AN OUTLINE OF

THE INSHORE SUBMARINE GEOLOGY OF SOUTHERN

SOUTH WEST AFRICA AND NAMAQUALAND

A thesis submitted in fulfilment of the requirements for the degree of Master of Science (Geology), University of Cape Town.

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1971.

ACKNOWLEDGEMENTS

The factual information contained in this thesis is partly the work of several organizations and of individuals too numerous to mention singly. There are, however, several parties whom I wish to acknowledge whose material assistance has been invaluable.

The Anglo American Corporation of South Africa, Limited, for the opportunities made available and for the leave of absence granted to attend University.

De Beers Consolidated Mines Limited, for the award of a De Beers Group Scholarship.

The boards of directors of Tidal Diamonds, Marine Diamond Corporation and Southern Diamonds, who kindly sanctioned the use of information from their concession areas.

Dr. A.O. Fuller of the Geology Department, U.C.T., who guided the author's studies, and Mr. D.K. Bowie of the same department whose willing assistance and instruction in laboratory techniques saved the author many hours of fruitless labour. Mr. Bowie also critically reviewed the draft of this work.

The assistance and encouragement of the following are also gratefully acknowledged:-

The Consulting Geologist (Diamond Division), Anglo American Corporation of S.A. Ltd.

The Resident Geologists, Sea and Land sections, of The Consolidated Diamond Mines of South West Africa Ltd.

My colleagues and associates of the Geology Dept., C.D.M.

Finally, I wish to acknowledge the co-operation of my shipmates - the Masters and crew of m.v. "Rockeater".

ABSTRACT

An outline of the inshore submarine geology of the south western coast of southern Africa is presented. The study is derived from diamond prospecting operations carried out between 1964 and 1970 in the shallow waters between Walvis Bay in South West Africa and the Olifants River mouth in Namaqualand, Republic of South Africa - a distance of approximately 1 000 km (600 miles). The area can be conveniently subdivided into three regions from north to south:

(i) Tidal Diamond's Concession (T.D.C.) from Sandwich Harbour to Hottentot Bay.

(ii) Marine Diamond Corporation's Concession (M.D.C.) from Luderitz to the mouth of the Orange River.

(iii) Southern Diamond's Concession (S.D.C.) from the Orange River mouth to the mouth of the Olifants River.

Onshore, the coast is semi-arid desert, washed by the northerly, slow flowing, cold Benguella current. Upper Cretaceous to Recent sediments unconformably overlie a sequence of Precambrian formations. A series of elevated Pleistocene storm beaches are mined for their diamond content north and south of the Orange River mouth and in the vicinity of the Buffels River.

The distribution of the submarine sediments were mapped by continuous acoustic profiling systems and the results are displayed as a series of seven maps (scale 1:100 000). The S.D.C. area is characterized by a relatively sediment-free rocky platform adjacent to the coastline. The platform steepens seawards and is bounded by the inshore edge of the principal unconsolidated sediment belt which in turn overlies a stratified sequence of older, so-called Intermediate Sediment. Several tongues of unconsolidated sediment trend inshore and one at least, that opposite the Buffels River mouth, represents a partly buried river channel.

Offshore, the unconsolidated sediment thins and terminates between 15 km and 20 km from the shoreline to expose the surface of the Intermediate Sediment. Lenses of the Acoustical Blanking Layer (A.B.L.), a sediment apparently impervious to the acoustic impulses of the Sparker-profiling system, screen details of the underlying sediment and bedrock between the Buffels River mouth and Cliff Point and also between Wreck Point and Mittag in the M.D.C. A wide and thick sediment body reflects the presence of the Orange River, at whose mouth a buried channel system is also present. The inshore coastal fringe between Mittag and Chameis is also largely sediment-free. The seaward edge of the unconsolidated sediment trends shorewards, being at least 30 km off the Orange River and only 10 km off Chameis. Inshore, between Chameis and Elizabeth Bay, is a persistent and relatively thin wedge of sediment. At Elizabeth Bay itself there is another well developed buried river

channel. The Intermediate Sediment suboutcrop is relatively shallow (-50 m) off Mittag but increases in depth to -95 m off Plumpudding Island, at which depth it remains at least as far as Luderitz.

The sediment distribution north of Hottentot Bay in the T.D.C. is more irregular than that further south. Areas of sediment-free bedrock are breached at several places by prominent tongues of sediment striking inshore and occupying depressions in the bedrock. A striking northeasterly trending rocky ridge, the summit of which comprises Hollams Bird Island, has trapped the sediment in a thick, curved belt on its southern side. The thickness of the sediment in general and the widespread presence of the A.B.L. have combined to obscure the details of the sediment distribution in the T.D.C.

The Intermediate Sediment's appearance on the Sparker records is illustrated. Work carried out elsewhere supports the contention that it is pre-Quaternary in age. The A.B.L. is thought to be a gas-rich, fine grained sediment.

Work on the grab samples collected at irregular intervals from the unconsolidated sediment surface is described. Determinations of the grain size distributions, supplemented by a section on the theory behind such determinations, show that in general the sand is fine to very fine grained, well sorted and only slightly skewed. The size distribution curves tend to be leptokurtic. The only statistically meaniful relationship is that between mean size and skewness: as the mean grain size increases the sediment has a wider range of fine grained constituents associated with it. The sediment is characteristic of those associated with unidirectional currents.

There is a highly significant statistical difference in the mean percentage (by weight) of heavy minerals in the surface sediment of the three sub-areas: M.D.C. has a mean value of 25%, T.D.C. has 15% and S.D.C. about 8%. The epidote-pyroxene-amphibole group of minerals is the most abundant, but garnet and ilmenite are also common. The local rivers appear to have been important contributors of heavy minerals.

There is also a highly significant statistical difference in the mean percentage (by weight) of total carbonate content between grab samples of sediment located south of the Orange River mouth and those north of the mouth. The mean carbonate content of the S.D.C. is 16% but it is only some 4% for both M.D.C. and T.D.C. The Orange River mouth thus marks the boundary between sediments with relatively high heavy mineral and low carbonate contents, and vice versa.

The general stratigraphic sequence of sand, shell, gravel and compacted silt on basement bedrock or shelly sandstone/conglomerate is described and amplified by detailed descriptions of the Plumpudding Island and Hottentot Bay deposits.

The Elizabeth Bay and Orange River buried river channels are described in detail. The Elizabeth Bay channel is 12 km long, 1 km wide and has been incised some 40 m to 50 m into the local bedrock. The offshore end of the Orange River channel is obscured but its dimensions appear to be comparable with the Elizabeth Bay channel. Each slopes some 40 m per 8 km seaward.

A submarine cliff about 3 m high has been traced for 15 km in the M.D.C. area. Its base lies between -18 m and -20 m below mean sea level, which agrees closely with prominent bedrock flattening between -18 m and -24 m traced intermittently through most of the areas for which reliable information is available.

Twenty-eight bedrock profiles located between Pomona and Dreimaster Bay in the M.D.C. were examined. They show that the bedrock at depths of -32 to -34; -40 to -42 and -52 to -54 m is anomalously flat; in more general terms the bedrock between -44 and -58 m appears to be planed off.

The closing chapter deals with events of the Pleistocene Epoch and their local effects. A postulated reconstruction of Quaternary events is presented, the most significant being as follows:-

Illinoian Glacial stage:	Marine regression to about -90 m.
Sangamon or Last Interglacial:	Marine transgression. Erosion of the Major cliff and deposition of the Upper C.D.M. beaches (Major Emergence?) Coastal warping.
Wurm I stadial:	Minor marine regression Coastal warping concluded.
Wurm I Interstadial (Epimonastirian):	Marine transgression. Erosion of the Minor cliff and deposition of the Lower C.D.M. beaches (Minor Emergence?)
Wurm II stadial and interstadial:	Minor fluctuations of sea level. Deposition of the Younger C.D.M. beaches at about 36 000 to 39 000 years B.P.
Wurm III Glacial (?) stage:	Marine regression to -50 or -60 m ± 12 000 yrs. B.P. Post glacial Flandrian transgression with halting stages.
Final recovery of sea level:	progradation of coastline.

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CHAPTER I:

INTRODUCTION

I. THE AIM OF THE STUDY:

The basic aim of this work was to learn more about the nature and distribution of shallow-water submarine sediments, particularly those off the south western coast of South and South West Africa. From a wealth of (often unrelated) raw facts and resultant speculative theories accumulated over the years, it was hoped that this study would produce a clearer picture of the environmental setting of the submarine deposits. The picture is still a very general one but perhaps more comprehensible.

Information has been collected, processed, recorded and discussed by many groups and individuals, including the author. Acknowledgement is given where due, but conclusions and theories set out in the text, unless stated to the contrary, must be attributed to the author only and should not necessarily be assumed to be the policy or opinion of any body, corporation or official.

II. BACKGROUND:

The south western shores of Africa have been known for their diamondiferous deposits since 1909, when the first diamonds were discovered near Luderitz in South West Africa, which was then a German colony. The several mining companies which had been established were amalgamated into what is now the Consolidated Diamond Mines of South West Africa by the late Sir Ernest Oppenheimer in 1920, following difficulties caused by over-production and the First World War. In the wake of discoveries of diamondiferous deposits in Namaqualand in 1925, investigations were instituted just north of the Orange River and the extremely rich marine deposits of the Consolidated Diamond Mines, (C.D.M.), were established. The Namaqualand discoveries were being freely exploited in the interim but the Government clamped down and proclaimed the State Alluvial Diggings, (S.A.D.), in 1927. Then followed the depression years and Second World War, during which relatively few developments occurred in the alluvial diamond mining industry. Large scale mining started in 1946 and today C.D.M., based at Oranjemund since 1941, is the largest producer of gem stones in the world, with mining being essentially confined to the coastal strip up to 50 miles north of the Orange River mouth. Apart from S.A.D., based at Alexander Bay on the south bank of the Orange River, several smaller prospecting and mining camps are located along the coastal fringe of Namaqualand, including that at Kleinzee at the mouth of the Buffels River. Mining and prospecting have also been practised north of Luderitz along the coastal fringes of South West Africa as far north as Cape Frio.

Although these coastal workings extended literally down to the beaches, no effort was made to pursue the logical extension seawards until Mr. S. Collins formed the Marine Diamond Corporation, (M.D.C.). Prospecting of the submarine deposits commenced in 1961 using the "Emerson K" - a converted 759 ton salvage tug fitted with an 8-inch (20 cm) airlift. In 1962 the world's first floating diamond mine started production, and by 1963 the results of these operations appeared sufficiently interesting for De Beers Consolidated Mines to negotiate a participation. Ocean Science and Engineering Inc., a firm based in the United States and known as O.S.E., were contracted by De Beers to survey and prospect the three major marine concessions between Walvis Bay and the Olifants River on a reconnaissance basis.

A general geophysical survey was undertaken using a "Sparker" continuous seismic profiler operated from the "Xhosa Coast", a chartered coasting vessel, with the object of delimiting areas for possible prospecting. This survey commenced in 1963 and continued until late in 1964. Ocean Science commenced prospecting early in 1964 using a specially converted United States Army supply vessel which was renamed "Rockeater". It is of passing interest to recall that she was a sister ship to the "Pueblo", the American Naval vessel captured by North Korea in 1968. On completion of their contract in September 1965, Ocean Science sold "Rockeater" to C.D.M. and she has since continued her sampling programme under the direction of the Marine Diamond Corporation.

On the basis of this survey and the promising results from the concurrent mining operations, De Beers exercised an option in the Marine Diamond Corporation. Several involved financial and administrative re-arrangements have taken place since and today C.D.M., a subsidiary of De Beers, effectively controls M.D.C. and in addition the Anglo American Corporation provides technical services and assistance.

Prospecting of the beach, defined legally as that area lying between low water and the high water mark, was also initiated late in 1963 and large scale mining is now carried out adjacent to (and from) the C.D.M. coastal operations. Beach and submarine mining operations were suspended indefinitely in March, 1971.

A group of companies, variously known as Suid Kunene, Eiland Diamante and Terra Marina, have been actively engaged in prospecting and mining certain of their concessions on a small scale.

The Anglo American Corporation established the Oceanographic Research Unit (O.R.U.) in 1963, based in Oranjemund. This unit has been engaged in various aspects of oceanographic and marine geological research aimed at expanding the knowledge of the geological controls in the marine environment, and lately in applying this research to the development of marine mining and exploration techniques.

III. METHODS OF STUDY AND LIMITATIONS:

a) The author's role:

The author is employed as a geologist by the Anglo American Corporation. At the end of 1963 he was transferred to the marine section and worked with Ocean Science as an observer. Tours of duty on the "Xhosa Coast" geophysical programme were alternated with periods spent on the initial phases of the beach prospecting at C.D.M. The author then sailed on "Rockeater" more or less permanently from her first voyage in April 1964 until February 1965, which covered the reconnaissance prospecting of the M.D.C. concession. Most of the Tidal Diamonds Concession prospecting was supervised by associates, and the author rejoined the vessel in June 1965 until the completion of sampling of the Southern Diamonds Concession in September of that year.

Following the transfer of the ship to C.D.M., the author was at sea on Rockeater again from October 1965 and subsequently trained more geologists so that sea-going geological duties were done on an alternating basis. The author remained closely associated with "Rockeater" until early in 1970 when he was transferred to the C.D.M. shore-based staff.

The author has, in addition, spent several months of relief duty on the O.R.U. vessel "Bellatrix", and has also assisted at times in the compilation of maps from the geophysical records.

b) Sources of information:

(i) Sampling: Geologists employed by M.D.C. before 1966 logged the material dredged up by the "Emerson K", although these notes are of a very general nature.

Every hole that has been drilled by "Rockeater", however, has been logged in fair detail. From these records local plans of the sediment distribution, both vertical and horizontal, have supplemented the geophysical surveys.

(ii) Geophysical records: Both Ocean Science and M.D.C. ran their own geophysical surveys using various C.S.P. instruments known locally as the Sparker, Lizard, Sonoprobe and Pinger. The Side Scan Sonar is also used. From all these sources maps had been compiled in variable detail depending on the scale and object of the particular survey. The author has in turn combined these maps to produce the most representative overall record available.

(iii) Laboratory work: The author spent most of 1967 at the University of Cape Town studying samples collected by Ocean Science. This involved size analysis, heavy mineral extractions, staining techniques, carbonate determinations and an attempt at electron microscopy.

(iv) Theoretical: In conjunction with his laboratory work, the author embarked on a comprehensive course of reading, embracing as many relevant topics as possible. Quoted references are listed under the appropriate heading.

(v) Independant studies: Associates of the author have, from time to time, prepared departmental reports on various aspects of their work. As these reports are private, facts elucidated from them are quoted as 'personal communications'.

c) Limitations of the study:

The exploration work mentioned has been spread along a coastal strip nearly 600 miles long, but less than 10 miles wide, over a period of some eight years. Only recently have some of the results been compiled and published, otherwise this work represents the only overall account of the submarine geology between Walvis Bay and the Olifants River mouth and is probably subjective to a certain degree. The account is of a rather general nature because of the distribution of the data collected, but for a few areas more detail is available and these areas have been described on the supposition that they are typical examples of the marine environment along the south west African coast. Furthermore, the degree to which an area has been surveyed and sampled is a reflection of its economic potential and not necessarily its geological "attractiveness".

d) Special notes:

i) The object of the exploration work has been to locate and evaluate diamond-bearing submarine deposits, so that studies of related subjects often had to be limited. As the results of the economic survey are confidential, references to the diamond bearing potential of the deposits have been intentionally omitted.

ii) Use of both the metric and British systems of measurements will be noticed. It results from the fact that the South West African survey system is based on metric units, whereas the Republic has hitherto used the British system. Where feasible, alternate units are quoted in parentheses.

IV. REGIONAL SETTING:

a) Geographical setting:

The area studied is shown on the map of southern Africa, Figure 1.

MAP OF SOUTHERN AFRICA SHOWING LOCALITY OF AREAS STUDIED

SCALE 1:11500000

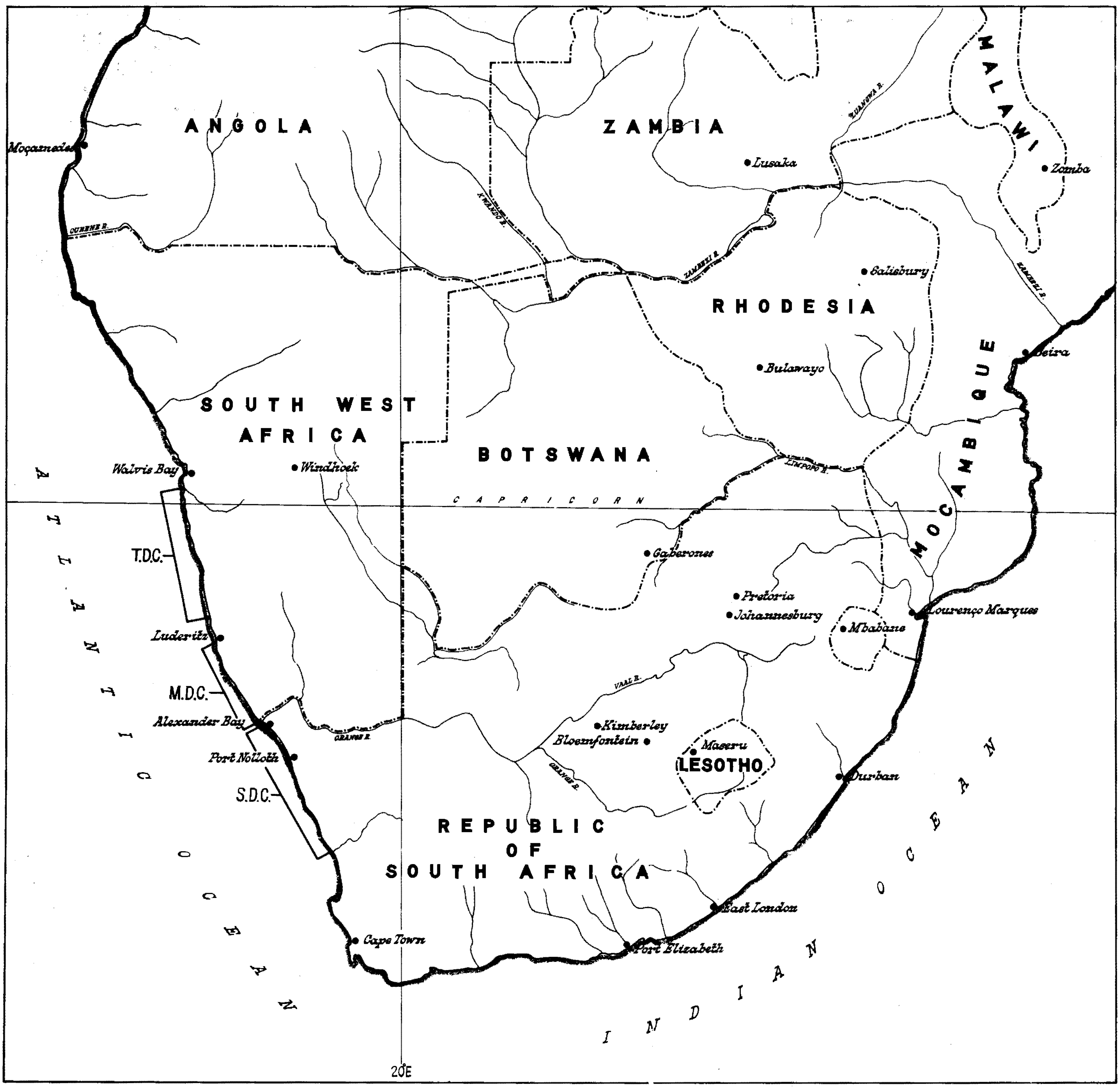


Fig. 1

It extends between Sandwich Harbour (23^{o} 15'5) and the Olifants River mouth, (31^{o} 45'5) - a distance of just over 1 000 km (600 miles). The Orange River locally forms the border between South West Africa and the Republic of South Africa. That portion of the Republic lying between Alexander Bay and Van Rhynsdorp is known as Namaqualand. The coastal strip is shown in more detail in Figure 2, following page 13.

As outlined by Martin (1965), South West Africa can be broadly subdivided into a western desert belt separated from the inland plateau by the transition belt of the Great Escarpment. The Namib desert borders the whole South West African coastline, and is characterized by a vast dune belt. Individual dunes have been seen to rise to a height of nearly 100 m (300 ft.) from the waters edge. These dunes have cut off nearly all the drainage directed toward the Atlantic Ocean. The desert is about 90 - 120 km (60 - 80 miles) broad and it extends south of the Orange River as a relatively flat sand-covered surface supporting a fairly dense milkbush vegetation of Arthroerua Beubritjia. In Namaqualand the coast rises gently to form a plain about 100 m high within 3 to 5 km (2 - 3 miles) of the shoreline. The Escarpment continues with few breaks throughout Namaqualand.

The only perennial rivers within the area are the Orange River and the Olifants River. The Orange, together with its tributary, the Vaal River, drains the interior and western half of South Africa and is the subcontinent's largest river. The Orange River exhibits a striking pattern of superimposed drainage where it flows through the eastern Escarpment, and it enters the sea by means of a wide, shallow estuary whose base level is about 90 m (300 ft.) below present sea level. The Olifants River flows north and drains part of the winter rainfall area of the Cape Province. Many of the other rivers marked on maps of the west coast are little more than outwash channels for the runoff from infrequent heavy showers. Namaqualand has a rainfall of between 100 and 250 mm annually, whereas the South West African coastal regions have less than 50 mm of precipitation - mainly in the form of dense fogs.

Despite the west coast of Southern Africa being a rich fishing ground, major towns are few and far between. Walvis Bay exports mineral and agricultural produce from its sizeable harbour besides being a large fishing base. The fishing village of Luderitz is situated 420 km (260 miles) to the south, and was once the headquarters of the early diamond mining industry. Oranjemund and Alexander Bay have no harbours themselves but are connected by road to Lüderitz and Port Nolloth. South of Port Nolloth the main road to Cape Town lies some 50 km (30 miles) inland.

The coast is washed by the cold, north flowing Benguella Current, which flows at about one knot and has an average water temperature of 10^{o}C. The presence of this current, combined with the predominantly southerly winds, is largely responsible for the arid climate, which is nevertheless cool on the shoreline - at Oranjemund the average maximum daily air temperature is 23°C.

The prevailing swells are generated in the south Atlantic and during the summer months exceed a significant height of 3 m about 25% of the time compared with 45% of the time during the winter (Murray et al, 1970).

b) Concession Areas:

The coastal waters to approximately 5 km (3 miles) seawards are divided into concession areas as indicated in Figures 1 and 2 (pages 4 and 13). The principal concerns and their interests from north to south, are:-

(i) Terra Marina has the concession from the Cunene River to Sandwich Harbour

(ii) Tidal Diamonds holds the concession between Sandwich Harbour and Hottentot Bay

(iii) Between Hottentot Bay and Luderitz the mineral concession is controlled by Suid Kunene.

(iv) Marine Diamond Corporation has the rights for the area between Luderitz and the Orange River mouth, except for areas around the islands which legally fall under South African jurisdiction and for which Eiland Diamante has the concession. (These are not shown in Figure 2).

(v) Southern Diamonds holds the rights between the Orange and Olifants Rivers; to the south of the Olifants River Terra Marina controls the concession.

The area of study was essentially that embraced by the concession areas of Tidal Diamonds, Marine Diamonds and Southern Diamonds, which are hereafter referred to as T.D.C., M.D.C., and S.D.C. respectively.

The Consolidated Diamond Mines of South West Africa, known as C.D.M., hold the onshore rights up to 80 km (50 miles) inland between the Orange River and Hottentot Bay, (which area is known as Diamond Area No. 1 or the "Sperrgebiet"), and also have a controlling interest in the area from Hottentot Bay to Sandwich Harbour (Diamond Area No. 2).

c) Geological Setting:

The onshore regional geology consists essentially of two groups of formations:-

(i) Precambrian formations, and

(ii) Upper Cretaceous to Recent deposits.

The latter group have been studied in fair detail because of their economic associations, but the Precambrian 'basement' rocks are still the subject of intensive research. Except for considering their effects on the bedrock topography, the basement rocks have largely been ignored for the purpose of this study and the following brief description is included purely for the sake of completeness.

(i) Precambrian formations:

Between Walvis Bay and Spencer Bay isolated outcrops of the Hakos and Khomas Series are found between the sand cover. They form part of the geosynclinal Damara System and consist mainly of dolomite-marble, schists and tillites. South of Spencer Bay, as far as Bogenfels, the coastal rocks are comprised of those of the Kheis System. At Saddle Hill the white quartzites form a range of prominent hills, while south of Lüderitz medium to high grade metamorphic rocks such as gneiss and biotite schists occur. Near Bogenfels these rocks are unconfirmably overlain by the Bogenfels Formation, which consists essentially of folded dolomites and interbedded shale. South of Bogenfels are the Marmora Beds which, according to Martin (1965), are probably the lower stages of the Grootdam Series of the Gariep System. The lower metamorphosed volcanic rocks are followed by an upper sedimentary stage which is reflected by the greenish phyllites, schists and occasional quartzite that are found between Oranjemund and Kerbehuk, some 50 km (30 miles) to the north. South of the Orange River as far as Port Nolloth are the sedimentary members (arkoses, greywackers, limestone) of the Gariep System. The coast between Port Nolloth and Kleinzee is cut into the Stinkfontein Formation, a uniform succession of quartzites, conglomerate, and arkoses with interbedded tuffs and lavas. Between Kleinzee and the Brak River, 75 km north of the Olifants River, the basement rocks belong to the Namaqualand Granite-gneiss massif. A fringe of rocks of the Malmesbury Formation form the cliffs between the Brak River and the Olifants River mouth, the Formation consisting of limestone, phylittes and quartzites.

In summary it can be said that the coastal 'basement' rocks consist of a great variety of limestones, quartzites and schists with granitegneiss bodies. The relationships between many of the Series and Formations have yet to be satisfactorily resolved.

(ii) Upper Cretaceous to Recent deposits:

The west coast of southern Africa is semi-arid desert and the climatic regime is largely reflected by the nature of the sandy deflation residua. It is not the intention of the author to describe these superficial deposits but simply to provide an outline of the more important units which occur.

The oldest of the Mesozoic deposits referred to in literature is the so-called "Pomona Series", a formation of conglomerate, laminated quartzite and silcretes which cap the Precambrian basement rocks. Remnants of this succession are preserved as isolated mesas between Oranjemund and Luderitz; an example located near Chameis Bay is illustrated in Plate Ic. These flat topped hills are capped by a ferruginized quartz breccia or silcrete which is taken to represent a formerly extensive, end-Cretaceous erosion surface. Reuning (1931) described an equivalent unit just north of the Olifants River mouth. Overlying these Pomona beds in places are Tertiary phonolite intrusions and Older fluviatile gravels which in turn are overlain by traces of a marine transgression. Remnants of the gravels deposited by this transgression occur between Buntefeldschuh and possibly Elizabeth Bay. Kaiser (1926) mapped the extent of the marine deposits which, on the basis of associated fossils, he described as of Eocene age but which Haughton (1931) suggested could be assigned to a wider spectrum of age, namely from Upper Cretaceous to Miocene. In 1909, H. Merensky suggested that fossils associated with marine sandstones at Elizabeth Bay were of Cretaceous age.

The Tertiary marine sequence is best preserved at Buntfeldschuh, just south of Bogenfels and a few miles inland from the beach. Between 30 m to 50 m high, it consists there of greenish coloured sands and silts with two distinctive gravel bands containing agates, jaspers and honey coloured pebbles of chalcedony.

Following uplift and the onset of renewed erosion in the Late Tertiary, aided by wetter conditions which may represent Early Pleistocene pluvial cycles, Younger gravels were deposited. These thick deposits of coarse, sub-rounded fluviatile gravels are characterized (and distinguished from the Older gravels) by pebbles of phonolite (Stocken, 1962).

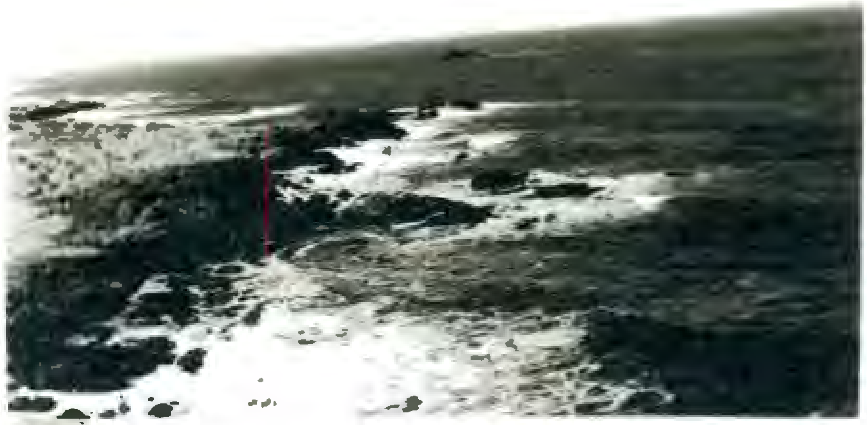
Characteristic of the south western coast of South Africa and of great economic importance are the diamondiferous raised beaches. Pleistocene to Recent in age, the deposits have been described in some detail by Hallam (1964) so that only a brief description is given here. Although deposits occur at higher elevations elsewhere along the coast, at C.D.M. the highest (and probably oldest) remnants occur at about +35 m above mean sea level just north of the Orange River. The succession is, however, most typically developed at lower elevations between Oranjemund and the coastal mining area of Affenrucken, just south of Chameis Bay (Map 4).

PLATE II

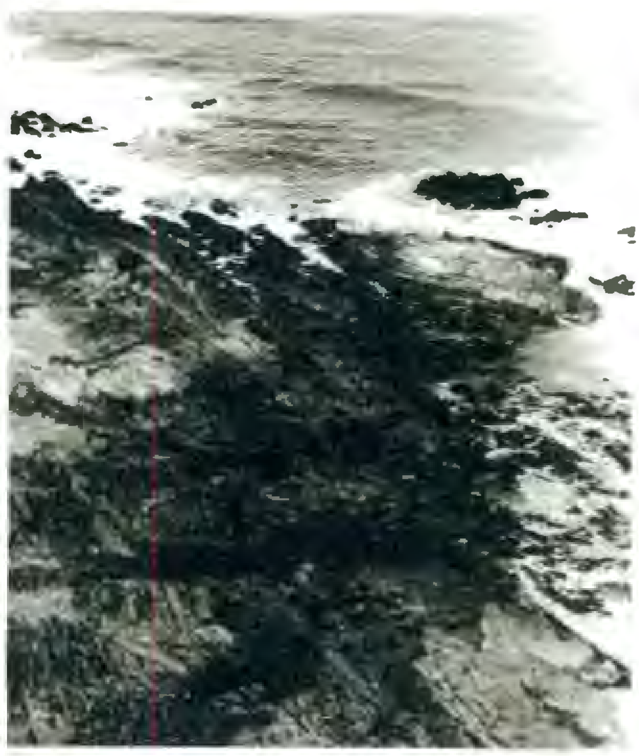
a) The major (oldest) wave-cut cliff exposed by mining operations at C.D.M. It is about 3 m high. The wave-cut notch at the base of the cliff is just discernible and occurs at an elevation of about 12 m above sea level at this site.

b) The so-called Minor cliff in the same locality as a). The cliff is about 2 m high and the elevation varies from 3 m at its base to 5 m at its well-planed surface. Note the irregular nature of the outcrop.

c) Gullied bedrock exposed by mining operations at C.D.M. The individual outcrops tend to display a concordant surface. The gullies are filled with sand, cobble gravel and bedrock debris.



a)



b)

c)

PLATE I

The Upper group of beaches abut against a distinct wave-cut cliff several metres high whose basal nickpoint decreases in elevation from about +26 m near Oranjemund to +10 m near Affenrucken, a difference ascribed to downwarping northwards. The beaches have faunal remains which indicate a slightly warmer water temperature in the past and they are characterized by the extinct mollusc Donax rogersi. Overlying the Upper beaches is a succession of terrestrial deposits; best developed in the north and termed Red Sands, they consist of clay lenses with dark and light-coloured (aeolian?) sands, and brown sands with angular quartz pebbles. The Red Sands are in turn capped by a distinctive layer of calcrete and covered by modern windblown sand.

The Lower group of beaches consist of three basic units which are characterized by a cold-water fauna such as Donax serra and Mytilus sp. (L. Kleinjan - personal communication). The Lower beaches appear to be unwarped and clearly demonstrate their younger age by cutting the terrestrial deposits and the distinctive calcrete which covers the Upper group of beaches, as well as covering remnants of older conglomerate which carries rogersi remains. The Lower beaches are covered by calcareous sand containing calcrete nodules.

The steepening of the coast to the north has not only led to a narrowing of the deposit but also to the development of a wave-cut cliff which cuts the Upper wave-cut platform(s); the base of this Minor cliff lies at a fairly constant elevation of between +3 and +5 m. Plate II shows both the (Upper) Major cliff and the Minor cliff at their most typical, as well as the gullied nature of the wave-cut bedrock platforms.

The raised beaches occur in the form of distinctive storm shingle beaches with well rounded, discoidal cobbles and pebbles and interbedded marine sands (Plate III). The sands frequently exhibit a remarkable concentration of heavy minerals, notably magnetite and ilmenite with subsidiary garnet and epidote. The pebbles consist predominantly of quartzites and a characteristic suite of banded ironstones, jasperlites and agates. The basal layers may be well cemented to form a tough conglomerate; the enclosed rogersi remains show them to be typical of the Upper group of beaches. The beach crests attain an average maximum height of 3 m above their bases.

Older than the local Pleistocene beaches and overlain by them are a series of clay-filled channels incised into the schistose bedrock. In addition, the raised beach deposits themselves have been eroded by later drainage channels to leave barren sand-filled gaps in the deposit.

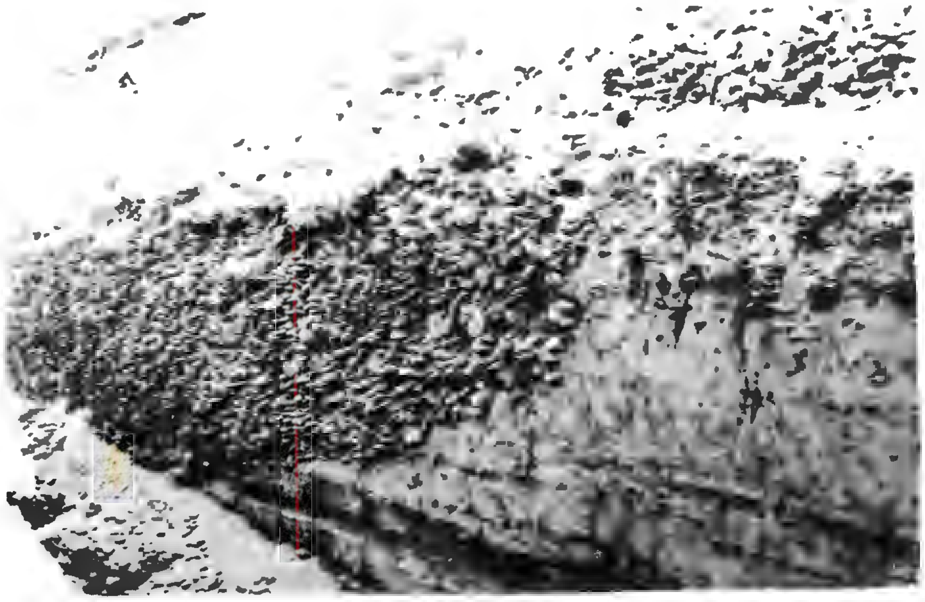
Raised beach deposits from several other localities are mined for their diamonds, for example at Alexander Bay and at Kleinzee, but further descriptions will be deferred to the section on the Late Quaternary history of the coastal region.

PLATE III

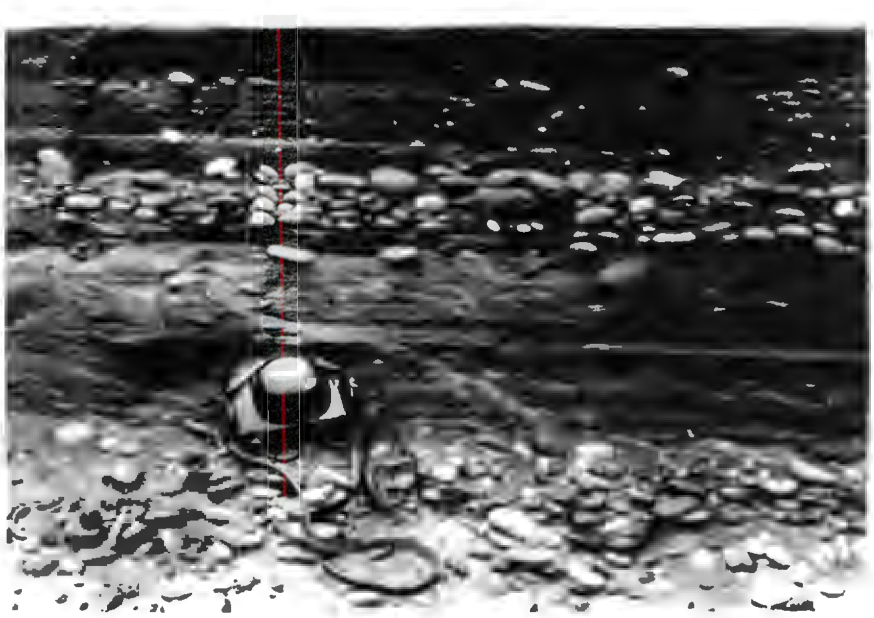
Raised beaches at C.D.M.

a) The north wall of a prospecting trench, showing imbricated pebbles and cobbles of a storm beach cutting the flatter-dipping marine sands of an older beach sequence on the right. Both types of material belong to the Older groups of beaches.

b) Details of bedding in another trench face. Bands of closely-packed, well rounded and discoidal cobbles in a sand matrix inter-bedded with sands containing varying amounts of heavy minerals. Some of these sands are almost black in colour. The camera case indicates the order of scale.



a)



b)

PLATE III

CHAPTER II:

GENERAL SEDIMENT DISTRIBUTION AND SUBMARINE TOPOGRAPHY

1. EQUIPMENT USED:

Because submarine mining is a unique venture, at least in South Africa, it is worthwhile to outline some of the principles used in investigating the deposits. The success or otherwise of the prospecting and mining of submarine placer deposits depends primarily on locating favourable areas of accumulation. The following factors are among those used to define a favourable area:-

1) The maximum and minimum water depths in which the sampling and mining equipment will be used.

