THE MARINE GEOLOGY OF FALSE BAY

D. K. BOWIE
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BY

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ABSTRACT.

The marine geology of False Bay, lying in the southwestern extremity of the Southern African continent, has been investigated. The object of the study was to elucidate certain problems associated with marine terracing developed in the area and to describe the nature and distribution of sediments occurring on the floor of the bay with emphasis on the distribution as related to both bottom and surf current patterns.

In past literature reference has been made to raised beaches at elevations of 50 to 60 ft; 20 to 25 ft; and 10 to 14 ft. The writer has surveyed certain of these features and has shown that erroneous elevations have been quoted, resulting in inaccurate age designations.

Global dating of terraces, exposed and submerged, is discussed and applied to the features in the Bay, in an attempt to record their history. The oldest feature, the Gordons Bay boulder beach at approximately 100 ft. above mean sea-level, is dated by the writer as of Great Interglacial age. It is pointed out that the Stellenbosch river terraces, dated by A. Krige (1927) as Last Interglacial, can in no way be related to this period. Evidence is presented which suggests that the 50 to 60 ft., 20 to 25 ft. and 10 to 14 ft. terraces formed during the Main, Intra and Late Monastrian periods respectively.

The submerged terraces, identified from evidence supplied by divers and bathymetric profiles are dated as follows:-

-5 m. terrace	3,000 years B.P.
-11 m. terrace	7,000 years B.P.
- 25 m. terrace (?)	9,000 years B.P.
- 35 m. terrace	Pre Main Monastrian
	± 150,000 years B.P.

Calcareous sandstones, from the northern shores of False Bay, have been identified as beachrock and dated as of Intra - Late Monastrian age. The identification was assisted by the application of electron microscopy to the study of grain - surface textures and the replication procedure used, partly developed by the writer, has been set out in detail.

Ingram's (1965) method of megascopic examination was used for the classification of the sediments. The method enables one to rapidly determine the various components making up the sediments of the Bay. Facies maps thus derived give results in close agreement with maps produced from statistical data.

The statistical parameters, and a reported lack of $\frac{1}{4}$ mm. material from beach and shallow marine sediments, has been used to identify an ancient shoreline at approximately -45 metres. Material of the above size ($\frac{1}{4}$ mm.) is considered to have been winnowed from the site of this ancient shore, and to have built dunes in the region now lying at depths of from -35 m. to -25m. in the western sector of the Bay.

Bottom current patterns, interpreted from statistical parameters, show good agreement with surface currents determined by direct observation.

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(I) INTRODUCTION

The Sedimentary Laboratory of the Department of Geology, University of Cape Town, has over the past few years collected sediment samples off the coasts of the Republic of South Africa. The most comprehensive sampling programme was carried out in False Bay, where samples were collected primarily for ecological studies by members of the Department of Zoology. The sediments were handed to the Department of Geology for further investigation.

An interest in Marine Geology and the availability of unprocessed material already collected, influenced the writer to undertake this thesis.

(A) REGIONAL SETTING.

(1) Physiography

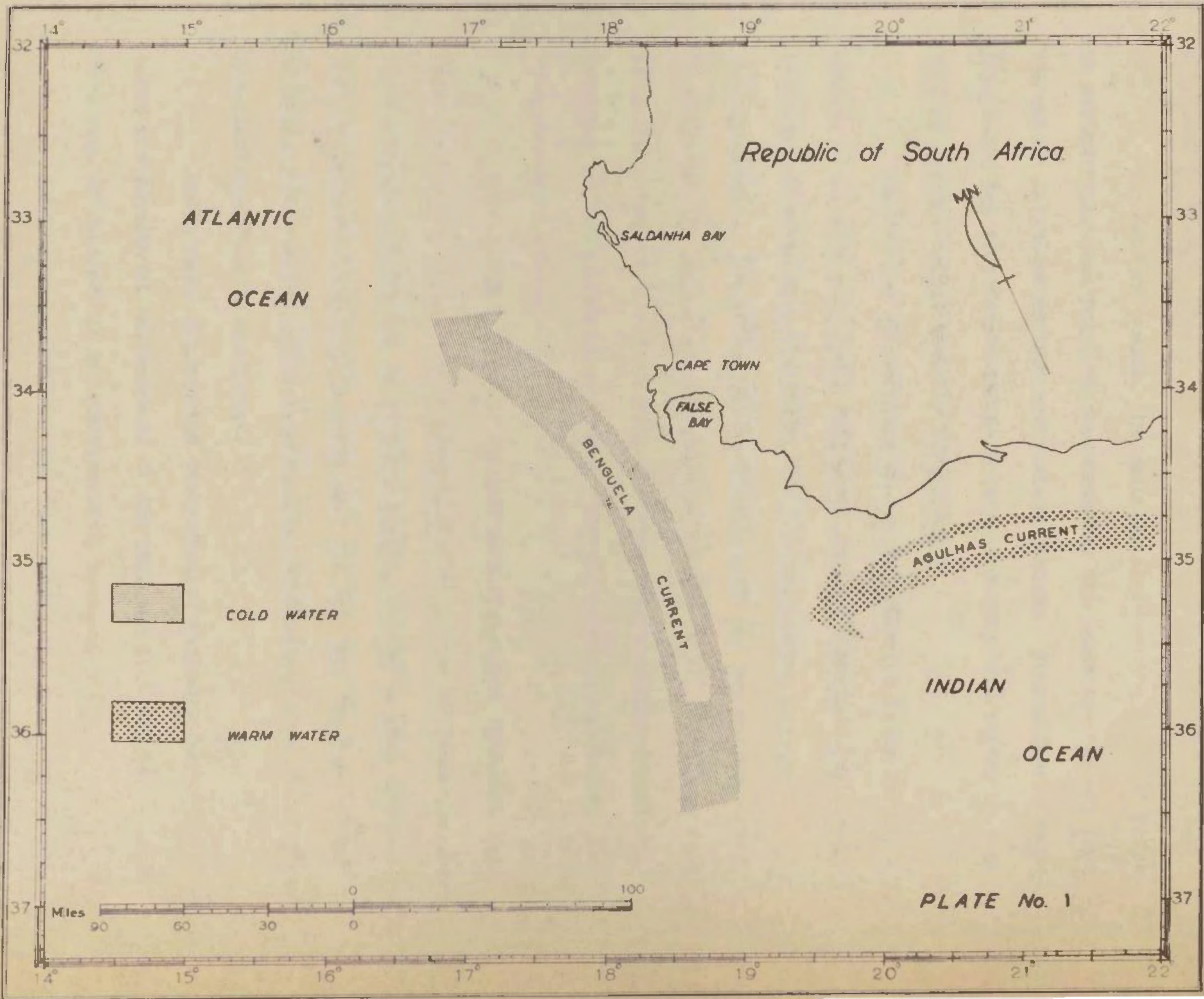
False Bay, lying approximately twelve miles south of Cape Town (Plate 1), is a well-defined bay, with a roughly square outline. The four 'corners' of the square (Plate 2) are Cape Point in the southwest, Muizenberg in the northwest, Somerset Strand in the northeast and Cape Hangklip in the southeast.

This area is demarcated geographically by the following lines of latitude and longitude:-

Lat.	$34^{o}05'$ South	$34^{o}22'$ South
Long.	$18^{o}26'$ East	$18^{o}50'$ East

PLATE I

Locality Map


Republic of South Africa
ATLANTIC
OCEAN
SALDANHA BAY
CAPE TOWN
FALSE BAY
MN
BENGUELA
CURRENT
AGULHAS CURRENT
COLD WATER
WARM WATER
INDIAN
OCEAN
Miles
PLATE No. 1

The position of the bay on the Marsden System is 442-2-~~47~~/48 (Duncan 1964, p. 18 & 19).

The Cape Peninsula, the westerly limit of the southern coast of Africa, with Cape Point as the southerly tip, cuts the bay off from the direct influence of the South Atlantic Ocean. Theoretically, therefore, False Bay lies in the Indian Ocean and should be affected by the Agulhas current rather than the Benguella.

The bay has no estuarine characteristics for it is large, 420 square miles, with only minor freshwater inflow. Numerous small mountain streams drain into the basin from the mountainous eastern and western shores. The inflow of fresh water into the bay during winter, is reflected in the surface isohaline chart (Plate 3). From this chart it appears that the Eerste and Lourens Rivers are the most important sources, the isohalines curving away from the northeastern corner due to fresh water inflow.

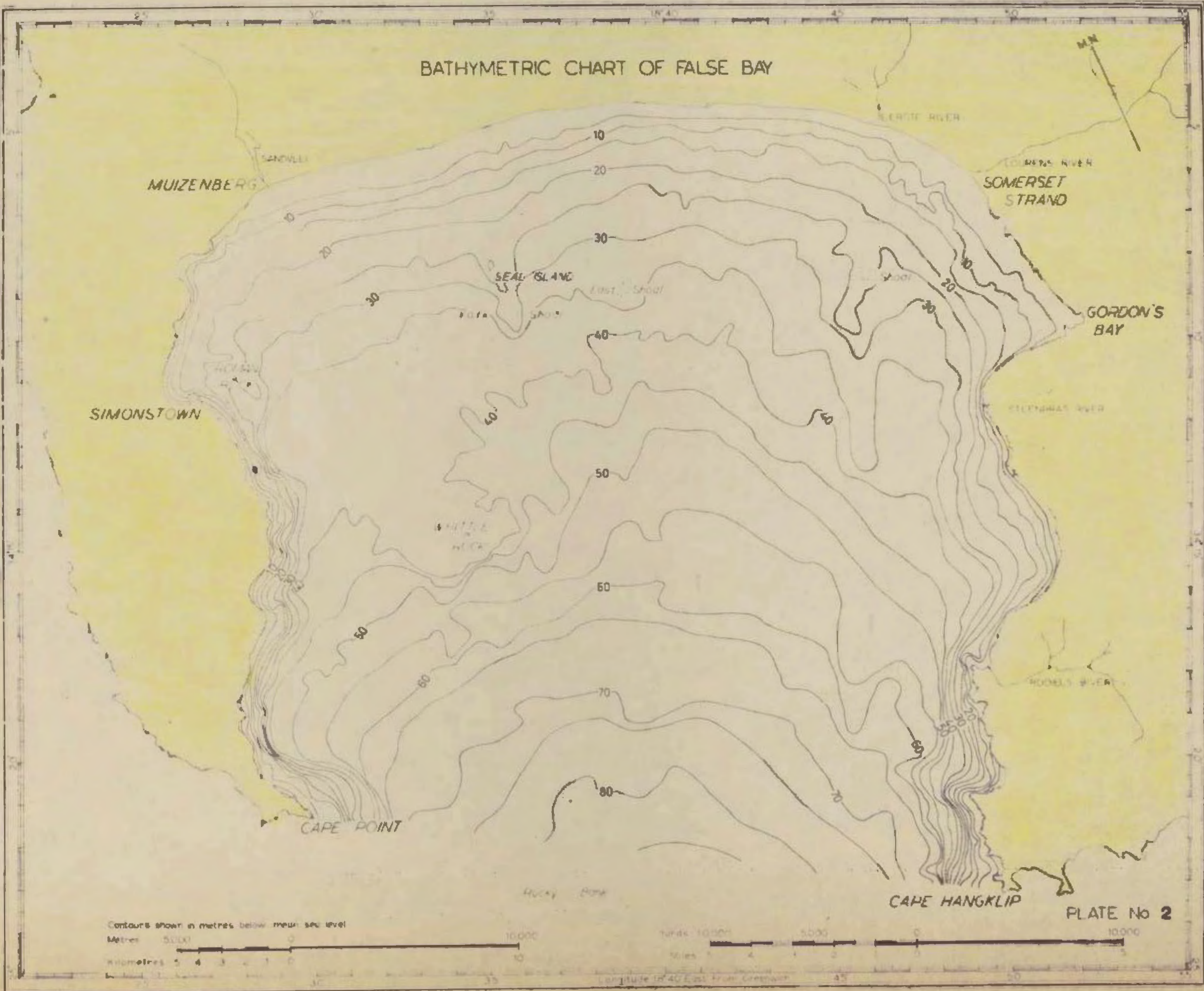
The southern limit of the bay is defined as a line from Cape Point to Cape Hangklip. The twenty-mile width of the entrance precludes classification of the bay as a marine lagoon, and it is best treated as part of the oceanic coastline where some shelter from the full effects of swell, storm and currents is afforded, particularly in winter, when the winds are from the northeast.

Rocky bank, a submarine topographical feature, forms an underwater obstruction at the entrance of the bay, and is a deterrent to the free flow of currents in the southwesterly section.

Other features of note are Seal Island and the rocky pinnacles known as Roman Rock and Whittle Rock (Plate 2). Three shoal areas, viz.

PLATE 2

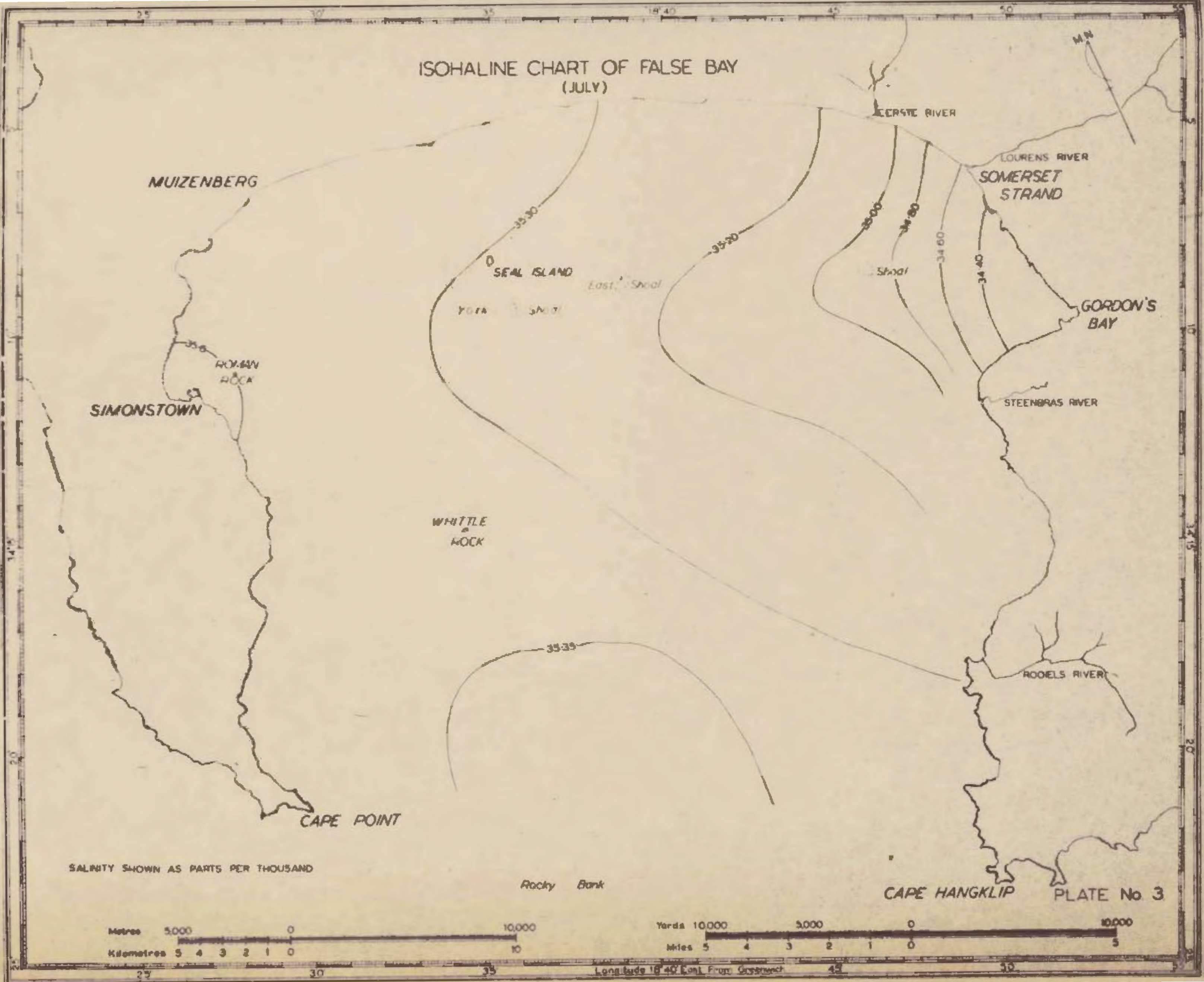
Bathymetric Chart of False Bay


BATHYMETRIC CHART OF FALSE BAY
M.N.
MUIZENBERG
SOMERSET STRAND
SEAL ISLAND
East Shoal
GORDON'S BAY
SIMONSTOWN
CAPE POINT
CAPE HANGKLIP
10
20
30
40
50
60
70
80
PLATE No 2
Contours shown in metres below mean sea level
Metres 5000 0 10,000
Kilometres 5 4 3 2 1 0 10
Yards 10,000 5000 0 10,000
Miles 5 4 3 2 1 0 5

SP.

PLATE 3

Isohaline Chart of False Bay (July)



ISOHALINE CHART OF FALSE BAY
(JULY)
MUIZENBERG
SEAL ISLAND
East Shoal
Shoal
EERSTE RIVER
LOURENS RIVER
SOMERSET STRAND
GORDON'S BAY
STEENBRAS RIVER
ROMAN ROCK
SIMONSTOWN
WHITTLE ROCK
ROOIELS RIVER
CAPE POINT
CAPE HANGKLIP
Rocky Bank
35·30
35·20
35·00
34·80
34·60
34·40
35·35
SALINITY SHOWN AS PARTS PER THOUSAND
PLATE No. 3
Metres 5,000 0 10,000
Kilometres 5 4 3 2 1 0 10
Yards 10,000 5,000 0 10,000
Miles 5 4 3 2 1 0 5
Longitude 18°40' East From Greenwich
M.N.

York Shoal, East Shoal and an unnamed area approximately 5.6 kms. southwest of the Strand, are marked by the white crests of breaking waves.

The marine chart, S.A. 4, False Bay, used for contouring the bay at five-metre intervals, shows that most areas are of moderate depth (Plate 2).

The area between adjacent contours was measured and is given as a percentage as shown below.

Depth range in metres.	Area in percent.
0-5	9.23
5-10	8.60
10-15	8.23
15-20	7.78
20-25	8.60
25-30	8.60
30-35	8.64
35-40	7.78
40-45	6.72
45-50	5.45
50-55	4.92
55-60	4.38
60-65	3.48
65-70	2.77
70-75	2.32
75-80	1.70
80-85	0.80

The principal physiographic regions bordering the bay are the

Cape Peninsula in the West, the Cape Flats in the North, and the Mainland to the East.

(11) Climate.

Although False Bay has a Mediterranean climate, rainfall differs considerably over the area. Cape Point and Cape Hangklip have an average annual rainfall of approximately 500 mm., whereas at Somerset Strand the average is somewhat in excess of 800 mm.

The temperature in the area ranges from 20°C. during January to 10°C. in July. The prevailing winds are southeast in the summer and northwest in the winter.

(111) Vegetation.

The natural vegetation of the land mass surrounding the bay consists entirely of what is known locally as Cape Scrub. The absence of grassland is a characteristic feature (Acock 1953). On the mountain slopes such vegetation as Sugar Bush (Protea Spp.) and Silver Trees (Leucodendrum Argenteum) are found. The inland valleys and planes are densely covered with a low bush or scrub, consisting mainly of Harpuisbos (Uryops tenuissimus), the Kapokbos (Eriocephalus umbellatus), and the Doringbos (Metalasia muricata). In those areas where man has upset the balance of nature, the Rhenosterbos (Elytropappus rhinocerotis) is usually dominant.

The common shrubs and bushes associated with the sand dunes of the Cape Flats are the Waxberry (Myrica cordifolia), the Dronkbos (Chymococca empetroides), the Kraaibos (Rhus crenata) and the Duinbos

(Mundtia spinosa), while, along the coast, one of the most characteristic bushes is the Witte melkhout (Sideroxylon inerme). Acacia and Eucalyptus have been introduced on the sand dunes as a means of binding the sand.

(B) PREVIOUS WORK AND SOURCES OF DATA.

The earliest record of bottom sampling in False Bay is that of H.M.S. "Challenger" in 1873, which was confined to Simons Bay. Moderately extensive research was carried out, with the emphasis on zoological data.

No further recorded samplings of the sediments was undertaken until 1946, when Professor Day and his associates in the Department of Zoology of the University of Cape Town initiated a sampling programme by dredging at various points within the area. The object of this initial survey was to determine the species of benthic fauna present, as well as their distribution.

F.T.C. Morgans (1956) used this material for a PhD thesis. He studied various sedimentary samples from False Bay, for the purpose of correlation between the sediments and the benthic organisms present.

The geology of the country surrounding False Bay was studied by S.H. Haughton (1933). More detailed studies of the Cape Peninsula include work by post-graduate students, (A.R. MacVicar (1963), W.J. van der Merwe (1963), G.C. Benfield (1964) and P.R.L. Browne (1963).) at the University of Cape Town.

Hydrographic information used in this work comes from the chart

S.A.4 False Bay. This chart was completed and published under the direction of Captain J.K. Mallory from soundings by Lieutenant W.A. Archdeacon (1869) and Commander J.C. Walters (1960/1).

Studies of currents, salinity and bacteriological data have been made in the area by the Effluent Branch of the University of Cape Town under the direction of G.R. Atkins.

Coastal and sedimentary shallow-water features have been investigated by the Sedimentary Laboratory, Department of Geology, under the direction of A.O. Fuller. Two papers covering various aspects of sediments in the intertidal, near-shore and beach environments have been published (Fuller 1961, 1962).

In a report entitled; "Progress report on the investigation of wave-cut terraces", to the Oceanography Department, University of Cape Town, I.D.M. Robertson (1964) briefly discussed diving operations carried out off Gordons Bay during January and February 1964.

(C) PHYSICAL FEATURES AND GEOLOGY OF THE SEDIMENT SOURCE AREA.

The most complete description of the geology surrounding False Bay is given by S.H. Haughton (1933, p.14). He lists the geological formations present as:-

Tertiary and Recent		Dune and beach sand
		Talus
		Alluvium
		Calcareous tufa
		Ironstone gravel
		Surface quartzites
		Older sands
		Marine clays
		Raised beach deposits
		High-level talus
		Older river terrace gravels
Cape System	Bokkeveld Beds	Lower Shales
	Table Mountain Sandstone	Upper sandstone
		Upper shales
		Glacial band
		Main sandstone
		Lower shales
Pre-Cape	Klipheuvel Beds	
	French Hoek Beds	
	Malmesbury Beds	
Igneous Rocks		Dolerite (Probably Karroo age)
		Granite (Just preceding the volcanics in the Malmesbury Beds)

PLATE 4

Geology of the False Bay Area

PLATE 4

Geology of the False Bay Area

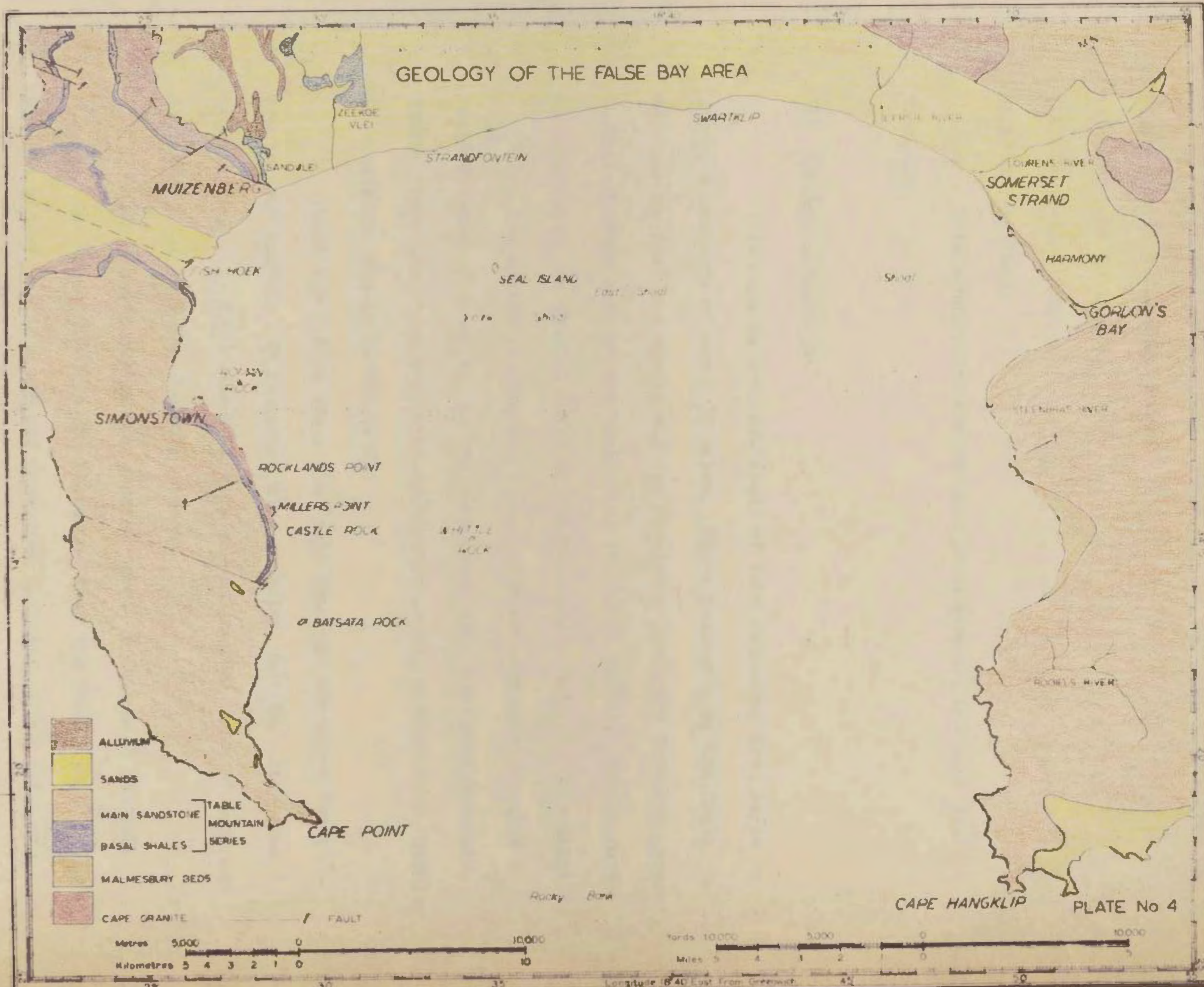

GEOLOGY OF THE FALSE BAY AREA
ZEEKOE VLEI
SWARTKLIP
STRANDFONTEIN
SANDVLEI
MUIZENBERG
SOMERSET STRAND
HARMONY
SEAL ISLAND
GORDON'S BAY
SIMONSTOWN
ROCKLANDS POINT
MILLERS POINT
CASTLE ROCK
BATSATA ROCK
CAPE POINT
CAPE HANGKLIP
ALLUVIUM
SANDS
MAIN SANDSTONE
BASAL SHALES
TABLE MOUNTAIN SERIES
MALMESBURY BEDS
CAPE GRANITE
FAULT
Metres 5,000 0 10,000
Kilometres 5 4 3 2 1 0 10

PLATE No 4

As previously stated, (page 3), the sediment source area can be physically subdivided into:-

(1) The Cape Peninsula.

(11) The Cape Flats.

(111) The Mainland.

This subdivision can be used in discussing the more general features.

(1) The Cape Peninsula.

This area is a narrow tract of land extending from north to south, a distance of about 33 miles. Rocks belonging to the Table Mountain Series form nearly all the prominent landscape features present. In the northern part of the Peninsula, the Table Mountain Series rests, unconformably, on denuded rocks of the Malmesbury Beds and Cape Granite.

The series is slightly folded into an open syncline with a northwest-southeast axis. In the Muizenberg area the Table Mountain Series forms the shoreline, whereas further south, at Fish Hoek, granite is exposed at sea-level (Plate 4).

Over the entire area, the Table Mountain sandstone forms precipitous cliffs. No important streams exist, but the minor ones present show juvenile characteristics and follow the lines of weakness offered by jointing and faulting present.

The faults follow the general trend of the joint pattern. W.J. van der Merwe (1963, p.75) suggests "that the faults in the area are not all of the same age but that they represent three different stages in the geological history of the area".

Two faults which could be important to the present work are those which strike from southeast to northwest, the first at Fish Hoek and the second at Smitswinkel Bay. Both are visible at sea-level.

Normal faults, with vertical fault planes showing no evidence of horizontal movement, are present. Due to overburden of sand and talus, little is known about the Fish Hoek fault, but it appears that the unconformable contact between the Table Mountain Series and the Cape Granite has been displaced vertically by an amount in excess of 200 feet to the south of the fault plane.

(11) <u>The Cape Flats</u>.

The Cape Peninsula is connected to the mainland by a broad sandy isthmus known as the Cape Flats. The sand cover, overlying Malmesbury Shales and Cape Granite, attains considerable thickness in places. Near the False Bay coast much windblown sand is present in the form of elongated dunes with a general alignment in a northwest, southeast direction.

Haughton (1933, p.41) differentiates between siliceous and calcareous sands in the area. The siliceous sands are sporadically developed, with a general occurrence to the west of the Cape Flats. These siliceous sands vary in colour from white to brown. Grain size varies from coarse to fine, with the coarse sand showing a greater degree of rounding than the subangular fine grains. The white sand rests on bedded brown sand, whose colour becomes progressively lighter with depth. Haughton (1933, p.42) suggests that these bedded sands probably owe their origin to lagoonal conditions.

The calcareous sands, containing the remains of both terrestrial gastropods and marine shells, cover large areas of the Cape Flats and occur along the northern coast of False Bay, from Strandfontein to Somerset Strand, as well as a considerable distance inland. To the northeast of Sandvlei calcareous sands with non-marine gastropods overlie similar deposits containing marine shells.

Percolating water has dissolved some of the carbonate present, and by evaporation has formed calcrete cappings over many of the dunes.

Silcrete and ferricrete have been reported from the western edge of the Cape Flats, but do not form a major feature.

(111) The Mainland.

The oldest beds present of Pre-Devonian age, the Malmesbury Beds, are exposed at Kogelbaai, Gordons Bay and Somerset Strand.

To the north of Gordons Bay the rocks of the above beds form low rolling hills. The hills are more prominent where granite masses outcrop together with the Malmesbury shales.

The eastern margin of the map (Plate 4) shows the more extensive succession of the Cape System present. The topography in this area is similar to that of the Cape Peninsula, only here the mountains reach a height of 4160 feet at Kogelberg, whereas in the southern sector of the Peninsula, Swartkop is the highest point, with a height of 2227 feet.

The southern part of the mainland area is drained by the Rooi Els and Steenbras Rivers. The Lourens River drains the northeast sector. It drains areas underlain by most of the rock types listed on page (7). Somewhat to the west of this, the Eerste River drains a large section of the country. The rock types of this area are mostly Malmesbury shales and granite.

Faulting on the Mainland coast is not prominent; only one small fault is shown by Haughton on the coastline near Kogelbaai.

(II) GEOMORPHOLOGY

(A) CLASSIFICATION OF THE COASTS.

To date the most significant published work on the geomorphology of False Bay is that by Krige (1927).

According to him (1927, p.4); "False Bay may be considered an anticlinal valley, where prolonged erosion has laid bare the Malmesbury Beds". He then classifies the coast as a type of Ria coastline, using the terminology of Johnson (1919, p.173). Thus Krige terms the shoreline one of submergence or partial submergence of a normally dissected and embayed plain, plateau or mountain shoreline. The use of the word "Ria" does not, in this instance, conform to the restricted meaning assigned to it (Holmes 1954, p.301).

According to Shepard's (1963, p.153) classification the coastline of False Bay may be termed a primary coast, having two facets:-

a) The Peninsula and Mainland coastline would be a Land Erosion Coast. That is, a coastline shaped by subaerial erosion and partly drowned by rise of sea-level or by downwarping.

b) The Cape Flats and Fish Hoek "Gap" as a Wind Deposition Coast. This is an unusual type, principally found in the tropics, where calcareous dunes have been lithified and drowned by rising sea-level. This type of classification is, to the writer, a more satisfactory one than that employed by Johnson. As Shepard points out (1963, p.166), all coasts of the world have been subject to fluctuations in sea-level in the Pleistocene. The words "submergence and emergence" as used by Johnson becomes ambiguous.

D.D. Smith (private communication) employs a classification which to the writer is even more satisfactory than Shepard's, and explicit in its application to the area under discussion. Using Smith's terminology, the Cape Peninsula and Mainland coastlines are termed Bedrock Dominated, and the Cape Flats would be Sediment Dominated. Krige, Mabbutt and Benfield (op. cit.) mention specific features of interest along the Bedrock Dominated coasts. Haughton mentions the same features on the Sediment Dominated coast of the Cape Flats.

Fuller, with the aid of Robertson (1964, p.6), showed that similar features can be found under the sea in the area.

The above features are:-

a) Raised Beaches

b) Submerged Terraces.

(B) PLEISTOCENE AND RECENT TERRACES.

Krige (1927, p.46) maintains that the fluctuations of sea-level, due to climatic changes during the Pleistocene, have irrevocably left their marks along the shores of False Bay. Mention of these eustatic sea-level fluctuations in False Bay is also made by Haughton (1933, p. 42), Breuil (1947, p.62), Gatehouse (1953, p.2) and Mabbutt (1954, p.17).

Krige reports that these higher stands of the sea are in evidence around the South African coasts. This evidence is in the form of wave-cut terraces, caves and river terraces. For the False Bay area he notes no less than 42 caves, 6 undercut ledges, and 4 tunnel caves and terraces at three different heights above sea-level. These terraces, he states, are at 50 to 60 feet above mean sea-level (Major Emergence), at 20 feet, (Minor Emergence), and a resting point at 12 to 14 feet, after the formation of the Minor Emergence terrace (1927, p.72). Mention is also made of a 7ft. "emergence" from evidence furnished by caves and under-cut ledges.

Haughton (1933, p.42) discusses the above raised beaches and describes a similar feature in the False Bay area as follows:- "East of Strandfontein, just opposite the islets, consolidated sands with land shells (Trigonephrus, etc.) crop out just below high-water mark. The upper surface of these is hardened and irregular, the material gradually hardening from below upwards until it becomes a hard crust often banded in a manner similar to that seen in the limestone crusts of the Cape Flats. This crust is hummocky and smooth. It is overlain by a raised beach some 2 to 3 feet thick, crowded with shells in layers alternating with bands of sand and comminuted shells, all prominently stained with iron. This beach material still fills hollows in the underlying rock, so that the hardening of the terrestrial deposit obviously preceded the deposition of the beach sediments. The marine bed is overlain by dunesand with Trigonephrus which itself has a hardened crust. The whole succession here is being denuded by presentday marine action".

The above features are clearly visible, but further indication of eustatic sea-level changes appear at the water's edge as well as underwater in False Bay. For instance, in the inter-tidal zone in the Somerset Strand - Gordons Bay area, where Malmesbury shales strike approximately parallel to the incoming waves, a rocky platform is exposed at low tide. This platform has been formed by the truncation of the steeply dipping Malmesbury Shales.

The area off the Harmony coast(± 8 kilometres west of Somerset Strand), has been investigated by skin divers who found a terrace at an approximate depth of 11 metres, as well as a possible terrace at a depth of 4.5 to 5.5 metres (Robertson 1964, p.6).

