SEDIMENT DYNAMICS ON THE CONTINENTAL SHELF BETWEEN DURBAN AND PORT ST JOHNS (Southeast African continental margin)

E.R. HAY

Thesis submitted in fulfilment of the
requirements for the degree of
Master of Science in the
Faculty of Science at the
University of Cape Town

April, 1984

ABSTRACT

This study deals with modern sediment dispersal and depositional processes on the continental shelf between Durban and Port St Johns, along the southeast African continental margin. The shelf is exceptionally narrow and is dominated by strong boundary flow of the Agulhas Current. Inshore counter currents and return flow eddies are produced and maintained by the southwesterly winds in conjunction with shelf morphology. These currents are strongest in the late winter to early summer months. Intense summer rainfall along the highlands of the hinterland results in an increased supply of sediment to the shelf during the same period in which the counter currents are strongest.

Over 300 sediment samples were recovered using a Shipek grab sampler. Grain size analyses were performed using an automatically recording settling tube. The $CaCO_3$ content of the sand fraction was obtained using a "Karbonat Bombe".

Detailed textural analysis and $CaCO_3$ contents were used to identify sediment sources and dispersal patterns. A number of independent hydraulic populations were distinguished. Specific sediment transport routes as well as major sediment sinks were identified on the basis of the distribution patterns of the various size fractions. Progressive mixing between adjacent hydraulic populations is clearly reflected in the sorting and the skewness trends of the grain size distributions. Such mixing patterns reveal the degree of overlap between different populations in any particular area.

The sediments on the shelf of the study area generally grade from slightly calcareous quartzarenites, which occupy the inner to middle shelf, to slighly quartzose calcarenites on the middle to outer shelf. More argillaceous sediments are found along the base of the Mfihlelo Spit and the Ilovu Spit, which are situated in the Waterfall Bluff area and offshore of the Ilovu River, respectively.

The carbonate fraction comprises mainly relict lag deposits on the outer shelf, but some modern biogenic material is found in the nearshore. Considerable quantities of modern quartzose material is supplied annually to the shelf by local rivers. This fluival source is characterized by multi-modal sediments. Depending on the source rocks, the sediment supplied to the shelf is either medium to coarse grained, fine to medium grained or very fine to fine grained. For example, the shelf sediments found between Scottburgh and Port Shepstone are derived from rocks belonging to the Natal Group and the Natal Structural and Metamorphic Province. They are therefore very much coarser grained than sediments derived from the Karoo Supergroup. South of Port Edward, on the other hand, the bulk of the material reaching the shelf is fine to very fine grained being derived mainly from the Ecca and Beaufort and Drakensberg Groups. Elsewhere the major rivers drain rocks of both the Karoo Supergroup and the Natal Group as well as the metamorphic gneisses, discharging a mixture of fine to medium grained sediments onto the shelf.

The relict, or rather palimpsest, carbonate material is generally coarse to very coarse having been laid down as gravel lag deposits during the Flandrian transgression. It is mainly exposed on the outer shelf where high current velocities prevent the deposition of modern sediments.

The physiography of the shelf reflects the interaction of modern sediment accumulations with the Pleistocene shelf topography in response to the modern hydrodynamic regime. For example, in those regions on the outer shelf where the topography is very irregular, the sediments are invariably coarse to very coarse grained with a high biogenic content ($\triangleright$ 40%). In some areas, notably on the outer shelf terraces, no sediment was encountered and seismic evidence indicates rocky bottom. Conversely, the inner shelf - which is always smooth and gently sloping - is dominated by fine to medium grained Holocene sands, generally containing less than 30% $CACO_3$ content. The middle shelf may be either smoothly undulating as off Port Edward, or relatively flat but irregular, as off Port Shepstone, the specific character mainly a function of the position and width of a submerged aeolianite ridge. Thus, whereas the ridge rises high above the sea floor and is situated closer to the inner shelf, a proper middle shelf is either absent or only poorly developed.

Medium to coarse sand is generally found on the middle shelf. Most of the mud and much of the fine to very fine sand is exported from the system because it is transported in suspension by the fast flowing Agulhas Current. Some of this material, however, can be found locally in the nearshore zone. The intermittent distribution of fine sand most strongly reflects the multi-modal terrigenous source.

The shore parallel facies zonation initially described on the basis of qualitative side-scan sonor evidence and now confirmed by the sediment dispersal patterns, is particularly well developed between Hibberdene in the north and Waterfall Bluff in the South. The lateral extent and development of each facies is a function of the interaction between sediment supply, the position and height of the midshelf ridge, and the local behaviour of the Agulhas Current. North of Hibberdene, and between Waterfall Bluff and Port St Johns, sediment distribution is controlled by the return-flow eddies of the Natal Gyre system and the Port St Johns eddy respectively. In the northern area the facies sequence follows an oblique north-easterly trend across the shelf. Between Durban and Scottburgh the water shelf palimpsest facies is altogether absent, being replaced by fine to medium sands. Similarly, fine to very fine sand mantles the entire shelf south of Waterfall Bluff, with very fine sand accumulating in the low energy centre of the eddy. The Mfihlelo Spit and the Ilovu Spit represent local bedload sinks, in which large volumes of Holocene sediments are being dropped.

The sediment distribution patterns clearly reflect varying energy regimes across and along the shelf. The degree of overlap between the dominant size fractions reveal progressive lateral mixing between the major hydraulic populations. CM-diagrams suggest that the finer-grained inner shelf sediments are moved in the saltation 2 (S2) mode, whereas the middle and outer shelf sediments move in Saltation 1 (S1) and/or traction modes respectively. A comparison between sediment distribution patterns, their sorting and skewness characteristics and the energy levels indicated by the CM-diagrams strongly suggests that the S2 populations are more closely related to the suspended sediments than to the S1 sediments. Similarly, the Saltation 1 populations associate with the traction populations rather than with the Saltation 2 populations. The results support the notion that CM-diagrams are good indications of relative energy levels in any particular hydrodynamic setting.

Threshold velocities for bedload and suspension movement of the sediment at each sample locality have been calculated using a modified Shields (1936) diagram and the Law of the Wall. It has furthermore been demonstrated that, within limits, it should be possible to predict minimum and maximum current velocities, flow patterns and specific transport modes using threshold criteria in combination with textural data and CM-diagrams. With some additional information on related volume transport this approach could eventually lead to a quantification of sediment transport and depositional processes through time.

ACKNOWLEDGEMENTS

This project was financially supported by the South African Council for Scientific and Industrial Research (C.S.I.R.), the Marine Geoscience Division of the National Research Institute for Oceanology (N.R.I.O.) and inadvertently also Nedbank. The study forms part of the wider CONTINENTAL MARGIN SEDIMENT DYNAMICS programme currently been undertaken at the N.R.I.O. by Dr Burg Flemming and his colleagues and I am particularly grateful to N.R.I.O. for the release of the material used in this study.

Special thanks are due to the master and crew of the C.S.I.R. research vessel "MEIRING MAUDE", as well as the scientific personnel who participated in Cruises 79-24, 80-19 and 83-10. I am most grateful to Ms Marian van den Meiracher, Mr Matthew Smith and Mr Henry Fortuin who assisted me with draughting work, laboratory work and the solution of many computing problems, respectively. Mrs Rose Kovats and Mrs Susan Sayers helped with last minute draughting. I also wish to thank Mrs Betty Knot and Mrs Joan Park, who typed the lengthy tables, and Mrs Grace Krummeck who found the time to type the manuscript. Mr Joe Apollis printed the final thesis.

Various members of the Department of Geology and in particular of the Marine Geoscience Unit at the University of Cape Town deserve special acknowledgment for the general support and stimulation I have received throughout.

From amongst this group I wish to thank Professor Arch Reid for his patience and encouragement throughout my undergraduate years at the University of Cape Town as well as Dr Chris Hartnady, Professor Richard Dingle and Mr Keith Martin for sacrificing much time in fruitful discussions and other forms of spiritual assistance.

Last but not least I wish to thank my external supervisor, Dr Burghard Flemming. He has been unstinting in giving of his time, knowledge and insight into both the science and the art of sedimentology. I am indebted to him for the expert direction and correction I have received throughout the course of this study. Teaching, as Stravinsky once wrote, makes of art a virtue.