2) The thickness of the sediment containing the mineral sought; conversely the absence of sediment-free bedrock.

3) A knowledge of the factors (like bedrock topography) affecting the distribution of this sediment; both on a local and regional scale.

4) The location of physical hazards such as rocky reefs or blinders.

5) Most important of all, perhaps - the concentration of the mineral sought.

The first four of these factors are most conveniently learned by remote sensing methods and the fifth by physical sampling. The most important remote sending method used is that of continuous seismic reflection profiling (C.S.P. for short), using acoustical sources. The principle of using sound to measure water depth became practical with the development of the echo sounder in the early 1920's. The basic phenomenon made use of is the lapse of time between the creation of some acoustic pulse and the return of the reflected echo. If, however, the acoustic pulses possess sufficiently low frequencies, the pulses will have some of their energy transmitted through sediment, with echoes being reflected whenever there is a change in the density of the medium or between interfaces. The equipment used to detect and record parameters of submarine sediments by acoustical methods consists essentially of 4 components:-

a) A sound source generator
b) A means of receiving the echoes or reflections
c) Suitable amplifiers and filters
d) A means of providing a record of the results.

With suitable filtering, unwanted echoes can be largely removed. Various means have been used to record these reflected echoes, but basically the visual display units depend on the amplifier to strengthen received signals, coupled with some sort of rotating arm and marker so timed that one sweep of the arm across a sheet of sensitized paper is equivalent to a convenient unit of depth.

Received echoes are then "processed" and recorded as a mark on the paper at the relative elapsed time/depth position. Instrumentation today allows continuous acoustic pulse generation to be coupled with continuous recording, so that surveys can be conducted with the ship carrying the equipment being underway and with instant visual display of the results, which can be stored for further detailed examination later. Various instruments are available, the use and nature of which depend on the objectives required bearing in mind that low frequencies (of higher power) are needed for penetration, but that resolution is correspondingly poorer. Other factors which affect the quality of the records are:-

1) the ship's speed and relative movement
2) the installation of the instruments
3) the frequency, shape and energy of the generated pulses
4) the water depth and sediment thickness
5) the nature of the (unconsolidated) sediment and underlying bedrock.

The quality of the surveys conducted depends also on sufficiently accurate position fixing to enable features to be located in the horizontal plane.

Below are some of the instruments and methods which have been used or are in use. Descriptions have been kept to a minimum as it is the results of the surveys that are considered to be important. Further details are available in the paper by Murray (1969).

a) Sparker:

Designed and operated by Alpine Geophysical Associates under subcontract to Ocean Science, the acoustic impulse is created by discharging a capacitor bank across a gap, so producing a spark from a 7 Kv potential and producing a pulse with a frequency of about 500 H_z. The transducer and hydrophones were towed (and floated) astern of the operating vessel, ("Xhosa Coast", a chartered coaster). As a reconnaissance survey, traverses were run perpendicular to the coastline for a distance of 9½ km (6 miles) and then parallel to the coastline for 1½ km (1 mile), but occasionally lines were extended further offshore. Positions were determined by distance measurement from two radar transponder beacons positioned at known points on the shoreline.

The records could be resolved to about 2 m; the instrument was effective in water depths of up to some 250 m (800 ft), with penetration of about 95 m (300 ft) of sediment being observed at times.

The survey was conducted from late 1963 to mid 1965 in the area between the Olifants River mouth and Luderitz, and between Hottentot Bay and

Sandwich Harbour. Because the only maps available at the time the survey was undertaken were enlarged Admiralty charts, the results were plotted at an unusual scale of 1: 48 000.

b) Lizard:

Designed and owned by Ocean Science, this instrument operated at 3.5 KH_z, with the transducer and hydrophones being combined and towed in a package, termed a "fish", alongside a converted fishing vessel (Plate IV b). Operating on a magnetostrictive principle, the semi-focused pulses induced a penetration of some 15 m (50 ft) of sediment, but resolution was to about 1 m (3 ft). The Lizard was used as a follow-up instrument to the Sparker survey, and traverses were accordingly run about 500 m apart with occasional lines crossing them as a check. Because the "fish" tended to vary its depth in the water, the records cannot be used to assess the elevation of the bedrock as this operation requires a constant reference surface. Many small areas were surveyed, including most of inshore sediment patches in the S.D.C.

c) Sonoprobe:

The model 410 Sonoprobe is manufactured by Summer and Mills, Texas, and leased from Socony-Mobile. The Sonoprobe was used by the Marine Diamond Corporation during 1965 and 1966. Operating at a frequency of 3.8 KH_z, the transducers were mounted in the hull of the vessel, providing quite good depth control. Surveys were run in a radial pattern from fixed beacons ashore along fixed line bearings with supplementary distance measurements provided by the Hydrodist, a tellurometer adapted for marine work (see Plate V). Resolution of the Sonoprobe was of the order of 0.5 m (1½ ft), and penetration about 6 m (20 ft). It was used for detailed surveys of potential mining or prospecting sites. McClure, Nelson and Huckaby (1958) describe a similar intrument.

d) Pingers:

The Pinger is a product of E.G. & G., (Geodyne), and since 1967 has been the routine inshore profiling instrument used by M.D.C. A 6 KH_z model is used (hull-mounted) in m.v. "Cypress" (see Plate IV c) for depth control. It has a potential penetration of some 15 m (50 ft), and a resolution of 0.2 m (say 1 ft). The surveys are usually run perpendicular to the coast in lines 50 to 500 m apart, according to the area, but most usually 100 m apart, using two theodolites or the Decca Hi-Fix navigation system, a semi-automatic electronic navigation system. The Pinger has been used to provide detailed information between Chameis Bay and Pomona and up to 7 or 8 km seaward in the M.D.C. concession area. Parts of the T.D.C., namely Hottentot Bay, Spencer Bay and to the north and south of Meob Bay, have also been investigated. Maps have been compiled on a routine basis at a scale of 1:5 000 and 1:25 000.

PLATE IV

a) General view of the mining barge "Colpontoon". Material is dredged up through flexible rubber hoses, seen suspended over the bows on the left. The dome-like structure on the right is the crew accomodation and it also supports a helicopter landing platform. The "Cypress" (see below) is moored alongside.

b) "Klipbok", a converted steel-hulled fishing boat used by O.S.E. as a geophysical vessel. The torpedo-like object on the deck in front of the brüge is the "fish", the transducer housing towed alongside the vessel during operations and part of the Lizard continuous profiling system.

c) "Cypress", the geophysical vessel of the Marine Diamond Corporation. The Sonoprobe and Pinger transducers are built into the hull. Note the hydrodist aerial abaft the funnel.

a)

b)

c)

PLATE IV

PLATE V

a) A permanent survey station ashore. The theodolite is mounted on a survey beacon. Next to it, on the left, is the M.R.B.2 Hydrodist slave unit, used for measuring distances accurately in all weathers. Usually the combination of a bearing and a distance is sufficient, but two distances or two angles from known positions also enable a position to be determined at sea.

b) An operator on "Rockeater" pictured with the M.R.B.2 Hydrodist Master Unit. Communication with the shore party is effected by V.H.F. radio. The aerial of the Hydrodist unit is mounted clear of the ships superstructure.

The Hydrodist operates on the principle of measuring the phase difference between a transmitted and reflected electronic signal. The signal is transmitted from the master unit, reflected from the slave unit and then received (and measured) by the master unit.

a)

b)

PLATE V

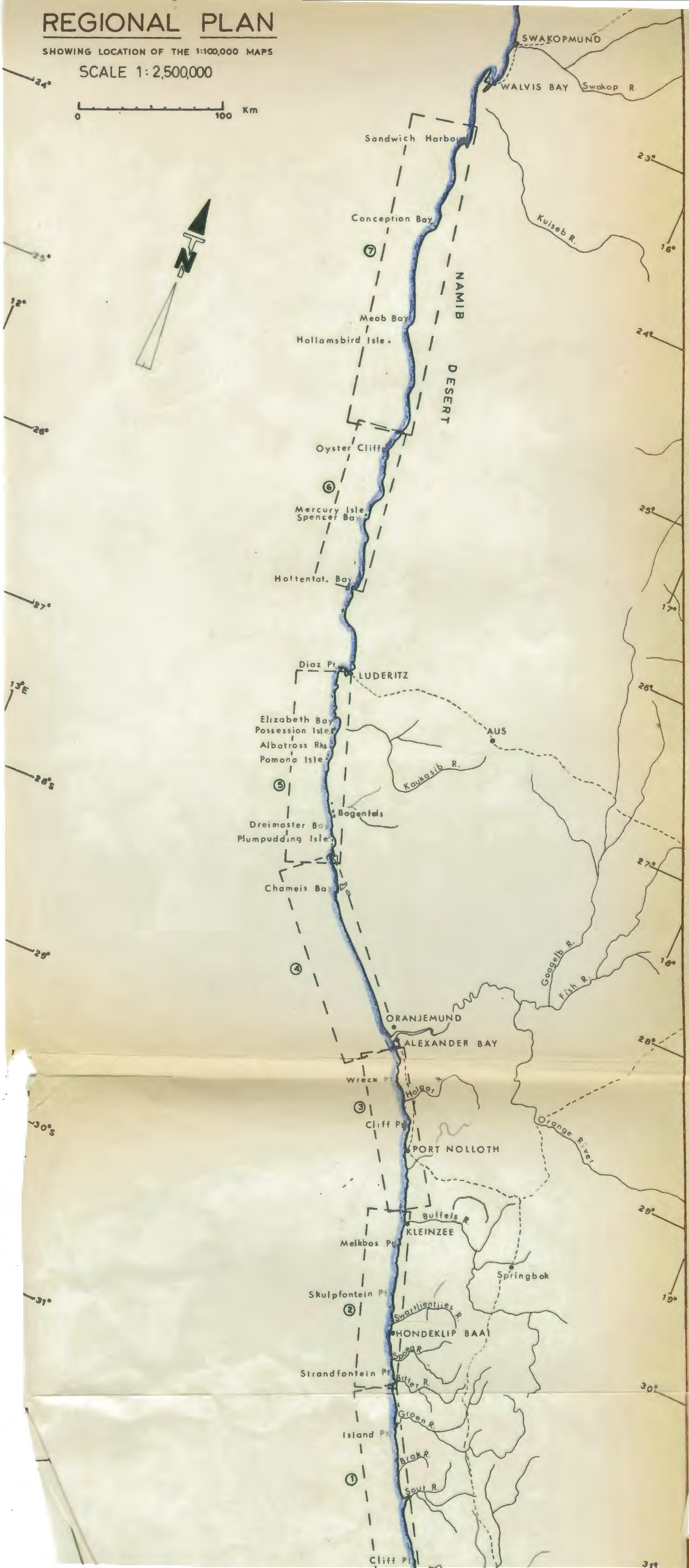
e) Side Scan Sonar:

The Kelvin Hughes MS 43 Mk I Transit Sonar is operated from "Bellatrix" and was used initially to locate favourable areas of sediment-free bedrock for examination by divers and the sampling of gullies by them. The transit sonar, as it is known locally, has two ranges (275 m and 550 m) with a single channel, and operates at a frequency of 48 KH_z/sec with a 1-millisecond pulse length. The acoustic pulse is directed both vertically downward and at all angles on a plane normal to the ship's heading, so producing an oblique picture of the sea floor. Mosaics of these records are shown in Plate VI. The encouraging results obtained, combined with a need for more detail, resulted in the purchase of an E.G. & G. Mk I Side Scan Sonar system which incorporates a dual channel recorder. This instrument scans each side of the vessel's track, has variable pulse rates and scales and operates at a frequency of 110 KH_z. Operators are able to make distortion free photographs of the records and combine them to make large scale maps rather than a picture mosaic. The -22 to -24 m cliff has been mapped in detail in this manner (see later).

II. COMPILATIONS AND MAPS.

The author has constructed compilations of most of the maps that have been produced in the geological department of M.D.C. This was a particularly time-consuming and trying task as the original maps are themselves compilations from the geophysical records and were drawn to a variety of scales to suit different requirements. The reconnaissance geophysical (Sparker) work was plotted at a scale of 1:48 000, often without adequate grid references. All these maps were reduced and fitted together and then redrawn to produce the series of maps numbered 1 to 7, at a common scale of 1:100 000, which are presented in a separate folder. Fig. 2 shows the areas covered by these maps. This scale was chosen as the best compromise between size, presentation of detail and illustration of general trends. The original geophysical records had to be re-examined in some cases where discrepancies were evident, and this was aggrevated by the fact that record quality has deteriorated over the years and some records have been mislaid. Preference was given to maps produced from Pinger, Lizard and Sparker surveys in that order, bearing in mind that the first two systems were used in relatively shallow water (less than 50 m). Occasionally, information from sampling operations suppliments the geophysical data. The information shown on these maps is not claimed to be absolutely accurate, as different workers may disagree on the interpretation of the records, but to the author's best ability and knowledge they represent the most complete, up to date compilation available.

In passing it may be mentioned that the geophysical records were interpreted assuming the speed of sound through sea water and unconsolidated sediments to be 1 460 m/sec (4 800 ft/sec) and 1 675 m/sec (5 500 ft/sec) respectively. Discrepancies introduced by these approximations are considered to be


REGIONAL PLAN
SHOWING LOCATION OF THE 1:100,000 MAPS
SCALE 1: 2,500,000
0
100
Km
N
SWAKOPMUND
WALVIS BAY
Swakop R
Sandwich Harbour
Conception Bay
Kuiseb R.
NAMIB
DESERT
Meob Bay
Hollamsbird Isle.
Oyster Cliffs
Mercury Isle
Spencer Bay
Hottentot. Bay
Diaz Pt.
LUDERITZ
Elizabeth Bay
Possession Isle
Albatross Rks
Pomona Isle
AUS
Kaukasib R.
Bogenfels
Dreimaster Bay
Plumpudding Isle
Chameis Bay
Goageib R.
Fish R.
ORANJEMUND
ALEXANDER BAY
Wreck Pt.
Holgat R.
Cliff Pt.
PORT NOLLOTH
Orange River
Buffels R.
KLEINZEE
Melkbos Pt.
Springbok
Skulpfontein Pt.
Swartlientjies R.
HONDEKLIP BAAI
Spoeg R.
Strandfontein Pt.
Bitter R.
Groen R.
Island Pt.
Brak R.
Sout R.
Cliff Pt.
①
②
③
④
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12°
13°E
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30°
31°
16°
17°
18°
19°

PLATE VI

Mosaics compiled from strip records of the Kelvin Hughes MS 43 Mk I Transit sonar system. In both illustrations the individual strips are aligned approximately true north-south and the shore lies close to the upper edge of the mosaics.

a) A large-scale mosaic of an area 3 km long and 2 km broad. The edge of the sediment can just be seen in the lower righthand corner. The dark borders of the strips are due to tuning difficulties.

b) A small-scale mosaic of an area approximately 1 km^2. The light coloured area is sand, the dark patterned areas represent gullied bedrock. The thin, dark line on the extreme left of the mosaic is sea-level and the blank space on its immediate right represents the water depth under the transducer. These features have been eliminated from the other strips.

a)

b)

PLATE VI

negligible for the relatively shallow waters and thin sediments investigated.

The maps show the sediment distribution as isopachs at 6 m (20 ft.) intervals, as well as water depth at 30 m (± 100 ft.) intervals. The geodetic grid lines are based on Longitude 17°E (Gauss Conform Projection, Clarkes 1880 spheroid). The grid is annotated in English feet for the S.D.C., in metres for the M.D.C. and T.D.C., and runs north-south. Some of the survey beacons are named as they are useful in referring to localities. The geographical grid is drawn around the margins of the maps at 15 minute intervals. Sample positions refer to only those samples quoted in the text. None of the survey tracks are shown as these would obscure the geology. The outline of the Acoustical Blanking Layer is shown by a dash-dot annotation; it denotes the area where the underlying sediment and bedrock is masked by what is presumed to be an acoustically impervious sediment. The contact between the basement rocks and the so-called Intermediate Sediment is marked by a feathered, broken line. The Intermediate Sediment is a thickening , stratified formation which is partially penetrable acoustically and which unconformably overlies the basement bedrock.

Several other maps have been prepared and are introduced in the text. They are either bound within or folded in the map folder.

III. DESCRIPTION OF THE GENERAL SEDIMENT DISTRIBUTION AND SUBMARINE TOPOGRAPHY.

The three concession areas conveniently tend to differ slightly in their pattern of sediment distribution and they are thus described separately.

Starting in the very south, off the Olifants River mouth (Map I) is a relatively wide blanket of sediment generally less than 20 ft. (6 m) thick, bounded inshore by an irregular area of bare (sediment-free) bedrock as far as Cliff Point. An interesting feature is noted just south of the river mouth - a pronounced hollow in the bedrock is filled with over 100 ft. (30 m) of sediment. It probably represents portion of a drowned river channel which may continued further south beyond the area investigated. The form of the present river mouth suggests such a drowning. No delta is present.

A prominent area of sediment-free bedrock strikes away from the coast opposite beacon Val and from beacon Klipbok the bare rock-sediment contact tends to follow the 200 ft. (60 m) isobath rather closely. The sediment thickens fairly rapidly seawards to an excess of 60 ft. (18 m), whereafter it gradually thins again and terminates well out to sea. Just north of the Brak River mouth and about 11 miles (19 km) offshore, the unconsolidated sediment's offshore boundary was relocated.

The rocky inshore area has occasional small patches or ponds of sediment. Those off the Sout and Groen Rivers are more prominant. A patch of sediment has also been deposited against what is probably an extention of a submarine ridge striking south from Island Point.

Isobaths are seen to be more irregular over the sediment-free areas than those across the area of sediment cover, reflecting the uneven topography of the bedrock. The water depth increases relatively slowly opposite the Olifants River mouth, but the isobaths gradually swing inshore further north until they parallel the coast from beacon Klipbok. Note that the configuration of the isobaths off, for example, Island Point suggest a sharp increase in slope of the sea bottom at the edge of the sediment, followed by a much gentler slope in deeper water.

The sub-outcrop of the Intermediate Sediment, annotated as a dashed feathered line on the map, unconformably overlying the basement rocks and on which the 'Recent' unconsolidated sediment has been deposited, also exhibits a linear strike. The Intermediate Sediment will be discussed in more detail in another section.

Further north, on Map 2, the inshore sediment outline becomes much less regular from the Spoeg River mouth. Pronounced tongues of the main sediment body trend inshore at several localities, namely at beacon Eifel, off Kommagapunt, at beacon Lost, off the Buffels River mouth and at Penquin Rock. Several patches of sediment are also present inshore, the most prominent of which is that off beacon Show, just north of the Spoeg River mouth. The main sediment body is closer to the coast, the inshore bare rock area being only about three quarters of a mile wide off beacon Tsumeb compared with figures of three to four miles off the Sout and Brak Rivers (Map I) further south. The sediment body also narrows to a minimum off the Swartlintjies River mouth and the isobaths show the sea bottom slope has increased off beacon Lost. This narrowing trend reverses again: the sediment body widens with a flattening of slope seawards.

The southern apex of a broad apron of the 'Acoustical Blanking Layer', a subsurface horizon in the sediment which is apparently impervious to acoustic impulses and screens details below it, is located opposite beacon Lost. This blanking layer appears to deepen irregularly as the sediment isopachs along its inshore margin vary from less than 40 ft. to an excess of 60 ft. Like the Intermediate Sediment, it does not trend inshore as do the tongues of the upper, 'Recent' sediment. The Acoustical Blanking Layer broadens gradually to a width of some 5 miles (8 km) off beacon Ben Hur (Map 3), but fades out quite sharply off Cliff Point north of Port Nolloth. From Port Nolloth the inshore edge of the main sediment body maintains a constant strike. We note that an elongated sediment patch is indicated as lying off the Holgat River mouth.

At Wreck Point the whole pattern changes: irregularly shaped patches of sediment inshore link up to form part of a vast sediment body undoubtedly associated with the Orange River. A lenticular outline marks another deposit of the Acoustical Blanking Layer. The sediment in general extends out to sea and the water shallows noticeably; the 200 ft. isobath lies some twelve and a half miles (20 km) seawards comapared with an average of about 2 miles (3 km) for the rest of the S.D.C. The vastness of this submarine deposit will be appreciated even further by referring to Map 4 whose units, it must be emphasized, are metric. The most striking feature of the southern boundary of the M.D.C. concession is the steep walled, buried channel system of the Orange River mouth. A more detailed discussion of this system will be found in another section. The Acoustical Blanking Layer obscures details of its extension offshore. Although a thick body of sediment is present, coupled with shallow water, there is no classic delta as such as the bottom wave-induced water surge and long-shore drift currents are sufficient to disperse the sediment introduced into the sea by the river. The unconsolidated sediments are estimated, from the few extented survey lines run in this area, to extend some 30 km (18 miles) out to sea. The offshore edge of the sediment is probably a lot more irregular than the smooth lines shown on the map. The thick wedge of inshore sediment thins out until about 40 km (25 miles) north of the mouth and off Uubvley, the inshore belt of sediment-free bedrock emerges again. Just to the north, off beacon Mittag, the Acoustical Blanking Layer terminates and at the same locality the sediment in general thins out and the isobaths swing inshore, denoting a gradual increase in sea-bottom slope. The Intermediate Sediment sub-outcrop can be traced relatively close inshore but it gradually trends seawards again following the zero isopach.

At beacon Round another large sediment body is located offshore. It's precise relationship to that further south is not clear but the sparse information available suggests that they are separated by sediment-free rock at this locality at least. At Chameis Bay the pattern changes again. A narrow, thin lens of sediment lies just seaward and adjacent to the surf-zone, being separated from the offshore sediment by a distinct area of exposed rock. The 90 m (300 ft.) isobath makes a distinct bend seawards offshore of Chameis Bay, marking a submarine topographic high in the vicinity. The offshore sediment forms a pronounced thick belt between Chameis and Bakers Bay (Map 5), after which it narrows appreciably to continue as a relatively narrow extension northwards before being separated into patches between beacons Square and Wales.

The inshore sediment body has been mapped in detail as far as beacon Coast, which accounts in part for its relatively irregular outline. In general, it thickens inshore to merge with the sandy beaches which are separated by cliffs and prominent headlands between Chameis and Pomona. The offshore contact is generally coincident with the 30 m (100 ft) isobath.

Off Bogenfels, the Intermediate Sediment outcrops have been mapped as occurring at a depth of some 90 m, which isobath it tends to follow when not overlain by the 'Recent' unconsolidated sediment.

At Elizabeth Bay is another prominent drowned river channel which is thought to have been cut by the Kaukausib River at a time of lower sea level. The river has since dried up on land but it's former course is marked by a wide valley filled with surface detritus. Only a few of the isopachs have been shown on the 1:100 000 Map 5 in order not to obscure the general trend; a more detailed discussion of the feature is to be found later. It is sufficient to record here that the precise extent of the Intermediate Sediment beneath the Recent cover within the channel is not clear.

The inshore sediment lens virtually terminates at Elizabeth Bay; a narrow lobe of sediment to the north terminates opposite beacon Wolf. The Bay itself has a wide low-lying sandy beach between beacons Eliz and Peak, and is bounded by a pan which in turn extends northwards into one of the valleys common in the region. Sediment transported up the coast by longshore drift would tend to be diverted into the south-facing bay and accumulate on the beach. On drying at low water the sand would be subject to wind action and be blown inland to become part of the train of sand dunes which are present in the region.

North of Elizabeth Bay the characteristic inshore sediment lens is absent, but a few thin, isolated patches of sediment occur as far (at least) as Diaz Point, the northern boundary of the M.D.C. concession area. Here too there is a prominent break in the coastline and the village of Luderitz is situated in the re-enterant of a local typically drowned coastline.

The area between Luderitz and Hottentot Point was not investigated but some indication of the sediment distribution is given by Maree (1966). He indicates the existence of a broad (up to 11 km) sediment lens inshore between Diaz Point and Marshall Rocks. This lens terminates offshore at a maximum depth of 72 m (40 fathoms), and it lies largely within two rock ridges extending north and south from Diaz Point and Marshall Rocks respectively.

From Hottentot Point northwards (the T.D.C. concession), the pattern of sediment distribution is different from that previously described, yet also distinctive. Broadly speaking, areas of sediment-free bedrock are breached by tongues of sediment, for example just north of Hottentot Bay, off beacon Hummock, off beacon Knoll and off beacon Sylvia (see Map 6). At all but the last locality, thick sediment is found well inshore whereas the isobaths show only a slight trend inshore which suggests the sediment occupies definite depressions in the bedrock. The Intermediate Sediment also follows the outlines of these depressions but it's offshore continuation has not been traced, although the windows mapped off Spencer Bay and Saddle Hill suggest that the Intermediate Sediment is found on bedrock without any appreciable Recent sediment cover. Isolated patches of acoustically impenetrable sediment are found off beacons Gibraltar and Knoll.

A striking feature is illustrated on Map 7. A rocky ridge strikes south from beacon South Rocks with Hollams Bird Island as a pinnacle showing above the water. The ridge is about 7 km (4½ miles) wide at its broadest extent and extends about 25 km (15 miles) seawards. The 30 m isobath shows the ridge to be fairly flat. Sediment has banked against its southern edge to a thickness of more than 40 m, but acoustically impenetrable sediment has obscured details of the distribution seaward. The sediment has also banked up inshore - the 30 m isobath swings seawards from beacon White Patch and sediment covers the inshore bare bedrock area just north of beacon Beach.

Little is known of the sediment distribution immediately to the west (seawards) of the ridge, but further north a wide apron of sediment narrows and the isobaths tend to swing inshore, indicating deepening water parallel to the coast. The details of sediment thickness are obscured by an extensive area of the Acoustical Blanking Layer, which continues northward beyond the boundary of the concession. The Intermediate Sediment presumably lies further offshore as it was not traced north of beacon Flat, just south of Conception Bay, with any confidence.

IV. THE INTERMEDIATE SEDIMENT.

The Intermediate Sediment, termed the "Osesa Formation" by O.S.E., has been referred to as a stratified sedimentary submarine deposit which unconformably covers the Precambrian basement and which in turn is overlain by younger (unconsolidated?) sediments. The Formation can be readily distinguished from the thinner Quaternary sediments inshore on the Sparker geophysical records.

Where the Quaternary sediments are very thick, this distinction is not so clear. Further offshore the dips of the Intermediate Sediment beds tend to flatten out and the Younger sediment cover may also be very thick and obscure details of the buried units.

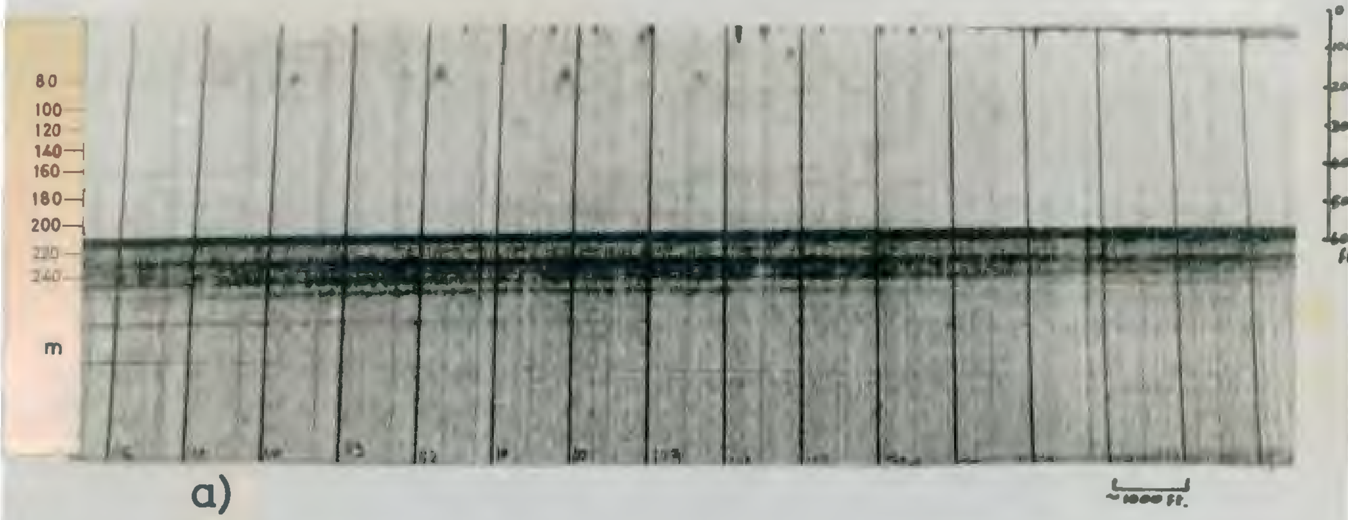
In the S.D.C., the suboutcrop of the Intermediate Sediment lies about 5 km (3 miles) from the coastline. The internal units or beds dip seaward between 1^{o} and 8^{o} with the steeper dip inshore. Where the modern sediment cover is thin or absent, land-facing scarps about 5 to 6 m (15-20 ft) high occur where the beds intersect the water-sediment interface. The inshore extremities of the internal beds appear to be gently folded, juding by the records. In the M.D.C. concession area dips of up to 17^{o} have been measured. Plate VII(b) illustrates part of a Sparker record which is typical of the in-

PLATE VII

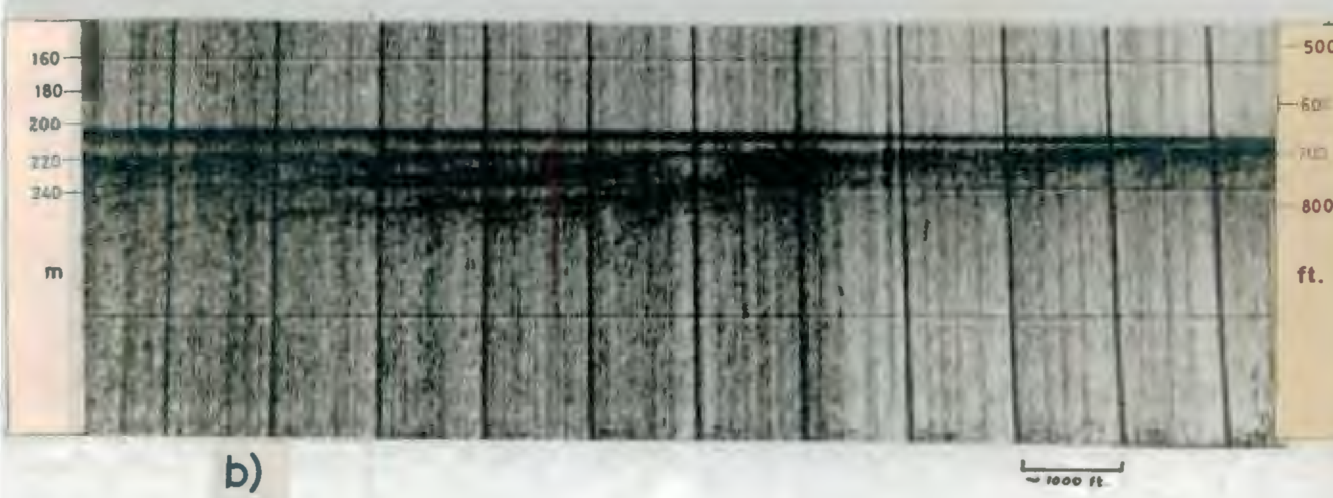
a) A section of a Sparker record taken some 50 km offshore between Meob and Conception Bays. It shows a lens of Recent unconsolidated sediment covering what is interpreted as Intermediate Sediment. The Intermediate Sediment displays internal units dipping gently seawards (to the left). Note the relatively rapid increase in water depth.

b) Portion of a Sparker record taken off the S.D.C. in deep water and illustrating the nature of the inshore suboutcrop of the Intermediate Sediment. Relatively steep dipping and contorted internal units can just be discerned in the middle of the illustration. The upper Recent sediment cover varies from 6 m to nearly 30 m in thickness.

c) A cliff-like feature noted 82 km off beacon Mutzel near Meob Bay in the T.D.C. Apparently cut into Intermediate Sediment, the feature is estimated to be some 25 m high over a horizontal distance of 150 m.



a)



b)

c)

PLATE VII

shore margin although in this particular case the water depth was in fact nearly 200 m deep. Plate IX(a) was taken of a Sparker record set at a one-quarter second sweep and the bedded nature of the Intermediate Sediment can be observed before it becomes obscured beneath a section of the Acoustical Blanking Layer. Further offshore, the internal bedding has a much shallower dip but is nevertheless slightly greater than the stratification within the overlying, younger sediment.

From the south of the M.D.C. concession the Intermediate Sediment suboutcrop gradually swings farther away from the coast and runs to deeper water between 8 and 10 km (5-6 miles) offshore. The variability in depth of the outcrop is illustrated by Fig. 25 (Page 91) and its significance is discussed in the section dealing with the postulated Quaternary history of the coast. In complete contrast to the more regular form of the suboutcrop further south, tongues of Intermediate Sediment appear to be located inshore north of Hottentot Bay as described in the previous section. The offshore extensions of these tongues were not traced continuously: the restriction of most of the survey lines to the vicinity of the coast, the apparently irregular distribution of the Intermediate Sediment itself in the T.D.C., and the blankets of acoustically impenetrable sediment all tend to confuse the picture. It is not impossible that younger stratified sediment has been confused with the Intermediate Sediment in places while interpreting the Sparker records from T.D.C. Occasional survey lines which extended well out to sea in the T.D.C. traversed what is almost certainly Intermediate Sediment with characteristic flat-dipping internal bedding planes. Plate VII(a) illustrates a section of record taken some 50 km offshore between Meob and Conception Bays (Map 7). It shows shallow dipping units overlain by a lens of younger (Recent) sediment which (in the original record) also displayed faint stratification. Included as a matter of interest, Plate VII(c) shows a Sparker record which displays the presence of an apparently local cliff-like feature some 82 km offshore from beacon Mutzel, just north of Meob Bay (Map 7). The feature is about 26 m high with an angle of repose of approximately 14^{o} and with its base in 220 m of water. Apparently cut into Intermediate Sediment, no explanation of its origin is feasible without more details.

Another example of the appearance of Intermediate Sediment offshore is shown by Plate VIII, which is a compilation of sections of the same Sparker record illustrated in Plate VII(c) but covering an area about 120 km offshore. The Intermedaite Sediment is also covered by what is interpreted as younger stratified sediment. Not so obvious in Plate VIII but clearly seen on the original record, the younger sediment surface is slightly concave in this area with a sympathetic decrease in water depth. Further offshore along the same traverse line, the sediment surface increases its slope and in about 300 m of water it appears that the upper Intermediate Sediment beds, maintaining their flat dip, are truncated by the younger sediments.

PLATE VIII

A composite picture of a Sparker record from the S.D.C., showing the dipping Intermediate Sediment beds covered by a thin verneer of Recent Sediment. Although the water depth appears to be constant, (see Plate VIIa by comparison), the sediment surface is in fact very slightly concave. The water depth is approximately 220 m.

The vertical lines are position references, and diverge slightly between successive photographs due to camera-lens distortion. The top of the strip is close to sea level.

No indisputable evidence as to the exact physical nature of the Intermediate Sediments has been recovered. Judging by its reflections on the Sparker records, it must be fairly well indurated and consist of relatively fine-grained, well-sorted constituents otherwise the acoustic impulses would have been scattered.

In his review article, Simpson (1970) recalls the observations of the U.C.T. - Geological Survey marine geophysical group who noted a similar stratigraphic sequence as far south as Cape Agulhas. The fig. 5 in Simpson's paper is based on data collected from an offshore traverse in the vicinity of Plumpudding Island (Map 5). Described as fairly typical of the seismic profiles recently measured between Cape Town and Luderitz, it is interpreted as showing "the smothering and levelling effect of prograded and slumped Cainozoic sediments superimposed on a 75 km wide pre-Tertiary continental shelf eroded across seaward-dipping Cretaceous strata", although the identification of the older strata as Cretaceous was not confirmed. The same group's investigations showed that there is a blanket of sediment covering a subsurface, sharp shelf break over most of the Atlantic continental margin along the west coast.

V. THE ACOUSTICAL BLANKING LAYER.

The Acoustical Blanking Layer (abbreviated to A.B.L.) is characterized by its screening effect on the acoustic pulses and wnich can be seen quite distinctly on the Sparker geophysical records. Plate XI illustrates the appearance of this layer on records from different localities; several distinctive features can be seen:- a) the Layer appears to be shallow beneath its younger sediment cover, approaching its surface but apparently not exposed on the sea bottom. b) it terminates abruptly both inshore and offshore so that no traces of it are visible, say, dipping at a steeper angle into the adjoining sediment. c) it is distinctly marked by denser lines on the record which in turn indicate a marked change (increase) of density within the sediment. d) little to no trace is seen of the sediment or bedrock which is easily visible on each side of the Layer. In some cases, for example opposite beacons Quicksand and Ninety Nine (Map 7), bedrock peaks jut through the sediment in a manner analogous to low, rounded inselbergs.

The distribution of the A.B.L. is limited. To the south of the area mapped a lens of the Layer is found between the Buffels River mouth and Port Nolloth (Map 3); the Layer covers a substantial area off the Orange River mouth, and a lens is present offshore between Chameis and Baker Bays (Maps 4 and 5). The Layer is best developed in the Tidal Diamonds Concession: relatively small areas are found off beacons Gibraltar and Knoll (Map 6), but long arcs of the Layer are found both north and south of the Hollams Bird Island ridge and a substantial blanket covers the area north of Conception Bay.

