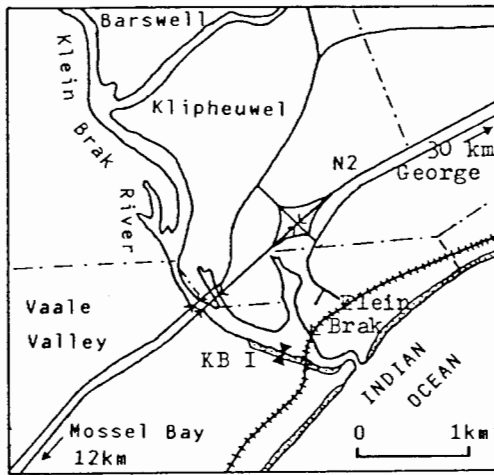


FIG. 23a Profile KB I, Klein, Brak Estuary.

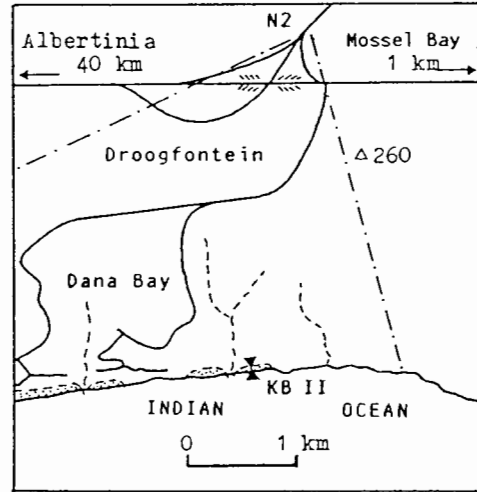


FIG. 23b Profile KB II, east of Dana Bay

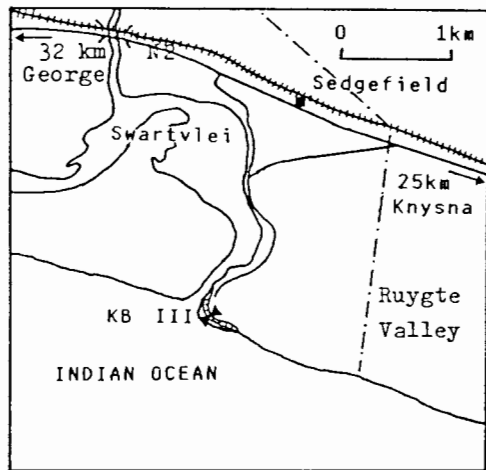


FIG. 23c Profile KB III, mouth of Swartvlei lagoon.

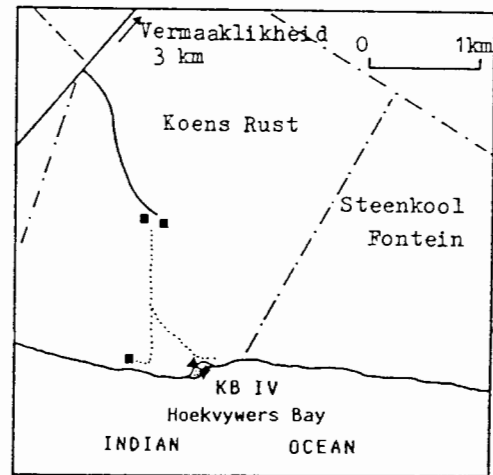

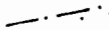



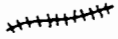



FIG. 23d Profile KB IV, Hoekvywers Bay, east of Duiwenkoks estuary

LEGEND

- | | | | |
|----------------------|--|---------------|---|
| Klein Brak Formation |  | Farm boundary |  |
| Profile locality | KB I  | Jeep track |  |
| Road |  | Railway line |  |
| Trigonometric beacon | Δ133 | Dry river |  |

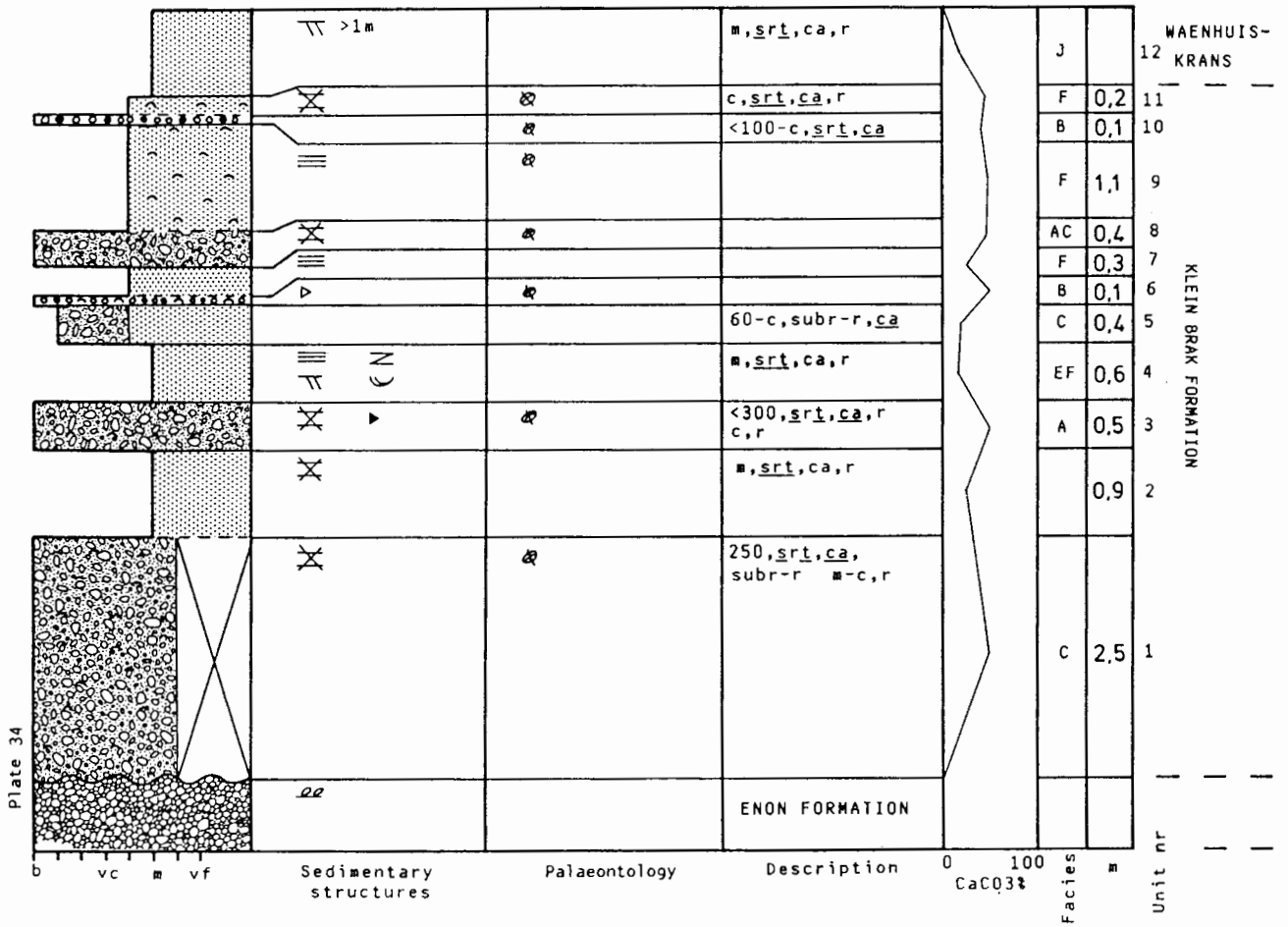


FIGURE 23e. Profile KB I, right bank of the Klein Brak Estuary.

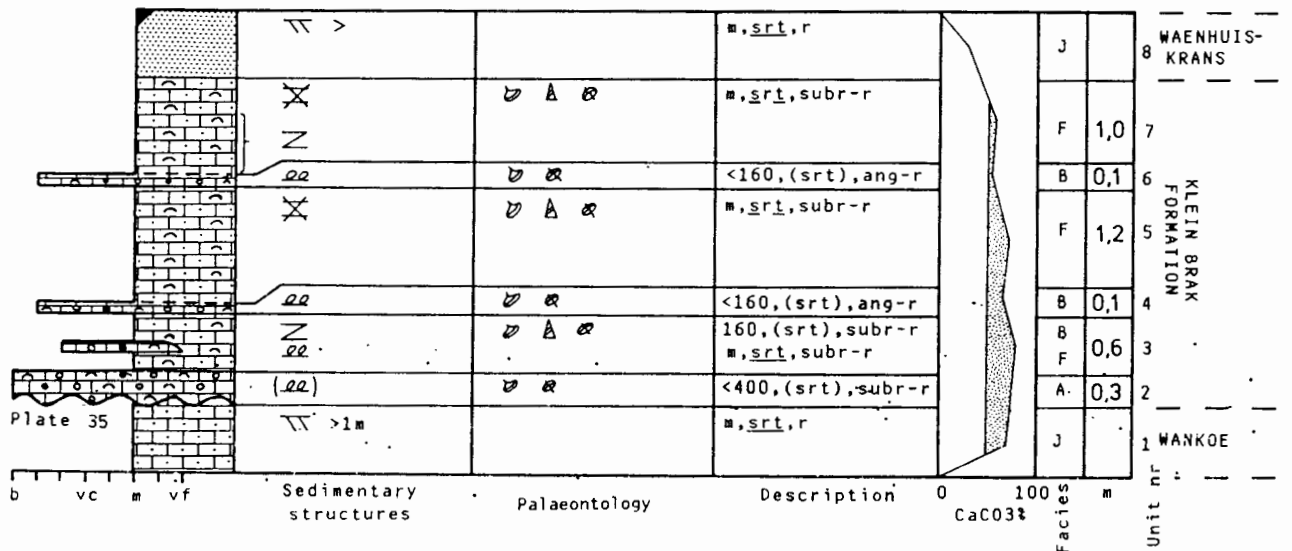


FIGURE 23f. Profile KB II, east of Dana Bay, immediately west of Mossel Bay.

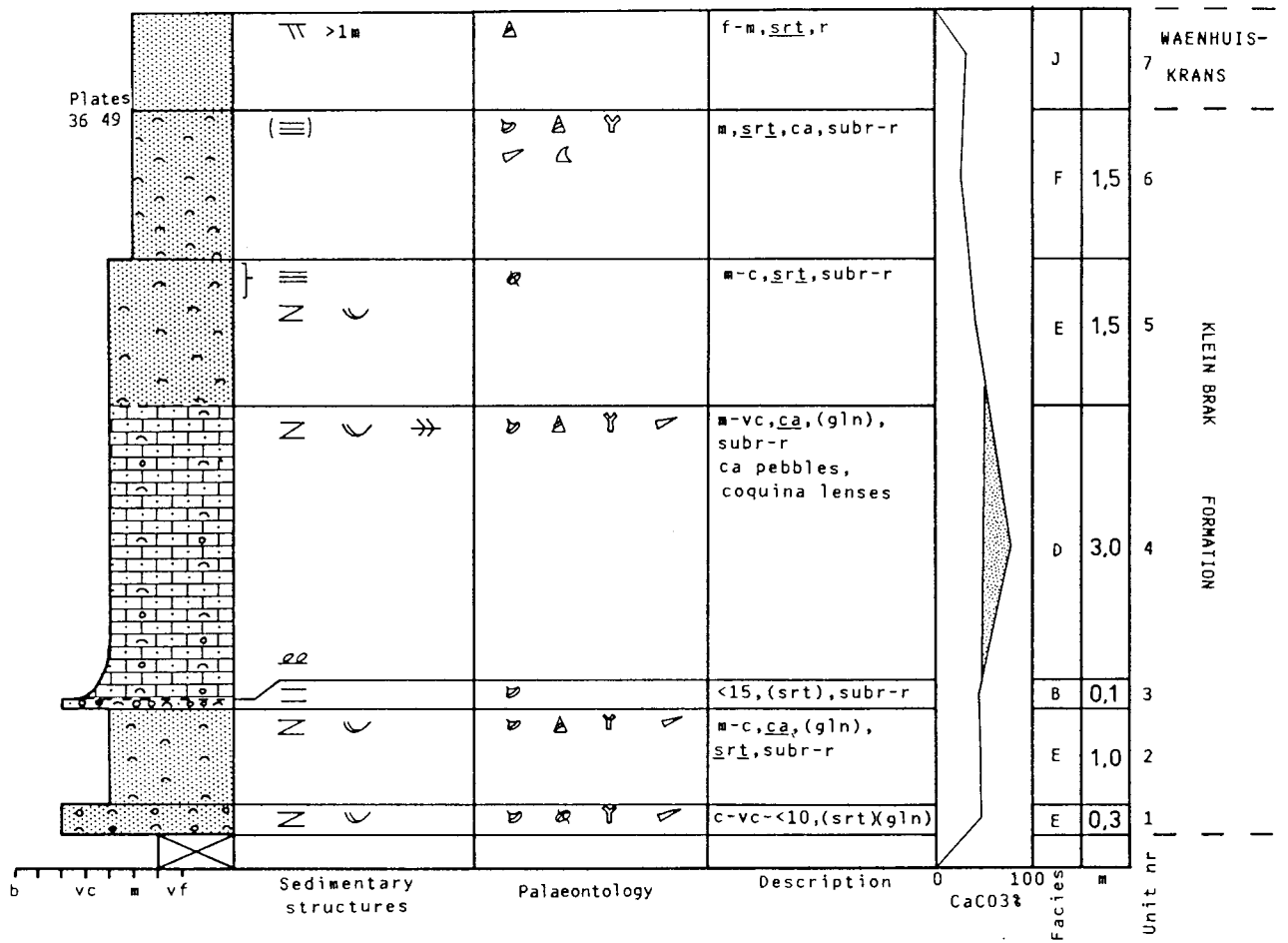


FIGURE 23g. Profile KB III, left side of the mouth of Swartvlei lagoon.

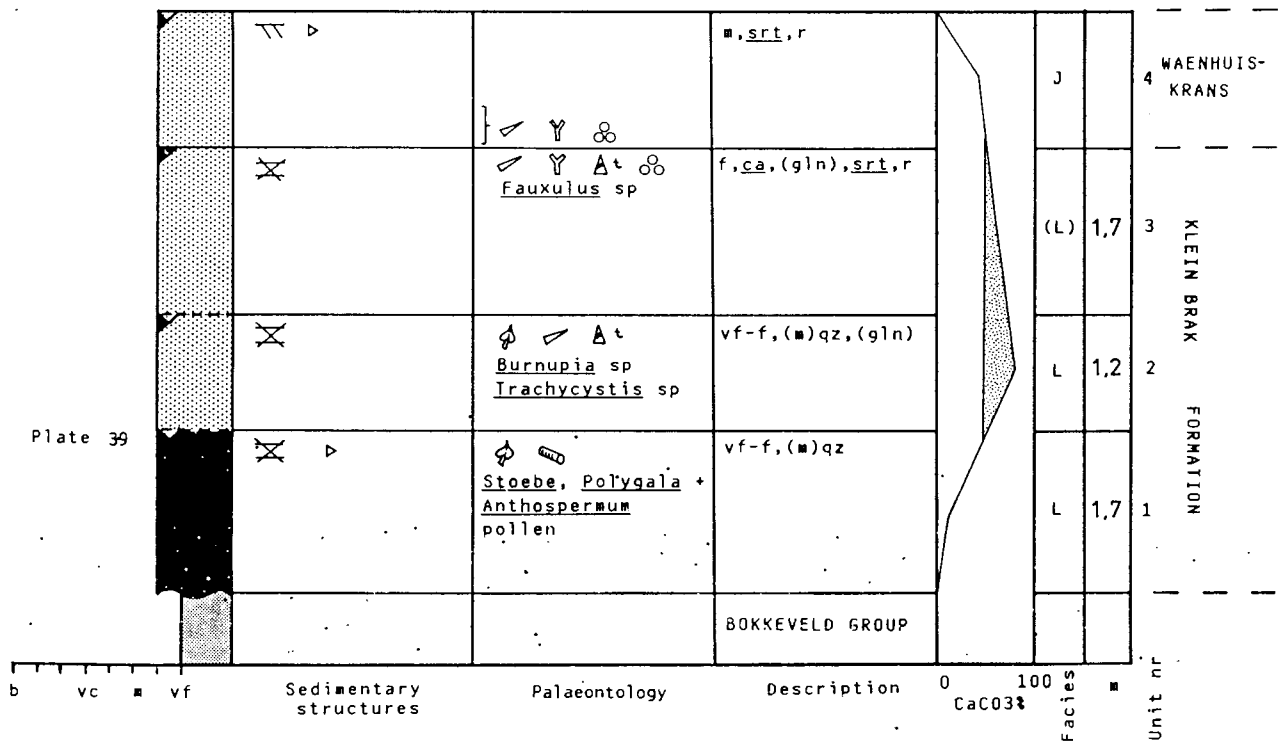


FIGURE 23h. Profile KB IV in Hoekvywers Bay, 4km east of Duiwenhoks Estuary.

FIGURE 24a to 24c. Locality diagrams for profiles KB V to KB VII, Klein Brak Formation.

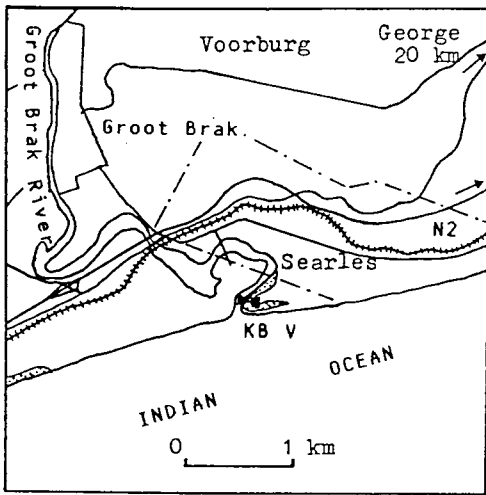


FIG. 24a Profile KB V, left bank Groot Brak River

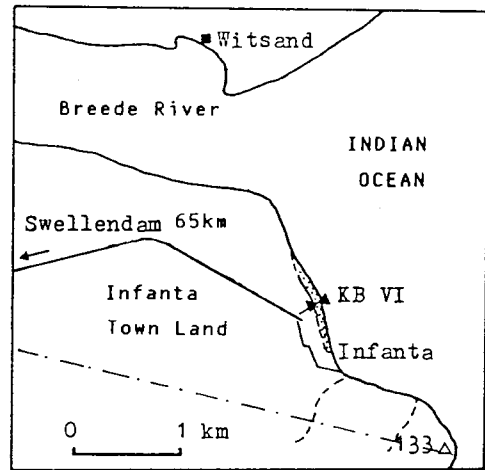


FIG. 24b Profile KB VI at Infanta Village.

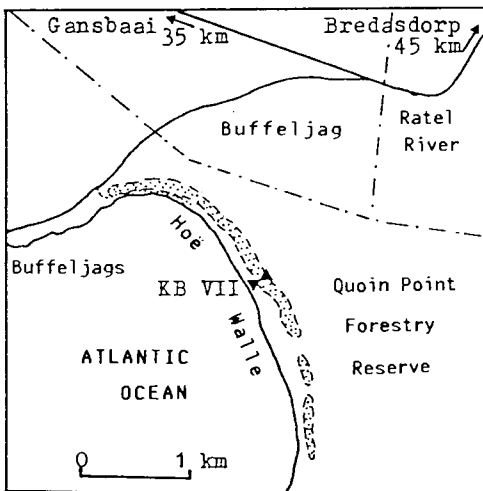

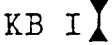



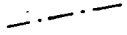
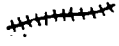
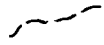


FIG. 24c Profile KB VII, Hoë Walle, north of Quoin Point.

LEGEND

- Klein Brak Formation 
- Profile locality 
- Road 
- Jeep track 
- Trigonometric beacon 
- Farm boundary 
- Railway line 
- Dry River 

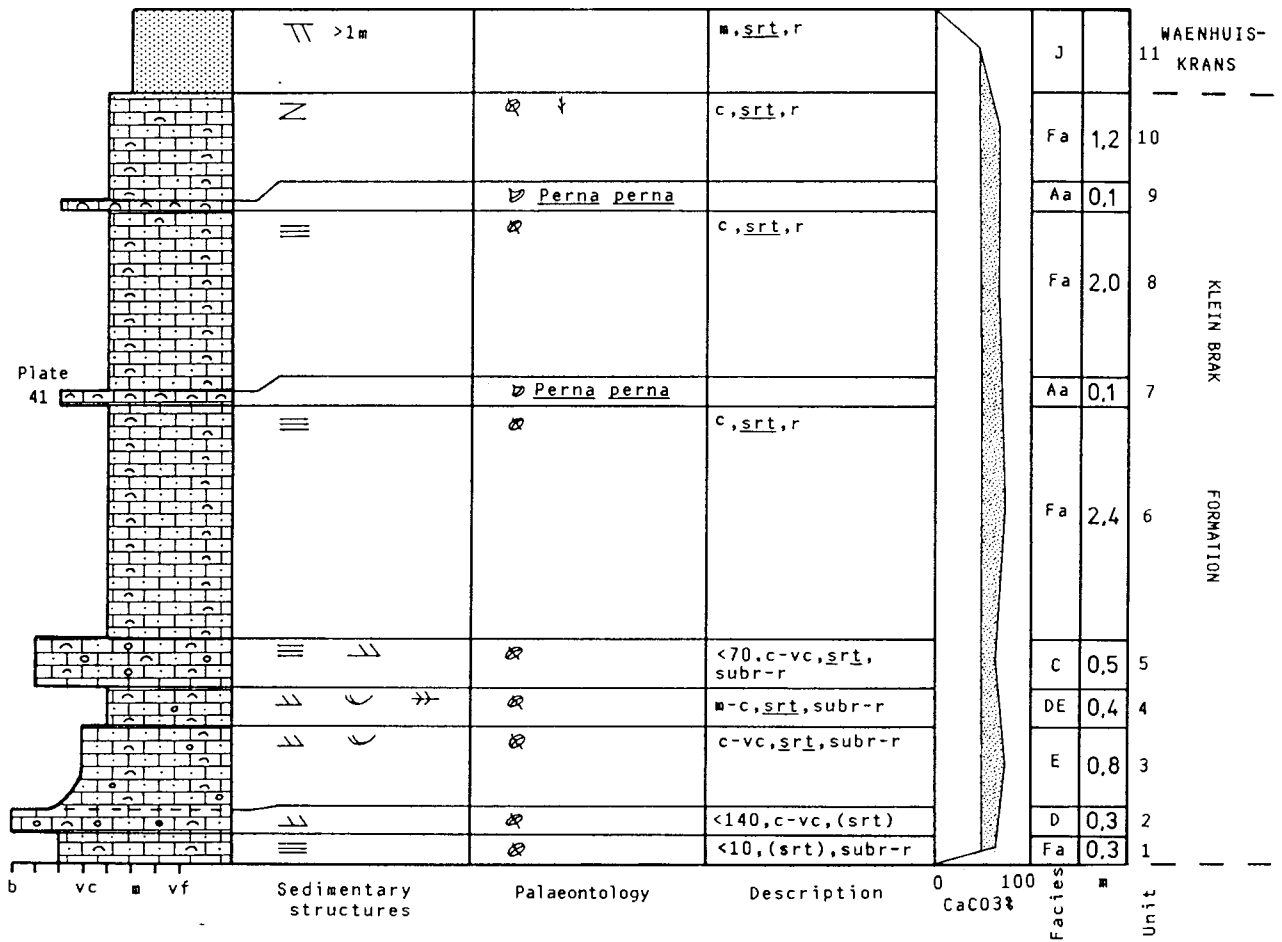


FIGURE 24d. Profile KB V, left bank of the Groot Brak Estuary.

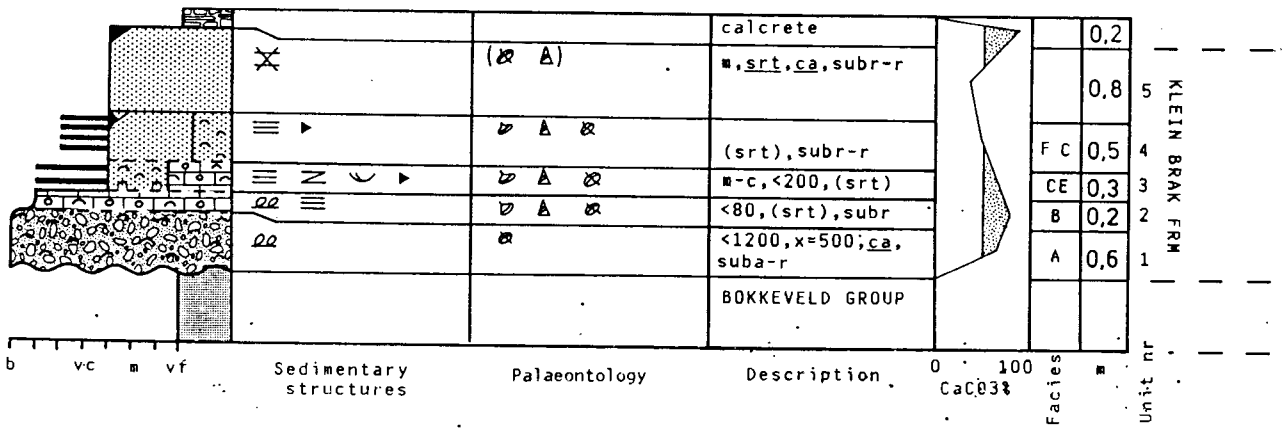


FIGURE 24e. Profile KB VI at Infanta Village.

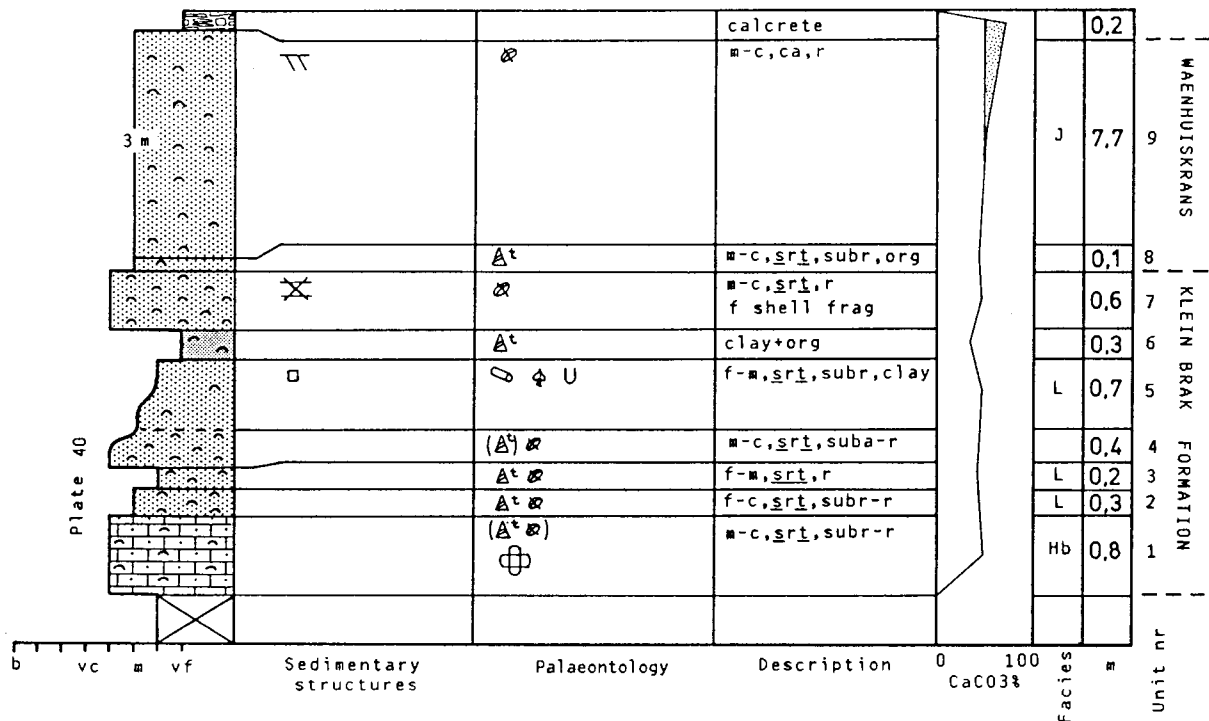


FIGURE 24f. Profile KB VII at Hoë Walle, north of Quoin Point.