Diving operations carried out by students in 1966 have found undercutting or a cave-like feature, in granite, off Castle Rock at a depth of ± 12 metres.

To summarize: the known and possible marine terraces in and around False Bay, lie at one of the following elevations:-

Krige	Higher terraces recorded, but not discussed.		
Krige	50-60 feet.	15-18.5 m.	Major Emergence.
Krige	20 feet.	5.5 m.	Minor Emergence.
Krige	12 to 14 feet.	3.5-4.2 m.	Resting point prior to formation of Major Emergence.
Krige	7 feet	2 m.	
Haughton	6-8 feet	2 m.	The Strandfontein exposure.
	Exposed at low tide		Bench at Somerset Strand.
	-4.5 to 5.5 m.		Possible?
Robertson	-11 m.		Considered as one by the writer.
Student Divers	-12 m.		Considered as one by the writer.

Before discussing these features, a brief summary of the events during the Quaternary, as seen by certain of the foremost authors on the subject, will be given.

(C) INTERNATIONAL DATING OF THE QUATERNARY.

The dating of the base of the Quaternary, at the Plio-Pleistocene boundary, is not only uncertain but it is the subject of controversy.

The fact that different definitions of this boundary have been in use for the past century, leads to conflicting views (Flint, 1965, p.500). One definition is based on evolutionary differences between fossil flora and fauna; whereas the other is based on climatic change as indicated by the physical characteristics of strata.

The International Congress of 1950 defined the Pliocene-Pleistocene boundary on the basis of the first appearance of Anomalina baltica in the Mediterranean. According to Emiliani et. al. (1966, p.121)this would place the boundary between 1 and 2 million years B.P.

This boundary, (according to Zeuner 1958, p.134) was placed by Penck at 600,000 years B.P. He further quotes a figure, deduced by Rutten, as one million years before the present. Penck has based his date on the onset of the Gunz Glaciation as determined by varve counting. Rutten worked on sedimentation rates in an unglaciated area, Java.

The date of 660,000 years B.P., calculated from radiation curves produced by Milankovitch, is accepted by Zeuner (1958, p.145) as the date of the onset of the Gunz Glaciation.

After Penck and Rutten had suggested the above dates, Eberl (1930) found evidence of glacio-fluvial aggragation on the Danube, indicating an earlier glacial period than the Gunz, named by Eberl and Knauer (1942) as the Donau Phases; (Zeuner, 1958, p.116; Table I. p.18).

Emiliani (1955, p.570) states that, "all Pleistocene time since the beginning of the Gunz Glaciation appears to be about 280,000 years", but adds that the insolation curve preceding the minimum, at ± 280,000 years, tentatively correlated with the Gunz Glaciation, does show several pronounced minima which extend back for a million years or more. On this he bases an estimate of 600,000 years B.P. as the boundary.

The dating of a composite section of Globigerina-ooze led Ericson, Ewing and Wollin (1964, p.731) to claim that the Pleistocene extends back 1.5 million years.

Potassium-Argon dating of an early glaciation in the Sierra Nevada, California, by Everndon, Savage, Curtis and James, (1964, p.171) resulted in a date of 960,000 years B.P. Everndon and Curtis (1965, p.356) date the Villafranchian fauna of Olduvai Gorge, Tanganyika, at 1,750,000 years B.P. They claim that this places the Donau between 1,000,000 to 1,200,000 years B.P.

Flint (1965, p.526) gives a date of 1.5 million years as a tentative base for the Pleistocene, but adds, that more Carbon-14 and Potassium-Argon dates are required for the Pleistocene so that the boundaries can be fixed.

By definition the Pliocene should have no glaciers, even in high altitudes, thus the boundary must be near the 1.5 million year mark. Schwarzbach (1962, p.200) considers Emiliani's low dating to be due to extrapolation and hence not correct.

TABLE I.

	European Terminology	American Terminology	Classical Terminology
Holocene (Recent)	Divided separately	Page 36	
Upper Pleistocene	Würm III (Glacial)	Late Wisconsin	Last Glaciation
	Würm II - III (Interstadial)		
	Würm II (Stadial)	(Early (Wisconsin	
	Würm I - II (Interstadial)	(	
	Würm I Stadial	(	
	Riss-Würm (Interglacial)	Sangamon	Last Interglacial
Middle Pleistocene	Riss II (Glacial)	Illinoian	Penultimate Glaciation
	Riss I - II (Interstadial OR Interglacial)		
	Riss I (Glacial)		
	Mindel-Riss (Interglacial)	Yarmouth	Penultimate Interglacial
Lower Pleistocene	Mindel II (Glacial)	Kansan	Ante-Penultimate Glaciation
	Mindel I - II (Interstadial)		
	Mindel I (Glacial)		
	Günz-Mindel (Interglacial)	Aftonian	Ante-Penultimate Interglacial
	Günz II (Glacial)	(	Early Glaciation
	Günz I - II (Interstadial)	(Nebraskan	
	Günz I (Glacial)	(	
	Donau-Günz (Interglacial)		
	Donau Glacial		

Flint's (1965, p.18) statement best illustrates the point the writer wishes to make; "The identification of a Pliocene-Pleistocene boundary is perhaps the most conspicuous problem of Quaternary stratigraphy".

One further boundary, the Pleistocene-Recent, requires a definition with respect to the time period involved.

Fair (1943, p.13 and 22) uses the term "Recent" to include sea-levels during the Riss-Würm Interglacial. This loose use of the term conflicts with that of leading authorities.

Flint (1957, p.284) suggests that the term, "Recent" be used informally, in restricted areas, where an encroaching sea, from the melting of the final Würm Glaciation, is in evidence. This melting, he states, commenced 18,000 years B.P. This period of time agrees with Russell's (1957, p.420) conception of the Recent (Holocene) period.

Two other authors quote dates very much in keeping with the above. They are Fairbridge (1962, p.113) and Shepard (1963, p.268) who state that rapid melting of the ice began at 16,000 and 17,000 years B.P. respectively.

Investigation of the Jordan Graben of Israel has led Picard (1965, p.362) to call the Holocene, "a short period of 10,000 years".

Fray and Ewing (1963) as quoted by Bigarella and De Andrade (1965, p.448) show that lowering of sea-levels, from Carbon-14 dating, in the Rio do Sol area in the Argentine was at a maximum of -120 m., or perhaps as much as -150 m. prior to 35,000 B.P., and further that at 11,000 to 12,000 years B.P. the sea level was at 110 m. below the present. Thus rapid melting could only have started at 10,000 years B.P.

This low stand of the sea, at that time, does not correspond to any date produced by other authors. At the other extreme, Wright (1964, p. 629), claims the Recent should encompass the last 5,000 years only. But he does state that the sea-level had at that time reached the present level.

Reports from Denmark place the Holocene as commencing at 8,300 B.P. (Hansen 1965, p.56).

The writer feels that Picard's, 10,000 year span for the Holocene would be a good average figure to accept. Melting of the ice must have advanced to a considerable extent, and temperatures become more stable, although minor fluctuations would still be expected to occur.

A few authors have attempted to date the entire Pleistocene, the foremost being Zeuner (op. cit.), Emiliani (op. cit.) as well as Ericson, Ewing and Wollin (op. cit.). The following table is given to show the great disparity existing between the various authors. Emiliani (1964, p.140) states that others, including Zeuner, have mistaken a point on the temperature curve for an interstadial, whereas the swing is in fact the last interglacial period, hence the large discrepancy at the onset. Further dates, by various authors, have been given to clarify the position.

TABLE II.

	ZEUNER 1958, p.133	EMILIANI 1964, p.133	STEARNS 1961, p.5.	FLINT & BRANDTNER 1961, p.322	WRIGHT 1964, p. 629	ERICSON et al 1964, p.731
		11,000		13,000	5,000	
Würm III	22,100		25,000	20,000 25,000 28,000		
Würm II	72,000		60,000	34,000 51,000		
Würm I	115,000			56,000		
———	———	75,000	———	70,000	50,000	100,000
Last Inter-Glacial	125,000 145,000 150,000		/			
———	———	103,000	———	———	———	340,000
Riss II	187,000		115,000			
Riss I	230,000					
———	———	125,000	———	———	———	420,000
Great Inter Glacial	270,000		/			
———	———	175,000	———	———	———	1,060,000
Mindel II	435,000		240,000			
Mindel I	476,000					
———	———	200,000	———	———	———	1,200,000
First Inter Glacial	500,000		/			
———	———	265,000	———	———	———	1,390,000
Gunz II	550,000		320,000			
Gunz I	590,000					
———	———	325,000	———	———	———	1,500,000
Donau/Gunz Inter Glacial					970,000	Everndon 1965
					1,000,000	Holmes 1959, p.204
———						
Donau					1,200,000	Everndon 1965.

All dates are Before the Present.

The most complete list of sea-level fluctuations, for the Pleistocene period is given by Zeuner (1958, p.133). This table plus suggested maxims by other authors is given below.

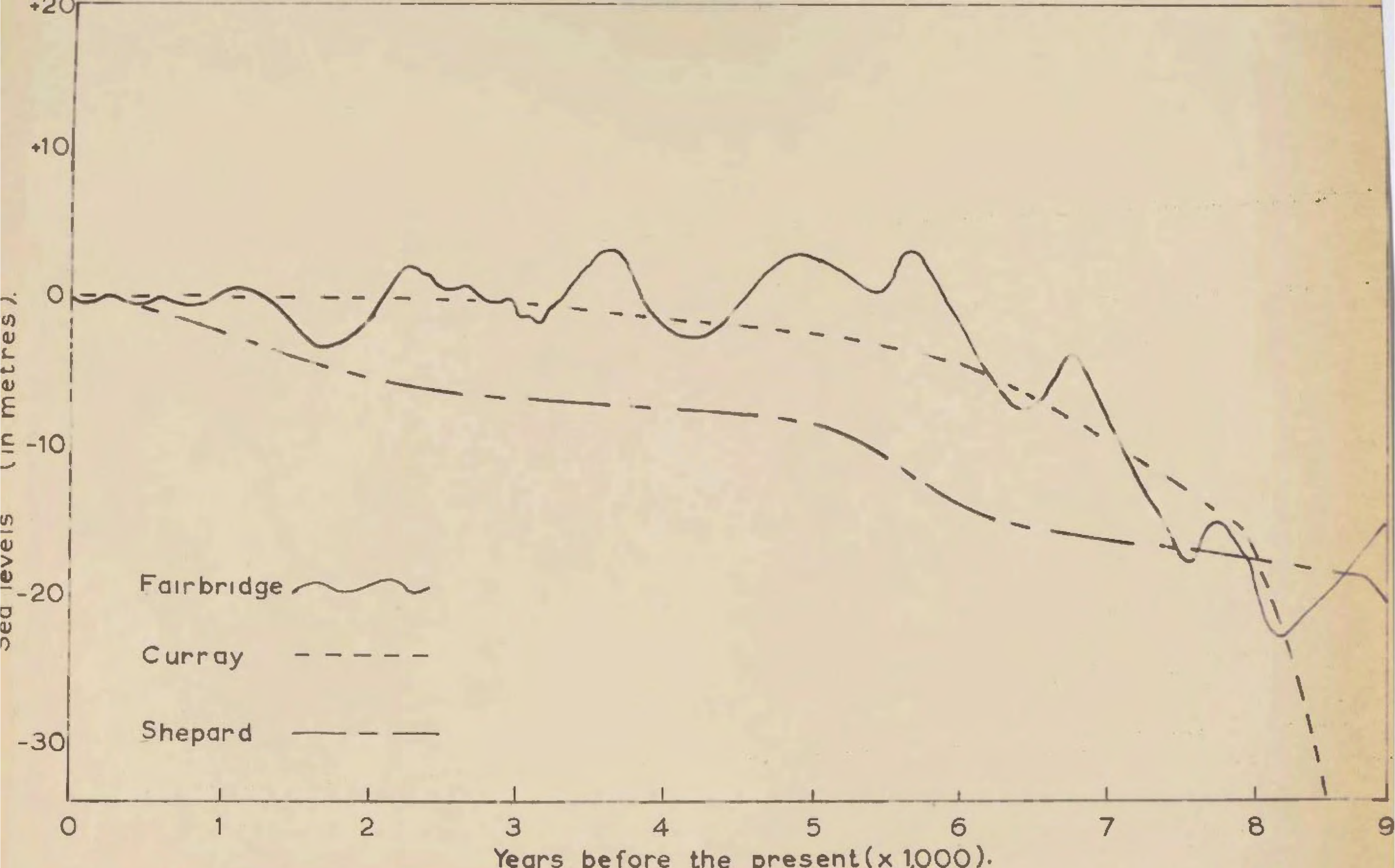
TABLE III.

	Zeuner (1958, p.133)	Donn et al (1962, p.212)	Flint (1965, p.498)	European Terminology
Würm III	? - 30 m.			
	? - 12 m.			
Würm II	? - 70 m.			
	+1 - +3 m.			
Würm I	- 100m.	- 105 or - 123 m.	- 90 m.	
Last Inter Glacial	+ 7.5 m.		+ 30 m.	Late Monastrian
				Intra "
	+ 18 m.			Main "
Riss II		- 145		
	Very Low	or - 158 m.		
Riss I				
Great Inter Glacial	+ 32 m.			Tyrrherian
Mindel II	Very Low			
Mindel I				
First Inter Glacial	+ 60 m.			Milazzian
Gunz I & II	?			
Donau/Gunz	+ 90 m.			Silician
Donau				

All Carbon-14 dates available for the Holocene period show a vast amount of contradictory evidence as to minor fluctuations of sea-level. Authors such as Shepard and Suess (1956, p.1083) show a continual rise in sea-level once the melting of the ice sheets commenced. Fairbridge (1958, p.471) claims that fluctuations are reflected on the

PLATE 5

The Post-Glacial Rise of the Sea-level



The Post Glacial Rise of the Sea Level.

PLATE No. 5

coasts of the world. The sea-levels, as determined by the various authors are shown in graphical form (Plate 5). This graph shows clearly that two schools of thought exist.

The temperature changes required to induce these oscillations, due to melting or advance of glaciers, would be extremely small. Emiliani (1964, p.130) states that the temperatures of the oceans varied only 4°C during the Quaternary. Flint (1957, p.486) estimates that the change of atmospheric temperature from glacial to interglacial was in the order of 6°C to 8°C. It must be borne in mind that it is not the great range in temperature fluctuations required, but the duration of small increases or decreases.

The general concensus of opinion, as listed below, is that sea-level is at present rising.

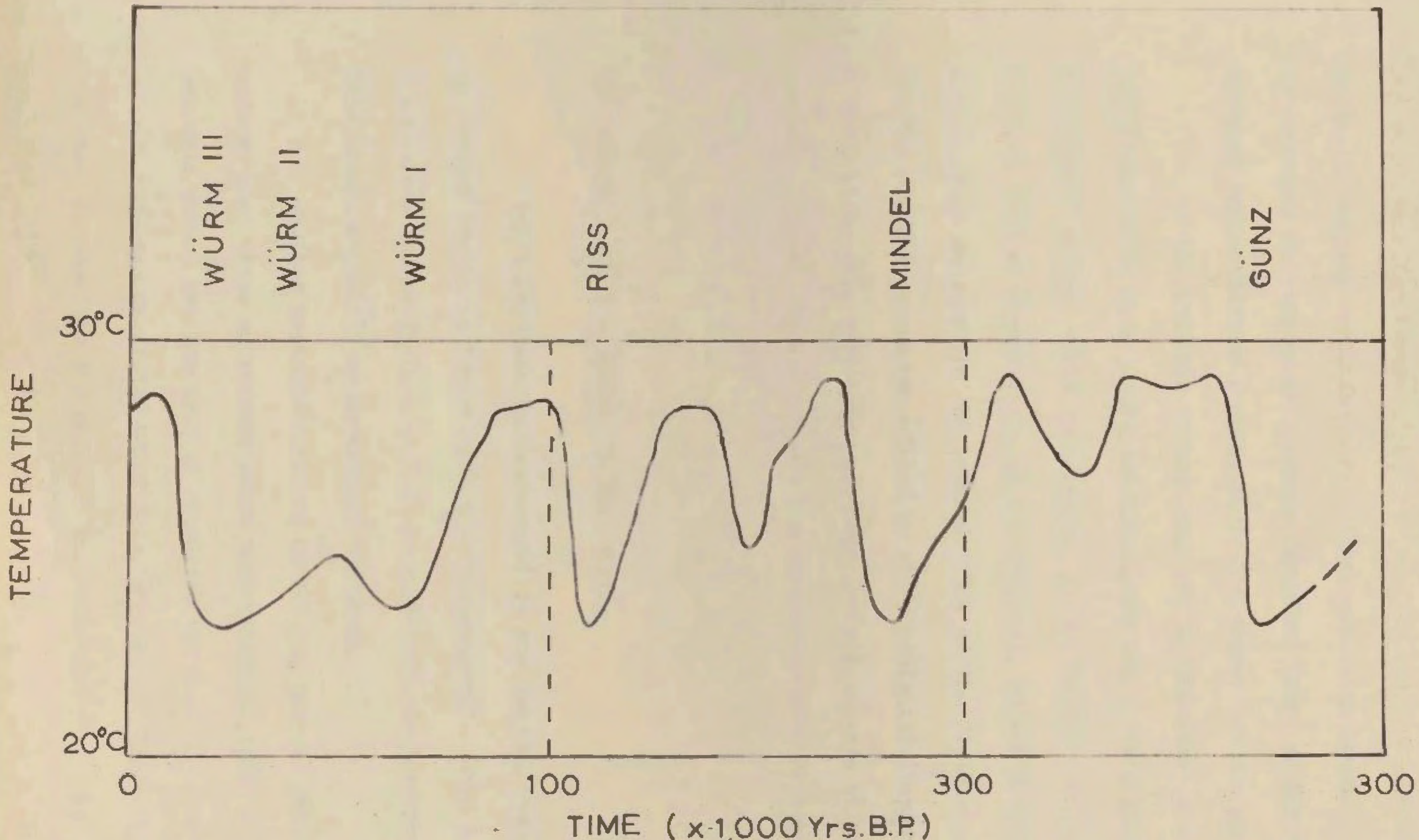
Figures quoted are:-

Hansen (1965, p.80) Denmark	1 mm. (Annual)
Flint (1957, p.261) World Average	1 mm. (Annual)
Russell (1957, p.428) World Average	3 mm. (Annual)
Fairbridge (1962, p.131)World Average	1 mm. (Annual)
Gutenberg (1941, p.730) World Average	1.2mm.(Annual)

The tide gauge at Simonstown Naval Base, where records only go back to 1957, reflects a rise of 3.0 mm. from 1958 to 1966 (A. Shipley private communication). At present, this increase in sea-level could be due to a general sea-level rise or to secular variation, which operates in 18.6 yearly cycles. Owing to the short length of time for which records have been kept, it is not clear whether this increase is

PLATE 6

Generalized Temperature Variation during the Quaternary



Generalized temperature variation during the Quaternary.

(After Emiliani 1955)

PLATE No. 6

due to a general sea-level rise with secular variation acting in an opposite direction (hence giving the low figures), or whether the rise is due to secular variation only. These questions cannot be answered by reference to tide gauge readings from Cape Town, as the material has been collected over a great number of years, but not processed.

If the readings listed above can be accepted, then one can state that there is a general warming-up of the earth's atmosphere. At the present average world temperature, it can be seen (Emiliani's Curve, Plate 6) that we cannot be in an interstadial, as world temperatures are too high compared to the interstadials of the Pleistocene. Neither can the present period be defined as an interglacial (Suggate, 1965, p.624), since this definition requires glacial periods at both the commencement and the end. Hence the Recent can only be termed a "Post-Glacial" period.

(D) RAISED BEACHES (EUSTATIC SHORELINES).

The term "eustatic shoreline" is one used by Stearns (1961, p.3) to replace the terms "emergence" and "submergence". This term refers to a shoreline caused by rise or fall in sea-level, in contrast to a shoreline caused by uplift or sinking of the land.

Various eustatic features in the bay were investigated by the writer, who, after an initial field reconnaissance, decided that an accurate survey was required to establish the elevations of these features.

In the Rocklands Point area, a Bessel's "Three Point" resection was used to establish the position and elevation of a traverse terminal

PLATE 7.

A boulder beach exposed in a road cutting at Rocklands Point. This beach is correlated with a 50-60 ft. stand of the sea during the Major Emergence.

point. An open traverse was carried along the road for a sufficient distance to determine spot heights of the various features required.

The position of the Gordons Bay eustatic shoreline was determined by a sideways intersection from a tertiary beacon. Backsighting on to this beacon and one other established the elevation.

The elevations at Swartklip and Strandfontein were determined directly from tertiary beacons in the vicinity.

All elevations given by the writer in the following brief report on the features associated with eustatic fluctuations in the bay were determined by survey, unless otherwise stated.

(1) The Peninsula.

(a) The Rocklands Boulder Beach.

One and a half miles along the road from Simonstown police station to Cape Point, in the vicinity of Rocklands Point, a road cutting exposes an old boulder beach.

The base of this exposure lies at an elevation of 56 ft. above present sea-level.

The exposure is reminiscent of present-day boulder-strewn coves, common in False Bay. The cove to the south of Millers Point is a typical example. These modern boulder beaches show typical imbrication of the boulders, with the long axis dipping seaward (Pettijohn 1957, p.78). The exposure at 56 ft. above sea-level also shows this feature over the whole 200 ft. section exposed. The material to seaward of the 56 ft. base level was removed during road construction. The material above this elevation is covered by scree. Because of this, it is impossible to determine the exact position of the ancient shoreline (Plate 7).

This boulder beach evidently formed a cove on the southern side of a granite outcrop, which was partially removed during road building. Coves facing in this direction are exposed to the larger 'rollers' entering False Bay, hence the rounding and positions of the material.

(b) Planation of Granite Boulders.

Below this old strandline, along the beach and protruding from the sea, are large, flat-topped boulders. These rocks form a very obvious feature between Simonstown and Smitswinkel Bay. Six of these boulders in the Millers Point-Rocklands Point area have maximum elevations of approximately 20 ft. above present mean sea-level. This feature can only indicate planation by a prolonged stand of the sea at a height slightly in excess of the above elevation.

(II) The Mainland.

On the eastern shore of False Bay a boulder beach, wave-cut terraces, cave formation and undercutting are found at varying elevations. These features are discussed below.

PLATE 8.

A boulder beach exposed in a road cutting 100 ft. above sea level at Gordon's Bay. Due to its elevation, an earlier, higher stand of the sea is indicated, possibly during the Great Interglacial.

(a) The Gordons Bay Boulder Beach.

In a cutting on the road above Gordons Bay, a further boulder beach is exposed. Rounded pebbles are exposed over a distance of 225 ft., at an elevation of approximately 100 ft. above mean sea-level, in the eastern wall of the cutting (Plate 8). Most of the boulders present are smaller than those at Rocklands Point, and appear to have been deposited by storm waves in a depression in the Malmesbury Shales. The western side of the road, a distance of 60 ft. away from the exposure, consists of scree material only, indicating that the depression was to shoreward of this point. This beach can in no way be related to the boulder beach near Rocklands Point, originally discussed. It indicates a very much higher stand of the sea.

(b) A cave and undercutting phenomena.

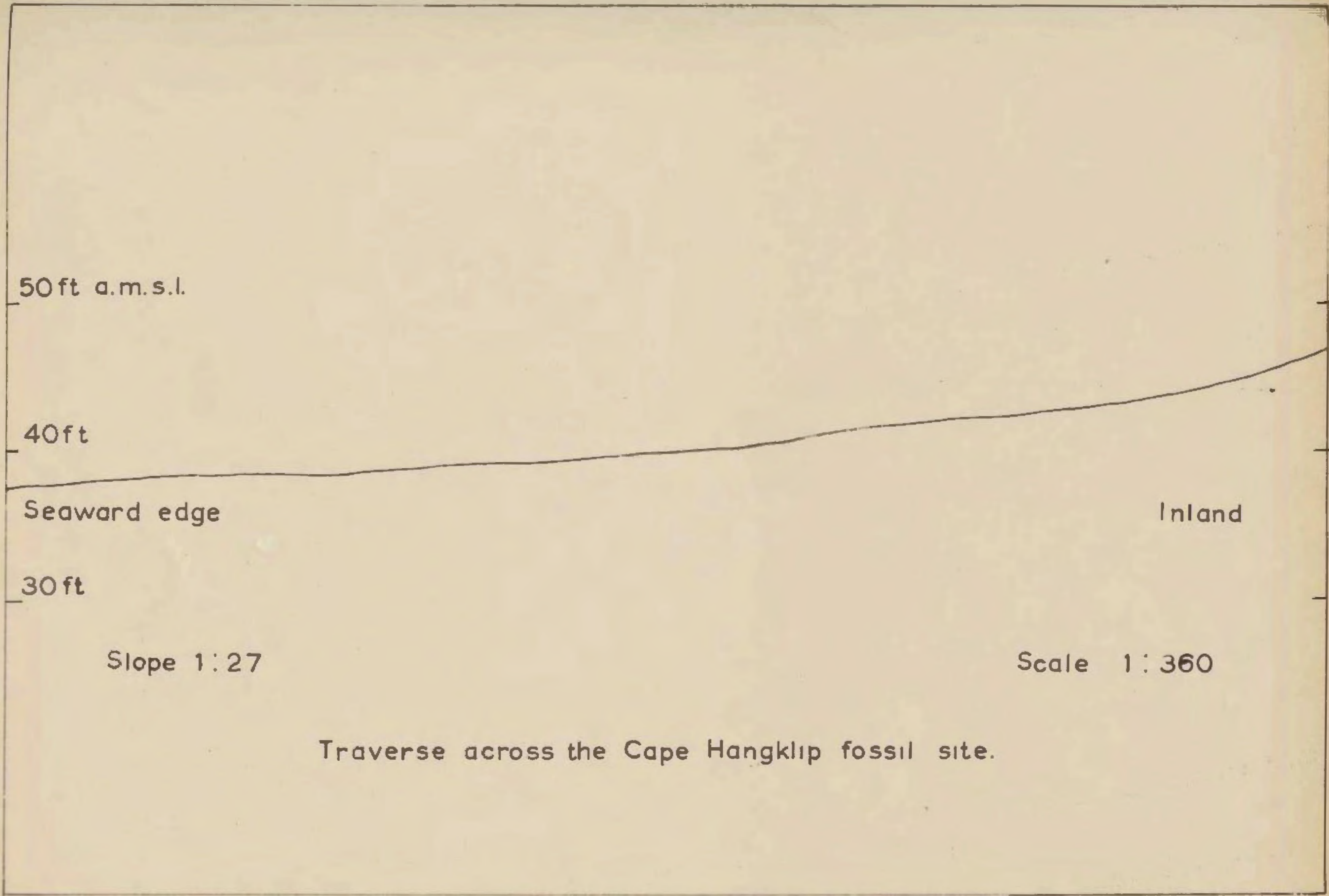
Below the Dirkie Binneman Memorial, along the Gordons Bay-Cape Hangklip road, undercutting and a cave at approximately 20 ft. above sea-level are found (Plate 9). (The elevations of these features were estimated, as traversing was not practical). The cave, formed on a joint plane in the Table Mountain Sandstone, lies within one hundred yards of the undercut cliff. The base of the cave cannot be seen, owing to scree and rock which has fallen from its roof. Apparently, no accurate record of a higher sea-level would be obtained from a cave, especially in Table Mountain Sandstone. This sandstone becomes very friable when immersed in water for long periods, and would result in the floor material being removed by the currents. The prominent cross-

PLATE 9.

Cave cutting along joints in T.M.S. below the Dirkie Binneman Memorial. The 'blocky' nature of the rock can clearly be seen.

PLATE 10

Traverse across the Cape Hangklip Fossil Site



Traverse across the Cape Hangklip fossil site.

PLATE No. 10

jointing and bedding planes permit rapid subaerial erosion in areas not under wave attack. The combined result is of a cave where the floor and the roof bear no direct relation to the level of the sea.

(c) The Steenbras River Mouth.

The mouth of the Steenbras River is flanked by a rock terrace with a maximum width of 200 yards. Krige (1927, p.66) gives an elevation of "50 to 60 ft. east of the river". The writer determined elevations of 70 ft. for the seaward side and 76 ft. for the inland side of this terrace. The rounded boulders normally associated with this type of feature could not be found; also, the terrace is formed in Table Mountain Sandstone where joints and bedding planes are common features. No wave-cut cliff is present on the landward side. This evidence does not indicate a wave-cut terrace, hence the writer cannot use this as an indication for a stand of the sea slightly in excess of 70 ft., which, due to its elevation, can in no way be associated with the 50 to 60 ft. emergence.

(d) The Cape Hangklip Terrace.

A virtually unbroken terrace stretches from Rooi Els Bay to Cape Hangklip. The width of this terrace to the south of Pringle Bay Peak, is in the order of 1000 yards. The major section of this terrace is covered by scree, but road construction and stream erosion has exposed the typical rounded boulders usually found on terraces of this type. Elevations in the order of 35 ft. to 56 ft. are common (Plate 10).

PLATE 11.

A view from the Somerset Strand pavilion looking towards Gordon's Bay. The truncated Malmesbury Beds are exposed during low tide and can be seen across the centre of the photograph.

(e) The Somerset Strand Platform.

A wave-cut platform in the Malmesbury Shales is exposed, at low tide, in the Somerset Strand area. This platform stretches from 750 yards west of the Pavilion to 3250 yards east of it. The average exposed width is approximately 500 ft., with a seaward gradient of approximately 1 ft. per 150 ft. (Plate 11).

Along this section of the coast the Malmesbury Shales strike at 350°, with a dip of 40°E. That is, the strike approximately parallels the coast with a shoreward dip. The inshore section of the platform is covered by beachsand for its entire length, thus the exact extent of truncation cannot be determined, but this is thought to be considerable.

Similar smaller features, at the same elevation, occur at Gordons Bay.

(E) THALASSOSTATIC TERRACES *

Various authors in South Africa have investigated and described stream profiles and terraces with reference to their relationship to eustatic sea-level fluctuations.

From the Stellenbosch area, Shand (1913, p.150 and 153) discusses 'fill' terraces (Leopold and Miller 1954, p.3) recorded near the Coetzenberg Bridge, Stellenbosch, occurring at the following elevations:-

The Youngest Terrace 12 to 14 feet above the present river bed.
The Second Terrace 18 to 20 feet above the present river bed.
The Oldest Terrace 45 feet above the present river bed.

* A river terrace formed under the influence of the changing sea-level may be called a thalassostatic terrace (Zeuner 1958, p.130).

Fair (1943, p.22) has correlated evidence from coastal terraces and stream beds in Southern Natal. His evidence is listed as:-

Coastal Evidence	Feet 15-18	Feet 19-25	Feet 50-70
Stream Profile Evidence	9-15	21-30	60-75
River Terrace Evidence		20-30	70-90

From the Sundays River, further evidence of eustatic sea-level fluctuations is available. These thalassostatic terraces are grouped by Ruddock (1947, p.368):-

The Harveyton and Kirkwood Terraces at 60 to 100 ft., correlated with the Major Emergence.

The Addo Terrace of 15 to 25 ft. elevation, corresponding to the Minor Emergence.

The Colchester Terrace of 12 to 14 ft., associated with the "resting stage in the final emergence".

Mebbutt (1957, p.11) correlated terraces of the Olifants River with those of the Sundays River, placing the higher terraces as Last Interglacial. This corresponds to Zeuner's 18 m. stand of the Main Monastrian. The second terrace, the Addo of Ruddock, is correlated with the Würm I and II Interstadial, with the Colchester and lower Olifants terraces as Recent.

As previously stated, the writer thinks these terraces represent a pre-Würm interglacial sea-level. The dating is not of the utmost importance, but the order of formation is, and all agree that the lowest terrace is the most recently formed.

The terraces from the Stellenbosch area cannot be used in a study of False Bay, unless one wishes to include terrace formation older and higher than the Major Emergence. Krige (1927, p.67) quotes these terraces as evidence of "The resting stage in the final emergence". But due to their approximate height above present sea-level (+ 300 ft.) it is considered by the writer that these terraces reflect a fluctuating sea-level during the Great or Yarmouth Interglacial.

The lower reaches of the Eerste River were briefly investigated by the writer for evidence of terrace formation, but none could be found.

(F) SUBMERGED EUSTATIC TERRACES.

Evidence of submerged eustatic features in False Bay is meagre, but there is sufficient data available to discuss the subject under various headings, as follows:-

(1) The Harmony Terraces.

After a model of the submarine topography had been constructed from a detailed bathymetric chart, Dr. A.D. Fuller suggested an examination of the Harmony coast. Two divers investigated the underwater features and concluded that a terrace was present at a mean depth of 33 ft., and that a further terrace could possibly be recorded at 15 to 18 ft. below mean sea-level. Robertson (1964, p.6) reported that features such as rounding of ridges in the Malmesbury shales, rounded boulders and pebbles were encountered. Further diving and underwater photography may prove conclusively that these two features are true, wave-cut terraces. (Evidence of similar features, at approximately the same depth, is discussed on page 44).

(11) Castle Rock Undercutting.

Exploratory diving off Castle Rock has disclosed undercutting to a depth of 2 ft. of two granite boulders, resting on a relatively flat sea bottom, at an approximate depth of 40 ft. These two boulders show undercutting at an angle to each other. The outermost boulder has been undercut on the shoreward side, whereas the one near the shore has the undercutting at an oblique angle to the coast, as well as to the undercut section of the first boulder.

To the writer, it appears that the mode of origin of this undercutting, during a lower stand of the sea, could have occurred by either of the following methods:-

a) A strong backwash current, heavily laden with detrital material, rushing through the restricted area between the two boulders,

or

b) Continuous surf action acting at an oblique angle to the boulders. The near-shore boulder would have received the most direct onrush of water.

In view of the fact that the undercut features appear on the northern side of the boulders, that is, away from the incoming waves, the writer thinks that the backwash current, acting through a 15 to 20 ft. gap between the boulders, caused the undercutting.

(G) DATING OF THE EXPOSED EUSTATIC TERRACES.

(1) Global Evidence.

For convenience, the terraces are considered under three groups:-

1.	50-60 feet;	15 - 18.5 m.	The Major Emergence Terrace.
2.	20-30 feet;	5.5 - 9 m.	The Minor Emergence Terrace.
3.	0-15 feet;	0 - 4 m.	The Lower Terraces.

A summary of the evidence available for the age of terraces at approximately the same elevations elsewhere in the world is discussed and followed by the writer's conclusions with regard to the False Bay evidence.

(a) The Major Emergence Terrace.

Wave-cut terraces of similar elevations as found in False Bay, have been reported by others from various parts of the world, e.g. Fuenzalida et al (1965, p.477) reports a 20 to 22m. terrace in the Bay Mehuin, Chile, which is dated as "Last Interglacial" by the authors. A further terrace at an elevation of 24 m. is mentioned by Flint (1957, p.264) at Nome, Alaska. Stearns (1945, p.1075) notes the terraces on the Hawaiian Islands and Atlantic coast of America at 23 m. above present sea-level. A 17 m. terrace on the Island of Oahu is dated by Stearns

(1961, p.10) as relating to a Yarmouth or Great Interglacial sea-level. Zeuner (1958, p.133) suggests a figure of 18 m. above present sea-level for the Main Monastrian stillstand. The dating of this would be between 97,000 and 150,000 years B.P. according to Emiliani and Zeuner respectively.