Finally, I recall the moral support of friends and family. The former remained friends and the latter could not help remaining family.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES Contd. Page

LIST OF FIGURES Contd. Page

LIST OF FIGURES | Page

LIST OF FIGURES Contd. Page

LIST OF FIGURES (Contd.) Page

LIST OF FIGURES Contd. Page

1. INTRODUCTION

Six years of intensive data collection from the CSIR research vessel "MEIRING NAUDE" along the east coast of Southern Africa has provided a vast amount of geological information in the form of side-scan sonar records, high resolution sub-bottom profiles and sediment samples. Considerable effort has gone into the interpretation of the side-scan sonar data (Flemming 1978, 1980, 1982), but little work has so far been done on the seismic records and the sediment samples. A good opportunity thus presented itself for an in-depth study of the distribution and dynamics of modern shelf sediments.

The study focusses on the shelf sector between Durban ($31^{o}02$`E/$29^{o}50$`S) and Port St Johns ($29^{o}33$'E/$31^{o}38$`S) which covers the smallest of the four sedimentary compartments identified by (Flemming 1980, 1982)(Fig.1). On account of the excellent survey data available from this area it can serve both as a case history and as a model for sediment dispersal within such compartments. The boundaries were chosen such that there is overlap between adjacent compartments. Thus, the shelf section between Durban and Scottburgh, which is dominated by a strong counter current, which forms part of the Natal gyre system, has been included, as well as the area between Port St Johns and Waterfall Bluff. In this way, dynamic processes active in the vicinity of these compartment boundaries can be better highlighted.

Previous studies in this area began with a basic regional description of sediment distribution by Moir (1976) based on

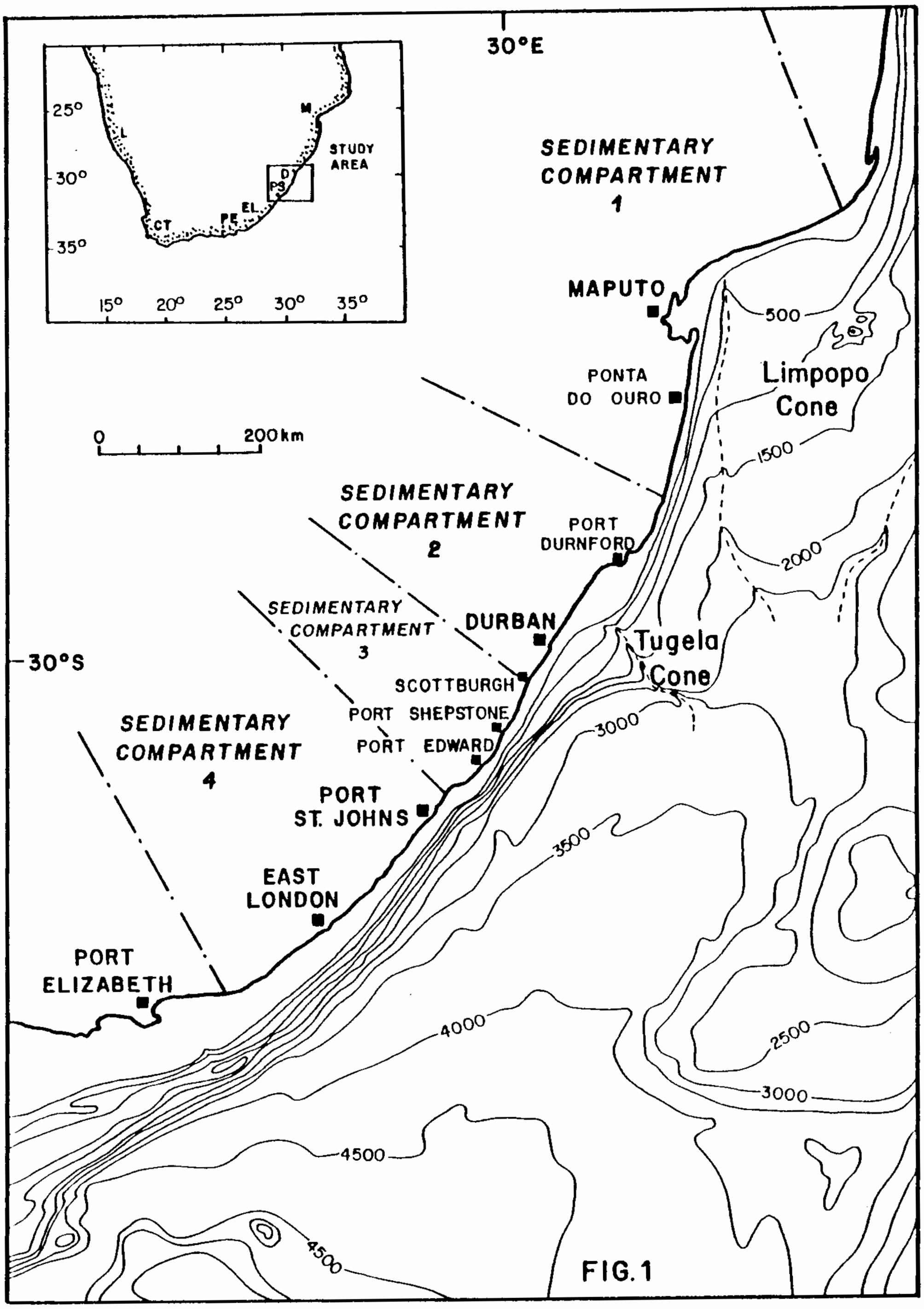
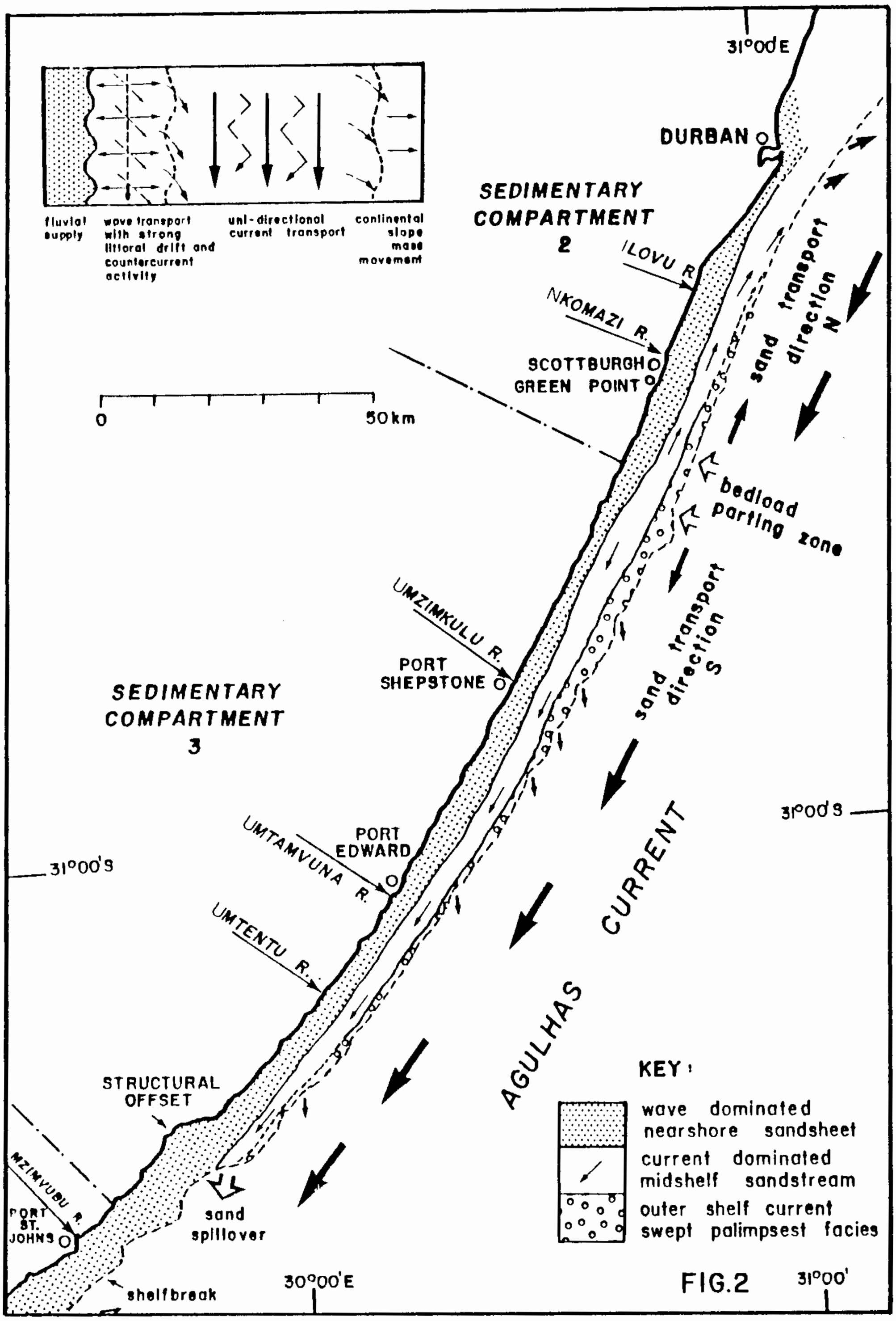