"Nature vibrates with rhythms, climatic and diastrophic, those finding stratigraphic expression ranging in period from the rapid oscillation of surface waters, recorded in ripple-marks, to those long-deferred stirrings of the deep imprisoned titans which have divided earth history into periods and eras. The flight of time is measured by the weaving of composite rhythms - day and night, calm and storm, summer and winter, birth and death - such as these are sensed in the brief life of man ...
... the stratigraphic series constitutes a record, written on tablets of stone, of the lesser and greater waves of change which have pulsed through geologic time".

Joseph Barrell (1917)

8.2 GEOGRAPHICAL DISTRIBUTION

Discontinuous outcrops of the Klein Brak Formation are preserved as a narrow strip along the present coastline and the lower reaches of some rivers and estuaries between Hermanus in the west and Knysna in the east (Figure 22). De Villiers *et al.* (1964) described the most westerly occurrence of the Klein Brak Formation at Hawston, west of Hermanus, and Davies (1972) reported extensively on similar occurrences as far east as Knysna. Outcrops up to 2,2m thick can be seen adjacent to the southern shores of Kleinriviersvlei, east of Hermanus (Figure 22). Pleistocene deposits reaching a thickness of 11m form the prominent sea cliffs, Hoë Walle, adjacent to the coastline between Buffeljags and Quoin Point (Figures 22 and 24c). A strandline-derived gravel layer containing boulders, pebbles and shells is preserved just above the low tide level in Munro Bay, between Cape Agulhas and Struis Bay (Malan and Viljoen, 1990, p. 19) (Figure 22).

Similar deposits are exposed on the wave-planed surface, 7m above the present sea-level, on Rietfontein west of Cape Agulhas (Figure 22). Farther to the north, shelly gravel deposits are exposed in a road cutting adjacent to the farm road leading to the homestead on Zoetendalsvlei (Figure 22). The stratigraphic relationship between the Klein Brak Formation and the overlying Waenhuiskrans Formation was observed along the coast at Waenhuiskrans and in boreholes drilled on Dollas Downs (Figures 22, 26a).

Isolated exposures of the Klein Brak Formation are preserved adjacent to the coastline between the mouth of the Breede River and Mossel Bay, as can be seen at the coastal village of Infanta (Figures 24b and 24e), on Koens Rust in Hoekvywers Bay (Figures 23d and 23h), at Rooikrans between Still Bay and Gouritsmond (Figures 22 and 26c), in Boggoms Bay, north of Vlees Bay, (Figure 22) and at Dana Bay (Figures 23b and 23f). Extensive occurrences of the Klein

Brak Formation occur on the narrow coastal plain between the towns of Mossel Bay and Groot Brak (Figure 22). The best exposures are along the banks of the Klein Brak (Figures 23a and 23e), Groot Brak (Figures 24a and 24d) and Hartenbos estuaries (Figure 22). Similar outcrops occur at the mouth of Swartvlei at Sedgfield (Figures 23c and 23g, Plate 33).

8.3 LATERAL VARIATION

Thickness and lithology vary considerably over short distances; lateral lithological changes, ranging from shelly gravels to boulders, silty peats and calcareous sand, were observed in the Klein Brak Formation. Unit thickness varies between 0,5 and 8,5m, with an average thickness of 4,0m. The resistant nature of the Table Mountain quartzites caused the higher topography of Danger Point, Cape Infanta, Vlees Point and Cape St Blaize (Figure 1), and prevented overstepping by the Late Pleistocene transgression pre-dating the deposition of the Klein Brak Formation. The main criteria for the lateral correlation of the marine Klein Brak Formation are i) the presence of diagnostic Quaternary fauna (Davies, 1971, 1972), ii) distinctive foraminiferal assemblages (Unit III of McMillan, 1986, 1990), and iii) coherent elevation values for the wave-cut surface underlying the Klein Brak Formation.

8.4 GEOLOGICAL DESCRIPTION

8.4.1 Stratigraphic boundaries

The lower boundary of the Klein Brak Formation is defined as the unconformity between this formation and the Wankoe Formation, Uitenhage Group or Cape Supergroup rocks. Compared with these units there is a marked increase in carbonate content resulting from marine shell material in the Klein Brak Formation. The unconformity is always sharp (Plate 34). It can be undulating and



PLATE 33. Klein Brak Formation outcrops at the eastern side of Swartvlei mouth; arrow indicates the position of profile KB III (Figures 23c and 23g).



PLATE 34. Sharp basal contact of the Klein Brak Formation with the underlying Uitenhage Group, Profile KB I on the right (west) bank of the Klein Brak River Estuary (Figures 23a and 23e).

filled with hollows, where softer Uitenhage claystone (Profile KB I, Figure 23e) or Bokkeveld shale (Profile KB VI, Figure 24e) is the underlying rock. Exposures of the basal unconformity can be seen adjacent to the coastline at Infanta, to the west (Voëlklip) and east (Hoekvywers Bay) of the mouth of the Duiwenshoks River, at Dana Bay (west of Mossel Bay) and along the western shore of the Klein Brak estuary (Figure 22, Plate 34). The unconformable relationship with the underlying Wankoe Formation was observed at only one locality directly east of Dana Bay (Figures 23b and 23f, Plate 35).

The upper boundary is defined as the base of overlying terrestrial deposits, including calcrete, soil, scree and aeolian sand. The contact between the marine/estuarine Klein Brak Formation and the base of the overlying semi-consolidated Waenhuiskrans aeolianite is exposed in sections at Waenhuiskrans (Figure 22 and Profile WK I, Figure 26d), Hoekvywers Bay (east of the Duiwenshoks River) (Profile KB IV, Figures 23d and 23h), Klein Brak (Profile KB I, Figures 23a and 23e), Groot Brak (Profile KB V, Figures 24a and 24d) and Sedgfield (Profile KB III, Figures 23c and 23g, Plate 36). Quaternary to Recent terrestrial calcrete, scree, soil and unconsolidated aeolian deposits of the Strandveld Formation overlie the Klein Brak Formation.

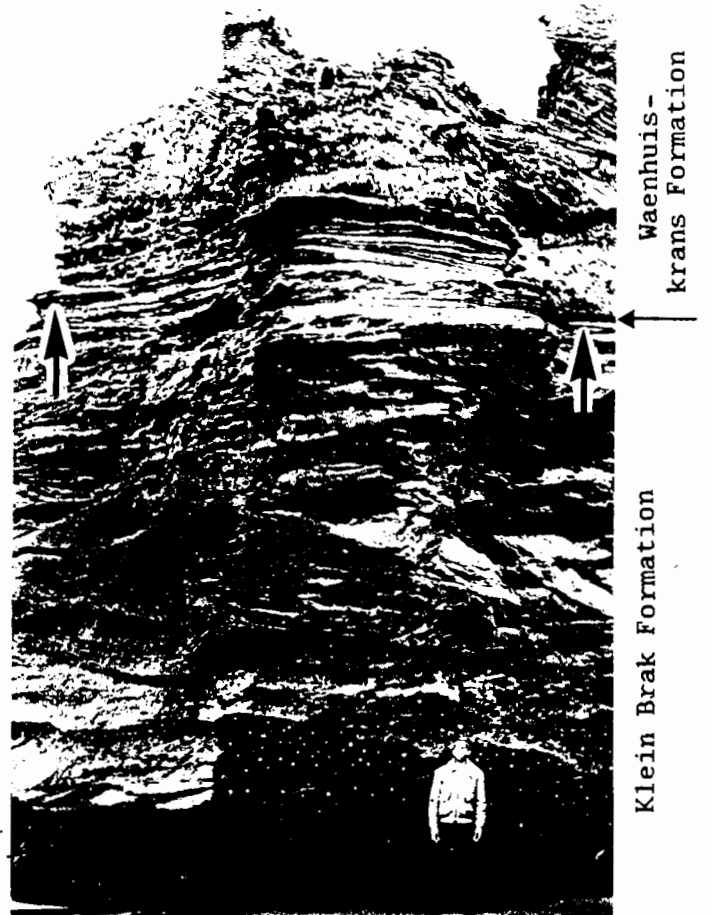
8.4.2 Unit thickness

The thickness of the relatively thin Klein Brak Formation varies between 0,5m and 8,5m. An average thickness of 3,3m was calculated for the basal marine unit in cores from nineteen boreholes drilled on Dollas Downs, northwest of Waenhuiskrans (Figure 22). The unit stratotype along the west bank of the Klein Brak Estuary is 7,1m thick (Profile KB I, Figures 23a and 23e). Thickness measured for the other profiles varied as follows:-



PLATE 35. Unconformable relationship of the Klein Brak Formation with the underlying Wankoe Formation observed in profile KB II, directly east of Dana Bay (Figures 23b and 23f).

PLATE 36. Horizontal laminated and trough crossbedded Klein Brak Formation overlain by large-scale crossbedded Waenhuiskrans Formation (Profile KB III, Figs. 23d and 23g) at Swartvlei mouth. (Unconformity indicated by thick arrows).



Dana Bay	3,3m	(Profile KB II, Figure 23f)
Sedgefield	7,4m	(Profile KB III, Figure 23g)
Hoekvywers Bay	4,6m	(Profile KB IV, Figure 23h)
Groot Brak	7,9m	(Profile KB V, Figure 24d)
Infanta	2,4m	(Profile KB VI, Figure 24e)
Hoë Walle	3,4m	(Profile KB VII, Figure 24f)

8.4.3 Lithology

The formation consists essentially of fine- to coarse-grained calcareous sand, calcareous sandstone and calcarenite with subordinate gravel, conglomerate, shelly limestone and shells as well as sporadic siltstone and peat. The Klein Brak Formation is distinguished from the underlying Cape Supergroup and Uitenhage Group by its highly calcareous nature, varying from a maximum of nearly 90 percent carbonate measured in profile KB II, east of Dana Bay (Figures 23b and 23f) and profile KB V, at Groot Brak (Figures 24a and 24d). The unit is distinguished from the overlying units by the absence of terrestrial deposits such as calcrete, soil, scree and aeolian sand and sandstone.

The lithological units of the Klein Brak Formation are divided into separate classes i.e.:-

- 1) conglomerate and gravel
- 2) calcarenite and calcirudite
- 3) calcareous sand and sandstone
- 4) siltstone
- 5) peat.

8.4.3.1 Conglomerate and gravel

The conglomerate and gravel fractions form between 10 and 50 percent of the total thickness of the measured Klein Brak profiles. The basal conglomerate unit and shelly gravel unit vary in thickness from 0,1 to 2,5m with an average measured unit

thickness of 0,2m. Clasts comprise quartzite (Table Mountain Group: TMG), shale (Bokkeveld Group), calcarenite (cannibalised older Bredasdorp Group) and quartz depending on the rock type of basement in the source area. The TMG clasts are dominantly spherical (Plate 37); the rest bladed to discoidal. A single large quartzite boulder (188cm x 78cm x 52cm) occurs in the basal unit at Infanta (Profile KB VI, Figure 24e). An average clast-diameter of 45cm were measured at this locality. No silcrete clasts were found in the Klein Brak Formation, in contrast to the older De Hoopvlei Formation, which contains a few silcrete clasts.

Single-clast layers, consisting of cobbles and pebbles, occurs on erosion surfaces throughout the formation. Matrix-supported polymictic conglomerate with extra- and intraformational clasts and interbedded thin conglomerate, gravel and sandy layers form nearly half of the unit stratotype at Klein Brak (Units 1,3 and 8 in profile KB I, Figures 23a and 23e). The conglomerate and gravel are usually structureless, only a few clasts showing imbrication (Units 3 and 5 in profile KB II, east of Dana Bay, Figure 23f). Upward-fining cycles occur in profiles KB III at Swartvlei estuary (Units 3 and 4, Figure 23g) and KB VI at Infanta (Unit 1, Figure 24e).

Wedge-shaped conglomerate units, up to 2,5m thick, occur interbedded with medium- to coarse-grained calcarenite and shelly sand in profile KBI at Klein Brak River (Unit 1, Figures 23a and 23e). Percussion marks, indicative of high-energy conditions, are seen on quartzite boulders in the basal conglomerate units of profiles KB I (Klein Brak, Figure 23e) and KB VI (Infanta Village, Figure 24e). Mussels, occurring in their living positions on reworked calcarenite clasts, are evidence of low energy environments.

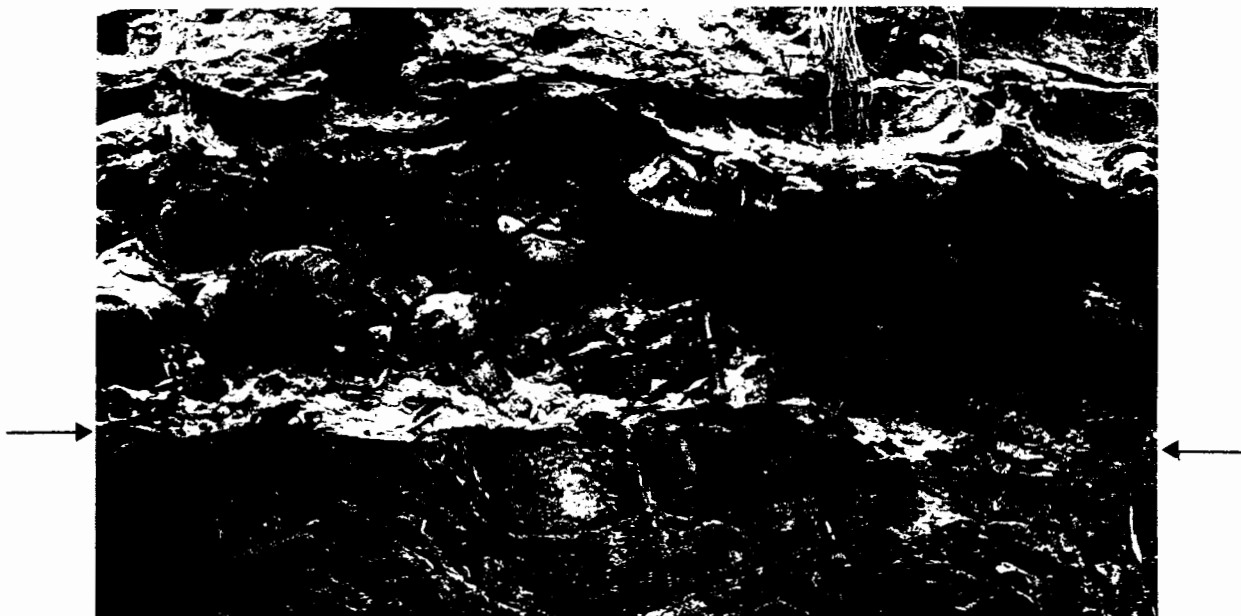


PLATE 37. Spheroidal quartzite boulders of the basal unit of the Klein Brak Formation overlying TMG bedrock in a roadcutting between Mossel Bay and Hartenbos (Figure 22).



PLATE 38. Horizontally laminated calcarenite overlying trough cross-bedding in the beach exposure of the Klein Brak Formation at Boggoms Bay, north of Vlees Bay (Figure 22).

8.4.3.2 Calcarenite and calcirudite

Klein Brak exposures along the coastline at Dana Bay (Figure 23b), Boggoms Bay (2,5km north of Vlees Bay, Figure 22) and Groot Brak River mouth (Figure 24a) consist entirely of calcarenite and calcirudite. The calcarenite consists of subrounded to rounded, medium to well sorted (average of 0,38phi), fine to coarse (average of 1,92 phi, i.e. medium sand) quartz, quartzite, shale and glauconite grains. Finely comminuted shell fragments, abundant echinoid spines, a few fish teeth and benthic foraminifera form part of the sand fraction. Scattered quartz, quartzite, shale and cannibalised calcarenite boulders are present in the calcirudite. Some of these clasts are orientated with long axes parallel to the dip of the foreset-laminae. Calcarenite varies in colour from yellowish orange to pale orange.

A maximum thickness of 3m (average thickness of 1m) has been measured for the calcarenite units. Vertical to angled burrows occur in some of the units characterised by a massive appearance, horizontal lamination or low-angle crossbedding. The calcarenite and calcirudite units are upward-fining in many places with a basal shelly conglomerate or shelly gravel in profile KB V at Groot Brak (Units 2 and 3, Figure 24d). The matrix-supported clasts, shell fragments and whole shells are orientated with their long axes parallel to the bedding plane of the low-angle crossbedded calcarenite in profile KB III at Swartvlei estuary (basal part of Unit 4, Figure 23g; Plate 36). At Boggoms Bay, 2,5km north of Vlees Bay (Figure 22), shoaling-water conditions are indicated by a horizontally laminated unit overlying a trough-crossbedded calcarenite (Plate 38).

8.4.3.3 Calcareous sand and sandstone

Subangular to well-rounded, fine- to coarse-grained, moderately to well sorted, consolidated to unconsolidated sandy units form as

much as 80 percent of the Klein Brak Formation. The mean unit thickness is 1,0m reaching a maximum unit thickness of 1,7m in places. The lithological units vary from tabular to lenticular in shape and can be pebbly in places. Sedimentary structures observed in the sand and sandstone units of the Klein Brak Formation are horizontal laminations, low-angled crossbedding, planar crossbedding, trough crossbedding (Unit 4 in Profile KB I, Figure 23e) and herringbone crossbedding.

Units can be structureless internally to horizontally laminated and light grey, yellowish grey, yellowish orange and greenish grey in colour. Whole shells and comminuted shell fragments form part of the coarser fraction of the more calcareous sandy units. Rounded echinoid spines, bryozoa fragments and benthic foraminifera occur in the top 1,7m of profile KB IV in Hoekvywers Bay, east of the Duiwenhoks Estuary (Unit 3, Figures 23d and 23h). Fine- to medium-grained sand, clay, organic material and terrestrial shells occur in the sandy units of profile KB VII along Hoë Walle, east of Quoin Point (Figures 24c and 24f).

8.4.3.4 Siltstone

Structureless siltstone units up to 1,2m thick form as much as 10 percent of the Klein Brak Formation. These light grey units are calcareous; slightly glauconitic, indicated by a colour change to greenish grey; and organic where dark grey. Sporadic well-rounded quartz grains, organic material, echinoid spines and terrestrial molluscan shells occur in the siltstone unit in profile KB IV on Koens Rust, Hoekvywers Bay, east of the mouth of the Duiwenhoks River (Units 2 and 3, Figure 23d and 23h).

8.4.3.5 Peat

A peaty unit 1,7m thick forms the basal part of profile KB IV (Figures 23d and 23h) along the coast in Hoekvywers Bay on Koens Rust. The peat unit rests unconformably on dark blueish black Bokkeveld shale (Plate 39). The brownish black peat contains unidentified plant and wood fragments, also Stoebe, Malvaceae, Compositae, Cliffortia and a few Polygala, Anthospermum and Chenopodiaceae pollen (J.A. Coetzee pers. comm., 1985). The pollen is similar to that of the present Cape fynbos and no indication of Tertiary vegetation could be seen (idem.).

During storms at sea, pieces of similar peat are washed onto beaches between the Duiwenhoks Estuary and Odendaals Point farther east, and at Rooikrans and Bloukrans between Still Bay and the Gourits Estuary. This phenomenon has been reported by Van Vuuren (1976). Several organic-rich horizons up to 30cm thick form part of profile KB VII along Hoë Walle, north of Quoin Point (Figures 24c and 24f, Plate 40).

8.4.4 Sedimentary structures

Sedimentary structures are not well preserved in the Klein Brak Formation due to its unconsolidated nature and the lack of well-preserved outcrops. Thin, mm- to cm-thick, horizontally laminated beds are characteristic of medium- to coarse-grained calcareous sand in most of the measured profiles. Horizontal laminations is obvious above the basal shelly gravel unit in profile KB V on the left bank of the Groot Brak Estuary (Figures 24a and 24d). A 0,5m thick coarse to very coarse-grained shelly sand, with pebbles and small cobbles up to 70mm in diameter, displays both horizontal laminae and crossbedding.

PLATE 39. Basal peat, sandy peat and silty units of the Klein Brak Formation, profile KB IV on Koens Rust, east of the Duiwenhoks Estuary (Figures 23d and 23h).

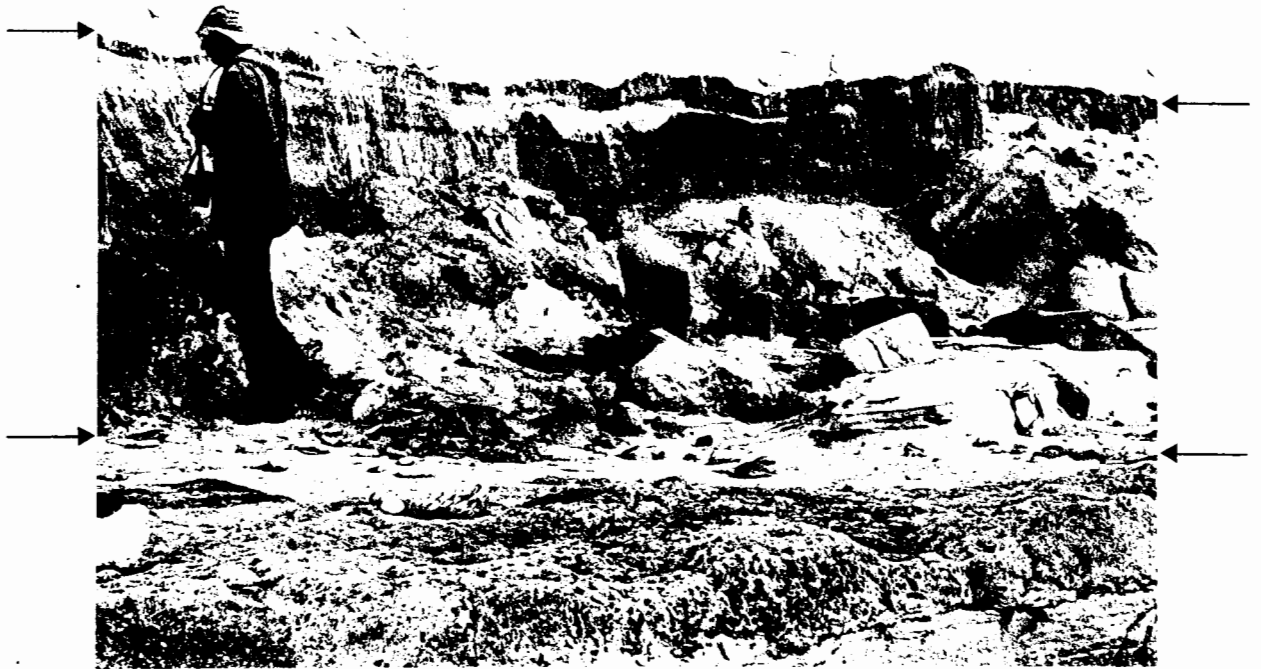


PLATE 40. Bioturbated basal calcarenite of the Klein Brak Formation with overlying sands and thin organic layers in profile KB VII at Hoë Walle, north of Quoin Point (Figures 24c and 24f).

Near the top of profile KB V a 4,5m-thick interval, consisting of two low-angle crossbedded and horizontally laminated coarse-grained sand units with comminuted shell fragments, is separated by a 10cm-thick layer characterised by shells of the bivalve, Perna perna (Units 6 to 8, Figure 24d; Plate 41). Swash action in the shoreface environment is responsible for the very low-angle seaward-dipping planar laminae (Galloway and Hobday, 1983) seen in the laminated shelly calcarenite with a 3-degree seaward dip (Units 6 and 8 in profile KB V; Plate 41).

Trough- and low-angle crossbedded calcareous sand units are associated with the shelly, matrix-supported conglomerate units. The contacts between these are gradational and form part of the upward-coarsening cycles in profile KB III at Swartvlei (Units 3 and 4, Figures 23c and 23g) and profile KB VI at Infanta (Units 1 and 2, Figures 24b and 24e). Possible storm deposits formed by interbedded sand and gravel layers occur near the top of profile KB I at Klein Brak Estuary (Units 6,8 and 10, Figures 23a and 23e).

Well-exposed trough-crossbedded units occur in outcrops just above high-water mark along the coastline between the resorts of Dana Bay and Boggoms Bay (Figure 22, Plate 38). Trough-crossbedding measurements indicate two distinct populations, i.e., a larger set with trough wave length up to 3,4m and trough depth of 45cm, and a smaller set with average trough length of 1,75m and depth of 15cm. A ripple index of 7,6 was calculated for the former set. The average strike of the troughs are more or less parallel to the strike of the present coastline. The troughs axes in the smaller set are perpendicular to both the larger set and the present coastline. Possible dominant longshore currents were responsible for forming the larger troughs with on/offshore-flowing ripcurrents forming the smaller troughs. Similar trough crossbedding is present in profile KB V at Groot Brak (Unit 3, Figs. 24a and 24d).



PLATE 41. Two low-angle crossbedded and horizontally laminated calcarenite units of the Klein Brak Formation at Groot Brak Estuary separated by a softer-weathering 10cm-thick layer containing the Perna perna bivalve (Unit 7 in profile KB V, Figures 24a and 24d).