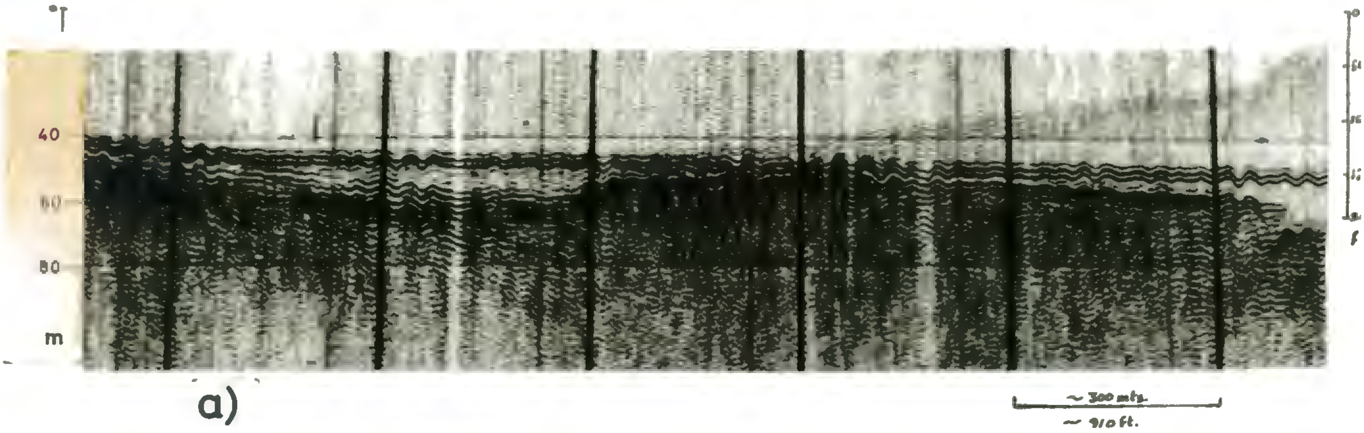
PLATE IX

The Acoustical Blanking Layer : Sparker records.

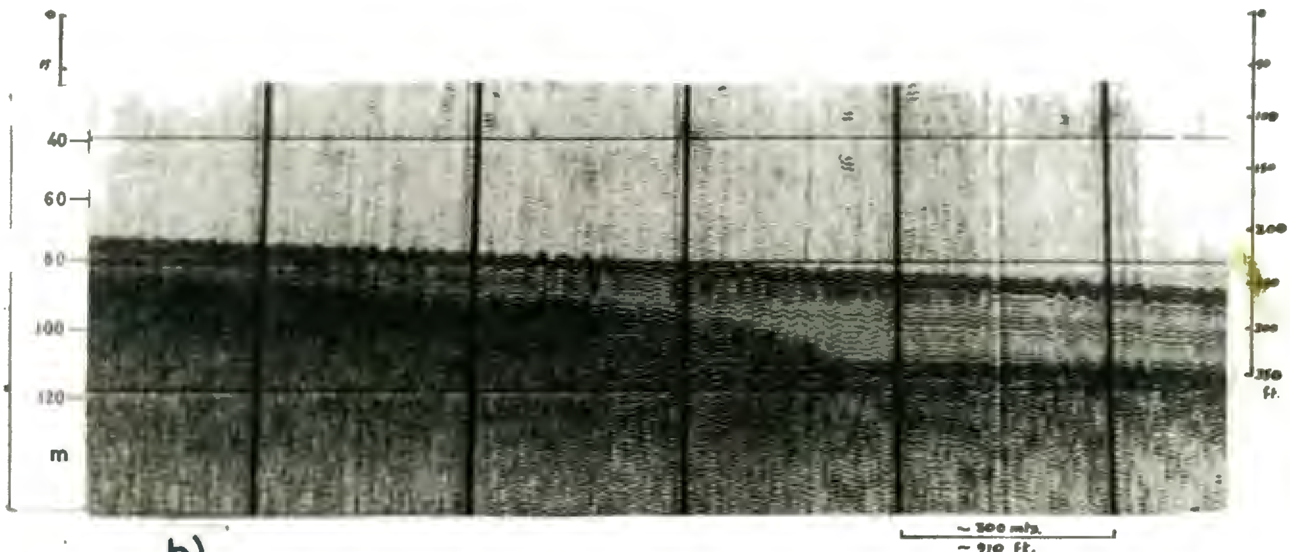
a) From the left, Recent sediment thickens offshore and covers the bedrock. Between the second and third position marks, Intermediate Sediment can be identified beneath the sediment before being screened by a patch of A.B.L., which terminates just before the righthand (offshore) margin of the picture. Note the depth of A.B.L. below the Recent sediment surface.

b) Details of the nature of the offshore edge of the A.B.L. lens. Note the presence of Intermediate Sediment beneath the Recent sediment cover offshore. A surface interface is marked by three wavy lines on Sparker records, as illustrated by the sediment surface. This record was taken just south of the Orange River.

c) Stratified Intermediate Sediments become visible after being screened by the A.B.L. Note the apparent irregularity of the A.B.L. surface beneath the relatively thin and faintly recorded (low density) Recent sediment cover. From the northern T.D.C.


40
60
80
m
~ 300 mts.
~ 910 ft.

a)


40
60
80
100
120
m
50
100
150
200
300
350
ft.
~ 300 mts.
~ 910 ft.

b)


40
60
80
100
120
m
50
100
200
300
400
ft
~ 300 mts
~ 910 ft

c)

PLATE IX

It was in this latter area that windows in the Layer were first observed: occasionally details of the underlying sediment could be seen with features, resembling normal faults, flanking the margins of the windows. In some areas the Layer appears to be less dense and faint indications of sediment and/or bedrock horizons are discernible, but these areas have not been mapped individually because of their irregularity.

When the features characterizing the Layer were first encountered, the margins were mapped as normal faults. The Layer was thought to represent gravel which, because of its granular nature, would tend to reflect and scatter the acoustic pulses impinging it. Sampling operations, however, suggested that gravel tends to be confined to the base of the sediment column and that it is limited in extent and thickness.. An alternative explanation was that the A.B.L. represents a sediment with a high gas content and which would therefore tend to strongly reflect acoustic pulses and thereby screen details of the underlying sediments. Drilling operations have verified that sulphurous gas is common, particularly in thick sediment (the author often suffered bad headaches as a result of the gas released from these sediments during drilling operations). The gas is probably generated by decaying organic matter which could be expected to be plentiful in the biologically productive waters. The African Pilot, a seaman's navigational handbook, records that in the year 1900 an island of mud and clay approximately 50 m long, 10 m wide and 4 m high emerged off Walvis Bay but disappeared again after six days, and that in 1951 similar (but shorter-lived) mud islands were also observed. On both occasions the "eruptions" were accompanied by a strong odour of hydrogen sulphide.

There is little evidence as to how thick this gas-rich sediment is, or indeed what type of material it consists of besides mud. It should also be pointed out that its delineation may depend on the characteristics of the instruments used to detect it. To date there is no evidence from the "Pinger" geophysical investigation concerning the presence of the A.B.L. although the instrument is admittedly limited in its powers of penetration.

CHAPTER III: CHARACTERISTICS OF THE SURFACE SEDIMENT.

An incidental programme of grab sampling was followed during the reconnaissance phase of sampling by drilling. This section deals with analyses of the grab samples and samples such as cores, which were gathered irregularly.

I. SAMPLE COLLECTION AND INITIAL TREATMENT.

Many different types of samples were collected during the reconnaissance sampling but of these, only one group was proved meaningful. The original results determined on board have not been used because the techniques used were, at best, crude. The following types of samples were dealt with:-

i) Grab samples: A standard Van Veen grab with a capacity of approximately 1 cubic foot was used to collect bottom sediment samples. A rough split was made on the ship, and the material dried and stored.

ii) Cores: A vibrocoring technique was developed by O.S.E. to collect 2 inch diameter cores up to 12 ft. in length.

iii) Feed-box samples: Samples of disturbed sediment were taken at the point of the drill's discharge and at roughly measured depths. A few of these were analysed for interest.

iv) Miscellaneous samples: include fragments of basal sandstone, clay, dune sands and one from the raised beach deposits.

The material remaining after preliminary ship-board investigations and several years of storage were recovered from a remote storeroom in the desert, where they had been packed in plastic boxes and steel cases. These remnants were investigated in the University Laboratories. The following paragraphs should be read as referring to the grab samples as they comprised by far the bulk of the samples investigated by the author.

Available sample weights varies between 200 gm and a kilogram in weight. The samples had originally been ovendried. All the unconsolidated samples were washed in luke-warm distilled water twice to remove the water-soluble sea salts, decanted when settled (often after a period of weeks), and dried in an oven at a temperature of less than 90°C. Desired weights of sample were split off as required using a Jones splitter.

These washings became necessary as the author noticed that in damp weather the material being handled became distinctly "sticky" due to the disseminated sea-water salts; this affected sieving efficiency.

It must be emphasized that the samples could not be collected according to the normal requirements of sampling techniques, as the nature of the evaluation sampling did not allow this. Grab samples were taken as often as time, space and equipment allowed. Cores were taken at a few localities, and did not always achieve 100% penetration. The cores were preserved in plastic liners, and later divided into one foot lengths, of which a few were located years later. The other types of samples were collected more at whim than on a routine basis, so that in all the author cannot pretend that the samples are systematic. It is hoped, however, that the results will afford some measure of comparison with other or later work of a similar nature.

The following exercises were carried out:-

a) Size analyses
b) Quantitative heavy mineral determination
c) Quantitative carbonate determination.

II. DETERMINATION OF SIZE DISTRIBUTION.

a) Sample Treatment:

Standard 8 inch sizing screens were calibrated by taking the average of at least 300 measurements of aperture length in two planes using a microscope with a graduated ocular lens. Accurately weighed samples of about 120 gm each were sieved for 20 minutes at $\frac{1}{4}$ Ø intervals (on the recommendation of Folk, 1966), using rubber balls to break up any aggregates of grains for the final 15 minutes of the sieving cycle. Before introducing the rubber balls, the coarser fractions were laboriously hand-sorted to remove shell fragments which would otherwise have been artificially crushed. These sorted shell fragments were then added to their appropriate size fractions prior to final weighing of the fractions.

After sieving, the fractions were checked by visual inspection to ensure that there were less than 1% by number of aggregates. Each fraction was then weighed to the nearest 0.001 gm on an electronic balance. Only the silty samples tended to aggregate and as these were subsequently handled by pipetting the problem was largely eliminated.

When more than 5% of the sample by weight was found to be finer than the +4 Ø size grade, (whose lower limit is 0.062 mm), the samples were divided into sand and silt-fractions by decantation in distilled water. The sandy fractions were sieved as above, and the standard pipetting technique used to examine the fine fraction, using (accurately weighed) 20 gm portions and a 10% solution of Calgon as a dispersant. The "clay" samples tended to dry to crusts of material after the initial treatment described on page 22 , so that the samples had to be crushed lightly with a rubber stopper prior to initial splitting. Special care had to be used not to lose sample material to the atmosphere. Prior to pipetting, the clay samples were slaked in distilled water and dispersant overnight to ensure separation of the grains, which inspection under a microscope then showed to be acceptable.

The cumulative weight percent of each size grade was compiled for each sample, and graphs (size distribution) of cumulative weight percent versus size in phi units were plotted on arithmetic probability paper. The desired intercepts were read off and processed on the University's I.C.T. 1300 computer. A programme compiled by Dr. Fuller of the Geology Department was used to calculate the Folk and Ward (1957) statistics. The results are tabulated in Table I.

In all, 183 samples were treated (excluding repeated determinations and incomplete determinations), made up as follows:

S.D.C.	-	37	grab samples
M.D.C.	-	38	" "
		8	feed box samples
T.D.C.	-	44	grab samples
		14	core sections
		11	feed box samples
Miscellaneous		21	beach and dune samples
		4	carbonate-free samples (i.e. after leaching)
		5	clay samples
		1	sample of "black sand" from the C.D.M. raised beaches.
		183	

b) <u>Some theoretical aspects of size analyses</u>:

The concept of size in sedimentology is a basic one, for the behavior of sedimentary particles subjected to the forces of nature is largely (but by no means entirely) dependant on their size. Thus from a knowledge of only the size or range of sizes of particles in a deposit we can to a certain extent deduce the possible history of the particle and deposit. The concept of size also allows us a degree of definition when describing sediments. Purely descriptive terms like "sand" or "clay" may mean different things to different people, but by implying that the geological term "sand", for instance, means all particles having diameters within a certain size range, interested parties can be more certain of what is being referred to. It is therefore important that a standard scale be used to define our terms.

The generally accepted standard scale of particle size is based on the geometrical grade scale of J. Udden, modified by C.K. Wentworth in 1922.

	Sample No.	Type	Mean M_z	Median Ø50	Std.Dev. σ_I	Skew Sk_I	Kurt. K_G	% H.M.	% CO_3
1	250 A4	Grab	3.43	3.32	0.53	0.37	1.11	2.70	5.9
2	249 A5	"	2.99	2.94	0.42	0.24	1.77	1.89	6.7
3	247 A1	"	2.75	2.81	0.39	-0.23	1.34	2.99	8.8
4	245 B3	"	2.84	2.84	0.33	0.02	1.31	1.55	15.3
5	242 B6	"	2.82	2.84	0.28	-0.09	1.55	1.06	12.5
6	242 A6	"	2.77	2.81	0.33	-0.16	1.28	7.88	8.9
7	235 B6	"	2.64	2.67	0.33	-0.22	1.29	10.58	4.7
8	235 A6	"	2.69	2.74	0.30	-0.27	1.16	6.62	6.9
9	234 C4	"		NOT	SIEVED			0.74	4.4
10	234 B6	"		NOT	SIEVED			2.81	6.5
11	232 A6	"	2.59	2.70	0.50	-0.51	1.85	15.25	12.4
12	229 B6	"	2.67	2.75	0.52	-0.32	1.81	3.27	15.3
13	211 A4	"	2.52	2.52	0.40	0.03	1.26	9.81	11.8
14	178 A2	"		NOT	SIEVED			3.13	28.5
15	177 A2	"	2.65	2.63	0.64	-0.05	1.59	3.07	24.4
16	144 A6	"		NOT	SIEVED			12.84	19.6
17	143 A5	"	2.81	2.79	0.45	0.00	1.34	8.81	17.1
18	139 A5	"	2.82	2.77	0.44	0.17	0.96	18.01	18.1
19	136 A4	"	2.45	2.45	0.50	0.02	1.57	20.96	10.1
20	125 A5	"	2.87	2.83	0.51	0.00	1.42	11.02	26.5
21	105 A1	"	2.68	2.72	0.41	-0.19	1.27	11.45	18.5
22	104 A3	"	2.72	2.73	0.46	-0.09	1.17	11.59	18.5
23	101 A3	"	2.79	2.79	0.30	0.02	1.06	3.47	25.7
24	96 A2	"	2.80	2.79	0.31	0.13	1.30	3.02	23.9
25	91 B4	"	2.70	2.76	0.64	-0.27	1.76	1.85	24.8
26	91 A3	"	2.63	2.63	0.40	-0.16	1.62	10.86	26.5
27	88 A1	"	2.77	2.82	0.41	-0.34	2.27	0.92	30.5
28	85 A5	"	2.60	2.61	0.42	0.00	1.33	6.52	17.8
29	77 A1	"	2.80	2.79	0.49	-0.08	1.59	12.16	18.1
30	75 D1	"	2.65	2.60	0.38	0.24	1.04	1.64	12.6
31	75 C4	"	3.10	3.05	1.12	0.44	2.96	2.35	22.0
32	73 B3	"	2.77	2.77	0.30	0.00	0.98	3.68	21.2
33	70 A2	"	2.14	2.14	0.43	0.01	1.31	9.23	7.8
34	40 A5	"	2.91	2.93	0.51	-0.13	1.56	4.06	21.4
35	31 B1	"	2.78	2.77	0.40	0.13	1.31	2.91	24.3
36	26 A1	"	3.07	3.04	0.39	0.12	1.10	6.81	20.0
37	19 B1	"	3.06	2.98	0.51	0.30	1.35	7.26	27.3
38	16 A3	"	2.98	2.92	0.43	0.27	1.33	3.46	23.4
39	12 A5	"	6.04	4.88	3.13	0.66	1.78	1.00	6.3
40	11 A2b	"	2.72	2.80	0.79	-0.16	0.89	5.26	18.5
41	7 A3c	"	3.31	3.33	0.34	-0.04	1.06	59.07	2.7

	Sample No.	Type	Mean M_Z	Median Ø50	Std.Dev. σ_I	Skew Sk_I	Kurt K_G	% H.M.	% CO_3
42	18 B	Grab	3.44	3.26	0.69	0.38	0.87	8.20	4.3
43	19 A	"	2.94	2.88	0.46	0.30	2.27	20.23	4.3
44	38 B	"	2.84	2.85	0.43	0.00	1.61	28.47	2.4
45	38 D	"	2.97	2.83	0.46	0.49	1.30	28.14	2.7
46	39 A	"	2.77	2.81	0.45	-0.11	1.43	33.48	2.3
47	47 A	"	2.91	2.93	0.47	-0.02	1.65	38.95	3.1
48	47 E	"	2.97	2.84	0.54	0.32	1.61	20.73	5.9
49	47 N	"	3.72	3.68	0.85	0.13	0.76	3.29	6.7
50	57.5 A	"	3.07	2.93	0.61	0.37	1.43	28.81	3.7
51	57.5 Y	"	2.87	2.84	0.50	0.26	2.23	7.18	4.5
52	70 B	"	3.05	2.90	0.42	0.53	1.44	22.75	3.9
53	70 C 1'	F.Box	3.00	2.98	0.36	0.13	1.28	40.74	3.3
54	2'	"	2.96	2.93	0.42	0.12	1.30	31.77	3.6
55	3'	"	2.91	2.90	0.39	0.09	1.21	31.20	3.0
56	4'	"	2.83	2.82	0.38	0.04	1.27	25.66	2.9
57	5'	"	2.83	2.84	0.39	-0.06	1.35	25.84	4.0
58	71 A	Grab	3.12	3.06	0.37	0.24	1.17	29.57	4.4
59	117.5	"	2.90	2.82	0.33	0.32	1.11	34.98	3.4
60	119.5	"	2.75	2.76	0.30	-0.09	1.17	29.00	2.4
61	120	"	3.17	3.14	0.41	0.10	0.92	33.90	3.9
62	121	"	3.00	2.99	0.54	-0.04	1.14	32.86	3.4
63	122.25	"	2.99	2.93	0.47	0.18	1.22	40.73	4.2
64	122.25 1'	F.Box	3.00	2.95	0.45	0.18	1.11	30.84	4.0
65	122.25 4'	"	2.81	2.75	0.44	0.21	1.13	22.03	5.0
66	7'	"	2.41	2.67	0.96	-0.48	2.03	19.51	6.0
67	122.5	Grab	2.62	2.64	0.36	-0.09	1.03	19.15	2.2
68	125 A	"	2.44	2.50	0.48	-0.22	1.04	19.79	2.6
69	125 B	"	2.85	2.82	0.37	0.18	1.40	24.17	2.9
70	126	"	2.90	2.87	0.34	0.11	1.28	43.07	2.7
71	127	"	3.11	3.09	0.36	0.08	1.22	43.39	3.4
72	128	"	2.71	2.75	0.41	-0.15	1.26	29.25	2.8
73	129	"	2.60	2.67	0.46	-0.19	1.01	30.43	2.4
74	130	"	2.72	2.76	0.36	-0.19	1.26	27.83	2.9
75	131	"	2.76	2.76	0.32	-0.02	1.20	28.09	2.0
76	144 B	"	2.93	2.85	0.36	0.32	1.57	25.20	4.6
77	144 X	"	2.99	2.93	0.29	0.27	1.64	11.78	5.5
78	144 Z	"	2.98	2.92	0.34	0.23	1.18	27.90	3.4
79	147 F	"	2.85	2.88	0.30	-0.11	1.42	38.09	2.8
80	147.5 A	"	2.81	2.82	0.39	0.04	1.41	14.07	4.6
81	155 F	"	2.87	2.82	0.40	0.09	1.35	54.01	2.8
82	214 A	"	2.88	2.86	0.28	0.13	1.39	17.78	2.4
83	218 B	"	2.88	2.86	0.27	0.13	1.62	12.27	2.8

	Sample No.	Type	Mean M_Z	Median Ø50	Std.Dev. σ_I	Skew Sk_I	Kurt. K_G	% H.M.	% CO_3
84	220 B	Grab	2.72	2.75	0.42	-0.13	1.31	4.39	11.3
85	222 A	"	2.24	2.32	0.78	-0.19	0.82	4.95	10.9
86	228 D	"	3.00	2.97	0.35	0.12	1.12	10.90	5.6
87	228 I	"	2.60	2.67	0.45	-0.24	1.07	3.80	5.4
88	302 A 0-1'	Core	3.53	3.50	0.52	0.17	1.32	13.75	7.2
89	3'10-4'8	"	2.95	3.00	0.85	-0.30	2.05	15.57	6.3
90	302 B 2'9-3'1	"	1.52	2.86	2.24	-0.77	0.69	25.54	45.1
91	302 U	Grab	3.63	3.60	0.48	0.16	1.17	10.59	6.1
92	302/1C 0-4"	Core	3.14	2.98	0.69	0.53	1.01	7.01	4.2
93	3'-3'8"	"	2.86	2.85	0.27	0.09	1.19	7.44	2.7
94	302/1 EE	Grab	3.64	3.65	0.46	0.05	1.17	12.71	8.1
95	302/1 FF	"	3.64	3.63	0.46	0.07	1.01	11.30	5.9
96	302/1 GG	"	2.99	2.97	0.75	-0.10	1.75	7.96	11.6
97	302/1 II	"	3.52	3.54	0.48	-0.02	1.08	13.16	6.7
98	302/1 KK	"	3.56	3.55	0.41	0.08	1.23	15.16	6.3
99	304 C 0-6"	Core	3.55	3.53	0.40	0.09	1.26	14.78	6.1
100	2'10-3'1	"	1.23	0.78	1.49	0.29	1.76	3.42	27.0
101	304 H	Grab	3.68	3.62	0.48	0.20	1.17	14.68	5.7
102	305 H	"	3.71	3.68	0.48	0.13	1.38	14.09	4.8
103	305/1 A	"	3.59	3.59	0.45	0.09	1.06	17.01	3.0
104	305/1 H 0-1'	Core	3.62	3.59	0.53	0.17	1.12	14.46	7.6
105	2-2-9	"	2.11	2.89	1.72	-0.65	0.81	14.67	15.3
106	308 B	Grab	3.70	3.70	0.34	0.01	1.07	16.31	4.0
107	308 G 1'	F.Box	3.55	3.55	0.39	0.01	1.15	20.39	5.3
108	4'	"	3.40	3.38	0.43	0.11	1.12	16.06	4.8
109	7'	"	3.32	3.26	0.41	0.26	1.04	17.16	6.2
110	10'	"	3.27	3.22	0.70	-0.10	2.41	14.70	8.6
111	13'	"	3.34	3.31	0.45	0.11	1.06	-	-
112	16'	"	3.18	3.18	0.56	-0.11	1.34	15.27	5.7
113	308 I 0-1'	Core	3.55	3.54	0.36	0.09	1.18	21.03	4.3
114	308 I 4'-4'8	"	3.53	3.56	0.58	0.11	1.37	13.99	5.5
115	6'8-7'2	"	3.35	3.28	0.90	-0.05	2.39	12.83	14.4
116	313 C	Grab	3.59	3.60	0.41	0.00	1.09	17.44	3.6
117	315 A	"	3.42	3.47	0.40	-0.08	0.96	21.47	4.7
118	327 C	"	3.31	3.26	0.44	0.31	1.13	27.46	3.9
119	342 C	"	3.03	2.95	0.46	0.21	1.13	17.25	2.4
120	346 E	"	2.84	2.81	0.33	0.14	1.21	18.76	3.2
121	352 B	"	3.00	2.94	0.30	0.23	1.39	16.60	3.6
122	357 I	"	2.81	2.91	0.58	-0.49	1.99	12.11	6.4
123	357 P	"	2.92	2.89	0.32	0.37	2.21	9.19	4.0
124	363 B	"	2.83	2.83	0.34	-0.10	2.85	8.14	4.5
125	363 G	"	2.60	2.62	0.37	-0.18	1.44	5.50	3.7

	Sample No.	Type	Mean M_Z	Median Ø50	Std.Dev. σ_I	Skew Sk_I	Kurt K_G	% H.M.	% CO_3
126	373 E	Grab	3.22	3.13	0.43	0.42	1.11	16.61	2.9
127	373 R	"	3.31	3.28	0.43	0.18	0.77	17.32	3.1
128	380 B	"	3.27	3.21	0.40	0.26	0.82	17.32	3.6
129	380 J	"	3.59	3.60	0.46	0.00	0.95	13.80	3.9
130	384 C	"	3.19	3.12	0.40	0.28	1.07	20.06	4.3
131	391 A	"	2.62	2.85	0.69	-0.48	1.36	7.46	8.1
132	396 D	"	3.30	3.23	0.57	0.17	1.02	12.62	5.4
133	400 A	"	3.31	3.28	0.39	0.19	1.06	20.98	3.0
134	400 I	"	3.25	3.20	0.32	0.30	0.93	12.58	2.4
135	405 D	"	3.21	3.10	0.37	0.48	1.14	14.14	3.4
136	405 O	"	3.37	3.32	0.40	0.30	0.96	19.2	3.2
137	409 G	"	3.27	3.20	0.47	0.39	1.17	13.3	3.4
138	414 B	"	3.65	3.55	0.40	0.07	0.98	13.6	3.4
139	422 F	"	3.63	3.58	0.49	0.21	1.23	10.2	3.1
140	425 L	"	3.61	3.57	0.45	0.17	1.09	14.6	3.5
141	448 J	"	2.61	2.67	0.63	-0.11	0.78	12.1	4.5
142	463 B	"	2.06	2.05	0.43	0.07	1.30	10.1	1.7
143	479 D	"	2.48	2.44	0.41	0.08	1.02	9.4	0.9
144	497 A	"	3.02	3.14	0.66	-0.27	0.91	29.0	2.5
145	502 D	"	1.31	1.01	0.77	0.55	0.90	1.0	1.8
146	505 K	"	3.02	2.99	0.30	0.25	1.54	13.4	2.2
147	505 T	"	3.20	2.92	1.05	0.48	1.22	6.8	3.9
148	507 C	"	2.96	2.96	0.41	-0.02	1.66	19.8	2.2
149	600 E 4'	F.Box	3.04	3.05	0.28	0.02	1.23	9.4	2.1
150	10'	"	3.02	3.11	2.02	-0.32	9.39	7.0	9.6
151	603 C	Grab	3.11	3.08	0.55	0.20	1.45	20.2	3.0
152	606 2'	F. Box	2.95	2.98	0.32	-0.14	1.19	7.7	2.3
153	8'	"	2.91	2.95	0.44	-0.30	1.70	8.1	7.9
154	13'	"	2.96	2.98	0.45	-0.28	2.31	8.4	5.1
155	607 E 0-1'	Core	2.85	2.85	0.31	-0.01	1.07	8.9	1.5
156	4-5'	"	2.91	2.93	0.29	-0.08	1.08	8.9	3.2
157	A 1	Misc.	1.43	1.42	0.50	0.09	0.84	1.0	-
158	A 2	"	1.70	1.73	0.45	-0.06	1.06	6.4	-
159	A 3	"	1.31	1.26	0.50	0.17	0.97	4.4	-
160	A 4	"	1.89	1.88	0.41	0.07	1.13	13.4	-
161	A 5	"	1.80	1.78	0.53	0.07	1.04	28.2	-
162	A 6	"	1.48	1.45	0.48	0.16	0.97	11.1	-
163	A 7	"	1.73	1.68	0.55	0.14	1.03	25.3	-
164	A 8	"	1.97	1.92	0.67	0.08	0.89	35.2	-
165	A 9	"	1.80	1.76	0.44	0.18	1.03	2.5	-
166	A 11	"	2.83	2.84	0.52	0.00	0.94	26.2	-
167	A 16	"	2.75	2.80	0.43	-0.21	1.08	12.0	-
168	B 1	"	1.31	1.35	0.58	-0.10	0.86	0.4	-
169	B 2	"	1.36	1.37	0.49	-0.02	0.88	1.4	-

	Sample No.	Type	Mean M_Z	Median Ø50	Std.Dev. σ_I	Skew Sk_I	Kurt	% H.M.	% CO_3
170	B 3	Miscell.	1.39	1.39	0.43	0.02	0.98	4.1	-
171	B 4	"	1.63	1.62	0.49	0.07	1.17	11.5	-
172	B 5	"	1.64	1.68	0.54	-0.09	1.18	3.4	-
173	B 6	"	1.81	1.75	0.74	0.12	0.74	4.9	-
174	B 7	"	2.56	2.59	0.46	-0.17	1.24	11.2	-
175	B 8	"	2.45	2.54	0.53	-0.26	1.09	5.9	-
176	B 9	"	2.29	2.47	0.63	-0.38	0.84	6.3	-
177	B 10	"	1.71	1.46	0.79	0.41	0.62	3.1	-
178	304C 2'10-3'1	Core	1.58	0.97	1.17	0.67	0.63	LEACHED SAMPLES	
179	88 A1	Grab	2.83	2.87	0.45	-0.27	1.63		
180	31 B1	"	2.75	2.73	0.34	0.18	1.18		
181	125 A5	"	2.77	2.77	0.52	-0.08	1.03		
182	208 A	Clay	4.99	4.13	2.59	0.51	0.88	-	-
183	304 H 2	"	5.74	5.66	2.24	0.12	0.89	-	-
184	380 A3	"	5.64	5.58	2.04	0.06	1.59	-	-
185	124 C	"	6.14	5.96	2.24	0.19	0.93	-	-
186	114 G	"	6.48	6.27	2.54	0.13	0.87	-	-
187	Raised Beach Sand	Miscell.	2.63	2.64	0.26	-0.06	1.00	99.1	-

The class limits of the Udden grade scale are related by a power of two and Krumbein (1934) subsequently defined the phi scale in order to simplify the Udden scale and to allow more rational digits to be used in statistical computations. He defined it as phi = $-\log_2$ of the particle diameter in millimetres. By this means the geometric or logarithmic scale is converted to an arithmetic scale, and one phi-unit is made equivalent to 1 Wentworth/Udden class interval. Zero phi is equivalent to one millimeter; sediment fractions with positive phi values are finer grained and negative phi values indicate coarse material. McManus (1963) and Krumbein (1964) caution against equating phi-values with size, for a phi value is a transformed interger and was originally intended to mean "Wentworth grades" rather than "millimetres".

The size frequency distribution of a sediment may be defined as a statistical summary of the frequency with which the clastic particles of that sediment fall within agreed size limits. This frequency may be expressed by numbers determined by counting, or, more usually, by weight. The distribution can be graphically illustrated by histograms, frequency curves, or cumulative frequency curves. **Many** early researchers realized that the size distributions of sediments tend to be lognormal (Pettijohn, 1957, pg. 39), but that few, if any, sediments could be said to be truly lognormal. This tendency to lognormality is graphically illustrated when the cumulative weight percentage of a sediment is plotted against the size in phi-units on arithmetic probability graph paper: lognormality is examplified by a straight line. This type of plot is the most frequently used nowdays and arithmetic probability paper is preferred to other types of graph paper because (1) the "tails" or ends of the plot are expanded - this is desireable because of the importance these tails assume in statistical analyses (2) the parameters (intercepts) can be fairly easily read to 0.01 phi units (3) departures from the (log) normal distribution are easily seen, and (4) composite distributions can be recognized. Thus cumulative curves have the following advantages:

a) They are a means of illustrating the nature of sediment in terms of size.

b) They can be used to test the approach to theoretical distributions and hence allow the drawing of conclusions as to that sediments possible history.

c) They can be used to compare the sediment graphically with other examples.

Several decades ago, research workers such as Doeglas (1946), recognized that "a sediment" is generally a mixture of several populations which depends on the nature of the original materials, their manner of transport and deposition and also the site of observation. This means that our theoretically straight-line plot or curve may in fact consist of two or more straight lines (or curves) connected by sharp(er) curves, termed inflexion points. This is especially true in the sand and silt size-range because particles in these size ranges react most significantly, for example, to changes in water current velocity. Doeglas himself, considering a river and its discharge, suggested that there were three major types of curves (i) those in which the coarse material only remains as, for example, in swiftly flowing river beds or heavy surf:- his R-curves (ii) those in which only very fine material settles such as in stagnant basins or the deep sea, will give T-curves, and (iii) those which embrace material of a fairly narrow size range in even proportions, such as dune sands, to give S-curves. Harris (1958), working with dune sand, found that five theoretical lines could be expected. They represent in each case:-

1) the finest grades present, which could be in suspension in very strong winds.
2) finer interstital material which would have a fairly wide size range.
3) the few large grains moved by saltation in the strongest wind.
4) the bulk of the deposit, falling within a narrow grade range
5) the moderate amount of grains of fair grade size range which are moved entirely by surface creep.

Harris maintains that in practise the type 3 line is either absent or masked by the type 5 lines, so that four principal lines can be expected. If each component is completely adjusted to it's depositional environment, a series of straight lines will result but curves may be seen in the terminal points, i.e. the coarsest and finest material, and when components are mixed or overlap. Using a measure of sorting for each component curve, he was able to distinguish dune sand from deltaic sand, and in 1959 Harris distinguished between dune sands and beach deposits.

Workers such as Udden (1914), Fraser (1935) and Plumley (1948) acknowledged that such mixtures could occur when they attempted to explain the polymodality of their curves (histograms). It was also recognized that some grades of sediment are characteristically absent or deficient in deposits. For example, Pettijohn (1957) mentions that in a study of a thousand published mechanical analyses (of fluvial deposits?) he found a general deficiency of material in the 2 to 4 mm range (-1 to -2 Ø), and a probable deficiency in the 1/16 to 1/8 mm range (+3 to +4 Ø). Udden (1914) found a particularly noticeable deficiency in the +3 to +4 Ø range for aeolian sediments. Such deficiencies have been attributed to several causes:-

a) a lack of natural disintergration (by weathering) of materials into these size ranges.
b) a greater tendency for these size-class materials to disintergrate or erode under conditions of transportation.
c) naturally occurring means of hydraulic transport favour material which can be carried either as bed load or in suspension so that intermediate material would be by-passed. This concept of "borderline" material has also been involved in more recent studies, for example Fuller (1961) noticed that shallow, marine shelly sand samples collected over a period

of time from different locations persistently showed inflexion points in the region of +0.8 ∅ and +2 ∅. He attributed the deficiency at 0.80 ∅ to material covering the traction-suspension load boundary, that is to say it could be transported in two possible ways, and material falling in the region covered by both the Stoke's and Impact Laws appears to be responsible for the 2 ∅ gap. This finer material may be either easily eroded or fractionated and removed from the beach by wind action (Fuller, 1962).

Tanner (1958 and 1964) also commented on curves which are basically comprised of straight-line segments, but preferred to explain Fuller's 2 ∅ gap as due to water current and wave motion interaction. It is worthwhile mentioning the several mechanisms which Tanner proposed (1964) as giving rise to "zig-zag" curves:-

a) Mixing: simple mixing of two components produces characteristic curves depending on the components i) a 3-segment curve if the components have equal variances and are mixing in roughly equal proportions, but have different means. ii) a 2-segment curve is produced if two components are mixed in equal proportions, but have different means and variances.
b) Censorship: the mildest form of selection, censoring means that the investigator does not see or have available the information concerning some of the components, for instance in one of the tails of a distribution.
c) Truncation: is invoked to describe distributions which have one or both tails of a distribution totally removed from the original sediment, for example, Doeglas's "R" curves would be typical for fluvial deposits in which the finer components have been removed by suspension.
d) Filtering: is the result of unknown or unsuspected variations in sample distribution and occurs when sediment is present which is not in hydrodynamic equilibrium.

Spencer (1963) persued a similar line of investigation to conclude that all clastic sediments are essentially mixtures of three or less fundamental populations of log-normal grain sizes and that most clastic sediments consist of "grains" and "matrix". The important point is to have a sufficient range of grain sizes present in a sample to be able to recognize their relationships. How can these curves be used to describe a sediment?

i) Sedimentological Statistics:

All distributions can be described in mathematical terms, namely by using moment measures, so called because the moments for each class interval can be calculated. There are four basic moments, usually calculated about the arithmetic mean of the distribution, and from them are derived expressions to describe the qualities of the distribution in terms of average size, spread, predominant component and normality. Moment measures are normally computed from an entire distribution, whereas mechanically analysed distributions are confined to convenient coarse and fine limits.

Because moment measures are also complex and time consuming to compute, we use approximate graphical analogies to determine these expressions, making use of the percentile intercepts by which the required parameters are read directly from the cumulative frequency plots. That this approximation is acceptable is stated by Folk (1966) in his characteristically forthright manner: "Presumably the same geologic conclusions would be reached no matter which method is used, because sample to sample variation in most geologic suites is so large as to outweigh precise hair splitting over details of statistical orthodoxy".

Several sets of formulae have traditonally been used to determine the approximated (moment) measures, notably those of Trask (1900), Inman (1952), and Folk and Ward (1957). The latter's formulae and descriptions are the most efficient of the popular expressions and were specifically compiled to deal with bimodal, non-normal and skewed sediments most usually found in nature; their expressions have been adopted by the author. A brief outline of the significance of the four basic measures follows:-

a) The Mean

$$M_Z = 1/3 \quad (\emptyset_{84} + \emptyset_{16} + \emptyset_{50})$$

The mean reflects the overall average of the grain sizes in the distribution and is the first moment measure. The mean may, however, lose it's genetic significance in a sediment with more than one mode (predominant size range) or in one which is spread over a large size range.

Another measure of average size is the median, defined as $M_{\emptyset 50}$. It is the size of the exact centre of the distribution , but it has little significance because it is independant of the rest of the distribution. To take extreme cases as an example, a mixture of 40% pebbles and 60% sand might have the same median as a mixture of 60% sand and 40% clay. Folk and Ward (1957) recommend that the use of the median be abandoned.

b) Deviation

$$\sigma_I = \frac{(\emptyset_{84} - \emptyset_{16})}{4} + \frac{(\emptyset_{95} - \emptyset_{5})}{6.6}$$

Measures of the standard deviation, related by square roots to the second moment, give a measure of sorting in sedimentological statistics by reflecting the range of sizes present in a population. From the cummulative frequency plot, the variation in slope between the outer edges and the extreme ends of the distribution is compared. Values of less than 0.5 indicate well-sorted sediment, and values greater than 1.0 indicate poor sorting.