FIG. 1

Regional location of the study area. Note the extremely narrow continental margin and steep continental slope (after Flemming, 1981).

about 40 samples. He divided the shelf into two, more or less shore-parallel provinces on the basis of the carbonate content of the sediments. The outer shelf province was carbonate-rich, with values exceeding 50%, whereas the inner shelf sediments consistently contained less than 50% $CaCO_3$. This model was subsequently refined by Flemming (1978, 1980) after extensive side-scan sonar surveys. While confirming the relationship between the carbonate content of the sediment and water depth as documented by Moir (1976), he further distinguished three process-related sedimentary facies in place of only two lithologically based facies. Thus, a nearshore wave-dominated terrigenous facies, consisting primarily of calcareous quartzarenites was found to grade into a mid-shelf mobile sand facies,characterised by a multitude of current generated bedforms. The sediments from which the bedforms are constructed could consist either of calcareous quartzarenites or quartzose calcarenites. The outer shelf on the other hand comprises a current-swept gravel and coarse sand facies consisting mainly of bioclastic lag deposits.

According to the process-response model of Flemming (1980, 1982) the nearshore sand sheet is thought to be in dynamic equilibrium with the prevailing hydrodynamic regime. As a result, any surplus sediment supplied to this region is constantly being expelled, either by longshore drift and subsequent loss into coastal dunes and other localized depocentres, or by offshore transport where it is eventually fed into the central shelf sand stream. From there the entrained sediment is then transported in conveyer-belt fashion, parallel to the coastline, until a major offset in the continental margin is reached where the current



Major physiographic features of the continental shelf between Durban and Port St Johns. Note the schematic presentation of the bedload dispersal model (inset), (after Flemming, 1978, 1981).

over-shoots the shelf and deposits its load onto the upper continental slope. Each offset in conjunction with the associated eddy systems, defines the boundaries of a sedimentary compartment (Flemming 1978, 1980, 1981). This regional bedload dispersal model is schematically presented in Fig.2 (after Flemming 1978, 1980). Sediment yield calculations (after Flemming and Hay, 1983) suggest that under present environmental conditions some 0,5 to 1,0 x $10^6 m^3$ or 0,75 to 1,5 x 10^6 metric tons of land derived bedload material reaches the shoreline of this study area (cf. compartment 3).

Even though sediment dispersal patterns would obviously be subject to seasonal and possibly much shorter scale variations, one might expect that the sediments should reflect the longterm trends observed in the oceanographic environment. In other words, they should present a picture of the net effect of those hydrodynamic events which regularly or episodically affect sediment supply, transportation and deposition (Swift et al., 1971). It is against this background that the objectives of the present study were formulated.

The main objectives and some key questions which will be addressed in the course of this study are outlined below:

- To describe the sediment distribution on this shelf sector
- Does the sediment distribution in any way reflect the dynamic model based on side-scan sonar surveys?
- Does sediment distribution provide information on dispersal patterns and hence flow structures.
- Can sediment sources, transport routes and sediment sinks be identified?

- What characteristic shelf facies and subfacies can be recognised?
- Can sediment distribution be of use in the prediction of current velocities?
- And finally, to address a fundamental question posed by Robert Ehrlich in a recent editorial, of the Journal of Sedimentary Petrology which is reproduced in full below.

EDITORIAL
SIZE ANALYSIS WEARS NO CLOTHES, or HAVE MOMENTS COME AND GONE?

ROBERT EHRLICH
Department of Geology
University of South Carolina
Columbia, South Carolina 29208

For a long time we have assumed that size frequency distributions contain a veritable treasure-trove of information. Mean (or median) size and measures of sorting have indeed become practical tools. Steadily over half a century papers have demonstrated that still finer nuances of distributions can be evaluated and so, of course, are of value. The present technological revolution in instrumentation and computers carries a threat that shortly we will be inundated by even more papers illustrating even more complex approaches which the authors will regard as Promising. Promises. Promises. . . . Hope springs eternal. . . . "The check is in the mail." A troubling thought inkles its way to the fore. Why don't we routinely use this tool of great worth to help solve the sorts of problems that our field addresses? Have the research objectives that stimulated this approach slowly and unobtrusively evaporated leaving complex size analysis a cure that has lost its disease? If such objectives are still viable, why has no one over the span of more than 50 years stumbled on the right "combination" to achieve them? One certainly can't attribute the lack of success to the intellectual level of practitioners inasmuch as many of our most honored colleagues have taken a hack at the problem at one time or another. The reason lies elsewhere. The time has come to reevaluate the effort, try to diagnose the roots of this unsavory situation. Perhaps the time has also come to stop plaguing generations of students with complex techniques that are never seriously used. It appears to me that their time would be more profitably engaged in tatting.

2. METHODS

2.1 FIELD WORK

All 310 sediment samples were recovered with a shipeck grab sampler in the course of three cruises on the CSIR research vessel the "MEIRING NAUDE". The bulk of the sediment samples (260) between Port St Johns and Durban were recovered on Cruise 81-19. The area immediately south of Port St Johns and the Waterfall Bluff area itself was sampled during an earlier cruise (cruise 79-24). An additional 38 samples were taken between Durban and Port Shepstone on Cruise 83-10 to fill some gaps in the overall sample pattern (Fig.3). In each case up to 800g of material was stored in plastic jars, although in some cases the grab returned empty or with very small amounts. Sample positions were in all cases fixed by radar and/or DECCA.

2.2 LABORATORY WORK

All bulk sediment samples were dialized to remove the salt. Thereafter the entire mud content (less than 63 microns size fraction) was separated by wet seiving. The suspended mud fraction was allowed to settle before the water was decanted and/or siphoned off. In each case the mud was then mixed with distilled water to make up either 1 or 2 litres depending on the amount of mud in the sample. It was thoroughly mixed before being split into four subsamples. The amount of water used in the washing process was carefully recorded. The volume of the largest subsample was measured before it was dried in a pre-weighed beaker. The dried weight was then multiplied up