A shoreline 13 to 15 m. above present sea-level is very prominent in the New Hebrides and the Caroline Islands, as well as the coasts of South America and California. This is again dated by Stearns as of Yarmouth age (Stearns, 1961 p.10 and 11).

Zeuner (1958, p.131) shows that aggradation of the Thames can be correlated with both the 18 m. and 7.5 m. stands. The Taplow Terrace marks the 18 m. stand during the Main Monastrian, and the Upper Flood-plain aggradation terrace with a 7.5 m. high stand during the Lower Monastrian.

Fair (1943, p.16) reports terraces from Port Edward, Scottburgh, Umdoni Park and Winkle Spruit on the Natal coast as consistent with elevations reported by Krige (1927).

(b) The Minor Emergence Terrace.

The 7.5 m. terrace, dated as Lower Monastrian, is reported by Zeuner (1958, p.128) for the Mediterranean region, Northern France, Southern England and the Pacific, as well as the east coast of America. Wright (1937, p.372) remarks that the 7.5 m. beach is the best marked in Scotland. In America, this 7.5 m. strandline, the Suffolk, extends for over 800 miles and is dated as Sangamon or Last Interglacial (Flint 1957, p.363).

The Minor Emergence Terrace, at 20 to 30 feet, is reported to be present in the Wilderness Lake District, Cape Province, by Martin (1962, p.35). He assigns no date or time period to this stillstand, except to place it during the Pleistocene, followed by a lowering of the sea-level by -30 m. This stand of the sea is apparently that of Zeuner, and thus Late Monastrian.

Mountain (1966, p.103) describes human and bird footprints in calcareous sandstone at Nahoon Point, East London. These prints are fossil imprints in calcite-cemented rock which came from approximately 33 ft. above mean sea-level. Deacon (1966, p.111) gives the results of carbon dating of this material as 29,090 years B.P. At first glance it would appear that this could give a possible date of the Minor Emergence shoreline with footprints formed in a spray zone. The dating places these imprints at a point during the Würm II to III Interstadial, which is consistent with Zeuner, Stearns and Emiliani as well as Flint and Brandtner, (1961, p.326). But temperatures and hence sea-level, did not rise as high as the present in this period, (Emiliani's Curve, Plate 6), therefore sea-level could not have been above the present. These prints can thus not be associated with the 20 to 30 ft. terrace.

(c) The Lower Terraces

Terraces of a lower elevation than the above have been reported from many parts of the world and dated as follows:-

1. 2 - 3 m. Nizza terrace of the Mediterranean - Recent. Schwarzbach (1962, p.19).
2. 2 - 3 m. Aleutian Islands - Recent. Powers (1961, p.36).

3. 12 ft. Oahu terrace - Older than 24,000 years B.P. Shepard (1963, p.268).

4. 5 ft. terrace U.S. Atlantic coast - Recent (?) Stearns (1945, p.7).

5. 5 ft. (now at 2 ft.) Manana Beach - Recent. Fairbridge (1958, p.7).

6. 5 ft. Oahu - Older than 24,000 years B.P. Shepard (1963, p.268).

7. 2.5 m. terrace at Sandvlei, Wilderness, South Africa - Recent. Martin (1962, p.35).

The dating of these lower eustatic terraces has its difficulties. Fairbridge, the exponent of a sea-level which has been "bobbing up and down repeatedly during the last few thousand years" (Shepard 1961, p.33), regards these lower terraces as having been formed during the last 5,000 years. The following table gives his, (Fairbridge's), elevations, above and below present sea-level, as well as their date of formation.

Present sea level.	0 m.	Base level
Paria Emergence	-1 m.	-700 years B.P.
Rottnest Terrace	1 m.	-1000 years B.P.
Florida Emergence	-3 m.	-1,600 years B.P.
Abrolhos Terrace	2 m.	-2,200 years B.P.
Pelham Emergence	-3 m.	-2,800 years B.P.
Younger Peron Terrace	3 m.	-3,800 years B.P.
Bahama Emergence	-3 m.	-4,300 years B.P.
Older Peron Terrace	4 m.	-5,000 years B.P.
	-33 m.	-10,000 years B.P.
Glacial Maximum	-100 m.	-20,000 years B.P.

(Fairbridge 1962, p.120).

To achieve the great swing from the Older Peron Terrace through the Bahama Emergence to the Younger Peron Terrace during the period 5,000 years B.P. to 3,800 B.P., a considerable oscillation of temperature is necessary. The fluctuation of the sea during the above period of 1,200 years was 44 m. or 36.5 mm. per year, if Fairbridge is correct. Various authors (p.23) have given evidence of a sea-level rising at approximately 1 mm. per year, only Russell (op. cit.) suggests a 3 mm. rise per year. The fluctuation as seen by Fairbridge would require a considerable climatic ch nge, very cold and warm periods for this rapid decrease and increase in the sea level.

Carbon-14 dating by Shepard (1963, p.267) of material off the northwest coast of Texas establishes a tentative correlation which differs greatly from that of Fairbridge.

	Sea-level at	- 6 m.	2,100 years B.P.
		- 9 m.	5,150 " "
Flandrian		-15 m.	6,100 " "
Transgression		-19 m.	8,900 " "
		-26 m.	9,300 " "
		-27 m.	9,800 " "

(Shepard 1956, p.1083).

Both Shepard (1963, p.268) and Stearns (1961, p.8) give Carbon-14 dates in excess of 20,000 years for material from the 5 ft. Abrolhos Terrace and 10 ft. Peron Terrace, which Fairbridge (1958, p.480) dates at 2,200 years and 3,800 years B.P. This, in Shepard's (1963, p.268) opinion, is due to the instability of the Island of Oahu, where the terraces occur.

In Powers' (1961, p.37) discussion of Carbon-14 dating from the Aleutian Islands, his final statement reads "Perhaps it is prudent to conclude that the shoreline features of the Aleutian Islands are compatible with, but do not demonstrate the validity of, the hypothesis of eustatic lowering of sea-level from 2 to 3 metres since the time of the latest glaciation, but prior to 5,000 years ago".

The Island of Mauritius has yielded no evidence of a higher stand of the sea during the Climatic Optimum or Hypsithermal period of 6,000 years B.P. (McIntire 1961, p.47). Bauer (1961, p.69) does claim evidence of a higher stand on the southern Australian coastline, at about 5,000 years B.P. He assigns a 10 to 15 ft. terrace to this age.

This fluctuation is agreed on by Gill (1961, p.76), who bases his hypothesis on Carbon-14 dating of material from Western Australia. Jennings (1961, p.83) dates a 6 to 10 ft. terrace on King Island, Bass Strait, as being of the above age. His dating is based on a particular Mollusc species.

In summary, the writer thinks that the present level of the sea is the highest reached since the last interglacial. The majority of evidence of higher sea-level strand lines comes from Australia and the Pacific Islands; although other areas of the world do not conform. Carbon-14 dating based on samples of peat and wood found in situ may provide reliable and consistent ages, but as Newell (1961, p.93) has shown, limestone, molluscan shells, corals etc. are not so dependable.

Contamination of the older calcium carbonate material by a younger form may give vastly erroneous dates. For example:-

True Age 100,000 years

Contamination by Modern $CaCO_3$ (%)	Apparent Age C^{14} (years)
50	5,600
10	19,000
5	24,500
1	37,000
0.01	74,000

(Newell 1961 p.93)

From the foregoing discussion it appears that the 12 to 14 feet terrace was formed during the last Interglacial period. Even the 2 to 3 ft. higher stand cannot be definitely correlated with the Climatic Optimum. This warmer period was placed at 7,500 to 4,000 years B.P. by Flint (1957, p.377), but Zeuner (1958, p.71) gives evidence for submergence of the Dogger Bank (-40 m.) just prior to this date.

Generally the botanists who recognise the "hypsithermal interval" in Europe and later North America on the basis of pollen analyses, do not agree about the time period with the geomorphologists who recognise a "climatic optimum" in the form of raised coastal benches or nips throughout the Pacific and Indian Oceans.

Until further positive evidence for fluctuating sea-level is obtained, the writer must relate the False Bay features to the Pleistocene and not the Recent.

(11) The False Bay Evidence.

(a) The Major Emergence Terrace.

Numerous features in False Bay have been cited by various authors as evidence of a stillstand at 50 to 60 ft. or 15 to 18.5 m. above present sea-level. The boulder beach at Rocklands Point (p.25) is considered by the writer to be conclusive proof of this ancient sea-level. The Cape Hangklip terrace could not have been formed by any other method than a transgressing sea during this stand of the sea.

The terrace at the Steenbras River mouth is not considered by the writer for reasons previously given (p. 28). Thalassostatic terraces of the Eerste River at Stellenbosch and the boulder beach at Gordons Bay are in no way related to this stillstand. The writer considers that a survey to determine the height above mean sea-level of the feature under discussion is of the utmost importance, prior to correlation of these eustatic terraces.

Needham (1962, p.74) working on features of a similar nature to those in False Bay, dated them as follows:-

	Late Monastrian	+ 10 to 15 feet	
Last Interglacial	Intra Monastrian	+ 20 to 25 feet	Above mean sea-level.
	Main Monastrian	+ 60 feet	

Evidence from river terraces, other than the Eerste River (p. 30), is consistent with the dating. From this, the writer suggests a date of 150,000 or 103,000 years B.P. according to Zeuner and Emiliani respectively, as the time period during which the Major Emergence features were formed in False Bay.

(b) The Minor Emergence Terrace.

The planation of the granite boulders off Millers Point-Rocklands Point area, at an elevation of approximately 20 ft. above present sea-level, bears witness to a sea-level slightly in excess of the above figure. The undercutting and cave at the Dirkie Binneman Memorial can only tentatively be suggested as further evidence. These features have not been surveyed and cave formation, in the writer's opinion, cannot give accurate elevations of this nature.

The date of formation of the terrace in question, is given by Krige (1927, p.67) as between 3,400 and 4,400 years B.P. This period, as Krige (loc. cit.) states, is termed the "Tapes" in the Kattegat-Skagerrak area. In time-span it covers the Lower Neolithic, Upper Mesolithic Stone Ages. (Possibly cultures associated with the 20 ft. strandline caused this incorrect dating). During the Tapes or Litorina Transgression in Denmark sea-level stood above the present. This is recorded by Hansen (1965, p.78) and by Fairbridge (1962, p.122) but refuted by others.

The position of the sea-level during the Recent period is in dispute (p.19), but no author claims eustatic fluctuations of this magnitude, that is, 25 ft. above present sea-level, during that period.

The Intra-Monastrian period appears to be the logical position to place this high stand of the sea, dated by Zeuner (op. cit.) as 145,000 years B.P.

(c) The Lower Terraces.

(1) The terraces at approximately 10 ft. above mean sea-level.

For the False Bay area, Krige quotes various heights as resting places of the sea during its regression from the 20 ft. wave-cut terraces. Caves and undercut ledges are quoted at 7 ft. above present mean sea-level, and at Cape Agulhas, he states there is evidence of a 10 ft. terrace.

Haughton (1933, p.42) describes a raised beach east of Strandfontein 6 to 8 ft. above present sea-level (p.13).

Similar terraces above present sea-level, have been noted elsewhere in the world and dated as both pre and post Würm Glaciation. As previously stated (p.38), the writer is of the opinion that there has been no higher stand than the present since the last Glaciation. The above features must have been formed during the Late Monastrian, prior to the onset of the Würm Glaciation.

(11) The "littoral" terrace.

The truncated exposure of Malmesbury Shales already mentioned in the intertidal zone at Somerset Strand could only have occurred during prolonged attack by the sea. (Wave-cutting of a terrace is discussed on page 43).

The present exposed surface reflects attacks by sea-levels dating back to the Pre Major Emergence period, with each subsequent high stand lowering the surface, until final attack, over the entire terrace by a sea-level slightly in excess of the present.

(H) DATING OF SUBMERGED TERRACES.

(1) <u>The Theory of Wave-cut Terraces.</u>

The classical theory demands that sea-level be stationary during the formation of these wave-cut platforms. (Johnson 1919, p.201 to 215; Keunen 1950, p.302 to 306; Thornbury 1954, p.433 to 437). But wave attack creates and drives a sea cliff inshore, leaving, under shallow water, a wave-cut platform thinly covered with detritus. The slope of the platform will be determined by the required declivity necessary for removal of the debris supplied by the sea-cliff. Landward extension of the platform requires continual lowering of the whole platform surface. Unless sufficient gradient can be maintained for the removal of the debris, sea-cliff erosion must cease. The process requires the material eroded from the sea-cliff to scour the platform as the debris moves across it.

Platforms cited by Bradley (1958, p.969) off Santa Cruz would require effective submarine abrasion at depths of at least 23 m. and 31 m., if these platforms are related to present sea-level.

Johnson (1919, p.80) claimed that submarine abrasion was effective up to 183 m. below sea-level.

Present evidence indicates that platform cutting takes place only within the surf zone, at depths of less than 9 m. (Dietz and Menard 1951, p.2011; Bradley, 1958, p.972; Dietz, 1963, p.982). Bradley's calculations indicate that a static sea-level may carve a platform 160 m. to 180 m. wide, but greater widths require a rising sea-level.

Dietz (1963,p.982) believes that appreciable rock erosion, especially rock truncation, occurs only where waves exert considerable bottom stress, that is, in areas where the waves are breaking into surf. From this he further suggests (p.988) that the term 'wave-cut' be discarded and 'surf-cut' terraces be used in its place.

Following Dietz, the surf-cut terraces found elsewhere and in False Bay must represent periods of a stationary or slowly transgressing sea-level. A rapidly transgressing sea would not have sufficient time to leave its imprint, and 'swamping' would be more likely to occur. (During continual regression, prograding of a beach occurs, hence the surf-cut terraces cannot be correlated with these periods.)

(11) Global Evidence

Submerged terraces from other coasts have been recorded at various depths below present sea-level. The summary by Emery (1961, p.27) after reviewing submerged terraces on a world-wide basis, shows that terraces in the Gulf of Mexico at 120, 85, 55 and 25 metres could possibly correspond to the Wisconsin, Tazewell, Cary and Mankato glacial stages. A further terrace at 5 to 12 metres appears around many coasts of the world. (Emery 1961, p.19).

The American terminology has been used in this instance as it recognises three stages of the Würm III. The whole Würm Glacial period is divided as follows:- (Stearns, 1961, p.5).

Würm I		Early Wisconsin	60,000 years B.P.
Würm II		Late Wisconsin	25,000 years B.P.
Würm III	(	Tazewell Advance	18,000 years B.P.
	(	Cary Advance	15,200 years B.P.
	(	Mankato Advance	11,400 years B.P.

In the table listing various stands of the sea (p.22) Zeuner shows an interstadial between the Würm I and the Würm II with a higher stand of sea-level than the present. No other available literature agrees with this. Thus, the more general attitude of a low stand during the Würm I or Early Wisconsin with successively higher stands until the present, is accepted by the writer.

Curray (1961, p.1709) produces evidence for a stand of -130 m., during 20,000 to 18,000 years B.P., on the continental shelf south of Mazatlan, Mexico. This depth and dating approximates that by Emery (op. cit.). From the literature it appears that most authors do agree on a low stand of the sea at approximately this depth during this period, e.g. Flint (1957, p.498) suggests a depth in excess of -90 metres; Zeuner (1958, p.133) states that sea-level probably was at -100 metres; van Straaten (1965) places the sea-level at between -110 and -120 metres below the present for the above period.

Flint (1957, p.265) discusses a later stillstand at -50 metres. He bases his argument on grading of rivers such as the Delaware and

Yangtze, but arrives at a figure which corresponds closely to the -55 m. surf-cut terraces of Emery. Parker and Curray (1956, p.2430) find evidence in the Gulf of Mexico, off Texas and Louisiana, of terraces at 58 and 16 metres below present sea-level.

Emery (1961, p.18) quotes Yabe and Tayama (1934) as having reported a submerged terrace at -20 to -30 metres around the coasts of Japan and Korea. Komukai (1956), as quoted by Emery (1961, p.19) mapped the above terrace in great detail, showing that the outer edge was at -42 m. while the inner edge appeared at -28 m.

Similar evidence comes from California where Emery (1958, p.39) finds a terrace at -32 to -42 m. and notes a terrace in the Persian Gulf at -32 m. to -50 m. as well as a terrace off the western coast of Australia at -35 to -42 m.

Flint (1957, p.264) reports a terrace at Nome, Alaska at -10 m. Fairbridge (1958, p.471) dates a terrace at -16 to -7 m. off Bermuda at 11,500 years B.P. Shepard (1963, p.267) places the sea-level at -15 m. 6,100 years B.P. and at -9 m. 5,150 years B.P. Further mention of terraces at approximately this elevation is made by Stearns (1961, p.7 and 10) off the island of Oahu at 18 m. <u>prior</u> to 39,000 years. B.P. Emery (1961, p.18) discusses a terrace off New England, as having formed at -5 m. 5,000 years B.P. Chatterjee (1961, p.53), discussing surf-cut terraces around the stable Indian coast, refers to peat bogs now 2 to 11 metres below present sea-level.

From the preceding discussion it appears that there is evidence, on a global basis, for the formation of submerged terraces at the following depths below present sea-level.

Deeper than -100 m. (These terraces are not considered).

± -55 m.

± -30 to ± -40 m.

-25 m.

± -10 to ± -15 m.

± -5 m.

(111) Submerged Terraces in False Bay.

(a) Depths greater than 40 metres.

During the period of the Würm I and II, False Bay must have been a large sandy valley with the Agulhas Bank partly exposed, the level of the sea being considerably lower than the present. By the year 18,000 B.P. the sea would only have reached the very entrance of the bay, at 85 metres, (Plate 12), if the terraces referred to by Emery are accepted as correct. Material from wind erosion would have been plentiful, thus dunes would have formed in the 'valley' of False Bay. Newell (1961, p.91) cites this period for dune formation off the Australian coast. Stearns (1961, p.7) refers to a period 39,000 years before the present as one of dune formation around the island of Oahu.

The -55 m. terrace reported by Emery (op. cit.) as well as Flint (op. cit.) cannot be determined in False Bay from the present information.

(b) Depths of 15 to 40 metres.

It appears from the bathymetric chart, Plate 2, that there was a stillstand at approximately -35 metres. This, the -35 metre contour, is situated in a very gently shelving area, in the western half of the bay. It appears that the sea had exposed the granite in this area, and the sinuous nature of the contour reflects the undulations in the area which prior to marine erosion, formed the granite, - Table Mountain Sandstone contact. Somewhat to the southwest of 'East Shoal' the Granite-Malmesbury contact appears to be present, and here the -35 m. contour reflects a more even type of topography because of the Malmesbury shales weathering by sub-aerial as well as marine attack, more rapidly than the granite.

During this period of stillstand and then encroaching sea, certain of the bottom sediments were moved onto the beach by wave action, end exposed to wind deflation. In the eastern section of the bay a large surf zone existed, from Whittle Rock to a line joining Roman Rock and York Shoal. This east-west line would have been an ideal point for the formation of dunes. To seaward was a surf zone of nearly six miles at its widest point in which material would have been moved rapidly shorewards.

This movemant of sediment from the marine environment to dunes fringing an ancient coastline, is reflected in the statistical parameters of the sediments. Sample No's. 4, 5, 386, 396 and 603 show characteristics similar to those found in the present dune environment. Further reference to the statistical parameters associated with the above zones is made on page 103.

To the east of this area the -35 m. and -25 m. contours swing to form a 'tongue' around the area termed 'shoal', off Somerset Strand.

PLATE 12

Quaternary Sea-levels in False Bay


QUATERNARY SEA-LEVELS IN FALSE BAY
MUIZENBERG
SOMERSET
STRAND
LOURENS RIVER
SEAL ISLAND
SIMONSTOWN
GORDON'S
BAY
CAPE POINT
BY 16000 yrs B.P. THE SEA HAD NOT REACHED THIS POSITION
CAPE HANGKLIP
PLATE No 12
Metres 5,000 0 10,000
Kilometres 5 4 3 2 1 0 10

This may be interpreted as terraces cut in the Malmesbury Beds. The -35 m. terrace would be consistent with the beach formation previously mentioned, and the -35 m. as well as the -25 m. terraces would agree with Emery's (op. cit.) observations. Diving and underwater photography may prove the presence of these terraces.

The continuation of the above two contours, east of the proposed terraces, swing towards the northern shore, probably marking an old river-bed of the combined Eerste and Lourens Rivers. The rectangular bends of the -35 m. contour, to the east of the shoal area, possibly mark the confluence of the 'Combined' River and the Steenbras River. The above terrace would have formed during the period 15,200 years to 11,400 years B.P., if Stearns' (op. cit.) dating is accepted and if the terrace is related to the last period of rising sea-level.

(c) Depths of 0 to 20 metres.

The terraces discussed by Robertson at -11 metres and the wave cutting reported by divers off Castle Rock, could be a reflection of a slowly encroaching sea during the past 7,000 years.

Robertson's terrace at -5 to -6 metres has its counterpart elsewhere, as previously mentioned. Emery (1961, p.18) dates this terrace at $\pm$ 5,000 years B.P. But unfortunately various other dates are again given by the numerous authors (e.g. Sheperd, -6 m. stand at 2,100 years B.P., Fairbridge, the Rhine Delta Emergence of($\pm$) -8 m. 6,500 years B.P.).

The dating, at present, cannot be more exact, since these terraces in False Bay may have been cut at a much earlier date, that is, during the Yarmouth or Great Interglacial.

(III) CALCAREOUS SANDSTONE

(A) THE FALSE BAY OCCURRENCES.

(1) Strandfontein Calcareous Sandstones.

A broken pavement of calcareous sandstone, approximately five hundred metres in length, occurs at the water's edge on the Strandfontein beach. The eastern end of the pavement occurs on the coast opposite the point where the Muizenberg-Strandfontein road turns sharply inland to Ottery. The pavement terminates abruptly approximately three hundred metres from a concrete retaining wall, on the old Muizenberg- Strandfontein road.

At this retaining wall the pavement reaches its maximum width, forming a 'V' shaped promontory jutting fifty metres out to sea. The open end of the 'V' is about 75 metres wide against the retaining wall. To the east the pavement narrows to about 4 metres, and remains at this width for its full eastern extension, until it terminates abruptly, giving way to normal beach sand. To the west, the exposure emerges from under the beach sands against the base of the wall. The length of this outcrop along the wall is approximately 200 metres and the average width is 9 metres.

The eastern exposure shows the true profile of the beach, as the road is further inshore. Here the shoreward edge of the calcareous sandstone coincides with the foreshore edge of a faintly discernable

PLATE 13.

Beachrock photographed at Swartklip. The numerous holes formed at the contact of the gastropod's pads and the rock, gives the rock the appearance of 'Stonelace'.

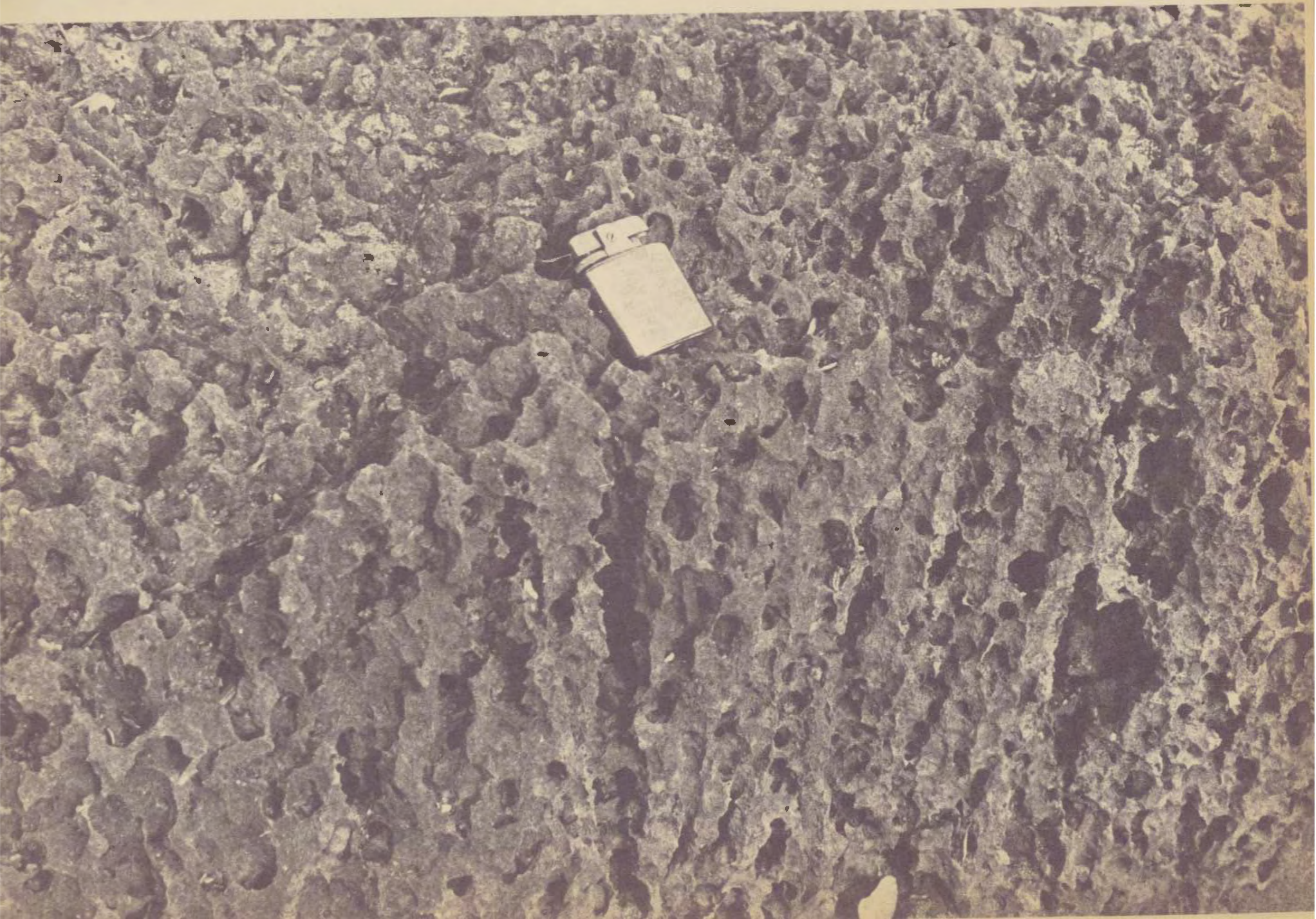


PLATE 14.

Undercutting by the sea has caused the pavement at Swartklip to slump and break. The three zones are clearly evident, the upper case hardened material, then the friable stonelace below which the third zone is seen.

berm, 1.75 metres above mean sea-level.

During low tide the 'rock' is exposed for the greater part of its length, although the apex of the V-shaped promontory remains covered. In the vicinity of the apex of the promontory a rocky bar, composed of the same material as the pavement, parallels the coastline. The general appearance is one of present day destruction. Large cracks have formed and sections have been moved out of place. Under-cutting of the platform appears to be in progress as shown by the slumping of sections and the formation of the small 'blowholes' at various points along the pavement. These cracks or 'joints' (Ginsberg 1953, p.85) occur in two directions, one roughly following the coast, the other perpendicular to it.

The eastern section, in particular, has a 'scoriaceous' appearance, termed by Ginsberg (1953, p.86) "stonelace". This appearance is caused by innumerable small holes, occupied by gastropods, (Plate 13).

Revelle and Fairbridge (1957, p.280-281) account for this 'stonelace' effect, by the liberation of CO_2 at the point of contact of the gastropod and the rock, which results in solution and removal of $CaCO_3$.

In the central and western sections, the upper surface of the calcareous sandstone has a very smooth, indurated appearance. (Plate 14). This indurated material has been termed case-hardened, by Russell (1959, p.229).

Cross 'jointing' exposes excellent sections showing that the thickness of the case-hardened material is generally from 2 mm. at the

PLATE 15.

Laminations in case hardened beachrock.

low tide mark to nearly 20 cm. on the shoreward side. This extremely thick, case-hardened material is present in the spray zone, which is only covered by the sea at springtides and times of storm.

Laminations in the case-hardened material are clearly discernable (Plate 15). The individual laminae vary from about 2 mm. to 10 mm. in thickness. The laminations show the same compositional characteristics as the adjoining beach material, that is, alternating layers of medium to fine grained quartz. The finer laminetions show a higher degree of polish, whereas the coarse material exhibits a rough exterior. Intergranular pore spaces within the layers are completely or nearly filled with a brownish carbonate.

Below this case-hardened surface the degree of consolidation decreases remarkably, and the material becomes crumbly and friable. This section can be divided into two zones, based on the degree of friability and on the presence of solution channels formed by gastropods.

Immediately below the hard outer crust is a friable zone in which there are solution channels. Generally, this material requires a sharp tap with a hammer to break off a piece. The zone ends somewhat abruptly and the second zone is of very friable material with no solution channels.

In general these two zones show open pores where cementation has stopped, or is in an immature stage. A certain amount of cementation is in progress at present, as shown by blocks obviously broken apart and moved, but which have now been welded. Emery, Tracey and Ladd (1954, p.44) describe a modern glass fishing-net float firmly

PLATE 16.

Looking East from the parking lot at Swartklip. The broken remnant of the beachrock pavement lies at the water's edge. At the top right hand corner, beachrock can be seen approximately 50 metres out to sea.

cemented into a rock of this nature, showing that the welding process can be very rapid.

It is difficult to determine the exact thickness of the pavement, but in areas where an indication may be obtained, it appears that the 'rock' is thicker towards the land, and wedges out towards the sea. The backshore section is thought to be as much as one metre thick. No bevelling of the platform can be seen, the general appearance is of a very gently dipping 'bed' covered by beach sand on its shoreward side.

Veinlets of chert appear in some sections of this exposure, but form a very minor feature.

(11) Swartklip Calcareous Sandstone.

Along the coast, immediately below the parking area, at the eastern end of the tarmac road at Swartklip (Plate 16), is the second occurrence of calcareous sandstone. The exposure stretches for over 1.5 kilometres, but is extremely broken, and sections of the pavement have been destroyed entirely. The easternmost remnant occurs approximately two and a half kilometres from the prominent point which gives its name to the area. Between this point and the parking area previously mentioned, there are three exposures of the calcareous material. The remnants of the pavement in this area, have the landward edge covered by beach sand at a height of 1.75 m. above the mean sea-level. Undercutting by the sea has resulted in large blocks being displaced, and in some cases moved seawards. No case-hardening has taken place

PLATE 17.

Pot-holing in beachrock at Strandfontein.

The raised 'doughnut' shaped rim encloses an area where stonelace formation is in progress.


Life

PLATE 18.

A pot-hole which had formed prior to undercutting and slumping. Fracturing of the pavement has occurred in the background.

here, but the material has the 'stonelace' appearance due to solution channels formed by innumerable gastropods.

At the southeastern corner of the parking area the coastline swings slightly north, forming a small cove. At this point the pavement is broken, but case-hardening, up to 15 cms. thick, is evident over most of the platform. The 'joints' present, probably due to movement of individual blocks, have not been welded as at Strandfontein.

Pot-holes (Plates 17 and 18) are remarkably common, but unlike those in stream beds, have 'doughnut' shaped ridges round the area abraded. These ridges are composed of the same material as that responsible for case-hardening - a brownish calcite. It appears that the 'pothole' is formed by the evaporation of sea-water held in undulations on the surface of the pavement. The calcite present in the sea-water would be precipitated, during evaporation, at the contact of the water surface and the calcareous sandstone. To the writer it appears that during the night, when the water is cold, calcite is taken into solution from the base of the 'pothole' and is also precipitated during evaporation. If this did not occur, then the base of the 'pothole' would become elevated above the original rock face, but it appears that a depression is formed.

The pavement in this more protected area, appears to dip seawards at approximately three degrees. The landward side of the pavement is again covered by beach or dune sands.

During low tide a rocky bar is visible about thirty metres off-shore. This 'bar' appears to be a calcareous sandstone similar to the pavement.

The remnants of a further calcareous sandstone body, 5.6 metres above mean sea-level, occur just east of the parking area. The unbroken section of this exposure protrudes from below beach sand, making it extremely difficult to obtain dip direction. The dip appears to be towards the shore, though the evidence is not good.

(B) THE ORIGIN OF THE CALCAREOUS SANDSTONE.

Fuller (Singer & Fuller 1962, p.205) refers to the cliff face at Swartklip as an "unconsolidated shelly sand which would be incapable of cliff formation, were it not for a thin crust of well cemented, calcareous tufa that blankets the deposit". Tufa crusts forming in the hollows between the dunes are also mentioned by Wyberg (1919, p.61). The writer thinks the term calcrete or caliche (Blank & Tynes 1965, p.1387) would be more suitable than tufa. Pettijohn (1957, p.409) describes tufa as "A spongy, porous rock which forms a thin, surficial deposit about springs and seeps, and exceptionally in rivers".

This caliche layer follows the outline of the dunes, resulting in a typical whale-backed shape (Kaye 1959, p.67). The material has the appearance of a 'lime-rich deposit formed in a semi-arid climate by capillary action' (Pettijohn 1957, p.409). Case hardening, approximately 5 mm. thick occurs, but in this instance it is due to reworking of the material by rain water.

The cliffs in this area are precipitous, standing up to 250 ft. above sea-level. Thus the caliche at the cliff top cannot be directly

PLATE 19

Diagram illustrating beachrock and cay sandstone

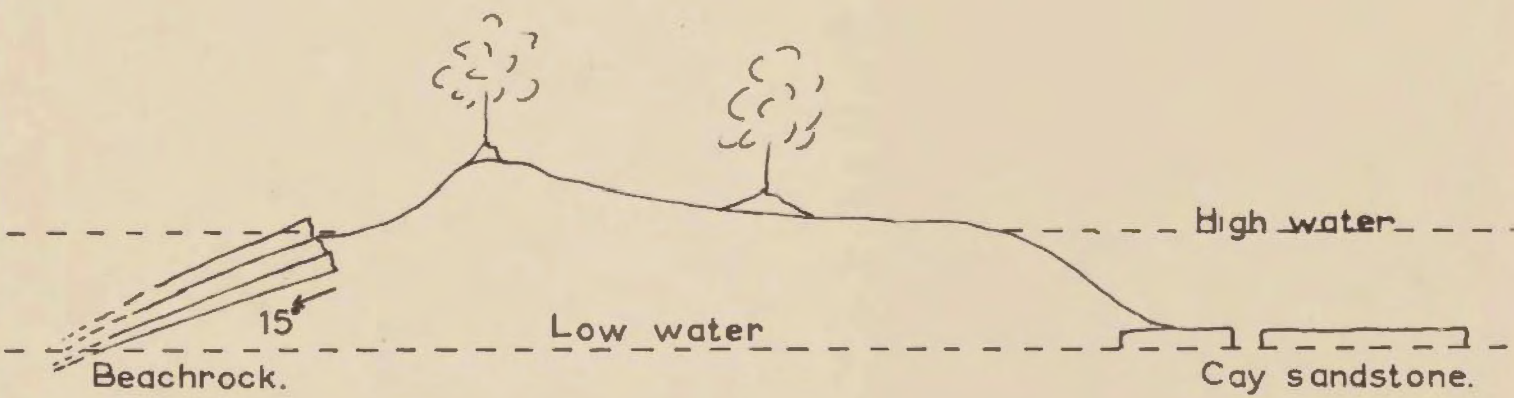


Diagram illustrating beachrock and cay sandstone.