As calculated above, the deviation is sensitive to the tails of the distribution, which is where variations in sorting of material from different environments are most noticeable.

c) Skewness:

$$Sk_I = \frac{(\phi_{84} + \phi_{16} - 2\phi_{50})}{2(\phi_{84} - \phi_{16})} + \frac{(\phi_{95} + \phi_5 - 2\phi_{50})}{2(\phi_{95} - \phi_5)}$$

Skewness is related to the deviation, but is not dependent on it in this formula. The skewness provides a measure of the degree of departure of the mean from the median and reflects the predominance of either coarse or fine components. The Inclusive Graphic Skewness, Sk_I, has values between +1.0 and -1.0. Distributions with $Sk_I = 0.0$ are perfectly symmetrical, while negative values indicate that the finer constituents are dominant and positive values that the coarse components are dominant. In practise, sediments with values greater than $\pm$ 0.8 are rare.

d) Kurtosis:

$$K_G = \frac{\phi_{95} - \phi_5}{2.44(\phi_{75} - \phi_{25})}$$

The "peakedness" of a curve is measured by kurtosis. In more specific terms, the kurtosis compares the ratio of sorting in the extreme ends of the distribution with the sorting in the central part and is thus a sensitive test of the normality of the distribution. The formula for the Graphic Kurtosis, K_G, is based on the fact that for a normal curve the spread between the 5 and 95 percentiles should be 2.44 times the spread between the 25 and 75 percentiles. $K_G = 1.00$ for a normal curve, which is described as mesokurtic (the standard bell-shaped frequency distribution curve). Values below 0.9 define platykurtic curves (flat-topped), and those greater than 1.2 describe leptokurtic curves (sharply peaked, narrow curves). Natural values range between 0.5 to 8.0 and Folk and Ward (1957) describe a function K_{G_I} which "normalizes" the range of values.

ii) Some practical applications for the statistics:

Besides providing a quantitative basis for describing sediments, the statistics provide a strong tool for distinguishing between sedimentary environments. Folk and Ward, investigating material from the Brazos River in Texas, showed that the statistics were definitely inter-related. By using a large size range of material with at least two populations, the plots of statistical combinations were found to yield significant patterns:-

M_Z	vs	σ_I	sinusoidal curve
M_Z	vs	Sk_I	" "
Sk_I	vs	σ_I	circular

M vs σ_I vs Sk_I yielded a helical plot in three dimensions.

Because Sk and K_G are so sensitive, they are powerful tools in interpreting the geneses of sediments. Most sands are leptokurtic and either positively or negatively skewed, because most sands consist of one predominant population with a subordinate coarser or finer population. Examples of the use of statistics in detailed comparisons are:

a) Sahu (1964) plotted σ_I against $\frac{S\ (K_G)}{S(M_z)} \cdot S\ (\sigma_I^2)$, where S was the standard deviation for each statistic, to distinguish between aeolian, beach, shallow marine, fluvial and turbidity environments in terms of increasing fluidity and decreasing energy.

b) Mason and Folk (1958) differentiated between beach, dune and aeolian flat environments by plotting skewness versus kurtosis, and

c) Friedman (1961), working with dune, beach and river sands, states that in general the unidirectional flow of wind and water results in a lack of coarse tail in sediments and leads to positive skewness (in beach and river sands,) while the winnowing effect (of wind) eliminates fines and leads to negative skewness, that is, a tail of coarse constituents is introduced.

Griffiths (1951), Hails (1967), Shepard and Young (1961), Duane (1964) and Martins (1965) are amongst those who confirm that skewness in particular is environmentally sensitive. The author, however, does not recall any workers who have determined the origin of a sediment by means of statistics alone. In the cases cited above, sediments of known origin were simply compared statistically.

c) <u>Discussion of results</u>:

i) <u>General</u>: The results of the mechanical analyses are listed in Table I. No isopleth maps could be compiled as the samples are relatively widely spaced in one direction, not having been collected with any specific object in view. Nevertheless, some general observations are worthy of comment as regards the grab samples: the overall mean size is about +3 Ø, which by definition would describe them as being fine to very fine sand. They are well sorted and although they are both negatively and positively skewed, about 30% can be described as having a symmetrical distribution. Most of the samples are leptokurtic. Table II lists the possible range of values and the relevant descriptions of the sediment as suggested by Folk and Ward (1957).

TABLE II:

Expressions to describe the properties of sediments in terms of their statistical values:

Sorting σ_I

Description	Range in values
very well sorted	< 0.3
well sorted	0.35 - 0.50
moderately well sorted	0.50 - 0.71
moderately sorted	0.71 - 1.00
poorly sorted	1.00 - 2.00
very poorly sorted	2.00 - 4.00
extremely poorly sorted	> 4.00

Skewness Sk_I

Description	Range in values
very negatively skewed	-1.0 to -0.3
negatively skewed	-0.3 to -0.1
very symmetrical	-0.1 to +0.1
positively skewed	+0.1 to +0.3
very " "	+0.3 to +1.0

Kurtosis K_G

Description	Range in values
very platykurtic	< 0.67
platykurtic	0.67 - 0.90
mesokurtic	0.90 - 1.11
leptokurtic	1.11 - 1.50
very "	1.50 - 3.00
extremely "	> 3.00

⊛ Mean size M_Z

Description	Range in Ø value
granule	-2 to -1
very coarse sand	-1 to 0
coarse sand	0 to +1
medium sand	+1 to +2
fine sand	+2 to +3
very fine sand	+3 to +4
silt	+4 to +8
clay	+8 to +12

⊛ after Wentworth.

What is fairly remarkable, in the author's opinion, is that 7 (of the 119) grab samples were "perfectly symmetrical", that is $Sk_I = 0.00$. Some of the grab samples are not typical, particularly with respect to the kurtosis values. Sample 12A5, for example can be described as a silt, it is very poorly sorted, very positively skewed, and very leptokurtic. These properties were not recorded for other samples in the vicinity, so the sample may be the result of local and special conditions of deposition for the Orange River sediments. Several other grab samples are also unusual in being very leptokurtic (with $K_G > 2.0$) although they appear normal in other respects. Since the term "leptokurtic" implies that the bulk of the sediment sample is very well sorted whereas the coarser and finer fractions are not, we may be dealing with sediments which are in equilibrium with their environment on the whole but which have immature finer and coarser constituents present.

ii) Scatter diagrams and statistical relationships:

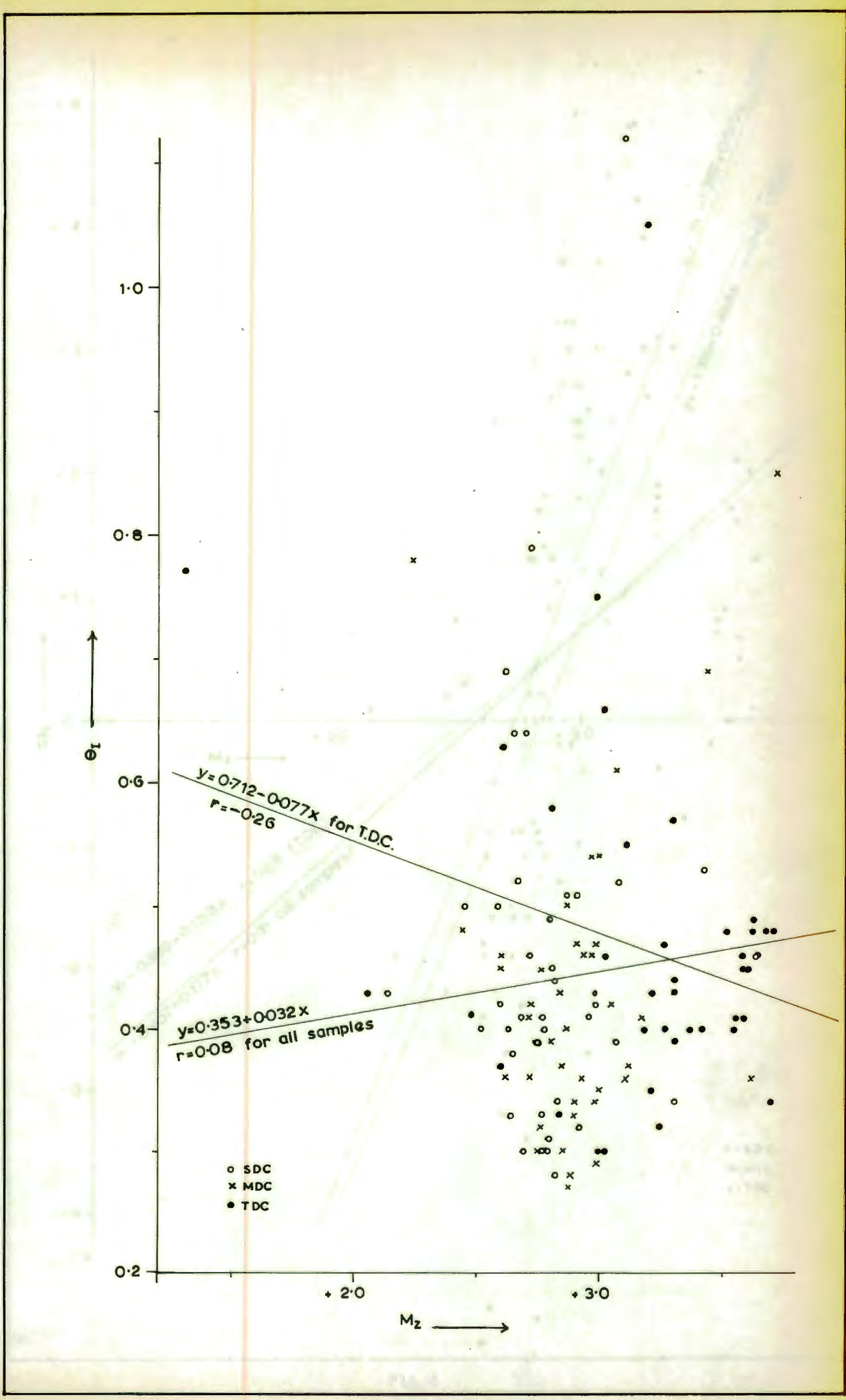
Because of the meaningful relationships found by other workers between various attributes of the sediments, (as discussed on pages 29 and 30), several scatter diagrams were drawn up and the linear correlation coefficients of regression calculated. The results are summarized in Table III.

TABLE III: Relationships between some of the sediment attributes:

Concession Area	Test	Correlation Coeff.	Remarks
All 3 (SDC, MDC, TDC)	M_Z vs σ_I	0.081	Not significant
do	M_Z vs Sk_I	0.310	Significant at .01 level
do	M_Z vs K_G	-0.074	Not significant
SDC	M_Z vs σ_I	0.143	" "
SDC	M_Z vs Sk_I	0.483	Significant at .01 level
MDC	M_Z vs σ_I	0.248	Significant at .10 level only
MDC	M_Z vs Sk_I	0.623	Significant at .01 level
TDC	M_Z vs σ_I	-0.257	Significant at .10 level only
TDC	M_Z vs Sk_I	0.282	Possibly significant at .05 level

The scatter diagrams for all the grab samples are shown in Figs. 3, 4 and 5. The formula used to obtain the correlation coefficient was $r = \frac{\Sigma xy}{\sqrt{(\Sigma x^2)(\Sigma y^2)}}$ (Spiegel, 1961), where x and y are the differences from the means $\bar{X}$ and $\bar{Y}$ respectively. Student's t-Test was used to test whether the coefficients differed significantly from zero as the number of samples was regarded as being small.

Skewness is the only property of the sediment samples which appears to be related to the mean size for all the samples, the highest degree of correlation being found for the samples just north of the Orange River mouth (the M.D.C. samples). The correlation is a positive one and tells us that as the mean grain size increases the sediment size distribution becomes more positively skewed (has a wider range of finer grainsizes associated with it.) According to Friedman (1961), positive skewness is typical of unidirectional water transport. It may also be significant that the samples from the T.D.C. are in general finer grained (Fig. 4) and that they yielded the lowest correlation: the grains that would constitute the tail of finer constituents in a positively skewed sediment may be so fine grained that they are periodically in



1·0
0·8
0·6
0·4
0·2
θ1
y= 0·712–0·077x for T.D.C.
r=–0·26
y=0·353+0·032x
r=0·08 for all samples
o SDC
x MDC
• TDC
+2·0
+3·0
Mz

Fig. 3

suspension under the influence of bottom water surge and can thus not be sampled using a grab.

The failure of the other tests to show any statistical interdependence may be due to several causes:-

i) the relatively small range of grain sizes involved

ii) the generally similar nature of the sediments

iii) the small number of samples tested

iv) correlations other than linear are present (but were not tested)

iii) <u>The effect of the carbonate constituents</u>:

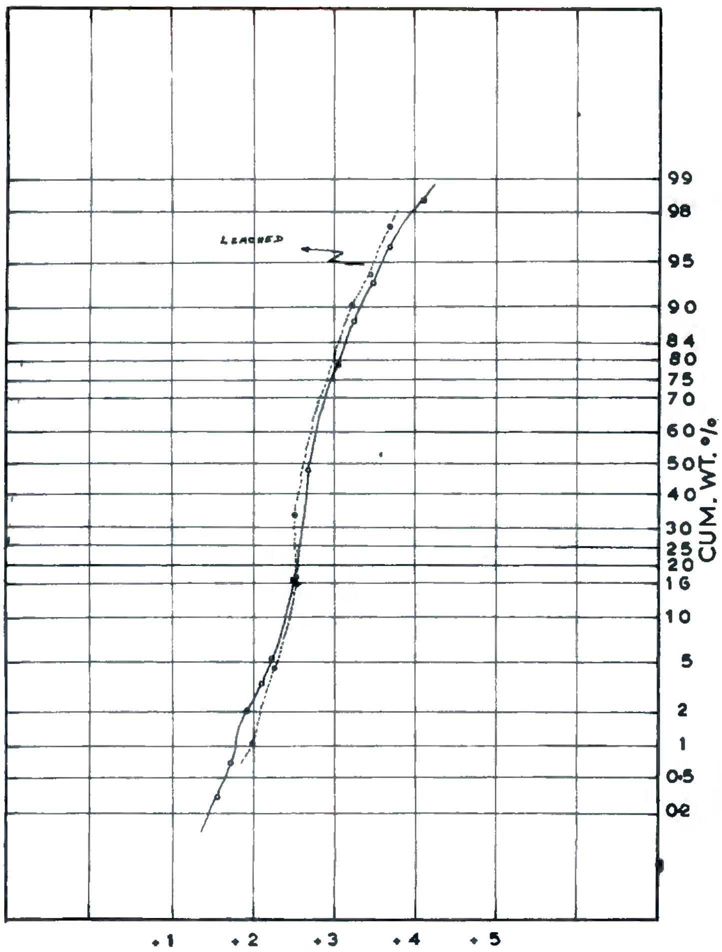
In order to assess what sort of effect the carbonate content has on the size distribution, four samples with similar, high values of carbonate content were resieved after they had been leached in cold, dilute hydrochloric acid for 24 hours. The four samples tested comprised three grab samples from the S.D.C. and a fragment of core (304c 2'10" - 3'1") from the T.D.C. which was known to have penetrated a shelly zone. The S.D.C. samples have the bulk of their carbonate present in the form of foraminiferal tests: this aspect will be discussed later. The statistical values of the original (O) and leached (L) samples are listed in Tabe IV and the distribution curves for two of the samples are illustrated in Fig. 6.

From Table IV it can be verified that the core sample has been the most affected by the presence (or absence) of carbonate in the form of shell fragments. In the case of the other (grab) samples, as illustrated in Fig. 6(a) by 31B1, the distribution curve of the leached fraction closely follows the shape of the original sample curve and it would appear that the carbonate (in the form of tests) tends to be distributed throughout the size grades. Fuller (1961), working with shallow water marine sands from the Cape of Good Hope, reached much the same conclusion.

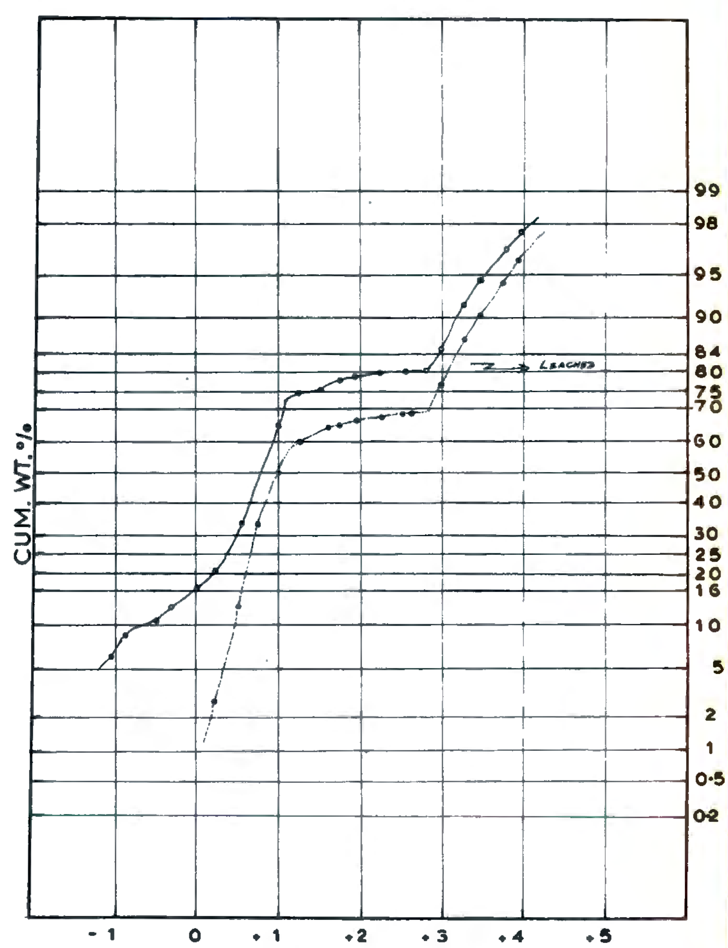
<u>TABLE IV</u>: <u>The statistics of four samples before and after leaching</u>:

	M_Z		σ_I		Sk_I		K_G		% CO_2
	O	L	O	L	O	L	O	L	by wt.
304C 2'10-3'1"	1.23	1.58	1.49	1.17	+0.29	+0.67	1.76	0.63	27.0
31 BI	2.78	2.75	0.40	0.34	+0.13	+0.18	1.31	1.18	24.3
88 AI	2.77	2.83	0.41	0.45	-0.34	-0.27	2.27	1.63	30.5
125 A5	2.87	2.77	0.51	0.52	0.00	-0.08	1.42	1.03	26.5

Skewness and kurtosis are the statistics most affected. The skewness has tended to become more positive (less negative) in the case of the leached samples, except for sample 125 A5, indicating a general rather than a specific distribution of carbonates in the coarser fractions. The kurtosis values indicate a trend from leptokurtic (very peaked) to meso- and platykurtic



a) SDC 31B1



b) TDC 304 C
Core 2'10"-3'1"

Fig. 6

frequency distributions, which probably signifies that the carbonates tended to be concentrated in the modal size grades.

Bowie(1966) suggests that the reason for relatively small effect of the carbonate or calcareous constituents on the size distribution is that thicker shell fragments behave more like sand grains if they are equant in shape, whereas thinner shell fragments tend to be "platey" and may react more strongly to the prevailing hydraulic conditions at the time of deposition, even though the specific gravities of calcite (2.72) and quartz (2.65) are similar. In the core section, 304C 2'10" - 3' 1", the shell fragments in the coarser size ranges were visibly more platey than the sand grains, so that the differences observed in the leached sample tend to confirm the sieving behavior of the platey and, in this case, coarser shell fragments. In the finer size ranges, the thin shell fragments appeared to behave in a manner similar to fine sand when being sieved, so that in this case the thickness of the shell appears to play a minor role; it is the (lack of) sphericity which signifies the difference in sieving behavior. Belderson (1961) found the same effect and elected to leach his samples prior to sieving. The author did not, as he considers the shell fragments to be an essential part of the sediment and in addition the grab samples with the highest carbonate content contained little to no macroscopic shell fragments.

iv) <u>Inflexion points and sediment populations</u>:

The deficiency of certain size fractions in natural sediments has been mentioned on page 26. These deficiencies are seen on the cumulative frequency distribution curves as inflexion points or "kinks" separating two or more constituent populations. The samples studied by the author were carefully sieved on standardized screens at ¼ Ø intervals and the inflexions found are thus accepted to be real features of the sediment rather than peculiarities traceable to the operation performed on them. The original curves were drawn on an exaggerated horizontal (size) scale from which more sensitive traces were constructed than those illustrated in the enclosed Figures.

The inflexion points can be classified into two broad categories - maximum and minimum points, as illustrated by Fig. 7(e). The reflex angle formed by the intersection has been called a maximum point and the obtuse angle a minimum point of inflexion. Several modifications of these two basic categories were noted. Instead of a straight-forward break in slope between two nearly straight lines, a flexure can be constructed to link gentle curves, as illustrated in Fig. 7, of which a) and b) are the most common. At the point of flexure, each of the populations can be said to have too little or too much material with respect to the other, specifically, the coarser (left hand) component has a deficiency of material, as in Fig 7(a), with respect to the finer (right hand) component, hence the term "minimum point". In Fig. 7(b) the coarser component has an excess of material at the flexure, hence the term "maximum point". In Fig. 7(c) both components appear to be deficient and in 7(d) they both have an "excess" of material, although the overall inflexions are maximum and minimum respectively.

A visual appraisal of the more obvious inflexion points shows that they tend to occur between the following phi values:

1.7 - 1.9 Ø minimum	3.0 - 3.2 Ø maximum
2.7 - 2.9 Ø minimum	3.3 - 3.5 Ø maximum
	3.7 - 3.9 Ø maximum

The 1.7 - 1.9 Ø group was the most common.

Fig. 6(b) illustrates typical inflection points - a maximum at 1.09 Ø and a minimum at 2.87 Ø. We note that the leached sample, that is without carbonate, does not show any significant change in the size range of the inflexion points. Fig. 8 illustrates the nature of modified points or flexures. We see that at about +2 Ø, we have an actual flexure at 1.90 Ø, but an inferred minimum inflexion point at about 2.25 Ø. The 2.55 Ø is a modified maximum type, while that at 3.03 Ø is a "pure" maximum inflexion point.

In the literature covering sedimentological size statistics that the author perused, little attention has been drawn to the possible presence of maximum and minimum inflexion points. The author stresses the word possible, as the form of the flexures is fairly subjective and may depend to some degree on the artistic talents of the investigator. However, Bowie (1966) found inflexion points to occur commonly between +2 and 2½ Ø, and at +3.2 Ø. Belderson (1961) also mentions the existence of inflexions between +2 and 2½ Ø, and between +2.75 and 3.0 Ø. A possible reason for the presence of a (minimum) point at +2 Ø is discussed by Fuller (1961, 1962) who noted prominent inflexion at about +0.8 Ø, and especially at +2 Ø, occurring in shelf sand samples collected off the Cape Province. The possible effects of sieve errors and sediment layering were thought to be of minor importance, and he concluded that the +2 Ø gap was the result of the differential removal and dispersal of sand of this size grade (approximate 0.25 mm) from its initial environment. It was also noted that the 2 Ø grade occurs in the size range in which the Impact and Stokes' settling laws merged. The +0.8 Ø gap was tentatively explained as being due to separation of the traction and suspension loads.

Tanner (1964) suggests that the 2 Ø gap could be explained in terms of simple mixing of two source sediments. He also maintains that a filtering process might also be involved (see page 27) but that it need not be invoked to explain the phenomenon discussed by Fuller. Tanner further implies that all 2 Ø gaps in curves with the right slope, (whatever that might be), are due to mixing processes but in view of the common

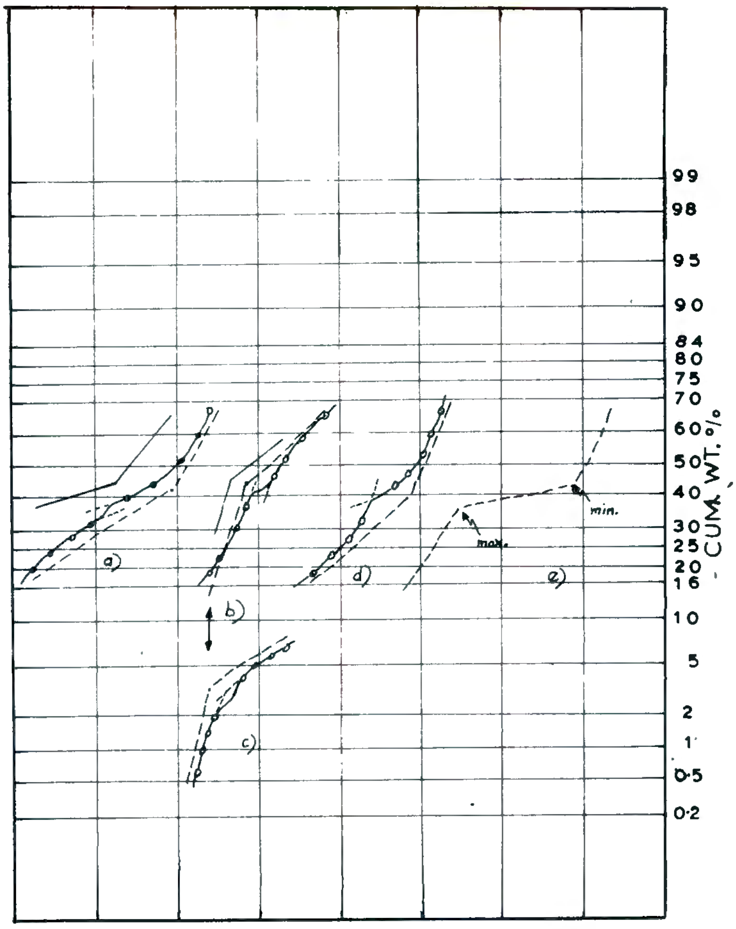
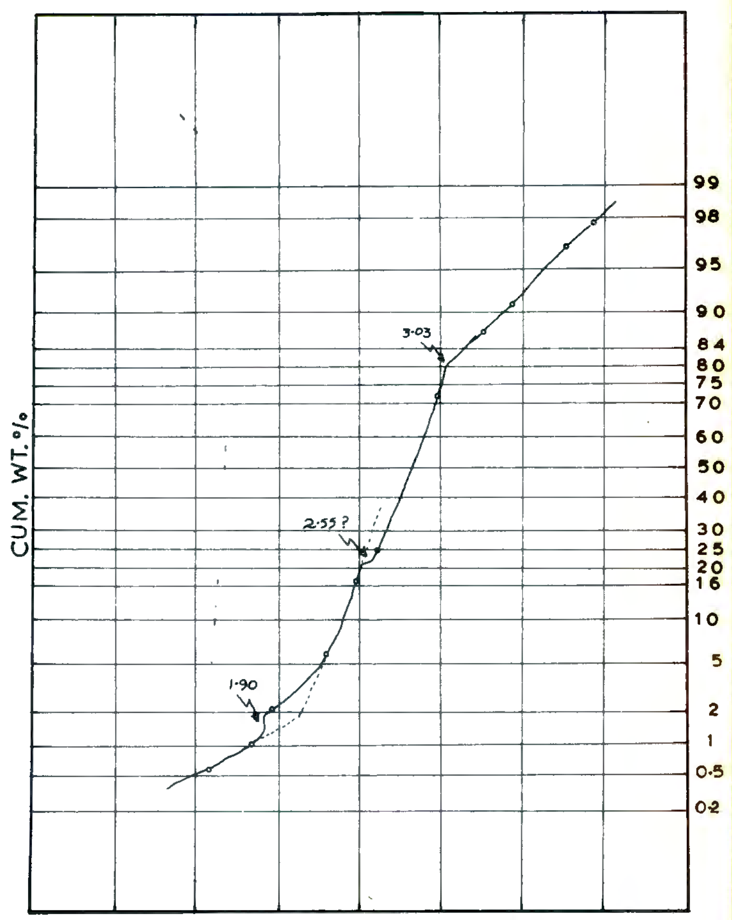


Fig. 7



M DC 147·5 A

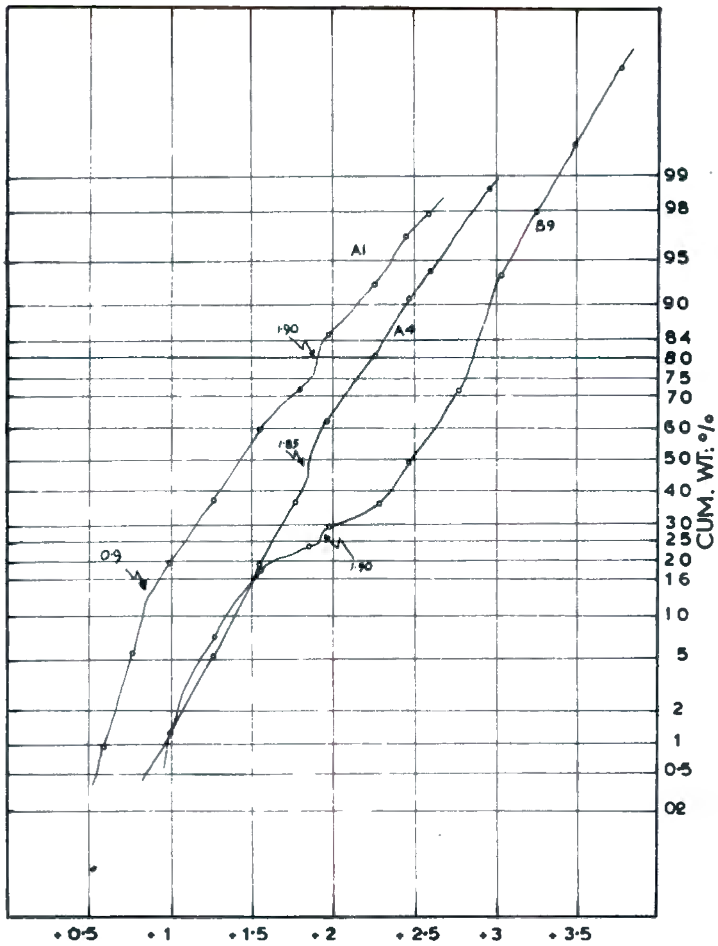
Fig. 8

occurrence of this 2 Ø gap his theories would carry more weight if they could be supported by convincing experimental results.

Inman (1949) noted that sand with a diameter of 0.18 mm (about 2.47 Ø) is most easily moved, or more precisely, that the threshold velocity necessary to initiate movement of grains in a sediment is a minimum for this grain size. Rogers, Kreuger and Krog (1963) argue that sand and silt originally form two distinct populations (by abrasion and chipping respectively) and that the boundary between the two sediment types falls at about 0.25 mm (2 Ø). To summarize, there is a general deficiency of material between 2 and 2½ Ø which can be largely accounted for in terms of source sediment and environmental processes acting on the sediment. The nature of the curves of the components comprising the cumulative frequency size distribution plot reflects the degree to which the sediment has responded to these processes.

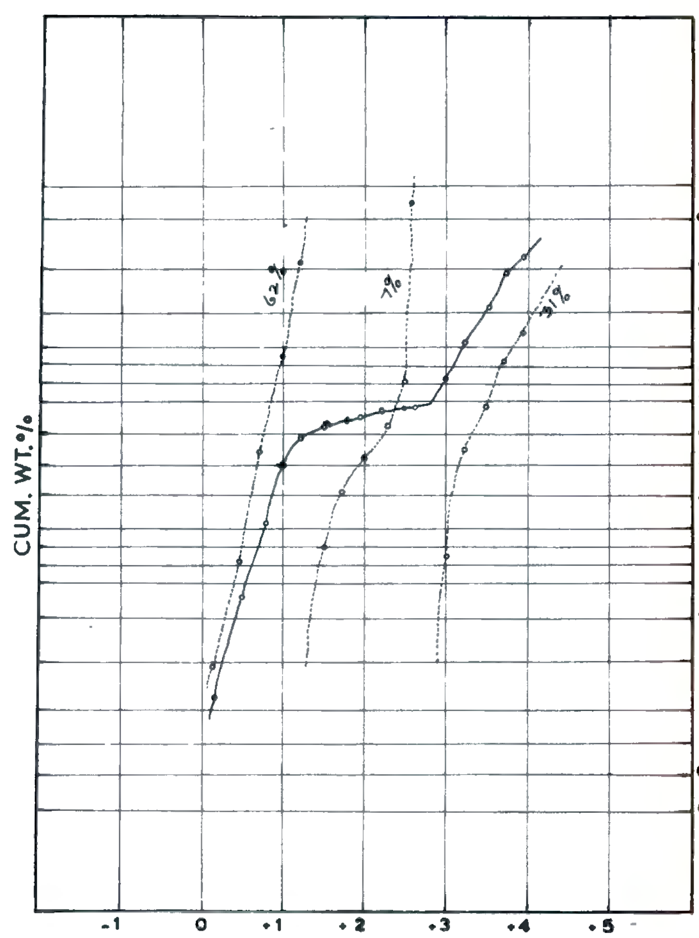
Two groups of samples, Series A and Series B, were collected at right angles to the coast from water about 1 m deep, across the beach and from inland dunes. The samples were taken just south of Meob Bay (Map 7) and south of beacon Gibralter (Map 6) respectively. While they cannot be considered representative, it is nevertheless interesting to record the changes the samples reflect with increasing distance from the water's edge. Their mean size decreases slightly from 1.2 - 1.4 Ø to 1.6 - 1.8 Ø about 100 m inland, but they remain well sorted and have a symmetrical skewness. Further inland, on the dunes, the sand is finer, moderately well sorted and becomes more skewed, both negatively and positively. However, nearly every one of the 21 samples analysed showed inflexions in their cumulative frequency size distribution curves between 1.8 and 1.9 Ø, with weakly developed inflexions between 2.7 and 2.9 Ø being present in a few samples. It is perhaps significant that the 1.8 - 1.9 Ø inflexions were maximum points in 13 cases, 2 samples had doubtful inflexions and 5 samples had minimum points. In addition, the inflexions tended to become minimum points inland. Some examples are illustrated in Fig. 9(a). Sample A1 was taken 10 m seaward of the water edge, and it can be seen to have a maximum point at 0.9 Ø - very close to Fuller's observed 0.8 Ø "gap" (1961). It will also be noted that sample A4, about 20 m on the landward side of the water's edge, has M_Z = 1.88 - close to the 2 Ø gap? It is not considered feasible to enter into a profound discussion on the significance of these results: they are recorded by way of interest. Harris (1959) provides sound treatment on the changes that intertidal sediments can be expected to undergo.

Harding (1949) presented a fairly simple graphical solution to separate the components, and the author analysed 13 grab and 2 core samples by this method: the samples were selected because their components tended to have straight segments of the cumulative curves. Harding's method involves selecting "pure" populations (which are terminated by flexures or changes in



a) TD C A1, A4, B9

Beach samples



b) TDC 304C (leached)

Core 2'10"–3'1"

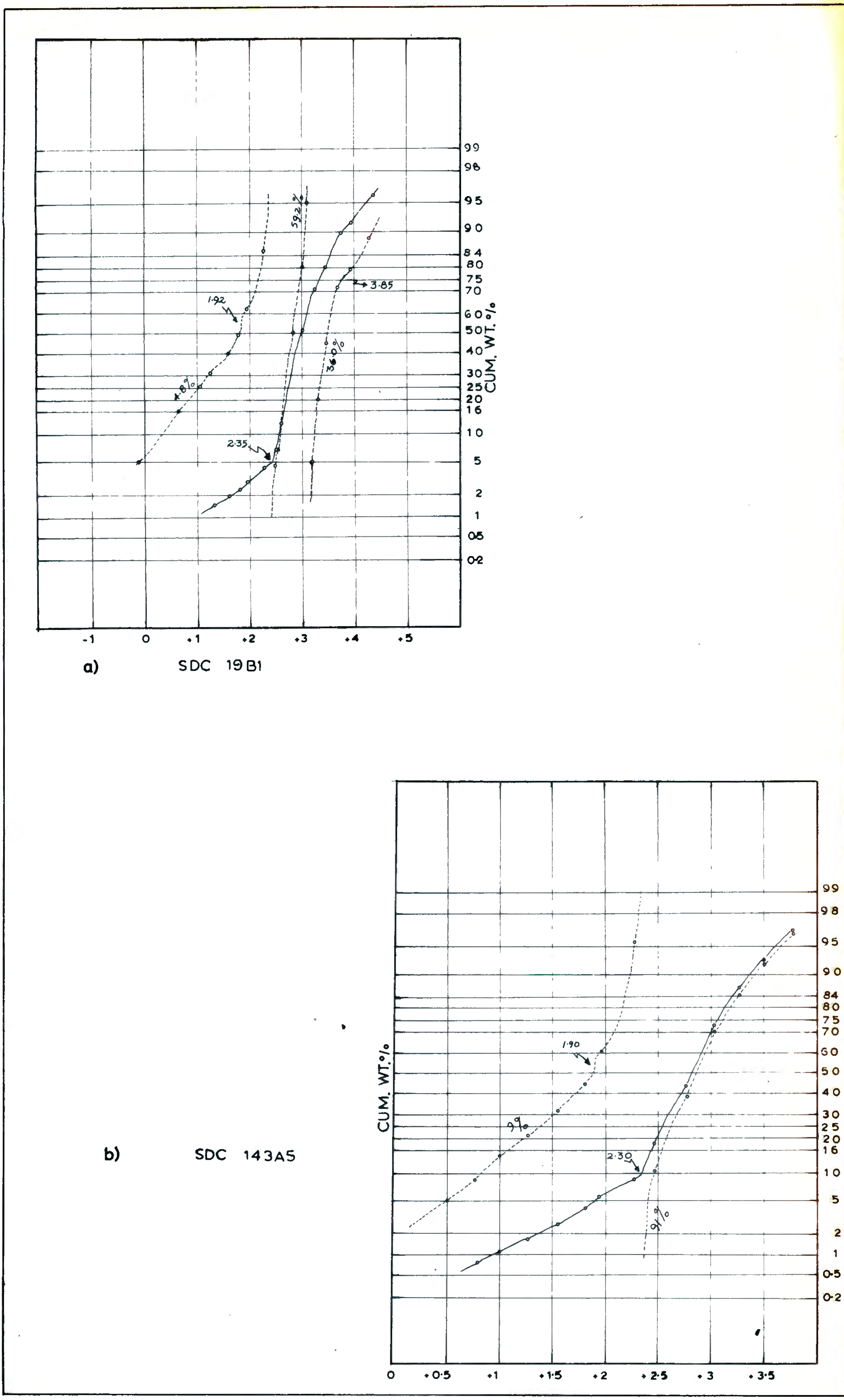
Fig. 9

slope) and expanding each population curve, within its size range, to the full range of the cummulative diagram. A certain amount of initial assumptions are necessary, for example to decide what size range any particular population component covers, and even in deciding how many components may be present. "Goodness of fit" tests can be made to determine how well the resultant curve (of the component curves) fits the original sample curve, and the population components can be changed until the best fit is obtained. These tests were not done by the author as the various manipulations and calculations are considered to be out of proportion to the significance of the results that would be obtained. The results are tabulated in Table V, and are illustrated by Figs. 9(b), 10 and 11.