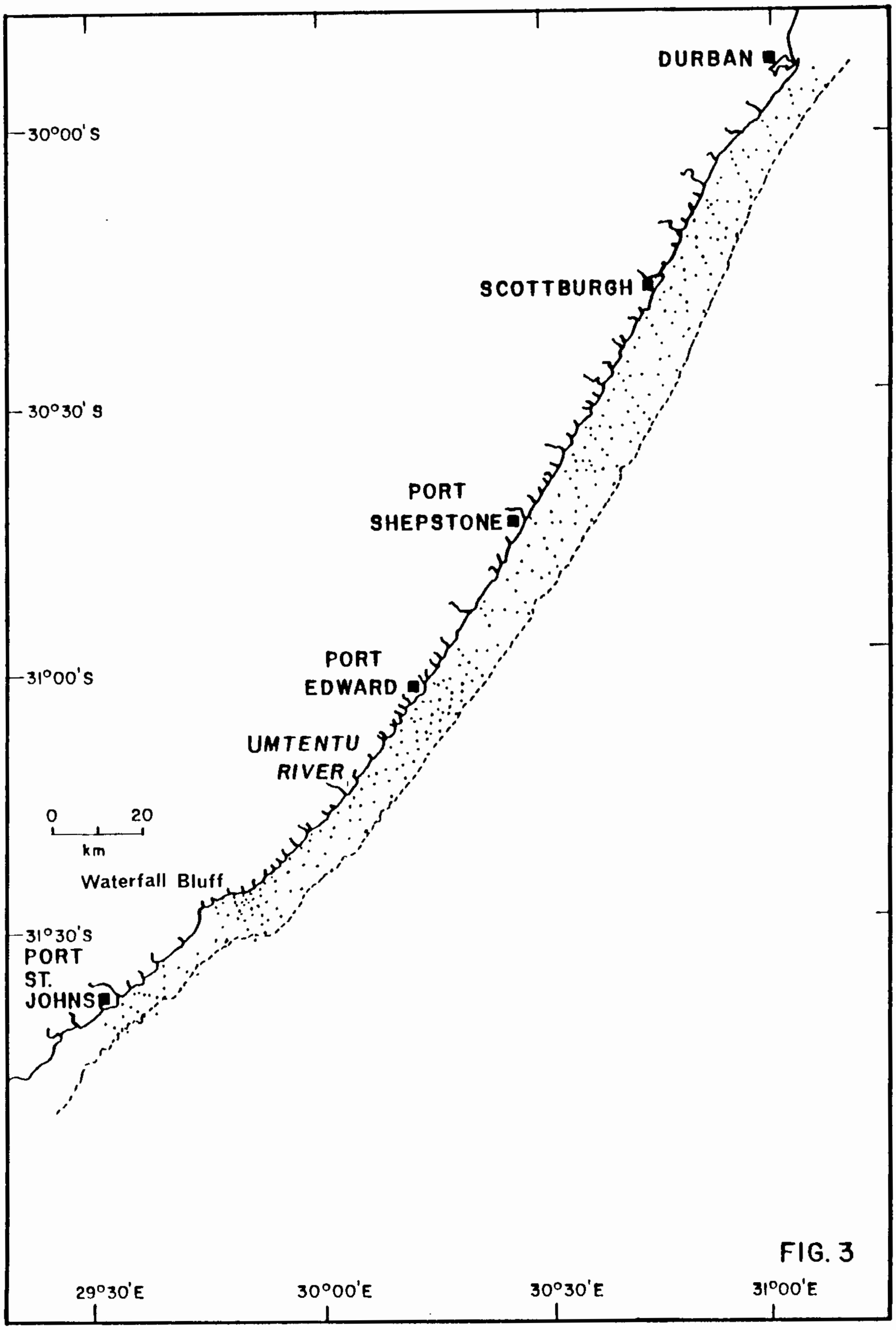


FIG. 3

Sample density on the continental shelf between Durban (31°Ø2'E/29°5Ø'S) and Port St. Johns (29°ee'E/31°38'S).

proportionally to the split volume to give the total percent mud present in the sample. This method assumes 1) that there has been no loss of fines in the operation and 2) that all subsamples have equal proportions of constituents. However, since the volumes involved were relatively large and the number of particles concerned in most cases very large, the statistical error should be negligible. Since the overall mud content in the study area was low, except for two localized areas (viz. the Mfihlelo Spit and the Ilovu Spit), the mud fraction was not analyzed any further.

The material greater than 63 microns was oven dried and sieved through a 2mm sieve to separate gravel and sand (Folk, 1968). Both fractions were weighed and the sand was further split into 3 subsamples: One of 1-2g, one of 2,9 to 3,1g and one bulk sample. In some cases less than 500g of total sediment was available and the gravel component might therefore have been under estimated. Such low-yield sampling localities, however, were invariably situated on the outer shelf which is in any case known to be covered with a gravel lag deposit (Flemming, 1978).

The smaller sand-sized subsample (1-2g) was crushed and reweighed. The "Karbonat-Bombe" (Müller,G. and Gaster, M., 1971) was used on this split to obtain a $CaCO_3$ value for every sample. The accuracy and precision of this method has been vigorously tested by Birch (1981) and was found to compare very well with other, more complicated procedures (cf. Siesser, W.G. and Rogers,J., 1971). Birch (1981) reports an error of only 2% for samples containing more than 10% carbonate material. Over 90% of the samples have a carbonate content in excess of 20%. The

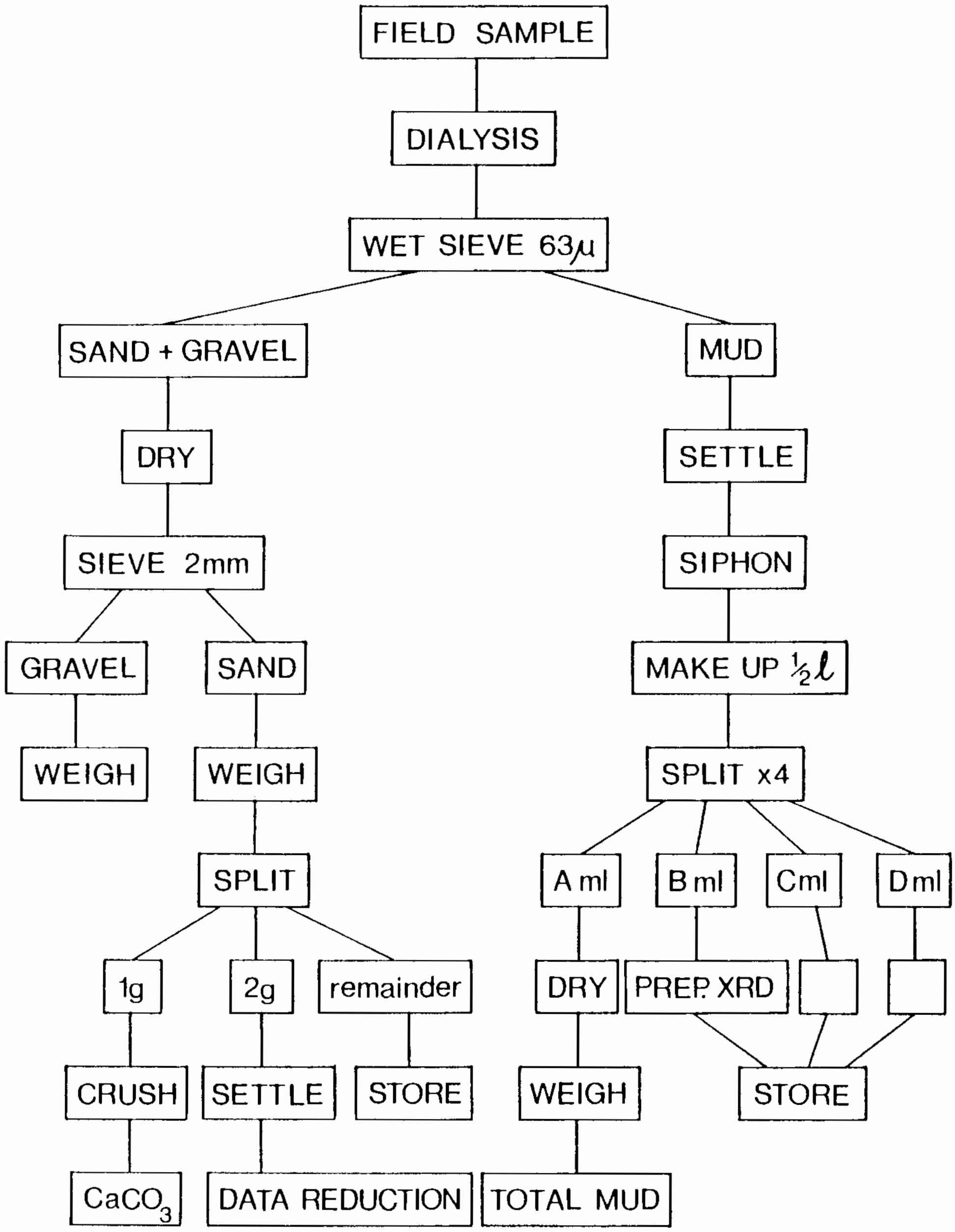


Fig. 4 FLOW CHART OF ANALYTICAL LABORATORY PROCEDURES.

carbonate material was found to be of both modern and relict origin and the distinction between the two components was therefore essential if modern input rates were to be estimated. Relict and modern biogenic material can in fact be easily distinguished under the binocular microscope on the basis of its outward appearance (cf. Koopman, 1979, Wilson, 1982).

The second uncrushed subsample was used for textural analysis. Hydraulic size analyses were obtained using a similar settling tube and procedure developed and described by Flemming (1977). The distribution patterns of the various parameters were hand contoured using the sample station charts as base maps (cf. Fig.1). It should be noted that not every sample station yielded sediment. All those stations at which rocky bottom was recorded and little sediment was retrieved are marked by open circles (see Figs.21, 36, 49, 62 in section 4, also Appendix 1).

The textural data are listed in Appendix I and the geochemical data in Appendix 2. A listing of the computer programme for size-transformation of settling tube data (Fortuin, 1983), including the relevant runstream and an example of the print-out is provided in Appendix 3. A schematic summary of the various laboratory procedures is illustrated in the flow chart of Fig.4.