PLATE No. 19

associated with the calcareous sandstone forming the pavement. If, on the other hand, the pavement formed a caliche capping of an older, smaller dune, now covered by the larger one, then this caliche exposure should show truncation at the inshore extremity, and a continuation of the calcrete should appear in the cliff face. The whale-backed shape would be expected rather than a continuous pavement with its inshore margin at a constant five feet above mean sea-level.

On a retreating coastline, (Russell 1963, p.26) in tropical and semi-tropical areas, this calcareous pavement along the beach is a common feature. As he (Russell) states; "Each band of beachrock approximates to the outline of the littoral at the time of its formation, so that divergences in trend indicate changes in strand lines between successive episodes of retreat".

Thus the argument now revolves around the question of whether or not this calcareous beach sandstone is beachrock or a calcrete now exposed by wave action.

Kuenen (1950, p.434) defined beachrock (he called it "beach sandstone") as a clearly stratified, generally dipping series of calcarenite beds commonly found in the intertidal zone. He specified layers 10 to 20 cm. thick, of fairly uniform hardness, comparable to that of poorly cemented sandstone. His diagram (Kuenen 1950, p.435, fig. 178) shows a seaward dip of 15^{o}. (Plate 19). He then defined caystone as forming in horizontal strata that may attain thicknesses of more than half a metre, with a hardness varying from scarcely cemented to firm limestone.

The dip, thickness and hardness of the material at Strandfontein and Swartklip fit this second type more accurately than beachrock. But Tanner (1956, p.307) classifies beachrock and caystone as one. Kaye (1959, p.67) states; "The writer does not find a real basis for considering the less typically horizontal bedded beachrock as different from the inclined, or dipping variety".

Russell (1963, p.24) states that beachrock is formed along the water-table under a beach. Hence it is "beach material that has been cemented by calcite deposited from ground water". But Ginsburg (1953, p.91) clearly states that "beachrock is produced by an intertidal precipitation of interstitial aragonite under the influence of increased temperatures and the rate and degree of beach drainage. The restriction of beachrock to the coral seas is due to its temperature dependence and the localization of this rock is related to beach stability and structure". This statement by Ginsburg adds further variables. To summarize, they are:-

(1) Geographic Location.

(11) Type of interstitial cement.

(111) Position and attitude relative to mean sea-level.

(1) <u>Geographic Location</u>.

Kuenen (1950, p.434) refers to beachrock on the island of Jarngoer Roeal in the East Indies. Kaye (1959, p.66) discusses beachrock on the coasts of Puerto Rico. Others such as Emery (1962, p.62), Stoddart & Cann (1965, p.244) and Fairbridge (1950, p.45) all describe beachrock from tropical waters.

Revelle and Fairbridge (1957, p.258) state; "Beachrock occurs even in favoured but isolated locations in some temperate regions. It is reported as far north as England and as far south as New Zealand". Russell (1963, p.24) refutes this statement, adding that when ground water temperatures, two or more feet below the surface of beaches, are less than 70°F., cementation will not occur. He restricts the formation to areas of tropical to sub-tropical climates. Hobday (1965, p.80) refers to beachrock on the Durban coast.

Calcrete or caliche has undeniably been formed in the Cape Flats, and this requires a semi-arid climate. This climate would have been appropriate for the formation of beachrock. The now broken pavement could indicate one of the following:-

a) A change in climate with lower evaporation rates than during formation.

b) The supply of $CaCO_3$ saturated ground water is no longer sufficient.

c) That the attack by the sea is more vigorous at present than during the period of formation.

Only careful study of present groundwater conditions and evaporation rates in the area, will enable one to answer this question.

(11) Types of Interstitial Cement.

Of all the variables mentioned in the literature on this subject, interstitial cement forms the focal point.

Aragonite has been stipulated by Ginsberg (1953, p.91) as the cementing material. Wholly aragonite cement occurs in beachrock from

Florida (Daly 1924, p.136), the British Honduras (Stoddard 1962, p.161), and the Marshall Islands (Emery, Tracey and Ladd 1954, p.44).

Conversely, Russell (1963, p.24) shows that beachrock is cemented by calcite, quoting Port Hedland and Hamelin Pool, Australia, as examples. Emery and Cox (1956, p.382) describe primary calcite cement. Kaye (1959, p.70) has found crystalline calcite cement in Puerto Rican beachrock, confirmed optically and by cobalt nitrate staining. (Meigens Solution, Friedman 1959, p.95). This test was applied to the various 'Zones' of beachrock in False Bay, with negative results. Staining with Alizarine Red S (Friedman 1959, p.93) for calcite, was strongly positive. This was checked microscopically as well as by X-ray diffraction. The results obtained from the X-ray indicated a low magnesium calcite. No traces of aragonite were reflected.

The mineral aragonite is metastable and under certain conditions it tends to recrystallize as calcite. These conditions, as given by Cloud (1962, p.105), are that of transferance from aragonite-saturated salt water to aragonite-undersaturated fresh water, or, under moist atmospheric conditions, aragonite will alter to calcite. Deer, Howie and Zussman (1962, p.311) state that at normal temperature and pressure, aragonite will fairly readily invert to calcite. Revelle and Fairbridge (1957, p.275) conclude that the alteration from aragonite to calcite may occur over a period of months, or take many thousands of years.

Modern shallow-water carbonate sediments are composed of aragonite and high-magnesium calcite with subordinate amounts of low-magnesium calcite, according to Friedman (1965, p.1191). As previously stated, the False Bay calcareous material is composed of low-magnesium calcite, that is, calcite with less than 4% magnesium carbonate in solid solution.

From the literature it becomes apparent that numerous workers have studied beachrock cement with strikingly contradictory results. Both aragonite and calcite have been reported from beachrock in north-west Madagascar by Guilcher (Stoddart and Cann 1965, p.244). In addition, Russell (1959, p.228) briefly describes a ferruginous beach-rock at Old San Juan, Puerto Rico.

It appears that the geographical position plays an important part in the type of cement present. Aragonite and high magnesium calcite as cementing agents in tropical and sub-tropical areas, with low magnesium calcite as the bonding material in cooler but semi-arid and arid environments.

(111) <u>Position and Attitude</u>.

As mentioned above (p.53), Russell (1963, p.24) considers that "cementation of beachrock occurs along the water table under a beach". His 1962 paper (p.11) indicates that true beachrock may form up to two metres above sea-level, as he claims has happened in Spain and Hawaii.

Kaye (1959, p.79) requires the formation of a beachrock pavement in a limited area, that is, the intertidal zone.

"Recent beachrock occurs discontinuously in the intertidal zone, on islands with sand beaches, as a series of thin beds which dip seaward at less than 15^{o} and whose strike is parallel to, or at slight angles with, the trend of the present beach". These are Ginsburg's (1953, p.85) requirements for beachrock.

Listing neritic carbonate sediment types in order of grain size, Revelle and Fairbridge (1957, p.285) describe beachrock as a lime clastic, adding; "characteristically inorganically cemented under conditions of intertidal exposure - - -".

Of the abovementioned authors, Russell alone forms beachrock out of the intertidal zone. Fairbridge (1950, p.61) gives examples of beachrock found at 12 to 15 feet above sea-level, but adds; "It must be assumed that it represents beach formations formed through a period of changing sea-level - probably during the rise of sea-level at the beginning of Recent times".

Tanner (1956, p.311) however, is of the opinion that; "the presence of beachrock, by itself, is not sufficient evidence for placing a shore-line in the vicinity of the exposure".

This statement could lead to utter confusion. If beachrock is not formed on a beach, then there is neither any method of predicting where this material may be found, nor possible explanations for its formation. A beach must be accepted as "the wave-washed shore of a body of water", be it seawater or lacustrine. Hence if beachrock is found in older stratigraphic horizons this must be taken as evidence of an old shoreline.

The writer will use the term beachrock for rock which has formed in the intertidal zone by precipitation of carbonate cements, principally calcite.

Thus summarizing; beachrock has the following features:-

1) Formed in the intertidal zone.

2) Formed from beach material.

3) Two sets of 'joints' may be present, one set parallel to the coast, the second set at right angles.

4) Seaward dips of 15° and less.

5) Wedge-shaped, thinning seawards.

6) A flat, comparatively clearly defined base.

7) Induration decreasing downwards from the exposed case-hardened surface.

8) The cement may vary, aragonite, high magnesium calcite, low magnesium calcite, as well as ferruginous material.

9) Abrupt lateral truncation of the platform.

The final controversial point is the mode of cementation.

In 1849 Dana suggested that the $CaCO_3$ cement is derived from seawater in the pore spaces of the beach sand and is precipitated by physicochemical processes, principally through evaporation and a reduction of CO_2 partial pressure. Daly (1924, p.138) Keuenen (1950, p.434) Ginsburg (1953, p.91) Emery, Tracey and Ladd (1954, p.45 to 47) agree with this mode of formation.

Russell (1963, p.24) and Fairbridge (1950, p.46) are the exponents of the formation of beachrock by a $CaCO_3$ cement, derived principally from fresh water that has leached either overlying calcareous beach sand or calcareous rocks in the hinterland. The precipitate is formed by a combination of evaporation and aeration.

The possibility of organic material playing a part in the cementation process was first mentioned by Daly (1924, p.139), who wrote; "An initial cementation from seawater was produced by the ammonifying action of decaying organic matter incorporated with bottom sediments, and which has been piled onto the beach by storm waves". The possibility that algae may be responsible for a biochemical cementation process is considered by Cloud (1962, p.93 - 103).

Russell, (1959, p.232) quotes two algologists from the University of Maryland as concluding their studies on this subject with the statement that "algae appear to take no part in cementing sands within beaches".

The beachrock pavement in False Bay is in the process of destruction, thus evidence for or against biochemical cementation is lacking. Moreover the writer does not feel himself to be competent to investigate this aspect.

Numerous examples of beachrock settings with a hinterland of limestone have been quoted in literature, e.g. by Russell (1963, p.24), Fairbridge (1950, p.47) and Kay (1959, p.76). This type of setting would supply the calcite-saturated ground water.

But the opposite is true as well. For instance, beachrock is found "on islands too small to support a permanent watertable; on narrow necks of land where a watertable is unlikely to occur; and on spits permanently awash, where there seems little possibility of a watertable being established". (Stoddart & Cann 1965, p.244).

If the formation of beachrock depends entirely on super saturating interstitial beach water with respect to $CaCO_3$, by evaporation, it is difficult to explain a thick beachrock pavement as having formed other than by the accretion of numerous layers. These layers would reflect their individual lengths of exposure by the amount of induration shown. The greater the period of exposure, the greater the induration. This is not so, for induration decreases downwards. In the False Bay promontory area of the Strandfontein pavement, the basal layer of beachrock is a plastic material, hence exposure, if any, was very brief.

In a description of the beachrock on Guam, Emery (1962, p.62 to 63) describes fresh water entering a beach where a beachrock pavement had formed. The fresh water had partially destroyed the pavement, cutting deep rills into it. From this evidence he suggests that fresh water would probably prevent the formation of beachrock. Mabesoone (1964, p.725) describes the exact opposite occurring at Bairro Novo, Brazil. The name Strandfontein, indicates that in the past, fresh water must have seeped out from the dunes onto the beach.

The only mechanism the writer can visualize for the formation of beachrock on the False Bay coast, is deposition by fresh, lime-bearing waters, coming in contact with saline waters. To this must be added the minor effects of evaporation by both sun and wind acting during low tide. Russell (1963, p.24) requires a temperature of at least 70^{o}F. two or more feet below the beach surface for beachrock formation, which would limit the formation to summer conditions, if any at all, in the area under discussion. Therefore, despite the above statement by Emery, the major cementing process must be one of intermingling of the fresh and saline waters in the area studied.

This method would explain the existence of a wedge-shaped section pointing seawards. The abrupt termination on the shoreward side and the level base where beachrock abruptly ends against underlying beach sand, would reflect the zone reached by salt water at high tide.

Various authors such as Russell (1959, p.233) maintain that beachrock is often associated with coastal retreat. From this it follows that the oldest 'rock' would appear to seawards and the youngest inland. Previous reference to 'reefs' of beachrock has been made in this thesis, (p. 51&54), off both Strandfontein and Swartklip. The writer thinks these reefs mark an earlier stillstand, with subsequent removal of beach material from behind the pavement, causing the shallow gully between the two ages of beachrock.

The consolidated sands referred to by Haughton (1933, p.42) as appearing east of Strandfontein must be the material under discussion. He describes the exposure as overlain by a raised beach. The writer could not determine the position of this old beach, which must have been covered by sand. But from Haughton's excellent description, it does appear that the beachrock now exposed, must have formed at a still higher stand of the sea.

That the beachrock formed at a higher stand of the sea than the present, is clearly shown at Swartklip, where the shoreward exposure disappears under the beach sand at an elevation 8 ft. above mean sea-level. The tidal range in False Bay is approximately 5 ft. during springtides and 2 ft. during neaptides. Since, by definition, beachrock is formed in the intertidal zone, and it is at least 3 ft. above this zone, it cannot have formed at present sea-level, especially as a raised beach deposit overlies it.

The writer thinks that this material must date back to the period between the Intra and Late Monastrian, that is, a period of regression between the Minor Emergence and the 12 to 14 ft. emergence. The 12 to 14 ft. emergence must be represented by the raised beach deposit which has been described by Haughton (1933, p.42).

Curray (1961, p.1711) has shown that beachrock can be of great age. He describes beachrock and coquina found by Scuba divers at a depth of 18 m. off Freeport, Texas, adding, "These rocks probably represent the few remaining remnants of a beach line development from an interstadial approximately 30,000 years ago. Parts of the beach were cemented to form hard beachrock and coquina and survived the long sub-aerial exposure".

(C) ELECTRON MICROSCOPY.

(1) Laboratory Procedure.

In order to substantiate the statement that the previously described beachrock was not a sub-aerially formed calcrete now partially submerged and reworked, the writer attempted a programme of investigation by use of the Electron Microscope.

The depositional environment and subsequent history of a sediment has previously been traced by this method. (Porter 1962, p.124) (Kinsley et al 1964, p.104); "The fundamental idea is that the depositional history is reflected in the surface features, based on the assumption that a water film protects the water-deposited grain, whereas the wind-blown equivalent is allowed to collide freely with its neighbours".

Samples were taken from the beach, beachrock and the backshore dunes in the Strandfontein area.

The obvious choice of grain material was quartz. This necessitated leaching of beachrock fragments for 24 hours in 0.1 normal hydrochloric acid. The quartz grain residue was then dried under an infra-red lamp.

Porter (1962, p.124) advocates that the quartz grains be cleaned by ultra-sonoration. This removes the fine particles attached chemically or by electrostatic forces. As the apparatus was not readily available, a chemical method was used. The procedure adopted was that of Krinsley and Takahashi (1964, p.423), as follows, "The grains are placed in concentrated nitric acid, boiled for one half-hour, washed with distilled water, boiled in a stannous chloride and hydrochloric acid solution for one half-hour, and finally boiled in distilled water for one half-hour". The grains are now ready for mounting and replication.

Two methods for replication are in common use; the single replica and double replica. The single replica method described by Biederman (1962, p.183) was first attempted, but the boiling in Hydrofluoric acid proved to be too vigorous for the platinum-carbon cast.

The second method, that of double replication, will be fully described, having given good results with comparative ease. The requirements of a double replica are described by Kahle and Turner (1964, p.605) as

(1) Lack of self-structure in the replicating film which could impair resolution.

(2) High contrast.

(3) Strength.

The writer thinks that a fourth criteria, ease of the removal of the first replica from the final, should be added.

The method employed by the writer was as follows:-

Strips of celluloid, 5 mm. x 20 mm. x 0.5 mm., are cut and dipped in acetone. Six to eight grains of the 'cleaned' quartz crystals are placed on the wetted section of the celluloid strip. The unit is now turned over onto a glass plate, and soft pressure is applied to the area holding the quartz grains. The celluloid strips are then placed in a dust-free glass container, to harden, for twelve hours.

After this period, the quartz grains are removed with a sharp-nosed tweezer without exerting downward pressure on the celluloid. The replica strips are now ready for shadowing.

The shadow casting is achieved by depositing, in a vacuum, a layer of electron dense material onto the specimen, at an angle. The technique is known as 'self-shadowing' since the parts screened by the irregularities are shielded, and thus not coated as thickly as the exposed sections. The shielded areas are more electron transparent than the heavily coated surfaces, resulting in a shadow-like appearance when photographed. The whole gives an impression of oblique illumination, resulting in a three dimensional effect. The angle of shadowing was kept at 45^{o} for all samples, so as to produce the highest relief possible.

During shadowing, a film (approximately 100 to 150 A^{o} thick), of platinum and carbon (Kay 1961, p.84) is the most satisfactory. This combination of coating material provides the highest resolution yet obtained (Kay 1961, p.127).

The coated celluloid strips are now ready for the removal of the platinum-carbon coating. The procedure followed is outlined below.

Small sections, containing the indentations, are cut and the slivers placed in an evaporating dish for the removal of the celluloid. It was found that the direct addition of acetone caused a rapid break-up of the platinum coating, resulting in loss of the replica.

But if the 3 mm. replica mounting grid is dipped in acetone and then placed over the replicated area required, acetone can be added without damage. (A dry grid, placed over the area of impression, floats off immediately the solvent is added).

The celluloid rapidly dissolves in the acetone and the unprotected platinum coating breaks up and floats off. Constant decanting and addition of fresh acetone is necessary, six washes appear to be sufficient. No traces of the celluloid must remain as this shows very dark patches when observed at high magnification, obscuring all features.

When the grid appears to be lying flat on the base of the evaporating dish, it is possible to turn it over, releasing the platinum

PLATE 20 A.

Electron micrograph of a quartz grain from the intertidal zone. The triangular pits identify the environment from which the grain comes. (Magnification ± 10,000 X.)

PLATE 20 B.

Electron micrograph of a quartz grain from the dunes to the north of Strandfontein. The fracture marks are associated with aeolian sands. (Magnification ± 10,000 X.)

replica held below. This replica should be allowed to float in clean acetone for approximately fifteen minutes, ensuring the removal of all celluloid. The grid is now held below the replica and moved upward, catching the replica as centrally as possible. When this unit is dry, it is ready for inspection.

(11) Interpretation of the Micrographs.

The four most representative micrographs taken at 10,000 magnifications are illustrated on plates 20 and 21.

Water-deposited grains show regular triangular pits which according to Biederman (1962, p.183) follow the crystallographic form and are the result of solution. The markings on plate 20A are etch pits on the prism faces. The grain represented in the micrograph was taken from the intertidal zone. The markings, typically V-shaped, correspond to markings of material from the same environment as shown by Biederman (1962, p.184 Figs. 2 and 3); and Krinsley et al (1964, p.112 and 113, Plate IV A & B). This micrograph can thus be regarded as a typical water deposited grain. The number of V patterns present reflects the turbulence of the water in which the material is found. (Krinsley et al 1964, p.112 and 116).

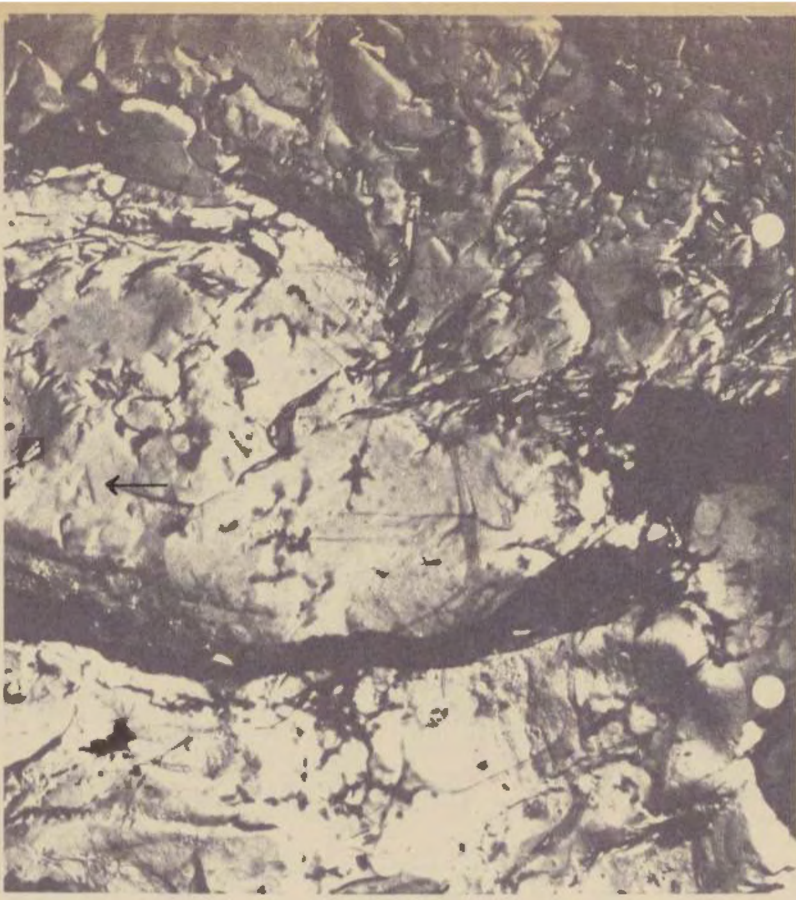
Plate 20B shows surface textures of a sand grain from the dunes immediately behind the Strandfontein beach. The dark pitted curved surfaces, of the moderate relief, are characteristics of the dune environment. These surfaces are not highly developed in the micrograph due to tha proximity of the shore-line. Krinsley and

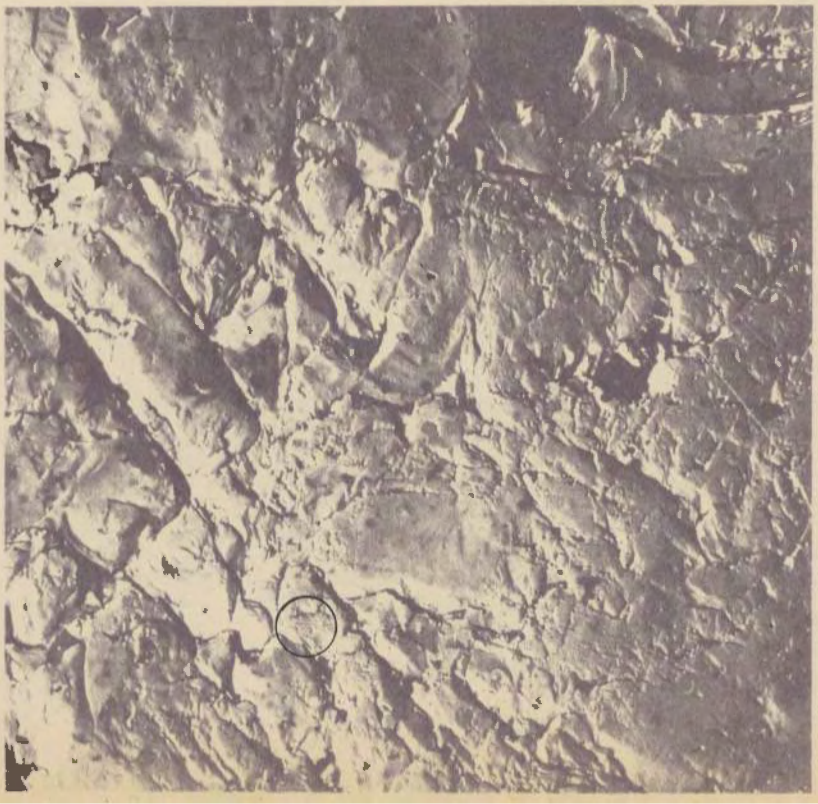
PLATE 21 A.

Electron micrograph of the lower layer of beachrock. The celluloid replica material had not been completely cleaned off the platinum cast hence the darker streaks and blebs. The arrow points to a typical inter-tidal pit mark, showing that the material is of marine origin.

PLATE 21 B.

Electron micrograph of case-hardened beach-rock. All evidence of the original environment has been destroyed by calcite attack. The area circled shows striations in a line with the crystallographic axis, a feature associated with the removal of quartz by calcite.





Takahashi (1962, p.426) have experimentally shown that the rounding of the surface texture increases with aeolian movement. The size of the 'pits' indicate the limits of the fine quartzose dust removed by abrasion (Biederman 1962, p.184).

The texture of a grain of quartz from the lower zone of the beachrock is shown on Plate 21A. The celluloid replica material has not been removed entirely, resulting in the darker 'blebs' present. Sufficient of the surface of the grain is exposed to distinguish the typical V-shaped pattern of the beach material. Attack by calcite is in evidence, the V-patterns being less pronounced than in Plate 20A.

A thin section * of the case-hardened material had been studied under the petrological microscope, where it was clearly seen that rounded, well embayed quartz grains 'floated' in a matrix of brownish calcite. The fourth micrograph, Plate 21B, is of a quartz grain from the above material. The resemblance to aeolian material is at first glance marked, but Porter (1962, p.132) describes these features as 'corroded'.

The micrograph shows clearly discernable 'striations' which, according to Porter (1962, p.133), are closely related to the lattice structure, thus indicating the corrosive effect of calcite on the quartz grains.

From the above evidence, the writer concludes that this material is a true beachrock.

* The thin sections were made by immersing a slice (approximately ¼ inch thick) in an epoxy resin. The resin was first diluted to one-third by the addition of the cleaning liquid supplied with it. The resin and rock slice were then placed in a dessicator and evacuated until the bubbling ceased. The slice was then removed and hardened under an infra-red lamp. Normal thin section mounting procedure then followed.

PLATE 22

Sampling Grid of False Bay

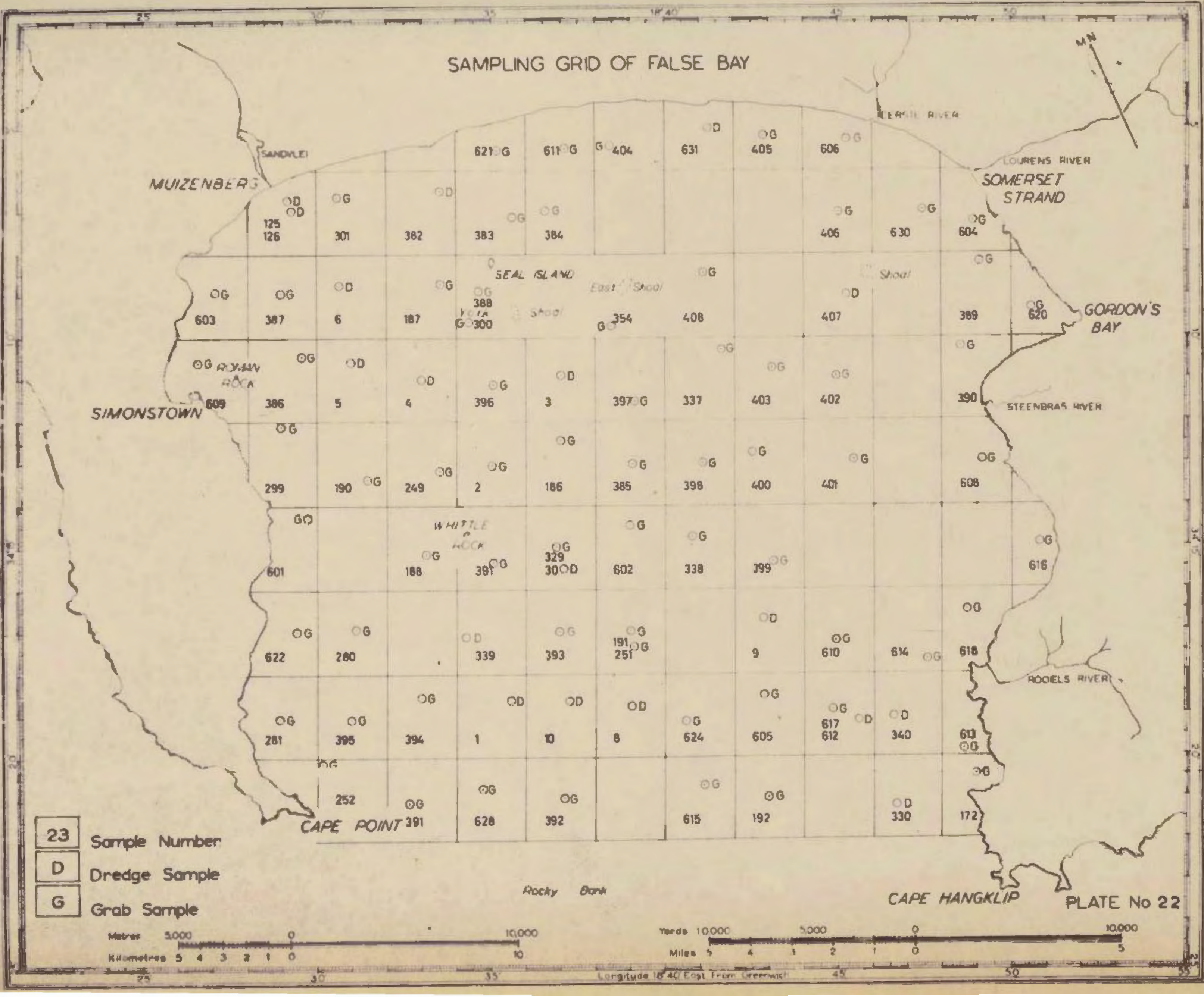

SAMPLING GRID OF FALSE BAY
MUIZENBERG
SANDVLEI
SEAL ISLAND
East Shoal
Shoal
ROMAN ROCK
SIMONSTOWN
WHITTLE ROCK
CAPE POINT
Rocky Bank
CAPE HANGKLIP
SOMERSET STRAND
LOURENS RIVER
GORDON'S BAY
STEENBRAS RIVER
ROOIELS RIVER
MN
23 Sample Number
D Dredge Sample
G Grab Sample
Metres 5,000 0 10,000
Kilometres 5 4 3 2 1 0 10
Yards 10,000 5,000 0 10,000
Miles 5 4 3 2 1 0 5
Longitude 18°40' East From Greenwich

PLATE No 22

(IV) SEDIMENT ANALYSES.

(A) COLLECTION OF SAMPLES.

A van Veen type grab was used throughout the sampling operations, and the following procedure was employed:-

The depth of grab was measured by a Marconi Echo Sounder as well as by direct reading of the winch. The grab was swung inboard, emptied into a large metal container, and the water removed, either by slow decanting or siphoning. If the sample was small the entire contents of the container was taken for further laboratory inspection. If large, the container's contents was quartered and a quarter retained.

When no grab sample could be obtained after repeated attempts, the sediment of the dredge was kept for further investigation. Dredge samples were collected at all stations by the Zoological Department for benthic studies. These samples taken from the dredge have been shown on the Sampling Grid (Plate 22).

It seems that sorting is probable in the dredge. Fuller (private communication) checked the sorting of samples taken by dredge in shallow water off Muizenberg. A skin diver plunged a bottle into the sediment, in approximately the same area as the dredge sample. The size analysis curve obtained in no way deviated from the curve for the dredged sediment. This experiment was similar to that of Morgans' (1956, p.11), who concludes that "Analyses show no significant difference".

The moderately shallow water at all stations in the bay favours the taking of unsorted representative samples both by dredge and grab.

Location of stations were of a high order of precision as visual "fixes" could be obtained from well-spaced shore stations at all times. The stations from which the samples were taken were spaced on a grid. This grid (Plate 22) was formed by two minute square spacings over the bay.

(B) ANALYSES AND PLOTTING OF RESULTS.

(1) Mechanical Analyses.

The samples were air-dried and described using Ingram's (1965, p.619 to 625) method of classification. The material was then split by a Jones Splitter and size parameters measured either with a settling tube or by sieving. (These two methods are further discussed on page 116).

For sieving, B.S.S. sieves, spaced at half phi intervals were used. This spacing accords with Folk (1966, p.75) who states that screens should be spaced at half or quarter phi intervals, as a full division is virtually uselesa, especially if one is studying the characteristics of the sediment tails.

A sub-sample of approximately 100 grams was obtained from the Jones Splitter and used for sieving. This sieving was done dry, by agitation for a period of twenty minutes on an Endrock machine. This is the optimum period determined from a series of tests run over times varying from 5 to 60 minutes.

Prior to, and after sieving, the screens were microscopically checked for aperture size. The greatest difference recorded was 0.07 phi (0.952 mm.), but most of the sieves showed no discrepancy between the measured size and that specified by the manufacturer.

Some False Bay samples contained as much as 1% aggregated material. During sieving these aggregates were broken down to individual grains by placing one inch diameter rubber balls in the upper sieves. These balls did not break individual grains, but achieved good disaggregation. Failure to disaggregate a sediment during sieving has a very marked effect on the more sensitive statistical measures, such as skewness and kurtosis, which reflect the normality of a distribution. In False Bay aggregation was found to occur after drying, caused by the various salts remaining after the sea-water had evaporated. This material could have been disaggregated by washing in distilled water, or if that failed, by the addition of a dispersing agent such as "Calgon", Duane (1964, p.866). But this was found to be unnecessary. After sieving, the material in each screen was weighed to 0.01 grams (Folk et.al. 1957 p.6) The cumulative weight was then taken and the cumulative percentage derived and plotted against the phi values, using arithmetic probability paper. When using this type of paper, a sediment showing zero skewness and kurtosis equal to 1 (p.101 & 105) is represented as a straight line, that is, a normal distribution appears as a straight line.

Harris, Inman, Mason and Rogers (op. cit.) all advocate the use of probability paper. Folk et. al. (1957, p.6) states "It is a waste of time to plot analyses on any other type of paper (ordinary squared paper for example) as interpolation between data points is much more inaccurate and not reproducible".

The size classification is based on the Wentworth scale, all values being converted to phi values before plotting. Phi (Ø) is the symbol for the negative logarithm to the base two of the grain diameters in millimetres. This notation was first introduced by Krumbein (1936, p.36), and because of numerous advantages, such as simplification of grade scale and the easy meaningful application of statistics to data, the notation has come into standard use.