TABLE V: Summary of analysis of components for selected samples:

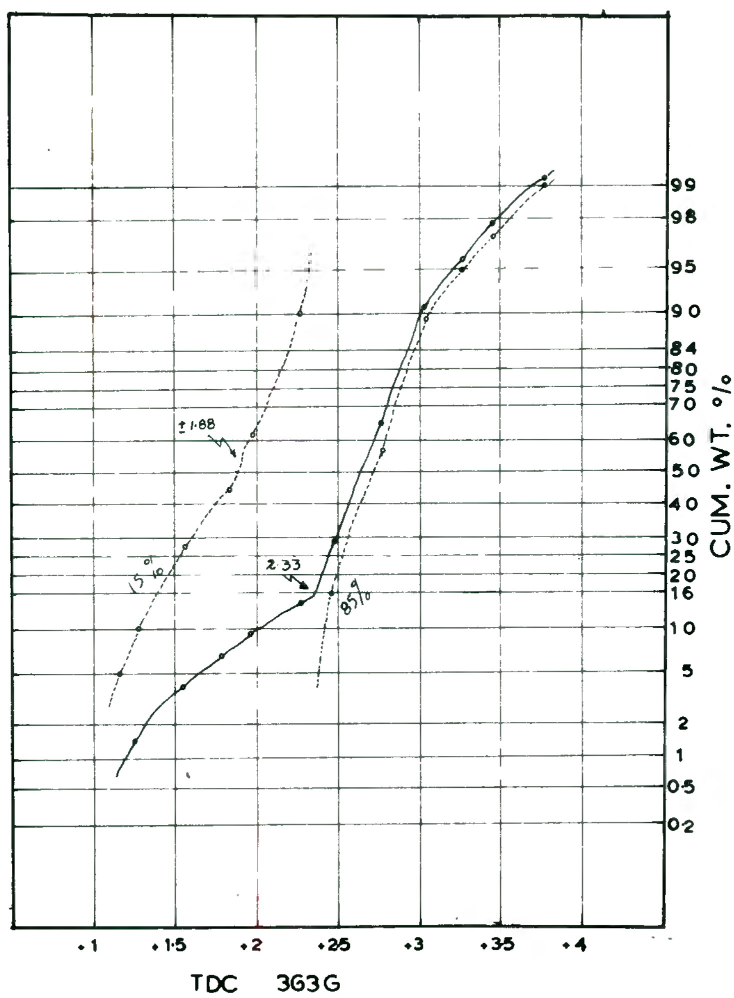
Sample	Original		Pop 1.		Pop. 2.		Pop. 3.	
	M_Z	σ_I	M_Z	σ_1	M_Z	σ_I	M_Z	σ_I
249 A5	2.99	0.42			2.82	0.22	3.60	0.40
235 B6	2.64	0.33	1.09	0.96	2.69	0.27		
143 A5	2.81	0.45	1.72	0.53	2.83	0.39		
91 B4	2.70	0.64	1.00	0.31	1.75	0.21	2.86	0.38
77 A1	2.80	0.49	1.30	0.67	2.85	0.37		
19 B1	3.06	0.51	1.57	0.83	2.82	0.19	3.61	0.45
47 N	3.72	0.85			2.84	0.19	4.22	0.66
57½ SY	2.87	0.50			2.74	0.26	3.89	0.57
302/1 GG	2.99	0.75	1.23	0.79	3.18	0.46		
308 B	3.70	0.34	2.27	0.22	2.91	0.06	3.47	0.35
363 G	2.60	0.37	1.80	0.37	2.71	0.25		
502 D	1.31	0.77	0.79	0.22	2.08	0.48		
505 T	3.20	1.05			2.70	0.45	4.66	1.03
304 C Core leached 2'10"-3'1"	1.58	1.17	0.74	0.28	1.97	0.42	3.32	0.50
305/1 H Core 2'-2'9"	2.11	1.72	-0.35	1.05	1.81	0.44	3.21	0.41

Thus of the 35 population components that are assumed to be present in these samples, the mean size of 11 fall between 2.61 - 3.00 Ø, 5 fall between 1.61 and 2.00 Ø and 4 have M_Z between 3.21 and 3.60 Ø; these sands can be described respectively as fine, medium and very fine sand respectively. The fine sand components tend to be very well sorted, the medium sands moderately sorted, and the very fine sands are well sorted. The occurrence of two component populations with M_Z values very close to Fullers possible 0.80 Ø gap is also noted; both are very well sorted. In the segment of core sample 304 C this fraction comprises 62% of the total by weight (Fig. 9(b). It is apparent that a detailed, systematic study of these component populations and their resultant sediment types would be enlightening.



CUM. WT. %
99
98
95
90
84
80
75
70
60
50
40
30
25
20
16
10
5
2
1
0.5
0.2
-1
0
+1
+2
+3
+4
+5
1.92
2.35
3.85
59.2%
36.0%
4.8%
a) SDC 19B1
b) SDC 143A5
CUM. WT. %
1.90
2.30
9%
91%
0
+0.5
+1
+1.5
+2
+2.5
+3
+3.5

Fig. 10



99
98
95
90
84
80
75
70
60
50
40
30
25
20
16
10
5
2
1
0.5
0.2
CUM. WT. %
±1.88
15%
2.33
85%
.1
.15
.2
.25
.3
.35
.4
TDC 363G

Fig. 11

It will be seen that in two of the samples illustrated, sample 19B (Fig.10(a) and 143 A5 (Fig.10(b), what were negligible flexures in the original distribution curves at 1.9 Ø become emphasized in the component distribution curves, which suggests that even the component populations may have inflexion points (are actually mixtures of other populations).

The two samples in question also have similar size distribution curves, but 3 components were assumed for 19B1 (Fig. 10(a) as against only 2 for sample 143 A5 (Fig.10(b). On the original plots it was noticed that there was a distinct break in slope at 3.10 Ø for 19 B1, whereas the fine-grained portion of 143 A5 displayed a smoother curve and did not suggest a separate, third component. As mentioned previously, "goodness of fit" tests could be used to test the validity of this assumption.

Moss (1962 and 1963) attempted to explain the formation of distinctive sediment types on a philosophic basis. He nominated three broad, natural populations on a size-shape basis of which C is the coarsest, A is of intermediate size and B is the finest. Combinations of these three common populations, by responding to natural transport media, would give rise to five principal sediment types:-

Type 1 sediments consist of population A only, and are characterized by wave-deposited beaches.

Type 2 sediments are associated with unidirectional currents, (for example rivers), and comprise a mixture of A and B, of which B is the finer, rarer fraction.

Type 3 sediments are a mixture of all three groups A, B, and C and are examplified by the common, sandy gravels.

Type 4 is a sandy gravel without fines, and Type 5 sediments are akin to aeolian deposits (such as coastal dunes).

Except for the A and B series of beach samples, the samples treated appear to be Type 2 sediments; possibly variations in transport and depositional processes have yielded more than one A or B population group.

Moss (1962 pg. 339) states that "no property of size frequency distribution that reliably characterizes any particular type of depositional environment, on a world-wide basis, appears to have been found".

III. DETERMINATION OF THE QUANTITATIVE HEAVY MINERAL DISTRIBUTION.

a) Sample treatment:

50 gm sub-samples were split from the whole size range of the

original samples for the extraction of heavy minerals. These sub-samples were accurately weighed and added to a solution of Bromoform in large filter funnels fitted with rubber tubes and stopcocks. The Bromoform solution was maintained at a specific gravity of between 2.85 and 2.90 for the tests. After initial and fairly violent stirring, the suspensions were allowed to settle for some 3 hours with occasional gentle stirring and scraping down of the funnel sides to free grains that had settled there. After 3 hours, the heavy minerals were tapped off and collected on previously weighed filter papers. After filtering, the product was washed with acetone (to remove excess Bromoform) and then dried in a low-temperature oven. The heavy minerals and paper were weighed, and the actual percentage of heavy minerals computed for each sample.

Samples which had more than 5% by weight of material finer than +4 Ø, as determined by sieving for size analyses, were treated differently. The 50 gm sub-sample was stirred up in a beaker of Bromoform and allowed to settle for 12 hours. The bottom half of the beaker, containing the settled heavy minerals, was then frozen with salted ice, and the "light" minerals (with an S.G. of less than 2.85) simply poured off and retrieved. Defrosting of the beaker contents allowed the heavy minerals to be cleanly collected after washing into weighed filter papers. This treatment was found to be convenient as settling could take place overnight, and separation was more satisfactory than centrifuging provided the beakers were handled carefully. Bates and Bates (1960) compared the efficienty of separations using 20 gm and 50 gm samples of sand with a mean size of 2.72 Ø and a sorting factor of about 0.5 Ø. They found that by simple gravity settling, 99 to 100% of the known quantity of heavy minerals were recovered within one hour, with results being better (more efficient) for the 50 gm samples. Rittenhouse and Bertholf (1942) compared centrifuge and gravity settling techniques for 5 gm sand samples of mean size about 3.5 Ø and found that the centrifuge method was better by a factor of only 0.4%. Standard errors were small and (page 87) "...... this shows that equally consistent results may be obtained by either method ...". Thus if it is assumed that sampling and splitting errors were reasonably constant, the methods outlined above can be considered entirely satisfactory.

The Bromoform was recovered from the minerals and filter paper washings of both heavy and light fractions by washing the mineral and filter paper with acetone, followed by removal of the acetone from the washings by shaking with water and settling in a separating funnel. The Bromoform was frequently checked to ensure a reasonably constant specific gravity was maintained during the exercise, which often meant further treatment of the liquid by standard techniques.

Rubey (1933) warns against the dangers of using the entire size range of samples for heavy mineral work. He points out that, because of their greater specific gravities and also possibly different shapes and hardness, the minerals do not behave in the same way as ordinary quartz grains under similar conditions of transport and deposition. The heavy mineral grains tend to be concentrated in finer size grades and in fact may have a size distribution different to that of the other (light) minerals present. Rittenhouse (1943) counsels in a similar vein and introduced the concept of hydraulic equivalence as a means of representing the heavy mineral composition of sediments because of their behavioral differences. It boils down to the fact that the heavy minerals of a sediment may be more sensitive to the conditions which characterize and determine the nature of the bulk of the sediment. However, because detailed analyses of the heavy mineral constituents were not carried out for this work and because the size distributions of the grab samples are similar in general, it was considered quite rational to use the whole size range of the samples to test for differences in quantitative heavy mineral content between difference areas. Further comment on this point is deferred to the section below:

b) Results:

i) Quantitative distribution:

The list of the percentage by weight of heavy minerals for the samples treated is presented in Table I (pg. 24(a). The values have been adjusted to a zero carbonate basis: that is, each result was computed as a percentage of the original sample weight less the weight of carbonate assumed to be present (from the determination outlined in the following section). This procedure was followed because the carbonate constituents (assumed to be shell fragments) are considered to be secondary sedimentary products in the sense that they are not related to the composition of the source sediments and furthermore their presence (or absence) may be dependant on factors such as salinity and sea-water temperature, conditions which hardly affect the abundance of heavy minerals.

The weight percentage of heavy minerals was plotted against location and the result is illustrated by Fig. 12(a). The trends are emphasized by a dashed line representing the moving average of groups of three successive samples. A difference in heavy mineral content between the three concessions can be discerned. These apparent differences were tested statistically by computing the Z scores for the average values of each area's samples (Spiegel, 1961 page 170). The statistic used is defined as

$$Z = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{\sigma_1^2}{N_1} + \frac{\sigma_2^2}{N_2}}} \quad \text{-------} \quad \bar{X}_1, \bar{X}_2 \text{ are means; } \sigma_1, \sigma_2 \text{ are sample deviations}$$

This test for differences between means is analogous to Student's t -Test; the latter is used for small samples (i.e. less than 30) and using estimates of the variance. The results of these tests are listed in Table VI.

TABLE VI. Tests between the mean heavy mineral content of samples from the three concession areas:

	S.D.C.	M.D.C.	T.D.C.
Total percentage of heavy minerals	313.65	931.60	632.41
Number of samples (N)	41	38	44
Mean percentage of heavy minerals	7.65	24.51	14.37
Variance of H.M. percentage	± 9.29	± 12.33	± 5.33
Z score versus M.D.C. samples	6.83	-	4.72
Z score versus S.D.C. samples	-	6.83	4.05

In all three tests, (MDC vs. SDC., MDC vs. TDC and TDC vs. SDC), Z scores of between 4 and 6.8 were recorded, so that the results show that there are highly significant differences between the mean percentages by weight of heavy minerals from the three areas. As it happens, the inclusion of the carbonate fraction in the sediment sample weight would serve to increase the differences, as the S.D.C. has the largest (mean) percentage of carbonate so that the "true" weight of heavy minerals would be decreased by a factor of some 10%.

The reason for this significant increase in heavy mineral content north of the Orange River is suggested to be the presence of the river itself. Unfortunately the number and distribution of the samples in the M.D.C. concession are too limited to formulate any definite quantitative answer.

The trend-line of Fig.12(a) suggests that there is a sharp increase in the percentage of heavy minerals just north of the river mouth and decreasing in a rather irregular manner northwards. This gradual decrease is also suggested by the trend-line for the T.D.C. samples. For the S.D.C. an increase in heavy mineral content is also apparent just north of the Olifants River mouth, with a secondary region of high values off the smaller rivers and channels such as the Swartlintjies and Spoeg Rivers. The theory that these channels and rivers constitute a significant source of heavy minerals as opposed to, say, erosion of the submarine bedrock, can only be proved by more detailed investigations; the present work strongly suggests this to be the case.

A sample of a dark, banded sand taken from one of the C.D.M. beach deposits gave a value of 99% by weight of heavy minerals - a remarkable concentration. Some 47% of this sand proved to be magnetic, that is, could be removed from the sample by passing a small magnet over the surface of the spread out sand. It is also rewarding to note that this sample possessed almost "perfect" kurtosis: in addition it was very well sorted and had a very symmetrical distribution curve.

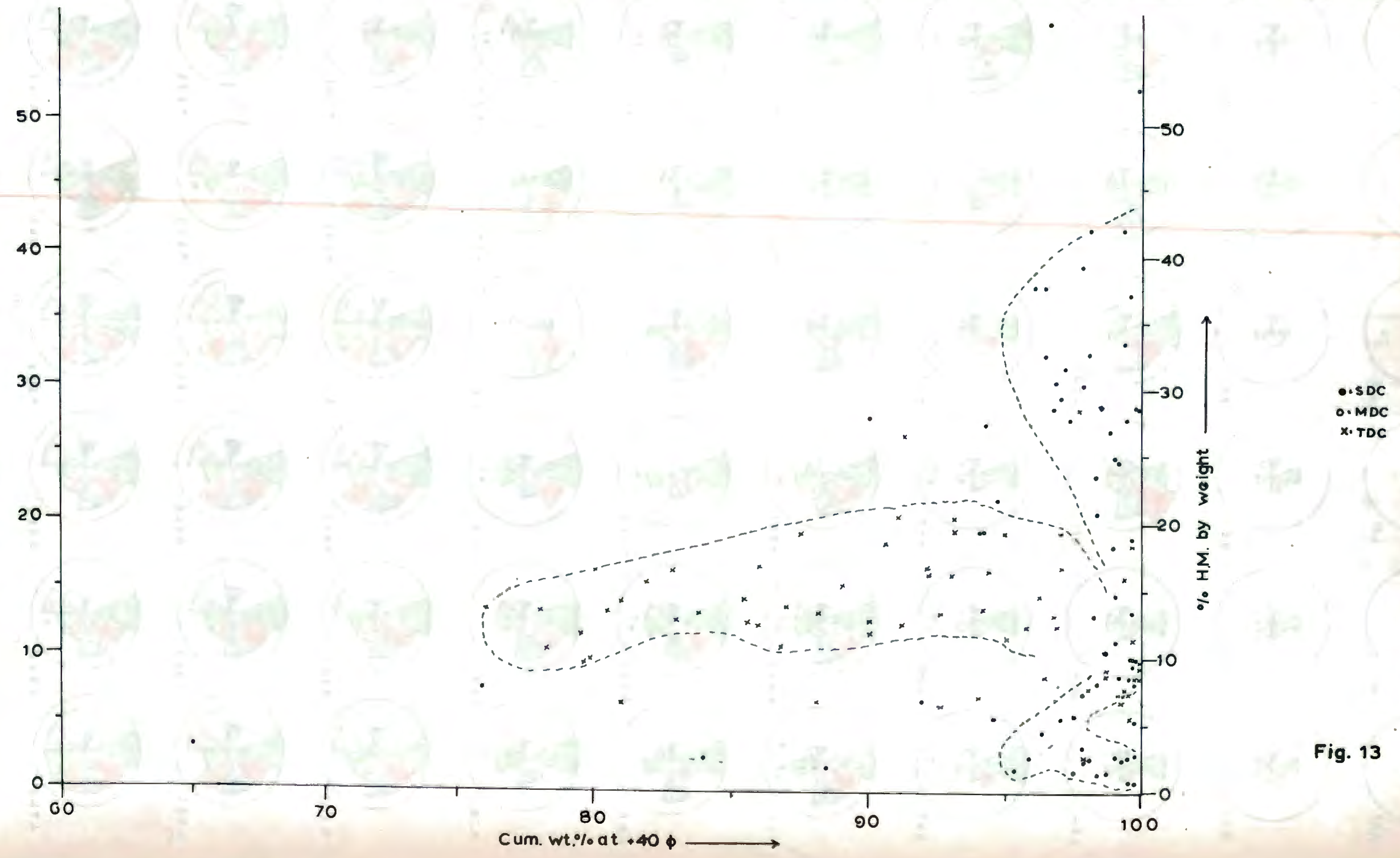
It is also interesting to note the variation of heavy mineral content in the A and B series of trans-beach samples. Negligible values at the waters edge increase steadily across the beach and decrease slightly from about 100 m inland. Speculation as to the significance of the features of these raised beach and shallow water samples is not called for here.

Fig. 13 is offered in support of the argument that the weight percentage of heavy minerals is not entirely dependant on the size range present in the samples investigated. The plot is one of percentage heavy minerals by weight versus the cumulative weight percent at the +4 Ø size grade; the latter parameter provides a measure of the percentage of fine grained material present. It is fairly obvious that the natural division is based on the value of the heavy mineral percentage. In the case of the T.D.C. samples however, which are denoted by crosses, there is a very slight tendency for the samples with little fine grained material to be poorer in heavy minerals.

ii) Relative abundances:

Detailed counts of mineral species were not undertaken for this study despite the fact that slides were prepared for that purpose. However, samples of untreated sand collected during sampling were submitted to the Diamond Research Laboratory from time to time and studied by that organization on a routine basis. The results were reported by denoting the relative abundances of the most common species of heavy minerals present. The author has examined this data and compiled diagrams, again for each area, to illustrate the trend found, be it real or co-incidental. The sand samples do not represent any particular bed or stratum below the sea floor but are composite samples of the sand produced by drilling through the unconsolidated sediments during sampling.

Fig. 14 represents the relative abundances of heavy minerals for the S.D.C. area. The figures next to each pie diagram denote the site and sample number, the locations of which can be followed on Map 1, 2 and 3. The samples in the south are represented at the bottom of the figure. Most species are abundant. It should be pointed out that the category "epidote" includes the other pyroxenes and amphiboles. By way of comparison, Potgieter (1944) analysed (by counting) a sample of beach and river sand from the north bank of the Olifants River, where concentration of minerals by wave action had been noted. After removing the magnetic minerals, he found the following percentage by weight of species:-



• SDC
o MDC
x TDC
% H.M. by weight
Cum. wt.% at +4.0 ϕ
0
10
20
30
40
50
60
70
80
90
100

Fig. 13

recovered from the beaches to the north of the mouth, one was found some 6 miles seaward, and one or two were found south of the mouth. This, it was postulated, suggested a strong northerly element of movement with smaller or weaker elements seawards and southwards.

c) Current measurements:

Current measurements have not been oustandingly successful. The currents indicated have been so weak as to render it difficult to distinguish oceanic current from swell action, but a north-westerly trend has been accepted and the speed simply stated as "less than one knot". Little is known of seasonal variations of currents in the larger bays or open sea. Stander (1964) stated that computed surface currents are very complex, but do not exceed half a knot.

d) Pebble measurements:

Williams (1965) notes that as pebbles were traced north along the beach at C.D.M. from a known source, (most probably a plant dump bordering the water's edge), the pebble size decreased with distance from the source and the pebble shape became less oblate. These changes were taken to mean that smaller, more spherical pebbles are more easily transported than bigger, flatter ones.

e) Direct and Indirect observations:

Divers working underwater have experienced bottom surge due to swell action. The oscillatory movement induced by passing swells is sufficient to stir the sand and even small pebbles, which would presumably undergo a small directional nett movement. There is a heavy suspension above the bottom, (experienced personally), presumably fine organic matter and sediment. The suspension is maintained by the surge, and becomes subject to current and drift movements. After a period of calm weather, say four successive days of swell less than 1 metre in height, good visibility of the order of 10 metres has been noted on the sea floor in water depths of between 30 and 10 m.

Geophysical acoustic profiling traverses across newly mined areas have shown submarine excavations in sediment with well-defined shapes. Traverses run over the same areas after varying periods of time show that these excavations fill in gradually with loose sediment, but that a slight depression in the sea floor is still observable some months later and, in some cases, up to a year later. No definite figures are available however: the sediment movement depends on many factors such as water depth, wave heights and periods, and frequency of storm conditions.

PLATE X

a) m.v. "Rockeater", prospecting and drilling vessel. The accomodation decks are aft and the processing plant is situated near the bows. Pipe racks take up the deck space between the drill tower and the plant. Note the anchor racks on the bow itself.

b) m.v. "Bellatrix", geophysical and prospecting vessel used by the O.R.U. A dredge pipe is suspended over the side and handled by divers on the sea bottom. Small samples are partly processed on board.

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a)


b)

PLATE X

Samples consist of single holes drilled at 10 m intervals along lines spaced at various distances apart depending on the sampling density required, but usually at 100 m or 500 m intervals. The lines are orientated roughly normal to the shore. In order to carefully control the position of the ship on and along the sample lines, "Rockeater" is fitted with four powerful winches wound with ultra-strong steel wire hawsers connected to Danforth anchors. Positions can be determined continuously using the hydrodist and theodolite combination, to within one or two metres.

Sampling operations are normally limited to water depths of between 40 ft. (12 m) and about 200 ft. (60 m). The system is capable of drilling holes 9 m deep through unconsolidated sediments while working in swells less than 10 ft. (3 m) high. Further details and discussion have been published by Murray (1969).

A geologist or experienced field officer is stationed at the point where the drilled products are discharged onto the screens to note the material being excavated and to ensure the samples are of an acceptable standard. Although the material arrives as a slurry, a reasonably clear idea of the stratigraphic succession can be determined. A hole takes an average of between 3 and 7 minutes to drill; depths of the bit are judged by the progress of the drill string past a fixed point. Readings have been correlated by direct measuring devices attached to the bit and very good agreement, to within a foot or two (0.3 to 0.5 m), has been found.

Grab samples were taken from "Rockeater" during the reconnaissance stages of prospecting and a few cores were collected by a vibrocoring unit lowered from an outboard hydrographic platform.

b) <u>m.v. "Bellatrix"</u>:

"Bellatrix" (Plate X(b)) is a steel hulled, converted trawler of 220 tons (gross) and 110 ft. long. She is used by the Oceanographic Research Unit (O.R.U.) for special projects and is fitted to carry a team of scuba divers and a comprehensive range of geophysical equipment. Professional divers work under the supervision of geologists trained as divers, and they are presently engaged in mapping the largely sediment-free bedrock areas offshore of the C.D.M. workings. Samples of sediment are gathered by a 4-inch airlift system handled on the bottom by the divers. An underwater telephone system enables on-the-spot reports to be monitored on the surface as well as doubling as a safety device. The most useful information concerning submarine bedrock morphology has come from teams working from "Bellatrix".

c) <u>s.t. "Emerson K"</u> was the vessel used by the Marine Diamond Corporation during its initial prospecting phase. She was an ex-salvage tug of 759 tons, fitted with a flexible 8-inch dredging hose, airlift system and small processing plant. Rough notes were made of the material excavated, so that some information is available from this source. Sample sites were spread throughout the M.D.C. and S.D.C. concession in up to 250 ft. (76 m) of water. The vessel was scrapped in 1966.

II. THE STRATIGRAPHIC SEQUENCE.

The vertical distribution of the various sediment types is dependant on the area and the thickness of sediment present, but a composite sample would typically exhibit the following sequence of principal sediment types:-

Description	Average Thickness
Silty sand with occasional shells	2 m
Shell horizon with sparse pebbles	1 m
Gravel mixed with shell	0.5 m
Clay; usually grey-blue-green	0.5 m
Sub-angular to angular bedrock rubble	0.5 m
Bedrock (often overlain by calcareous sandstone)	

Fig. 17 illustrates in detail the nature of the inshore submarine sediment stratigraphy.

a) Silty sand.

The sediment consists of quartzo-felspathic sand, mixed with shell grit, and contains a small fine-grained fraction. The most common heavy mineral constituents are garnet, ilmenite, rutile and pyrobole. Variations in heavy mineral and carbonate content of the surface sediment have already been dealt with.

b) Shell.

A wide assemblage of shallow-water marine Molluca is present although only a few species occur in abundance. Preliminary work indicates that the assemblage has a modern aspect and is certainly Pleistocene to Recent in age and probably of late Pleistocene to Recent age (Carrington, personal communication, as reported in Murray et al, 1970). Some of the most common types are illustrated in Plates XI - XV. The names are tentative and I would acknowledge the assistance of J. Fields and J. Anderton of the Zoology Department, U.C.T., in this respect.

Comminuted shell is ubiquitous, but whole valves are common even for such fragile species as Kraussina rubra, Solen capensis and Tellina triangularis. Bullia is the only gastropod commonly found to be living on the sandy sea-bed and the common black mussel, Chloromytilus meridionalis, is frequently found as living colonies on sediment-free bedrock.

No systematic relationship between sediment type and shell species has been found, except that the Ostrea type usually occurs in the thicker, basal

PLATE XI

a) Terminology of the Pelecypod shell

b) Solen capensis

c) Phaxas pellucidus

d) Solen capensis

e) Tellina triangularis

f) Tapes corregatus

g) Loripes clausus/Phacoides capensis

h) Loripes clausus

i) Tapes corregatus

PLATE XII

a) Ostrea margaritacea (?) - internal view

b) Ostrea margaritacea (?) - external view

c) Ostrea valves in sandstone

d) Ostrea valves - loose

e) Lutraria lutraria

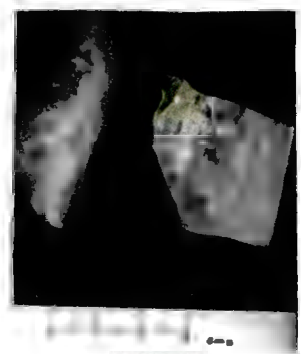
f) Lutraria lutraria

g) Aulacomya magellanica

h) Tivela compressa

a)

b)



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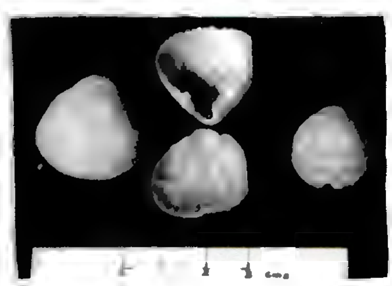


e)

PLATE XV

PLATE XV

a) Bryozoan skeleton

b) *Vermetus*

c) *Chloromytilus meridionalis*

d) and e) *Kraussina rubra*

a)

b)

c)

d)

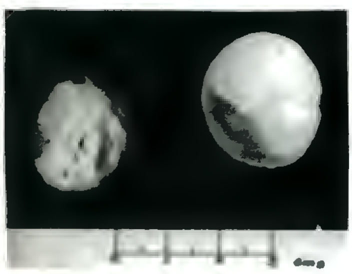
e)

f)

g)

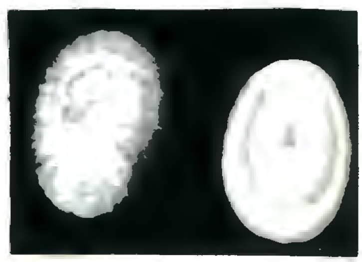
h)

i)



j)

k)



l)

m)

n)

o)

PLATE XIV

PLATE XIV

a) Fasciolaria rutila

b) Fasciolaria lugubris

c) Fasciolaria hynemani

d) Argobuccium gemmifer

e) Argobuccium argus

f) Turitella sanguinea

g) Natica genuana

h) Patella barbara
Patella granularis
Patella compressa

i) Volutidae sp.

j) Crepidula porcelana (?)

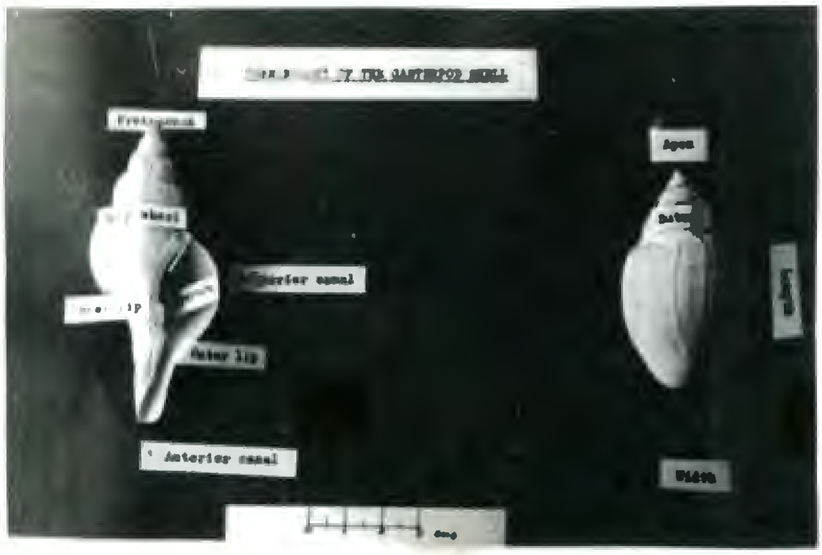
k) Volutacorbis lutosa

l) Patella argenvillei

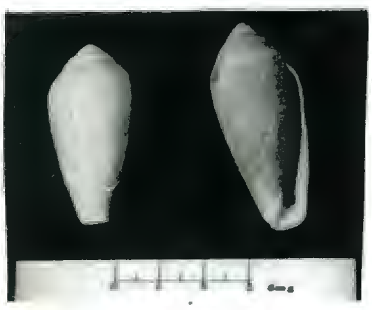
m) Patella barbara (?)

o) Amblychilepas scutellum

n) Crepidula porcelana



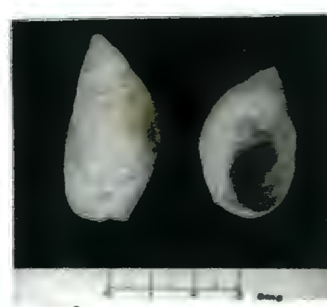
a)



b)

c)

d)



e)

f)

g)

h)

PLATE XIII

i)

PLATE XIII

a) Terminology of the Gasterpod shells

b) Conus elongatus

c) Conus patens and Conus elongatus

d) Bullia rhodostoma

e) Bullia laevissima

f) Thais squamosa

g) Thais cingulata

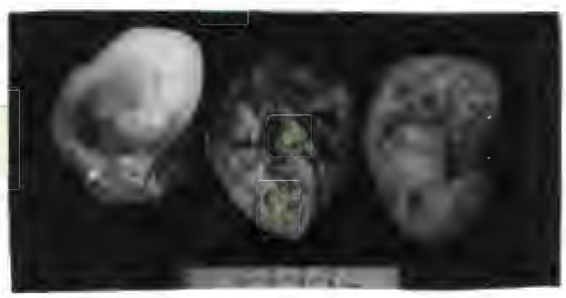
h) Marginella musica

i) Ancilla bullioides

a)

b)

c)



d)

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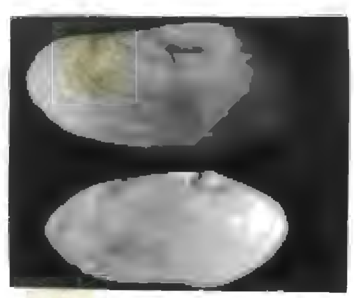
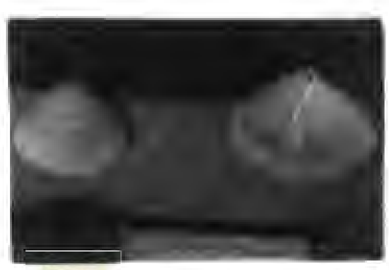


f)

g)

PLATE XII



h)

gravel horizons, perhaps because it is one of the few species that could survive the turbulent environment associated with gravel accumulation.

Shell fragments display a surprising degree of freshness in that they are little worn and have almost no overgrowths. The "shell horizon" is not always present but at times the amount of shell brought up by drilling operations indicate that shells must locally constitute some 60% at least (by volume) of the succession.

No species typical of the Upper raised beaches at C.D.M., such as Donax rogersi or Ostrea prismatica, have been noted from the present submarine sediments, but several species quoted by Krige (1927) as originating from the west coast raised beaches are found in the submarine sediments as well as:

Tapes corregatus
Patella compressa
Purpura squamosa

Solen and Purpura are quoted by Krige as being common in warmer waters.

Little significance can at present be attached to the presence of abundance of species because there appears to be so little known about the South African forms. Names have been changed and species have been reclassified and the author does not consider himself competent to undertake detailed studies of the multitude of shell types found.

c) Gravel.

The term "gravel" in local terminology covers the size range from granules to cobbles and includes four types distinguishable by textural characteristics:-

i) A well rounded, spherical, well sorted gravel which is rather distinctive. It is comprised of pebbles of vein quartz, jasperlites, agates, banded ironstones and epidosite, and is termed "terrace gravel" because of its superficial similarity to the material mined on the local raised beaches. This terrace gravel is most common in the southern half of the M.D.C. concession, especially between Chameis Bay and Dreimaster Bay, and represents rock types not found in situ along the shore. The pebbles are sometimes quite remarkably spherical. The agates tend to be dark blue-gray in colour with rather poorly developed banding.

ii) A sub-rounded gravel, consisting predominantly of quartzite, whose pebbles are moderately to poorly spherical. This gravel is widely distributed but always in small amounts. It is believed to be derived from local bedrock. Disseminated pebbles are found within the sediment but concentrations of gravel are always found on the bedrock.

iii) Bedrock rubble is characterized by its coarse-grained pebble and cobble constituents, it's angularity and proximity to bedrock, from which it is derived. This rubble represents the untransported bedrock fragments which have been locally accumulated.

iv) "Birdseed" is the local term for a well-sorted, well-rounded, very coarse sand about 2 mm in diameter. It occurs where the sediment is thin and has presumably accumulated under turbulent water conditions which have been responsible for its roundness and lack of finer matrix. Finely broken shell comprises a small percentage of its constituents.

Gravel is found scattered on the bedrock and is locally concentrated into bedrock irregularities. It also appears to occur in thin layers(of the order of 0.1 m thick) in clay accumulations, as reported by divers working from mining units. The most abundant gravel, however, is thought to lie on or near the surface of such clay deposits when these sediment types occur together. Full penetration of the clay is followed by angular, non-spherical cobbles of bedrock rubble in small quantities. Plate XVI illustrates the excellent degree of roundness and spherity sometimes observed.

d) Clay.

The term "clay" is used locally to describe compacted fine-grained material which is dredged up in lumps rather than as a suspension. Clay is described in terms of colour and three fairly distinctive types are recognized on this basis:-

i) A dark green-blue-gray suite which is of undoubted marine origin as it contains small (juvenile) marine shells and Foraminifera of Recent aspect. It often has a finely laminated texture and exudes a hydrogen sulphide odour, probably derived from decomposed organic matter. It is usually penetrated with comparative ease by the "Rockeater's" drill.

ii) An olive green to reddish brown suite which contains traces of plant remains and possibly terrestrial molluscs. Coupled with limited distribution, these factors suggest the suite to be of terrestrial or at least brackish-water origin. The suite is typically accompanied by an angular quartz grit (2 mm to 10 mm in size range), an assocation analogous to outwash deposits frequently found overlying the C.D.M. raised beaches. Red and black equivalents have been noted in one of the offshore sediment lenses near Bogenfels.

iii) A yellowish-brown clay which is seldom penetrated for more than a metre is interpreted as decomposed bedrock. It is similar to the decomposed schist bedrock which is seen on land to weather to a yellowish-brown to white kaolinitic clay.

No detailed chemical analyses have been done on these so-called clays because of the lack of suitable samples at the time the laboratory work was done. The five small samples mechanically analysed for size distribution (see end Table I) yielded mean sizes of between 5 and 6 Ø, so that these marine clay specimens should be, on this basis, termed compacted silts.

PLATE XVI

Distinctive pebble shapes

a) Well rounded pebbles of distinctly cylindrical shape, known as "rollers". They consist predominantly of quartzite.

b) Rounded pebbles which are discoidal in shape. Many quartzites have this shape where they are found forming shingle beaches. The schistose (bedrock) varieties are also numerous.

c) Well rounded, spherical pebbles of agate and jasper. These "foreign" pebble types are characteristic of the terrace-type gravels mentioned in the text.

a)

b)

c)

PLATE XVI

Clay is found as relatively thick bodies of sediment and as thin horizons overlying bedrock; more specific examples will be given later.

e) Calcareous sandstone and conglomerate.