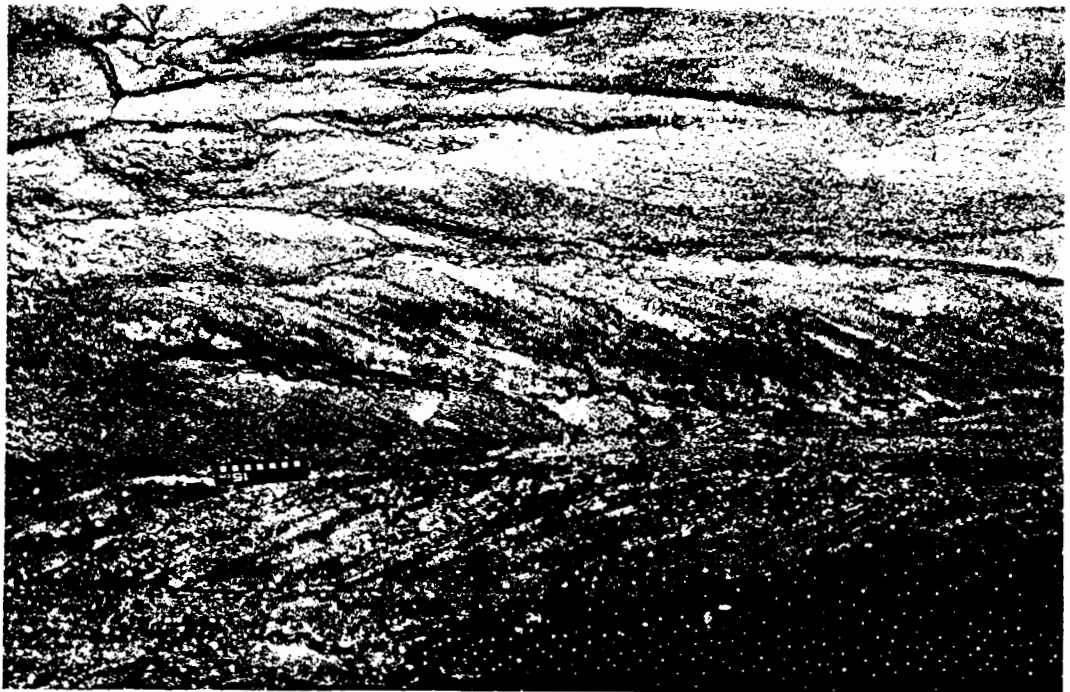


PLATE 42. Opposing cross-bedding forming a herringbone crossbedded unit in beach outcrops of the Klein Brak Formation at Boggoms Bay, north of Vlees Bay (Figure 22).

Low-angle reactivation surfaces indicate an ever-changing foreshore environment due to changes in wave action, wave direction and sediment supply. Herringbone crossbedding, present at outcrops at Boggoms Bay, 2,5km north of Vlees Bay, are developed in this zone under tidal conditions (Plate 42). Opposing 15cm- to 30cm-thick crossbed sets are separated by a thin, horizontally laminated layer. Perna perna bivalves and scattered, well-rounded pebbles and cobbles are orientated parallel to foresets of the crossbedding. Transgressive depositional cycles (upward-coarsening) are preserved in profiles KB III (Swartvlei) and KB V (Groot Brak) (Figures 23g and 24d), where low-angle, crossbedded and horizontally laminated medium- to coarse-grained calcarenite and calcareous sandstone (tidal conditions in shallow water) are overlain by trough-crossbedded coarse-grained calcarenite (deeper water).

8.5 PALAEOLOGY

8.5.1 Introduction

Abundant complete and broken shells, benthic foraminifera, echinoids, bryozoa and a few trace fossils were observed in the Klein Brak Formation. The macrofossils found in the Klein Brak Formation's raised-beach deposits are well documented along the Cape South coast. Estuarine species, recorded by Rogers (1906), form a shell layer up to 1m thick (Plate 43) on the farm Klipheuwel, along the left bank of the Klein Brak Estuary inland of the National Road (Figure 23a). The occurrence of dominantly estuarine fauna was documented by Barnard (1962), Martin (1962), and Davies (1971, 1972) at several localities between Hermanus and Plettenberg Bay.

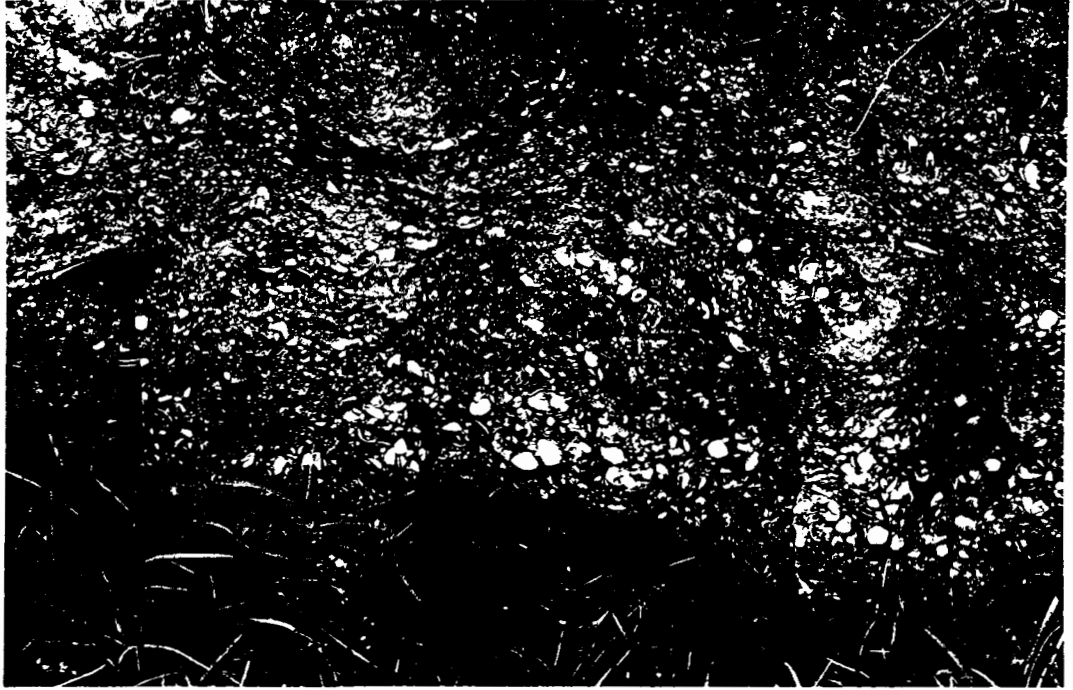


PLATE 43. An exposure of the Klein Brak Formation formed only of Quaternary shell species, preserved just north of the farm buildings on Kliphewel in the upper reaches of the Klein Brak Estuary (Figure 23a).

8.5.2 Macrofossils

More than 130 species were described from Late Pleistocene raised-beach deposits and a list of species type and localities is given in Table 6 (Identifications by J. Pether (S.A. Museum) pers. comm. 1987, 1988). Extinct Late Pleistocene gastropod species such as Monilea obscura ponsonbyi and Cerithium scabridum rufonodulosum are found in the Klein Brak Formation, with the former living during the Late Pleistocene in warmer water of the estuaries of the Southern Cape (Kilburn and Rippey, 1982). Bivalve species extinct today on the Cape South coast, i.e. Loripes liratula and Anodontia edentula, but preserved in the Klein Brak Formation, are washed up along the modern beach (Kilburn and Rippey, 1982).

TABLE 6. Consolidated list of Quaternary molluscs and localities where they were found in the Klein Brak Formation (Barnard, 1962; Martin, 1962; Davies 1971, 1972) (Figures 22, 23a, 24a and 24b).

Identifications by J. Pether (personal communication, 1987 and 1988).

(+ Extinct Late Pleistocene species)

(* Extra-limital extant species not extant on the south coast today).

(B: Bivalvia G: Gastropoda T: Terrestrial species)

Species	Localities						
	Infanta	Mosse! Bay	Voorbaai	Harterbos	Klein Brak	Groot Brak	Sedgefield
<u>Alaba pinnae</u> G					x		x
<u>Alvania fenestrata</u> G					x		x
<u>Amblychilepas scutellum</u> G					x		x
<u>Amalda obtusa</u> G							x
* <u>Anodontia achaeus</u> B	x		x	x	x		x
<u>Anomia ehippium</u> B							x
<u>Arcuatula capensis</u> B							x
<u>Assimineia</u> sp. G	x						x
<u>Atrina squamifera</u> B							x
<u>Barbatia</u> cf. <u>foliata</u> B		x					
<u>B. obliquata</u> B		x			x	x	x
<u>Bulla ampulla</u> G					x		x
<u>Bullia annulata</u> G	x		x				
<u>B. digitalis</u> G	x				x		
<u>B. laevissima</u> G					x		x
* <u>Burnupena limbosa</u> G	x						
<u>B. pubescens</u> G	x						
+ <u>Cantharidus suarezensis fultoni</u> G		x			x		x
+ <u>Cerithium scabridum rufonodulosum</u> G	x		x	x	x		x
+ <u>Cerithidium fragrans</u> G					x		
<u>Charonia lampas pustulata</u> G					x		
<u>Chlamys tineta</u> B							x
<u>Choromytilus meridionalis</u> B							x
* <u>Chione costellifera</u> B							x
<u>Crassostrea margaritacea</u> B	x				x		
<u>Crepidula porcellana</u> G							x
<u>Cryptomya philippinarum</u> B							x
<u>Cylichna</u> sp. G							x
<u>Cymatium cutaceum africanum</u> G	x				x		
<u>C. delarium</u> G					x		x
<u>Diala infrasulcata</u> G					x		x
<u>Donacilla africana</u> B							x
<u>Donax burnupi</u> B	x						x
<u>D. serra</u> B		x			x	x	x
<u>D. hepatica</u> B	x			x	x		x
<u>D. lupinus</u> B							x
<u>Dorcasia coagulum</u> GT	x				x		

TABLE 6 (continued). Consolidated list of Quaternary molluscs and localities where they were found in the Klein Brak Formation.

Species	Localities						
	Infanta	Mossel Bay	Voorbaai	Harterbos	Klein Brak	Groot Brak	Sedgefield
<u>Eumarcia paupercula</u> B							x
* <u>Felania diaphana</u> B				x			x
<u>Fissurella mutabilis</u> G	x				x		
<u>Gastrana matadoa</u> B					x		x
<u>Gibbula multicolor</u> G	x						
<u>Glycymeris connollyi</u> B		x				x	x
* <u>G. queketti</u> B					x		
<u>Haliotis midae</u> G							x
<u>H. spadicea</u> G	x						
<u>Helcion pectunculus</u> G	x	x					
<u>Hydatina</u> sp. G							x
* <u>Leporimetis hanleyi</u> B					x		x
* <u>Limaria fragilis</u> B							x
<u>L. rotundata</u> B	x				x		x
<u>Littorina</u> sp. G							x
<u>Loripes clausus</u> B				x	x		
* <u>L. liratula</u> B	x	x		x	x	x	x
<u>Lutraria lutraria</u> B					x		x
<u>Macoma litoralis</u> B							x
<u>M. retrorsa</u> B							x
<u>Mactra glabrata</u> B		x	x		x	x	x
* <u>M. ovalina</u> B					x		x
<u>Marginella</u> sp. G		x				x	
<u>Melanella algoensis</u> G							x
+ <u>Monilea obscura ponsonbyi</u> G	x				x		x
<u>Musculus cuneatus</u> B							x
<u>Nassarius capensis</u> G	x						x
<u>N. kraussianus</u> G	x				x		x
<u>Natica tecta</u> G	x	x			x		x
<u>Odostomia jucunda</u> G					x		x
<u>Ostrea atherstonei</u> B		x		x	x		x
<u>Oxystele tabularis</u> G							x
<u>O. sinensis</u> G	x						
<u>O. variegata</u> G	x	x					
* <u>Panopea glycymeris</u> B					x		
<u>Paphia</u> sp. B							x
<u>Fulvia papyracea</u>					x		
<u>Parvicardium turtoni</u> B							x
<u>Patella granularis</u> G	x	x					
<u>P. longicosta</u> G	x	x					
<u>P. miniata</u> G	x						x
<u>Pecten maximus sulcicostatus</u> B							x
<u>Perna perna</u> B	x	x		x			
<u>Phalium labiatum iredalei</u> G					x		

TABLE 6 (Continued). List of Quaternary molluscs and localities where they were found in the Klein Brak Formation.

Species	Localities						
	Infanta	Mosel Bay	Voorbaai	Hartenbos	Klein Brak	Groot Brak	Sedgefield
<u>P. labiatum zeylanicum</u> G					x		
<u>Philine aperta</u> G							x
<u>Pitar madecassinus</u> B	x						
<u>Polinices didyma</u> G					x		
* <u>P. tumidus</u> G							x
<u>Protomella capensis</u> G	x						x
<u>Psammotellina capensis</u> G							x
<u>Pyramidella aganea</u> G					x		x
<u>Rictaxis albus</u> G							x
<u>Ringicula turtoni</u> G							x
<u>Siphonaria aspera</u> G	x						
<u>Solen capensis</u> B			x	x	x		x
* <u>Stomatella sulcifera</u> G					x		x
* <u>Siliqua fasciata</u> B	x						
<u>Sunetta contempta</u> B	x	x				x	
* <u>Tapes deshayesii</u> B					x		x
* <u>T. sulcarius</u> B							x
<u>Tellina canonica</u> B							x
* <u>T. madagascariensis</u> B							x
<u>T. trilatera</u> B					x		x
<u>T. cf. virgata</u> B							x
* <u>Terebra suspensa</u> G							x
<u>Thais capensis</u> G	x	x			x		
<u>T. dubia</u> G				x	x		x
<u>Theora alfredensis</u> B							x
<u>Thracia alfredensis</u> B							x
* <u>Timoclea arakana</u> B							x
<u>Tivela compressa</u> B	x		x	x	x	x	
* <u>T. transversa</u> B					x		x
<u>Tomichia sp.</u> GT							x
<u>Tricolia sp.</u> G	x	x					
<u>Triphora africana</u> G							x
<u>Tropidophora ligata</u> GT							x
<u>Turbo cidaris</u> G	x						
<u>Turbonilla kraussi</u> G							x
<u>T. similans</u> G					x		
<u>T. carinifera</u> G	x	x	x		x	x	x
<u>T. ferruginea</u> G					x		
* <u>Ungulina alba</u>					x		x
<u>Venerupis corrugatus</u> B	x		x		x		x
<u>Venus verrucosa</u> B	x		x	x	x		x

Gastropod species like Nassarius kraussianus, Bulla ampulla and bivalves like Anodontia edentula, Dosinia hepatica, Solen capensis and Loripes clausus live in sheltered environments such as estuaries and lagoons, whereas Protomella capensis, Oxysteles variegata, Turritella carinifera (gastropods) and Donax serra (bivalve) live in the open-marine environment near the estuaries. Oxysteles sinensis, Turbo cidaris (gastropods) and Perna perna (bivalve) are living in a rocky coastal environment with bivalves like Glycymeris connollyi and Venus verrucosa burrowing in shallow-marine coarse-grained sands and gravels (Kilburn and Rippey, 1982).

Also characteristic of the marine Pleistocene Klein Brak Formation is the widespread presence of mollusc shells and shell fragments retaining their original life colours of pink, purple and blue (not evident in the older De Hoopvlei Formation, where all the mollusc shells are white). Echinoid spines are particularly characteristic of the Klein Brak Formation, and are nowhere as abundant in the De Hoopvlei Formation (cf. McMillan, 1986).

8.5.3 Microfossils

Selected samples from Klein Brak Formation exposures in Hoekvuywers Bay (east of the mouth of the Duiwenhoks River, Figure 23d), from Rooikrans (east of Still Bay, Figure 26c) and from the post office tree site at Mossel Bay (Figure 22) were studied by I.K. McMillan of Soekor (1986). The following benthic foraminifer species are characteristic of the Klein Brak Formation:- Poroepionides lateralis, Pararotalia nipponica, Spiroloculina communis, Elphidium advenum, Triloculina bertheliniana, Elphidium crispum, Ammonia parkinsoniana, Triloculina tricarinata and Glabratella australensis, whereas the only planktonic foraminifera in the formation is Globorotalia inflata (McMillan, 1986). Off the south

coast, Klein Brak Formation sediments (Unit III of McMillan, 1986) are extensively preserved as a thin veneer over the majority of the Agulhas Bank. This sequence has been encountered in the top section of numerous boreholes drilled by Soekor on the Agulhas Bank (cf. borehole F-A 13 in the F-A gasfield) and as far offshore as the outermost shelf (McMillan, 1990).

The macrofossils, microfossils and pollen are considered to be indicative of a Late Pleistocene age for the Klein Brak Formation.

8.5.4 Trace Fossils

Only trace fossils belonging to the Skolithos ichnofacies were found in the Klein Brak Formation. Vertical to subvertical Ophiomorpha burrows occur in a low-angle crossbedded calcarenite unit overlying the basal calcrudite at Witsand harbour (Figure 22). Burrows with lengths of up to 10cm are exposed near the top of this calcarenite unit. At Boggoms Bay, 2,5km north of Vlees Bay (Figure 22) a few Ophiomorpha burrows were also found at the base of a low-angle crossbedded unit overlying a trough- crossbedded unit.

An intense bioturbated, structureless, medium- to coarse-grained calcarenite forms the basal part of profile KB VII at Hoë Walle north of Quoin Point (Unit 1, Figure 24f and Plate 40). Vertical burrows and tubes also occur in a medium- to coarse-grained shelly sand unit, 1,3m above the base of the profile (Unit 4, Figure 24f). This is overlain by a clayey, upward-fining sand with vertical burrows and calcified reeds and plant material (Unit 5, Figure 24f). Deposits at Hoë Walle were laid down during an interglacial period and represent marsh and backbarrier environments of the palaeo-Ratel River (Figure 24c).

CHAPTER 9. WAENHUISKRANS FORMATION

9.1 INTRODUCTION

The Waenhuiskrans Formation is the Late Pleistocene aeolian formation of the Bredasdorp Group (Figure 8). In the description of the Mossel Bay Sheet Haughton et al. (1937) mention sandstone containing small terrestrial gastropods forming the sand ridge east of the Groot Brak River Estuary (Plate 44). Unconsolidated sands of Bredasdorp age containing terrestrial gastropods and calcified plant roots were described by Spies et al. (1963) from the Gansbaai - Bredasdorp area. SACS (1980) gave no formal stratigraphic connotation to these sediments.

Rogers (1986) correlated the Langebaan Limestone Member with the semi-consolidated aeolianite in the area between the Kafferkuils and Gourits Estuaries. The term Waenhuiskrans Formation was used by Malan (1986) for vegetated, semi-consolidated dunesand occurring along the coastline between Hermanus and Plettenberg Bay. The type area of the Waenhuiskrans Formation is at the coastal village of Waenhuiskrans (Figures 25, 26a and 26d, Plate 45). In 1989 SACS gave formal stratigraphical recognition to the Waenhuiskrans Formation (Malan, 1989c). The Waenhuiskrans Formation (WK) will be discussed with the aid of three stratigraphic profiles (WK I to WK III, Figures 25 and 26).

9.2 GEOGRAPHICAL DISTRIBUTION

The Waenhuiskrans Formation forms a narrow, 0,2 to 3km-wide discontinuous outcrop following the present coastline from Hermanus to Plettenberg Bay (Figure 25). Extensive outcrops occur along the coast of Walker Bay and south of Kleinriviersvlei near Hermanus, where calcified dunes with large-scale crossbedding can be followed over a distance of 14km (Figure 25). Similar outcrops can be seen along the coast at Quoin Point, Cape Agulhas, Struis Bay, Skipskop,



PLATE 44. Prominent sand ridge directly east of Groot Brak Estuary formed by the large-scale aeolian crossbedded Waenhuiskrans Formation overlying horizontally bedded Klein Brak Formation.



PLATE 45. Large-scale aeolian cross-bedding present in the Waenhuiskrans unit stratotype, at the Waenhuiskrans wave-cut cave. Person standing on a prominent surf-cut platform revealing the gravelly Klein Brak Formation (Figure 26d).

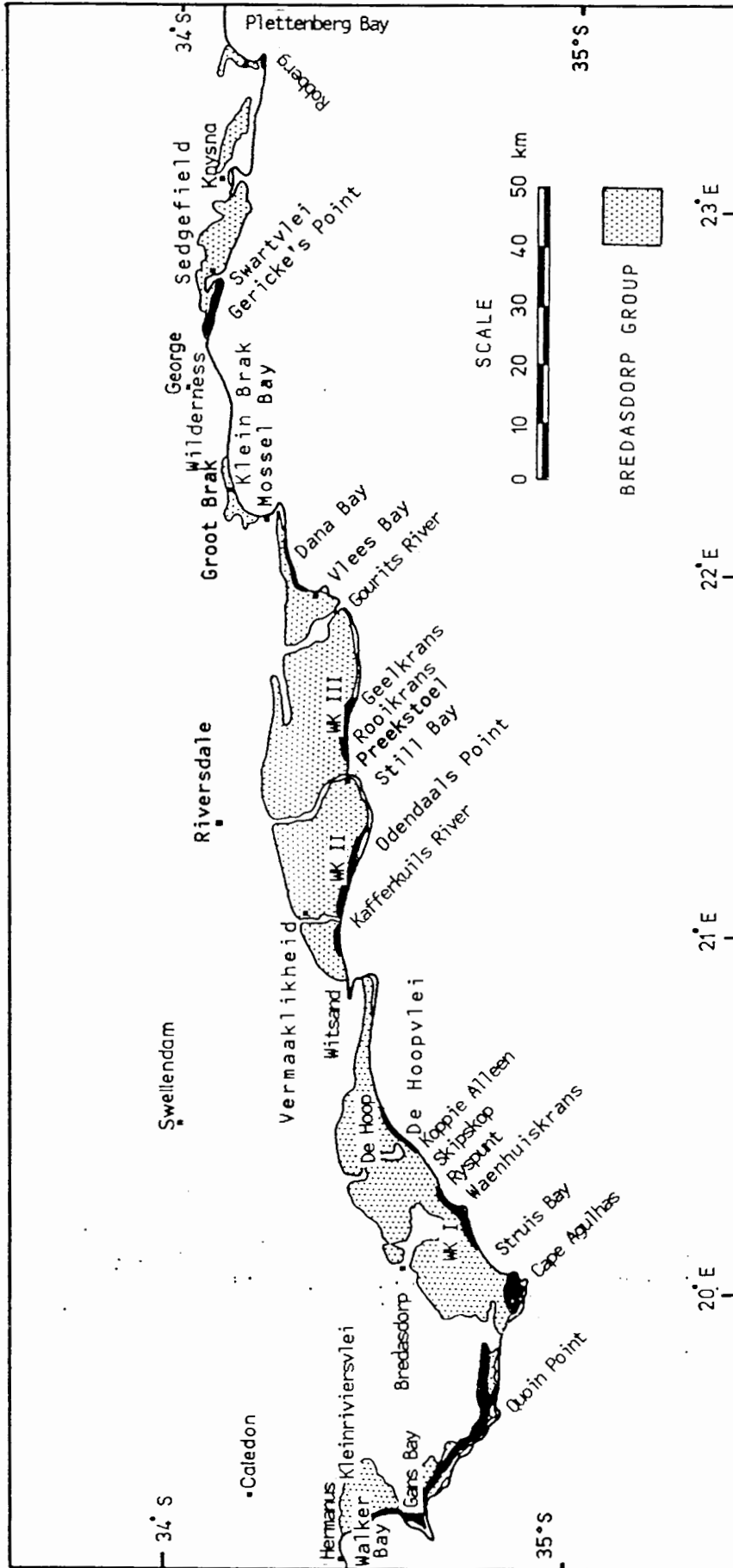


FIGURE 25. Profile localities and locality diagram for the Waenhuiskrans Formation, Bredasdorp Group. Outcrops of Waenhuiskrans Formation indicated by black colour. WK I = Profile WK I at Waenhuiskrans WK II = Profile WK II in Hoekvywers Bay. WK III = Profile WK III at Rooikrans, east of Still Bay.

FIGURE 26a to 26c. Locality diagrams for profiles WK I, WK II and WK III of the Waenhuiskrans Formation.

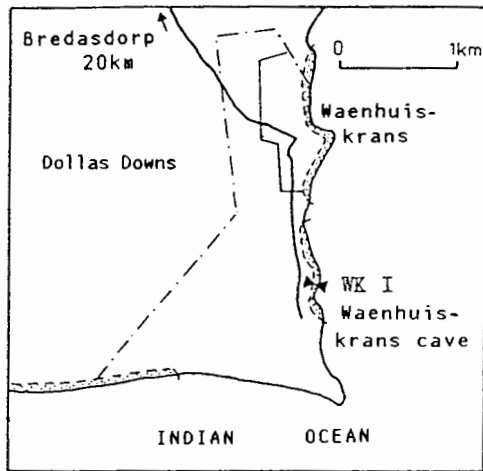


FIG 26a Waenhuiskrans village.

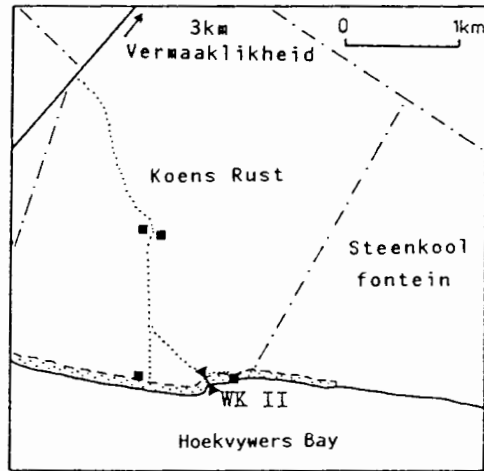


FIG 26b Hoekvywers Bay, east of the Duiwenhoks Estuary.

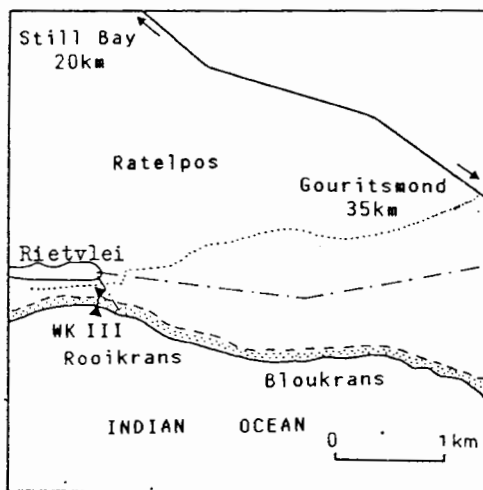


FIG 26c Rooikrans, east of Still Bay.

LEGEND





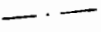

-  Waenhuiskrans Formation
-  Profile locality
-  Road
-  Jeep track
-  Farm boundary
-  Farm buildings

FIG. 26d. Profile WK I south of Waenhuiskrans village.