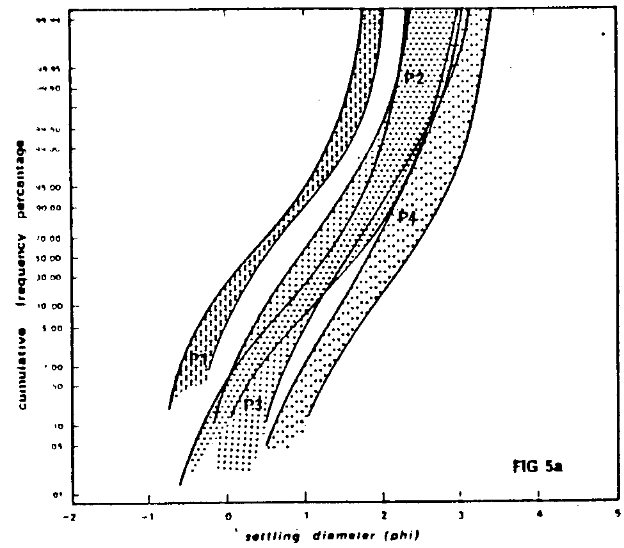
2.3 PROCESS-RESPONSE MODELLING

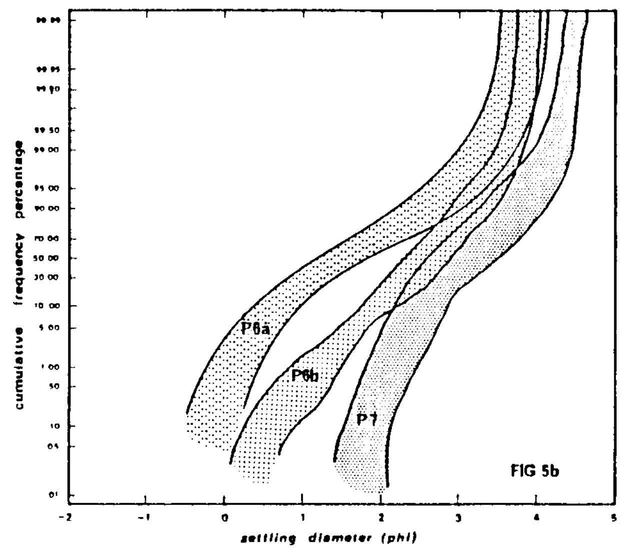
Modern unconsolidated sediments can be regarded as the products of source and environment related factors (Pettijohn, 1957). Whereas sediment sources determine the compositional and textural characteristics of the parent material, the depositional environment reflects the hydrodynamic conditions at the time of deposition as well as the post-depositional physico-chemical and biological milieu (Reineck and Singh, 1973). In order to assess the influence of the former and the effects of the latter it would appear important to identify source or parent sediments and then to observe how this material is dispersed and what textural and chemical modifications occur during transport and after deposition.

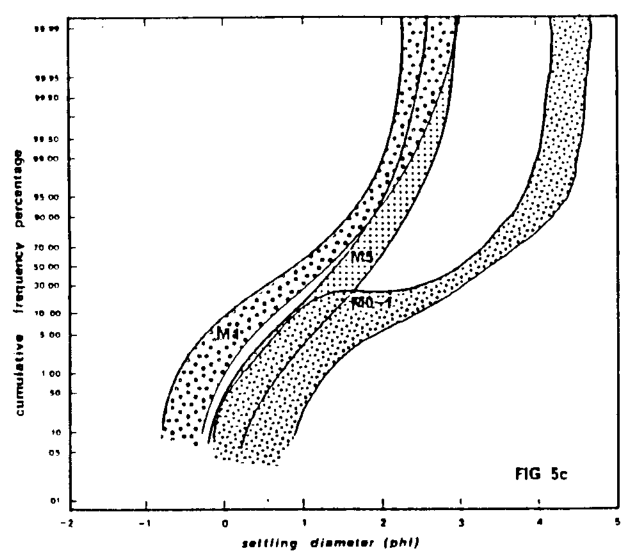
While Flemming (1978, 1980) provided a rational framework for bedload dispersal along the east coast of Southern Africa, he did not at the same time determine detailed compositional and textural characteristics of the sediments, nor how these might have been affected in the course of their dispersal. In order to elucidate such dynamic aspects of sediment dispersal, especially with respect to sediment source, textural characteristics, transport mechamisms and hydrodynamic conditions, a number of process-response models have been applied. These are briefly outlined below.

The distribution of individual size fractions as well as other textural parameters have been individually plotted and contoured. In this manner it was possible to identify major dispersal patterns. At the same time it became evident that there was some degree of overlap between adjacent size fractions, a feature which suggested lateral mixing. To document the mixing process one attempt was made to use the model which was first developed by Folk and Ward (1957) and which was more recently so successfully employed by Flemming (1977). Using this approach mixing between different sediment populations can be recognized by the characteristic trends which emerge when plotting various grain size parameters against each other in three-dimensional diagrams. Such trends can also be recognized on two-dimensional projections if the parent populations are lognormally distributed, but they become increasingly more obscure the greater the parent material is skewed. (cf. Appendix 4).

In the present study, two-dimensional scatter plots did not reveal the expected mixing trends with sufficient clarity to justify their use without multi-dimensional computer processing. Unfortunately the necessary software for such data reduction was not available at the time of this study and thus a simpler, more qualitative approach was chosen in which the cumulative curves of all the sediment samples were superimposed. In this manner several curve groupings could be distinguished whereby the scatter of each group did not exceed a 1-1,5 phi interval and the variation in the tails remained under 10% (Fig.5 and Appendix 4). The least skewed and best sorted populations were in each case labelled as parent populations, representing the least mixed sediments. The most platykurtic and least well sorted curve groups on the other hand, were considered to represent the most mixed sediments. Various combinations of the different parent groups result in composite-curves which reflect the degree of mixing between two or more such parent sediments. Individual parent curve groups, as well as various mixed curve groups, were then plotted and contoured. In this way it could be shown that the overlap between adjacent size fractions corresponded to areas characterized by mixed curve groupings. By adding this dynamic interpretation the procedure outlined above goes beyond the purely descriptive approach previously followed amongst others by





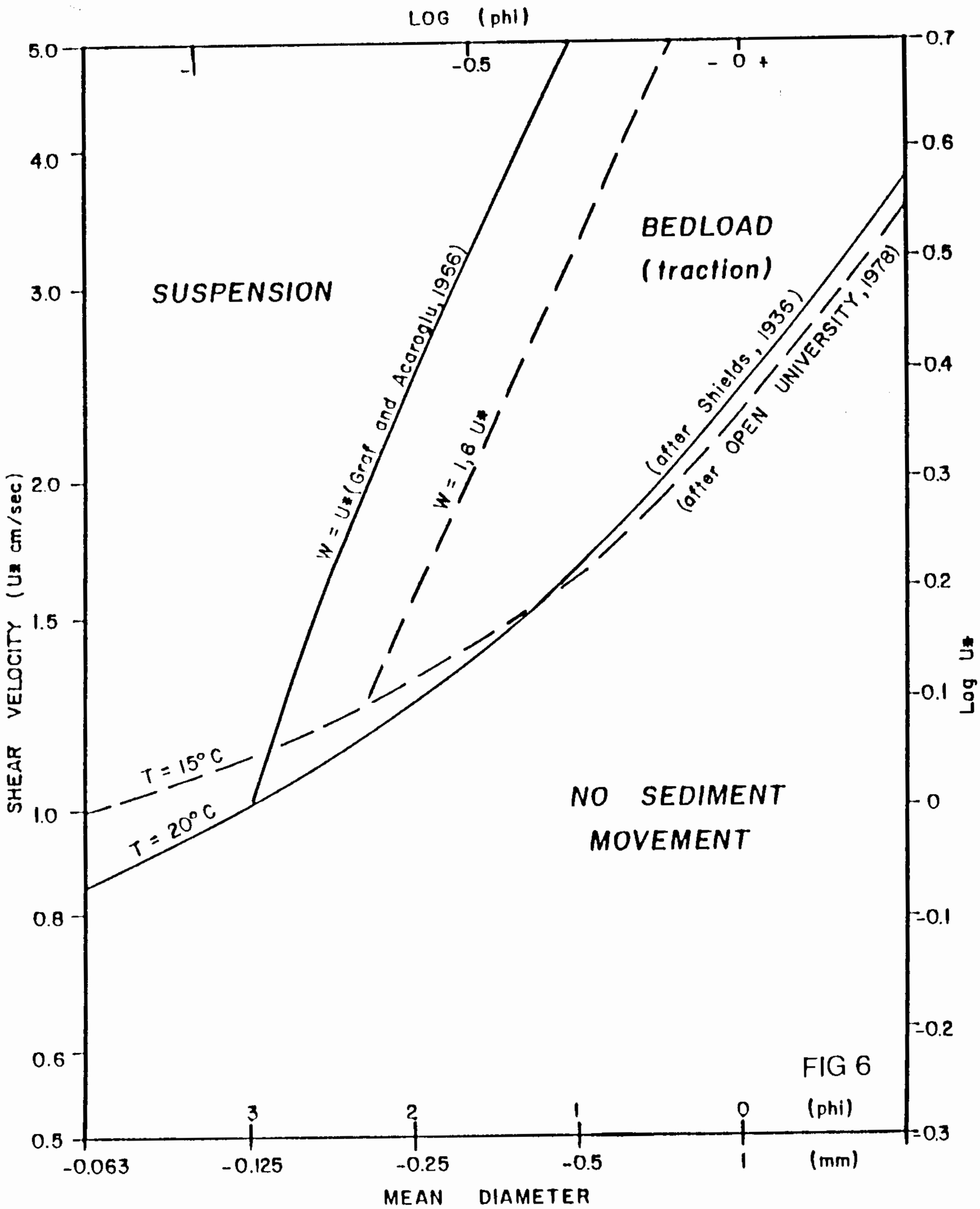


Cumulative curve groupings. P groups represent relatively 'unmixed' hydraulic populations; M groups represent 'mixed', poorly sorted, skewed sediment groups.