Calcareous sandstone and conglomerate (including coquina) are found as remnants of a formerly extensive deposit covering the bedrock, although they occur in places as a thin bed (less than half a metre thick) separating bodies of unconsolidated gravel. The conglomerate contains rounded pebbles and granules similar to the "terrace" gravel described above, together with broken shell fragments and sand, whereas the sandstone is little more than cemented shell and sand. Plate XVII and XVIII endeavour to illustrate some of the forms of sandstone and conglomerate found. Because marine carbonate rocks have received a fair amount of attention from other workers, investigations were instituted to provide more information on the samples at hand.

i) Staining techniques were carried out according to the procedure described by Friedman (1959) on chips or slices where this was possible. Friedman's methods of using a few dyes on etched specimens allows fairly confident results after testing to obtain the optimum reactions. The typical marine sandstones and conglomerates were shown to be cemented by high magnesiam calcite with some low-magnesian calcite: high magnesian calcite is defined by Friedman (1964) as having more than 4% $MgCO_3$ in solid solution, although in Friedman's example 10% to 12% seemed common. The crystal structure of high-magnesian calcite is not stable. Auxiliary tests done using an alternative scheme of Friedman's (namely Titan Yellow dye) proved that some low-magnesian calcite was also present: no doubt most of the principal tests would show some degree of positive reaction, but those for high magnesian calcite were very strong. It is recorded that little aragonite was noted, except for some of the shell fragments: in view of this poor reaction by the shells the staining technique may be suspect for this mineral.

It was suggested that the sandstone/conglomerate may represent beach rock. Beach rock is defined by Ginsburg (1953) as being beach material which is cemented by calcium carbonate and occurs, often discontinuously, in the intertidal zone as a series of thin beds dipping seaward at less than 15° and striking parallel to the shore. The surface is often pitted and worn to form "stonelace". Ginsburg maintained that beach rock is limited to latitudes of coral growth. Beach rock can thus consist of any material capable of forming a beach, although shelly sand and skeletal debris seem to be the most common constituents mentioned in literature. Because of the accent on the association of beach rock and beaches, an attempt was made to determine if this littoral (or some other) environment had been instrumental in the formation of the local, basal calcareous lithological units by making use of the electron microscope.

a)

b)

c)

PLATE XVI

PLATE XVII

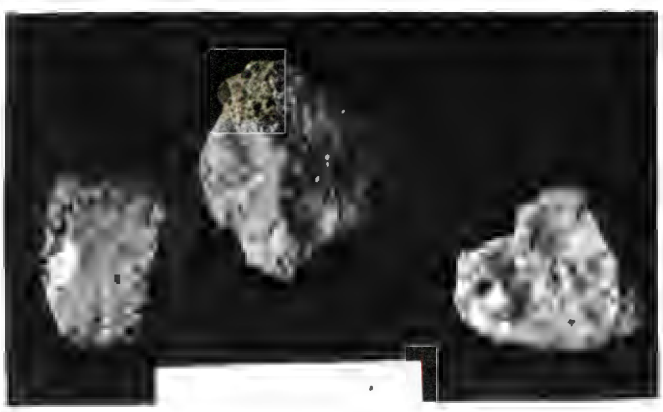
Examples of calcareous sandstone

a) A compacted shelly grit, the valves showing preferred orientation (bedding) habit. Small pebbles are also visible in the sandy matrix.

b) A cemented shelly sandstone composed of a greyish quartz sand with occasional pebbles and shell fragments cemented by carbonate.

c) Sandy, bedded and shelly grit.

a)



b)

c)

PLATE XVII

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b) A cemented shelly sandstone composed of a greyish quartz sand with occasional pebbles and shell fragments cemented by carbonate.

c) Sandy, bedded and shelly grit.

PLATE XVIII

Shelly conglomerate and sandstone

a) Section through pebble conglomerate encrusting an older, hard and shelly mudstone.

b) Quartz breccia cemented by quartz.

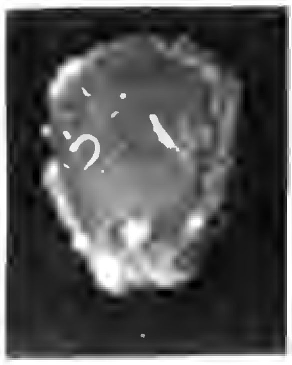
c) Conglomerate comprised of well rounded and well sorted pebbles including agates.

d) Well consolidated, coarse-grained sandstone with a white (calcite) cement.

e) Reverse of specimen in a) showing the pebble encrustation.

f) A hard, coarse-grained sandstone with a shell-fragment clearly visible.

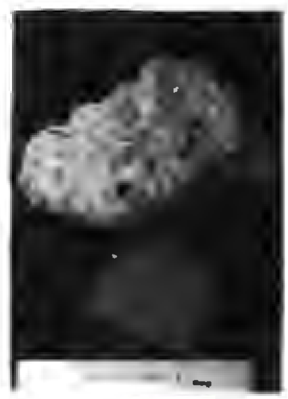
g) A medium grained sandstone. The upper fragment exhibited what appeared to be a weathered surface.



a)

b)

c)



d)

e)

f)

g)

PLATE XVIII

ii) The <u>electron microscope</u> was evidently first used as a tool to examine the surface texture of individual sand (quartz) grains in the early nineteen sixties, for example by Biedermann (1962) and Krinsley and Takahashi (1962). They described the imprint of certain environments on the surface markings of quartz grains, although Porter (1962) stressed the relationship between particle size and frequency of pattern occurrence. The technique involves examining a replica of cleaned quartz grains which is pervious to an electron beam. The procedure followed is that outlined by Krinsley and Takahashi (1964), and I am grateful to Mr. Bowie for the benefit of his experience in the practical aspects. Sand grains of more than 0.25 mm were pressed into clear X-ray film which had been softened with acetone. After carefully removing the grains, which were cleaned by alternately boiling in concentrated nitric acid, distilled water and hydrochloric acid for half an hour at a time, the impressions were shadowed at 45° with platinum alloy under vacuum, followed by the evaporation of carbon onto the film. The platinum-carbon films were thinner (50Å) than the ideal thickness (100-150Å) and were very fragile as a result. The plastic base was dissolved with acetone and the minute replicas mounted on fine copper mesh screens and inserted into an A.E.I. model EM3A electron microscope for scanning and photographing. Messrs. L.G. Fowles and P.A. Back of the Physics Dept., University of Cape Town, most patiently operated the microscope and processed the photographs.

The results were not entirely satisfactory. Grains taken from known beach and aeolian environments showed typical surface markings, namely triangular pits and meadering ridges and arcs, but the images of the sandstones were either generally featureless or possessed undiagnostic markings. Flat, featureless surfaces with occasional identations or curved lines are interpreted by Krinsley and Donahue (1958) as diagenetic features. A few triangular pits were observed (Plate XIX(a), so that it is probable that surf acted on the grains but the effects have been largely eliminated by subsequent cementation by carbonate. Repeated attempts to obtain satisfactory results produced no improvement. Plate XIX(b) is typical of the indifferent results.

The standard polarizing microscope was used to examine three slides of "typical" sandstone from the M.D.C. concession: other specimens were either too small or fragile to prepare satisfactory slides, and two other "interesting" specimens proved to be quartzite! The specimens exhibit clastic testure with grains about 0.3 to 0.4 mm in diameter floating in a finely crystalline micrite cement of carbonate. The grains tended to be rounded but also exhibited corroded contacts, which might explain the lack of meaningful electron microscope images. The average size of the largest grains varied from 0.6 to 1.5 mm in the specimens examined. The grains are moderately to well sorted and are comprised of some 55% quartz, 10% rock fragments, 15% diopside/augite, 10% felspar and 10% accessory minerals such as opaque ore and hornblende/biotite. In one case it was noted the the dioside(?) was well-rounded: it was not possible to positively

PLATE XIX

Electronmicrographs

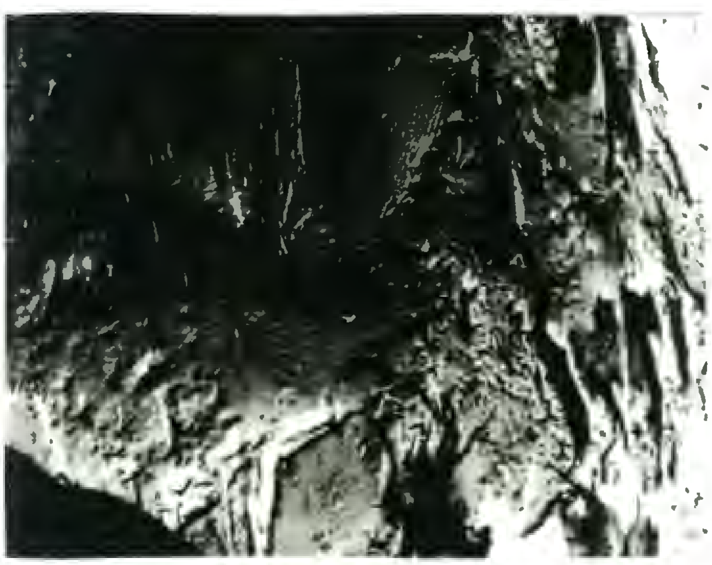
a) Photo of the image produced under the electron microscope of the surface of a grain of sand. Specimen from that illustrated in Plate XVIII e.
Magnification : 5400 X

Black spots and smudges are undissolved fragments of the plastic film used for replication.
Acute-angled pits can be observed.

b) Electronmicrograph of the specimen illustrated in Plate XVIII f)
Magnification : 5000 X

The illustration has an indeterminate pattern, more typical of the results actually achieved.

a)



b)

PLATE XIX

identify the clinopyroxene. No shell fragments were observed under the microscope as they appear to have been destroyed during preparation of the slide. In two of the slides a poor degree of dimensional orientation was noted. The specimens were classified as lithic arenites, with one specimen possibly an arkosic arenite.

The presence of clinopyroxene in significant amounts is rather surprising, for Pettijohn (1941) lists both augite and diopside as being of low persistence. In addition, the relatively well sorted and rounded nature of the grains suggests a texturally mature sediment, so that the clinopyroxene (and possibly felspar) appear to be of local origin, but little else can be inferred from three isolated samples.

iii) Discussion. There has recently been a wide divergence of opinion concerning the origin of beach rock and its cement. Ginsburg (1953) favoured cement formation by the direct precipitation of carbonate from interstital sea water, whereas Russel (1957, 1962) suggested that precipitation from groundwater charged with carbonate was responsible. Friedman (1964, 1965) recognized that there were three principal cements in carbonate submarine rocks, namely: low magnesian calcite, high magnesian calcite and aragonite. High magnesian calcite is the most stable cement in shallow water sediments, whereas in deep water sediments low magnesian calcite is the most stable form. However, Fischer and Garrison (1967) were among the first to appreciate that calcite, particularly as the high magnesian form, can be precipitated directly from sea water and lithify sediments at depths between 200 m and 3 500 m - the reason or precise mechanism being uncertain. This theory inferred that a replacement origin for cement was not obligatory. Shinn (1969), Taylor and Illing (1969) and Alexandersson (1969) have all concluded that high magnesian calcite and aragonite precipitate directly from sea water under largely unknown conditions, (organisms are thought to be required), but high magnesian calcite can also replace aragonite. This process can occur below water level as evidenced by units a few centimetres thick in, and separated by, unconsolidated sediment (Taylor and Illing, 1969). It is clear that more work is needed to explain the mechanisms and conditions under which these cementing processes occur and whether beach rock is an extension of these or whether it represents a completely different regime.

Divers working on the sea bottom off the west coast confirm that the local submarine sandstone may cover unconsolidated sediments: roofs of sandstone have been observed spanning shallow gullies (R. Foster, personal communication), and in one instance a diver located unconsolidated gravel below a sheet of sandstone that had been penetrated by prospecting equipment (B. Blatchford, personal communication).

Calcareous sandstone and conglomerate are common basal members of the raised beach succession between Oranjemund and Affenrucken (at least). Lenses of relatively small dimensions (say 1 cm thick and 3 m long) occur in compact sand and towards true bedrock the sandstone becomes massif and includes pebbles, cobbles and shell fragments. Molluscs appear to have provided at least some of the cementing agents as they are commonly observed to be partially or wholly dissolved, but little detailed work has been done on this subject.

As regards the submarine succession, it has rarely been possible to distinguish between the true (Precambrian) bedrock and the sandstone horizons by the geophysical methods that have been used.

III. GENERAL CONSTITUTION OF THE INSHORE SUBMARINE SEDIMENT.

A general outline of the submarine sediment's constitution as deduced from reconnaissance prospecting is presented below. By the nature of these operations only the thinner sediment is usually penetrated (less than about 7 m or 8 m), so that the picture is limited accordingly. In further sections two small areas will be described in detail.

a) S.D.C.

Directly offshore of the Olifants River mouth (Map 1), seawards of the sediment-free bedrock outcrops, the sediment consists of a semi-compacted green mud (best described a "sludge") with dispersed shell. Inshore and just north of the mouth shell fragments are common and patches of subangular gravel and subrounded pebbles are irregularly scattered on the bedrock. The sediment tongue northwest of beacon Dons consists mostly of dark silty sand with greyish clay developing in deeper water. By way of contrast, the area inshore of the sediment-free bedrock and just to the south of Cliff Point, has abundant shell and a basal gravel which is comprised mostly of rounded quartz pebbles and some angular bedrock fragments.

Further up the coast beyond beacon Christine and towards beacon Val, yellow sand containing blue mussel shells overlies a well sorted and well rounded quartz and quartzite pebble and cobble gravel which in turn covers a distinctive tough white clay - thought to be the weathered equivalent of the underlying granitic bedrock. Off beacon Val itself and north of it the proportion of shell increases significantly whereas the gravel thins out. Coarse "birdseed" sand is a common constituent of the thinner sediment. The edge of the main sediment body diverges from the coast and the sediment thickens rapidly offshore; little information is available until Island Point. A line of holes was, however, drilled in the inshore sediment patch off the Sout River. They successively penetrated sand with plentiful shell, angular quartzitic gravel and 2 m of clay to bottom on calcareous sandstone and/or weathered schist.

The inshore sediment patches immediately south of Island Point have the familiar green silty sand with shell and a moderate amount of subangular bedrock rubble deposited on remnants of calcareous sandstone. Off the Groen River mouth a mixture of 2 m to 4 m of dark brown sandy clay and subangular gravel was recorded. Seawards the percentage of yellowish brown sand increases giving way in turn to gravelly shell and dark coloured fine sand. Little is known about the sediment until the Spoeg River (Map 2): the sediment off the mouth (mainly mixed shell and subangular gravel) covers a soft white sandstone or a hard, dry, sandy silt. The shallow water sediment patch off beacon Show has little gravel but thin clay horizons and lenses of birdseed were noted at the base of the sulphurous, smelly sand. The sediment tongue which trends inshore at beacon Eifel carries a coarse (cobble) gravel with rounded fragments of calcareous sandstone. The tongue off Kommagapunt on the other hand is predominantly silty shell with traces of gravel under the thicker sediment and birdseed in the thin sediments in shallower water. There is another gap in the records until the channel-like feature off beacon Lost which, like the one off Eifel, has a basal quartzitic gravel with rounded, bedrock-derived pebbles; again drill holes often bottomed on calcareous sandstone. North of beacon Lost, past Melkbospunt and beacon Flags, both the inshore sediment ponds and the main offshore deposit consist principally of shelly sand carrying a large proportion of shell and only occasionally clay and pebbles. Several holes were drilled off the Buffels River mouth; shell and subangular to subrounded gravel are abundant on the northern side of the sediment body but are apparently sparse in the middle and southern portions. The gravel thins and becomes finer grained northwards, but gullies inshore that were dredged also yielded gravel.

The sediment tongue off Penguin Rock contains no gravel and as far as beacon Cuba (Map 3) the succession consists of silty sand and shell although thick clay was detected off beacon Cuba itself. The surface of the sediment is evidently quite well compacted in this area as "Rockeater's" drill had difficulty in penetrating the surface. The shelly sand body, which has a distinct odour of hydrogen sulphide, persists with little change at least as far as Port Nolloth, at which point the coast line and offshore sediment body diverge.

Patches of sediment inshore and off Cliff Point (Map 3) have angular bedrock fragments overlain by thick (2 m) clay: again a false calcareous sandstone bedrock was often noted. In this area balls of greenish-brown compacted sandy silt which have an internal concentric ring structure were recovered; they evidently represent eroded remains of thinly bedded silts. A narrow sediment patch extending seawards from the Holgat River mouth has interbedded clay and angular gravel which thins and pinches out to the west. To the south of Wreck Point the inshore sediment ponds have sand covering a thin horizon of shelly, angular gravel whereas just north of the Point rounded gravel is an additional constituent. Hard green clay is found under the thicker inshore sediment. Off beacon Krisjan relatively large volumes of subangular gravel are present and the clay thickens inshore.

The large inshore sediment patch which trends east-west between Harrison Cove and Homewood Harbour has a large proportion of shell and a hard, greenish and musty smelling clay in the southern portion. Coarse angular gravel and schist rubble are present near the coastline but pinch out to the north and west to yield a succession of silty sand with copious shell and minor basal clay. The inshore sediment north of Cape Voltas reflects the proximity of the Orange River mouth as the sediment is brown, finer grained and contains little shell. Terrace type (well rounded) gravel was extracted from some drill holes and is apparently interbedded with brown mud. Green clay was noted well inshore.

b) M.D.C.

The holes drilled in shallower water and just north of the Orange River mouth (Map 4) did not reach bedrock but simply penetrated up to 22 ft. (7 m) of dark sand with sparse shell and fragments of twigs and other organic remains. Just to the north of beacon Uubvley and off beacon M66 the principal sediment constituent was clay (i.e. compacted silt). The surface of the clay is only 2 m to 3 m below the sediment surface and the clay becomes harder with increasing hole depth.

Occasionally calcareous sandstone bedrock is encountered and patches of both angular and well rounded gravel are present. The clay thickens offshore: shell like Tapes corragatus and bleached Mytilus meridionalis are typical of the species present just above bedrock.

The inshore deposit off beacon S44 has moderate amounts of sub-to well-rounded gravel. Calcareous sandstone is very common but soft brownish siltstone with angular white quartz grit is also present. The bedrock surface is particularly uneven in this area, the deeper holes being characterized by a rush of gravel, which suggests the presence of gullies and potholes beneath the sediment. From this point the deposit trends seawards and has not been sampled in detail. From the meagre data reported from the Emerson K prospecting logs the deposit invariably consists of silt and shell, grading to a fine gravel of subrounded schist, quartzite, agate and sandstone pebbles. Holes were bottomed on a sandy and greyish coloured compacted silt. Even further north off beacon Bay, a succession of shelly and silty sand, soft greenish clay and fine subrounded gravel overlies a tenaceous and impenetrable grey coloured clay.

Chameis Bay marks the southern end of the persistent inshore sediment lens. In the far south off beacon SC7 thick green marine clay is present, pinching out southwards in the vicinity of the headland north of beacon Bay and being replaced by a birdseed gravel and thick shell beds. From beacon SC 9 northwards the sediment consists of the inevitable shelly sand followed by varying amounts of gravel, frequently very well rounded and often overlying green clay. Patches of calcareous sandstone and conglomerate are common. Along the seaward edge of the sediment lens the gravel thins out and gives way to birdseed and coarse sand. The bedrock topography is in the form of (roughly) north/south trending ridges separate by shallow sediment-filled valleys.

The lens narrows towards beacon Dunkel: little clay is present but this area is characterized by an abundance of basal, rounded gravel with a relatively large proportion of cobbles and large pebbles in coarse sand. Oyster shells are common and occur in the gravel bed. In the north towards Sinclair Island (Map 5) the gravel is sparse and consists of a minor rounded fraction mixed with angular bedrock rubble. The bulk of the sediment consists simply of shelly sand with birdseed located opposite the headlands of Durnberg and Vohsen. The pattern of sediment-filled valleys persists further along the coast. In the vicinity of beacon Drei, silt and shelly sand overlies birdseed inshore but seawards an easily dredged, basal rounded gravel is present in which angular white quartz chips reveal the proximity of bedrock. Little clay is present in Dreimaster Bay itself, nor is the calcareous false bedrock common; possibly the gravel present has played a role in eroding the sandstone during deposition thereby contributing to the coarse sand present in the vicinity. A few holes drilled in the deep water sediment lens offshore yielded 2 m to 3 m of clay, with subrounded to angular bedrock pebbles and cobbles scattered on fine grained calcareous sandstone.

North of Dreimaster Bay the sediment thickens inshore and there is a general paucity of gravel and clay. Scattered angular gravel is overlain by a thick deposit of silt and dispersed shell. Holes which touched sediment-free bedrock often showed the schist bedrock to be corroded to yellowish or gray clay. This uninteresting succession continues at least as far as beacon Pomona. Clay is present again in Jammer Bay and is about 5 m thick in places between Albatross Rock and the shoreline off beacon Wales. Between the Prince of Wales Bay and Elizabeth Bay the sediment is excessively thick: from the holes drilled, silty sand containing an appreciable proportion of shell appears to comprise (at least) the upper portion of the deposit, giving way to clay at depths of 5 m to 6 m.

The inshore sediment lens effectively terminates at Elizabeth Bay. The narrow offshoot off beacon Hoffie is virtually a shell bank with minor subrounded gravel present in the thinner sediment off beacon Wolf in the north.

The few sediment ponds located inshore towards Luderitz are essentially fine shelly sands with a few pebbles scattered on the bedrock. Wolf Bay and Big Bay presumably have gravel deposits as they were actively sampled by shallow-draft vessels some ten years ago.

c) T.D.C.

The first information avilable north of Luderitz refers to Hottentot Bay (Map 6) at the southern boundary of the T.D.C. The Bay is north facing embayment with thick sediment along the shoreline and in the southern part of the bay. Clay is present in the southern and easterly sections, but seawards and northwards it thins and gives way to subangular gravel and shell. The sub-bottom is characterized by a grey to faint pinkish sandstone which is partly gypsiferous (see detailed description following). The northern extension of the bay, off beacon Gibralter, is characterized by thick sediment-predominantly shell-rich silty sand covering traces of rubble. The holes drilled in the principal offshore deposit in 30 m of water off Gibralter penetrated 1 m of fine sand followed by over 6 m of olive-green clay. As the sediment body narrows inshore the standard column of sandy shell with sub-rounded basal gravel overlying sandstone false bedrock was recorded. Just south of beacon Saddle Hill South, shelly gravel is present in the thinner sediment but only 100 m from the zero isopach the volume of shell and the thickness of clay increase sharply. A line off beacon Clara confirmed that the sand-shell-clay-bedrock succession persists. Northwards from beacon Clara is a fairly regular inshore sediment lens, drilled at 3 to 5 km intervals. There is little gravel present off beacon Pan but seaward of Mercury Island and its submarine extension the gravelly basal shell bed in the east grades seawards to a closely packed angular rubble containing occasional rounded quartz pebbles, whereas in the thinner sediment further westwards shell and birdseed become the predominant sediment types. Beyond Spencer Bay the inshore sediment lens reverts to the shelly sand-basal pebble succession, but birdseed is notably absent from the thinner sediment along the western edge of lens. Sandstone is common between the beacons Wreck and Shelf. A line drilled midway between beacons Knoll and Black Cliff in thick sediment penetrated 3 m of silty sand shell, 2 m of gravel and angular pebbles, and then up to 2 m of clay. A few holes bottomed angular pebbles, and then up to 2 m of clay. Occasionaly holes bottomed on calcareous sandstone under the clay. The inshore sediment lens terminates as a pool of sediment off Black Cliff beacon: this pool has a basal clay layer containing rounded pebbles of quartz, rock fragments and a few agates, which overlies the bedrock or sandstone. From Easter Point the sediment boundary lies away from the coastline, gradually closing to the identation known as St. Francis Bay. Immediately north of the Easter Point sand and sparse gravel overlie about a half a metre of loosely consolidated sandstone, in turn covering about a metre of shelly mud which overlies the bedrock. Off beacon Sylvia the sandstone is about 1 m thick and rests directly the bedrock. Little clay is present, which leads one to speculate that the Acoustical Blanking Layer detected in this region may be represented by sandstone. In the region of the beacon St. Francis (Map 7) some 3 m of sub-angular gravel is mixed with shell and calcareous sandstone is again common. The gravel thins until about 4 km northwards it is represented by a few pebbles only, and from here the incidence of sandstone becomes less common. The shelly sand continues beyond beacon Black Rocks. To the north of beacon White Patch a sediment tongue is placed well inshore and copious coarse gravel was extracted from this depression as well as large *Ostrea* shells, which are fairly common in the whole area between beacons Sylvia and Meob. Little gravel is present off beacon Meob South, but holes penetrated a soft shelly clay to bottom on a hard bedded dry clay, possibly a fine grained sandstone, and it can be observed that the Acoustical Blanking Layer sweeps close inshore in this area. The hard grey-green clay often lies only 0.3 m below the sediment surface all along the inshore edge of the sediment body off beacon Beach and was frequently penetrated for 3 m or 4 m by the drill bit; the A.B.L. however apparently lies much further seaward. *Ostrea* shells continue to be common constituents of the otherwise sparse shell fraction. Lime sand and shells form the bulk of the sediment where it abuts against the Hollams Bird Island submarine ridge, but pebbles and clay are present in the thicker sediment which lies inshore.

The area between beacons South rocks and Mutzel is known as Meob Bay and it is interesting in that strong evidence of subaerial exposure was recovered in the form of desert rose, delicate intergrown crystals of gypsum, which are fairly common in the pans and lagoons along the coast. The form of the submarine topography suggests that the bay was probably a well protected north facing coastal indentation during times of lower sea level. Sediments in the bay include basal angular gravel and dark-coloured sulphurous mud and gypsiferous sandstone.

Little sampling in the form of drilling has been done between Meob and Conception Bays because of the prohibitively thick sediment inshore.

Northwards from Conception Bay is an area of sediment-free bedrock adjacent to the coastline and from which the sediment thickens rapidly seawards. Several lines were drilled between beacons 99 and the northern boundary of the concession. Holes drilled in the thin sediment (less than 1 metre) encountered abundant shell and gravel, but those drilled in thicker sediment revealed the sediment to be fine grained only (i.e. silt or clay). The compacted silt does contain a large proportion of shell and judging from the organic remains and offensive odour represents a reducing or anaerobic environment. The sediment is so soft and fine on the surface that great difficulty was experienced in anchoring the vessel: the anchors were simply drawn home when attempting to winch between drill holes. Map 7 shows that from Meob Bay northwards the A.B.L. lies close inshore and masks virtually all detail of the true sediment thickness.

Attempts to decide why certain sediment types occur in some areas and not in others are probably not feasible at this stage. In the following pages details are given of the sediment distribution in two restricted areas which will throw more light on the problem.

CHAPTER V: THE SUBMARINE GEOLOGY OF TWO AREAS

1. THE PLUMPUDDING ISLAND DEPOSIT:

a) Introduction.

The area lying immediately to the north of Plumpudding Island is known locally as the Plumpudding Island deposit. It lies roughly midway between Luderitz and the Orange River mouth (see Map 5). The area has been sampled in fair detail by the m.v. "Rockeater" - nearly 2 000 holes were drilled along lines spaced at 100 metre intervals across the inshore section of the deposit.

b) General bedrock topography.

Map 8A illustrates the relationship between the sediment and the bedrock topography. The map was compiled by the marine section of the geology department of C.D.M. from acoustic profiling records produced by the Pinger geophysical equipment. It should be noted that by local convention, the submarine bedrock contours, which are synonymous with the term isobaths in sediment-free areas, are referred to as "elevations" below the mean sea level. Water depths in areas covered by sediment may be inferred by subtracting the sediment thickness (isopach) from the bedrock elevation values.

The area is characterized by a group of bedrock ridges (topographic highs) which strike northwest-southeast and have a relief of between six and ten metres. Two major sets of ridges are present in the area illustrated: one is manifested ashore by the rocky headland (False Plumpudding) adjacent to the north arrow, and the other set of ridges lies seawards of the inshore deposit and is associated with the area of reefs and blinders marked "foul ground" in the north. Along the inshore ridge the summits lie between -14 and -16 m as a rule, whereas along the offshore ridge the elevations occur between -22 and -24 m. The ridges tend to be steeper on their seaward sides, particularly in the case of the offshore ridge. Neither ridge persists across the whole length of the area illustrated; the inshore ridge flattens out to the south and the offshore ridge has been broached in the north . The existence of the ridges is probably due to the presence of rocks relatively more resistant to erosion than those in the intervening areas, a theory supported by observations from divers who noted a similar pattern in another area, where the ridges tended to be made up of quartzite and the intervening areas of schistose rocks.

The areas between the ridges are termed "valleys" for lack of a better word. The valleys are relatively wide and shallow but this impression masked slighly because of the overall gentle slope seawards. The very hollows are boat-shapea in that they narrow and close, but are invariably ed on the seaward (western) side. 1 valley floors do not have such well defined levels, but flat areas with elevations of between -36 and -38 m are common offshore, and elevations of -26 to -28 m generally mark a flat (low relief) area in the centre of the deposit. The whole question of ridges, valleys and cliffs is expanded in the section dealing specifically with submarine bedrock topography.

c) General sediment distribution.

As Map 8A illustrates, the deposit is broadly divided into an inshore lens and an elongated, offshore lens.

The inshore lens, which lies essentially between Plumpudding Island in the southeast and an area of foul ground in the north west, has an irregular outline across its width but has a more regular outline in a north south direction. The sediment thickens overall towards the shoreline to at least 6 metres, but seawards of the inshore ridge a slight thickening is evident before the sediment thins out completely. In the south and just offshore of the Island is a continuation of the sediment body; this has not been investigated in any detail.

The offshore lens is a relatively narrow body about 300 m wide and nearly 3½ km long. The sediment is between 2 m and 4 m thick with the thicker portions occupying shallow depressions in the bedrock. The bedrock contours show that this lens, as a unit, occupies a narrow valley and is banked up against the offshore ridge. To the north a more irregular body of sediment is also banked up against the foot of a relatively steeply sloping bedrock surface.

Between the inshore and offshore sediment lenses small, isolated ponds of sediment have built up against valley closures.

d) Detailed sediment distribution.

i) Gravel: Map 8B illustrates the distribution of gravel by volume. The contours were derived from the product of estimated gravel percentage and sediment volume as recorded for each drill hole. They therefore tend to reflect the "volume" of gravel present in the sediment rather than an estimated proportion. Anomolies occur where holes took longer to drill than those adjacent to them, but the data has been smoothed by the moving average method.

It is apparent that inshore the gravel becomes more abundant with thickening sediment. On the seaward side of the inshore bedrock ridge the gravel appears to be more common where the sediment is slightly thicker, [illegible]d in addition there is more gravel around the southern perimetres of bed[illegible] outcrops.

Semi- and well-rounded pebble gravel is common throughout the area and the two types usually tend to occur together. Well rounded gravel is, however, predominant inshore in the region off the north arrow and is especially plentiful north of that, off False Plumpudding headland. The gravel occurs as pebbles scattered on the bedrock and is seldom thicker than about a metre.

ii) False bedrock: The distribution of false bedrock is illustrated by Map 8C. The false bedrock consists basically of two lithological types - a sandstone and a yellow-brown clay, with gradations between the two types. The sandstone is brownish and yellow in colour and frequently occurs in a schistose ("platey") form with what looks like one eroded surface. The sandstone is evidently thin because quartzite schist bedrock was frequently interesected beneath the sandstone. Where the sandstone is thicker (than about 0.2 m) it often grades to a clayey sand, which suggests that the clay represents a mud fraction, weathered schist bedrock or both. Over the relatively small area for which information is available, there appears to be no pattern to the false bedrock distribution except that the patches tend to lie within the sediment body. No signs of large scale continuation across sediment-free bedrock was observed. Off False Plumpudding the apparent contact does, however, co-incide with the zero sediment isopach.

A coarse, white, semi-angular quartz grit was characteristically associated with the false bedrock in several areas, particularly in the southern inshore region. The grit is not limited to the occurrence of sandstone however, but may be found in the absence of false bedrock as well. It is postulated that the grit represents the weathered products of quartz veins which occur in the bedrock.

iii) Other sediment types: Shells, particularly mytilus and bullia species, are abundant wherever the sediment thins to about 1 metre, off the rocky headland in the north, and along the eastern margin of the inshore bedrock ridge.

Birdseed (coarse rounded sand) is relatively uncommon but was noted in some holes.

Green marine clay occurs in one small area within the inshore sediment body but forms a significant portion of elongate sediment lens offshore.

The Plumpudding Island deposit is a good example of the influence of bedrock topography on sedimentation. The profile X - X', Fig. 18, (location on May 8A) illustrates the manner in which the sediment has filled up hollows in the bedrock and is tending to produce a smoothly sloping submarine surface, the slope flattening seawards. The profile also illustrates the definite occurrence of coarse, gravelly sand above a silty-clay layer in the offshore sediment lens.

II. HOTTENTOT BAY.

a) Introduction.

Hottentot Bay is a relatively large, shallow water, north-facing bay situated approximately 65 km north of Luderitz at the southern end of the Tidal Diamonds Concession (see Map 6). The Bay has been sampled on a broader grid than the Plumpudding Island deposit as lines were mostly 66 m apart and the drill holes spaced at 30 m intervals.

Note that the Maps 9A and 9B are drawn at a scale of 1:20 000, half the scale for the Plumpudding deposit maps, so that the areas are thus twice as large by comparison.

b) General bedrock topography.

May 9A illustrates the area for which the detail is known. The map has been compiled by the author but is based on maps drawn up by the Geology Dept., C.D.M., from surveys done using the Sonoprobe and Pinger profiling systems.

The most prominent feature of the Bay is the headland of Hottentot Point. A sandy shoreline curves around to the south before swinging east and north. It is broken by rock outcrops near beacon Blue Mountain and at beacon Black Rock. The eastern side of the Bay has steep, dune covered slopes with occasional outcrops of the basement rocks. The southern shore of the bay marks the edge of a flat, low lying sandy plain suggestive of a tidal pan.

The submarine topography is dominated by an extension, striking northeast-southwest, of the bedrock ridge of which the Hottentot Point headland is the subaerial equivalent. To the northeast the bedrock emerges from beneath a thin sediment cover but is evidently covered again further inshore as rocks do not outcrop on the beach just north of Black Rock. The broad ridge of sediment-free bedrock has a very low relief, being less than 4 or 5 metres over an area of some 5 km^2. The whole bay is very flat, but we note that the slopes steepen on the western (seaward) side of the sub-outcrops. It is also noticeable that the whole area appears to be planed off to between -18 m and -24 m. The bedrock contours are rather irregular but tend to follow the general trend of the coastline in the south, whereas in the north (beyond Black Rock) they curve round to the west before swinging north again further offshore. A minor but interesting feature is found along an imaginary line joining beacons Black Rock and Hottentot Point. Almost a third of the distance from the Point is a small bedrock rise represented by the -18 contour. It is flanked by bedrock "lows" (of -22 m) and thicker sediments. About two-thirds of the distance along this imaginary line from the Point is another multiple topographic high-point also outlined by the -18 m contour. This seemingly minor feature has had a significant effect on the distribution of the sediment.

During interpretation of the geophysical records the bedrock reflection was sometimes very difficult to identify, particularly for the survey conducted in the south eastern section of the bay. This was attributed to the possible effect of a sandstone horizon known to be present in the area and consequently the exact positions and values of the contour lines are not certain in this region.

c) General sediment distribution.

The prominent sediment-free 'ridge' running northeast of Hottentot Point forms the western boundary of a large sediment body some 6 km long and over 2 km wide which swings northwest off beacon Black Rock to join the principal, thick offshore deposit about 3½ km away. It is thus convenient to speak of two sections, the Bay itself between Black Rock and the Point, and the sediment pond located northwest of Black Rock.

Within the Bay the sediment thickens slowly to the east and south, but because of the apparently flat bedrock surface the water shallows so that it is only 12 m deep some 2 km seaward of the coastline opposite beacon Blue Mountain. The isopachs strike northeast, however, so that towards Black Rock the sediment is relatively thin and the water deep by comparison. It is this thickening of the sediment combined with the shallow water that precluded detailed investigation in the southern and eastern portions of the Bay.

In the pond-like area northwest of Black Rock the sediment has filled the flat, shallow valley which is flanked by two submarine headlands and which then thickens to more than 8 m in the extreme northwest.

The sediment outline (zero isopach) tends to follow the general structural trend of the bedrock, the only anomalous section being the north eastern end of the bedrock ridge where the zero isopach cuts right across the general strike of the bedrock contours: the reason for this phenomenon is not too clear but may partly be accounted for by geophysical record interpretation which is particularly uncertain in areas of low relief and thin sediment cover (less than 1 m).

The thickening of the sediment in the southern portion of the Bay is not surprising when it is appreciated that the Hottentot Point headland forms a protection from the oceanic waves and swells and also that the prevailing southerly wind must carry sand across the pan in the south to be deposited in the Bay. The east wind, which blows fiercely during the winter months, must contribute an appreciable volume of sand to the Bay.

d) Detailed sediment distribution.

Map 9B illustrates the distribution of the three most important sediment types encountered: clay, gravel and sandstone.

i) Clay: Clay is limited virtually to the southern and eastern areas of the Bay. It was frequently intersected by the inshore ends of drill lines so that its exact distribution is uncertain. Minor patches of clay are also present in the thinner (less than 4 m) sediment northeast of Hottentot Point, but on the whole there appears to be no discernible relationship between the bedrock topography and clay distribution except to say that it tends to occur in a relatively protected environment and to be overlain by thick sediment.

The clay is dark green to brownish in colour and represents a compacted silty sand, in fact it is sometimes difficult to distinguish from the finer sandstone recorded as false bedrock.