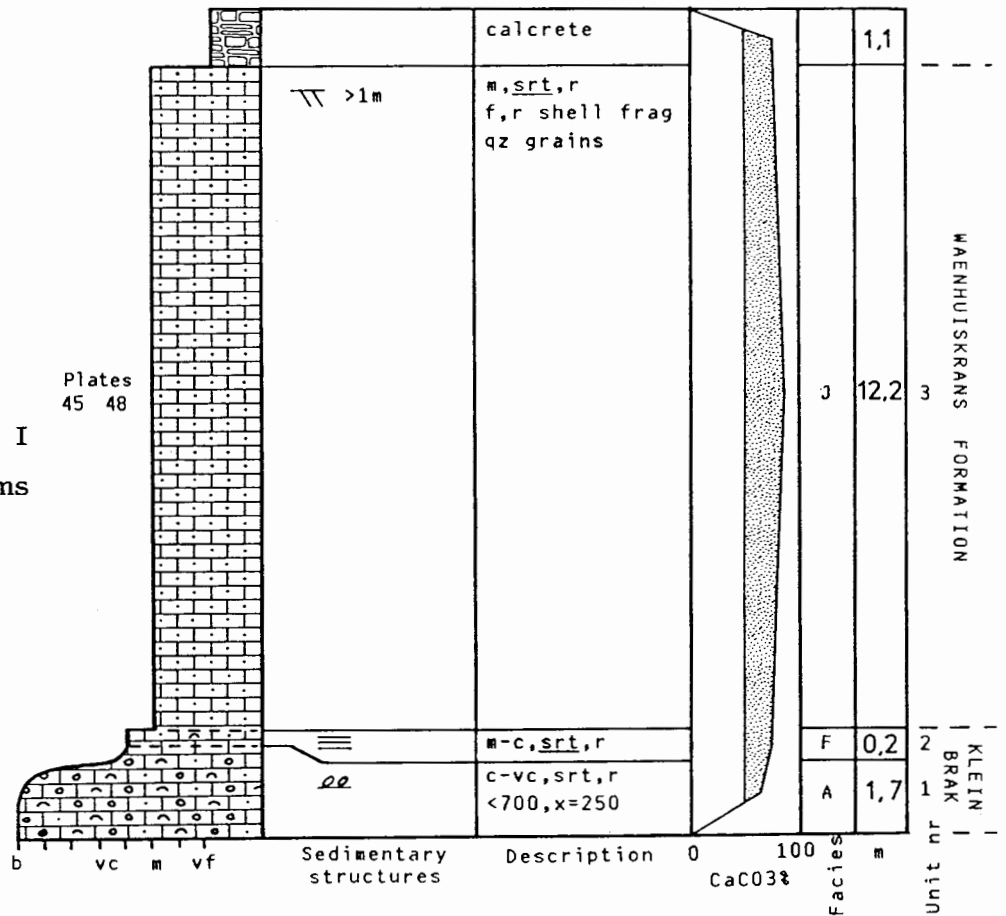
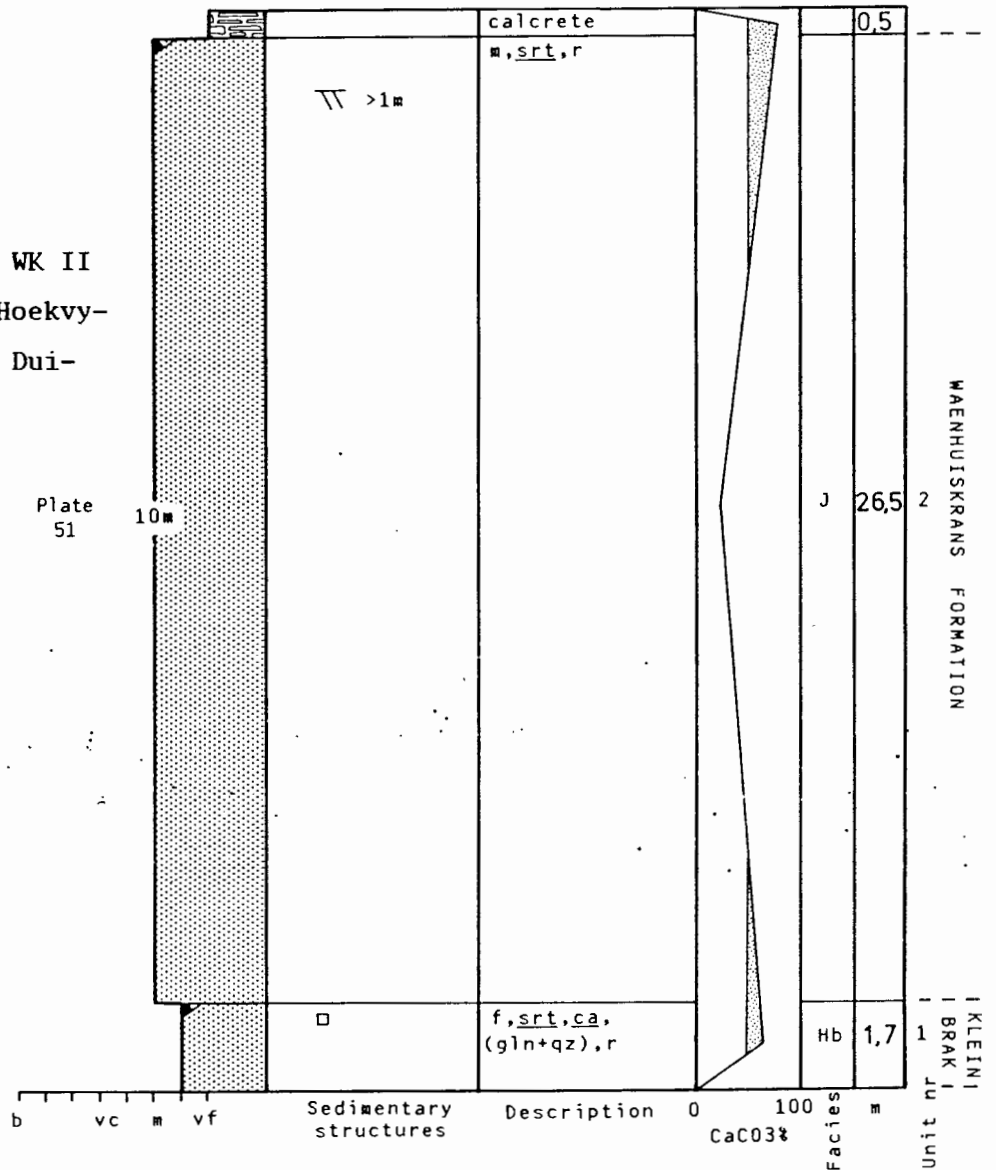


FIG. 26e. Profile WK II at Koens Rust in Hoekvuyers Bay, east of Duiwenhoks Estuary.



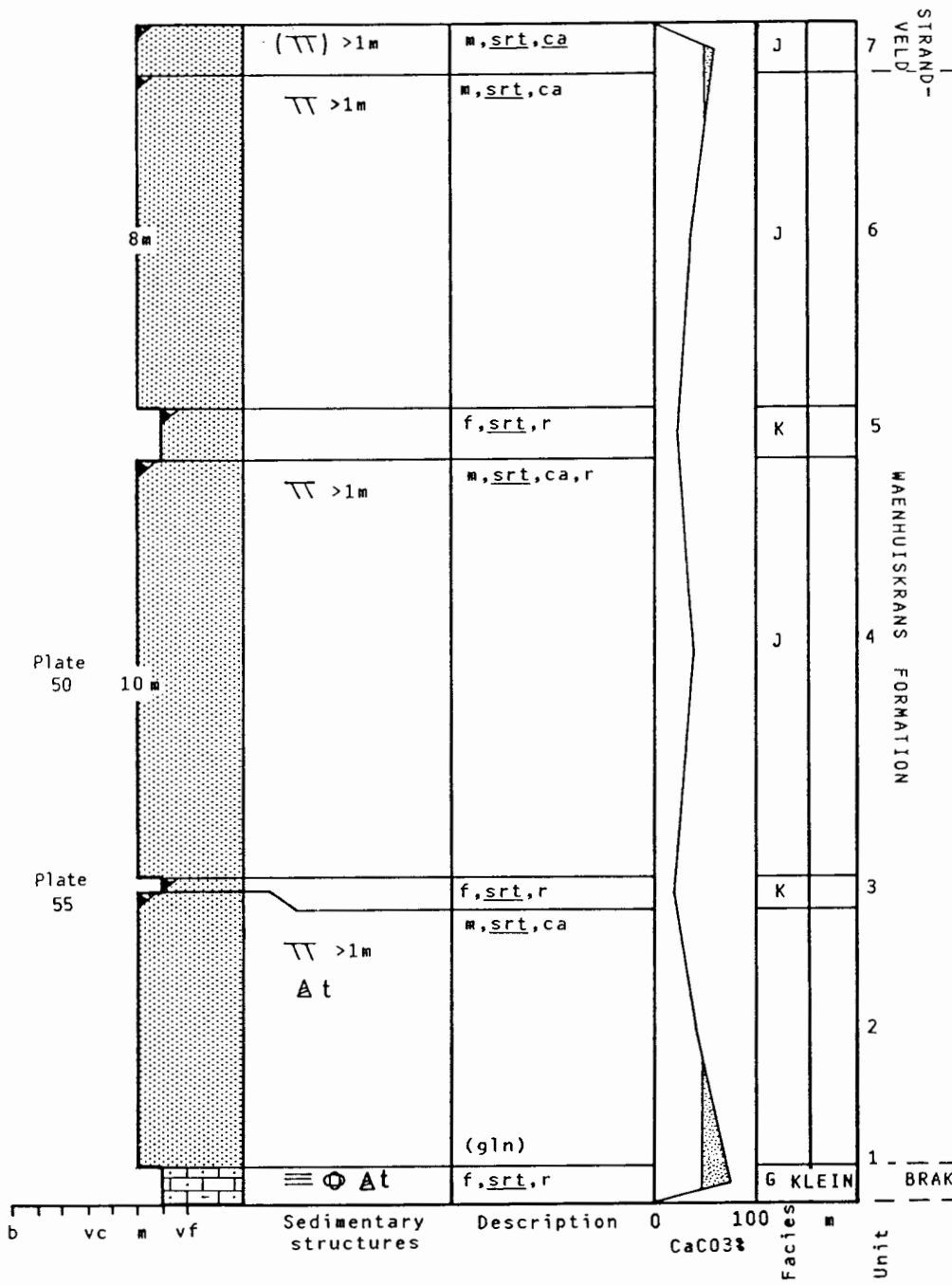


FIGURE 26f. Profile WK III at Rooikrans 10km northeast of Still Bay.

Koppie Alleen and in the type area of Waenhuiskrans (Figure 25, Plate 45). These deposits, forming coastal cliffs in places, can be traced for more than 10km to the east of Koppie Alleen on the De Hoop Nature Reserve (Plate 46).

Consolidated to semi-consolidated exposures of the Waenhuiskrans Formation form up to 25m-high cliffs in St Sebastian Bay where the best exposures are situated along the coast between Witsand and Odendaals Point (Figure 25). Similar sediments can be seen over a distance of 22km east of Still Bay where Rooikrans, Geelkrans and Bloukrans cliffs are formed by semi-consolidated, calcareous sand (Figure 25). Semi-consolidated to unconsolidated Waenhuiskrans Formation outcrops can be seen along the coast from Vlees Bay to Dana Bay, as well as east of Mossel Bay to Groot Brak (Viljoen and Malan, in preparation) and eastwards from Wilderness to Knysna (Figure 25). Excellent exposures can be seen at Groot Brak Estuary, Gericke's Point, Swartvlei Estuary and Robberg (Plettenberg Bay) (Figure 25).

The Waenhuiskrans Formation can be mapped on aerial photographs as the vegetated, consolidated to semi-consolidated dune ridges along the present coastline (Malan et al., in preparation). This unit is correlated with the stabilized calcareous sand unit (Unit A2), which the pedologists, Schloms et al. (1983), traced over extensive areas in the Overberg and South Coast regions. Terrestrial gastropods, large-scale crossbedding and well-developed soil horizons serve as the main criteria for the lateral extension of the Waenhuiskrans Formation.

The offshore extension of the palaeodunes of the Waenhuiskrans Formation can be seen off the Wilderness - Knysna coast (Birch et al., 1978; Flemming et al., 1983; Martin and Flemming, 1987) and beside Walker Bay (Tankard and Schweitzer, 1974). East of Still Bay, the large-scale crossbeds are exposed in plan view on surf-cut platforms during low spring tide (Wickens, 1984) (Plate 47).



PLATE 46. The Waenhuiskrans Formation forms coastal cliffs of calcarenite with large-scale aeolian crossbedding east of Koppie Alleen (Figure 25). Note the formation of platforms by a combination of surf-erosion and the action of marine algae in the rock pools.



PLATE 47. Bedding planes of the large-scale crossbedded Waenhuiskrans Formation exposed in plan view on surf-cut platforms during low spring tide, east of Still Bay (Figure 25).

Similar exposures are inferred offshore of Still Bay and Gourits and off the coast of the De Hoop Nature Reserve (pers. comm. K. Lord, 1990) and southwest of Cape Agulhas (Bremner and Malan, in press).

9.3 LATERAL VARIATIONS

The thickness of the Waenhuiskrans Formation varies significantly, with a maximum thickness of about 200m in the Wilderness-Sedgefield area (Figure 25) and an inferred average thickness of 30m. Exposures are consolidated and highly calcareous in the Waenhuiskrans (Plate 45), Koppie Alleen (Plate 46) and Walker Bay areas. The formation is indeed hard enough for wave action to cut the well known Waenhuiskrans cave (Title page) into a sea cliff south of the coastal village of Waenhuiskrans (Figure 26a)(Malan and Viljoen, 1990). Also evident is a well-developed surf-cut platform covered during high tide, and a distinct visor at the sea entrance to Waenhuiskrans cave (Plate 48). East of the Breede Estuary the formation is semi-consolidated to unconsolidated and less calcareous, as can be seen in exposures at Hoekvywers Bay (east of the Duiwenhoks Estuary), Rooikrans and Geelkrans (east of Still Bay), Groot Brak Estuary, Wilderness, Swartvlei Estuary and Gericke's Point west of Swartvlei (Figure 25). In general, few, if any petrographical and mineralogical variations are known for the Waenhuiskrans Formation (cf. Siesser, 1970, 1971, 1972).

9.4 GEOLOGICAL DESCRIPTION

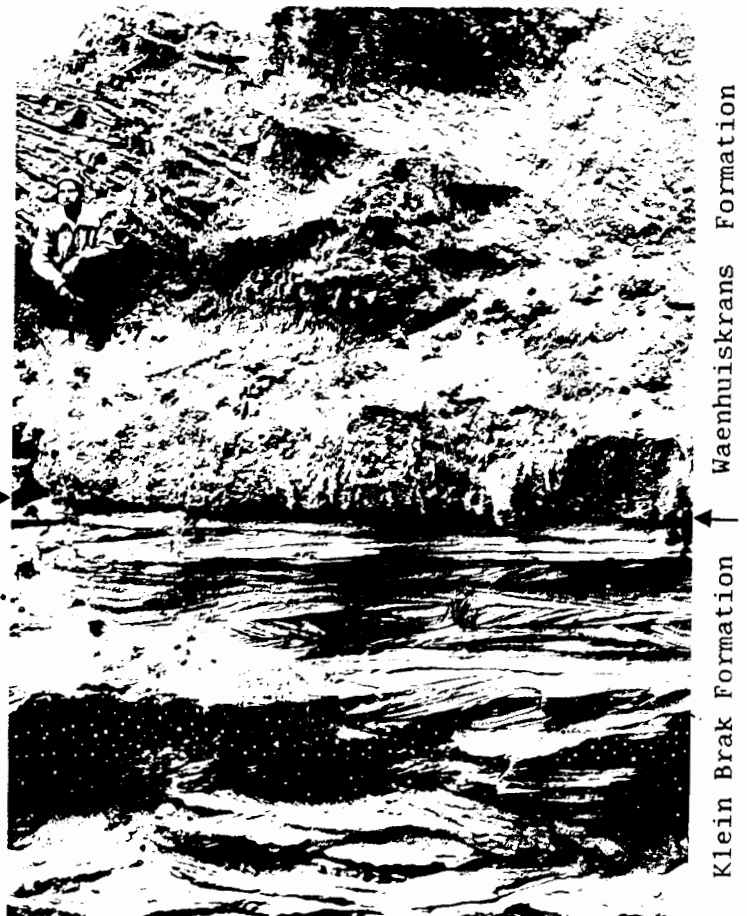
9.4.1 Stratigraphic boundaries

The Waenhuiskrans Formation overlies the marine/estuarine Klein Brak Formation and was deposited during the Würm glacial period responsible for lowering sea-level to -130m below present sea-level in the Late Pleistocene. The basal contact of the Waenhuiskrans



PLATE 48. Well-consolidated Waenhuiskrans calcarenite forming the coastal outcrops south of the village of Waenhuiskrans. Note the well-developed surf-cut platform, visor and modern boulder beach.

PLATE 49. Contact between the strand-line Klein Brak Formation and the overlying Waenhuiskrans Formation → aeolianites exposed in profile KB III at Swartvlei Estuary (Figs. 23d, 23g).



Formation and the Klein Brak Formation is defined at the top of the uppermost shelly gravel marine unit of the latter formation (Profile WK I, Figure 26d and Profile KB III, Figure 23g; Plate 49). This boundary is transitional over a distance of a few centimetres. The upper boundary of the Waenhuiskrans Formation is defined as the base of the overlying calcrete, soil, scree or unconsolidated aeolian sand of the Strandveld Formation (Unit 7, Figure 26f).

The type area is at the Waenhuiskrans ("wagon house cliff") cave (Plate 48, Title page), 500m south of the fishing village of Waenhuiskrans or Arniston, named after the British troopship, the "Arniston", shipwrecked on Saxon Reef (Figures 26a and 26d). The basal contact and the large-scale aeolian crossbedding are well exposed at this locality (Plate 45). Extensive cored drilling on Dollas Downs (Figure 26a), northwest of Waenhuiskrans, revealed a gradational relationship between the aeolian Waenhuiskrans Formation and the underlying marine Klein Brak Formation.

The basal contact of the Waenhuiskrans Formation is sharp in places, but is otherwise transitional over 20cm. This boundary is taken at the top of the last horizontally laminated unit with pebbles, gravel, coarse (diameter of more than 5mm) shell fragments and whole marine fossils. The transition zone is 10cm thick in the Waenhuiskrans stratoprofile WK I (Figures 26a and 26d), whereas sharp in profile WK II in Hoekvywers Bay, east of the Duiwenhoks Estuary (Figures 26b and 26e). The upper boundary is defined as the base of younger overlying calcrete, yellow to reddish coloured soil and recent unconsolidated aeolian sand of the Strandveld Formation.

In the Waenhuiskrans profile the formation is overlain by a calcrete 1,1m-thick (Figure 26d) and in profile WK III at Rooikrans; east of Still Bay (Figure 26c and 26f) by at least 20m.

of unconsolidated dune sand of the Strandveld Formation (Plate 50). In a borehole drilled southwest of Ryspunt (Figure 25), a 0,8m thick calcrete separates the older Waenhuiskrans aeolianite from the younger overlying Strandveld dune sands.

9.4.2 Unit thickness

The thickness of the Waenhuiskrans Formation varies, as could be expected from observations of Holocene coastal aeolian deposits of the Strandveld Formation forming dune ridges and interdune areas. A maximum thickness of more than 200m is inferred for Waenhuiskrans occurrences in the Wilderness - Knysna area (Figure 25). However, younger dune sands could also form part of these dune ridges and only drilling could determine a true thickness for these units. An average thickness of 30m is inferred from the available measured profiles, boreholes and topographic information.

9.4.3 Lithology

The formation consists of calcarenite and calcareous sandstone with fine comminuted shelly material. The well-sorted sand fraction is made up of medium-grained, well to very well rounded quartz grains, finely comminuted shell fragments, a few very well rounded glauconite grains as well as a few well-rounded echinoid spines, cirriped (barnacle) fragments and wind-abraded benthic foraminifera. Molluscan fragments are the most common biogenic grain whereas planktonic foraminifera are rare.

The colour of the Waenhuiskrans Formation varies from pale orange to yellowish grey for newly exposed outcrop, and light grey to white for weathered surfaces. The aeolianite consists mostly of sand-size fragments of littoral and nearshore organisms and terrigenous grains cemented by sparry calcite. Only traces of pseudospar and microspar were seen in calcarenite thin sections



PLATE 50. Sea-cliff at Rooikrans, east of Still Bay, showing the relationship between the consolidated Waenhuiskrans and unconsolidated Strandveld Formations. Note the sloping palaeosol horizon in the older succession (Profile WK III, Figures 26c and 26f) and the figure for scale.



PLATE 51. Characteristic large-scale aeolian crossbedding of the Waenhuiskrans Formation in profile WK II on Koens Rust east of the Duiwenhoks Estuary (Figures 26b and 26e). Note figure for scale in bottom right-hand corner.

giving a relative "clean appearance" when compared to the marine facies (Siesser, 1971, 1972).

Analysis of Waenhuiskrans profiles shows a carbonate content range of between 23 and 92 per cent depending on the amount of shell material present. In profile WK III, at Rooikrans near Still Bay (Figure 26f), the carbonate content varies between 23,8 and 34,6 per cent, compared to that of profile WK I at Waenhuiskrans (Figure 26d) varying between 86,0 and 91,7 per cent and a value of 76,5 per cent for a sample from the borehole to the southwest of Ryspunt (Figure 25).

9.4.4 Sedimentary structures

The Waenhuiskrans Formation is characterized by large-scale planar crossbedding with bed thickness of up to 12m and bedding surfaces with dip up to 30 degrees. The internal structures of the formation are exposed in 25m-high coastal cliffs; examples at Waenhuiskrans (Plates 45, 48), to the east of Koppie Alleen (Plate 46), west and east of the Duiwenhoks Estuary (Plate 51) and east of Still Bay (Plate 50). A rose diagram, displaying the palaeotransport directions, shows a polymodal distribution of maxima to the southeast and northwest (180 bedding-plane measurements at 4 different localities, i.e. at Walker Bay, Waenhuiskrans, Koppie Alleen and Hoekvywers Bay) (Figure 27). The varied distribution of the dip directions of coastal-dune deposits is the result of an ever-changing coastal environment controlled by the vegetation, changing seasonal wind directions, onshore/offshore-blowing day and night winds, changes in the soil moisture and atmospherical conditions (Galloway and Hobday, 1983).

Kocurek bounding surfaces are present in exposures at Preekstoel, Geelkrans and Rooikrans, all east of Still Bay (Figure 25, Plate 50). First-order bounding surfaces form the boundaries

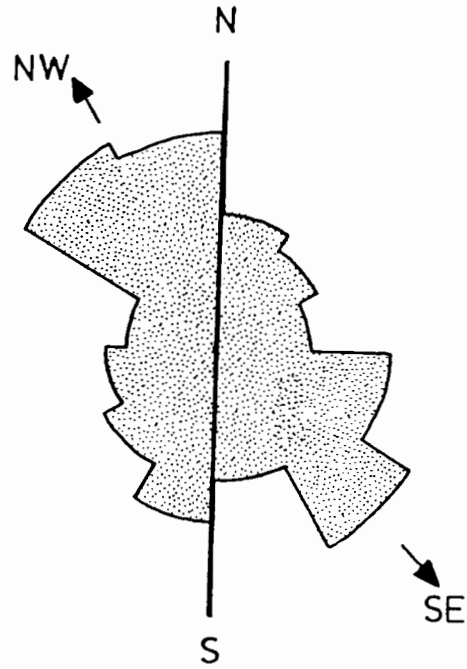


FIGURE 27. Rose diagram displaying the palaeotransport directions of the Waenhuiskrans Formation (180 bedding-plane measurements at 4 different localities).

between the large-scale aeolian crossbeds and up to 3m-thick well-developed structureless horizons (Figure 26f). These semi-consolidated structureless units, characterized by brownish calcareous sand with sharp uneven bases and terrestrial gastropods, formed as soil horizons in the interdune areas. At Geelkrans and Rooikrans these palaeosols can be traced over distances of hundreds of metres following the original topography of the dune ridges and interdune areas (Plate 50).

Second-order bounding surfaces occur throughout the Waenhuiskrans Formation and mark the migration of individual bedding planes and dune slipfaces responsible for the abundant erosional unconformities. These can be seen as the separating surfaces and planes observed between the tangential foresets of varying dip directions (Plate 52). Where groundwater action played a role, the bounding surfaces are in many places calcified to stand out as positive-weathering layers, as seen at exposures at Hoekvywers Bay, east of the Duiwenhoks Estuary and Preekstoel, east of Still Bay (Figure 25).

During spring low tide, foresets of aeolian crossbedding are exposed over large areas between Preekstoel and Geelkrans, east of Still Bay (Figure 25, Plate 47). Viewed in plan, the individual foresets appear straight or curved, and migration directions from the west and the south-east. This crossbedding is indicative of transverse dunes with mainly planar or tabular foresets, dipping steeper than 25 degrees (Bigarella, 1972). The foresets appear horizontal in sections perpendicular to the wind direction. Bedsets with asymmetrical ripples, parallel-oriented peaks and a high (>15) ripple index are exposed on some bedding planes. The coarse sand fraction gather in the troughs orientated perpendicular to the bedding surface.



PLATE 52. Second-order Kocurek bounding surfaces seen as separating planes observed between the tangential foresets show varying dip directions. Rooikrans, east of Still Bay (Figure 26c).



PLATE 53. Soles of ripple marks parallel to the dip foresets of cross-bedding present in the roof of the Waenhuiskrans cave (Figure 26a).

Orientation directions of ripple sets, exposed on adjacent surfaces, can differ by as much as 60 degrees. Sole structures of ripple marks parallel to the dip of foreset slopes of crossbedding are present in the roof of the Waenhuiskrans cave (Plate 53). Small-scale deformation features, resulting from grain flow and loading on dune foresets and foresets dipping against the main transport direction (Bigarella, 1972), are present in exposures east of Still Bay.

9.5 PALAEOLOGY.

Terrestrial gastropods, freshwater molluscs, finely comminuted shell fragments, microfossils and a few trace fossils are present in the Waenhuiskrans Formation. The terrestrial gastropods are scattered throughout the formation and include the following identified species:- Achatina zebra, Tropidophora sp., Trigonephris sp. and Natalina sp. Molluscs such as Burnupia, Planorbis and Succinea as well as winderoded echinoid spines, bryozoan fragments and benthic foraminifera are present in the basal part of profile WK III at Rooikrans, east of Still Bay (Figure 26f). Identified wind-abraded benthic foraminifera include species like Elphidium crispum, Poroepionides pateralis and Ammonia sp. (McMillan 1986).

In many places traces and feeding trails are exposed on foresets of the aeolian crossbedding. A trace, measuring 17 mm in diameter, was found on a foreset layer in aeolian crossbedding at Koppie Alleen (Plate 54). This specimen displays meniscate backfill and is oriented parallel to the depositional dip of the cross-strata, suggesting that the creator moved down the lee side of the dune. Similar meniscate trails are produced in modern sand dunes by the larvae of tipulid insects (crane flies) (Ekdale and Picard, 1985).

Traces are present on ripple-marked foresets exposed in the roof of the Waenhuiskrans cave and in coastal exposures north of Die Plaat, along Walker Bay (Figure 25). Near the top of the Waenhuiskrans Formation dikaka, (calcified roots and plant stems: Glennie and Evamy, 1968) cut through the aeolian crossbedding. At places along the coastline, such as at Quoin Point, the dunes are covered with dikaka when the unconsolidated sand is blown away (Figure 22).