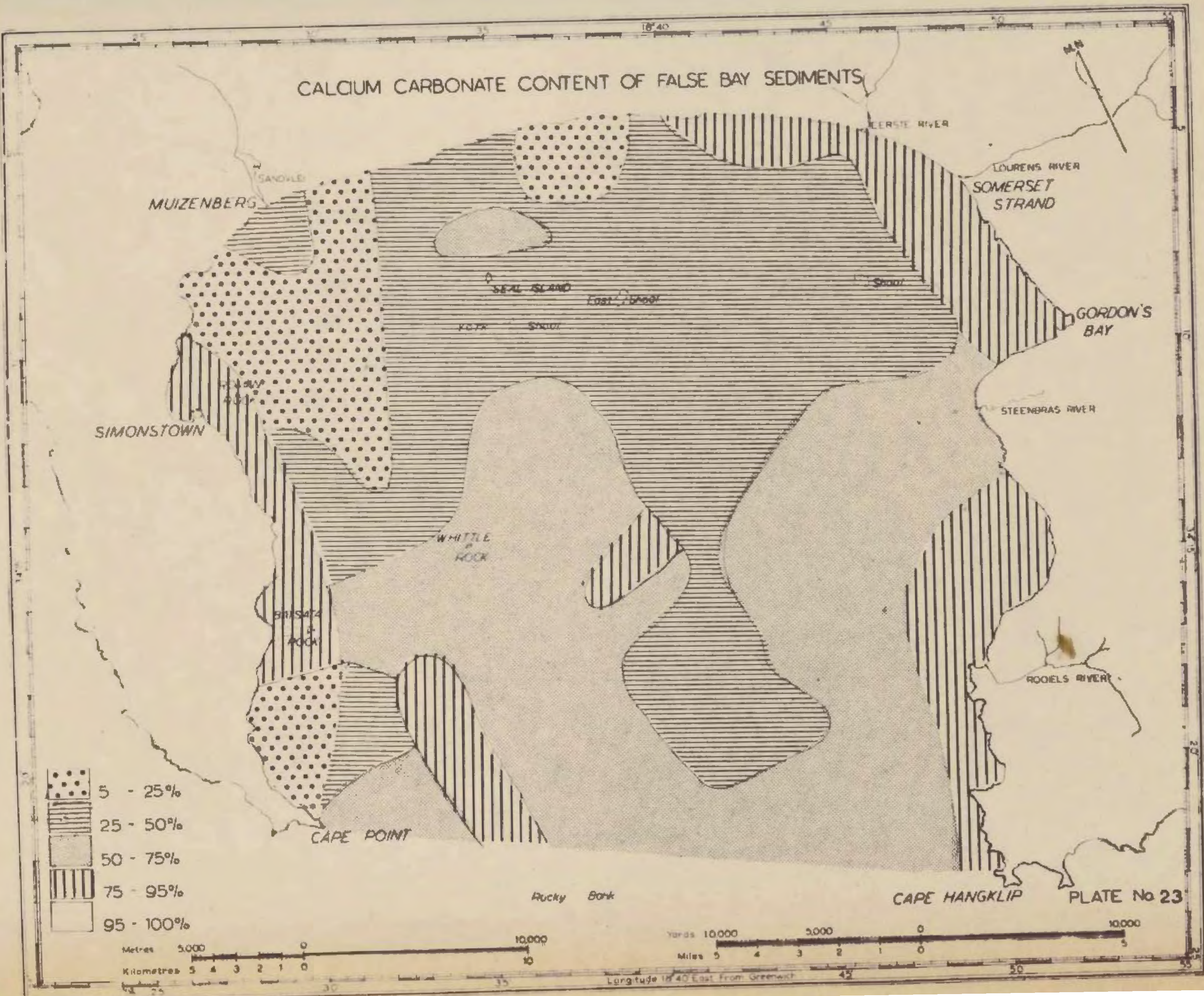
Conversion is as follows:-

	MM.	Phi (Ø)	Mesh B.S.S.
	2.0	- 1.0	10
Very coarse		- 0.5	14
	1.0	0	18
Coarse		0.5	25
	0.5	1.0	35
Medium		1.5	45
	0.25	2.0	60
Fine		2.5	80
	0.125	3.0	120
Very Fine		3.5	170
	0.0625	4.0	230

All statistical calculations were made on an I.C.T. 1301 computer.

PLATE 23

Calsium Carbonate Content of False Bay Sediments


CALCIUM CARBONATE CONTENT OF FALSE BAY SEDIMENTS
MUIZENBERG
SIMONSTOWN
SOMERSET STRAND
GORDON'S BAY
LOURENS RIVER
STEENBRAS RIVER
ROOIELS RIVER
SEAL ISLAND
WHITTLE ROCK
CAPE POINT
CAPE HANGKLIP
Rocky Bank
5 - 25%
25 - 50%
50 - 75%
75 - 95%
95 - 100%
PLATE No. 23

(11) Calcium Carbonate Determination

The percentage carbonate distribution over the area studied is illustrated on Plate 23. The percentage $CaCO_3$ was determined as follows:-

The sediment sample was split down to approximately 10 grams for leaching. Greater quantities were not used owing to the length of time and ease of handling. The weighed sample was transferred to a 1 litre beaker and 1/10N. hydrochloric acid added until effervescence ceased.

The contents of the beaker was then filtered off and dried under infra-red lamps, after which the sediment was weighed. From the weight loss the percentage weight loss was calculated. The carbonate percentage given by this rough method of analysis is not highly accurate but sufficient for the purposes of this investigation. Duplicate analyses varied by as little as 0.1%, but variation increased for samples composed mainly of carbonate material.

In general, the $CaCO_3$ content of the samples are high, values of 25% to 75% occurring in most of the sediments. The northern section of the bay shows values in the 25% to 50% range, while the deeper water shows a higher percentage i.e. 50% to 75%. The eastern and western coastlines, both of a rocky nature, show values ranging from 75% to 95%. A further two small areas occur, one to the north of Rocky Bank and the other to the east of Whittle Rock.

(C) MEGASCOPIC DESCRIPTION OF THE SEDIMENTS.

The procedure followed in this section is that suggested by Ingram (1965). This method is rapid, allowing approximately 50 samples to be described per day.

From this rapid initial investigation, facies maps may be produced. These maps are based on areal variations in shell content, colour changes, minimum grain size, modal class and maximum grain sizes present. If required, these features may be combined to give a gross lithology map.

Slight variations to the procedure, outlined by Ingram, were made by the writer, thus the procedure followed is briefly outlined.

(1) Preliminary.

1. The sample was placed in a plastic dish and allowed to dry in air.
2. The colour index was noted by placing a representative sample on a sheet of white paper and comparing the sample with the National Research Council Rock Colour Chart, on which black is number one and white number nine.
3. Six slides were prepared with grains corresponding to the Wentworth Size Classification, granules to silt.

(11) Procedure.

1. A representative sample, one grain thick, was placed in a Petri dish. This sample was studied under a binocular microscope for the

determination of :-

a) Shell content.

b) Minimum grain size.

c) Modal Class.

d) Maximum Grain Size.

(111) Shell Content.

Since the False Bay samples show a large percentage range of shell material, the frequency estimation table as given by Ingram (1965, p.619) was altered to read as follows:-

Percent	Descriptive Term	Abbreviation.
95 - 100	Dominant	D
75 - 95	Abundant	A
50 - 75	Plentiful	P
25 - 50	Very Common	V.C.
5 - 25	Common	C
0 - 5	Scarce	S

This table employs all the measures suggested by Ingram but sub-divides his large "Plentiful" class covering the 25 - 75% into two more realistic groups as far as False Bay is concerned. If further sub-divisions are required, then a division into plus and minus values similar to that suggested by Ingram could be made.

In an area the size of False Bay, where the shell contents vary so greatly, it seems that the subdivision of the range 0 - 25% and 75 - 100% into eight groups, after Ingram, may obscure the broad outline.

Since this method is designed for preliminary investigation only, it is felt that the further sub-division of the above groups should only be attempted if the shell content of the samples do not cover a large range.

1V) <u>Size Analyses</u>.

For the size estimation, use is made for comparison purposes of the previously mentioned slides (page 77). One further point mentioned by Ingram (p.621), which is worthy of note, is that clay is not resolved and is regarded as silt.

The writer found Ingram's method of notation very rapid, but adapted a very slightly different procedure as follows:-

The modal class is first determined and underlined with a double line. A letter symbol is used to denote each class (S - silt, VF - very fine sand, F - fine sand, M - medium sand, C - coarse sand, VC - very coarse sand, G - granules).

The amount of the various classes appearing is then shown as follows:-

_ (underlined) almost the modal class.

x common

o scarce

- (above) very small amounts

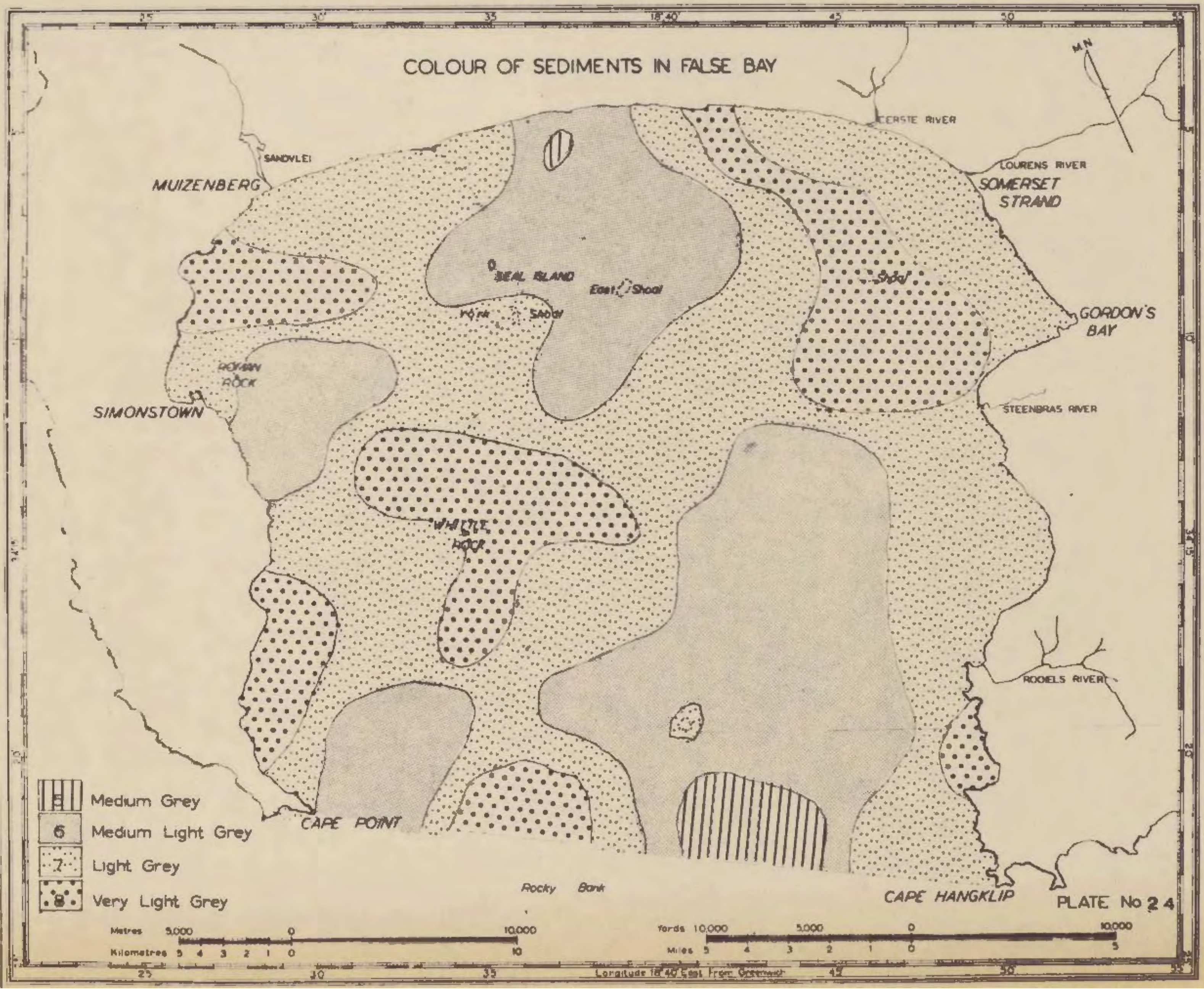
Thus an entry such as:-

S,	VF ,	F ,	M ,	C
	o	-	=	x

would read; Medium grain size as modal class, coarse grains common, fine grains nearly equal to modal class, very fine sand occurs but scarce and some silt does appear.

PLATE 24

Colour of Sediments in False Bay


COLOUR OF SEDIMENTS IN FALSE BAY
SANDVLEI
MUIZENBERG
EERSTE RIVER
LOURENS RIVER
SOMERSET STRAND
SEAL ISLAND
East Shoal
York Shoal
Shoal
GORDON'S BAY
ROMAN ROCK
SIMONSTOWN
STEENBRAS RIVER
WHITTLE ROCK
ROOIELS RIVER
CAPE POINT
Rocky Bank
CAPE HANGKLIP
PLATE No 24
5 Medium Grey
6 Medium Light Grey
7 Light Grey
8 Very Light Grey
Metres 5,000 0 10,000
Kilometres 5 4 3 2 1 0 10
Yards 10,000 5,000 0 10,000
Miles 5 4 3 2 1 0 5
Longitude 18°40' East From Greenwich

(D) FACIES MAPS.

(1) Colour Index Map. (Plate 24).

The colour range of the bay sediments varies from 5, Medium Grey, to 8, very light grey. Only the basic colour is recorded, not the hue.

Generally the sediments of the bay are light in colour. A light grey colour (number 7) covers the greatest area, and forms the "background". This light area extends from north of Rocky Bank, and lies in a broad zone along the east coast of the Peninsula. To the northeast of Rocky Bank, the deep entrance to the bay shows the darkest zone of sediments. One small dark area occurs in the extreme north. The colour of this area is probably caused by the organic content of the sediment.

(11) Shell Content Map. (Plate 25).

Four of the six groups referred to on page 78 are present. The following table lists their relative percentages.

Dominant	3.0 %
Abundant	18.5 %
Plentiful	31.0 %
Very Common	33.0 %
Common	14.5 %

PLATE 25

Shell Content of False Bay Sediments

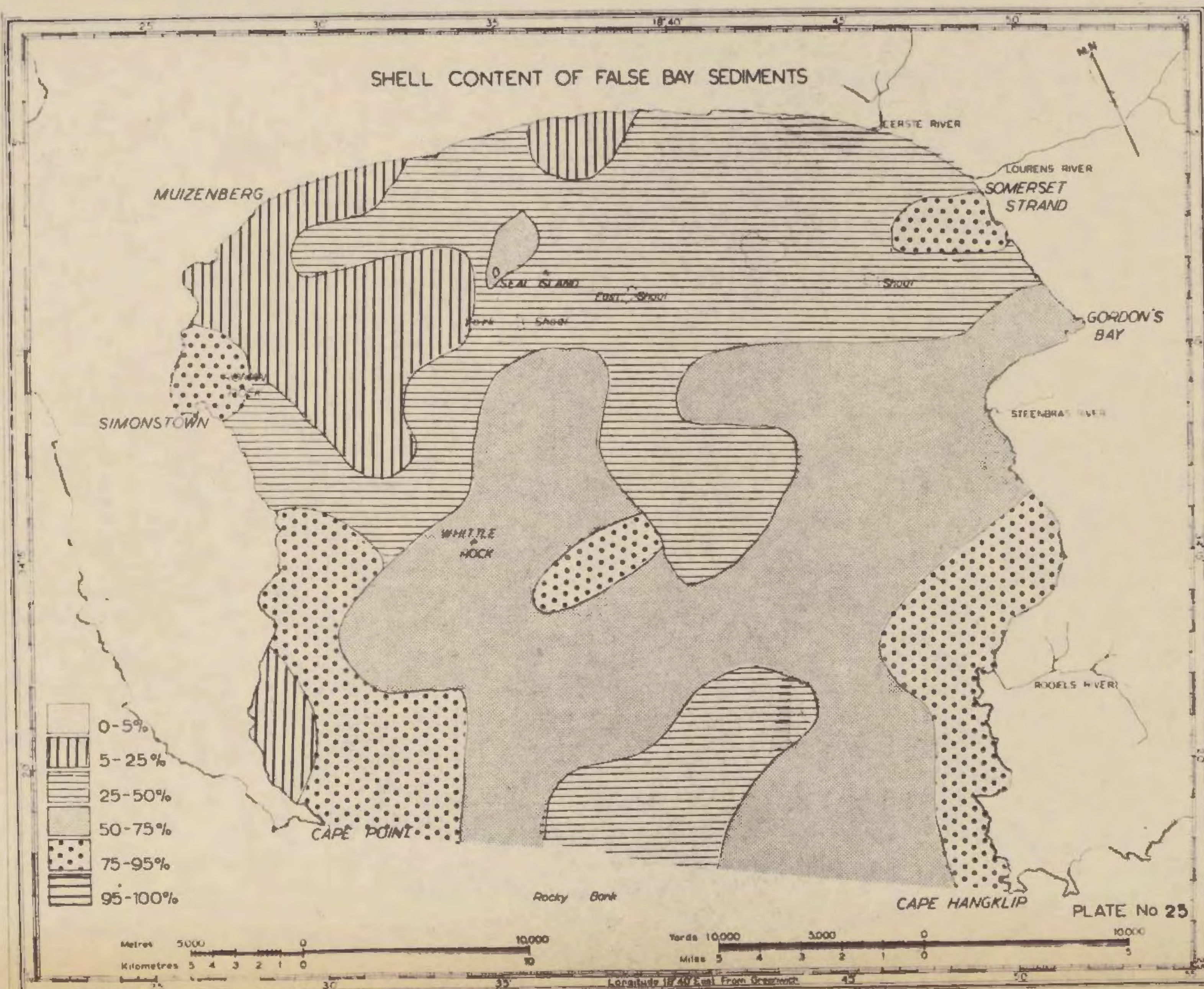

SHELL CONTENT OF FALSE BAY SEDIMENTS
EERSTE RIVER
LOURENS RIVER
SOMERSET STRAND
MUIZENBERG
SEAL ISLAND
East Shoal
Shoal
GORDON'S BAY
SIMONSTOWN
STEENBRAS RIVER
WHITTLE ROCK
ROOIELS RIVER
0-5%
5-25%
25-50%
50-75%
75-95%
95-100%
CAPE POINT
Rocky Bank
CAPE HANGKLIP
Metres 5000 0 10,000
Kilometres 5 4 3 2 1 0 10
Yards 10,000 5000 0 10,000
Miles 5 4 3 2 1 0 5
Longitude 18°40' East From Greenwich

PLATE No 25

The largest zones where shells occur abundantly are the coast of the southeastern section of the Peninsula and the coast of the south-western section of the mainland. Both these areas are rocky with sharply shelving coastlines.

Just north of Cape Point a single sample records a shell content of 5 - 25% as opposed to the 75% plus samples surrounding it. This sample (No. 281) was checked but no alteration could be made. Therefore this is possibly a sample which does not reflect the average conditions at this point.

The two small areas, which show "abundant" shell content are in shallow water. These areas, one off Simonstown and the other near Somerset Strand, are probably due to a high benthic population in areas of effluent discharge.

A spurious high zone has been found in the southern central section. At this stage no attempt will be made to explain the reason for its occurrence.

The plentiful zone occurs mainly in a broad swath from Gordons Bay, extending towards deeper water at the mouth of the bay. One small area is directly west of Seal Island.

Along the northern shores of the bay, in shallow to moderately deep water, is the largest zone of sediments with a "Very Common" shell content. One further area occurs at the mouth of the bay in deep water. This zone may be due to water circulation.

The area classified as "Common" is in shallow water where the movement of the water possibly results in the relatively low percentage of shell material.

PLATE 26

Minimum Size of False Bay Sediments

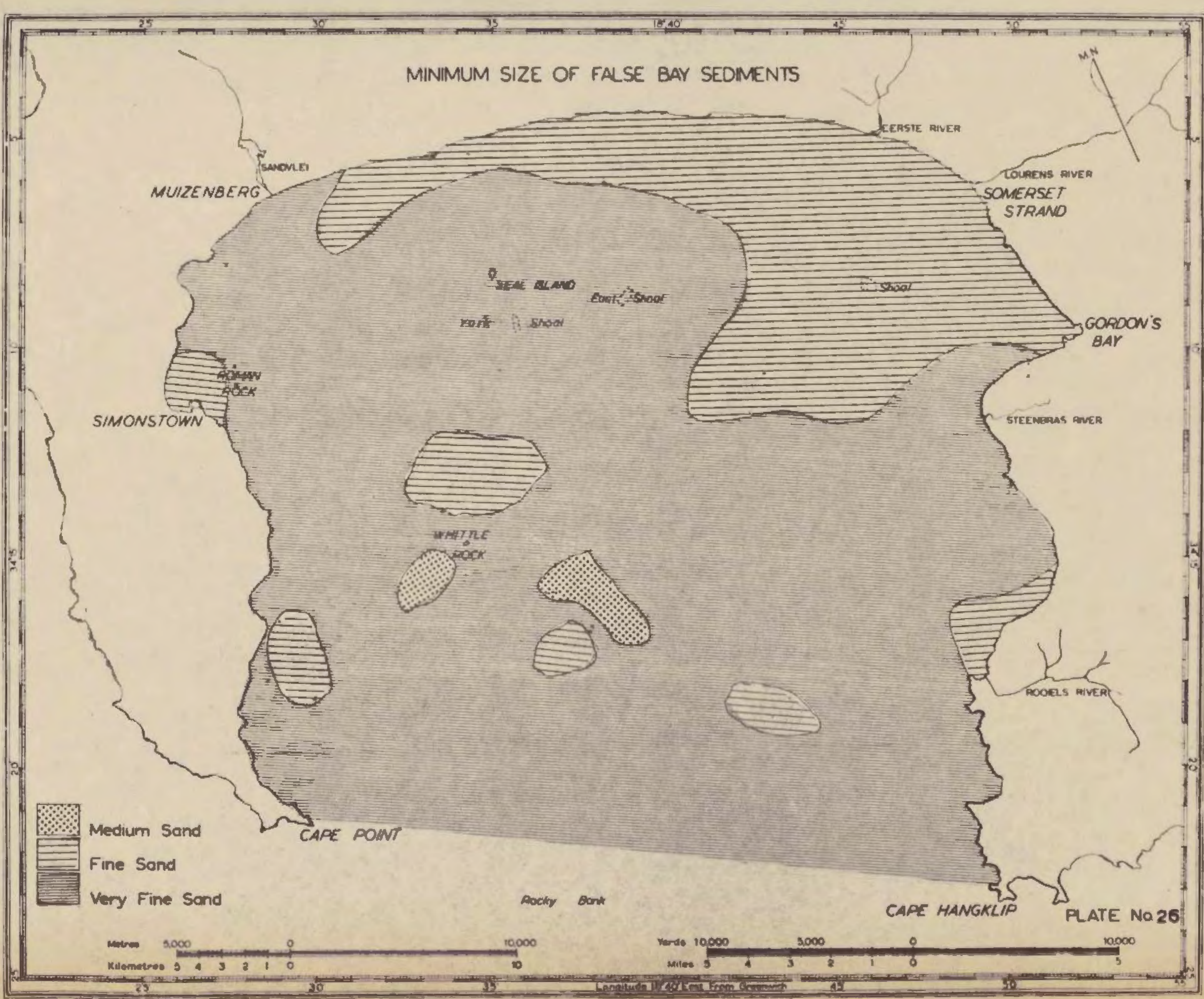
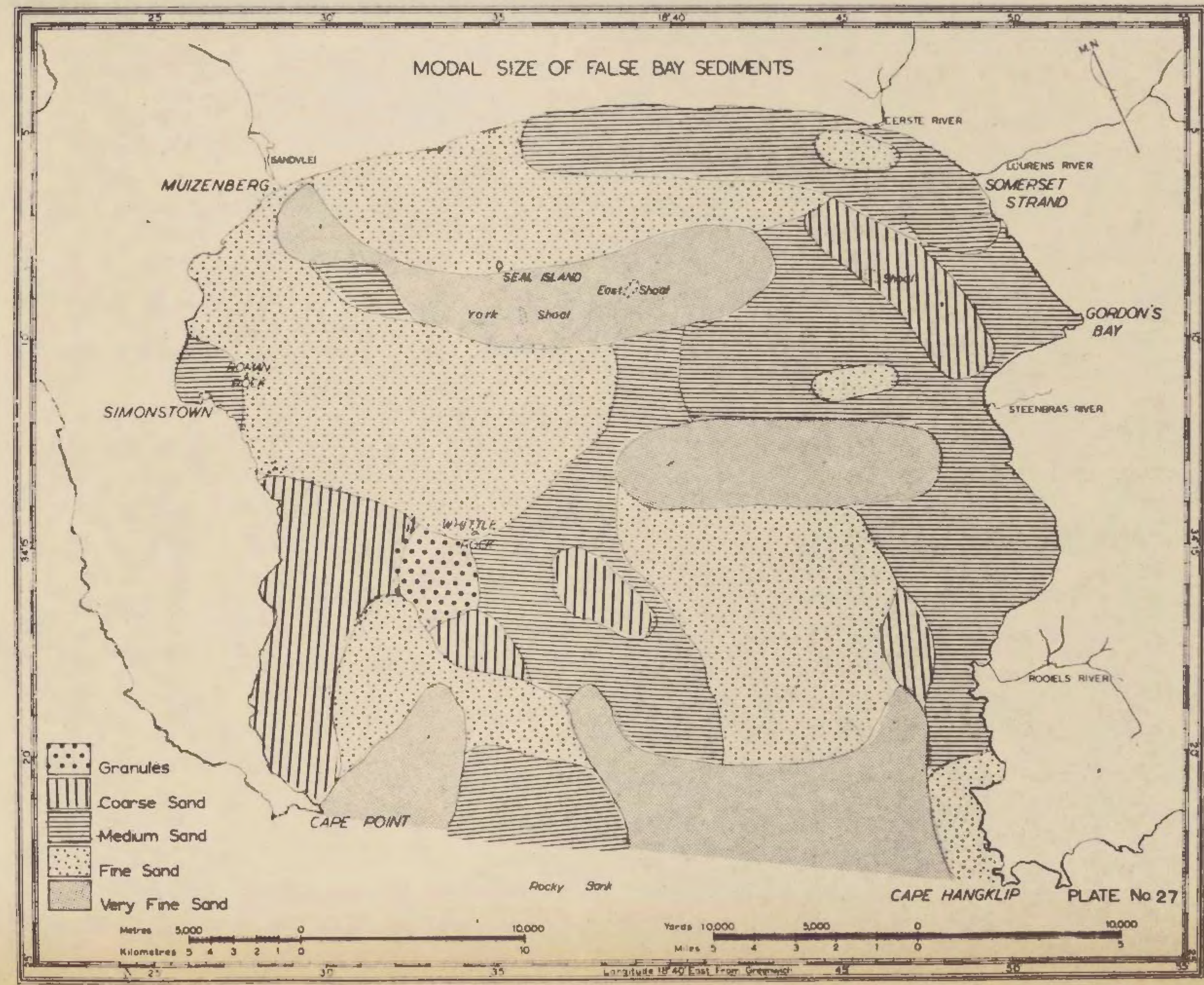

MINIMUM SIZE OF FALSE BAY SEDIMENTS
EERSTE RIVER
SANDVLEI
MUIZENBERG
LOURENS RIVER
SOMERSET STRAND
SEAL ISLAND
East Shoal
Shoal
York Shoal
GORDON'S BAY
ROMAN ROCK
SIMONSTOWN
STEENBRAS RIVER
WHITTLE ROCK
ROOIELS RIVER
Medium Sand
Fine Sand
Very Fine Sand
CAPE POINT
Rocky Bank
CAPE HANGKLIP
PLATE No. 26
Metres 5,000 0 10,000
Kilometres 5 4 3 2 1 0 10
Yards 10,000 5,000 0 10,000
Miles 5 4 3 2 1 0 5
Longitude 18°40' East From Greenwich

PLATE 27

Modal Size of False Bay Sediments


MODAL SIZE OF FALSE BAY SEDIMENTS
EERSTE RIVER
SANDVLEI
MUIZENBERG
LOURENS RIVER
SOMERSET STRAND
SEAL ISLAND
East Shoal
York Shoal
Shoal
GORDON'S BAY
ROMAN ROCK
SIMONSTOWN
STEENBRAS RIVER
WHITTLE ROCK
ROOIELS RIVER
CAPE POINT
Rocky Bank
CAPE HANGKLIP
PLATE No 27
Granules
Coarse Sand
Medium Sand
Fine Sand
Very Fine Sand
Metres 5,000 0 10,000
Kilometres 5 4 3 2 1 0 10
Yards 10,000 5,000 0 10,000
Miles 5 4 3 2 1 0 5
Longitude 18°40' East From Greenwich

(111) Minimum Grain Size Map (Plate 26).

Very fine sediments predominate as the minimum grain size over the largest part of the bay. Along the northern coast, from Gordons Bay to Muizenberg extends a zone of sediments with fine grains forming the minimum size. This zone is in shallow water, where the wave base must disturb the sediments, removing the very fine material.

Two areas, off the central southeastern coast of the Peninsula show medium grain sizes as the finest present. This area also shows anomalous results on Plates 27 and 28. The plate depicting shell content (Plate 25) shows a small area, in this region where the shell content is 'Abundant'. This area falls across the eastern zone of medium grain size. Thus it appears that in this region coarse shell particles are accumulating, while the finer material is being winnowed away.

(1V) Modal Class Map. (Plate 27).

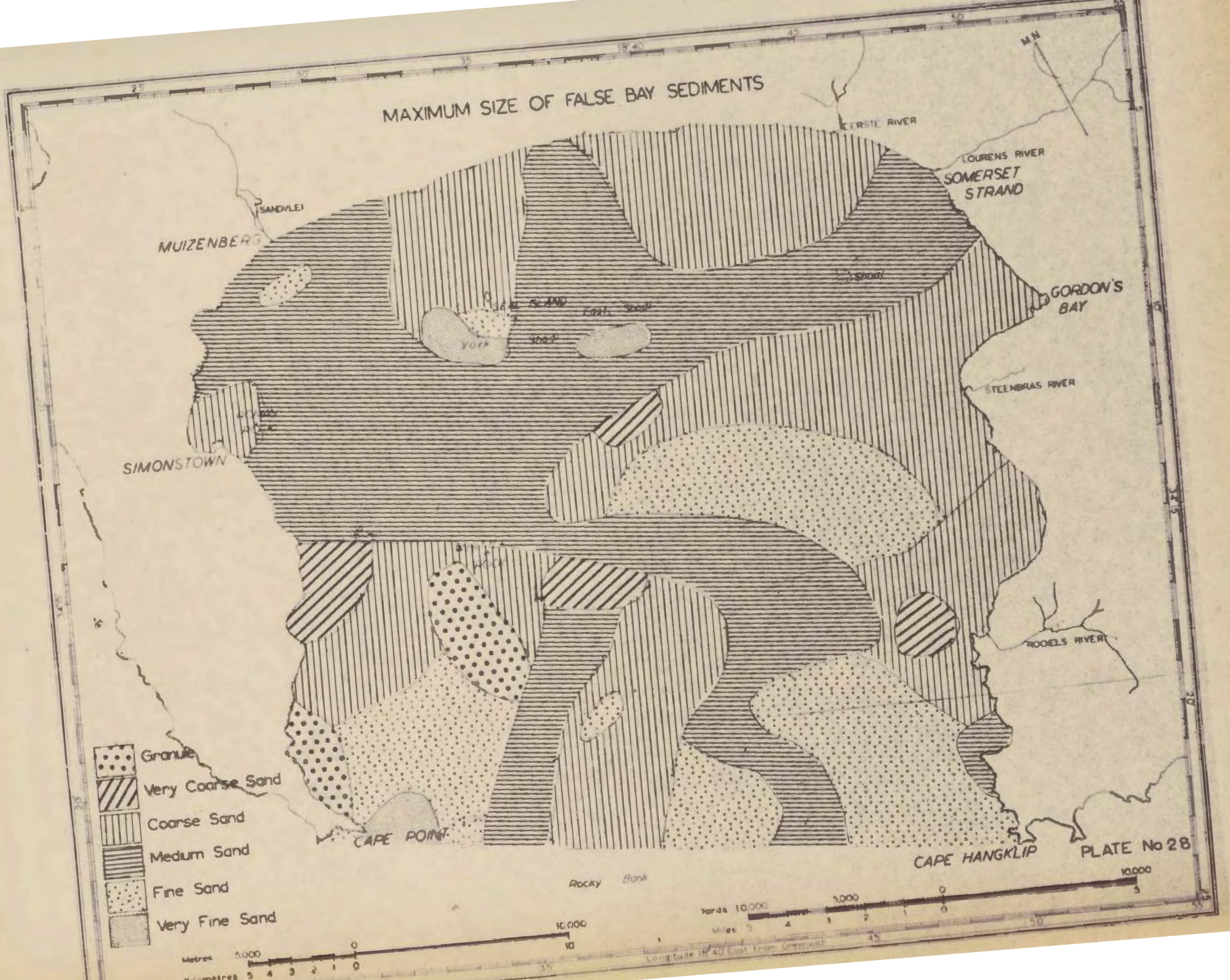
The modal class, or most commonly occurring value, shows that the finest sediments of this class found in the bay are at the entrance, just east of Rocky Bank. Immediately to the north of this underwater obstruction there is an increase in the modal class size.

The coastal areas are generally composed of a coarse sediment, with the exception of the areas off Muizanberg and Fish Hoek.

The picture is again complicated in the zone just off the east coast of the Peninsula, where the preceding three parameters also showed an involved pattern.

PLATE 28

Maximum Size of False Bay Sediments


MAXIMUM SIZE OF FALSE BAY SEDIMENTS
ERSTE RIVER
LOURENS RIVER
SOMERSET STRAND
SANDVLEI
MUIZENBERG
GORDON'S BAY
SEAL ISLAND
East Shoal
York Shoal
STEENBRAS RIVER
SIMONSTOWN
ROOIELS RIVER
CAPE POINT
CAPE HANGKLIP
PLATE No 28
Rocky Bank
Granule
Very Coarse Sand
Coarse Sand
Medium Sand
Fine Sand
Very Fine Sand
Metres
Kilometres
Yards
Miles
Longitude 18°40' East From Greenwich

(V) Maximum Grain Size Map. (Plate 28).

According to the Wentworth scale, medium sediment grains form the major group under the above heading. Zones of fine material are present, one at the entrance, in deep water (80 fathoms). A further belt of fine material, running east-west, appears to the west of the centre of the bay. This belt corresponds to the belt of very fine material reflected on the modal class plot. Small areas of very fine sediment, indicative of very calm water, appear off Seal Island. "Coarse" and "Very Coarse" material appears off the coasts with the exception of the Muizenberg - Fish Hoek zone. Once again spurious results are recorded off the east coast of the Peninsula.

A north-south zone of coarse material appears just north of Rocky Bank.

(V1) Comparison of Facies Maps.

No Gross Lithology Map was drawn as the writer feels that this would confuse rather than clarify the position.

The shell content map (Plate 25) prepared from visually estimated values, shows comparatively close agreement with Plate 23 which depicts the calcium carbonate content of the sediments of the bay. It is thought that closer agreement would have been shown if the shell material was of a finer nature, and not as in some cases, practically whole shells.

Plates 26, 27 and 28, referred to in the previous section, show an area to the south and southeast of Whittle Rock where the size of the sediment is of a coarser nature for each of the size classes than is common in the bay. It appears that winnowing of the finer material is in progress, with possible addition of large shell fragments.

(E) <u>The Cumulative Curves</u>.

One of the fundamental purposes of extracting sediment parameters is for the correlation of sediment types and their environments. Thus the size frequency distribution is a fundamental physical property of a clastic sediment. It may be considered as a direct expression of the physical conditions within the environment of the deposition. Indirectly, it expresses the mode of transport of the material available.

Many sediment-size frequency distributions approximate to a normal distribution, or one of the family of curves (Doeglas 1946, p.33) derived from it. Tanner (1964, p.163) concedes to this by stating; "The notion that sediment size distributions are essentially normal (Gaussian) is adapted as a working hypothesis." Harris (1958, p.154) points out that if a deposit is fully adjusted to its depositional environment, that is, normally distributed, the use of arithmetic probability paper will produce a straight line or a series of straight lines. Each of these lines correspond . to a particular factor, or group of factors, in the physical environment.

If in plotting a straight line does not appear, this indicates non-adjustment to the depositional environment, or faulty sampling.

Doeglas (1946, p.33) describes three types of size-frequency distribution curves found along the coasts of Holland. Harris (1958, p.155) states that theoretically five lines are possible, but that only four are known in practice. These four may occur under aeolian or aqueous environments.

The five theoretical lines suggested by Harris correspond to:-

1. The finest grades, subject to total suspension when the current is at its strongest.
2. The finer interstitial material, consisting of a moderate amount of material covering a fairly wide grade range.
3. The bulk of the deposit, with a limited grade range.
4. The larger grains which have moved wholly by surface creep.
5. Large grains moved only at a period of extremely strong currents.