The thick sediment of the main offshore deposit in the northwest corner of the map has a hard, relatively thick (some 2 m) horizon of gray clay located 5 or 6 m below the sediment surface. Its precise distribution is unknown because of the sparse drill data.

ii) Gravel: The predominant gravel type is an angular to subangular pebble to cobble-sized rubble consisting of local and false bedrock fragments. The hard-rock fragments are a mixture of quartzite, gneiss and schist and exhibit a low degree of sphericity. The gravel is widespread but only those areas where it can be described as being abundant (approximately 0.4 m or more thick) are shaded. Subrounded pebbles and a few well-rounded quartz pebbles are also present in smaller quantities, but apart from one locality it is not possible to delimit or adequately define it's distribution. The one locality is the northern flank of the slight bedrock elevation 2½ km southwest of beacon Black Rock. Only three holes were noted as yielding well-rounded, spherical pebbles of terrace gravel; these holes fall within the gravel patch located in the far west off beacon Blue Mountain.

Gravel in general is most common in the central and eastern portions of the Bay and is located above the clay or bedrock, when these are present. Gravel also occurs in thin sediment off beacon Black Rock and also in the thickening sediment in the extreme northwest, but gravel is conspicuously absent in the northern sediment pond.

iii) False bedrock (sandstone): Calcareous sandstone is very common in Hottentot Bay, particularly in the northern and western sections. The distribution of sandstone on the otherwise sediment-free bedrock is unknown, but drilling shows that beneath unconsolidated sediment it can occur between elevations of -12 m and -30 m at least.

The sandstone varies somewhat in character but may be described as a greyish to pale green or brownish coarse-grained friable sandstone. In places it is conglomeritic with subrounded to subangular pebbles set in a matrix of felspathic, shelly sand. A few small samples showed that gypsum and dolomite are prominent cementing agents with calcite also present. Locally, the sandstone has partly altered to a greyish-white clay. The sandstone was usually imprenetrable and could not always be defined on the geophysical records.

iv) Other sediment types: Shell is present throughout the sediment-covered area in minor quantities. It was noticed that *Cultellus cellecidus* was predominant in the upper sediment whereas *Lutraria capensis* favoured the basal sediment. *Tellina* and *Tapes* were also common species.

Birdseed in its usual form appears to be absent in Hottentot Bay but coarse sand is present in the thinner sediment.

Hottentot Bay is rather different from regions in the M.D.C. in that it lacks a strongly developed bedrock topography with accompanying rapid facies changes. To summarize, it can be said that Hottentot Bay is characterized by the large areas of relatively thin sediment and the low relief of the bedrock over wide areas.

CHAPTER VI. BEDROCK MORPHOLOGY

Detailed geophysical surveys and physical sampling have been concentrated over sediment-covered areas and information on the bedrock morphology is therefore largely limited to small areas of incidental or supplementary coverage in the M.D.C. concession. Several features are nevertheless presented as examples of submarine bedrock morphology and, for convenience, are divided into "regional" features such as drowned river channels and "local" features such as gullies, platforms and cliffs.

I. DROWNED RIVER CHANNELS:

Sub-bottom acoustic surveys reveal that features which can be interpreted as drowned river channels occur not only off mouths of such streams (in the S.D.C.) as the Groen, Swartlintjies and Holgat Rivers, but also in Elizabeth Bay and off the Orange River. A possible channel is also present in the vicinity of the Buffels River mouth.

a) Elizabeth Bay.

Elizabeth Bay lies some 40 km south of Luderitz (see Map 5). "Sparker" geophysical traverses showed that a slightly sinuous submarine channel feature had been cut into the bedrock across the bay and had subsequently been filled and largely covered by thick (up to 50 m) sediments. The channel, illustrated by Fig. 19, is thought to be the seaward extension of the "fossil" Kaukausib River whose present drainage course is out of proportion to present-day precipitation and run-off. The precise location of the site where the old river course crossed the coastline is not obvious from aerial photographs but the form of the bedrock contours suggests that it flowed to the sea opposite Possession Island. There is a large pan adjacent to the shore on the northern side of the Bay, representing an infilled section of one of the prominent north-south valleys characteristic of the coastal area between Chameis Bay and Elizabeth Bay (inland). The southern extension of this valley is also represented by a submarine depression of the bedrock which links up with the old river channel and may well have acted as a tributary drainage course.

Fig. 19 was constructed by the author from the "Sparker" records available. Many of the records are of indifferent quality and combined with the relatively thick sediment present over most of the area, rendered interpretation difficult, particularly with respect to the precise paths of the bedrock contours in the centre of the channel. The area was relatively well covered by the survey as some twelve traverse legs crossed the area portrayed, but coverage is poor offshore for depths exceeding 100 m. To avoid confusion, isopachs other than the zero value have been omitted and bedrock contours are shown at ten metre intervals.

The channel extends some 12 km WSW approximately normal to the coastline and it is of the order of 1 km wide, varying between about 0.7 km

Fig. 19
DROWNED RIVER CHANNEL
ELIZABETH BAY

and 2 km in width. The floor of the channel has been cut some 40 to 50 m into the bedrock during times of lowered sea level to an apparent base level of some 120 m to 130 m below present sea level. Unfortunately only one survey traverse passed over the deepest part of the channel and -130 m bedrock contour is largely a figment of style where it forms a re-entrant curve in the channel. In the western half of the channel it appears that the northern flank has a steeper slope than the southern, being 1 in 5 which represents a dip of 11° to 15° at its steepest (see profile 3 of Fig. 21(a). The floor of the channel slopes at less than half a degree along its length (about 50 m over 8 km), which suggests that the stream was fairly well graded. The channel widens at its mouth, the northern bank extending further seawards than the southern bank: a small stack of resistant rock stands at the former mouth.

Of interest are the areas of flatter bedrock adjacent to the channel at -30 m and between -50 and -60 m, as well as a flattening about -20 m between Possession Island and the coastline. Originally the channel was interpreted (by Ocean Science personnel) as containing Intermediate Sediment. The author certainly recognizes the presence of definite bedding but would hesitate to describe some or all of these as Intermediate Sediment without further evidence.

b) <u>The Orange River Channel</u>.

Fig. 20 is a map showing the surmised form of the sub-marine extension of the Orange River. The figure was constructed by the author from a detailed map of the sediment thickness which was compiled in turn by earlier workers. The original "Sparker" records were no longer available for direct interpretation so that the bedrock depths were computed by adding the sediment thickness to the interpolated water depth at the same locality. The subsurface information on shore was obtained from holes which had been drilled in the area.

A striking point is the fact that the present mouth of the Orange River does not co-incide with the submarine channel, which indicates that the river has changed its course since the last fall in sea level. This channel is the only major submarine channel that has been discovered in the region although excavations on land suggest that the Orange River has shifted its mouth at least 3 km southward during its history.

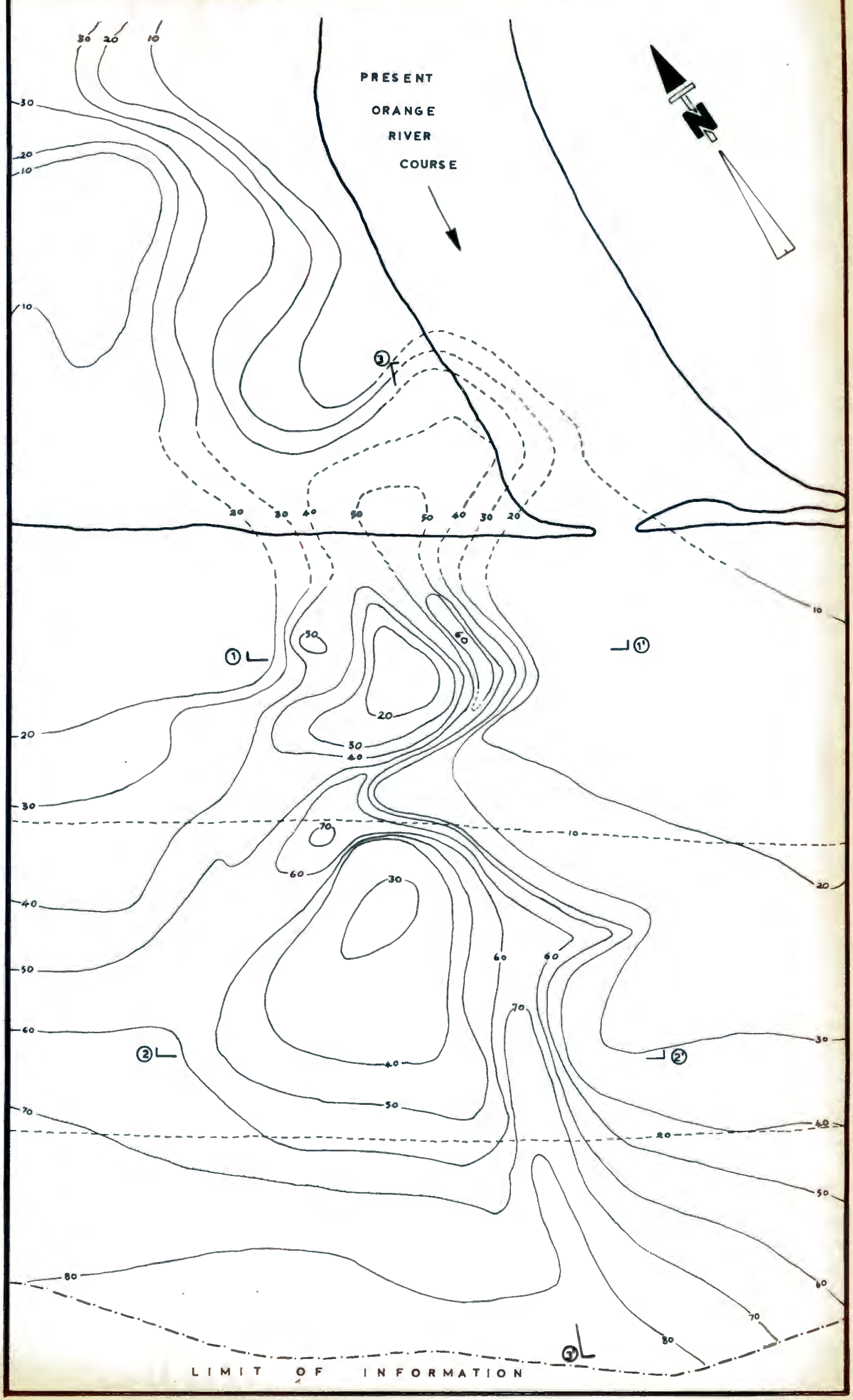
The channel extends an indefinite distance seawards: excessively thick sediment and the presence of the Acoustical Blanking Layer mask its path beyond an elevation of -80 m. Several elongated depressions in the channel suggest possible alternative courses were followed, as shown for example by profile 1 of Fig. 21(b). One such subsidiary channel lies northeast of the most prominant channel, which itself has been cut some 40 m into bedrock. The banks of the main channel are relatively steep (about 9°) and the channel is relatively narrow in places (some 700 m). The base, like that of the Elizabeth Bay channel, has a gentle slope of 40 m over a length of 9 km.

DROWNED ORANGE RIVER CHANNEL

Fig.20

SCALE approx. 1: 50,000

Bedrock contours in metres below mean sea level



These figures are all comparable with those of the old Kaukausib River channel. The water is shallow off the Orange River mouth - it is only 20 m deep about 6 km offshore - which is attributable to the mass of sand and silt which has been deposted there. Hoyt, Oostdam and Smith (1969) point out that the absence of a subaerial delta is the result of intensive wave attack by the obliquely impinging South Altantic swells which have created an appreciable longshore drift northward.

By extrapolation of the slopes of the channel floor and the adjacent bedrock, Hoyt, Oostdam and Smith estimate that the channels interset the bedrock platform at depths of -76 m and -92 m, which suggest two or more emergences to approximately those levels. The author, on the other hand, estimates the channel base levels to be about -63 and -85 m. Excavations for the Ernest Oppenheimer bridge some 3 km upstream show that bedrock lies at least 40 m below the river level at that point. The historical significance of these figures will, however, be deferred to a later section. It is of interest to note that there is an implied flattening of the bedrock at about -20 m adjacent to the coastline.

c) The Buffels River mouth.

The Buffels River enters the sea 135 km south of the Orange River (Map 3). The submarine expression of the river is illustrated by Map 10, compiled from "Lizard" acoustical profiling records as interpreted by Ocean Science. As the records are no longer suitable for measuring the sub-sediment bedrock contours, only the isopachs are illustrated here. The "Lizard" surveys were conducted on an irregular triangular pattern and contouring is accordingly unreliable on the large scale but may be considered adequate for a casual examination of the area.

A contrast exists between the zero isopach lines which run seawards of the river mouth. Whereas the northernmost isopach trends in a westerly direction, the southern isopach has a southerly trend offshore. Scanning of the isopachs suggests that the main submarine channel also trended south (at least as far as beacon Late), if one may equate isopachs with general expressions of topography, but directly seawards of the mouth is a small saddle at a depth of some 210 ft. (98 m), which might have been part of a river course during times of lower sea level. The sea bed shallower than 100 ft (30 m) is largely devoid of sediment, present as isolated ponds only.

A highly characteristic feature of this area is a system or series of steep slopes and cliffs cut in the bedrock and which form the inshore boundary of the main sediment body. The river appears to have cut this cliff-line during times of lower sea level as the isopach pattern does not reflect the presence of the cliffs beneath the sediment off the present mouth. The cliff-line is also cut between beacons Rocky Bay and Wreck. The approximate base of the cliff (or cliffs) tends to increase in depth southwards - an indication of the trend is given by the wavy, broken line on Map 10 (which should not be taken as actual base of the feature). The profiles A - B and C - D in Fig. 22 illustrate the scale in cross section. Insufficient survey coverage does not permit one to confidently correlate a feature with the one adjacent to it, but the overall trend is significant. The reason for this plunge to the south may well be found in the crustal history of the area, but the author is not competent to discuss this aspect in detail.

Where best developed, the cliff is some 100 ft. (30 m) high (see profile C - D) and by comparison the bedrock surfaces above and below it may be described as submarine platforms. The base of the cliff lies between 125 ft (-38 m) off beacon Drum and 235 ft. (-72 m) off beacon Late. As mentioned earlier, most of the area within the S.D.C. between beacons Val, near the Olifants River mouth (Map 1), and Wreck Point (Map 3) is characterised by a break in slope at a depth of just over 200 ft. (60 m) and is manifested by rapidly increasing sediment thicknesses in addition to which the edge of the Intermediate Sediment lies seawards of the break.

Apart from cutting the pronounced slope, the submarine extension of the Buffels River is not easy to trace from the information available. The bulk of the sediment illustrated in Map 10 consists of shelly sand with sparse gravel and thin basal clays as far as the sediment was penetrated: maximum penetration was 29 ft. (8.5 m). Abundant gravel was noted from the holes drilled on the northern side of the deposit. This gravel may reflect the longshore drift at the time of deposition if it can be assumed that the gravel was introduced by the river. The gravel was noted as being subrounded and comprised of quartz, occasional agates and bedrock fragments.

II. GULLIES, CLIFF AND PLATFORMS.

a) Gullies.

The bedrock on which the raised beaches have been emplaced just north of Orange River is characterized by areas of gently sloping bedrock (platforms) into which gullies have frequently been cut. Two generally recognized cliffs or steep slopes are also in evidence. The upper and better developed cliff-line reaches its maximum elevation of some 25 m in the south near Oranjemund and decreases in elevation northward to about 9 to 12 m above sea level. This drop is attributed to crustal warping. Approximately 50 km north of Oranjemund the upper and older platform is cut by a younger cliff which lies at a relatively constant elevation of between 3 and 7 m. The bedrock also tends to steepen northwards so that the cliffs tend to approach the coastline, especially noticeable in the case of the upper cliff because of its range in elevation. The cliffs apparently terminate just south of Chameis.

Wright (1964) investigated the gullies exposed in the C.D.M.

workings. He found no consistent relationships between directional gully trends and bedrock structural planes, but concluded that gully trend is determined largely by the direction of shelf slope. Wright concluded that the dominant gully trend was normal to former coastlines, which were slightly oblique to the present coastline. The gullies often reach depths in excess of 6 m and their sides and floors exhibit well-rounded, water worn smooth faces, depending on the local rock type. The best developed gullies are thought to have been formed by coalescing, alongated potholes. Submarine gullies have been examined by the O.R.U., especially between Mittag and Kerbehuk, north of the Orange River. From these investigations three major and two subordinate classes of gullies have been recognised on the basis of the principal control of their genesis (Murray et al, 1970):-

i) Slope gullies are the most common type of gully on the raised beach platform at C.D.M. but they are less common beneath the sea. They tend to be oriented down-slope, approximately normal to the coast, and they are typically U-shaped or slightly pear-shaped with well-rounded edges.

ii) Joint gullies are common the harder types of bedrock and have formed along the joint planes oblique to the coastline. These gullies are generally pear-shaped with the upper sides often overhanging and occasionally meeting to form a tunnel. Between 3 and 5 m deep, joint gullies commonly have a small trough cut along their length which marks the original joint plane.

iii) Strike gullies have irregular, V-shaped cross-sections and they have formed as a result of differential erosion of alternating hard and soft strata. Following the strike of the local rocks, these gullies may be traced for relatively long distances.

Fracture zone gullies are shallow, U-shaped features often several kilometres in length and are thought to be expressions of faults in the bedrock. They are irregularly spaced and may change direction abruptly over a short distance. Dyke gullies are relatively rare. They have been formed by differential erosion of basic dykes which cut the bedrock.

The gully floors are usually verneered by sediment up to about half a metre thick in areas otherwise regarded as sediment-free (so called "bare bedrock"). The sediment is unusual in that it is basically a cobble and pebble gravel with a minor coarse sand fraction and worm casts made of agglutinated sand grains. The coarse-grained constituents are either well-rounded or subangular, the latter group being comprised of local bedrock fragments whereas the well rounded grains include "foreign" material such as quartzites with agates and banded ironstones. Conglomerate is commonly present as sheet-like masses or angular fragments: in one locality conglomerate was observed to span the top of a gully. By appearances alone it would seem to be the same as the typical sandstone/conglomerate mentioned in a previous section.

b) Cliffs.

Submarine cliffs of modest proportions, like gullies, are not readily detectable on the records produced from the vertical profiling equipment. The conical shaped acoustic beam transmitted by the type of apparatus used only provides the "average highest" bedrock elevation at any locality. However, oblique scanning equipment and divers complement each other in defining small-scale bedrock features. One of the most significant discoveries is a marked submarine cliff situated between Mittag and Kerbehuk. It is between 1 m and 5 m in height (average 3 m) and has been traced for some 15 km along its length parallel to the present coastline. The base of the cliff lies between -18 and -20 m below sea level and frequently contains a wave-cut nick. The cliff is extremely dissected by gullies and may thus be visualized as a series of planed, small-scale promintories and stacks. It is described in detail by Murray et al (1970). The base of each gully is continuous with the slope of the platform which exists at the foot of the cliff-line. Seaward of the cliff, this platform is covered with large boulders which decrease in size and abundance seawards. The width of the platform has not been clearly established.

The cliff tends to die out towards Chameis but Chameis Bay itself is characterized by flat areas between -18 m and -24 m below sea level, separated by low ridges. Flat areas of similar elevation were mentioned in the sections dealing with the Plumpudding and Hottentot Bay deposits. In addition, extensive areas at elevations between -22 m and -24 m, which are backed by steep slopes, have also been noted at Meob Bay and Conception Bay in the T.D.C. The divers have also found indications of another cliff-like feature at about -30 m.

c) Platforms.

It has become clear that the formation of cliffs, gullies and platforms is dependant on many factors including rock types, ferocity of wave (surf) attack, length of time for erosion, the amount and nature of abrasive material available and the initial slope of the bedrock. In an effort to determine if any regional pattern of platform or slope development can be determined from the results of acoustic profiling, bearing in mind that marked but small-scale features may not show up on such records, an area was selected for study. Profiles of the bedrock topography were drawn up and examined.

At this point it must be ascertained just what is being looked for. The author is looking for signs of lower sea levels manifested as persistent erosional cliffs or platforms cut into bedrock over a depth range of -40 to -50 m for which information is available. Zeuner (1958) listed fifteen different criteria which could be used in determining the mean sea level of Pleistocene shoreline features. These criteria are for what he termed erosional shore lines, constructional shore lines and estuarine terraces; the last two categories are not very definitive and would be difficult to identify by the methods which have been employed in the prospecting programme. As regards erosional coast lines, however, he cites the following points (amongst others) as pertinent in defining former shore lines: the presence of an abrasion platform, a cliff-platform junction, an undercut or notch at the cliff-platform junction, and lines of rock boring organisms. He maintains that as active platforms carry little or no deposits, sediments on such platforms will have been deposited as a succession of storm beaches. This statement was not presumably, meant to include submerged platforms, which may be subject to deposition or non-deposition depending on the type and amount of sediment being introduced into the area in question.

The next problem is how to define such platforms or wave-cut terraces. In literature one finds such statements as that given by the Dictionary of Geological Terms (1962): "Benches and terraces are relatively flat, horizontal or gently inclined surfaces, sometimes long and narrow, which are bounded by a steeper ascending slope on one side and by a steeper descending slope on the opposite side. Typically they are steplike in character". C. King (1959) defines platforms by explaining their formation, but the problem remains: how flat is "flat?". It is not the present authors intention to develop a treatise on submarine erosion features and the subject can be summarized by citing the opinions of several well-known workers such as those above and Bradley (1958), Flemming (1965), Emery (1961) and Dietz (1963). Their general consensus is that platforms are gently curved features resulting chiefly from abrasion in the surf zone during periods of constant or slowly rising sea level, the process being confined to a depth of some 30 ft. below sea level at that time. The platform will seldom develop a width of more than a third of a mile (500 m) under normal circumstances. Scheidegger (1962) used mathematics to support his contention that a marine terrace is indicative of the change of the rate in the rising or falling of sea level.

Because direct observations of the submarine bedrock has been very limited, an indirect method (such as the results of acoustic surveys) must be utilized. Map 11 is a generalized plan of the area between Dunkel and Dreimaster Bay (see Map 5) showing the sediment outline and bedrock topography as compiled from surveys using the "Pinger". The letters A to I mark the lines of nine bedrock profiles roughly 2 km apart. Nineteen other bedrock profiles, located between Dreimaster Bay and Pomona, were drawn from similar maps and are numbered consecutively from the north; All of the 28 profiles are illustrated in Fig. 23. In order to exaggerate the topography, the vertical scale is fifty times the horizontal scale; one profile is duplicated to illustrate that a vertical exaggeration of the usual factor of ten times shows the topography to be very subdued compared to the distance covered by the profile. It should be pointed out that the contours of Map II have been smoothed out in the sense that small, local irregularities have been removed. This applies particularly to the shallow, sediment covered areas inshore, for which more detail was available than for the area further offshore.

The profiles from 1 to 14 in Fig. 23 have a convex shape when the bedrock exceeds -40 m, whereas from profile 16 through A to profile I they tend to be more concave in general shape as well as having a more gentle slope.

These trends probably reflect the structural and regional change of bedrock type which varies from a metamorphic/sedimentary provenance in the south to an igneous/metamorphic provenance north of Bogenfels.

It is difficult to assign a numerical value to a topographic feature of limited extent. Because the geophysical methods which were used were unable to resolve small-scale cliffs, the following questions have to be dealt with: what are the significance of slopes and changes of slope and how are they best divided into flat areas, gentle curves and steep slopes? How does one distinguish between geomorphic features of subaerial and submarine origin using profiles of this kind? An added difficulty is that the profiles lie between different depth ranges.

In order to formulate some sort of quantitive test the author devised a system of examining the profiles and awarding points for the features noted, using rather arbitrary presumptions. On the basis that a mature submarine platform will have developed a slope of 1 in 100, a figure accepted by the authors mentioned on page 76, this factor was used as a basis for the examination. Most points were awarded to features two hundred metres wide (a purely arbitrary choice) with a change in elevation of less than two metres. Fewer points were awarded to features of lesser extent and having steeper slopes. A hill or ridge, which might have acted as an obstruction to normal surf action, was defined as a feature more than 2 m in height and characterized by a temporarily decreasing elevation seawards. Slopes occurring within the shadow of the hills (that is, which occurred on the shoreward side and within the same depth range as the obstruction) were awarded the least scores. The precise system of scoring was:-

i) A slope more than 200 m wide and less than 2 m in vertical extent - 5 points.

ii) Hill/ridge more than 2 m high whose summit is more than 200 m wide - 3 points.

iii) A slope more than 100 m wide and less than 2 m in vertical extent - 2 points.

iv) As i) occurring behind an obstruction more than 2 m high - 1 point.

v) As ii) but with summit between 200 m and 100 m wide - 1 point.

Each profile was traced using a transparent overlay on which 200 m by 2 m and 100 m by 2 m rectangles had been marked out, so that features were measured in these combinations. Scores were assigned to class intervals of 1.9 m of elevation, the class being determined by the depth at which the greatest length of profile, within the rectangular template, occurred. On the assumption that each class interval had a potential score of five points for every profile which extended across that interval, the actual scores were totalled and converted to a percentage of the theoretical score. Table VIII lists the percentage for each class. Classes which had a potential score of less than 50 points have been omitted as they were considered to be unrepresentative, i.e. there were too few profiles in that depth range.

TABLE VIII. The percentage of points recorded for slopes and features of 28 profiles.

Class interval	Percentage	Class interval	Percentage	Class interval	Percentage
20.2 - 22.1	14	44.2 - 46.1	53	68.2 - 70.1	19
22.2 - 24.1	10	46.2 - 48.1	69	70.2 - 72.1	19
24.2 - 26.1	14	48.2 - 50.1	59	72.2 - 74.1	14
26.2 - 28.1	39	50.2 - 52.1	68	74.2 - 76.1	14
28.2 - 30.1	21	52.2 - 54.1	106	76.2 - 78.1	13
30.2 - 32.1	20	54.2 - 56.1	78	78.2 - 80.1	17
32.2 - 34.1	73	56.2 - 58.1	86	80.2 - 82.1	28
34.2 - 36.1	35	58.2 - 60.1	42	82.2 - 84.1	36
36.2 - 38.1	36	60.2 - 62.1	50	84.2 - 86.1	17
38.2 - 40.1	37	62.2 - 64.1	50	86.2 - 88.1	7
40.2 - 42.1	59	64.2 - 66.1	47	88.2 - 90.1	13
42.2 - 44.1	38	66.2 - 68.1	18	90.2 - 92.1	7

Without submitting the results to statistical tests, inspection shows the following:-

i) Elevations of -32 - 34, -40 - 42 and -52 - 54 m, and to a lesser extent -26 - 28 m, -56 - 58 m and -82 - 84 m, show an anomalous degree of flattening/ truncation.

ii) All elevations between -44 m and -58 m have more than half the theoretical score.

iii) The -24 to -26 m range of elevation, which was noted as being characteristically flat in some area (such as Chameis and Hottentot Bays) is shown to be not significant in the area examined using profiles.

iv) The -52 - 54 m interval scored more than the theoretical points allowed for - this may be partly due to a structural (tectonic) bedrock flattening or any other of a variety of reasons.

Factors which might tend to diminish the impact of the excercise are:

i) The profiles were drawn from contours which had been smoothed out to a certain extent and may thus be of too general a nature.

ii) The assumptions on which the scoring system was based may be quite erroneous.

iii) The original slope of the bedrock could not be taken into account. For example an event which might have led to the development of a platform on gently sloping bedrock may be manifested as a cliff or steep slope on steeply sloping bedrock. Many of the profiles from number 12 to 19 scored heavily at class intervals between -58 and -64 m, whereas the remaining profiles scored relatively few points in this range.

In a limited examination of this sort one is unable to deduce the historical sequence of events which lead to these "abnormally" flattened features, nor can one assess the effect of previous, similar events which may have initiated bevelling at one or several depths.

III. SUMMARY OF POSSIBLE DIAGNOSTIC FEATURES OF LOWER SEA LEVELS.

To summarize the features which, the author feels, may be indications of previous low-level stand of the sea the following points are listed:-

I. Apparent flattening of the bedrock in the vicinity of the Orange River mouth at -20 m.

Flat bedrock between Possession Island and the coast line:- -20 m
Submarine cliff base off Mittag:- -18 - 24 m
Chameis Bay platform:- -18 - 24 m
Bedrock floor in Hottentot Bay:- -18 - 24 m
Extensive flat areas in Meob and Conception Bays:- -22 - 24 m.

II. Flat bedrock adjacent to the Elizabeth Bay channel: - 30 m
Planation of the Hollams Bird Island ridge about - 30 m
Anomalous flattening as noted from test profiles -32 - 34 m

III. Flat bedrock adjacent to the Elizabeth Bay channel: -50 - 60 m
Possible base level of a sub-channel off the Orange River: - 63 m
Prominent flattening noted from test profiles: -52 - 54 m

IV. Further indications, which do not tie in so readily with the above but which at the same time were noted as being possibly significant are:-

a) The sub-outcrop of the Intermediate Sediment varies somewhat:

S.D.C: -67 m in the south, -100 - 110 m in the central section to about -88 m in the northern part of the concession.

M.D.C: -60 to -63 m in the south, deepening fairly steadily to -90 to 100 m towards Luderitz.

T.D.C: very erratic outline and depths.

b) Possible base level of a sub-channel of the Orange River: -85 m
c) Base level of the Elizabeth Bay channel: -120 to -130 m
d) Less prominent flattening noted from test profiles: -26 to -28 m, -40 to 42 m and -56 to -58 m.
e) The deepening system of cliffs off the Buffels River mouth whose bases lie between -38 m and -72 m. The cliffs or steep slopes tend to mark the seaward limit of platforms at about -30 m and -45 m.

CHAPTER VII:
QUATERNARY EVENTS AND THEIR POSSIBLE EFFECTS ON THE LOCAL SUBMARINE GEOLOGY.

Comparatively little work has been published on the Quaternary geology of Southern Africa, especially in relation to the well documented events of the northern hemisphere. It is desireable to review the topic and to relate the few facts and many theories which have emerged to the geology of the western coast of Southern Africa.

The Pleistocene Epoch in particular is fairly well documented as being characterized by climatic variations of widespread significance. The resulting large-scale vertical movements of sea level can thus be expected to have left some impression on the local geology.

I. THE PLEISTOCENE EPOCH:

For someone not formally educated in the European traditions of Pleistocene terminology, it is a difficult task to make sense of the wealth of seemingly authorative literary information.

It would appear that the only facts generally accepted are:-

a) That the Pleistocene was characterized by stages of glaciation and deglaciation in the northern hemisphere.
b) There were appreciable fluctuations in sea level.

The picture is confused by terminology and the facts established for local type areas being expanded to a continental scale, but even more by the fact that climatic, tectonic/eustatic and faunal terms are freely interchanged. In addition there are various "schools of thought", such as the American, Alpine and Scandinavian, which have their own terminologies. These various systems have developed for good reasons but the novice becomes overwhelmed when encountering them.

It is recognized that there were four major glacial stages within the Pleistocene, separated by three major interglacial stages, as well as a preglacial and a terminal, post-glacial stage. Each of these stages in turn had cooler and warmer phases, leading to further subdivisions. Suggate (1965) proposed that the warmer phases within a glacial stage be termed "interstadials" and that "stadials" be defined as the colder or coldest phases of a glacial stage. The term "glacial stage" describes a period when the climate was cold enough to have resulted in the development or extension of substantial ice sheets.

Attempts have been made to fix an absolute time scale to the phases and stages of the Pleistocene Epoch and the number of scales proposed or inferred is in direct proportion to the volume of literature on the subject. For example, Ericson, Ewing and Wollin (1964) state that the base or initiation of the Epoch to be about 1.5×10^6 yrs. B.P. as marked by faunal changes observed in deep-sea cores. Emiliani (1955), on the other hand, advocated an age of about 300,000 yrs. from oxygen-isotope studies on deep-sea cores. Other workers, of whom Zeuner (1958) is typical, have divided the Pleistocene up on the basis of the Croll-Milankovitch mechanism, which involves the variation of solar radiation on the earth due to perturbations of the earth's orbit. Whatever the cause of the Pleistocene Ice Age was, the criteria used to time or subdivide it have been numerous so it is really not surprising that there is disagreement, especially when considering the immeasureable factors involved such as "local conditions", time lags between events, adaptability of fauna and flora and geographical location.

The same factors have caused disagreement as to the official termination of the Pleistocene in terms of absolute chronology. The Epoch is defined as terminating at the general retreat of the glaciers, accompanied by a general warming of the climate and consequent rise in sea level. The boundary is especially difficult to pinpoint in the American succession as the Wisconsin stage overlaps the classic European equivalent (the Wurm) into the Recent Epoch, which is also called the Holocene. In fact it is within this section of the geological time scale that confusion is most rampant. For instance, in the American school examplified by Leighton (1960), a succession of stadial phases is given by such names as Farmdale, Iowan, Tazewell, Cary, Mankato and Valders, which cover the period between 29,000 and 11,000 years B.P. Broecker, Ewing and Heezen (1960) make divisions based on climatic phenomena such as Dryas, Bolling, Alleröd and pre-Boreal between 13,000 and 10,060 years B.P. Many subdivisions are explained by the service of radiocarbon dating, which allows some degree of absolute dating up to about 35,000 years ago. Shotton (1967) points out glaring inconsistencies in dating methods, so that the implication is that one shouldn't be too categorical in using such data.

In the past few years several authors have called for a differentiation between the Pleistocene and the Recent at 9,000 to 10,000 years B.P.; for example Mörner (1969) says that the Holocene is marked by the onset of the Flandrian Transgression at this age (of 10,000 yrs. B.P.). Morrison (1969) points out that estimates originating from the United States vary from 20,000 to 4,000 years, but he maintains that pollen-zone boundaries are the most reliable time/climate markers and would consequently establish the Pleistocene - Recent/Holocene boundary within the interval 12,000 to 10,000 years B.P. Broeker, Ewing and Heezen (1960) present evidence of a marked change of climate (warming) about 11,000 years ago, so that this order of age would appear to be a fairly widely recognized and significant break.

Tables IX and X respectively summarize the standard Pleistocene subdivisions and illustrate views on the chronology of the Pleistocene Epoch.

Table IX: Comparison of subdivisions of the Pleistocene Epoch.

Status	Description	European (Alpine)		N. American	Mediterranean
IS ?	Post glacial	Recent		Holocene	Flandrian
G	Last glacial 3	Wurm III	UPPER	Wisconsin	Pre-flandrian regression
IS	Interglacial	II - III			
S	Last glacial 2	Wurm II			
IS	Interglacial	I - II			(Epimonastirian)
S	Last glacial I	Wurm I			
IG	Last inter-glacial	Riss-Wurm		Sangamon	Late Monastirian
					Intra "
					Main "
G	Penultimate glacial 2	Riss II	MIDDLE	Illinoian	
IS		I - II			
G	do. 1	Riss 1			
IG	Penultimate interglacial	Mindel-Riss		Yarmouth	Tyrrhenian
G	Antepen. glacial 2	Mindel II	LOWER	Kansan	
IS		I - II			
G	Antepen. glacial	Mindel I			
IG	Antepen. Interglacial	Gunz-Mindel		Aftonian	Milazzian
G	Early glacial 2	Gunz II		Nebraskan	
IS		I - II			
G	Early glacial I	Gunz I			
IG		Donau-Gunz			Sicilian ?
G		Donau 3			
		Donau 2			
		Donau 1			Calabrian

*G = glacial stage IG = interglacial stage S = stadial phase
IS = interstadial phase.

Table X: Views on the absolute chronology of the Pleistocene Epoch.

Stage	Emiliani (1955)	Fairbridge (1960)	Stearnes (1961)	Ericson et al (1964)	Zeuner (1958)
Post glacial	7-8,000	<2,000 is Recent	11,500		
Wurm III		Late Wisconsin 10,000			22,000
Wurm II		Early Wisconsin 70,000			72,000
Wurm I					115,000
	60,000		60,000	120,000	
Riss-Wurm		Sangamon 75-90,000			125,000 145,000
	103,000			340,000	150,000
Riss II		Illinoian 117,000	115,000		187,000
Riss I					230,000
	125,000			420,000	
Mindel-Riss	175,000	Yarmouth			270,000
		125-200,000		1,060,000	
Mindel II					435,000
		Kansan 230,000	240,000		
Mindel I					476,000
	200,000			1,200,000	
Gunz-Mindel		Aftonian 250-270,000			500,000
	265,000			1,300,000	
Gunz II					550,000
		Nebraskan 280-325,000	320,000		
Gunz I					590,000
	290,000			1,500,000	
Donau-Gunz		600,000			

E N D P L I O C E N E

Note: The precise boundary between the Pliocene and Pleistocene Epochs has, to the author's knowledge, not been defined. The onset of the Pleistocene is simply characterised by "a general cooling".

II. EUSTATIC SEA LEVELS.

An implication of the work on the extent and effects of the continental ice sheets was an awareness of changes of sea level. Eustatic changes of sea level are defined as those which are world-wide. They are relative to a fixed datum (usually present sea level) and may be classified in one of two categories on the basis of their cause: a) those due to glacio-climatic eustasy, that is, those caused by changes in water volume in basins of constant shape, and b) those due to tecton-eustasy (changes in basin shape with constant volumes of water) (Fairbridge 1958). In actual fact eustatic oscillation of sea level may be combinations of these, as well as being complicated by local factors such as isostasy and coastal warping.

With the development of geochronology many attempts have been made to date terraces and other manifestations of old sea levels, particularly those younger than thirty to forty thousand years, and to relate and compare the results with the patterns emerging for regions elsewhere on the globe. Early attempts were based largely on mathematical calculations which estimated the volume of water required to form the large ice sheets and consequently the fall in sea level assuming that this water was withdrawn from the sea. The concept that widespread glaciation induced low sea levels is thus a fundemental one, as is the converse theory that melting of the glaciers resulted in high sea levels. The principal query is how low or high did sea level fall or rise during a particular event. Here again the author can but gloss over the wealth of facts and figures to be found in literature.

Zeuner, (1958 and 1959), in referring to Dalys work in 1934, maintains that sea levels higher than 40 m to 60 m above present sea level cannot be ascribed to glacial eustasy alone. However, Zeuner presents a summary of Pleistocene (high) sea levels, which tend to be named after the Mediterranean terminology. The earliest, generally recognizeable level is the Sicilian (often correlated with the Donau-Gunz Interglacial) of between 80 m and 110 m above the present sea level, which Zeuner estimates as occurring 600,000 to 700,000 years B.P. He advocates an overall decrease in altitude of the high sea levels during the Pleistocene, but as with most contemporary authors, evidence is most numerous for the Late Pleistocene as this period includes the effective range of radiocarbon dating methods: (to about 35,000 yrs. B.P.)(Polach and Golson 1966).