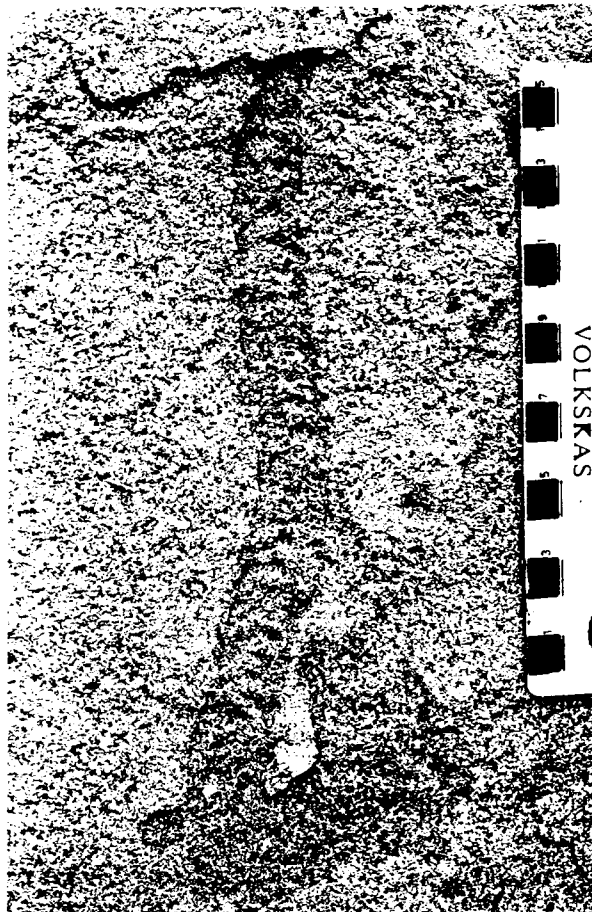


PLATE 54. Meniscate backfill trace suggesting that the creator moved down the lee side of the dune, i.e. from the top to bottom. Waenhuiskrans aeolianite at Koppie Alleen (Figure 25).

CHAPTER 10. STRANDVELD FORMATION

10.1 INTRODUCTION

The Strandveld Formation comprises the unconsolidated, partially-vegetated to unvegetated windblown sand of Holocene age, thus forming the youngest formation of the Bredasdorp Group (Figure 8).

Haughton et al. (1937, p. 25) described "dunes of recent origin" in the area around Mossel Bay, whereas De Villiers et al. (1964, p. 47) mentioned "Waaissand in trekduine op gelyker gebiede wat yl met growwe grassoorte begroei is" (Windblown sand forming mobile dunes on level areas which are sparsely vegetated with species of coarse grass) from the coastal plain west (Bot River Estuary) and south of Hermanus (Strandveld). In the description of the Gans Bay Bredasdorp sheet, Spies et al. (1963, p.19) mention the largest occurrence of windblown sand north of Die Kelders to the north of Gans Bay. SACS (1980) gave no formal stratigraphic connotation to the sediments. Pedologists, Schloms et al. (1983), mapped these sands as "A1 sediments" west of Mossel Bay, and "A2 sediments" to the east of Mossel Bay.

In the western Cape, similar sands have been designated the Witzand Calcareous Sand Member of the Bredasdorp Formation (Rogers, 1982). This unit is correlated with the unconsolidated dune sand with a scrub-covered veneer in the area between the Kafferkuils and Gourits Estuaries (Rogers, 1986). The term Strandveld Formation was used by Malan (1987, p. 506) for the unconsolidated wind-blown dunes of Holocene age occurring along the coastline between Gans Bay and Mossel Bay. In 1989 SACS recognised the Strandveld Formation as the youngest unit of the Bredasdorp Group (Malan, 1989; Table 1 and Figure 2).

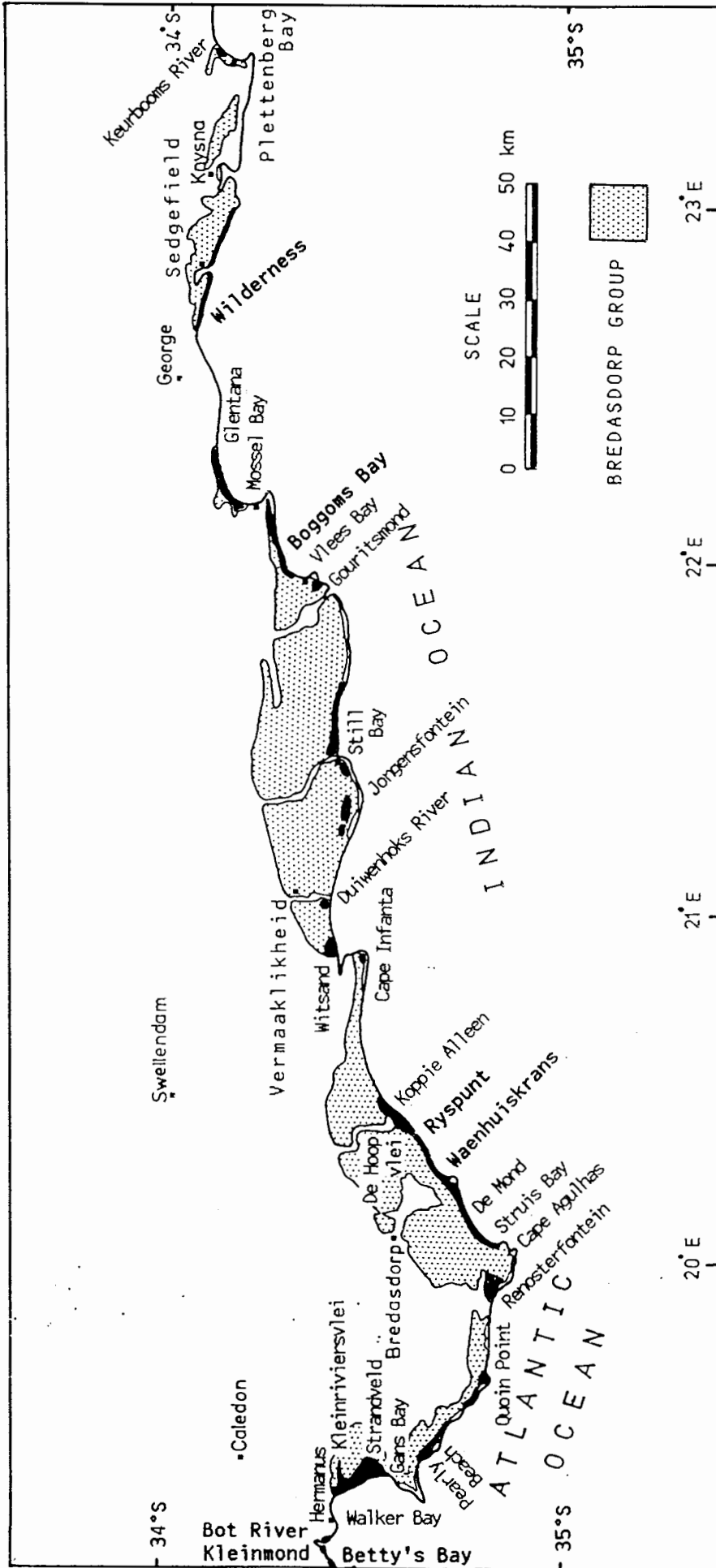


FIGURE 28. Locality diagram for the Strandveld Formation, Bredasdorp Group. Outcrops of Strandveld Formation indicated by black colour.

No fixed stratotype section could be selected for the Strandveld Formation because of the shifting nature of the coastal sand dunes. However, the Strandveld Forestry Reserve along the eastern shores of Walker Bay, between Kleinriviersvlei and Die Kelders, was chosen as the stratotype locality for the Strandveld Formation due to the presence of an extensive coastal dunefield (Plate 55).

10.2 GEOGRAPHICAL DISTRIBUTION.

The Strandveld Formation is found along the coastline between Kleinmond, in the west, and the Keurbooms Estuary, near Plettenberg Bay, in the east and occurs up to 4km inland from the present coastline (Figure 28).

Coastal dunefields occur along the coast of Walker Bay (south of Kleinriviersvlei in the area of the Strandveld Forestry Reserve and adjacent to the mouth of the Bot Estuary). Similar dunes occur between Pearly Beach and Quoin Point, on Renosterfontein (west of Cape Agulhas), along the shore of Struis Bay between the coastal villages of Struis Bay, Waenhuiskrans, Ryspunt and northwards to Koppie Alleen (on the De Hoop Nature Reserve) (Figure 28). The coastal dune belt continues east of Witsand at the mouth of the Breede River, on the western bank of the Duiwenhoks Estuary, east of Jongensfontein, east and west of Still Bay and between Gouritsmond and Vlees Bay (Figure 28). The dune cordons can be followed farther to the east along the coast between Boggoms Bay and Dana Bay, between Mossel Bay and Glentana and along the coast between Wilderness, Sedgefield and Knysna as well as along Plettenberg Bay and the Keurbooms Estuary (Figure 28).

The Strandveld Formation can be mapped on aerial photographs as the partially vegetated to unvegetated, unconsolidated mobile dunefields and ridges along the present coastline. This unit is correlated with the mobile, shelly aeolian dunes of "Unit A1



PLATE 55. Aerial photograph of the Strandveld Forestry Reserve and the coastal dunefield formed by the Strandveld Formation (Photo nr. 1779, Strip 30, Job 719). Prevailing southeasterly winds form excellent examples of transverse dunes with a southwest-northeast orientation and lee sides dipping to the northwest. Note the partially vegetated eastern part of the dunefield. Exposures of the Waenhuiskrans Formation are to the east of the jeep track running north-south. A programme of active dune stabilisation was followed in the mid-1980s.

sediments", which was mapped over large areas along the Southern Cape coast (Soil maps 2 and 3: Overberg) and the stable shelly aeolian dunes of "Unit A2 sediments" mapped in the Outeniqualand region (Schloms et al., 1983). The unconsolidated nature of the finely comminuted shelly calcareous sands, the obvious aeolian duneforms and dune topography, as well as the presence of shells of terrestrial gastropods serve as the main criteria for the lateral extension of the Strandveld Formation.

10.3 LATERAL VARIATIONS

The thickness of the Strandveld Formation varies significantly, depending on dune height; it attains a maximum thickness of 125m in the Koppie Alleen dunefield. The formation attains its maximum width (up to 4km) and thickness in the Strandveld and Koppie Alleen dunefields, whereas elsewhere the unit may consist of a narrow (0,2 to 1km) shore-parallel dune ridge, clearly preserved between De Hoopvlei and the village of Struis Bay, along the shores of Struis Bay (Plate 57). The distribution of the dune areas is broken where mountains and sandstone benches extend to the coast. Whereas in the western Cape local blowouts and duneplume trails extending inland are a notable feature, in the Southern Cape the mobile sands occur as more continuous fields of transverse dunes in a zone parallel to the coast (Schloms et al., 1983). Exceptions to this are the Strandveld, Renosterfontein, Koppie Alleen and Witsand dunefields lying favourably with relation to the orientation of the coastline and the prevailing winds blowing sand off the sandy beaches into the dune areas.

A few isolated patches are preserved, particularly along rocky shores, e.g. at Danger Point, Cape Infanta and directly west of Mossel Bay. The eastern limit for the Strandveld Formation is proposed at Nature's Valley, 20km east of Plettenberg Bay, due to the apparent absence of unconsolidated aeolian sands farther east along the Tsitsikamma coast. The western limit is proposed at Betty's Bay, west of Kleinmond. The Hottentot's Holland Mountains



PLATE 56. The Strandveld Formation forming a narrow (0,7 to 1km) shore-parallel dune ridge to the north of the coastal village of Struisbaai (Photo nr. 1861, Strip 35, Job 135). The longitudinal dunes are orientated parallel to the southeasterly wind direction.

form the cut-off between the Strandveld Formation (Bredasdorp Group) and the unconsolidated aeolian sands of the Witzand Formation (Sandveld Group of Rogers et al., 1990) preserved on the Cape Flats. In some areas the aeolian features are obscured by fynbos and thick alien Rooikrans (Acacia cyclops) vegetation and in such cases the typical undulating topography of the dunes facilitates recognition and mapping of the Strandveld Formation.

10.4 GEOLOGICAL DESCRIPTION

10.4.1 Stratigraphic boundaries

The Strandveld Formation represents the youngest formation of the Bredasdorp Group (Figure 8) and disconformably overlies the Waenhuiskrans, Klein Brak and Wankoe Formation and pre-Cainozoic rocks. It is distinguished from the underlying older aeolian Waenhuiskrans and Wankoe Formations, marine Klein Brak Formation and from the pre-Cainozoic formations by its unconsolidated nature. The absence of clasts distinguishes the Strandveld Formation from the modern beach-deposited sands, which are excluded from this formation.

The landward boundary may be located up to 4km inland from the coast whereas the seaward boundary is taken at the upper-backshore environment of the modern beach. The formation is still receiving wind-borne sediment derived from adjacent sandy beaches. In the area to the west of Mossel Bay the formation is mostly vegetated, especially along the inland edges of active dunefields.

10.4.2 Lithology

The Strandveld Formation consists of unconsolidated calcareous sand of aeolian origin. A few intercalated pockets of Strandloper (beachcomber) middens and poorly developed soil horizons are also

present. Examples of these are exposed near the eastern edge of the Koppie Alleen dunefield, south of the Koppie Alleen parking area on the De Hoop Nature Reserve.

Lithologically the formation consists of calcareous sand and fine comminuted shelly material. The well-sorted sand fraction is made up of fine- to medium-grained, rounded to subrounded quartz grains, finely comminuted shell fragments and a few heavy mineral grains. Small fragments of marine macro-organisms (shells and calcareous algae), wind-abraded benthic foraminifera and echinoid spines, all still retaining their real-life colours, form part of the sand-size fraction. The unit is characterised by high-angle (up to 35 degrees) crossbedding sets, up to 20m thick.

Terrestrial gastropods, such as Achatina zebra, Trigonephrus sp., Burnupia sp., Trachycystis sp. and Fauxulus sp. can be found in, as well as living on, vegetated areas of the Strandveld Formation. In shell middens sand-mussel (Donax serra), limpets (Patella sp.) and arikreukel (Turbo sp.), as well as scarce artifacts and pottery fragments can be found (pers. comm., G. Avery, 1990). At the open midden station in the Koppie Alleen dunefield, there is a clear relationship between a shell midden and both underlying (older) and overlying (younger) structureless, brownish grey soil horizons.

10.5 OTHER ASPECTS

The characteristic thick-bedded, high-angle crossbedding, combined with textural features such as good sorting, well-rounded quartz grains, the absence of matrix, and the undulating dune topography and duneforms, indicate an aeolian origin for this formation (Bigarella, 1972).

Schloms et al. (1983, p. 210) differentiate between the "Al mobile shelly aeolian sands of the Overberg" (Hermanus to Mossel Bay) and

the "A2 stable shelly aeolian sands of the Outeniqualand" (Mossel Bay to Plettenberg Bay) regions. This is ascribed to the following: "The proximity of the mountains to the coast in this region (Outeniqualand) contributes to higher orographic rainfall and precipitation occurs in all seasons. Under these conditions dunes are rapidly stabilized by vegetation (A2 sands) and only the outermost and youngest dunes are markedly calcareous" (Schloms et al., 1983, p.82).

The formation comprises a number of active coastal dunefields such as the Strandveld, Renosterfontein, De Mond, Koppie Alleen (Plate 57), Witsand and Jongensfontein dunefields, some of which can be compared with the largest coastal dunefield along the South African coastline, the Alexandria dunefield in the eastern Cape Province (Illenberger, 1986). The Sout River at De Hoopvlei is blocked by the Koppie Alleen dunefield to form the De Hoopvlei lagoon. This barrier is so effective that, during the winter floods of 1957, water had to flow westward over the low-lying Coastal Vlakte towards Bredasdorp, joining the Kars River on its way to the sea (pers. comm. M. Scott, De Hoop Nature Reserve, 1986).

The age of the Strandveld Formation is inferred to be Holocene with deposition probably starting at the beginning of the regression from the transgressive maximum of the Flandrian transgression at about 6500 yBP (cf. the Alexandria and Schelm Hoek dunefields along Algoa Bay in the eastern Cape, Illenberger, 1988).

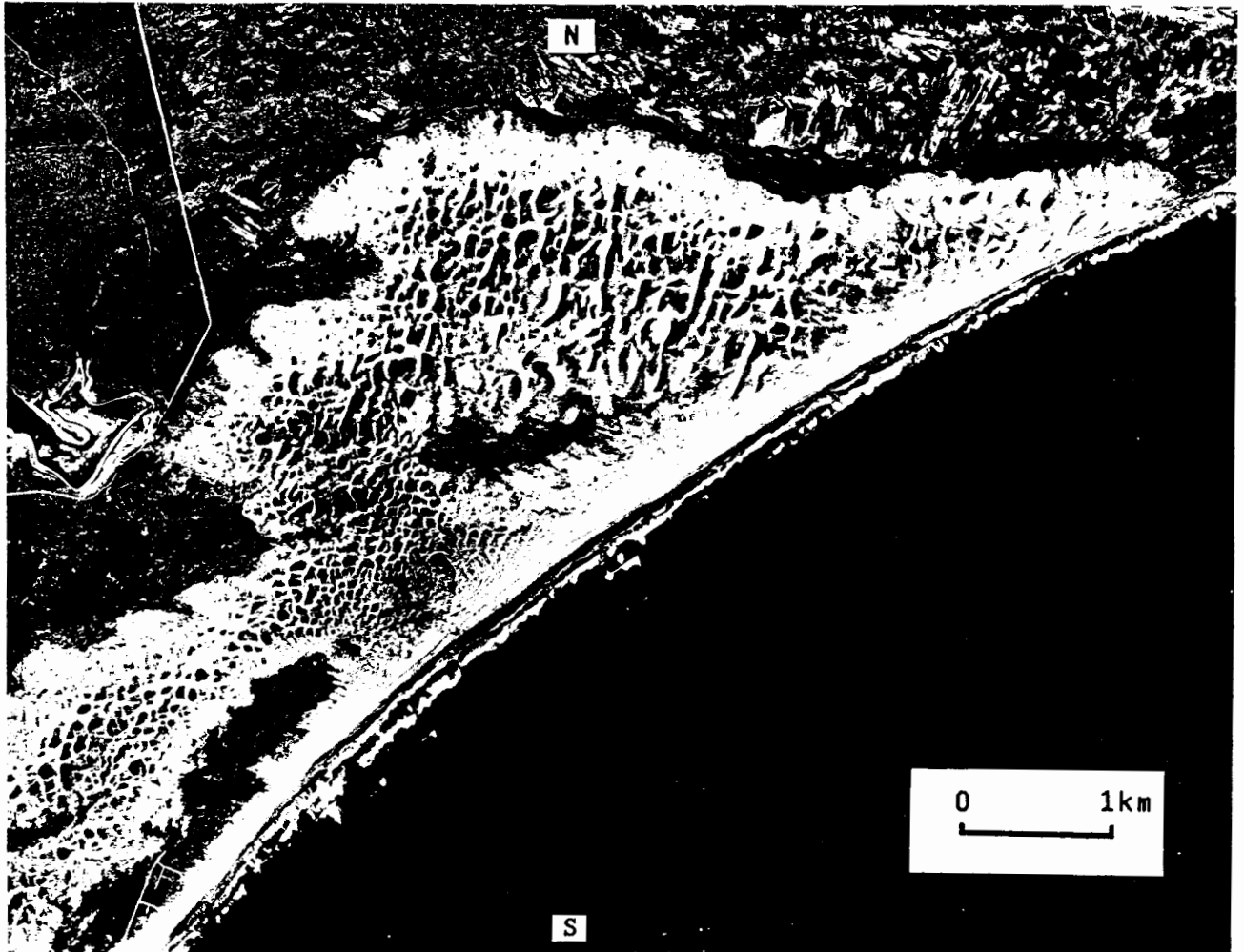


PLATE 57. Aerial photo of the Koppie Alleen dunefield at the southern edge of De Hoopvlei (Photo nr. 9748, Strip 21, Job 735). The crests of the transverse dunes are orientated east of north with their lee sides to the northwest indicating a prevailing southeasterly wind direction. This dunefield is part of the De Hoop Nature Reserve and no dune stabilisation programme is followed (pers. comm. D. Scott, 1988).

CHAPTER 11. DEPOSITIONAL ENVIRONMENTS

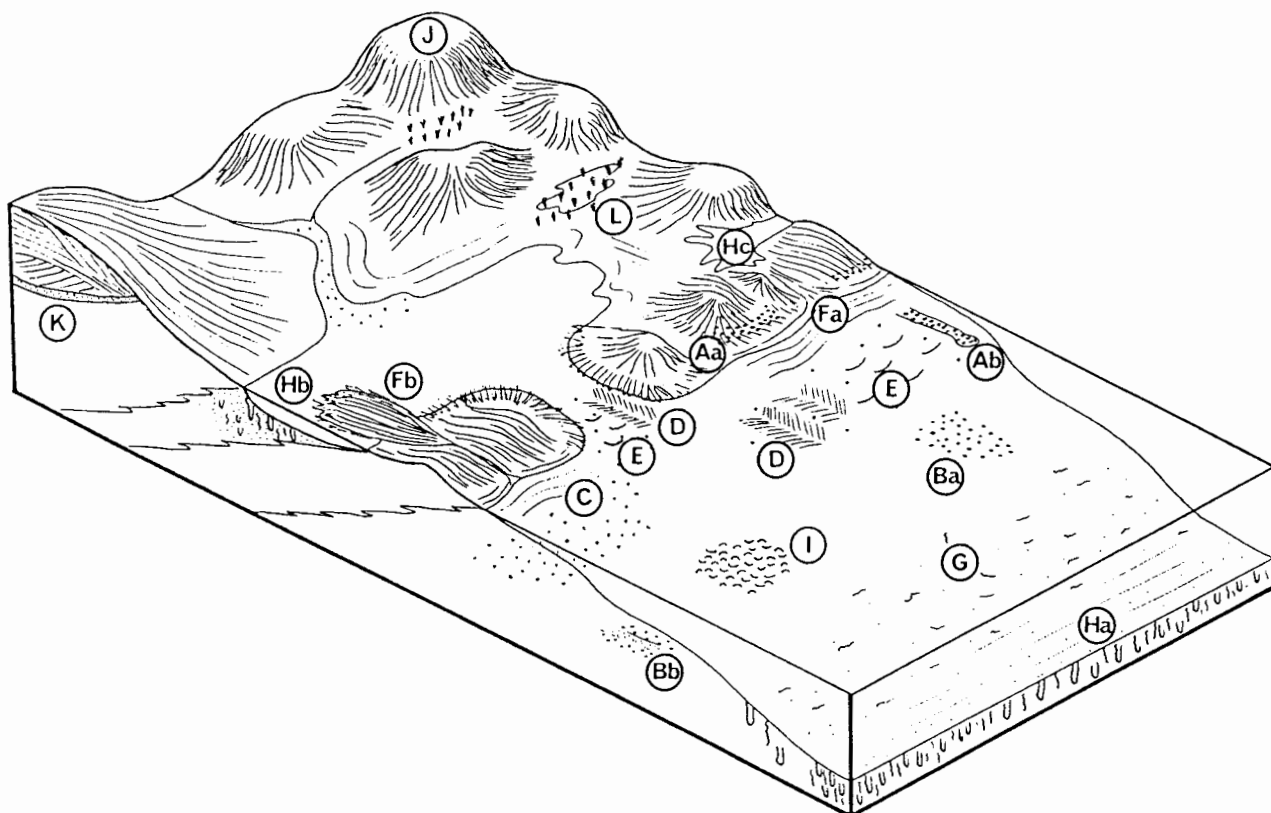
11.1 INTRODUCTION

The Bredasdorp succession comprises marine and aeolian coastal deposits. The strandline depositional settings of the De Hoopvlei and Klein Brak Formations include shoreface, intertidal, tidal, supratidal, back-barrier lagoonal and estuarine environments overlaid by the Wankoe and Waenuiskrans Formations deposited as coastal dunes and dunefields (Figure 29). Various facies have been identified from the geometry, lithology, sedimentary structures, biogenic structures, fossil content and palaeocurrent patterns of the formations. A cross-section through idealised offshore, transitional zone, shoreface, foreshore, backshore and coastal dune environments has been drawn to relate the facies to different depositional environments (Hunter *et al.*, 1979) (Figure 30).

In general, four major lithological units are recognised, i.e. conglomerate/calcirudite, calcarenite/calcareous sandstone, coquina/shelly sandstone and siltstone/organic-rich units. Based on sedimentary facies criteria (Selley, 1982) these are divided into twelve facies - Facies A to Facies L. These facies will be discussed according to lithology, starting with the coarsest facies (Facies A, conglomerate/calcirudite facies) and ending with the finest unit (Facies L, peat and sandy peat facies).

11.2 FACIES A (CONGLOMERATE/CALCIRUDITE)

The basal massive conglomerate/calcirudite facies (Facies A) contains a variety of extraformational clasts (quartzite, quartz, shale and silcrete), intraformational clasts (calcarenite and mostly oyster shells), subrounded to rounded pebbles, cobbles, boulders (diameter up to 1,2m) and shell fragments (cf. Plates 3 and 37). The massive gravelly calcarenites, which lack any



(Aa) Symbols indicate different Facies.

Figure 29. Block diagram representing depositional environments in the Bredasdorp Group.

- A: Conglomerate/calcirudite facies, foreshore and backshore (Aa) and shoreface environment (Ab).
- B: Single-clast facies (Ba), interbedded thin conglomerate facies (Bb).
- C: Calcarenite and subordinate conglomerate facies.
- D: Low-angle, herringbone and planar crossbedded facies.
- E: Trough-crossbedded facies.
- F: Low-angle calcarenite facies, beach (Fa) and washover fans (Fb).
- G: Bioturbated laminated calcarenite facies.
- H: Intensely bioturbated calcarenite facies, offshore (Ha), backbarrier (Hb) and interdune (Hc) environments.
- I: Coquina facies.
- J: Large-scale crossbedded calcarenite facies.
- K: Calcrete and homogeneous fine calcareous sand facies.
- L: Peat and sandy peat facies.

stratification, are interpreted as having been deposited rapidly with no subsequent reworking by currents (Unit 1 in profile KK III near Still Bay, Figure 14d; Units 1,7 and 9 in profile KK IV along Kafferkuils River, Figure 15b; Unit 3 in profile KB I, Figure 23e) (Raddysh, 1988).

Conglomerates exhibiting crude, low-angle cross-stratification may have been tractionally reworked after the initial depositional event (Oppelt, 1988). The clasts show well-developed imbrication (Unit 1 in profile DR I along Duiwenhoks River, Figure 13b; Unit 9 in profile KK V along the Kafferkuils River, Figure 15c and Unit 1 in profile KB VI at Infanta, Figure 24e). Facies A is reasonably continuous and well developed on the basal unconformity (i.e. Unit 1 in profiles RK I to RK IV at Rooikrans north of De Hoopvlei, Figures 11b to 11e; Plate 8) and Unit 1 in profile KB II at Dana Bay and profile KB VI at Infanta (Figures 23f and 24e).

The basal conglomerate/calcirudite unit was deposited on a high-energy foreshore and backshore (Aa in Figures 29 and 30) (Massari and Parea, 1988) such as the present cobble beach at Waenhuiskrans (Plate 48). The massive calcirudite of Unit 7 in profile DH VII (southern end of De Hoopvlei, Figure 10h) filling a channel, cut into low-angle and trough-crossbedded very coarse-grained calcarenite. The channel is orientated perpendicular to the palaeostrandline and is interpreted as a boulder-filled trough eroded by a fast-flowing rip current in the lower part of the shoreface environment (Ab in Figures 29 and 30).