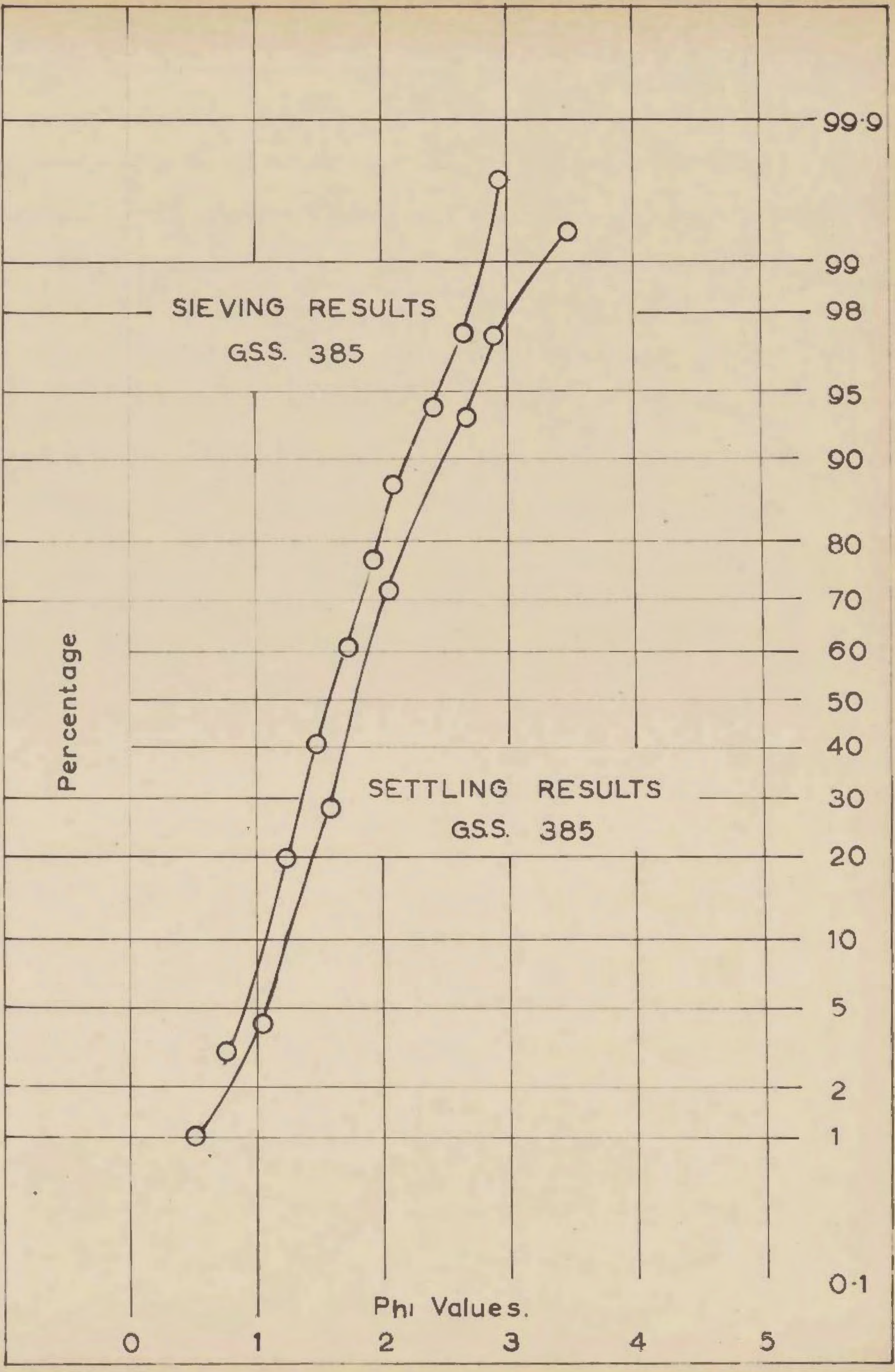
Line (5) is purely theoretical, as it merges with number four, and would be indistinguishable from four in practice.

Doeglas (1946, p.34) further shows that complications arise during mixing or reworking of sediments. An 'S' shaped curve results from mixing, the steeper or centre part of the 'S' representing the major part of the sample. Thus the possibility arises of multi-component curves occurring in any environment.

In False Bay the samples contain varying amounts of shelly material. These amounts range from approximately five to ninety-five percent. Fuller (1961, p.257) in a discussion on shallow marine sands, reports that the cumulative curves of shelly sands, containing 20 to 40 percent acid soluble material, do not show a significant change in

PLATE 29

Displacement of the Cumulative Curves



99·9
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
0·1
SIEVING RESULTS
G.S.S. 385
SETTLING RESULTS
G.S.S. 385
Percentage
Phi Values.
0
1
2
3
4
5

PLATE No. 29

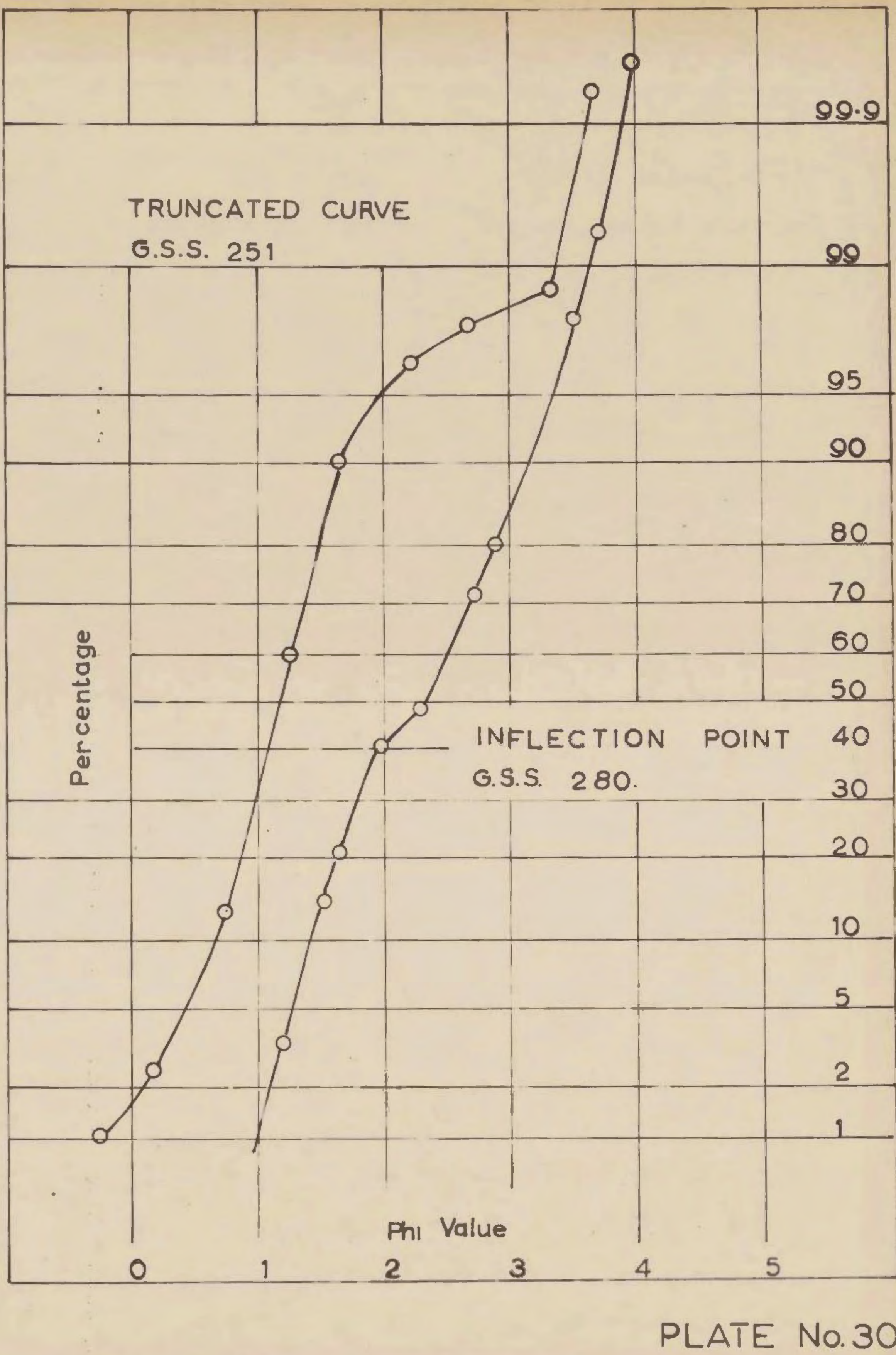
shape or position of the cumulatives once the samples have been leached. The type of shelly component found in this beach in the intertidal to shallow marine zone is generally a thick shell, that is, the three dimensions of the granulated shells do not differ greatly and thus will not act in a platy manner. Instead, these shells will behave very much like quartz grains. The specific gravity of calcite is 2.72, whilst that of quartz is 2.65, but the slight porosity of the calcite shell material reduces its specific gravity to a value very similar to that of quartz, and the two major components can be considered to be practically hydraulically equivalent. The deeper parts of the bay contain very much more platy material. A noticeable difference is seen in the way the shelly component behaves in sample No. 385 from 25 metres of water. This has a calcium carbonate content of 47.0 percent. A comparison of the cumulative curves obtained from settling tube results with those from sieving, (Plate 29) shows that the curve from the settling tube results are displaced by a large amount, 0.2 phi towards the finer material. Here the sieve passes the platy material according to the intermediate measurement. The settling tube probably gives a closer reflection of natural conditions by displacing this material towards the finer, hydraulically equivalent grains owing to the 'floating' action of the shell particles.

Certain of the cumulative curves (Plate 30) show strongly truncated characteristics in the finer grades. This truncation probably occurred during sampling. As previously stated, the winnowing effect of the grab moving through the water has been investigated and found negligible. Thus the loss of the fine fraction must have occurred

PLATE 30

Truncated Curve and Curves showing

the 2 phi Inflection point



TRUNCATED CURVE
G.S.S. 251
INFLECTION POINT
G.S.S. 280.
Percentage
99·9
99
95
90
80
70
60
50
40
30
20
10
5
2
1
Phi Value
0
1
2
3
4
5

PLATE No. 30

once the contents of the grab had been emptied into the metal container (p.72) on the deck. If the material had been given insufficient time to settle, or if the water contents had been 'roughly' removed, this fine fraction in the 3.5 range would have been decanted with the water.

Inflection points in the cumulative curves of shallow marine sediments have been described by Fuller (1961, p.256 and 1962, p.602) and Belderson (1961, p.29).

Two such points are reported by Fuller, working on samples taken around the coasts of the Cape. A number of these samples was taken in less than 20 m. depth in False Bay. The first inflection point he notes, is that at 0.8 phi, and suggests that this is the size that separates the traction from the suspension load. The more characteristic and more easily noticeable point, he states, is at the 2.0 phi mark.

If this two phi fraction has been differentially removed in the shallow marine environment, then he suggests two possibilities:- "Either the sand removed has been carried seawards into deeper water, or it has been left on the beach and made available to the prevailing onshore winds".

Belderson (1961, p.29) says that most of the Durban sands seem to show two points of inflection, one between 2 and 2.5 phi, and the second between 2.75 and 3 phi.

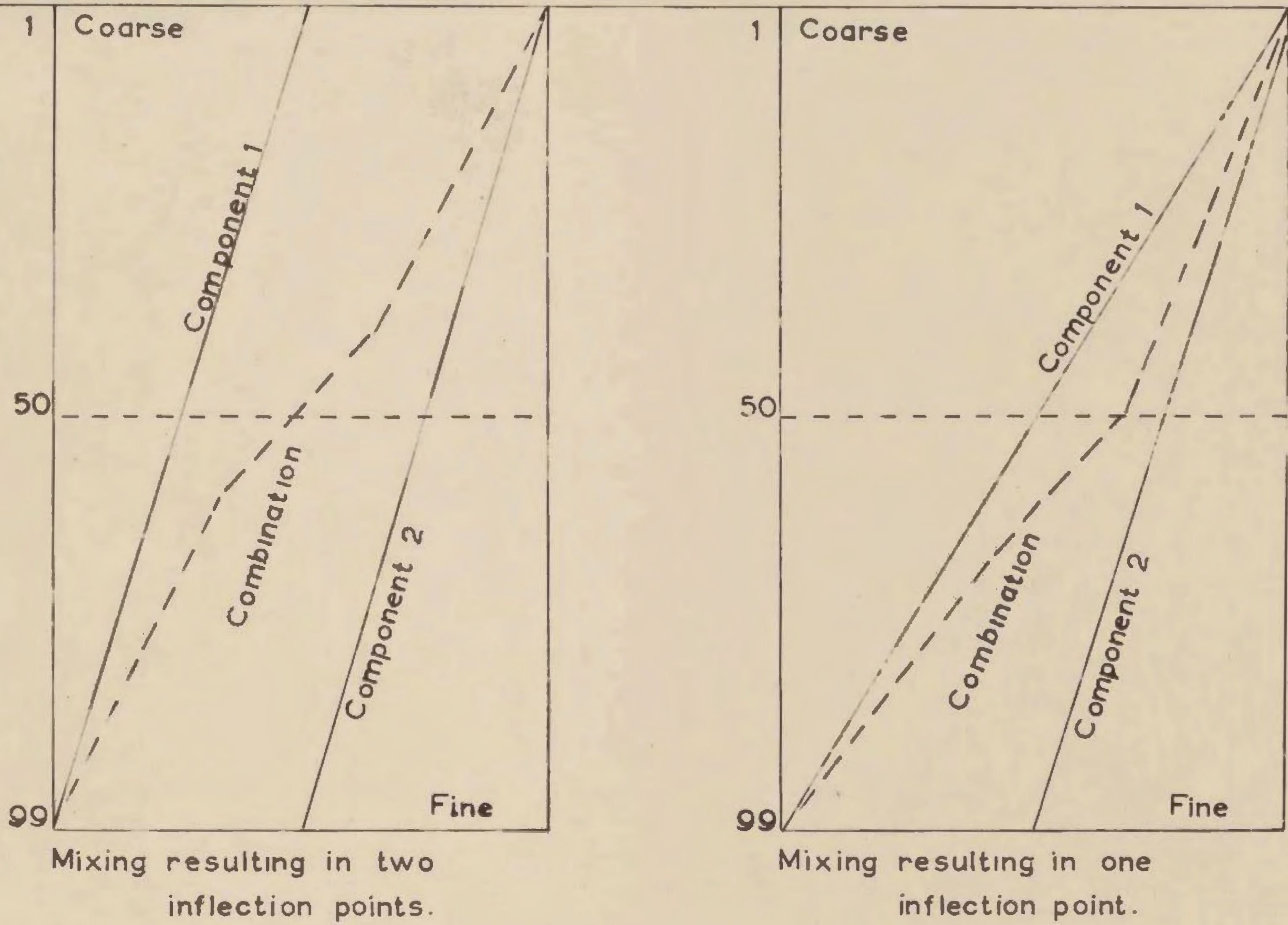
The writer studied the cumulative curves of the False Bay sediments to see if the 2 phi material reported missing by Fuller, had been moved to deeper water. During this investigation two inflection points were noticed in samples from varying depths. These results are set out in the table below.

Sample No.	Inflection Point	Depth in Metres.
608	2.15	18
605	2.20	71
125	2.30	8
126	2.30	8
251	2.50	27
191	2.25	27
280	2.15	50
392	2.50	86
402	2.00	38
399	2.50	52
— — —	— — —	— — —
301	3.20	13
398	3.25	53
610	3.20	57
400	3.20	45

The upper group shows inflection points in the 2 to 2.5 phi range. This is exactly what Belderson found.

The second group reported by Belderson, appears to have moved up on the phi scale by approximately + 0.50 phi.

Two of the characteristic weight precentage cumulatives given by Fuller (1961, p.258) show a possibility of an inflexion point at the 99th percentile, or 3.2 phi mark. Being shallow marine sediments, sufficient fine material is not recorded to confirm or refute this suggestion.



Tanner's diagram of the mixing of sediments.

PLATE No. 31

Unlike the samples by Fuller and Belderson, the majority of the above samples are bimodal. The sediments although straddling the two and three phi range only show an inflection at one point.

For movement of material from rest, a current that has a critical drag force known as the 'threshold velocity' is required. This force is a function of grain size. Inman (1949, p.61) states that the threshold velocity decreases with decreasing grain size until a diameter of approximately 0.18 mm. is reached. The velocity necessary to start surface movement increases with decreasing grain size below 0.18 mm. or 2.47 phi.

The arithmetic mean of the points of inflection, of the samples listed above, is 2.285 phi. Thus a value near the optimum for movement, both by wind and water, is reflected in the 'gaps' of the cumulative curves.

Walger (1962) found that single layer sediment samples invariably show three normally distributed components. As individual units, each component was better sorted than the whole. On combining the three units, minima (gaps) were reflected. Hence the deficiencies quoted earlier by the writer could be due to the mixing of either two or three components. But Tanner (1964, p.158) shows that two types of curve could result from the mixing of two components (Plate 31). As can be seen from Tanner's diagrams, the 'gap' requires two variables which are essentially equal. Thus if the material deficient gap in False Bay was due to mixing, it would be the mixing of two equal components. This, in the writer's opinion, would be extremely fortuitous, since samples were taken up to 10 miles apart.

Tanner (p.158) suggests one of three possibilities for Fuller's curves. His argument would apply to the curves found by the writer. He, (Tanner), lists the possibilities as:-

1) "A shelf area, fed by two streams, each of which delivers a sediment load with distinctive parameters, might show such mixing in various proportions; or
2) Mixing might involve two components, one derived from stream flow, and one from wave erosion of sandstones exposed beneath the shelf waters; or
3) Mixing might reflect two different hydrodynamic regimes".

Plate 22 shows that Tanner's first suggestion cannot be accepted. The sample positions, showing this deficiency, are separated to such an extent that no two streams could ever have been responsible for the characteristics observed.

The widely-spaced position of the samples reflecting this gap, refutes the second suggestion of mixing as well.

For his third suggestion he points out that Fuller's samples could consist of 3.75 percent water current mode and 96.25 percent wave-mode. (Tanner 1964, p.158). This argument may apply for near-shore samples and for sample numbers 125, 126 and 301. But if this is correct, deeper water samples showing this gap, reflect a possible current mode combined with an unknown mode, not a wave mode at 80 m.

Tanner supplies three further processes which may apply. They are: Censorship, Truncation and Filtering. He dismisses them, stressing the improbability of wind filtering in favour of mixing.

The writer discards mixing as the answer to the 2 phi gap, for the reasons previously stated. Instead, the wave-backwash-wind combination, as suggested by Fuller is thought the more likely, especially in view of deeper water samples. Further comment will be made on this section when the statistical parameters have been discussed.

The 3.2 phi gap, in contrast to the above, does appear to be due to a mixing of sediments. In all probability this gap reflects the current strength at the time of sampling, as explained below.

During periods of turbulence, fine material possibly in excess of the 3.20 phi mark, would be taken into suspension. Once in suspension it would be carried by the bottom current towards the open sea. Thus if the current were active for long enough, fine material, entering perhaps at the Lourens or Eerste River mouth, would be moved to the sea. But if the current velocity dropped, this material would be dumped, causing a temporary mixing until such time as currents again removed the material. If sampling was carried out at a time when the fine material was temporarily resting on a coarser substratum, sieving analyses would reflect a 'gap', as has occurred for samples Nos. 301, 398, 400 and 610.

(F) STATISTICS OF THE SEDIMENTS.

Modern statistical approaches to analyses of size frequency distributions have furnished methods for representing the physical environment in terms of size parameters. These parameters are related to one of the four mathematical moments and can be listed as:-

1) The first Moment or arithmetic mean. This parameter together with the median are measures of central tendency.

2) The second Moment, or standard deviation, measures the sorting or spread about the mean size.

The above two are considered by Folk & Ward (1957 p.145) to be 'tough' parameters. That is, results may be fairly accurate even if method or apparatus is not perfect. The other two moments are 'delicate' ones, they are:-

3) Skewness, the third Moment, a parameter reflecting the asymmetry of a distribution.

4) Finally, the fourth Moment, or kurtosis, a measure comparing the sorting in the central part of the curve with the sorting in the tails, resulting in a measure of peakedness.

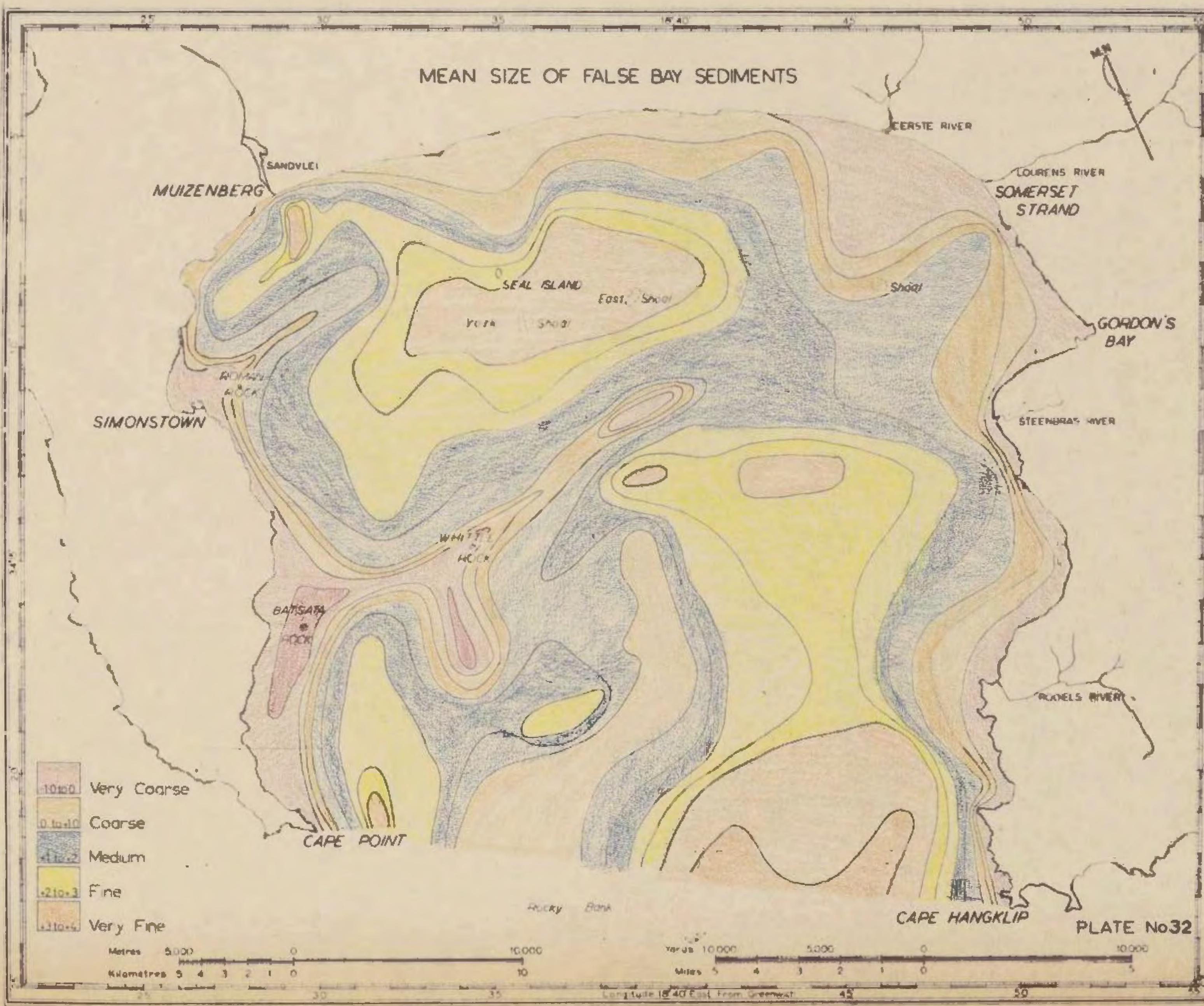
The interpretation of these statistical measures in False Bay, does not take into account any alteration or variation in the nature of the bottom material with seasonal variations of currents. As previously stated, these sediments have been collected over a period of 10 years, mainly during the summer months, but not exclusively so. Inman and Chamberlain (1953, p.128) found that seasonal changes in sediments were not of sufficient magnitude to overshadow properties that can be attributed to the environment of deposition.

(1) Mean Size.

This parameter reflects the overall average size of the

PLATE 32

Mean Size of False Bay Sediments


MEAN SIZE OF FALSE BAY SEDIMENTS
EERSTE RIVER
LOURENS RIVER
SOMERSET STRAND
SANDVLEI
MUIZENBERG
SEAL ISLAND
East Shoal
York Shoal
Shoal
GORDON'S BAY
ROMAN ROCK
SIMONSTOWN
STEENBRAS RIVER
WHITTLE ROCK
BATSATA ROCK
ROOIELS RIVER
Very Coarse
Coarse
Medium
Fine
Very Fine
CAPE POINT
Rocky Bank
CAPE HANGKLIP
PLATE No32
Metres
Kilometres
Yards
Miles

sediment as influenced by source of supply and environment of deposition.

The mean size is determined by the formula:

$$M = \frac{\phi 16 + \phi 50 + \phi 84}{3} = \text{graphical mean size}$$

The graphical mean sizes were plotted and isopleths drawn at 0.5 Ø intervals (Plate 32).

Generally three distinct zones occur in the bay. These zones are defined by the grouping of the isopleths, which in each case show normal sediment gradation from the shoreline, i.e. the coarsest sediments appear in the surf zone with decreasing size towards deeper water. But in two sectors, both in the vicinity of Whittle Rock, this gradation is reversed, the finer material grading into coarse and then back to fine (Plate 32). These zones are indicated in an anomalous area on Plates 26 to 28 which show the data according to Ingram's method of classification. The previously mentioned three zones can be defined as follows:-

Zone 1. This extends from a point east of Rocky Bank to Cape Hangklip. then northwards along the coast, after which the pattern is broken along an east-west line off Steenbras River.

Zone 2. The northwest corner of the bay with Seal Island approximately in the centre.

Zone 3. This zone lies just east of Cape Point and directly north of Rocky Bank.

Most agents of transport tend to sort the particles carried according to their size, shape and specific gravity. One of the results therefore of progressive sorting is a systematic down-current decrease in the mean grain size of the sediment. The coarse grain sizes of beach sands are the result of this sorting action. In this zone the surf action removes the fines either by deposition on the beach where they are exposed to wind action, or by removal to deeper water by current action. The size change in a down current direction is in all probability a product of both abrasive and sorting processes and hence will lead to moderately rapid destruction of a shelly component.

(a) An Ancient Shoreline.

Pettijohn (1957, p.606) divides the criteria for recognising ancient shorelines into three classes as follows:-

1) Areas which show various beach markings such as swash marks, beach cusps and beach structure.
2) Recognition of fresh water, brackish and marine faunas.
3) An areal pattern which is closely associated with the position and trend of a shoreline. For an example, he gives concentration of land pollens or similar material parallel to the shore.

Since one is dealing with an unconsolidated sediment in False Bay these criteria cannot be used. But he, (Pettijohn lot. cit.) adds; "In a general way sediments are coarser towards their source. Presumably therefore the clastic marine sediments would be distributed in texturally defined belts parallel to the shoreline".

The zone of coarse sediments extending from Batsata Rock to a point south of East Shoal could indicate one of the following:-

(1) An ancient shoreline at approximately -40 m.

(11) An area where a strong current sweeps up towards Somerset Strand from Batsata Rock.

This second hypothesis will be considered under section (b) below.

The evidence in favour of an ancient shoreline at approximately this depth can be listed as:-

(1) Known terraces at about this depth have beeh reported and mehtioned in this thesis, p.44.

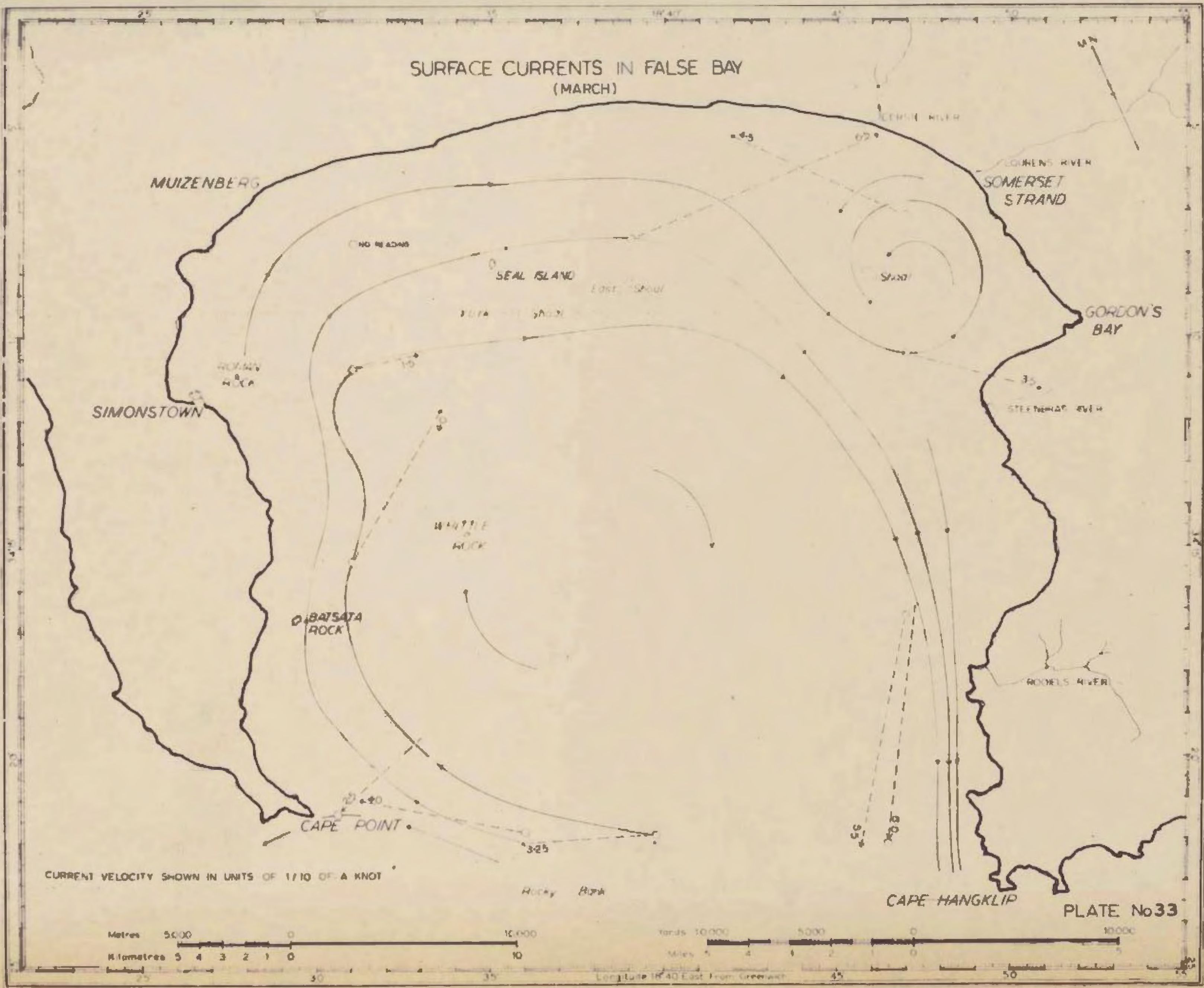
(11) The second zone of coarse material to the north of Rocky Bank, could have resulted from complex high energy currents on the lee side of the Island of Rocky Bank during a low stand of the sea.

(111) The possible dunes to the south of a line joining Roman Rock and Seal Island, mentioned on page 47, could have occurred during this low stand of the sea.

Other statistical parameters which may throw light on the problem will be considered prior to further discussion.

PLATE 33

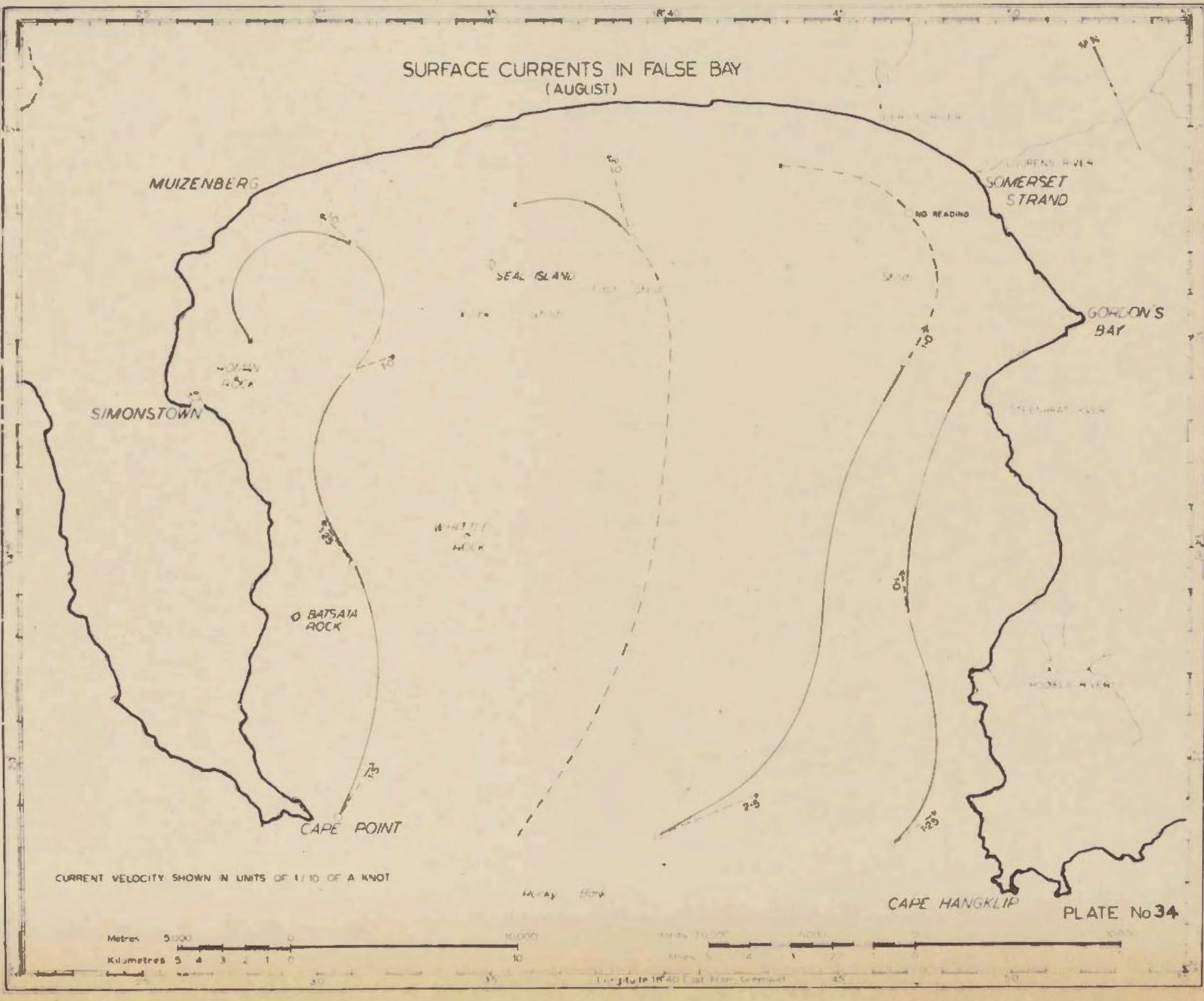
Surface Currents in False Bay (March)



SURFACE CURRENTS IN FALSE BAY
(MARCH)
MUIZENBERG
SOMERSET
STRAND
SEAL ISLAND
GORDON'S
BAY
SIMONSTOWN
BATSATA
ROCK
CAPE POINT
3·25
CAPE HANGKLIP
CURRENT VELOCITY SHOWN IN UNITS OF 1/10 OF A KNOT
PLATE No 33
Metres
Kilometres
Yards
Miles

PLATE 34

Surface Currents in False Bay (August)


SURFACE CURRENTS IN FALSE BAY
(AUGUST)
MUIZENBERG
SOMERSET
STRAND
NO READING
SEAL ISLAND
GORDON'S
BAY
SIMONSTOWN
O BATSATA
ROCK
CAPE POINT
CAPE HANGKLIP
CURRENT VELOCITY SHOWN IN UNITS OF 1/10 OF A KNOT
PLATE No 34
Metres
Kilometres 5 4 3 2 1 0
10

(b) Current Patterns.