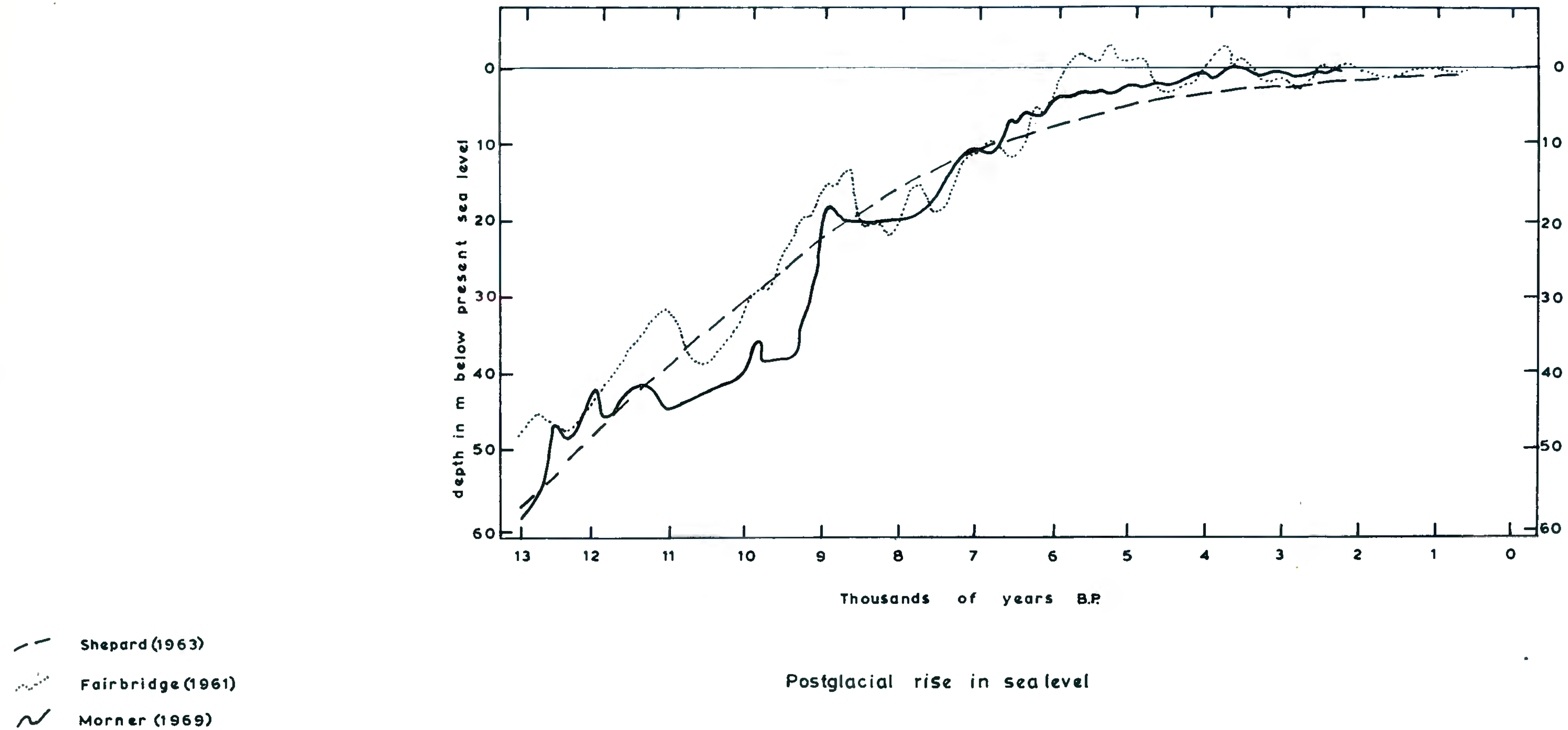
The last low stand of sea level occurred during the Late Wurm/ Wisconsin stages and is estimated to have been some -130 m at 16,000 years B.P. (Milliman and Emery, 1968). In the so-called post-glacial times sea level has risen as the "Flandrian transgression", but there is disagreement as to the precise rate of the rise. Some, as for example Shepard (1965), have detailed a fairly steady rise of sea level until the present time, whereas other prefer a rapidly oscillating rise with sea levels reaching near-present levels up to 5,000 years ago. Godwin, Suggate and Willis (1958), for example, mention 5,000 years and Coleman and Smith (1964) estimate sea level arrived at very near its present level between 3,500 and 4,000 years ago. It was the pioneering Daly who suggested that there was a rise of sea level following the last glacial period such that sea levels rose above the present during a "climatic optimum" and then subsequently dropped slightly to the present position. Stearns (1961), examining evidence of high sea levels from the Pacific Islands (especially Hawaii) found signs of a 12 ft. terrace amongst others. He then tentatively correlated this terrace with two others of similar elevation, one of which was subsequently dated as being 20,000 years old and the other as 4,000 years old (Russel, 1963). The dangers of correlation by altimetric evidence alone is thereby clearly demonstrated. There now appears to be no clear evidence to support the concept of a post-glacial high sea level on a eustatic scale, a concept that is now regularly refuted, e.g. Shepard et al (1967) - Micronesia, MacIntyre (1961) - Mauritius; Scholl and Stuiwer (1967) - Florida; Thom, Hails and Martin (1969) - Australia.

The most recent ideas on the rate and manner of post-glacial sea level rise are summarized in Fig. 24 which shows the eustatic curves for the past 11 000 years as advocated by Mörner (1969), Shepard (1963) and Fairbridge (1960). Based on individual studies in widely separated areas, these curves show an overall agreement, although Fairbridge's curve is the only one shown here which advocates frequent sea level rises above present sea level. His critics state that his figures (based on data from Australia) are not typical and require "re-interpretation". The generally accepted order of magnitude for the last low sea level is between -120 to -130 m.

e.g.	Emery and Garrison	(1967)	- 123 m	19 000 yrs.	B.P.
	Milliman and Emery	(1968)	- 130 m	16 000 "	B.P.
	Curray	(1961)	- 120 m	20 000 "	B.P.
	Tija	(1970)	- 130 m	18 000 "	B.P.

These figures compare favourably with Shepard's figure of -137 m (450 ft) as the average depth of the continental shelf break around the world.

There are numerous references concerning emerged terraces, but the literature dealing with specific submerged terraces is scanty; in fact the only convincing literature dealing with the elevations of submarine terraces in any detail is presented by Emery (1958 and 1961). Using an echo-sounder and later a Sonoprobe tool in the Gulf of Mexico, he noted that flat areas were common at about -12 m, -24 m, -49 m and -78 m, with the shelf break at -90 m. Moore's (1960) fig. 2 is a composite profile off Pigeon Point, California, and shows bedrock platforms with distinct breaks in slope at -105 to -120 m and at -50 to -60 m. It may be pointed out that the -24 to -26 m and -44 to -58 m ranges (amongst others) were found to be flattened off the local coast (see page 79). Shepard (1963) mentions that there is a prominent worldwide flat at -18 m. The eastern seaboard of South America could have



Postglacial rise in sea level

Fig. 24 (after Morner, 1969)

been expected to provide further evidence of (local) eustatic levels, but Richards and Broecker (1963) explain that the several terraces and emerged shorelines of that continent have been severely affected by tectonic warping during and after the Pleistocene. It is a patent that a lot more research is required to formulate any sort of global scale with regard to submarine platforms, especially as the effect and extent of the early and mid-Pleistocene glacial stages are unknown.

What can be said of events in southern Africa?

III. THE PLEISTOCENE IN SOUTHERN AFRICA:

There was no large scale development of glaciers in the southern hemisphere during the Pleistocene epoch and there are certainly no signs of ice movements in southern Africa which can be related to the Quaternary. In fact, as Haughton (1969) points out, there is not even a clearcut division between the Tertiary and the Quaternary and that attempts to unravel the Quaternary history of the sub-continent are hampered by the paucity of distinct and comparable markers such as glacial moraines and faunal changes. Indirect lines of thought concerning recent geological events have tended to follow two main avenues: a) examination of the relative positions of sea level, and b) examination of climatic variations. Each of these topics is not easily comparable with similar trends or events of the northern hemisphere. The popular premise is that glaciation (inferring a cooler and possibly wetter climate) is synonymous with lower sea levels and that these low sea levels are truly eustatic. To date there has been little direct evidence to link climatic changes with changes of sea level in southern Africa although Mabutt (1955) suggested that such a relationship can be postulated.

To put the Pleistocene in perspective it is convenient to follow the broad outline of local events since the Late Cretaceous.

By the end of the Cretaceous an extensive erosion surface had been developed along the local coast. Widely silicified temnants of this surface can be seen as isolated, flat-topped hills capped with Pomona Quartzite (often a silcrete in fact). Uplift and warping in the Early Tertiary were accompanied by outpourings of phonolitic lavas. Erosion during and following the tectonic movements led to the deposition of thick, Early Tertiary streamflood gravels which can be distinguished from younger deposits by the absence of phonolite constituents. Remnants of a marine transgression in the form of a fossilferous gravel overlie the streamflood gravels and are the result of what Kaiser and Beetz (1926) termed the "Eocene Sea". Haughton (1969) points out that the actual age lies between Upper Cretaceous and Miocene. Tanner (1968) advocates a general fall of sea level from Mid-Tertiary times accompanied by a cooling of the Antarctic climate, which may be significant. As seen in the remants at Buntefeldschuh (inland from Plumpudding Island) and in the vicinity of Bogenfels, these Tertiary marine gravels contained distinctive pebbles of chalcedony and jasper. With falling sea level rivers incised their courses. Erosion of the landsurface continued to Miocene times, which marked the termination of the African erosion cycle (L. King, 1951). Near the coast the African surface was eroded away following up-doming of the continental interior, which initiated further river downcutting, the emplacement of Younger streamflood gravels and the development of a coastline characterized by valleys: in these valleys there was further erosion by deflation action (Stocken, personal communication).

With the onset of the Pleistocene there were fluctuations in sea level and possibly alternating drier and wetter (pluvial) conditions which affected the continued erosion but it is difficult to correlate the variances of detail which are still visible.

Krige (1927) investigated the raised marine deposits from Port Nolloth southwards around the Cape as far as Natal. Along the southwestern coast can be found two groups of raised beaches: an Upper group between 18 m and 27 m above present sea level (but +12 to +15 m in the Van Rhynsdorp coastal district) which he attributed to epeirogenic uplift of Late Tertiary Age and termed the Major Emergence, and a Lower group of benches and beaches at about +6 m formed as a result of the Minor Emergence. Krige attributed the Minor Emergence features to an interglacial high sea level which suffered a halting stage at +4 m when subsequently receding. The choice of the term "Emergence" is unfortunate as the features associated with the Emergences were undoubtedly the direct result of marine submergence. Krige also recognized that between the Upper and Lower levels there was an extensive regression, accompanied by deepening of river mouths, as well as an interlude of warping which affected the Major Emergence features; the relatively minor regression which accounts for the Minor Emergence was, in Krige's opinion, evidence of a Recent eustatic fall in sea-level. An analysis of the molluscan remains recovered from the raised beaches suggested to Krige that at the time the Upper beaches were deposited the sea temperature was slightly warmer than they are at present. Wagner and Merensky (1928) and Haughton (1932) all recognized the variable elevations of the older beaches. Subsequent workers have verified that two groups of raised beaches and wave-cut platforms can be widely recognized. Fair (1943) noted a +6 - 8 m strandline in Natal (but found no clear evidence for beaches of higher elevation); Bowie (1966) measured features at +15 - 18 m and +6 - 8 m in False Bay; Gatehouse (1955), Breuil (1948) and Mabutt (1955) recorded similar elevations. The existence of an Upper and Lower group of raised storm beaches at C.D.M. has already been described: they have pronounced wave-cut notches at elevations of +10 - 25 m and +3 - 5 m. There is an anomalous situation just south of the Orange River in the State Alluvial Diggings where de Villiers and Söhgne (1948) described a series of terraces and their probable sequence of formation. Vigorous transgressions, regressions, warping and vertical tectonic movements resulted in terraces at +44 - 47 m, followed by the Middle terrace (+29 m to 10 - 15m) and then by the Upper terrace at the higher elevation of +36 - 38 m. Following regression of the sea and/or elevation of the coast the Lower terrace (0 - +7 m) was cut. However at C.D.M., apart from remnants of a planation at +33 m, the elevation of the Upper beaches and associated wave-cut platforms does not exceed 25 m. Moreover the Upper beaches (at least) appear to have been deposited during a regressive period with minor trangressive stages. The Upper group of beaches carry faunal remains (such as Donax rogersi) which indicate that the water temperature was slightly warmer than the present, whereas the Younger, Lower beaches are not warped and have a distinctly modern faunal assemblage. Molluscs from the youngest raised beach were submitted for Radiocarbon dating by O.R.U. personnel: the results gave two ages with a possible span of 34,000 to 39,000 years B.P. The order of age and altitude agree with the eustatic curve of Milliman and Emery (1968) who infer that sea level was close to the present level about 36,000 years B.P. The inference is that the Lower beaches at C.D.M. are Late Wisconsin or Wurm in age.

The latest information concerning Namaqualand is given by Carrington and Kensley (1969). They established a succession of marine deposits and related them to fluctuating Pleistocene sea levels as follows:-

Surface sand + 2 m Transgression complex	Recent
+ 5 m " " + 7 - 8 m " "	Upper Pleistocene
Terrestrial sands + 17 - 21 m Transgression complex + 29 - 34 m Beach	Middle Pleistocene
+ 45 - 50 m Transgression complex	Lower Pleistocene - (Milazzian?)
+ 75 - 90 m " "	(unfossilferous) Basal Pleistocene
Phosphatic siltstones Fluviatile beds (unfossiliferous)	Tertiary
Basement gneiss	Archaean.

At this point it may be recalled that both Fairbridge (1960) and Zeuner (1959) have represented the Pleistocene Epoch as one of transgressions which decreased in altitude:

* Sicilian +80 - 100 m
+Nebraskan/Kansan $\pm$ 0 m
Milazzian +50 - 60 m
Kansan? $\pm$ 0 m
Tyrrhenian + 28 - 32 m

Illinoian -85 m

Monastirian: Zeuner:	+18 m	Main	(Fairbridge: +0 - 15 m)
	+7.5 m	Late	
Wisconsin Early:	-80 m	Late -100 m	

* elevations of trangressions given by Zeuner: agree fairly well with Fairbridge.

\+ elevations of regressions given by Fairbridge, whose eustatic curve is ambiguous for the Lower Pleistocene when comparisons are attempted.

Bowie (op.cit.) presents comprehensive lists of features and their elevations gleaned from literature in order to categorize evidence which he investigated in False Bay near Cape Town. He summarized the Late Quaternary history of that area as follows:-

	Yarmouth Interglacial	(Tyrrhenian)	+100 ft	(30 m)
	Riss Glacial	(Illinoian)	?	
Sangamon Interglacial	Main Monastirian		+50 - 60 ft.	(15 - 18 m)
	Intra "		+20 ft.	(6 m)
	Late "		+10 - 15 ft.	(3 - 5 m)
	Wurm Glacial (pre-Flandrian)		?	(-100 m?)
	Post glacial transgression (Flandrian) to present sea level.			

Digressing for a moment to consider evidence of Pleistocene events on a climatic basis, the relationships are not clearcut in southern Africa. Work has been done on the Vaal River gravels, the Vaal being the main tributary of the Orange River. The history of these deposits may be significant in determining the sequence of events at the coast, but there is little in the way of direct correlation as the Vaal gravel sequence is dated by artifacts and comparison with coastal sequences is accordingly highly speculative. In addition, the erosional and depositional history of the Orange-Vaal river system would be largely dependent on the climate of the continental interior and again the relationship between former coastal and interior climates is not very clear. Van Riet Lowe (1952) postulated a link between the four or five gravel horizons and East African pluvial periods recognized for the early Quaternary. Cooke (1952, 1955) goes so far as to list tentative correlations between classical Pleistocene glacial sequences but he points out quite clearly that such correlations have not been proved. Mabutt (1955) examined the Olifants and Berg River deposits and correlated the thalassostic terraces with local marine features. His thesis was that the Western Cape climate was synchronous with that of the Vaal River chronology and he also correlated the pluvial periods with the glacial stages. His argument is that thalassostatic terrace formation and river deepening and widening can only be explained by such a correlation; to quote: "the Recent marine deposits of the winter rainfall area (the south western Cape Province) support the conclusions from the river terraces that pluvial rhythms have been shared in common by regions of differing rainfall regime". Mabutt (op.cit) proposed a sequence of a post-Major Emergence regression, a post-Minor Emergence regression and finally a minor transgression to + 2m. The present author feels that this climatic correlation is strongly suggested, but not clearly proven, although such a convenient relationship would fall neatly into the classical sequence of events. It is, in any case, of little direct application to the areas investigated because north of the Olifants river the climate is at present very much drier than that of the Cape. The review does, however, give an indication of the possible avenues which have been explored.

The most promising evidence of correlation is given by the faunal similarities between the Upper C.D.M. beaches and the +17 - 21 m Transgression complex of Namaqualand (Carrington and Kensley- op.cit.) Both units are characterized by coarse sediments (artificially induced at C.D.M., perhaps, as storm beaches of boulders derived from the Orange River), and both are characterized by the now extinct Donax rogersi. This species is confirmed to the +17 - 21 m complex in the Namaqualand succession. The lack of marine features at elevations greater than +30 m just north of the Orange River mouth has not yet been explained: the answer may conceivably lie in the history of coastal movements combined with temporary departures of the Orange River from its present course. Some of the Upper beaches north of Oranjemund are covered by one or more sequences of sheetwash and thin-bedded, possibly aeolian, deposits collectively termed Red Sands because of their brownish-red hue. The Namaqualand +17 - 21 m complex, it will be recalled, is unconformably succeeded by "Terrestrial sands". Although details of the complex in Namaqualand are not available, three fairly persistent beaches are recognized in the Upper group at C.D.M., each tending to exhibit a trangressive habit with respect to their older and higher counterparts as well as the Red Sands. The three succeeding transgressions listed by Carrington and Kensley (1969) would appear to compare favourably with the three Lower C.D.M. beaches, the oldest of which is unwarped but has apparently been overridden and disappears in the vicinity of Mittag, some 50 km north of Oranjemund (L. Kleinjan, personal communication). North of this point, the second youngest beach becomes the significant member of Lower Group and it abuts against the so-called Minor Cliff, a prominent break in bedrock slope between +3 and 5 m in elevation. The difference in faunal remains, the transgressive attitude to the Upper beaches and the development of an unwarped, prominent nick in the bedrock imply a regression between the development of the Upper and Lower groups. While the use of elevations alone for correlation purposes is inconclusive, the general similarities of several factors in the Namaqualand and C.D.M. successions is strong argument for correlation between them.

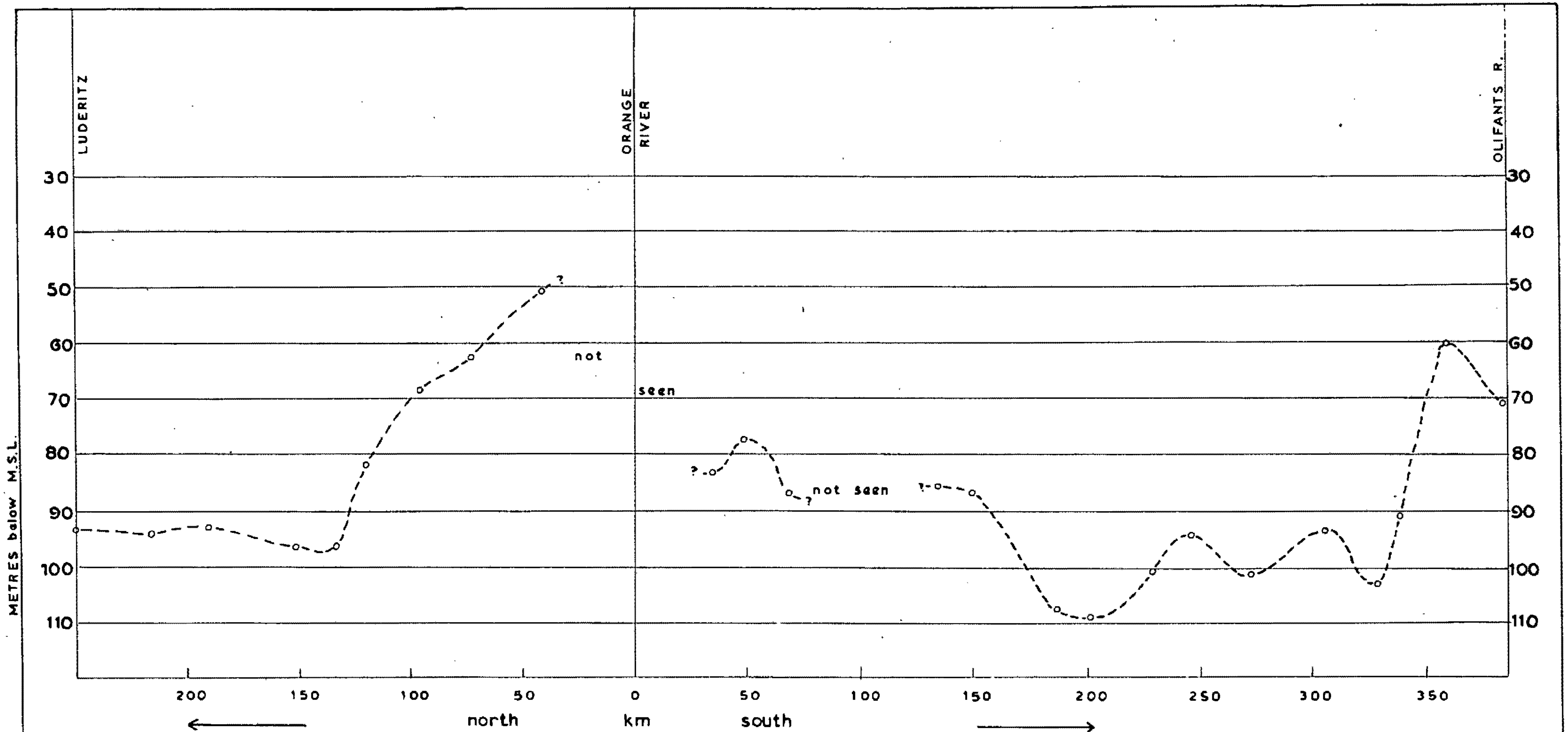
The age of the Upper beaches (20 m complex of Namaqualand) can be tentatively assigned to Monastirian (Sangamon) times on the basis of elevations and the position in a generalized sequence which compares well with contemporary knowledge. It is interesting to record that Zeuner (1958) mentions a faunal change from cooler to warmer water species during Tyrrhenian times in the Mediterranean; the warmer water species of the Upper beaches may therefore indicate a post-Tyrrhenian age.

The extent of the (interglacial) regressions are unknown and little information is given in published literature. Both King (1951?) and Donn, Farrand and Ewing (1962), however, maintain that the most intense glaciation and thus lowest sea level occurred during the Illinoian when sea level fell to between -137 and -159 m. Zeuner (1958), page 368, tentatively proposes a value of -200 m. The Illinoian stage was followed by the transgressive Main and Late Monastirian stages, represented by the Upper beaches at C.D.M. A slight drop in sea level marks the interstadial Würm I, followed by the interstadial Würm II also referred to as the Epimonastirian. Zeuner has found good evidence of notches, cliffs and platforms of the order of +4 m which can be related to this phase. The author would assign the oldest (at least) of the Lower beaches to this phase. Then followed the Würm II stadial and the final interstadial (which may have emplaced the other Lower beaches). The last glacial phase of the Würm/Wisconsin is thought to have been a truly glacial phase. Emery (1961), Curray (1961) and Fairbridge (1960) agree that the lowest Würm/Wisconsin sea level occurred during the Würm III and that sea level fell to about -100 to -120 m, as discussed on page 85, about 17,000 to 20,000 years B.P. The most recent event has been the Flandrian (post-glacial) recovery of sea level to the present.

At the end of the previous chapter were listed some factors considered to be significant in the submarine geology of the coast. These can be incorporated into a general pattern of postulated events.

IV. A POSTULATED LATE QUATERNARY SEQUENCE.

The lack of the submarine Intermediate Sediment in the shallow, inshore waters, coupled with the regular sub-outcrop south of Hottentot Bay, may well mark the lower limit of the Quaternary sea levels. If one accepts Fairbridge's (1960) interpretation, the low Illinoian stand was the first major Pleistocene regression to fall to a depth below the present sea level. In Fig. 25 is illustrated the variation in depth below mean sea level of the Intermediate Sediment outcrops. This variation can be accounted for by subsequent warping: for example the increase in its depth between Mittage and Chameis is calculated at 20 m over the 50 km which is equivalent to 0.4 m to the kilometre. Kleinjan has recently measured the descent of the Major cliff at C.D.M. as 0.3 m to the kilometre (personal communication). This warping occurred during or shortly after the emplacement of the Monostirian Upper beaches. The Illinoian regression, coupled possibly with a wetter climate, would have intensified river downcutting and valley widening such as the



Variation in depth of the Intermediate Sediment beteen the Olifants River and Luderitz

Fig. 25

Kaukausib (Elizabeth Bay) channel and the deeper Orange River channel represent. The channel in Elizabeth Bay would certainly have required a major river system or a long period to have cut some 40 or 50 metres into bedrock - the estimate in Table X would suggest that the Illinoian stage extended over some 20,000 to 50,000 years.

The Main Monastirian transgression followed the Illinoian and was characterized by the cutting of the major cliff with assistance from the boulder sediment largely flushed out the Orange River drainage system by the previous regression. The slight drop in sea level of the Intra Monastirian encouraged the emplacement of the older Red Sands; truncated by the Late Monastirian recovery to a slightly lower elevation. A general period of warping was probably concluded after this phase. A slight regression followed (Würm I) during which time the younger Red Sands and calcrete capping were developed. The Epimonastrian recovery to about 3 - 5 m marked the emplacement of at least the older of the Lower beaches and +5 m transgression complex of Namaqualand. Where the coast steepens between Mittag and Affenrucken at C.D.M., a minor cliff was cut into the bedrock. The calcrete cover, younger Red Sand and Upper beaches were cut and their lower portions reworked although remnants of the indurated Upper beaches, represented by conglomerate with Donax rogersi fragments, remained intact. Faunal remains suggest that the water was cooler by Epimonastirian times.

Minor fluctuations of sea level then occurred, which may have emplaced the younger of the Lower group of beaches such as the A beach and the +2 m complex of Namaqualand, about 36,000 to 39,000 years B.P.

The onset of the Last glacial phase of the Würm/Wisconsin stage led to a final regression. It has been pointed out that the Intermediate Sediment sub-outcrop lies between -50 and -60 m deep just north of the Orange River mouth - the shallowest exposed sub-outcrop. This could be taken to signify the lowest level of this Würm III glacial stage, a view supported by the prominent flattening of the bedrock between -45 and -60 m; the shallower Orange River channel may have been incised to -60 m (approximately) during this low stand of sea level. The vast amount of unconsolidated sediment left exposed across the inner shelf must have been subject to a certain degree of deflation action.

Sea level then rose in Recent times, commencing between 10,000 and 15,000 years B.P., with possible halts at -40 - 42 m, -32 - 34 m and -24 - 26 m to explain the flattening of the bedrock observed at those elevations. These wave-cut platforms may well be modified features initiated during the Illinoian low stand. The opinion that the -24 - 26 m halt at least is Recent (post-glacial) in age is enforced by the nature of the notch off C.D.M. and its regular but intermittent appearance as far north as Meob

Bay. The presence of a platform and its inshore extension as gullies cut into the cliff/notch and the presence of numerous blocks of relatively unrounded bedrock fragments testify to it's Recent origin. During the transgression there was a final re-distribution of gravel on and into the compacted silt in some areas such as Chameis Bay. The clay may have been partly protected by the deposits of sand available from the Orange River: there was little sand nearer the mouth in the same way that there is little sand inshore today between Mittag and Chameis. The halt at -24 m may also account for the weathered and dolomitic nature of the sheltered, basal Hottentot Bay deposit. Since the sea reached its near-present level 3,000 - 5,000 years ago, the beaches have prograded slightly and the coastline shows signs of tending to straighten itself by the silting up of lagoons behind the rocky headlands north of Chameis. Sediment from the Orange River and other drainage courses has led to a widespread Recent deposit of sand and silt north of the mouth. South of the Orange River much less sediment has been introduced into the sea, leading to a higher concentration of carbonate in the Upper layers of the sediment.

The picture above is of necessity greatly simplified. It can not take into account the effects of the minor regressions which presumably accompanied the stadial and interstadial phases of glaciation and it has been shown that the inner shelf and lower shoreline has suffered 3 major and 3 minor phases of transgression and regression. However the overall fit of observed and surmised facts and documented theory is satisfactory.

As a final summary, the postulated sequence of local events is listed in point form below:-

1) Development of end-Cretaceous erosion surface with submarine deposition.
2) Early Tertiary tectonism: intrusion of phonolites and related rocks.
3) Period of erosion and deposition of Older streamflood gravels.
4) Fall of Tertiary sea level: river incision.
5) End of African erosion cycle in Miocene.
6) Updoming of continental interior : modern coastline eroded : deposition of Younger streamflood gravels.
7) Lower Pleistocene with fluctuating sea levels : effects not observed north of the Orange River.
8) Tyrrhenian high sea level - (+35 m remnants near Oranjemund?).
9) Illinoian major regression to possibly -90 m.
10) Monastirian transgressions : erosion of Major cliff and deposition of Upper beaches between +7 m and +18 m (Major Emergence).
11) Phase of coastal warping.
12) Wurm I stadial : minor regression with terrestrial deposition on shore. Warping concluded.
13) Epimonastirian transgression : erosion of Minor cliff and deposition of Lower beaches at +3 -5 m (Minor Emergence).

14) Minor fluctuations in sea level : deposition of Younger beaches at 36 000 - 39 000 yrs. B.P.

15) Wurm III regression to -50 to -60 m about 12 000 yrs. B.P.

16) Flandrian transgression with possible halting stages at -40 to 42 m -32 - 34 m and -20 - 26 m.

17) Near present sea level reached about 3 000 yrs. B.P.

18) Final recovery of sea level : progradation of modern beaches, formation of lagoons and partial silting up of bays.

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Fig. 18

Profile: Plumpudding Island Area.

1968

Scale: 1:500 Vert. / 1:5000 Horiz. metres

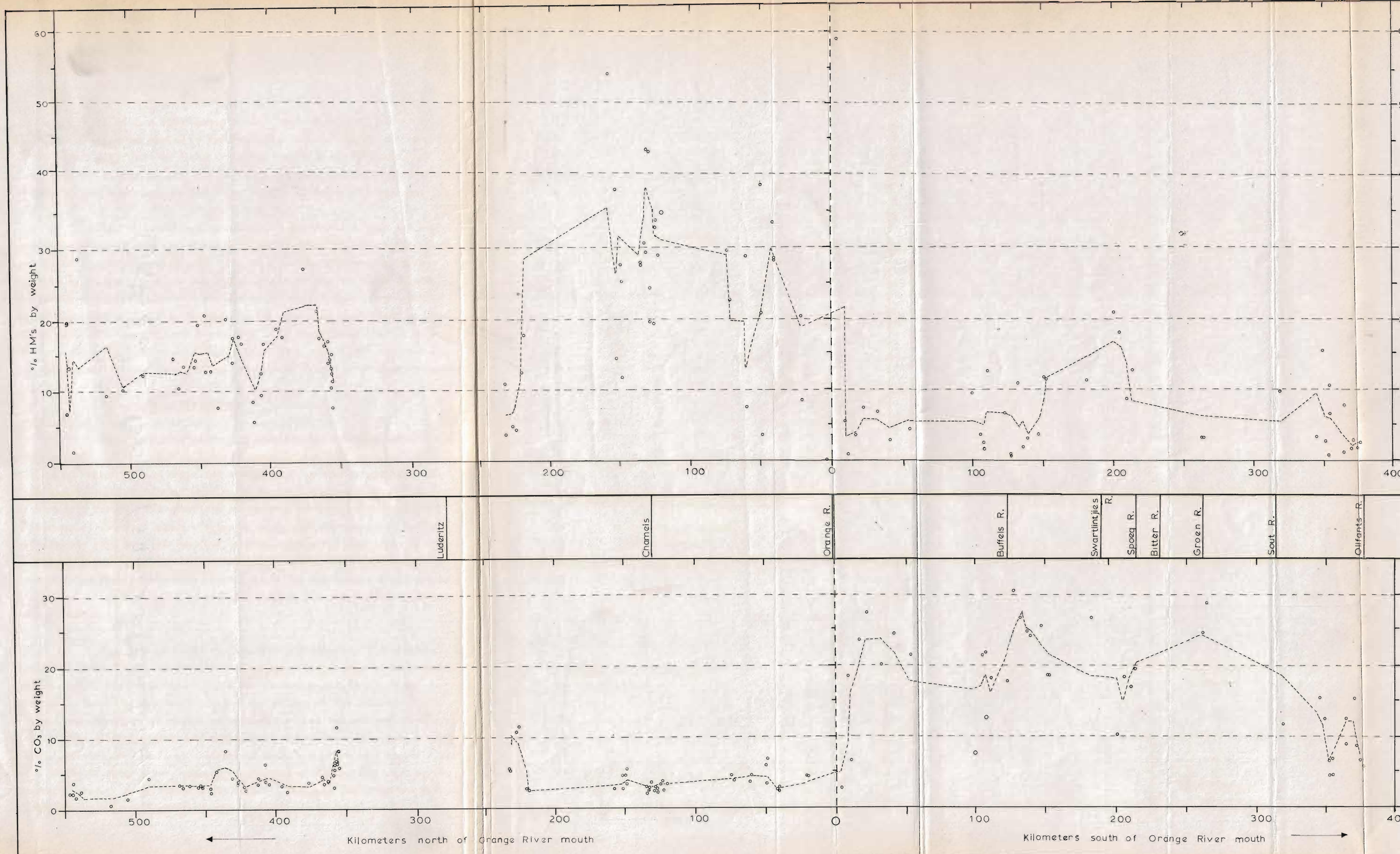
Based on Geophysical and Sampling data

BEDROCK PROFILES

Fig. 23

LOCATION: BETWEEN BEACONS 'DUNKEL' AND 'POMONA'

SCALE: 1:25 000 HORIZONTAL
1: 500 VERTICAL
vertical exaggeration=50 X



Variation of % Heavy Minerals with locality

Fig. 12 a)

----- Trendline based on 3-sample moving averages

Variation of % Carbonate with locality

Fig. 12 b)


MAP 3
WRECK POINT TO ALEXANDER BAY
SHOWING SEDIMENT DISTRIBUTION
SCALE 1:100,000 Eng. ft.
(based on Lo17)
APRIL 1970
Survey beacons (named)
Reefs
Sample sites
Unconsol. sed. isopachs at 20 ft. intervals
Isobaths in feet
Acoustical blanking layer
Intermediate sed.-basement contact
PORT NOLLOTH
Church spire
North Point
Knoll
Xmas
Wolf
Cliff Point
Misty
Gene
Holgat R.
Castle
Suzy Wong
Wreck Point
Die Uur
Rock
Dolly
Shone
Wreck Point
Erasha
Cuba
Ben Hur
N


MAP 1
OLIFANTS RIVER MOUTH TO GROEN RIVER MOUTH
SHOWING SEDIMENT DISTRIBUTION
SCALE 1:100,000 Eng. ft.
(based on Lo17)
APRIL 1970
Survey beacons (named)
Reefs
Sample sites
Unconsol. sed. isopachs at 20ft. intervals
Isobaths in feet
Acoustical blanking layer
"Intermediate sed."-basement contact


MAP 4
ORANGE RIVERMOUTH TO CAPE DURNBERG
SHOWING SEDIMENT DISTRIBUTION
SCALE 1:100,000 metres
(based on Lo17)
APRIL 1970
Survey beacons (named)
Reefs
Sample sites
Uncon sol. sed. isopachs at 6 mt. intervals
Isobaths in metres
Acoustical blanking layer
"Intermediate sed."-basement contact
ORANGE RIVER
Fig 20


MAP 3
WRECK POINT TO ALEXANDER BAY
SHOWING SEDIMENT DISTRIBUTION
SCALE 1:100,000 Eng. ft.
(based on Lo17)
APRIL 1970
Survey beacons (named)
Reefs
Sample sites
Unconsol. sed. isopachs at
20 ft. intervals
Isobaths in feet
Acoustical blanking layer
"Intermediate sed."-basement contact
PORT NOLLOTH
ALEXANDER BAY
State Alluvial Diggings

BEDROCK PROFILES

Fig. 23

LOCATION: BETWEEN BEACONS 'DUNKEL' AND 'POMONA'

SCALE: 1:25 000 HORIZONTAL
1: 500 VERTICAL
vertical exaggeration=50 X


MAP 2
BITTER RIVER MOUTH TO PENGUIN ROCK
SHOWING SEDIMENT DISTRIBUTION
SCALE 1:100,000 Eng.ft.
(based on Lo 17)
APRIL 1970
450 ft ISOBATH IS
2 5000 ft TO SEAWARD
KLEINZEE
map 10
Roodeklipbaai
-90000Y
30°45'


MAP 5
CAPE DURNBERG TO LUDERITZ
SHOWING SEDIMENT DISTRIBUTION
SCALE 1:100,000 metres
(based on Lo17)
APRIL 1970
Survey beacons (named)
Reefs
Sample sites
Unconsol. sed. isopachs at 6mt. intervals
Isobaths in metres
Acoustical blanking layer
Intermediate sed.-basement contact
map 11
map 8
Baker bay
Dreimaster bay
Jammer bay
Bogenfels
Albatross Rock
Plum Pudding Isl.
Sinclair
Durnberg
Chip
Schultzberg
Nelson
Plum
Bogen
Arch
Coast
Reenen
Square
Black
Top
Elisa
Wales