Nota (1958), Van Andel and Veevers (1967) and Lessing and Nota (1973).

Having established both the main transport directions of individual hydraulic populations, as well as the interaction between them, it seems logical to estimate the critical flow velocities required to move the sediment at a particular locality and to compare this with actual measured or otherwise estimated flow velocities. This was achieved by converting the dimensionless Shield`s diagram (Shield, 1936) into a more useful form (cf. Blatt et al., 1978) in which mean grain size is plotted against critical shear velocities for a water temperature at 20°C. Two curves representing the bedload criterion and the suspension criterion (after Graf and Acaroglou, 1966), respectively, have been used to read off critical shear velocities for specific grain sizes found at the various sample localities of the study area. Such critical velocity values represent a sensitive criterion for the entrainment or deposition threshold of the sediment. Thus, in areas of obvious erosion and transportation, one should expect higher than threshold conditions, whereas in areas of deposition one should expect conditions close to or below the threshold. Used in this way the critical shear velocities reflect the relative energy conditions at any particular locality on the seabed. The energy conditions required for sediment transport are usually expressed in terms of bed shear stress (τ_o). These are related to shear velocities (U_*) through the equation:

$$U_* = (\rho/\tau)^{0.5} \qquad (1)$$



Modified Sheilds' diagram (after Shields, 1936).

in which ρ is the density of the fluid. In this study preference was given to shear velocities because these are required for the calculation of flow velocities at 4 specific levels in the water column using the logarithmic relationship first observed by Von Kariman and Prandtl (Schlichting, 1956)

$$U_z = 1/k.U_* \ln(Z+Z_o/Z_o) \qquad (2)$$

where U_z is the velocity in m/sec at a specified height above the bed, U_* is the shear velocity in m/sec, k is the Von Karman`s constant (k =0,4), Z is the height above bed in metres and Z_o is the roughness length in metres. When calculating the surface velocities with Z being equal to the water depth (d) at a particular locality, then the equation reads

$$U_d = 1/k.U_* \ln(Z+Z_o/Z_o) \qquad (3)$$

In this case the roughness length Z_o is very small relative to the water depth (d) and by substituting $k = 0.4$ equation (3) can be simplified to read

$$U_d = 2,5\ U_* \ln(Z/Z_o) \qquad (4)$$

Equation (4) was used to calculate threshold velocities at the sea surface required to initiate sediment movement at the seabed. The only problematical variables in this equation remain the roughness length (Z_o) and the von Karman`s constant (k).

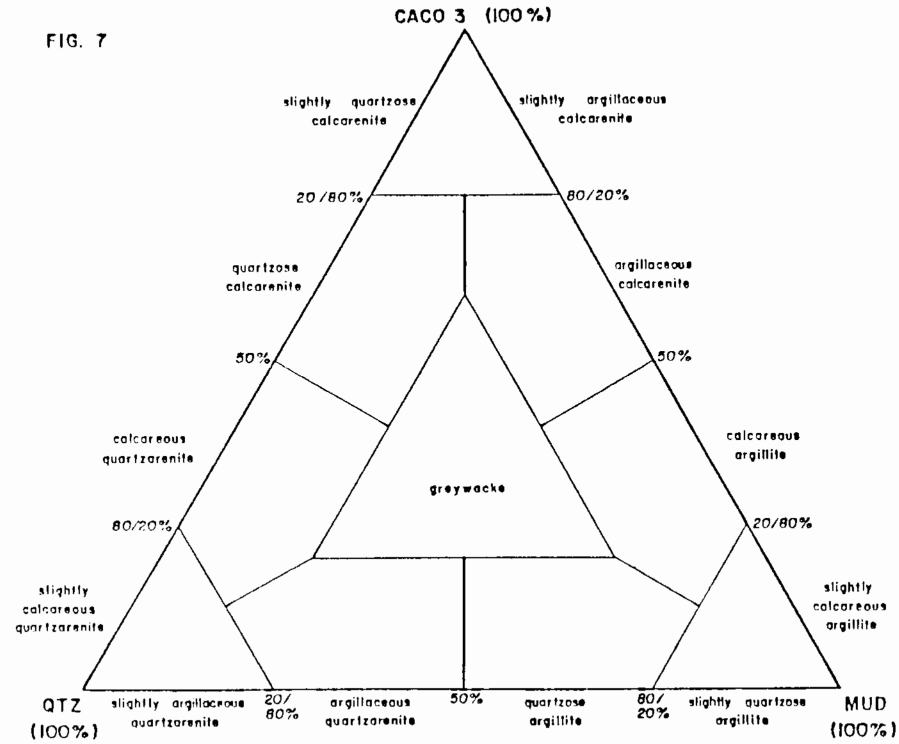
For smooth beds Z_o was found to closely approximate D/30 where D is the mean particle diameter. However, no reliable measures have yet been established for various types of rough beds, i.e. in the presence of bedforms or other roughness elements. Under such conditions Sternberg (1972) suggested the use of a constant drag coefficient of $C_{100} = 3.10^{-3}$ in his quadratic stress law.

This drag coefficient closely corresponds to a roughness length of about Ø,8mm, which indicates that in the case of rough beds the actual grain diameter would appear to be a good approximation of z_0 and in this study D expressed in metres has therefore been used as the best compromise. Furthermore, it was recently found that the von Karman`s constant of Ø,4 strictly applied to clear water conditions only, and that it could be as low as Ø,2 in the presence of highly concentrated suspended material (Blatt et al., 1978). Since the mud content of the sediments in the study area was found to be very low, it was decided that the use of k = Ø,4 would be a safer proposition. In any case when consulting equation (4) it will be noted that an increase of z_0 coupled with a decrease of to some extent counteract each other. As a result the effect on the velocity readings produced by lower values of k would be minimised.

The calculated values of U_d were then plotted and contoured to produce surface threshold velocity maps of the shelf region under investigation. In this form they can be compared with real-time current measurements in order to obtain some measure of the expected levels of sediment transport. It should be noted that in this first approach wave effects as well as tidal currents have been ignored (cf. Komar et al., 1975 and Komar, 1976). Had they been considered, the effect would be to reduce the calculated threshold velocities. A similarly empirical approach based on near-bottom current meter records was recently and independently adopted by Carter et al., 1983.

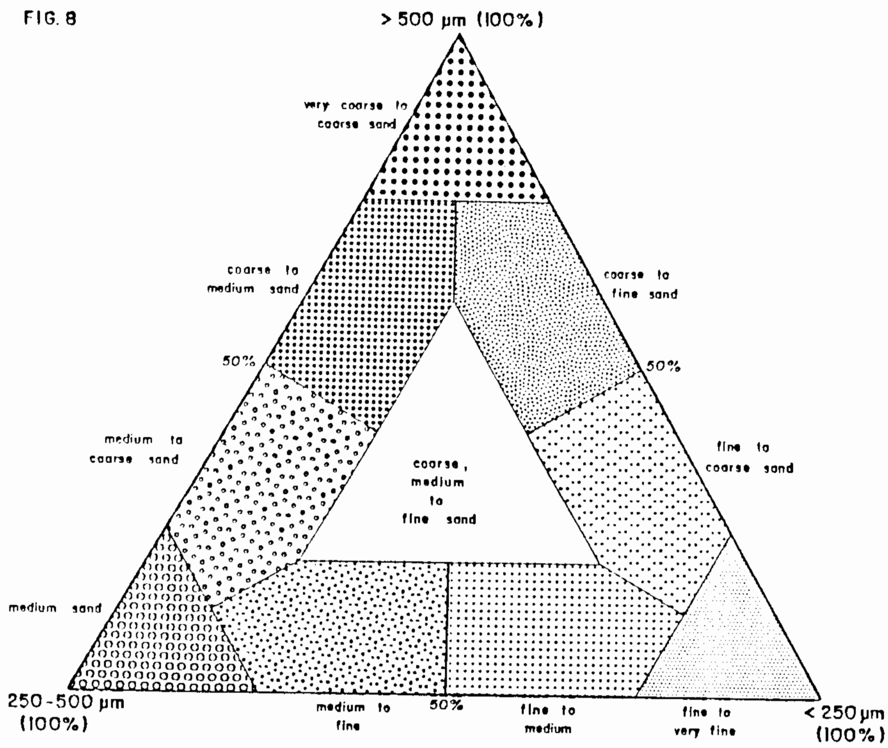
Unfortunately actual current measurements on the east coast shelf are far and few between and marine navigational charts only show

FIG. 7



Lithological classification scheme (after Shepard, 1954).