11.3 FACIES B (SINGLE-CLAST LAYERS)

Facies B, consisting of cobble and pebble units of single-clast thickness (Facies Ba) and slightly thicker, interbedded, upward-fining conglomerate layers (Facies Bb) are well preserved in both the De Hoopvlei and Klein Brak Formations (Profiles RK I to RK IV along Rooikrans, Figures 11a to 11e) and profile KB II at Dana Bay

(Figures 23f, 29 and 30). These units, reaching a maximum thickness of 40cm, are present at the base of upward-fining cycles. In places the basal contact of this facies is formed by planed erosion surfaces, which may be slightly irregular, on which the pebble or gravel lag of Facies B is deposited (cf. basal contact of Unit 4 in profile DH I along De Hoopvlei, Figure 10b and Plate 5). Facies B could be interpreted as a lag, which heralds the deposition of a new sedimentary facies on a scoured surface. The basal surface marks a disconformity, resulting from a temporary shoreface retreat during a transgressive pulse in a chiefly progradational sequence (Massari and Parea, 1988).

Heavy mineral grains occur at the base of a cobble/pebble unit at Rooikrans (Unit 10 in profile RK II, Figure 11c and Plate 6). Similar lenticular deposits, with comminuted shells and whole Ostrea shells, are also present in parts of the Rooikrans exposure. These single-clast layers show well-developed imbrication (Units 3, 4 and 5 in profile KB II at Dana Bay, Figure 23f and Unit 2 in profile KB VI at Infanta, Figure 24e). The deposition of coarser fragments such as shark's teeth, echinoid spines and bryozoan fragments are further proof of deposition of a shallow-marine environment, due to reduced energy conditions of a fast-flowing sheet current incising into foreshore calcarenites (Hunter et al., 1979) (Unit 6 in profile DH IV along De Hoopvlei, Figure 10e).

With the reduction of flow velocity, settling of the finer fractions completes the upward-fining sequence (cf. profiles RK I, RK II at Rooikrans near De Hoop and BR II near Bredasdorp, Figures 11b, 11c and 12c). Single-pebble layers (Facies Ba) occur as lenticular deposits in calcarenites in profile BR I (Bredasdorp) and Units 3 and 5 of profile KK IV along the Kafferkuils River (Figures 12b and 15b). Scoured surfaces are only recognised by the presence of the thin lags produced during conditions of continuous removal of the finer sediments by the winnowing action of waves and currents (Levell, 1980).

11.4 FACIES C (CALCARENITE AND SUBORDINATE CONGLOMERATE)

Facies C consists of calcarenite units up to 2m-thick containing intra- and extra-formational matrix-supported boulders, cobbles and pebbles deposited in the foreshore and backshore environments (Figures 29 and 30). The clasts are Ostrea shells, subrounded to well-rounded quartzite, vein quartz, silcrete, shale and reworked calcarenite clasts. Horizontally laminated calcarenite containing imbricated broken and unbroken shells, fish bones and shark's teeth is present near Still Bay in Unit 2, profile KK I (Figure 14b) and Units 3 and 5, profile KK III (Figure 14d).

The cycles of alternating calcarenite and conglomerate beds in profiles DH V along De Hoopvlei (Units 2 and 4, Figure 10f), SR I along Sout River (Units 2,4 and 6, Figure 11f) and KB I in the Klein Brak Estuary (Units 6 and 10, Figure 23e) are representative of fairweather and stormy conditions. The stormy conditions are responsible for the deposition of the coarser fraction (Clifton et al., 1971). Fairweather progradation of the upper shoreface is responsible for the upward decrease in clast size and unit thickness (Massari and Parea, 1988) (Unit 8 in profile RK III at Rooikrans, Figure 11d and Unit 7 in profile SR I in Sout River).

11.5 FACIES D (LOW-ANGLE, HERRINGBONE AND PLANAR CROSSBEDDED)

Low-angle, herringbone, and planar crossbedded calcarenite units are representative of Facies D. Unit 4 of profile DH III at De Hoopvlei is formed by a gradational transition from Facies B (single-clast layers) to Facies D, which is characterised by low-angle and herringbone crossbedding containing whole and comminuted shells (Figure 10d). Crossbedded units are described from the foreshore environment increasing in abundance seawards towards the upper shoreface (Howard and Reineck, 1981). Locally developed horizontal laminations and rare burrows, usually limited to Ophiomorpha nodosa, can be seen in Unit 9 at profile DH I at De

Hoop restcamp (Figure 10b). Facies D and E (trough crossbedded calcarenite facies) are normally associated, as seen in Unit 6 in profile DH II at De Hoop restcamp (Figure 10c and Plate 13).

The herringbone crossbedded units are indicative of tidal conditions (De Raaf and Boersma, 1971). In profile RK II at Rooikrans in Sout River two sets of herringbone crossbedding (Units 7 and 9 in Figure 11c, Plate 14) are separated by a thin single-clast pebbly calcarenite of Facies B (Unit 8, Figure 11c). This possibly indicates a change in bar orientation and bar geometry due to changes in current direction and flow velocity. These tidal bundles are overlain by sediment of Facies B (single-clast layer) and Facies E (trough-crossbedded calcarenite) (Units 10 and 11, Figure 11c; Plate 15).

Bimodal-bipolar palaeocurrent patterns, as measured from herringbone crossbedding, characterise Facies D (Unit 9 in profile DH I at De Hoopvlei, Units 7 and 9 in profile RK II at Rooikrans in Sout River and Unit 4 in profile KB III at Swartvlei Estuary) (Figures 10b, 11c and 23g). The coarsening-upward cycle of Unit 5 in profile DH III near De Hoop restcamp (Figure 8d) is indicative of a transgression (Allen and Allen, 1990). The presence of bimodal palaeocurrent pattern, reactivation surface and low-angle crossbedding are proof of depositional conditions in the upper-foreshore environment (Howard and Reineck, 1981). The near absence of bioturbation and trace fossils in Facies D indicates high-energy conditions (fairweather wave base to high tide) and ever-changing surface conditions making living conditions nearly impossible for dwelling and burrowing organisms (Semeniuk and Johnson, 1982).

11.6 FACIES E. (TROUGH-CROSSBEDDED CALCARENITE)

Facies E is represented by trough crossbedded and low-angle crossbedded calcarenites as seen in Unit 4 in profile BR II near Bredasdorp (Figure 12c), Unit 10 in profile RK I (Figure 11b),

Units 6 and 11 in profile RK II (Figure 11c), Unit 7 in profile RK III (Figure 11d) along Rooikrans in Sout River, Units 1, 2, 4 and 5 in profile KB III at the mouth of Swartvlei lagoon (Figure 23g, Plate 36) and in the beach exposure at Boggoms Bay, east of Vlees Bay (Figure 22, Plate 38). Unit 11 of profile RK II (Figure 11c) and Unit 7 of profile RK III (Figure 11d) at Rooikrans in Sout River are the tops of upward-fining cycles from Facies B (single-clast layers) to Facies E (Plate 15).

The thickest accumulation measured for Facies E is the 5,6m-thick Unit 10 in profile RK IV (Figure 11e), giving a bimodal palaeocurrent distribution of 075 and 195 degrees. Both unimodal and polymodal palaeocurrent patterns were measured in other sections (Units 6, 7 and 9 in profile DH I, Figure 10b). Inclined bedding, low-angle crossbedding and well-developed biogenic structures are associated with the trough-crossbedded calcarenites of Facies E in profiles DH I - DH III (Figures 10a to 10d, Plates 10 and 58). Unit 12 in profile GR II on Vogel Valley beside the Gourits River (Figures 16a and 16c) is the basal part of an upward-coarsening cycle with a calcarenite/conglomerate unit of Facies C developed at the top.



PLATE 58. Trough-crossbedded calcarenite overlying inclined bedding and low-angle crossbedding in Unit 3, profile DH III along the left bank of De Hoopvlei, near the restcamp (Figure 10d).

Facies E can be compared with the trough-crossbedded sand and gravel lithofacies described by Semeniuk and Johnson (1982) from the proximal subtidal zone in the shoreface, i.e., the upper-shoreface environment (Clifton *et al.*, 1971; Hunter *et al.*, 1979). Predominantly trough-crossbedded sands with laminated bioturbated units and vertical to oblique *Ophiomorpha* burrows are described by Ramli (1986) from the upper-shoreface. This environment is dominated by wave action and littoral currents depositing medium- to coarse-grained sands with gravel layers and pebbly sand lenses. Intense reworking during stormy periods removes the finer sediment, while depositing the coarser fractions as trough-crossbedded units (Semeniuk and Johnson, 1982). Orientation of crossbedding can be directed landwards or seawards. Biogenic structures are usually absent as physical reworking of the sediments destroys all burrows in a biologically hostile environment (Semeniuk and Johnson, 1982).

11.7 FACIES F (LOW-ANGLE CALCARENITE)

Facies F is dominated by low-angle and horizontal laminations, low-angle crossbedding and no biogenic structures. This facies is representative of parallel, horizontal laminated and low-angle crossbedded sand, formed by the wash and backwash action of the waves (Hunter *et al.* 1979, Rahmani and Smith, 1988) in the foreshore environment (Heward, 1981; Howard and Reineck, 1981; Mee and Shone, 1989). Angle of bedding planes varies between 2 and 10 degrees, dipping in a seaward direction, with numerous low-angle discontinuity surfaces (Environment Fa, Figure 28) (cf. Figure 34, Balsley, 1988). Similar structures are described from the "inner planar and outer planar facies" by Clifton *et al.* (1971) with low-angle crossbedding increasing seawards towards the lower-foreshore. Stormy conditions are confirmed by thin conglomerate layers deposited on truncated (discontinuity) surfaces formed by erosion (Clifton *et al.*, 1971). Semeniuk and Johnson (1982) relate the discontinuity surfaces to tidal action.

Facies F is the most conspicuous unit forming more than 30 percent of the measured sections of the De Hoopvlei and Klein Brak Formations (cf. Plate 41, profile KB V at the left bank of Groot Brak Estuary, Figure 24d). Examples of Facies F present in the De Hoopvlei and Klein Brak Formations can be seen in profiles BR I at Bredasdorp (Figure 12b), RK I, RK III and SR I in Sout River (Figures 11b, 11d and 11f), DH I (Figure 10b, Plate 5), DH V (Figure 10f, Plate 9) and DH VI along De Hoopvlei (Figure 10g), KK V along Kafferkuils River (Figure 15c), GR I and GR II on Vogel Valley, eastern bank of Gourits River (Figures 16b and 16c), KB I in Klein Brak Estuary (Figure 23e) and KB V in Groot Brak Estuary (Figure 23f, Plate 41). Evidence of a prograding coastal environment can be seen in the beach exposure at Boggoms Bay, north of Vlees Bay (Figure 22) where Facies F (foreshore, Fa) overlying Facies E (shoreface) (Plate 38) (Allen and Allen, 1990 figure 7.19). The top of upward-fining cycles in profiles RK I and RK III in Rooikrans along the Sout River is formed by Facies F (Units 4, 8 and 12 in Figure 11b and Units 2, 5 and 9 in Figure 11d).

Thin conglomerate and gravel lenses and layers (Facies B and C) form part of a thicker Facies F sequence, as can be seen in Unit 2 of profile RK II at Rooikrans, Sout River (Figure 11c), Units 2 and 3 in profile DH IV (Figure 10e) and Units 2 and 4 in profile DH V along the east bank of De Hoopvlei (Figure 10f). These conglomerate and gravel lenses and layers are deposited in the foreshore environment during high energy associated with stormy or spring tide conditions (Clifton *et al.*, 1971).

Examples of Facies F, interpreted as washover fans (Environment Fb, Figure 29), can be seen in profile DR I, near Vermaaklikheid. Here medium- to very coarse-grained calcareous sand (Unit 3, Figure 13b) is overlain by an intensely bioturbated medium-grained calcarenite (Unit 4, Figure 13b) interpreted as the product of a back-barrier lagoon/estuarine environment (Hb in Figure 29).

11.8 FACIES G (BIOTURBATED LAMINATED CALCARENITE)

Inclined bedding, horizontal laminations, low-angle crossbedding and biogenic structures characterise the calcarenites of Facies G. Ophiomorpha, Skolithos and Planolites burrows occur at Rooikrans in the Sout River (Profiles RK I to RK IV, Figures 11a to 11e; Plates 23 and 24), along the shore of De Hoopvlei (Profiles DH I to DH III and DH VII, Figures 10a to 10d and 10h; Plates 20 to 22) in profile KK V along Kafferkuils River (Figure 15c, Plates 18 and 19) and profile GR II, Gourits River (Figure 16c). Ramli (1986) describes vertical to oblique Ophiomorpha burrows from parallel-laminated sands in the middle-shoreface environment. Vertical burrows are present in the upper-shoreface, horizontal burrowing organisms live in the lower-shoreface and less bioturbation is seen along higher-energy coastlines (Heward, 1981).

Sand prawns (Callianassa) burrow actively in the lower-foreshore and upper-shoreface environments of the modern beach (Hoyt and Weimer, 1963). Facies G indicates a lower-shoreface to transitional zone setting for Units 2 and 3 of profile DH I (Figure 10b, Plate 25) and Unit 2 of profile DH II at De Hoop restcamp (Figure 10c). Higher up in these profiles scattered Ophiomorpha burrows suggest an upper-shoreface and lower-foreshore environment (Units 4, 6 and 8 in profile DH I, Figure 10b and Units 3 and 5 in profile DH II, Figure 10c) (Plates 20 and 21). In situ Echinodiscus sp. in Units 5 and 6 in profile DH I (Figure 10b, Plate 16) and Unit 5 in profile DH II (Figure 10c) are described by Clark and Courtman-Stock (1976) in the zone from below the low tide level to a water depth of 20m, thus suggesting the palaeosetting of Facies G (i.e. lower-shoreface to transitional zone environment) (Figures 29 and 30).

11.9 FACIES H (INTENSELY BIOTURBATED CALCARENITE)

In the De Hoopvlei and Klein Brak Formations, Facies H consists of intensely bioturbated fine- to medium-grained calcareous sand and

calcarenite. The basal unit in profiles DH I and DH II (Unit 1 in Figures 10b and 10c, Plate 25) consists of Facies H. This is overlain by coars sediments of Facies G, forming an upward-coarsening sequence. Bioturbation decreases towards the top where horizontal laminations can be seen (Unit 2 of profile DH I, Figure 10b and the top of Unit 1 of profile DH II, Figure 10c). Low energy conditions created an ideal environment for intense bioturbation in profile DR I near Vermaaklikheid (Units 4 and 6 in Figure 13b) and KK V along the Kafferkuils River (Units 12 and 13 in Figure 15c).

Intensely bioturbated sand, deposited in the lower-shoreface, i.e., below wave base, has been described by Howard and Reineck (1981) from a high-energy coastline. Intensely bioturbated units of Facies Ha indicate a transitional to offshore environmental setting (Ha, Figures 29 and 30) (cf. Hunter *et al.*, 1979) (Unit 1 in profiles DH I and DH II, Figures 10b and 10c) and in back-barrier environments (Hb, Figures 29 and 30) (cf. Heward, 1981) (Unit 1 in profile KB VII at Hoë Walle, Figure 24f). Unit 1 in profiles DH I and DH II at De Hoop restcamp (Figures 10b and 10c), deposited below wave base in the transitional zone, is overlain by the prograding lower-shoreface (Balsley, 1988) of Facies G (Bioturbated laminated calcarenite facies), indicating a regressional phase.

Evidence of regressive conditions can be seen where back-barrier lagoon deposits (Units 4 and 6 in profile DR I, Duiwenhoks River, Figure 13b) overlie low-angle laminated calcarenites of Facies Fb, interpreted as washover fans in the upper-backshore environments (Unit 3, Figure 13b). The back-barrier deposits of Facies Hb are in turn overlain by large-scale aeolian crossbedding of Facies J (Unit 8, Figure 13b). Possible back-barrier bars or washover fans (Units 5 and 7, Figure 13b) develop landward of the foreshore and backshore and cut into the back-barrier lagoon environment (Fb in Figures 28 and 29).

11.10 FACIES I (COQUINA)

Facies I consists of coquina and shelly calcarenite, formed chiefly by Ostrea shells (Plates 4, 11 and 12). Unit 2 in profile DH VII, at the southern end of De Hoopvlei (Figure 10h), is a 0,5m thick accumulation of Ostrea atherstonei. A vague orientation can be ascribed to the preferential growth-direction of the oyster-bank in a sheltered area just below wave base and overlying the intensely bioturbated Facies H (Unit 1 in profile DH VII, Figure 10h; Plate 17). However, the wavy erosional base cutting into Facies H of Unit 1 could also indicate a high-energy depositional environment where the shells were deposited by migrating rip currents (Bremmer *et al.*, 1985).

11.11 FACIES J (LARGE-SCALE CROSSBEDDED CALCARENITE)

The laminations in large-scale crossbedded, medium-grained calcareous sand and calcarenite of the Wankoe, Waenhuiskrans and Strandveld Formations feature dip values of up to 30 degrees; this is characteristic of Facies J (Plates 27, 29, 45 and 48). This facies can be followed over large distances as a fairly uniform unit with only a change in the direction of the laminations (Profiles WAN I in Wankoe Valley and WAN II at Rooikrans in Sout River, Figures 20b, 20c and profiles WK I at Waenhuiskrans, WK II in Hoekvywers Bay, east of Duiwenhoks Estuary, and WK III at Rooikrans, 10km east of Still Bay, Figures 26d to 26f) (Plates 30 and 50 to 52). No marine fossils, except finely comminuted shelly material, occur in Facies J. Terrestrial gastropods, i.e. Achatina zebra, Trigonephrus sp., Dorcasia sp., Tropidophora sp. and Natalina sp., were found in the formations at several localities eg. Rooikrans in Sout River (Unit 1 in profile WAN II, Figure 20c), Rooikrans to the east of Still Bay (Unit 2 in profile WK III, Figure 26f) and in the quarry on Hectorskraal, southwest of Albertinia (Figure 19).

Ripples of which both the ripple index value and the ripple symmetry index value are high, are rare in Facies J; some of the few examples can be seen in the roof of the Waenhuiskrans cave (Plate 53) and in the coastal exposures to the east of Koppie Alleen (Figure 25). Ripple crests and troughs are parallel to subparallel to the dip direction of the cross-strata. The high ripple index and orientation relative to cross-stratification are distinctive features of wind-formed ripples (Bigarella, 1972)

The medium-grained quartz, glauconitic and shelly material was transported from the backshore environment into longshore coastal dune fields during major regressions. Sedimentary structures indicating an aeolian origin for Facies J are:- large-scale, high-angle sweeping cross-stratification, aeolian ripple marks and soft sediment-deformation (Ekdale and Picard, 1985).

11.12 FACIES K (CALCRETE AND HOMOGENEOUS FINE CALCAREOUS SAND)

Facies K consists of structureless, white to light brown fine-grained calcareous sand, calcarenite and calcrete. Exposures of Facies K occur in the Wankoe (Units 2 and 4 in profile WAN I in the Wankoe polje, Figure 20b) and Waenhuiskrans Formations (Profile WK III at Rooikrans, east of Still Bay, Figure 26f and Plate 50). In profile WK III, two units of variable thickness, with gradational basal contact and sharp top, are formed of light brown, fine-grained, well-rounded and well sorted sand (Plate 59). In profile DH IV, along the east shore of De Hoopvlei, Facies K at the base of the Wankoe Formation (Unit 9, Figure 10e and Plate 60) rests directly on the De Hoopvlei Formation. Facies K is interpreted as a palaeosol marking the palaeo-topography of the underlying dunes (Plate 30).



PLATE 59. A 1,8m thick palaeosol horizon (indicated by arrows) forming the basal part of profile WK III at Rooikrans, east of Still Bay (Figures 25 and 26c).

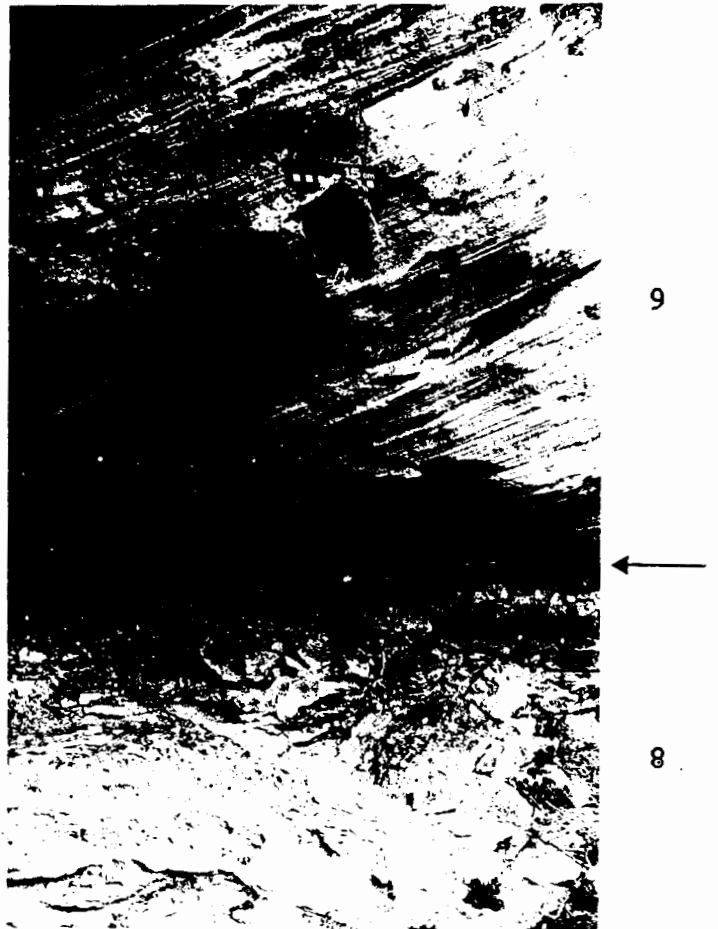


PLATE 60. Calcrete developed between the De Hoopvlei and Wankoe Formations at profile DH IV on the left bank of De Hoopvlei (Unit 8, Figures 10a and 10g).

In the coastal cliffs of Rooikrans and Geelkran, east of Still Bay (Figure 22 and Plate 50) the undulating Kocurek surfaces clearly represent soil horizons draped over original dune shapes. These fossil soil horizons resemble similar features described from Woody Cape, northeast of Port Elizabeth (Rust and Obbes, 1990). These soil horizons developed during periods of reduced wind erosion or higher rainfall, resulting in increased dune vegetation stabilising the dune surfaces. As aeolian activity resumed, the vegetated soil horizons were transgressed by windblown sand and covered by migrating dunes. The partially calcretised palaeosol, seen as Unit 9 in profile DH IV (Figure 10e, Plate 60), could have formed at the top of the ground water table at the base of the porous Wankoe Formation (cf. Rust and Obbes, 1990).

11.13 FACIES L (PEAT AND SANDY PEAT).

The dark brown to black peat and sandy peat of Facies L are confined to exposures of the Klein Brak Formation. Upward-coarsening, structureless, very fine to fine sand containing organic, plant and woody material, forms a sequence 4,6m-thick in profile KB IV east of the Duiwenhoks Estuary (Figure 23h, Plate 39). This exposure of Facies L was deposited on a floor of Bokkeveld bedrock during a regression in a vegetated swampy back-barrier or marsh, and later buried under southward (seawards) advancing coastal dunes of the Waenhuiskrans Formation as sea-level dropped further.

In the Hoë Walle seacliff, north of Quoin Point, Facies L can be seen as several organic-rich clay horizons reaching a thickness of 30cm in places (Unit 6 in profile KB VII, Figure 23f and Plate 40). At this locality Facies L was deposited in the marshy back-barrier environment of the palaeo-Ratel River as the Klein Brak Formation deposits were laid down during the start of a regressive cycle at the end of an inter-glacial period.

CHAPTER 12. DEPOSITIONAL MODEL FOR THE BREDASDORP GROUP

12.1 INTRODUCTION

A sedimentary environment is a part of the earth's surface which is physically, chemically, and biologically distinct from adjacent terrains that can generally be divided into sub-environments (Selley, 1982). Facies can be related to present-day depositional environments in order to construct a depositional model for the ancient rocks (idem, 1982).

The depositional framework of the Bredasdorp Group consists of a typical shoreline environment formed by offshore, transitional, shoreface, foreshore and backshore zones with rocky shores, sandy beaches, back-barrier lagoons, estuaries, backshore dunes and coastal dunefields. However, the shoreline environment is subjected to a variation in physical conditions, i.e. wave energy, wind regime, stormy periods, etc., all of which determine the spectrum of sedimentary structures (Clifton et al., 1971; Hunter et al., 1979; Short, 1984; Wright and Short, 1984).

Numerous sub-environments can be recognised from profiles of the individual formations of the Bredasdorp Group (Figures 29 and 30). The Bredasdorp Group was deposited under wave-dominated, microtidal conditions comparable with the modern day coast in the Struis Bay - De Hoop area, showing dune, backshore, foreshore and shoreface units with coast-parallel bars beside the foreshore in the upper shoreface (Plate 57) and complex rip currents seen as sediment plumes extending into the offshore (Plate 56). The measured profiles are dominated by the low-angle bedded, "beach laminated" calcarenite facies (Facies F). The development of tidal flats will be limited, as is expected in a wave-dominated, microtidal shoreline setting (Heward, 1981). Barrier-bar complexes and estuaries are poorly developed, forming isolated outcrops in or

near modern drowned river mouths, e.g. Klein Brak, Groot Brak and Swartvlei (Figure 1).

The depositional model for the Bredasdorp will be described with the aid of the various facies, beginning with the offshore environment and ending with the coastal aeolianites. This sequence of description highlights the regressive nature of the Bredasdorp sedimentary record: its stratigraphic record demonstrates offshore units at the base, progressively overlain by shoreface, foreshore, backshore and coastal dune deposits at the top.

12.2 DEPOSITIONAL MODEL

The offshore environment is characterised by fine-grained, horizontally laminated sand, dominated by biogenic structures of Facies H (Ha in Figures 29 and 30) (Hunter *et al.*, 1979). This is overlain by parallel bedded, near-horizontal laminated, fine- to medium-grained bioturbated sand of the transitional zone (Facies G) deposited during conditions of fast-flowing currents or from clouds of suspended sediment (Galloway and Hobday, 1983). The lower-shoreface, between the storm and fairweather wave base (Rahmani and Smith, 1988), is dominated by low-angle crossbedded fine- to medium-grained sand with horizontal burrows of Facies G (Figures 29 and 30). The upper-shoreface, lying between fairweather wave base and low tide, is under the influence of longshore currents and rip currents, responsible for the crossbedding, low-angle crossbedded and trough-crossbedded units of Facies E and D (Howard and Reineck, 1981) (cf. Plate 56). Herringbone-crossbedded calcarenite (Facies D) is indicative of tidal conditions in the lower-foreshore and upper-foreshore environments (De Raaf and Boersma, 1971), or of complex bar geometry on an intermediate beach (Reineck and Singh, 1980).

During storms single-clast layers of cobbles and pebbles (Facies Ba) are deposited in the upper-shoreface and lower-

foreshore. The up to 1,5m-thick gravel units contain basal clast and shell lags (Facies Bb), grading up into crossbedded and parallel-laminated calcarenite (Facies D). These washout deposits formed during periods of net sand removal during high-energy conditions (Kumar and Sanders, 1976). Discoidal clasts of shale and calcarenite (cannibalised Bokkeveld and Bredasdorp rocks) are formed during swash and backwash processes in the intertidal zone of the foreshore environment in rocky sectors of the coast (Reineck and Singh, 1980).