Atkins (1965, Figs. 10 and 13; Plates 33 and 34) shows the pattern of surface currents in the bay during the months of March and August when these currents are clockwise and anti-clockwise respectively.

The plate depicting the surface currents during March (No. 33), the clockwise currents, reflects an area off Somerset Strand - Gordons Bay where a circular movement is generated by the wind. The sediments appear to show the same characteristics in the mean sizes. The Eerste and Lourens Rivers enter the sea to the north of this area. The finer sediments which would be expected off these rivers are not shown, instead a tongue of finer material pointing shorewards is shown to the south of Somerset Strand, where Atkins indicates an onshore current.

Plate 34 shows a similar occurrence in the north-western corner of the bay during August. In this instance the circular motion is shown by a tongue of coarse material extending approximately 6 kilometres off-shore.

Atkins (1965, Figs. 10 & 13) indicates that the ocean currents which set up the clockwise and counter clockwise motion in the bay are the Agulhas and Benguella respectively. A branch of the Benguella current enters on a broad front from the southwest and sweeps around the bay. The entry of the Agulhas current is greatly influenced by the angle of approach near Cape Point. This promontory deflects the current into the bay.

The writer is of the opinion that, depending on the angle of entry of this current into the bay, the current movement would either follow the coast or would split, one section moving in a clockwise direction around the bay, the other more strongly deflected current moving obliquely across the bay from Batsata Rock towards Somerset Strand.

Further statistical evidence must be discussed prior to acceptance or rejection of either of the above hypotheses.

(11) Median

The mean and median values are equal in a symmetrical distribution but differ from each other in an asymmetrical distribution. The median is the fiftieth percentile diameter of a cumulative frequency curve. Geometrically the median is the diameter value of the ordinate that divides the frequency distribution curve into two equal areas. This value may be obtained from a cumulative curve without interpolation.

Inman (1952, p.132) states that it is useful to obtain both a median and mean diameter since one may be more significant than the other. His reason is that the median is less affected by extreme values of skewness since it is closer to the modal diameter than the mean.

Folk and Ward (1957, p.13) believe that the median is a very misleading value and should be abandoned as a measure. The inaccuracy, they contend, lies in the fact that the measure is based on one point (the 50th percentile) on the cumulative curve. Mason and Folk (1958) ignore this parameter in their paper. Others such as Batten (1962, p.198), Harris (1958, p.157) and Inman (loc. cit.) make use of it.

The writer does not wish to ignore this parameter but feels that for the present purposes it will provide no further information than that obtained from the use of the arithmetic mean.

(111) Standard Deviation.

Otto (1939, p.65) was one of the first to use the 16th and 84th percentile diameters to obtain a standard deviation. This moment, when using the phi notation, can be approximated graphically for many distributions, by obtaining one half of the distance between the sixteenth and eighty fourth percentile diameters on a cumulative frequency curve.

Inman's (1952, p.135) formula for the calculation of standard deviation is exactly this and reads, Standard Deviation (s) $= \frac{1}{2}$ (Ø 84-Ø 16). This formula may give misleading, good sorting values if there is a small amount of coarse or fine material present, as it ignores a sixth of the sample at either end of the distribution. The formula is however an improvement on Trask's sorting co-efficient where the seventy fifth and twenty fifth percentiles were used.

Folk and Ward (1957, p.13) use the "Inclusive Graphic Standard Deviation" formula, which makes use of values within two standard deviations of the mean, and reads as follows:-

$$\text{Standard Deviation} = \frac{\text{Ø } 84 - \text{Ø } 16}{4} + \frac{\text{Ø } 95 - \text{Ø } 5}{6.6}$$

Friedman (1962, p.738) states that there are practical considerations against the use of the inclusive graphic standard deviation. He is possibly considering the determination of the fifth and ninety fifth percentiles, which in many instances cannot be done without extrapolation. But Friedman does add (1962, p.748) that, "The data available indicate that, of the sorting measures presently in use, the Folk and Ward measure provides the most satisfactory correlation with the standard deviation".

King (1966, p.281) lists the results obtained from Folk and Ward's (op. cit.) formula for the sorting of sands as:-

under 0.35	very well sorted
0.35 - 0.5	well sorted
0.5 - 1.0	moderately sorted
1.0 - 2.0	poorly sorted
2.0 - 4.0	very poorly sorted
over 4.0	extremely poorly sorted.

The sorting of a sediment depends on two basic factors. Firstly the hydraulic conditions of the body of water in which the sediment occurs and, secondly, the physical properties of the individual grains of the sediment. Wood (1964, p.180) states that "It is generally conceded that sorting is best in fine to medium sediments, with minor exceptions which depend on hydraulic conditions affecting the sediment whereas sorting is poor, in varying degrees, towards the fine to very fine and coarse to very coarse ends of the distribution".

Isopleths spaced at 0.2 phi intervals were drawn on a plot

PLATE 35

Sorting Values for False Bay Sediments

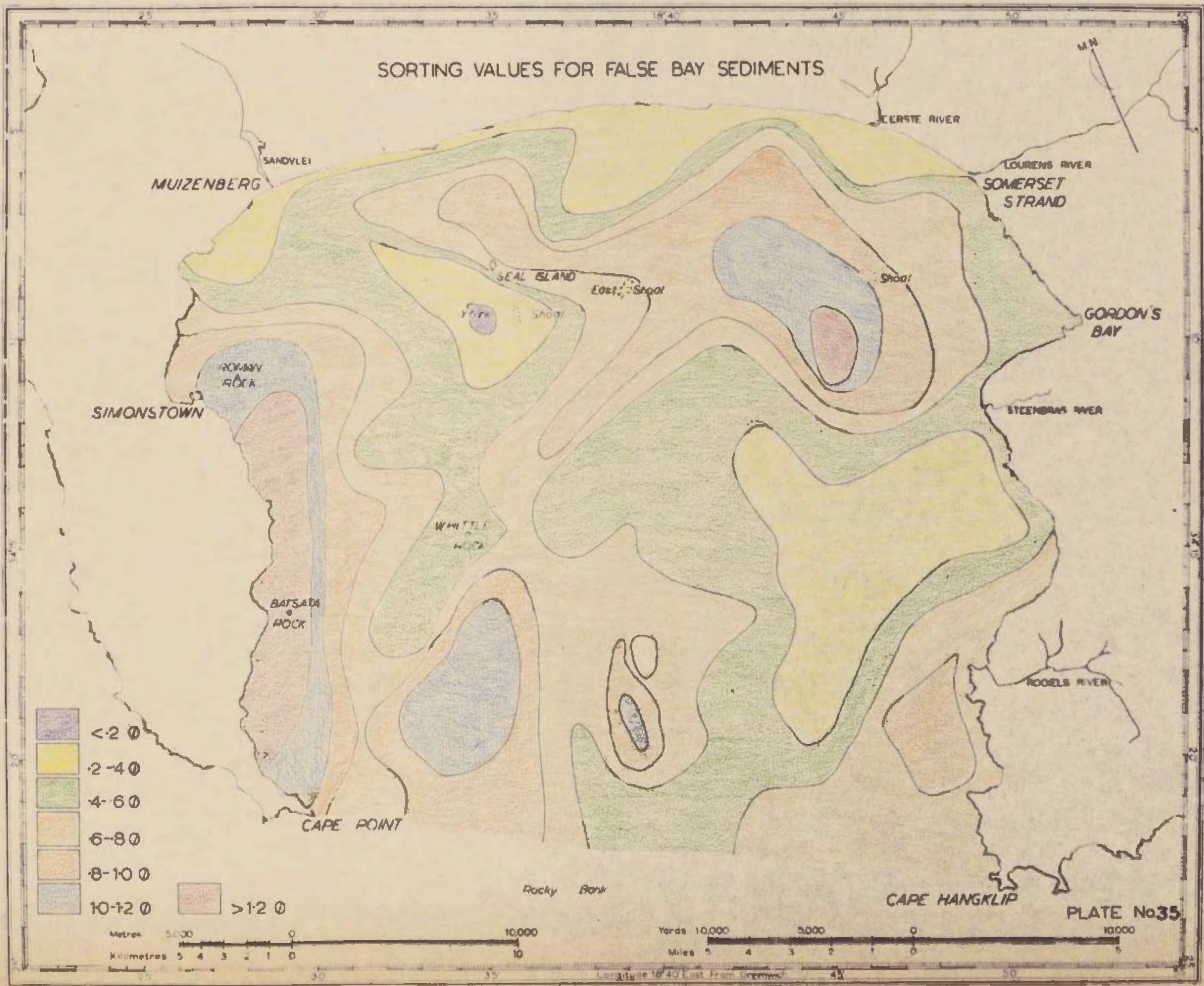

SORTING VALUES FOR FALSE BAY SEDIMENTS
EERSTE RIVER
SANDVLEI
MUIZENBERG
LOURENS RIVER
SOMERSET STRAND
SEAL ISLAND
East Shoal
Shoal
GORDON'S BAY
SIMONSTOWN
STEENBRAS RIVER
WHITTLE ROCK
BATSATA ROCK
ROOIELS RIVER
CAPE POINT
Rocky Bank
CAPE HANGKLIP
<·2 Ø
·2–·4 Ø
·4–·6 Ø
·6–·8 Ø
·8–1·0 Ø
1·0–1·2 Ø
>1·2 Ø
Metres 5000 0 10,000
Kilometres 5 4 3 2 1 0 10
Yards 10,000 5000 0 10,000
Miles 5 4 3 2 1 0 5
Longitude 18°40' East From Greenwich

PLATE No. 35

of the standard deviation values. This plot (Plate 34) shows three large areas of poorly sorted material, the largest of which lies along the east coast of the Peninsula. The latter is understandable as erosion of the cliffs, dumping of material by short mountain streams and a high benthic population would result in an area of very coarse material, resulting in poor sorting. This agrees with Wood's (op. cit.) observations.

The effect of Rocky Bank on the current pattern of the bay is indicated by two poorly sorted areas to the north of the Bank.

The remaining poorly sorted area lies to the northeast, off Somerset Strand and Gordons Bay. The sediment grain diameters here are classified as 'Medium' ($\pm$ 1.35 Ø) and thus according to Wood, sorting should be good. This area lies at a point where Atkins (1965, Fig. 10; Plate 33) shows the clockwise current in False Bay splitting, to form a circular motion in the Somerset Strand-Gordons Bay area. The writer can only suggest that this poorly sorted zone is a reflection of these conditions.

The material off the northern coast is well sorted. This is a zone where the surf action as well as current movement plays a large part. The sediments in the anomalous area off Whittle Rock fall into this well sorted category.

South west of Seal Island and off the coast of the Mainland are two zones of well sorted material, both covering areas where the finest sediments of the bay are found. The Seal Island area contains well sorted sediments, and in a small section some very well sorted material. This zone, contrary to Wood's (op. cit) findings also consists of the finest material in the bay.

The anomaly to the west shows evidence of current action in that the 0.4 standard deviation isopleth cuts across mean size ranges of from below + 1.0 Ø to + 3.40 phi.

(IV) Skewness.

In a symmetrical distribution, the mean and median coincide and skewness is zero. But in an asymmetrical distribution the mean departs from the median and skewness is either positive or negative. This measure can be obtained by dividing the amount the mean has departed from the median by the standard deviation of the distribution (Inman 1952, p.137):

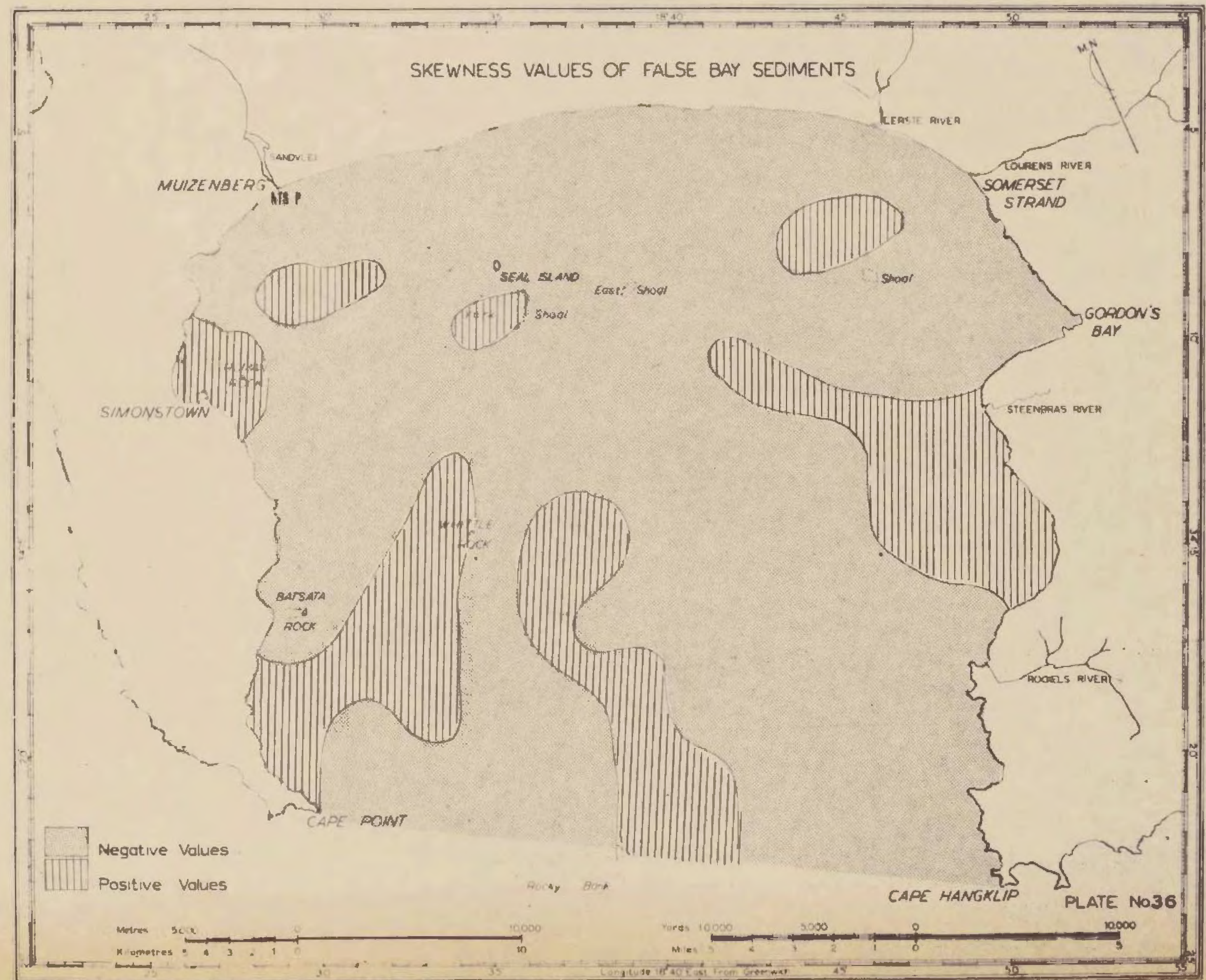
Krumbein and Pettijohn (1938, p.220) referred to skewness as an indicator of selective action of a transporting agent. Skewness was one of the parameters used by Mason and Folk (1958, p.211) in distinguishing beach, dune and aeolian flat environments. Here they state that "skewness and kurtosis are the ones that identify the environments studied". They found that beaches were negatively skewed and dune aeolian flats positively skewed. Friedman (1961, p.83) agrees with their findings.

Martins (1965, p.769) records the result of an investigation along the Rio Grande do Sul as:-

Beach sands.	Sk	between	-0.40 to + 0.08
Dune sands	Sk	"	+0.10 to + 0.50

PLATE 36

Skewness Values of False Bay Sediments


SKEWNESS VALUES OF FALSE BAY SEDIMENTS
MUIZENBERG
LERSTE RIVER
LOURENS RIVER
SOMERSET STRAND
SEAL ISLAND
East Shoal
Shoal
Shoal
GORDON'S BAY
SIMONSTOWN
STEENBRAS RIVER
BATSATA ROCK
ROOIELS RIVER
CAPE POINT
Negative Values
Positive Values
CAPE HANGKLIP
PLATE No36
Metres
Kilometres
Yards
Miles

These values for skewness are calculated by using Folk and Ward's (1957, p.14) formula:-

$$Sk = \frac{\phi 16 + \phi 84 - 2\,\phi 50}{2\,(\phi 84 - \phi 16)} + \frac{\phi 5 + \phi 95 - 2\,\phi 50}{2\,(\phi 95 - \phi 5)}$$

Folk (1962, p.146) ascribes Shepard and Young's (1961) misinterpretation of the skewness and kurtosis parameters, not only to settling tube measurements but also to the calculation of this moment by use of the formula as given by Inman.

If the skewness is negetive the mean is less than the median and the distribution is skewed towards the smaller phi values, i.e. the coarser particles. Mathematical limits for skewness are plus one to minus one. King (1966, p.284) states that few curves have a skewness greater than or less than $\pm$ 0.8.

Of the seventy three samples taken in False Bay only twenty show positive skewness. That is, the majority of samples are skewed towards the coarser diameters. Inman (1949, p.61) has shown that samples with median diameters near 2.47 Ø (0.18 mm.) were predominantly well sorted and symmetrical, those with smaller median diameters, poorly sorted and skewed towards the fine grains, and the coarser samples poorly sorted and skewed towards the coarse or fine grains.

Twelve of the False Bay sediments have median diameters in the vicinity of 2.47 Ø and these were examined in order to test the applicability of Inman's (loc. cit.) conclusion with regard to the symmetry of size distributions in sediments with about this mean grain size. The data are given below:-

Sample	Median	Skewness	$CaCO_3$
301	2.09	- 0.03	20.5
603	2.26	- 0.23	6.5
386	2.10	- 0.23	13.5
5	2.71	- 0.41	19.0
4	2.46	- 0.34	35.5
396	2.76	- 0.33	54.5
3	2.48	- 0.30	54.5
190	2.22	- 0.30	19.0
9	2.35	- 0.06	50.0
610	2.69	- 0.43	69.5
395	2.54	- 0.25	81.5
605	2.52	- 0.30	41.5

As can be seen from the above, all of the sediments are negatively skewed, i.e. all skewed towards the coarser fraction, and most are significantly smaller than zero, a fact not in agreement with Inman's findings.

An explanation of this negative skewing was sought in the shell content of each sample. This explanation had been used by Folk and Robles (1964, p.285) in explaining negative skewness in samples from Ilsa Perez, where coral and shell fragments were present, where they find that "there are two possible causes for this; either addition of a coarse tail to a normal population, or subtraction of a fine tail".

The samples in False Bay mostly reflect addition of a coarse tail, in the form of shells. Sample No. 603, with a skewness value of

-0.23 and calcium carbonate content of 6.5% comes from inshore, i.e. from moderately shallow water, and reflects removal of the fine tail.

Samples No. 9 and 301 are nearly symmetrical but differ in calcium carbonate content. In both instances the shell material present is not of the platy variety, the medians are 2.35 Ø and 2.09 Ø respectively. The Maximum Grain size is reflected as 'medium grained' for both (Plate 28). The shell material present must be hydraulically equivalent to the other components.

The mejority of the positively sorted samples have median diameters less than 2.47 Ø. (Only samples 300 and 615 deviate from this). These samples lie in the moderately to poorly sorted range. This conforms with Inman's (1949, p.61) statement that "the coarser samples are poorly sorted and skewed towards the coarse or fine grains". (In this instance towards the coarser value).

That there is no definite correlation between shell content and the symmetry of the distribution is shown by the fact that in False Bay skewness values range from -0.79 to + 0.32, with two values showing perfect symmetrical distributions. Of these sediments one positively skewad sand contained 4.5% calcium carbonate; while another positively skewed sediment contained 91.5%. The sediments showing zero skewness contain 45.5% and 81.5% calcium carbonate respectively.

Generally one may state that in areas dominated by winnowing, that is a high energy environment such as in the tidal zone, the littoral zone and on the beaches, the sediments show marked skewness. In areas where no particular sign dominates, winnowing may be intermittently active. Positively skewed sediments are correlated with low energy levels. Thus areas of negative skewing are areas of total - or by - passing, whereas positively skewed distributions indicate deposition. Where both positive and negative values occur would indicate an area in a state of flux.

(V) Kurtosis.

Kurtosis is a measure of peakedness and, statistically, is related to the fourth moment about the mean. It may be thought of as the ratio of the average spread in the tails of a distribution to the standard deviation and is thus a measure of peakedness.

Mason and Folk's (1958, p.218) formula for "Graphic Kurtosis" was used for all calculations in this section. The formula reads as follows:-

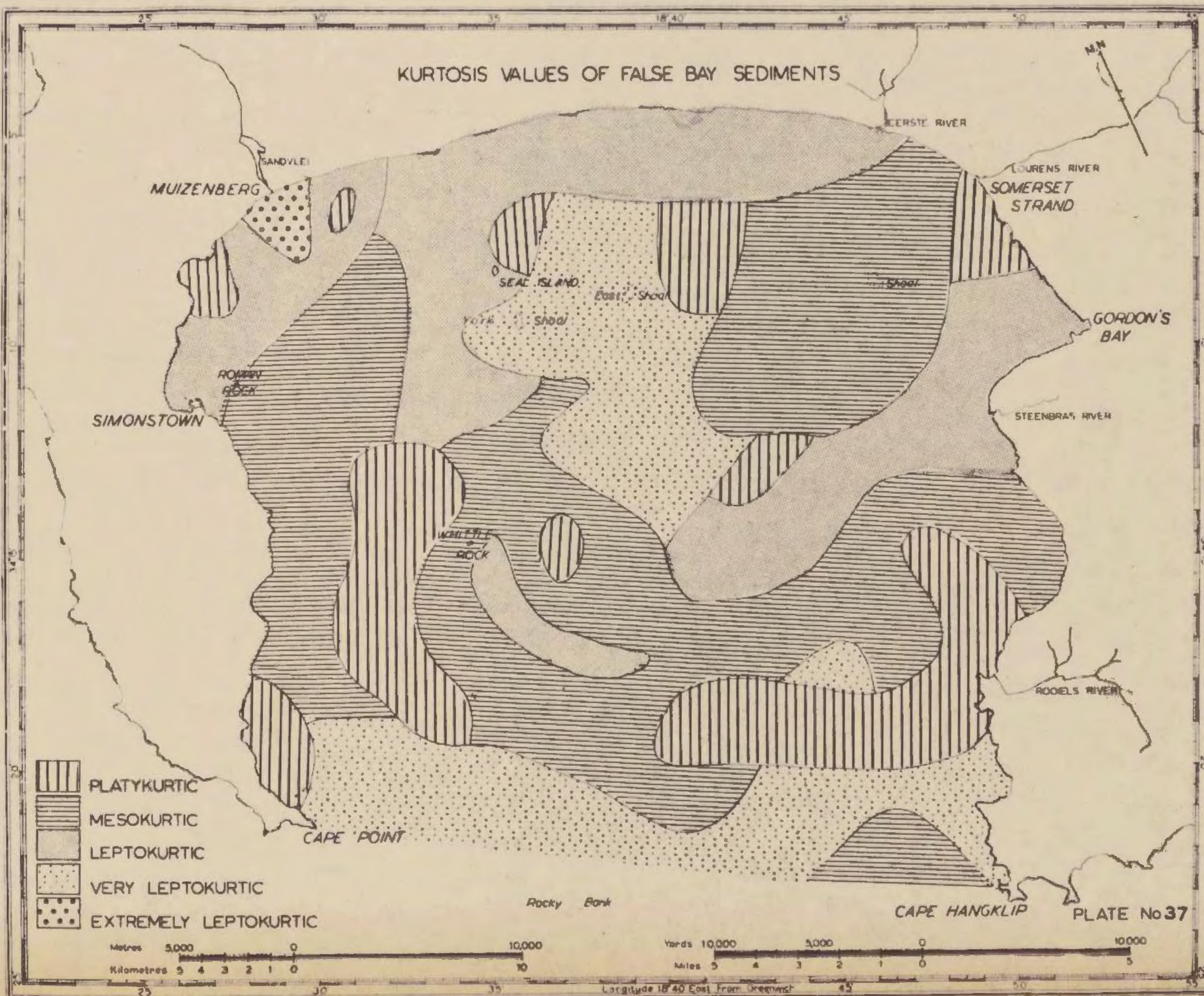
$$K_G = \frac{\phi 95 - \phi 5}{2.44\,(\phi 75 - \phi 25)}$$

The results for a normal, or Gaussian, curve would be 1.00, a mesokurtic curve. A curve with a kurtosis value of + 1.00 would be leptokurtic, that is, better sorted in the central part than in the tails. A result of - 1.00 would indicate a platykurtic curve.

Folk and Ward (1957, p.15) note that most sediments average 1.00 as a kurtosis value. This is found to be the case for the sediments under discussion, with the exception of the negatively skewed samples No. 125 and 126 (Plate 36). These reflect kurtosis values in excess of 3.00, indicating extreme sorting in the central part of the curve. Both are fine grained sediments, with means of 3.48 Ø and 3.13 Ø

PLATE 37

Kurtosis Values of False Bay Sediments


KURTOSIS VALUES OF FALSE BAY SEDIMENTS
EERSTE RIVER
SANDVLEI
MUIZENBERG
LOURENS RIVER
SOMERSET STRAND
SEAL ISLAND
East Shoal
York Shoal
Shoal
GORDON'S BAY
ROMAN ROCK
SIMONSTOWN
STEENBRAS RIVER
WHITTLE ROCK
ROOIELS RIVER
PLATYKURTIC
MESOKURTIC
LEPTOKURTIC
VERY LEPTOKURTIC
EXTREMELY LEPTOKURTIC
CAPE POINT
Rocky Bank
CAPE HANGKLIP
PLATE No 37
Metres 5,000 0 10,000
Kilometres 5 4 3 2 1 0 10
Yards 10,000 5,000 0 10,000
Miles 5 4 3 2 1 0 5
Longitude 18°40 East From Greenwich

respectively and appear at the mouth of the Sandvlei River, reflecting the size of material brought down by the stream.

(VI) An Ancient Shoreline or a "Current Pattern?".

Various statistical parameters have been suggested by authors (op. cit.) for the distinction of environments associated with marine sediments. Pettijohn (op. cit.) finds that in a general way sediments are coarser towards their source. Mason and Folk (op. cit.) distinguish between beach and dune material by the use of skewness values. Martin (op. cit.) records skewness values for beach sands as -0.40 to + 0.08 and + 0.10 to + 0.50 for dune material. Good sorting values can be found in material from the present surf zone, an area of high energy. Fuller (op. cit.) has shown that the beach material in False Bay has a sediment size deficiency at approximately the 2 Ø or 2.47 mm. mark.

Now that the statistical parameters of the sediments have been discussed, use can be made of the results in an attempt to determine whether the area immediately to the south of Whittle Rock, stretching from near Batsata Rock to approximately the middle of the bay, is in fact an ancient shoreline or if the sedimentary features indicate a strong bottom current active at present.

The above area has shown anomalous results on the facies maps (Plates 25 to 28) as well as marked characteristics on the mean size map (Plate 32). The sediment in this zone is moderately sorted according to King's (op. cit.) classification and has a range of skewness values between - 0.36 to + 0.07. Sorting alone cannot be used as a direct guide to environment, a strong bottom current could accomplish this sorting. The skewness values for these samples conform to those found associated in a beach environment (Martin op. cit.). But since the samples from the bay show numerous values of this range, the parameters cannot be used to support an argument for an ancient shoreline between the -45 m. and the -38 m. contours.

The sample to the south of Seal Island has a skewness value of + 0.23 which from Martin's (op. cit.) findings is typical of dune sands. To the west of this sample site, three further samples have approximately the same value. On this evidence alone the presence of dune formation in the area can only tentatively be suggested. Fuller's work shows that False Bay beach sands have an inflection point at approximately 2 phi and that this 2 phi material has moved shorewards to build the dunes, thus dune material should reflect an abundance of this size sediment present. The mean values of samples from the Roman Rock - Seal Island area are grouped around the 2 phi mark. Thus the writer feels justified in suggesting that an ancient shoreline existed at approximately -45 to - 38 m. with dunes to the north, in spite of this dune material showing negative skewness. The negative sign of this parameter can be explained by a later addition of a coarser shell component. (Folk and Robles, op. cit.).

(V11) Correlation.

The various parameters, such as mean, median etc. have been briefly discussed. In the above, measurements of a single variable were considered. In assessing the degree to which these individual parameters are related, two variables are plotted against each other on a graph, as a scatter diagram.

If the two variables are associated they appear on the scatter diagram with non-random distribution. In certain instances it is quite clear from the scatter diagram that the plotted points are linearly related, and a linear regression equation can be determined to describe their relationship.

The scatter diagram plots of False Bay sediments do not show sufficiently strong correlation to allow a line to be fitted by eye. Thus a line of 'best fit' has to be calculated by the method of least squares. Accepting 'Y' as the variable and 'X' as the independant variable, the line now plotted would be a line of regression of 'Y' on 'X' or the line of prediction for 'Y'.

To measure the spread of a set of points about a line of regression two measures are commonly adopted. They are:-

a) The standard error of estimate.

b) The correlation co-efficient.

Of the two, the correlation co-efficient is the most commonly used. According to Alder and Roessler (1960, p.146) the correlation co-efficient satisfies the following properties.

1) If all points of the scatter diagram lie on a line, then $r = +1$ or -1. (r = correlation co-efficient).

2) If no linear relationship exists between the X's and Y's then $r = 0$.

3) From the above it follows that 'r' must always fall between -1 and $+1$.

PLATE 38

Scatter Diagram: Mean v. Depth

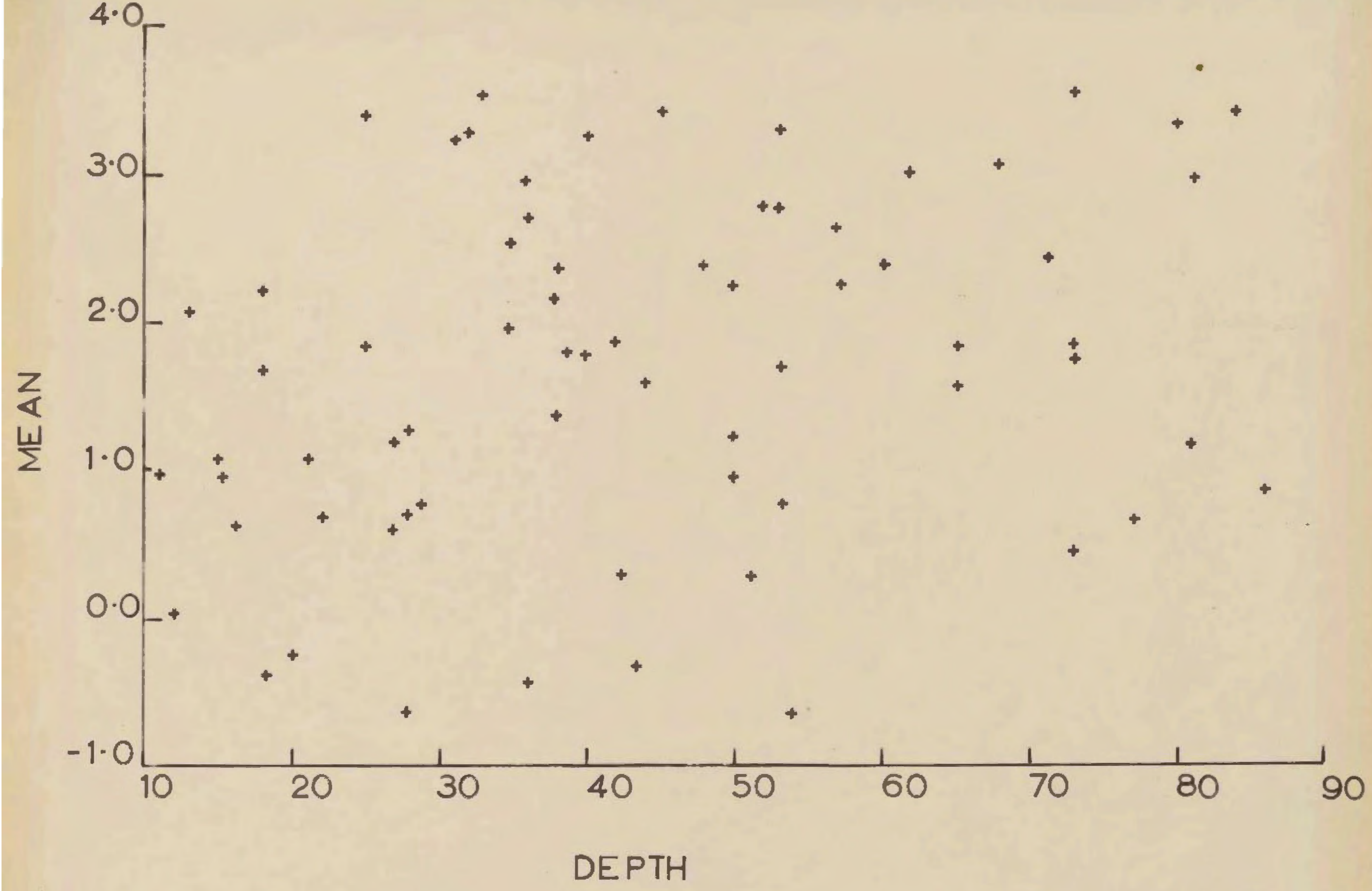


PLATE No. 38.