FIG. 8



Textural classifiction scheme.

the magnitude of order of expected current velocities. As a result it is difficult to estimate actual shear velocities at various localities and to compare these with the threshold values. In order to overcome this problem the empirical approach developed by Passega (1957) has been used to obtain some indication of the relative transport modes of different sediments prior to deposition. Passega (1957) has documented that such transport modes can be inferred from scatter diagrams in which the coarsest one percent is plotted against the mean or medium diameter. Flemming (1977) has demonstrated that this approach can in fact be used to determine relative energy levels by presenting a continuous sequence of inferred transport modes from traction to full suspension which correspond to various energy regimes in Langebaan Lagoon. Such CM diagrams have been constructed and again it could be shown that they corresponded to specific areas of the shelf, comparing well with and thus complementing the critical velocity charts.

Finally, lithologies have been determined by plotting triangular diagrams with $CaCO_3$, SIO_2 (Quartz) and Mud as respective end members. Since the sediments consist predominantly of terrigenous quartz and biogenic carbonate the classification ranges from almost pure quartzarenite through slightly calcareous quartzarenite, calcareous quartzarenites, quartzose calcarenites and slightly quartzose calcarenites to almost pure calcarenites (cf. Fig.7). Similarly, in order to include a textural description, triangular plots have been constructed with very coarse plus coarse sands, medium sands and fine plus very fine sands as end members (cf. Fig.8). Most sediments plotted as fine to very fine through to medium sands on one axis or medium through to very coarse and coarse sand on the other.

3 REGIONAL SETTING

3.1 CLIMATE

The meteorological setting and prevailing weather conditions along the east coast of southern Africa have been extensively described by Schulze (1965), Tyson (1969) and Tyson and Jackson (1971).

The climate of the east coast and its hinterland as well as the offshore wind regime is dominated by the movement of the subtropical South Indian anticyclone. The southern Indian anticyclonic circulation is a dominant feature over the land in the winter. In the summer there is a slight weakening when the high pressure cell moves south through a few degrees latitude (at least 5^{o} according to Taljaard and Davies, 1961).
The region to the south of this anticyclonic circulation system is dominated by strong westerlies associated with mid-latitude frontal depressions which travel eastwards as cyclonic low-pressure systems. It is the combined effect of these atmospheric disturbances which determine local wind patterns, rainfall conditions and the wave climate around southern Africa (cf. Fig.9).

3.1.1 Precipitation

As the fronts, generated in the south Atlantic move eastwards, winds along the coast change from north west to south west (Fig.10a). In summer, the strong temperature inversion produced by the south Indian anticyclone is reduced, moist maritime air is

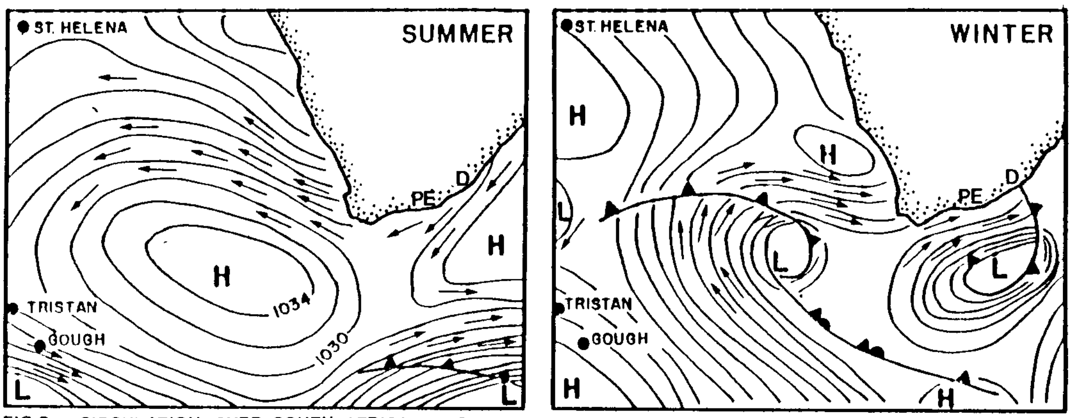


FIG 9. CIRCULATION OVER SOUTH AFRICA TO SHOW THE SOUTHERLY MOVEMENT OF THE SUBTROPICAL SOUTH INDIAN CYCLONE IN SUMMER.

DURBAN WIND PATTERN

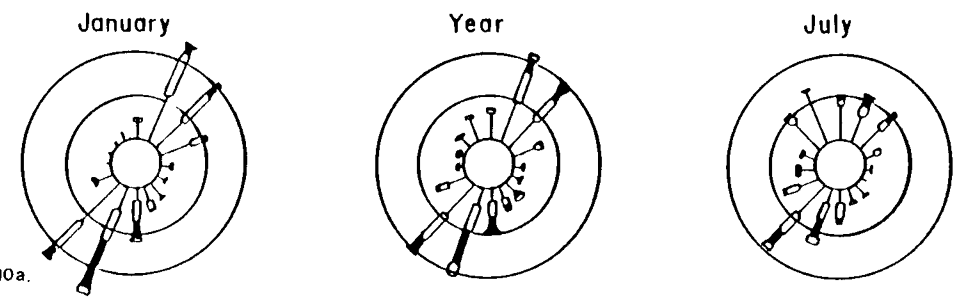
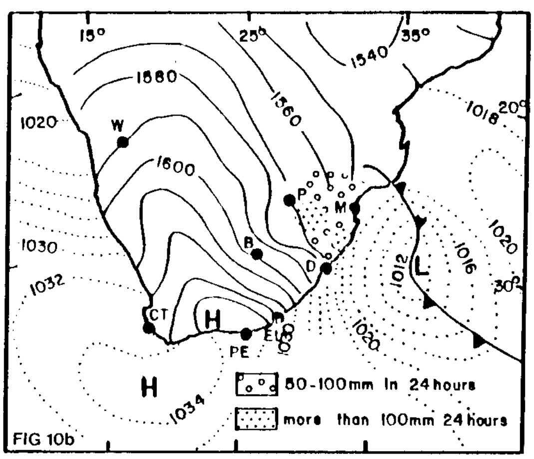
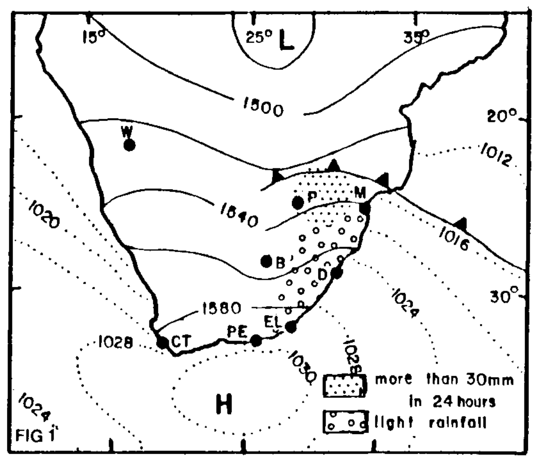


FIG 10a.



SYNOPTIC CIRCULATION ASSOCIATED WITH HEAVY RAINS OVER NATAL AND ZULULAND (3·7·63), (after Tyson,1969).



GENERAL RAINS ASSOCIATED WITH AN ANTI-CYCLONE TO THE SOUTH OF THE SUB-CONTINENT (18·11·67) (after Tyson, 1969).