Discoidal clasts with well-developed seaward-dipping imbrication are observed near the high-water mark, the more spherical clasts occurring near the low-water mark (Galloway and Hobday, 1983). Storm and fairweather conditions in the upper-foreshore and lower-backshore are responsible for the cyclic calcirudite/conglomerate/shelly gravel and calcarenite units of Facies C (Figures 29 and 30). Evidence of a regression is evident from the northward-thinning and pinchout of Facies C exposed in the De Hoopvlei section (Profile DH VI, Unit 7 in Figure 10g).

Pebble, cobble and boulder deposits (Facies Aa and C) are present on the lower-backshore with upward-fining gravel units, up to 2m-thick, deposited in the upper-foreshore environment (Facies C) during storms (Hunter *et al.*, 1979). Strong rip currents transport gravel to the lower-shoreface, where channels are cut into foreshore and upper-shoreface sediments. This can be seen where Facies Ab (Unit 7, Figure 10h) eroded into the trough-crossbedded Facies E (Unit 6, Figure 10h) (Plate 61). Older Bredasdorp Group sediments (calcretised strandline deposits) are eroded by wave processes and reworked as intraformational cannibalised clasts e.g. Units 2, 4, 7 and 8 in profile DH III, Figure 10d; Units 2 and 4 in profile DH V, Figure 10f and Plate 9 (Strasser and Davaud, 1986). Planar low-angle, seaward-dipping, parallel laminations and low-angle discordances form under wave swash and backwash processes

are the dominant sedimentary structures of the upper-foreshore environment in Facies F (Harms *et al.*, 1975; Balsley, 1988).

Facies G (bioturbated, laminated calcarenite) forms a critical facies in developing the depositional setting of the De Hoopvlei and Klein Brak Formations. In the basal parts of the Rooikrans section along the Sout River, there appears to be clear evidence of a transgression where shoreface deposits are overlain by transitional deposits (Unit 1, Facies A (Plate 8) overlain by Unit 2, Facies G in profile RK IV, Figure 11e). This transgressive phase was followed by a regression, transitional sediments being overlain by upper-shoreface and foreshore sediments (i.e. Facies H overlain by Facies C, E and F in profile DH VII, Figure 10h, Plate 61 and Facies G and H overlain by Facies D, E and F in profiles DH I and DH II, Figures 10b and 10c).



PLATE 61 Bioturbated transitional zone sediments (Facies H) overlain by shoreface (Facies C and E) and then by foreshore (Facies F) sediments in profile DH VII along the eastern part of De Hoopvlei (Figures 10a and 10h). Possible rip-currents eroded and formed pebble filled channels in the shoreface (Facies Aa).

The upper-backshore environment is characterised by low-angle, landward-dipping, planar crossbedding (cf. Figure 3, Mee and Shone, 1989) indicative of a back-barrier complex (Facies Fa). Bimodal bipolar palaeocurrent patterns from trough-crossbedded (Facies E) and herringbone crossbedded (Facies D) units indicate a possible barrier inlet (Figure 29). Intensely bioturbated siltstone and fine-grained sand (Facies Hb) are indicative of a back-barrier lagoonal environment; possible washover fans (Facies Fb) were observed in profile DR I near Vermaaklikheid (Units 3 to 8, Figure 13b). In summer the lagoon or estuary could be closed, only to be opened when winter rains force the barrier to be breached (cf. Bot Estuary; Rogers, 1985). Silt, mud and organic material such as reeds and plant material can accumulate in the back-barrier swampy environment (Facies L).

The environmental setting of the estuarine part of the De Hoopvlei and Klein Brak Formations is possibly comparable with the modern-day Keurbooms Estuary. This estuary lies on a wave-dominated, microtidal coast; the lower estuary contains a back-barrier lagoon separated from the sea by a coastal barrier (Reddering, 1983). Lateral migration of the tidal inlet (southwards for the Keurbooms) leaves an imprint on the beachface and backshore environment.

During dryer periods, and during regressions, the organic-rich swamps are overlain by migrating back-barrier coastal dunes of Facies J. During wetter periods these dunes were partly vegetated and stabilised, forming optimal conditions for the development of soil profiles (Facies K, Plates 50 and 59). In the absence of back-barrier bars and lagoons, shallow backshore lagoons form during storm or spring-tide conditions, mainly in the winter, on the upper backshore (cf. the modern Noordhoek beach). These restricted water bodies could be colonised by organisms responsible for short-lived periods of intense bioturbation (Facies Hb). The

backshore environment could then be overlain by beach gravel brought in by high-energy breakers during storms and spring-tide periods.

This highly dynamic coastal environment with sub-environmental zoning (offshore, transitional zone, shoreface, foreshore and backshore) developed parallel to the coast, can be disrupted by short-lived high-energy storms, which are most effective during spring-tides. These stormy periods of intense concentration of energy temporarily disrupt the shore-parallel fairweather zones.

"Then God said, "Let the water beneath the sky be gathered into oceans so that the dry land will emerge". And so it was. Then God named the dry land "earth", and the water "seas".

(Genesis 1:9 and 10)

CHAPTER 13. PALAEOSETTING OF THE BREDASDORP GROUP

13.1 INTRODUCTION

In order to understand the depositional history of the different units of the Bredasdorp Group, it is necessary to review Southern African sea-level fluctuations during the Cainozoic.

The subject of sea-level changes throughout geological time has long aroused interest from scientists all over the world. Changes in mean sea-level have been invoked to explain geological phenomena since the days of Hutton in the eighteenth century. The sea may either rise relative to the land (marine transgression) or fall (regression), and the timing and magnitude of these changes can be estimated from the following (cf. Fairbridge, 1961 and Russell, 1968):

- 1) Movements caused by plate tectonics on a global scale (tectono-eustatic changes).
- 2) Volume changes of spreading ocean ridges and ocean basins (tectono-eustatic changes).
- 3) Changes in the volume of the polar terrestrial ice-caps (glacio-eustatic changes).
- 4) Local uplift or subsidence of a subcontinent (isostatic changes).

The global tectonically controlled eustatic sea-level changes were characteristic of the Cainozoic era until the Middle Miocene (Pitman and Golovchenko, 1983). Thereafter, the principal controlling factors were 1) changes in the volume of the polar ice-caps, which either withdrew from or added to the oceans large quantities of water, and 2) local isostatic uplift or subsidence, causing exposure or flooding of the coastal zone (Guilcher, 1969). Glacio-eustatic sea-level changes were generally of lower amplitude

than those tectonically controlled (Partridge and Maud, 1988), but they occurred with greater frequency: Milankovitch cycles being 100 000 years on average (Pisias and Imbrie, 1986), and some Late Quaternary cycles being as short as 10 000 years (Hendey, 1983; Deacon, 1987).

13.2 SOUTHERN AFRICAN CAINOZOIC SEA-LEVEL FLUCTUATIONS.

Numerous authors have discussed the problem of Tertiary and Quaternary sea-level movements around southern Africa and several sea-level curves have been constructed; in order to compare these curves, several were selected and redrawn at the same scale.

A first regional overview of Tertiary sea-level fluctuations (Dingle, 1971) listed evidence of several major regressive-transgressive cycles recognised in seismic profiles of Tertiary strata on the Agulhas Bank. Dingle (1971) dated the transgressions as Late Palaeocene and Middle Eocene and a major regression at the end of the Eocene. Siesser and Dingle (1981) reinterpreted these data and published the first sea-level curve for Southern Africa (Figure 31a). With the addition of Hendey's (1981) information, a curve spanning the Late Cretaceous and Tertiary was published by Dingle et al. (1983) (Figure 31b). Hendey (1983) gave a diagrammatic representation of the sea-level fluctuations during the entire Cainozoic Era (Figure 31c).

For the present study, new information from the west coast (Pether, 1986) (Figure 31d), south coast (Malan, 1987a) (Figure 31e) and east coast (Le Roux, 1989) (Figure 31f) were combined with the earlier results and compared with a worldwide sea-level curve of Haq et al. (1987). These results were used in order to construct a revised sea-level curve for the Southern Cape area. Following earlier authors (Siesser and Dingle, 1981; Tankard et al., 1982; Partridge and Maud, 1988), it is not implied here that the

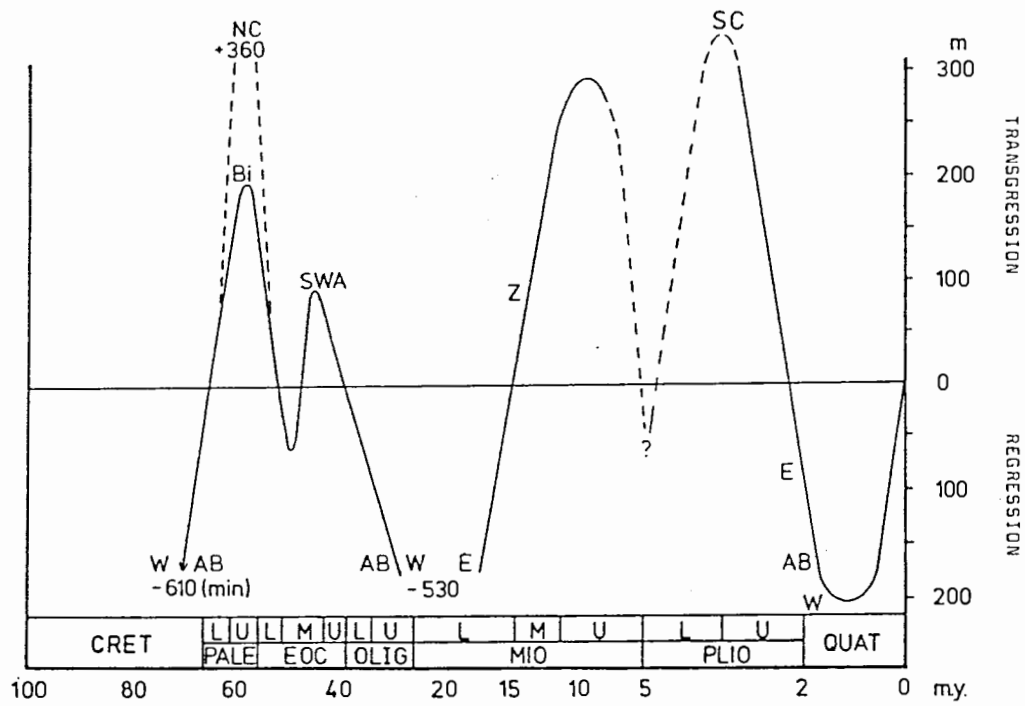


Figure 31a. Sea-level curve from Siesser and Dingle, 1981.
 AB Agulhas Bank, W West Coast, Bi Birbury, NC Needs Camp,
 SWA Namibia, Z Zululand, SC South Coast, E East Coast

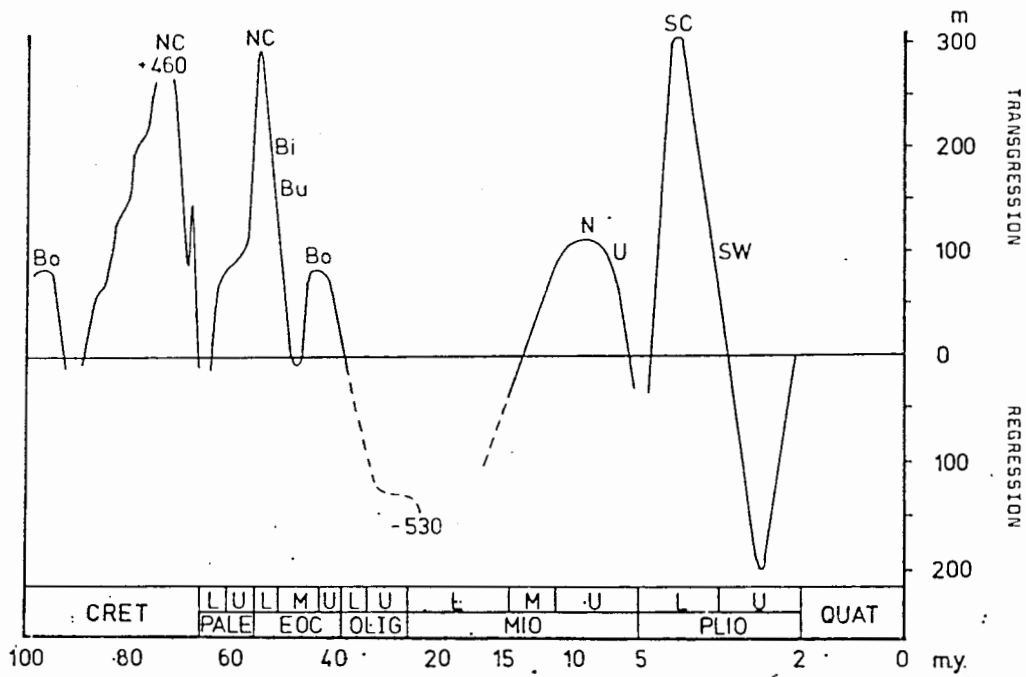


Figure 31b. Sea-level curve from Dingle *et al.*, 1983.
 Bo Bogenfels, NC Needs Camp, Bi Birbury, Bu Buntfeldschuh
 N Needs Camp, U Uloa, SC South Coast, SW Southwestern Cape

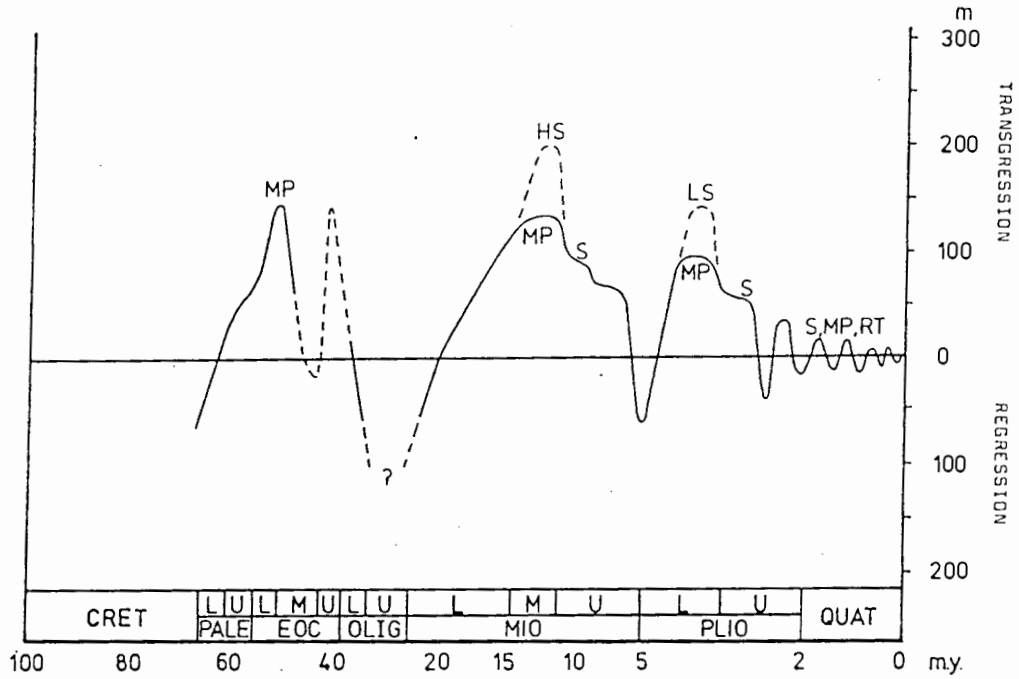


Figure 31c. Sea-level curve from Hendey, 1983.
 MP Marine Platform, HS Higher Swartland Surface, S Shoreline,
 LS Lower Swartland Surface, RT River Terrace

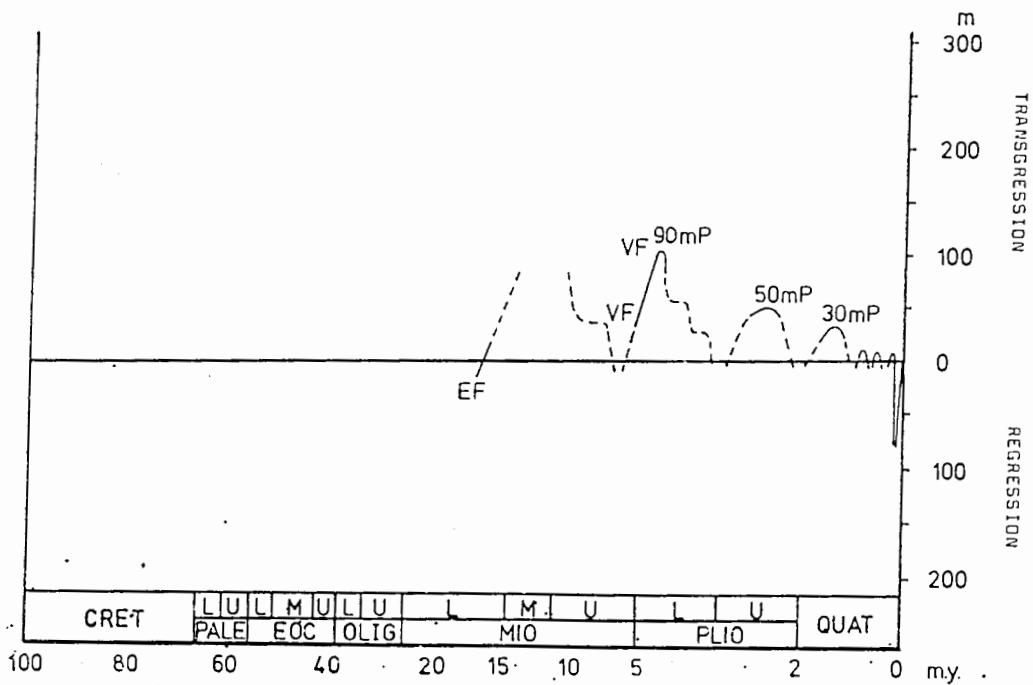


Figure 31d. Sea-level curve from Pether, 1986.
 EF Elandsfontyn Fm, VF Varswater Formation, 90mP 90m Package,
 50mP 50m Package, 30mP 30m Package

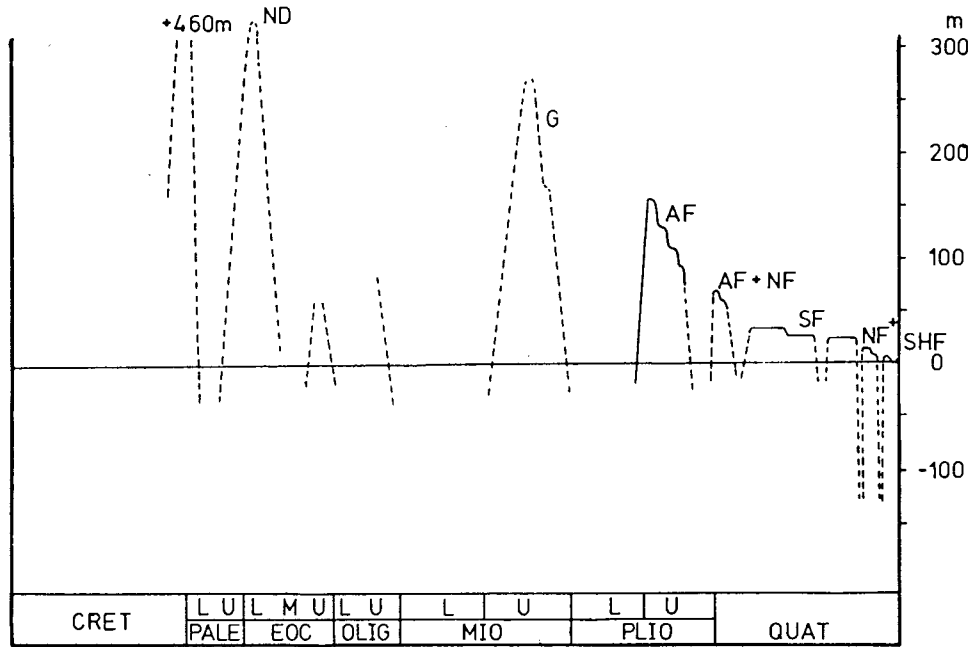


Figure 31e. Sea-level curve from Le Roux, 1989.
 ND Needs Camp, G Grassridge Platform, NF Nanaga Frm, NF+ Nahoon Frm, AF Alexandria Frm, SF Salnova Frm , SHF Schelm Hoek Frm

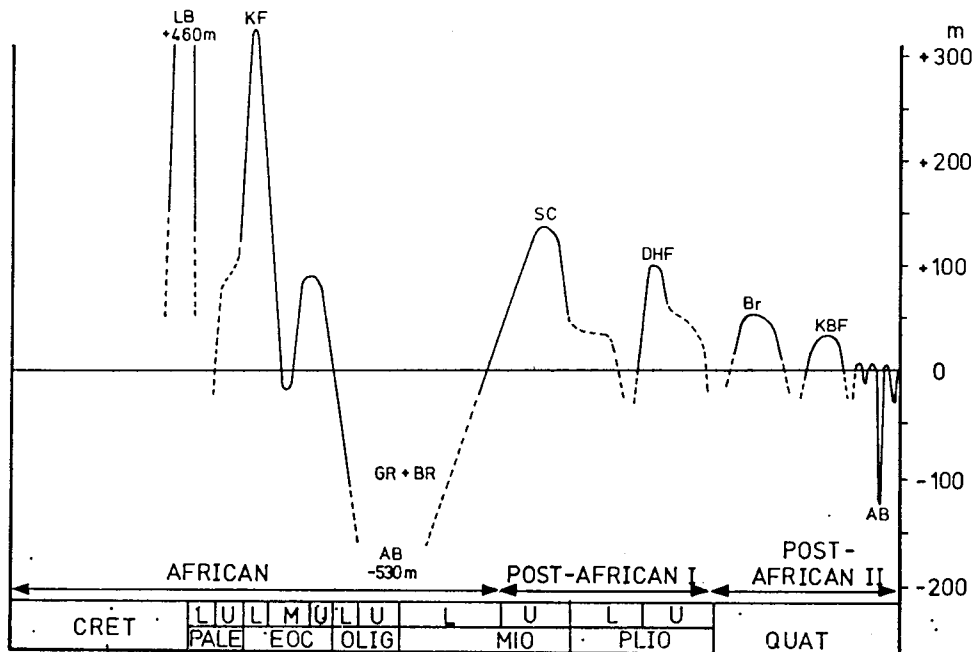


Figure 31f. Sea-level curve from Malan, 1987.
 LBM Langeberg Mountains, KF Knysna Formation, GR Gourits River, BR Breede River, AB Agulhas Bank, SC South Coast, DHF De Hoopvlei Frm, Br Bredasdorp, KBF Klein Brak Frm.

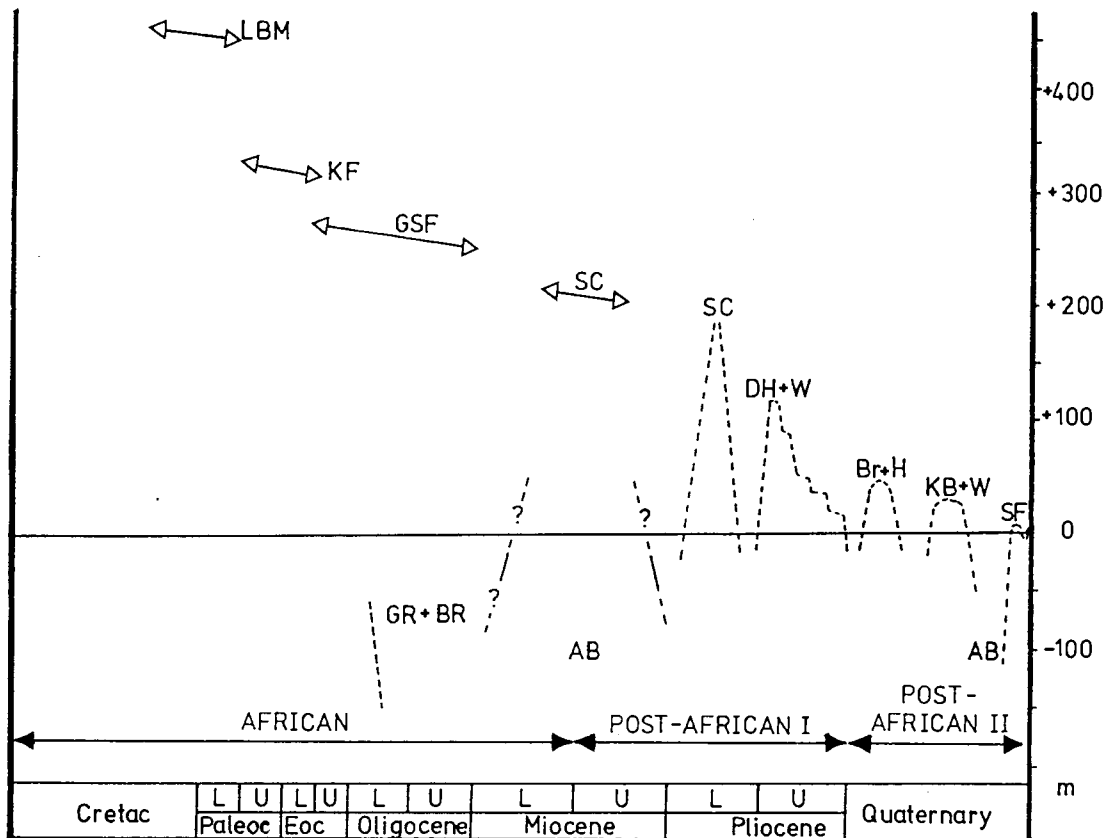


Figure 32. Relative sea-level curve for the southern coast, Cape Province.

- LBM Subaerially formed pediplain reaching the foothills of the Langeberg Mountains.
- KF Terrestrial Knysna Formation deposited on the 260–320m pediplain.
- GSF Development of the Grahamstown Silcrete Formation.
- GR+BR Incision of the Gourits and Breede Rivers.
- AB Eroded marine strata observed on the Agulhas Bank.
- SC South Cape coastal plain.
- DH+W Deposition of the De Hoopvlei and Wankoe Formations.
- Br+H Bredasdorp and Hermanus terraces.
- KB+W Deposition of the Klein Brak and Waenhuiskrans Formations.
- SF Deposition of the Strandveld Formation.
- ◄—► Subaerially planed surface. --- Surf-eroded surface.
- ◄—► Erosion cycles (Partridge and Maud, 1987).

cycles of Cainozoic sea-level changes outlined above are controlled solely by eustatical, but that some of the fluctuations may have been the result of local isostatic imbalances.

In the Late Pliocene a major asymmetrical uplift of the subcontinent, including monoclinical warping along the southeastern and eastern coastal margins, is postulated (Partridge and Maud, 1987). Tectonism has continued on a reduced scale throughout the Pleistocene with different effects on the coastal zone of southern Africa (McMillan, 1986). Local uplift or subsidence may have caused one area of the coast to emerge or submerge slightly earlier than another.

13.3 DEPOSITION OF THE BREDASDORP GROUP.

Well-developed elevated planation surfaces fringing the coastal mountain ranges of the Langeberg, Aasvoëlberg and Potberg are among the most striking features of the Southern Cape coastal scenery (Taljaard, 1949). These surfaces, traced seawards, show distinctive relationships with the Neogene marine and aeolian Bredasdorp sediments. In order to understand the deposition of the Bredasdorp Group it is necessary to review the geomorphic evolution of the Southern Cape coastal plain.