PLATE 39

Scatter Diagram: Median v. Depth

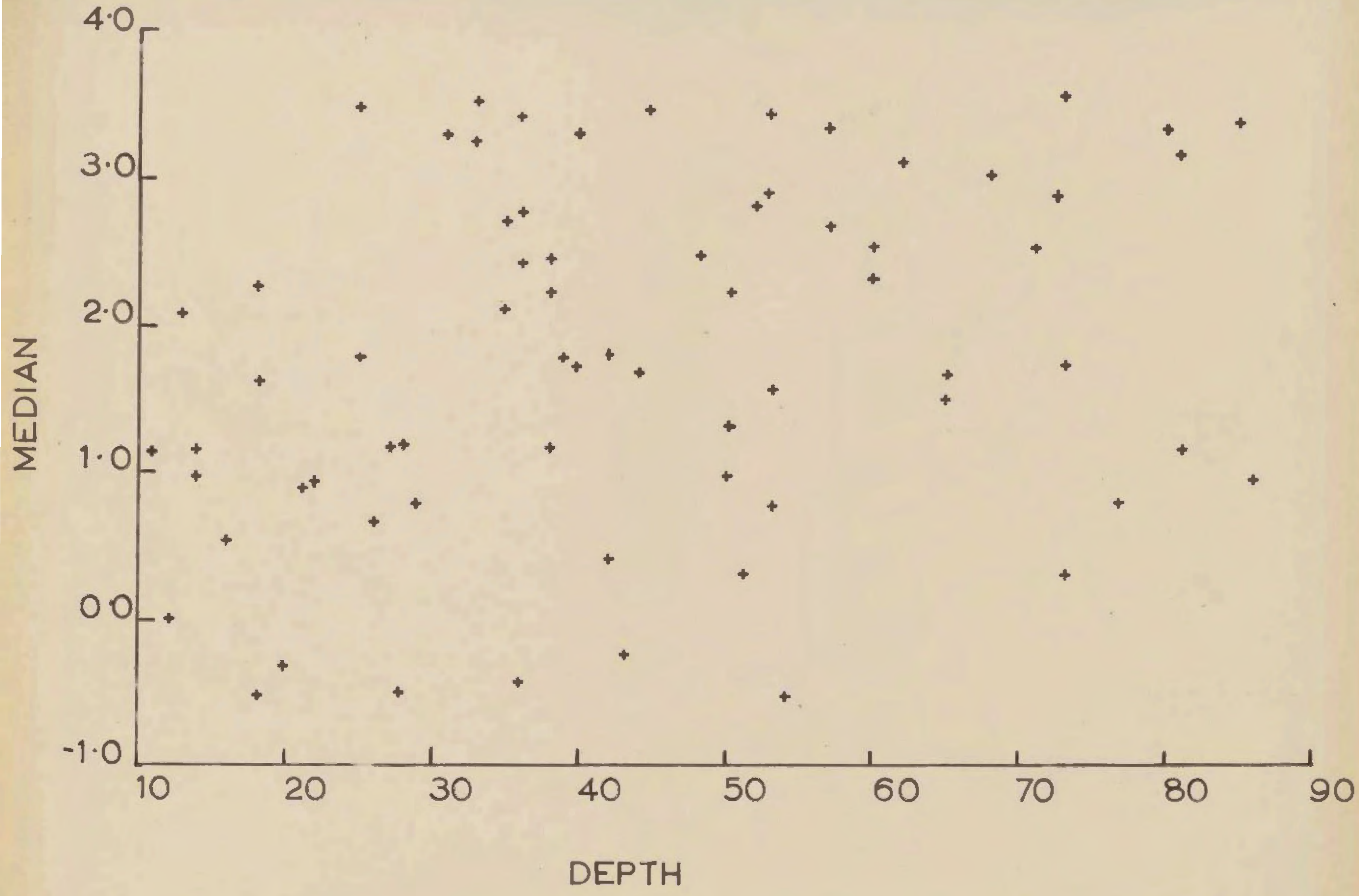
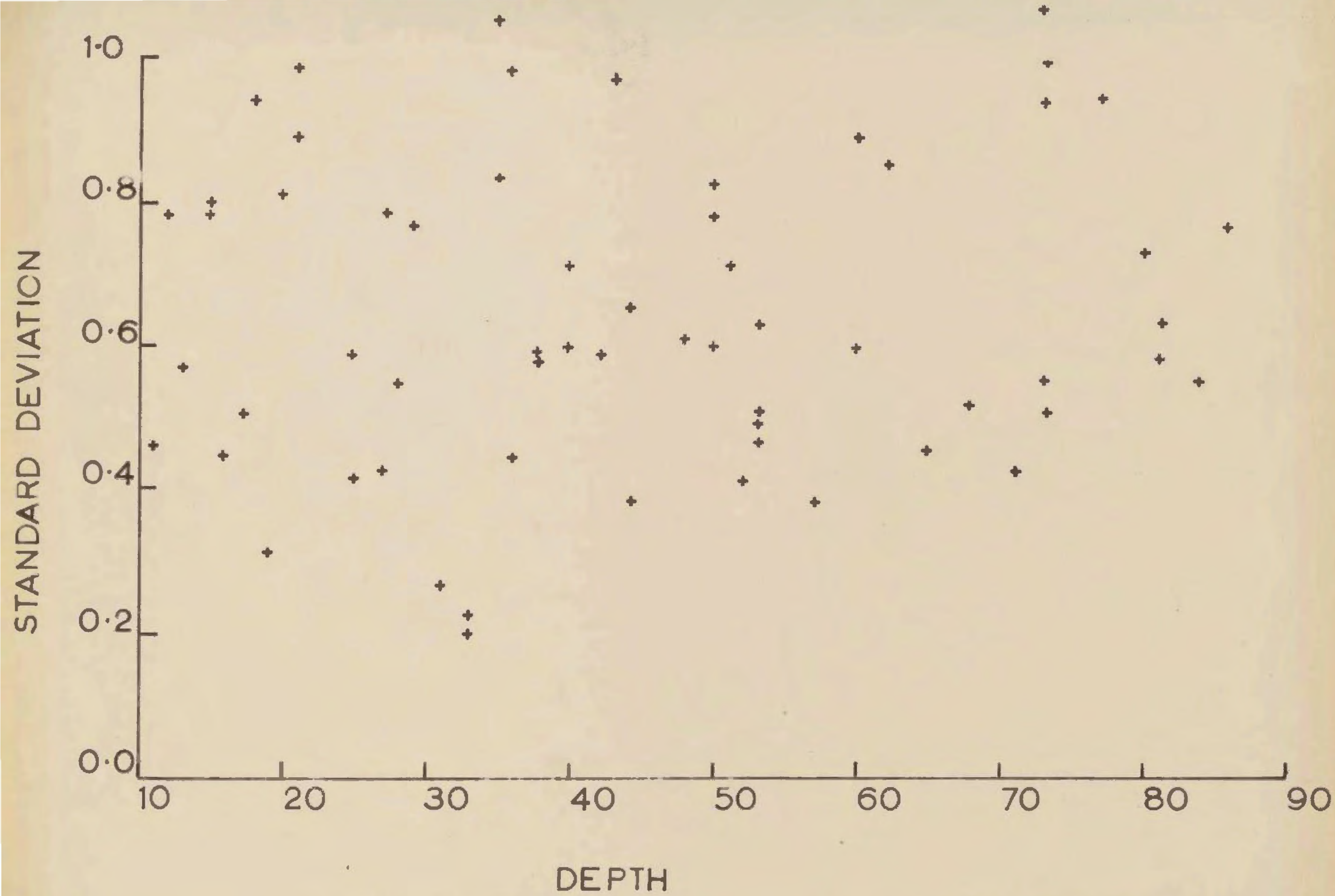


PLATE No. 39

PLATE 40

Scatter Diagram: Standard Deviation v. Depth



1·0
0·8
0·6
0·4
0·2
0·0
STANDARD DEVIATION
10
20
30
40
50
60
70
80
90
DEPTH

PLATE No. 40

PLATE 41

Scatter Diagram: Kurtosis v. Median

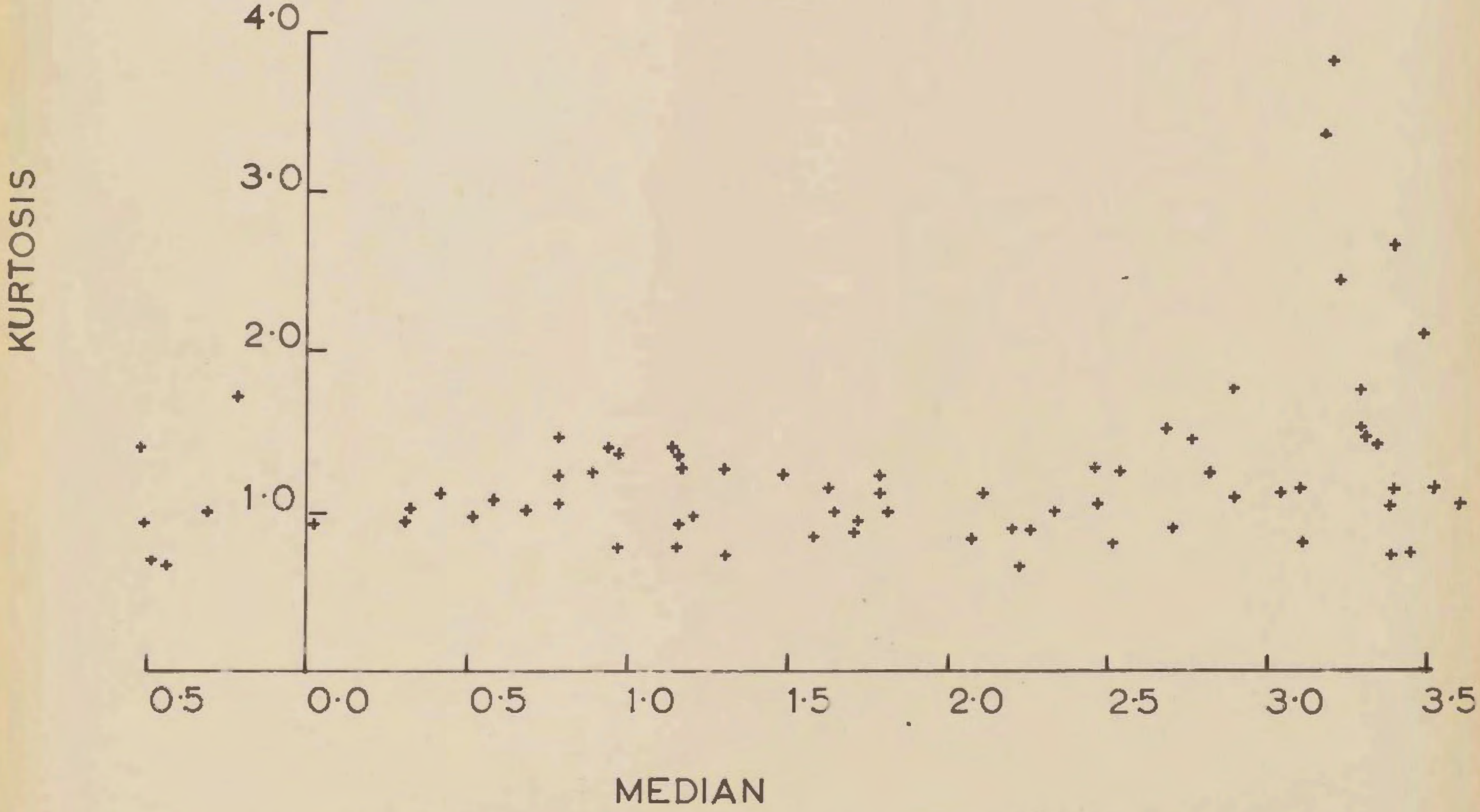


PLATE No. 41

PLATE 42

Scatter Diagram: Skewness v. Median

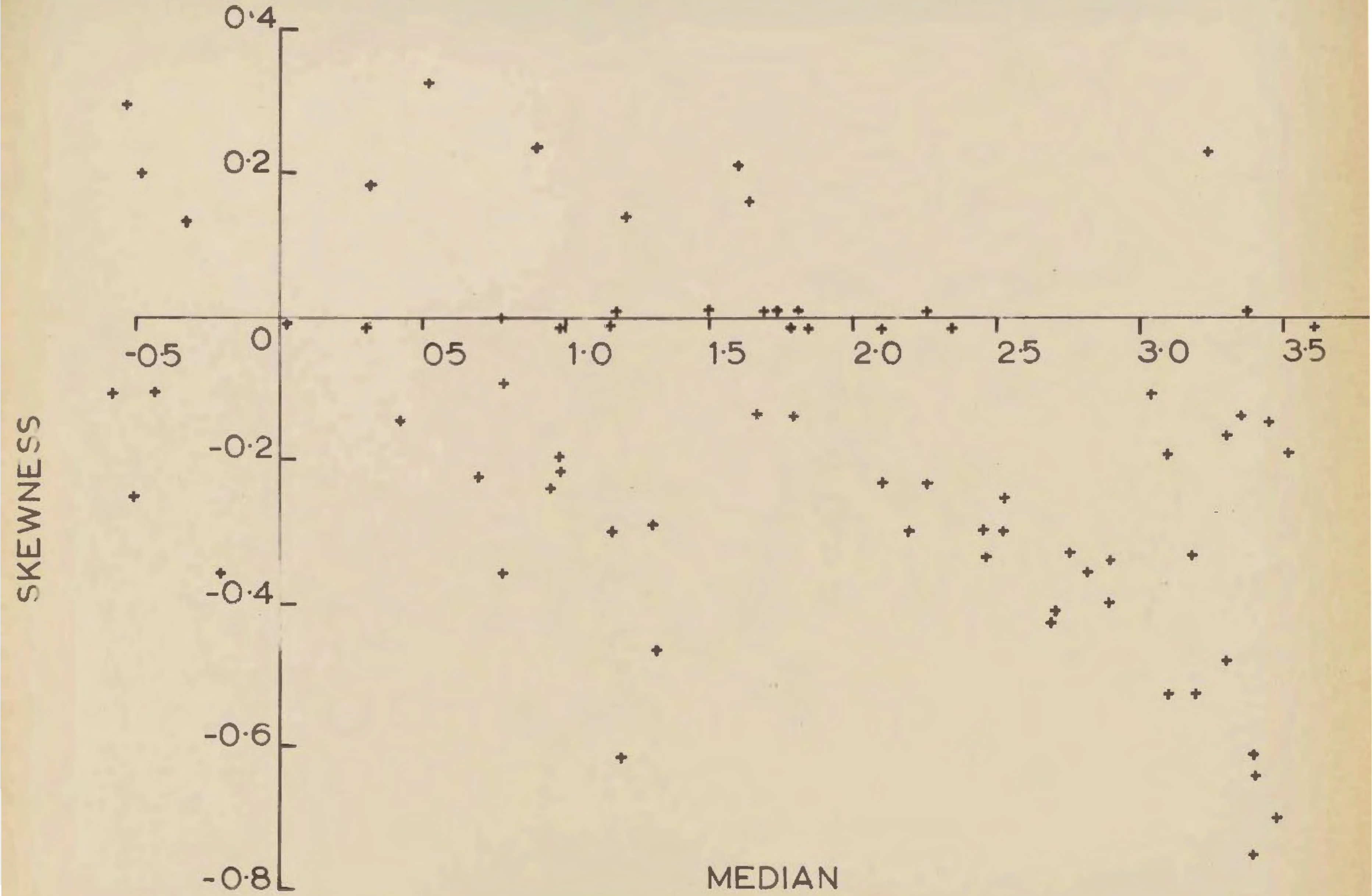
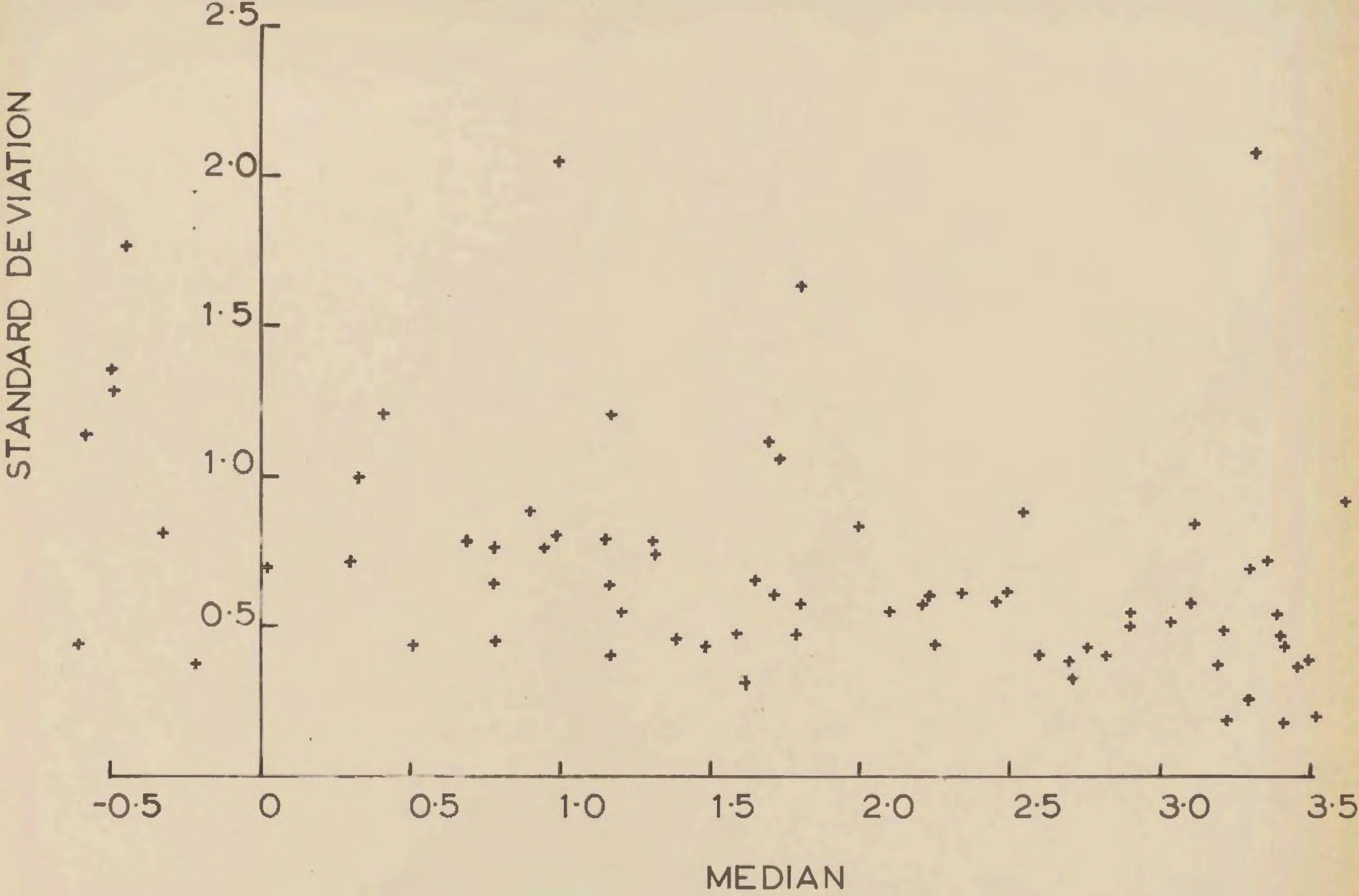


PLATE No. 42

PLATE 43

Scatter Diagram: Standard Deviation v. Median



STANDARD DEVIATION
2·5
2·0
1·5
1·0
0·5
-0·5
0
0·5
1·0
1·5
2·0
2·5
3·0
3·5
MEDIAN

PLATE No. 43

Lines of regression were not drawn on the scatter diagrams of the False Bay sediments. The co-efficient correlation figures were calculated by computor. These figures are as follows:-

	Median	Std. Dev.	Skewness
Mean	-0.405	-0.473	0.309
Median		0.014	-0.251
Std. Dev.			-0.328

From the above it can be seen that correlation between the statistical moments is very poor. This is confirmed by the scatter diagrams, Plates 38 to 43, which show no obvious straight line relationship.

The slight possibility of correlation between Mean and Sorting, ($r = -0.473$) is shown in the areas of coarse and fine material. As sorting decreases the sediment size increases and vice versa. This only applies at the extreme values in the Bay and does not reflect an overall picture. The east coast of the Peninsula and the area off Seal Island are typical examples.

(G) SUMMARY OF THE QUATERNARY HISTORY OF THE FALSE BAY AREA.

The first major event in the history of False Bay as recorded in this thesis is a high stand of the sea at ± 100 ft. at Gordons Bay. During this period the 'Cape Straight' as referred to by Shand (1913, p.155) must have been in existence. As shown in Table 1, this probably occurred during the Great or Yarmouth Interglacial.

With the onset of the Riss Glaciation the sea level receded, leaving a dry, sandy, wind-blown valley which caused dune formation in an area between Cape Town - Blaauberg Strand and Cape Point - Cape Hangklip.

A rising sea-level during the Main Monastrian reworked this dune material. Sea-level rose until the 50 to 60 ft. eustatic terrace was formed. Evidence of this stand is found in the boulder beach at Rocklands Point and Cape Hangklip. The 'terrace' at the Steenbras River mouth, and the thalassostatic terraces at Stellenbosch are in no way associated with this stand of the sea. The Cape Straight may again have been open, but as a narrower channel than previously.

With the onset of a glacial period eustatic lowering of the sea gave rise to lagoonal conditions, leading to the intermingling of marine and terrestial gastropods.

Russell (1957, p. 414) indicates how lagoonal conditions exist during periods of regression. Haughton (op. cit.) reports the mingling of marine and terrestial shells in the Cape Flats area. A rising sea-level drowned the dunes in the above area, without destruction of the aeolian features.

During the Intra Monastrian period a transgressing sea reached a height slightly in excess of twenty feet above present sea-level.

The planation of the Rocklands Point - Millers Point granite boulders and the undercutting of cliffs in the Gordons Bay area bear witness to this stand. Further truncation of the Malmesbury Shales in the north eastern corner of the bay must have occurred.

There followed a period of regression prior to a high stand of the sea at 10 to 15 feet during the Late Monastrian. It appears that the regression was not of a large magnitude and in all probability the terracing 2 metres above the present mean sea-level formed during this period. Truncation of the Malmesbury Beds at Somerset Strand and beachrock formation occurred during this time.

At the onset of the Würm Glaciation, approximately 75,000 years B.P., the sea receded to a position in excess of -100 m. The minor fluctuations during the two interstadials associated with the Würm Glaciation did not affect the bay at all. The area remained a dry, sandy wasteland with dune formation continuing in the present Cape Flats area.

At the close of the Würm III Glacial and the beginning of the Flandrian Transgression, approximately 18,000 years B.P., the sea-level stood at the mouth of the bay 85 m. below the present level. A rising sea-level with a stillstand at -45 to -38 m. ± 13,000 years B.P. resulted in dune formation in the Roman Rock - Seal Island zone. These sediments rest on a terrace which must have been cut under an encroaching sea after the Riss Glaciation. The ancient beach associated with this period is indicated by sediments reflecting the 2 Ø gap.

Further transgression occurred with stillstands at - 11m., and - 5 to - 6 m. before the sea reached its present level and dated at approximately 7,000 and 3,000 years B.P.

No evidence has been found of a Climatic Optimum with a higher stand of the sea during the post-glacial period.

Table (1V) overleaf, shows the various eustatic fluctuations in chronological order.

TABLE IV.

FEATURES ASSOCIATED WITH STANDS OF THE SEA

IN FALSE BAY DURING THE QUATERNARY

Period	Date B.P.	Elevation in Metres Above or below present sea-level.	Evidence
	± 3,000	- 5 (?)	Possible terracing off the Harmony coast.
	± 7,000	- 11	Terracing off Harmony Coast and undercutting of Granite Boulders at Castle Rock.
	± 9,000	- 25 (?)	Possible terrace in the Malmesbury Beds near the confluence of the Steenbras River and combined Eerste and Lourens Rivers.
Holocene.	± 13,000	- 30 to - 35	Drowned dunes, due to rapid encroachment of the sea in the Roman Rock - Seal Island area. Identified by the mean size of the sediments.
		- 35 to - 45	An Ancient shoreline formed at the same time as the above dunes. The sediment present in this area lacks material in the 2 phi range.
	18,000	Below - 80	Sea at the mouth of the bay.
Würm Glaciation.	18,000 to 75,000		The area a wind-swept, sandy valley.

	Period	Date B.P.	Elevation in Metres Above or below present sea-level.	Evidence
Pleistocene	Late Mon-astrian	75,000	+ 3.5	Terraces reported by Krige (op. cit.) and Haughton (op. cit.).
			+ 2.0	Truncation of the Malmesbury Beds in the Somerset Strand Area. Probable period of Beachrock formation at Swartklip and Strandfontein.
	Intra Mon-astrian		+ 5.5	Cave cutting and undercutting below the Dirkie Binneman Memorial as well as planation of the granite boulders near Millers Point and Rocklands Point.
	Main Mon-astrian		+ 15 to + 18.5	The boulder beach at Rocklands Point and the terrace at Cape Hangklip.
		103,000		A rising sea-level due to waning of the Riss Glaciation and leading to the exposure of the granite between the -40m. and -30m. contours in the Whittle Rock - Roman Rock - Seal Island area.
	Riss Glac-iation	125,000		A sandy barren wasteland. The sea-level had retreated beyond the mouth of the bay.

Period	Date B.P.	Elevation in Metres Above or below present sea-level.	Evidence
	125,000	± 100	The melting of the ice after the Mindel
		± 33	Glacial Period is indicated by two high
			stands of the sea, one at Gordons Bay
			(boulder beach at ± 33 m.) and the
			thalassostatic terraces at Stellenbosch.
			It is not possible to determine the
			order in which these occurred from
	175,000		present information.

(V) APPENDIX.

SIEVING VERSUS SETTLING.

As previously discussed, both sieving and settling were used to determine the various grain size percentages.

Sieving has been the most widely used method for the measuring of size parameters of sands since the pioneer work of Udden, (1898, 1914) and appears to have produced the most useful results. Folk (1962, p.145) considers that the settling tube can give a good approximation to sieving results when one considers the mean, median and standard deviation of the sediment. But he adds that the other statistical moments are radically different.

The settling tube method was used for twelve of the seventy-three samples taken in False Bay. This method has the advantage that no weighing is required, and the process itself is rapid. The major obvious disadvantage is that it is limited to the treatment of material in the approximate limits of 2.0 Ø to 4.0 Ø. Below 2.0 Ø the material becomes too coarse for the tube and results in extremely rapid settling. For sediment finer than 4.0 Ø, particles remain in suspension for an excessively long period.

The graph of Time v. Size (Plate 44) shows that for grains coarser than 2.3 phi two sets of values can be obtained, and for material finer than 3.35 phi water temperature plays an important part. This graph (Plate 44) was plotted from screening results of a very clean sand

PLATE 44

Graph of Time v. Size

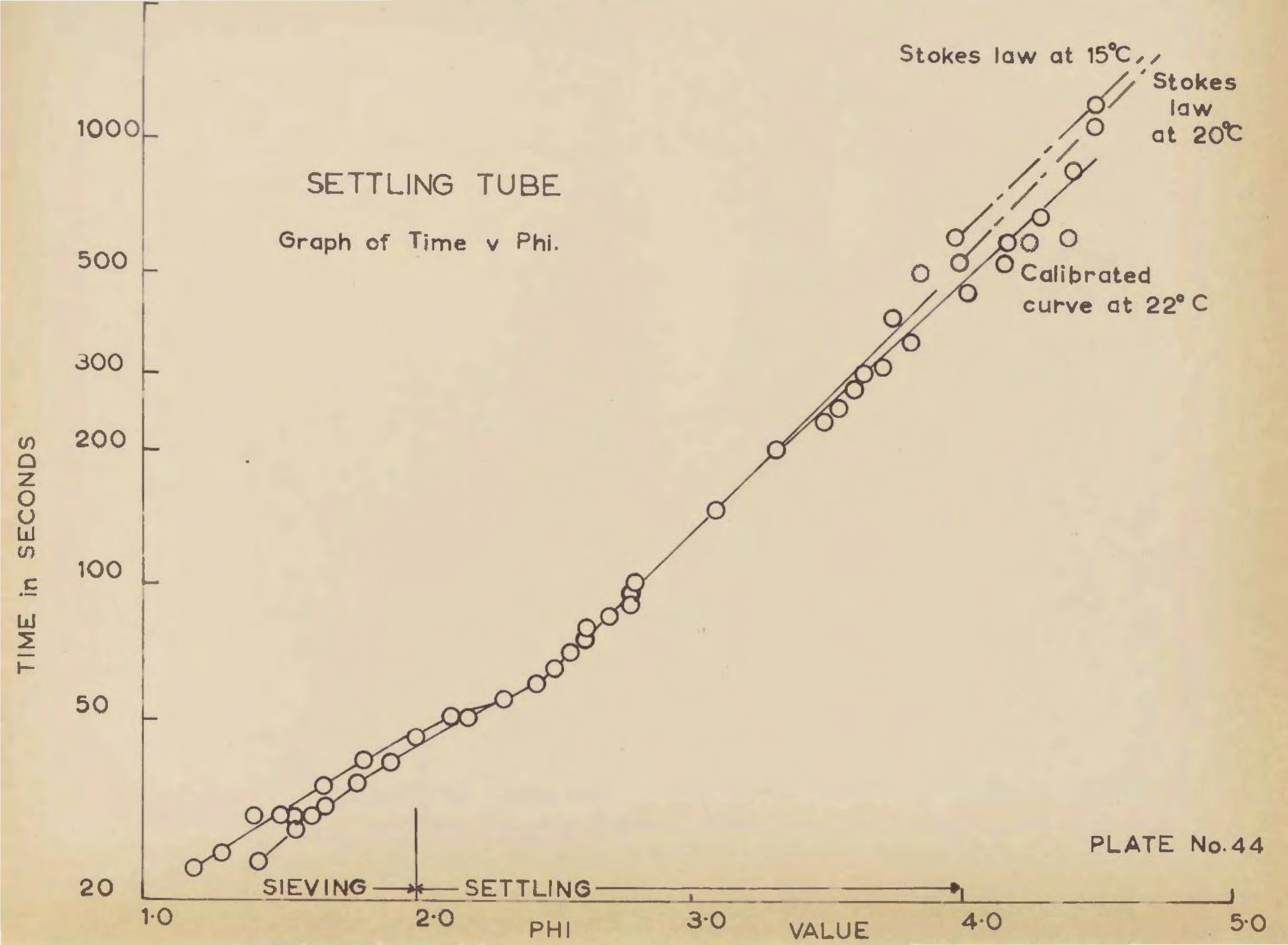

SETTLING TUBE
Graph of Time v Phi.
Stokes law at 15°C
Stokes law at 20°C
Calibrated curve at 22° C
TIME in SECONDS
1000
500
300
200
100
50
20
SIEVING
SETTLING
1·0
2·0
3·0
4·0
5·0
PHI VALUE

PLATE No. 44

for the calibration of the settling tube in use at the University.

Mason and Folk (1958, p.211) used sieving results to distinguish beach from dune sands. Shepard and Young, (1961, p.196) working on the same problem as the aforementioned, failed to find any specific statistical difference, calculated from results obtained when using a settling tube. Folk (1962, p.145) puts this failure down to the incapability of the settling tube to accomplish "such a delicate task of discrimination".

Doeglas (1946, p.21) working on sands off the coast of Holland compared the accuracy of the settling tube and sieving. He found that for material between 50 and 500 microns the settling tube gives an error of less than 2%.

Fuller, (1962, p.604) discussing work by Shepard and Moore (1955, p.1538) states "The authors used a settling velocity technique in their analyses so that their results are not strictly comparable with the writer's - - -".

Folk's reply (1962, p.146) to Shepard and Young after the abovementioned experiment was; "The fault, dear friends, be not in the sands; but in your tubes, that they are skewing things"; induced the writer to sieve the twelve samples for comparison purposes.

The results from both methods are listed below:-

	Mean			Median		
GSS	Sieve	Settling	Diff.	Sieve	Settling	Diff.
399	2.45	2.73	+0.28	2.54	2.82	+0.28
400	3.04	3.40	+0.36	3.20	3.45	+0.25
401	2.88	2.93	+0.05	3.20	3.22	+0.02
172	0.79	1.02	-0.23	0.75	0.90	-0.15
610	2.30	2.60	+0.30	2.36	2.69	+0.33
384	3.11	3.37	+0.26	3.26	3.49	+0.23
387	1.62	1.80	+0.18	1.62	1.78	+0.16
388	3.17	3.51	+0.34	3.20	3.52	+0.32
608	1.30	1.65	+0.35	1.25	1.62	+0.37
190	1.76	2.11	+0.35	1.80	2.22	+0.42
385	3.06	3.29	+0.23	3.23	3.41	+0.18
398	2.46	2.77	+0.31	2.53	2.90	+0.37

All values in phi units.

GSS No.	Standard Deviation Sieve	Settling	Diff.	Skewness Sieve	Settling	Diff.
399	0.45	0.41	-0.04	-0.23	-0.36	+0.13
400	0.38	0.38	000	-0.87	-0.15	-0.72
401	0.44	0.58	+0.14	-0.28	-0.53	+0.25
172	0.76	0.89	+0.13	+0.11	+0.23	-0.12
610	0.51	0.38	-0.13	-0.28	-0.43	+0.15
384	0.40	0.41	+0.01	-1.17	-0.70	-0.47
387	0.44	0.48	+0.04	+0.02	+0.09	-0.07
388	0.21	0.22	+0.01	-0.38	-0.19	-0.19
608	0.51	0.31	-0.20	+0.25	+0.16	+0.09
190	0.58	0.58	000	-0.09	-0.30	+0.21
385	0.43	0.46	+0.03	-1.15	-0.64	-0.51
398	0.45	0.51	+0.06	-0.13	-0.40	+0.37

Kurtosis				Calcium Carbonate
GSS No.	Sieve	Settling	Diff.	%
399	1.00	1.27	-0.27	56.5
400	1.19	0.76	+0.43	48.5
401	1.16	1.13	+0.03	55.0
172	0.92	1.25	-0.33	91.5
610	1.37	1.52	-0.15	69.5
384	2.47	2.10	+0.37	47.0
387	1.08	1.21	-0.13	4.5
388	2.09	1.17	+0.92	30.5
608	1.34	1.12	+0.22	51.5
190	0.88	0.89	-0.01	19.0
385	2.41	2.69	-0.28	47.0
398	1.04	1.78	-0.74	47.0

These tables show that the two methods give differing results for all parameters. The Mean and Median differences between the two methods show constant positive variation, except for one sample, number 172. From the differences between settling and sieving of the eleven other samples, it would appear that the settling tube records a smaller grain size.

Once the calcium carbonate content is taken into account, it is immediately seen that the irregularity of sample 172 is due to the presence of 91.5% $CaCO_3$. This calcium carbonate is in the form of broken, platy shells. Measurement of twenty pieces of this material gave an arithmetic mean value for the long and short axis as 0.9mm. and 2.1mm. respectively. This platy material would tend to 'float' down the settling tube, rather than sink in accordance with its volume, hence imitating a smaller grain size. This sample should never have been settled.

The standard deviation results obtained from settling show both positive and negative differences. The arithmetic mean of these units gives a value of 0.07, thus either set of values could have been accepted.

Since the mathematical limits for skewness are + 1 to - 1, the difference in the two methods is considerable, with the exception of sample number 387. A check on the calcium carbonate content shows that this is the only sample with a low $CaCO_3$ content.

The kurtosis figures obtained by the two methods differ sufficiently to alter the class type of 8 out of 12 samples. This is not surprising, as one is measuring the ratio of the sorting in the extremes of the distributions, and comparing this with the sorting in the central section. The shelly content would not act as a normal sediment, and thus false values would be obtained making the figures obtained for this moment valueless. But sample 387 with a shell content of 4.5%, differs by 0.13 units. This difference is not proportional to differences obtained where sediments contain ± 50% $CaCO_3$.

The graph of time versus size (Plate 44) governs the results obtained from the settling tube. As previously stated, this graph was drawn from results obtained from a very clean quartz sand. Adjustment of the graph, using the results obtained from samples containing a shelly component, may eliminate the error. The writer has, as yet, not attempted this correction.

Thus at this stage it cannot be stated whether the difference is due to method alone, calibration or a combination of the two.

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