13.3.1 Cretaceous Period

Since the Mesozoic the fluctuation of sea-level caused by isostatic or eustatic movements has been the dominant process in shaping the Southern Cape Coastal plain (Hendey, 1983). The oldest peneplane ("African erosion surface"), dated as Late Cretaceous (Dingle *et al.*, 1983), reach the foothills of the Langeberg Mountains (at a present-day elevation of 460m) (Partridge and Maud, 1987). The Late Cretaceous date is based on microfossiliferous Campanian to Maastrichtian sediments at present situated above 330m at Needs

Camp, near East London (King, 1962; Dingle, 1971; Maud *et al.*, 1987), which may have been deposited by a marine transgression up to 460m above present sea-level (Dingle *et al.*, 1983). The polycyclic "African" erosion cycle was initiated by the breakup of Gondwanaland and persisted until its termination in the Early Miocene (Partridge and Maud, 1988).

Planed terraces associated with silcrete and gravel could represent this erosional period to the south of the Langeberg Mountains (Figures 5 and 17). In the Southern Cape this surface is characterised by deeply weathered (kaolinised) soil profiles consisting of Palaeogene silcrete (Grahamstown Formation) and gravel. This surface is the same as the subaerially planed "African" surface of King (1962) and, where it survives, it is characterised by a duricrust capping of silcrete and a deeply weathered (usually kaolinised) underlying profile (Plates 62 and 63). No evidence of any marine deposition could be found on this beveled surface in the Southern Cape area. Micropalaeontological data gathered from offshore boreholes drilled by Soekor suggest that this surface must have been planed by subaerial processes. The succeeding regression, at the Cretaceous-Tertiary transition, was probably accompanied by major incision of the local rivers (proto-Gourits and proto-Breede).

13.3.2 Palaeogene Period

A subsequent transgressive/regressive cycle occurred in the Late Eocene to Early Oligocene (Siesser and Dingle, 1981); no Southern Cape (Bredasdorp Group) deposits seem to be related to this cycle. However, the non-marine sand, silt, clay and lignite of the Knysna Formation (Hendey, 1983) were possibly deposited during the Eocene transgression at elevations of 320m and 260m at the foothills of the Outeniquaberg farther to the east (Thwaites and Jacobs, 1987). Pollen evidence suggests an age for the Knysna lignites of at least Middle Tertiary, possibly Middle Eocene (i.e. approximately 45 Ma)



PLATE 62. Silcrete capping of the Grahamstown Formation, forming hill tops (shown by arrows), indicating the "African" surface in the vicinity of Wydgeleë, east of Potberg (Figure 3).

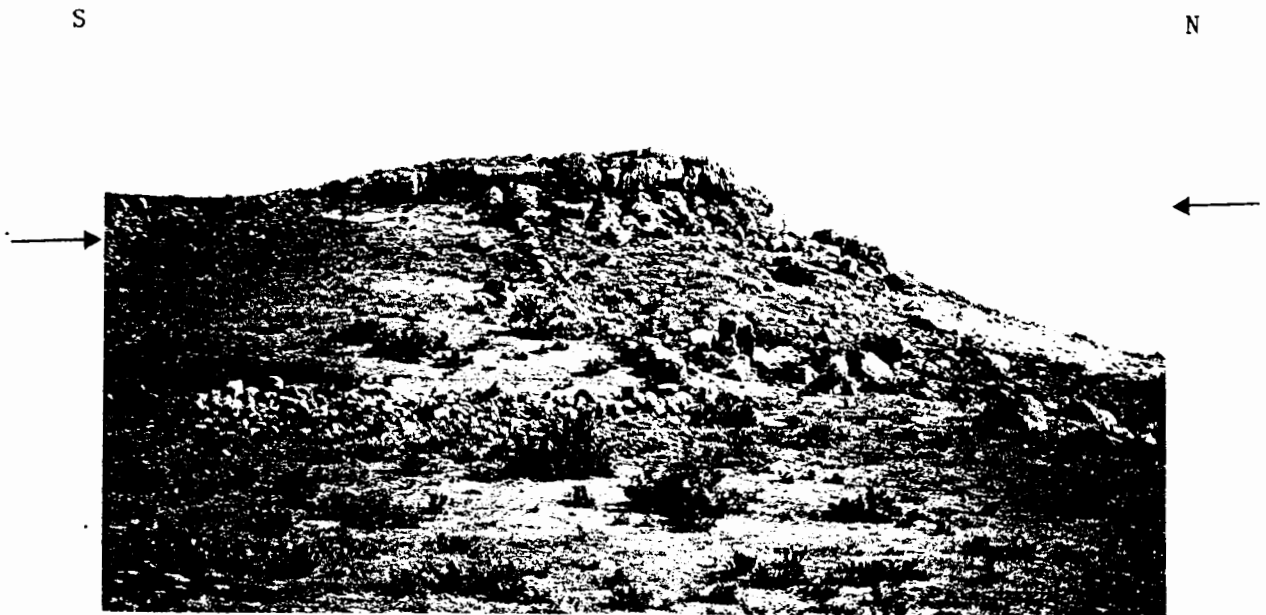


PLATE 63. Southward-dipping silcrete cap 12m thick on the "African" surface, north of Wydgeleë (Figure 3) (Arrows indicate the southerly dip).

(Coetzee *et al.*, 1983), but also Miocene (Jacobs and Thwaites, 1988). An episode of silcrete formation took place sometime during the Palaeogene, an association of thick silcrete and deep kaolinisation being considered as possibly of Early Tertiary age (Mountain, 1980; SACS, 1980). However, Lambrechts (1983, p. 66) states in his discussion of the soils of the fynbos region "All these silcretes are thus Pliocene and older".

13.3.3 Neogene Period

A major regression to 530m beneath present sea-level is the feature of the Oligocene period (Dingle *et al.*, 1983), the proto-Gourits and proto-Breede Rivers incising their courses deeply into the coastal plain (Hendey, 1983) (Figure 33). Early Miocene uplift in the eastern Cape terminated the "African" cycle of erosion and initiated the "Post-African I" erosion cycle which lasted to the end of the Pliocene (Partridge and Maud, 1987).

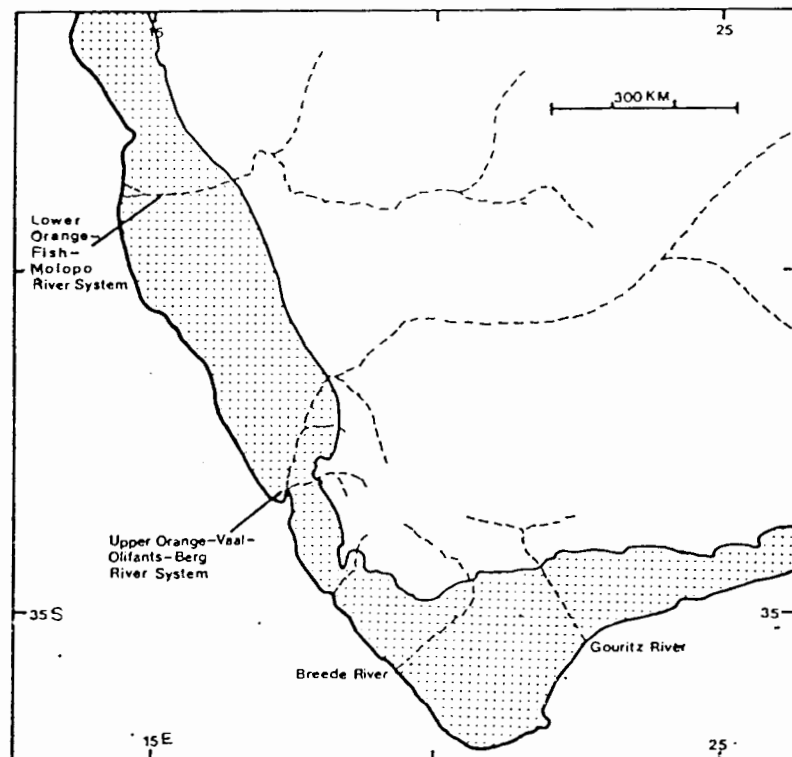


FIGURE 33. Drainage systems in southwestern Africa during the early Tertiary. The shoreline indicated is that which existed at the time of the maximum regression during the Oligocene (From Hendey, 1983, Figure 5).

The southernmost part of the platform along the Southern Cape is considered to belong to the "Post-African I" erosion cycle. The difference in elevation between the higher-lying "African" erosion surface (associated with the Grahamstown Silcrete Formation) and the lower-lying "Post-African I" erosion surface is clearly visible at Van Riebeeckshoogte along the N2 road between Heidelberg and Riversdale (Malan and Viljoen, 1990, Figure 1). The "Post-African I" erosion surface coincides with the Middle Miocene transgression which reach a maximum elevation of 140m above present sea-level in the Heidelberg/Riversdale area (Figure 17). Well-rounded Table Mountain quartzite boulders and cobbles, derived from possible remnant pre-Bredasdorp deposits, are found between the Kafferkuils and Duiwenhoks Rivers. This surface can be traced southwards to the foothills of Potberg, where the relationship between the older "African" and younger "Post-African I" surfaces can be seen as the two different terraces (Figure 17) (Plate 64).



PLATE 64 The relationship between the higher "African" (A) and the "Post-African I" (PAI) surfaces along the northern slopes of Potberg (Figure 17). Person standing on the lower "Post-African I" surface.

Marker (1987) recognised a 120m to 140m bench in the George - Knysna area and Butzer and Helgren (1972) recorded a bench at 120m in the Knysna-Cape St Francis area. This probably corresponds to the Middle Miocene transgression and the related "Post-African I" erosion cycle. The Middle Miocene to Early Pliocene transgressive period was interrupted by a regressive pulse near the Miocene/Pliocene transition (Siesser and Dingle, 1981). The lack of unequivocal evidence for marine deposits on any of the above-mentioned surfaces may be due to the sea-level never reaching the present south coast area due to local isostatic control.

This deduction seems to be supported by evidence from Soekor boreholes drilled in the offshore Bredasdorp Basin between the Agulhas and Infanta Arches (Figure 1). Samples from borehole tops in the E-D and E-P areas, directly north of the Agulhas Arch, show clear evidence of only shallow-marine conditions for the Eocene and Early Miocene intervals. It is therefore difficult to envisage the sea reaching as far north as the present Southern Cape coastal plain, 150km to the north. This seems to be confirmed by data based on boreholes in the F-A, E-M area (60 to 70km due south of Still Bay, Figure 1) indicating shoreline environments for this time period. According to this argument all the pre-Langhian (Middle Miocene) surfaces south of the Langeberg Mountains were most probably formed by subaerial processes, not related to marine (surf) erosion (Figure 32).

Palaeontological evidence (cf. dated molluscs by Le Roux, 1986) indicates that the deposition of the basal part of the Bredasdorp Group, specifically the De Hoopvlei Formation, took place during the Pliocene regressive phase (Figure 32). Accepting that this regression was caused by a glacial episode, the resultant drier climatic conditions would have been accompanied by an increase in wind activity due to the distortion of the climatic belts (Hendey, 1983; Rogers *et al.*, 1990). These conditions could have been favourable for the formation of the Wankoe aeolianites as backshore

dunes and coastal dunefields when the sea retreated during the regression (Dingle et al., 1983). From a transgressive maximum of 120m, the Late Pliocene regression experienced several relatively long still-stands which probably account for several benches in the Port Elizabeth area (Le Roux, 1989). On the basis of micropalaeontological evidence in the De Hoopvlei Formation McMillan (1986) differentiates between an older part (Unit II) and a younger part (Unit IIA): this could be evidence that the Late Pliocene regression included at least two relatively long still-stands along the south coast.

The deposition of the De Hoopvlei and Wankoe Formations predates the latest phase of incision of coastal river systems such as the Kars, Sout, Duiwenhoks and Kafferkuils Rivers (Figure 32). Evident in all their valleys is the youthful incision of these drainage systems through the De Hoopvlei and Wankoe Formations. Subaerial exposure during the regressive phase allowed lithification to be completed by the solution of the aragonitic shells and reprecipitation of the solute as sparry calcite (Siesser, 1972); this must have promoted rapid lithification of the De Hoopvlei and Wankoe Formations prior to the Quaternary regressions causing the rock units to be well consolidated at the time of river erosion. Evidence of this is the steep, calcareous, interlocking spurs lining the banks of all the coastal rivers (e.g. Plate 1 and Figure 9).

The deep incision of the coastal platform by these rivers probably resulted from a Late Pliocene uplift introducing the "Post-African II" cycle of major valley incision (Partridge and Maud, 1987). Alluvial terraces occur at an elevation of about 45m above the present river level along both the Gourits and Breede Rivers. These river terraces probably predate Late Pliocene regression responsible for the last major phase of river incision.

The present-day topography of the Wankoe aeolianite is characterised by the striking elongate depressions of Canca se

Leegte, Grootkloof, Rietvlei and Wankoe (Figure 34) (Rogers, 1988). These closed depressions appear to be karst-related landforms called poljes: "In a wetter Pleistocene climate they were probably coast-parallel lakes; like Rietvlei east of Still Bay" (Rogers, 1988, p. 429). These features tend to be aligned fairly parallel to the present coastline and could have been former positions of the shoreline during stillstands of the Late Pliocene regressions. In the Alexandria area of the eastern Cape Le Roux (1989, p. 222) describes similar features as "... palaeo-beach ridges encountered on the Coega Plateau (often expressed due to karstic processes)..." (See also Marker, 1988 and Stear, 1987).

13.3.4 Quaternary Period

The terrace at 50m above present sea-level seen along the fringes of the coastal plain east of Bredasdorp (Coastal Vlakte in Figure 34) and around Mossel Bay could be dated as Early Pleistocene based on evidence given by Gribnitz and Kent (1989). They give probable ages for benches and terraces from Gough Island, considered by them as a good "measuring rod" for "shifts" in the surrounding sea. Gough Island (38 million year-old oceanic crust) qualified for the study because, lying far from plate junctions, it was regarded as tectonically stable (Gribnitz and Kent, 1989).

Evidence for a 30m shoreline can be seen at the back of the coastal platform at Hermanus and Kleinmond. This shoreline is considered by Tankard (1975) to be Early Pleistocene in age, with the 20m to 30m shoreline possibly dating from the Early to Middle Pleistocene (Figure 32). This is partially supported by Gribnitz and Kent (1989), who date the 30m, 15m and 12m benches of Gough Island as Middle Pleistocene. Evidence for Quaternary shorelines is recognised in the Bredasdorp/Agulhas area, where the Early Pleistocene transgression removed previously deposited sediments of the De Hoopvlei and Wankoe Formation up to a height of 35m above present sea-level on the Coastal Vlakte (Figure 34). Spies *et al.* (1963) drew attention to the development of the Coastal Vlakte between Bredasdorp and Potberg (Figure 34), where it appears that a

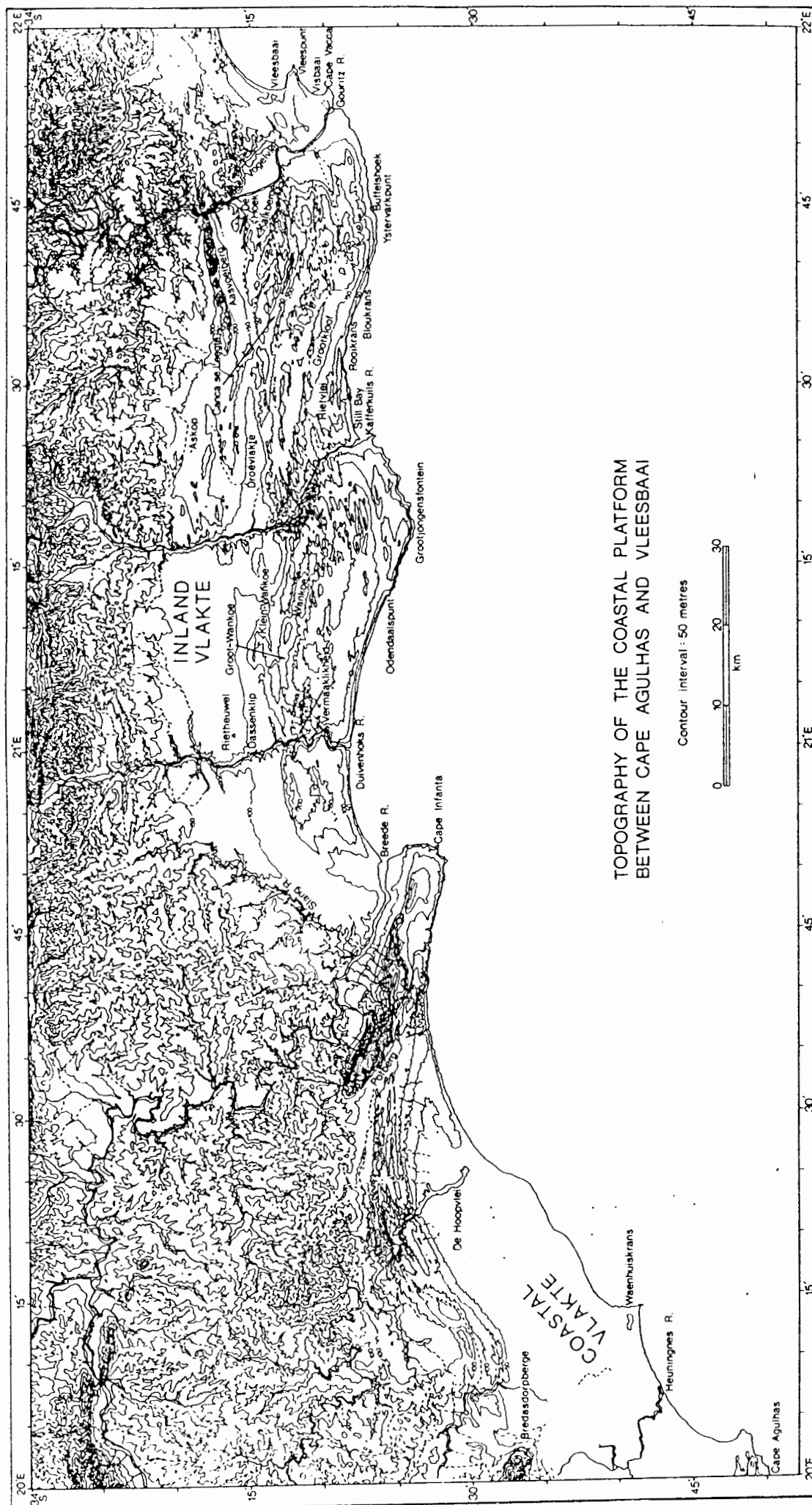


FIGURE 34. Topography of the coastal plain between Cape Agulhas and Vlees Bay. (Figure 1 from Rogers, 1988).

transgression eroded the older Bredasdorp sediments up to a height of 35m above present sea-level. Krige (1927) probably refers to the subsequent Pleistocene transgression responsible for the lower lying wave-cut bench at Hermanus as his "Major Emergence" (60ft = 18,3m) (See also Taljaard, 1949, Photo 15).

The Klein Brak Formation was deposited during the Late Pleistocene Eemian interglacial period (125 000 yBP) when the sea reached a height of 7 to 8m above present sea-level (Barwis and Tankard, 1983) (Figure 32). Krige (1927) ascribed the development of the 6 to 8m bevel to his "Minor Emergence" (20ft = 6m) (cf. Taljaard, 1949, Photo 14). During this period the lower reaches of numerous rivers were flooded and the deposition of estuarine deposits occurred along the left (south) bank of Kleinriviersvlei, near Hermanus, at Swartvlei and in the Hartenbos-, Klein Brak- and Groot Brak estuaries. During the subsequent Würm regression (20 000 yBP) to the -140m isobath (Dingle and Rogers, 1972) extensive areas of the exposed Agulhas Bank were under the influence of aeolian activity (Figure 35).

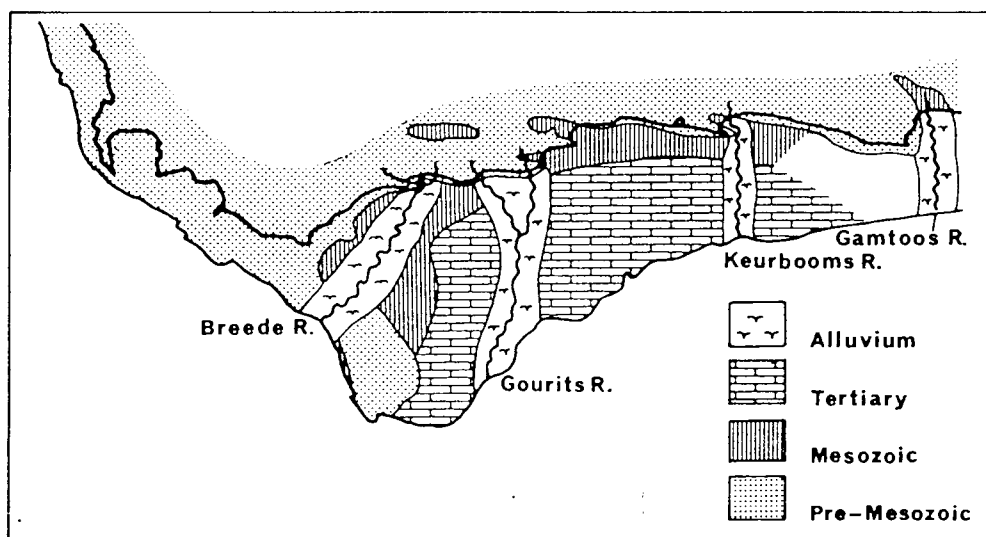


FIGURE 35. Palaeogeography of the Agulhas Bank showing the -140m isobath at the regressive maximum before the start of the Flandrian transgression at about 20 000 yBP (After Dingle and Rogers, 1972).

The Waenhuiskrans Formation formed during this period, but most of it was eroded during the following Flandrian transgression in the Early Holocene. The eroded remnants of the Waenhuiskrans aeolianites were recognised as submerged dune-cordon "stumps" on bathymetric charts off Wilderness (Martin and Flemming, 1987), between Still Bay and Gourits River mouth and offshore of De Hoopvlei (Lord, pers. comm., 1990). At the end of the Flandrian transgression (5 000 yBP) the sea rose 2 to 3m above present sea-level (Flemming, 1977; Yates *et al.*, 1986) (Figure 32) and formed a Holocene raised gravel beach up to 6,5m above sea-level in several places, notably at Waenhuiskrans; west of Cape Agulhas; east of Uilkraals River (east of Gans Bay); and westwards of the mouth of Gourits River to Ystervarkpunt (cf. Rogers, 1986, 1988).

Along the south coast unconsolidated mobile and unvegetated coastal dunes are extensively developed beside Walker Bay; at Renosterfontein (west of Cape Agulhas); between Struis Bay and De Hoopvlei; at Witsand (east of the Breede River mouth); Still Bay; Vlees Bay; and between Wilderness and Knysna. These Recent unconsolidated dune sands of the Strandveld Formation represent the youngest sediments of the Bredasdorp Group in the area.

13.4 CORRELATION WITH OTHER DEPOSITS

The Cainozoic deposits of the Southern Cape (Bredasdorp Group) can be correlated with the Algoa Group (Le Roux, 1989) of the Eastern Cape and the Sandveld Group (Hendey and Dingle, 1983; Rogers *et al.*, 1990) of the Western Cape. Marine and coastal deposits from the Eastern Cape are well documented (cf. Schwarz, 1908; Haughton, 1928 and Mountain, 1946).

The basal De Hoopvlei Formation is correlated with the Alexandria Formation (Le Roux, 1987) on the grounds of their mollusc content; height above sea-level; and distinctive assemblage of benthic

foraminifera (Unit II of McMillan, 1986). The aeolian Wankoe Formation is correlated with the Nanaga Formation of the Algoa Group in the Eastern Cape (Le Roux, 1989). The Pleistocene Klein Brak and Waenhuiskrans Formations can be correlated with the Velddrif and Langebaan Formations (Rogers, 1988; Rogers et al., 1990) of the Saldanha area along the west coast, and with the Salnova and Nahoon Formations (Le Roux, 1989) in the Eastern Cape. The youngest unit present in the Southern Cape, the Strandveld Formation of Holocene age, is correlated with the Witzand Formation of the Sandveld Group in the Western Cape (Rogers et al., 1990) and the Schelm Hoek Formation of the Algoa Group in the Eastern Cape (Le Roux, 1989).

It is now proposed that these groups should be called the "Coastal Limestone Supergroup" encompassing all the Cainozoic marine and marine-related (coastal aeolian) formations characterised by calcareous clastics along the South African coast (Wybergh, 1920, p. 46; Siesser, 1972, p. 179).

"Sea-level rise joins death and taxes as the
inexorable fate of mankind."

(W.S. Newman and R.W. Fairbridge, Nature 27.3.1986)

CHAPTER 14. CONCLUSION

The stratigraphy of the marine and coastal Cainozoic deposits of the Southern Cape has been consolidated on established lithostratigraphic grounds. Thus, four new formations (Wankoe, Klein Brak, Waenhuiskrans and Strandveld) were described and one existing formation (De Hoopvlei) redescribed and the all-encompassing Bredasdorp Group has also been defined. These units have been tentatively linked to the latest findings on Southern African sea-level fluctuations during the Cainozoic Era. However, the following points can be made regarding the Bredasdorp Group sediments and the Southern Cape coastal plain:

- 1) Correlation of raised beaches and other deposits, by determining their height above present sea-level and then tracing this height and its associated deposits along any coast, is too simplistic.
- 2) Although a comprehensive study of the Cainozoic marine deposits was undertaken, the aspect of local variations due to diastrophism received scant attention during the present study and should be pursued further.
- 3) More palaeontological work should be done in order to determine distinct zone-fossils and to reach finality on the age of the De Hoopvlei Formation.
- 4) More crucial dating of the onshore units should be undertaken.
- 5) Effective correlation of all the youngest marine sequences around the coast of Southern Africa should be undertaken.
- 6) These correlations should be related to more complete Pliocene and Quaternary sequences intersected on the upper continental slope.
- 7) Without all the above-mentioned data it will be impossible to construct a reliable sea-level fluctuation curve for the southern part of South Africa.

It should be stressed that certain aspects related to the Cainozoic geology of the Southern Cape coastal plain have not been investigated in this study, so that it is not yet possible to gain a complete picture of the geological evolution of this area. Several types of terrestrial deposits in the Southern Cape await further research and should include the following:-

- 1) The high-level silcrete and gravel of the Grahamstown Formation.
- 2) The Knysna Formation in the Saasveld area (Thwaites and Jacobs, 1987).
- 3) The iron-stained deposits of quartzose sand (possible Knysna Formation?) between the Duiwenhoks and Gourits Rivers (Rogers, 1988).
- 4) The river-terrace gravels of the Breede, Duiwenhoks, Kafferkuils and Gourits Rivers (Malan et al., in preparation).
- 5) Terrestrial terraces along the foothills of the Langeberg, Aasvoëlberg and Potberg Mountains (idem).
- 6) Thick accumulations of terrestrial clay and sand on the coastal plain west of Mossel Bay (Viljoen and Malan, in preparation).

"In Nature's infinite book of secrecy
A little I can read."

(Shakespeare: Anthony and Cleopatra)

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