TABLE I Average monthly rainfall (in mm) on the hinterland between Durban and Port St Johns (after Thompson, 1936)

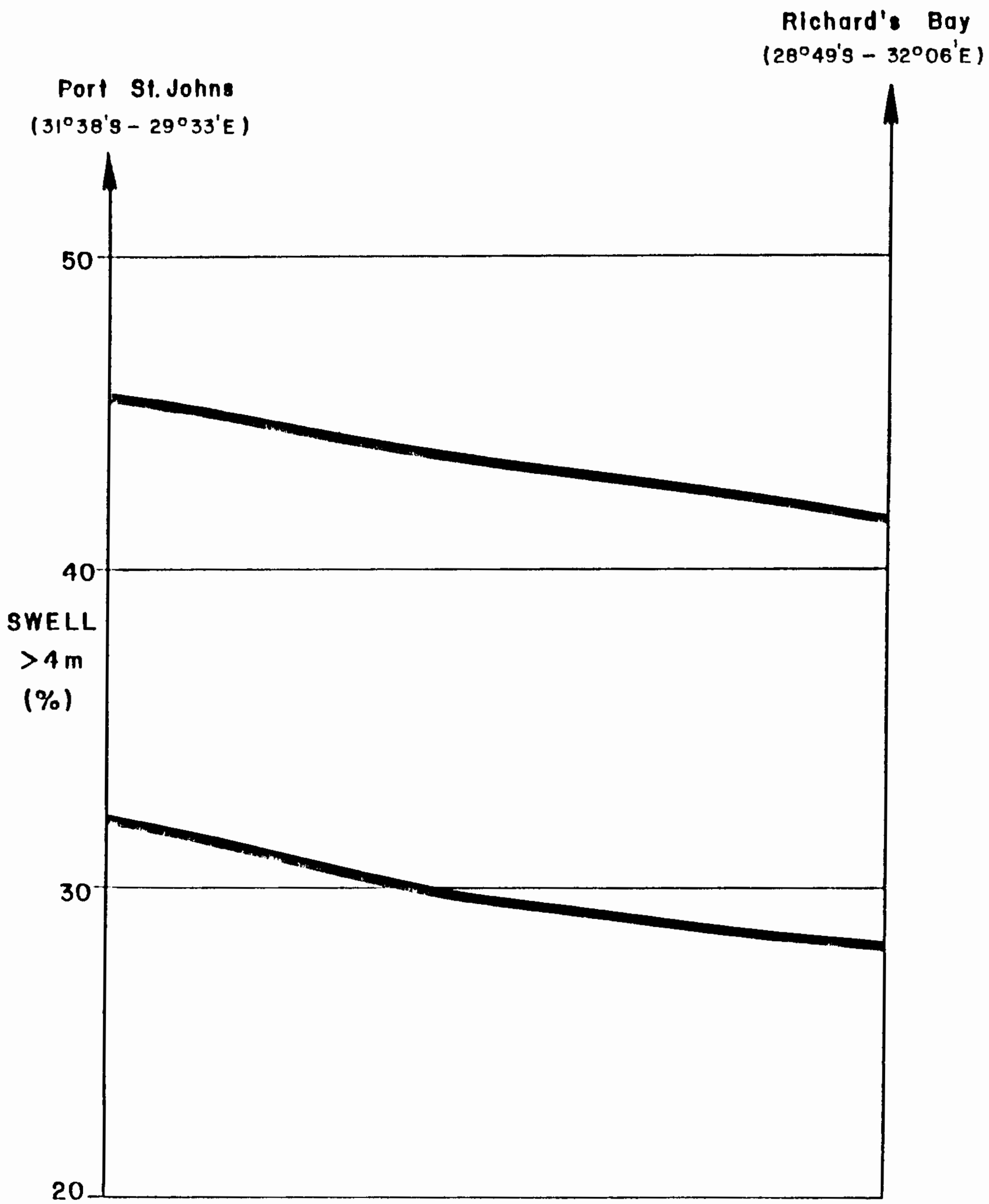
AREA (Rainfall in mm)	J	F	M	A	M	J	J	A	S	O	N	D	Ave p.a	Ave Sum. p.m.	Ave Win. p.m.	% Sum
Coastal plain Port St. John's to Port Shepstone	28,5	28,7	29.7	19.3	13.0	8.4	7.1	12.2	22.4	30.0	26.4	30.2	69.1	19.6	13.5	59
Coastal plain Port Shepstone to Durban	31.0	30.2	32.3	18.0	11.7	4.8	6.9	8.1	16.7	29.5	31.5	32.5	89.7	31.2	11.2	74
Uplands Port St. John's to Port Shepstone	39.6	39.9	35.1	15.0	8.3	4.1	3.3	6.6	13.0	19.8	31.0	38.4	102.9	30.7	8.3	81
Uplands Port Shepstone to Durban	42.2	38.4	33.8	14.0	6.4	2.3	2.5	6.6	12.7	23.6	33.3	38.9	99.6	31.1	11.3	83

able to penetrate inland and heavy showers and thunderstorms frequently occur on the escarpment (Fig.10b, see Pietermaritzburg). Throughout the year, but reaching a maximum in January to April (18% frequency, cf. Tyson, 1969), heavy rainfalls occur along the mountains adjacent to the study area as successive cold fronts move slowly eastwards through the area (Fig.10c). Precipitation, is of course, also influenced by local winds such as the berg and valley winds.

Nearer to the coast, the air circulation is complicated by coastal lows. A low cloud cover accompanied by light precipitation is common after the onset of southwesterly winds, especially in the early summer. Rainfall figures averaged between 1890 and 1936 (Thompson, 1936) are presented in Table 1. These show that up to 83% of the rain in the uplands falls during the summer months (November to March) and that slightly more rain falls on the escarpment than in the coastal regions.

3.1.2 Wave and wind driven circulation

Over the coastal areas, the passage of a cold front is frequently preceeded by low pressure systems (coastal lows). As the combined system moves eastward, the wind directions change rapidly from northwest to southwest, whereby southwesterlies are dominant (cf. Fig.10a). Wind speeds exceeding 8 m/sec (15 knots) are attained with frequencies of up to 60% throughout the year. In late winter and early summer wind speeds greater than 20 m/sec (40 knots i.e. gale force) occur with a frequency up to 20%. In the late summer and early winter such speeds are only achieved



The long term swell regime along the east coast
(after Flemming, 1981)

FIG. 11

with a frequency of 5%. Considering the high frequency of gale force winds, it is easy to understand why Davies (1972) classified the area as a high energy environment dominated by southwesterly swells (see Fig.11). Occasionally heavy swells from the southeast also occur (Flemming, 1980).

The southwesterly gales generate local short-period waves and strong nearshore currents which move in a northeasterly direction, parallel to the coast and against the Agulhas current. The northeasterly winds, on the other hand, can generate similar waves and currents which propagate in the opposite direction in sympathy with the Agulhas current. Such short-term oscillations contribute much to the general unsteadiness of the shelf currents in this region.

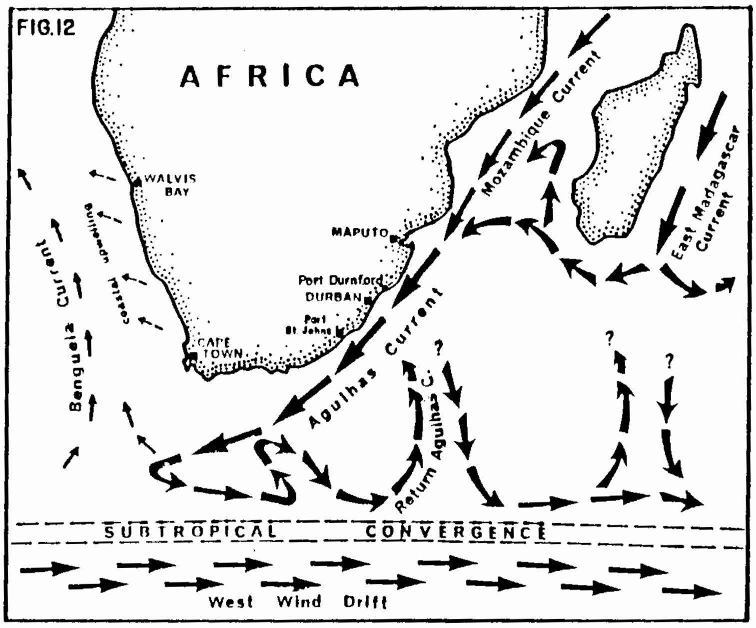
Research by Pearce (1977), Bang and Pearce (1978, Pearce et al. (1978) and Stavropoulos and Duncan (1974) suggests that the clockwise eddies, situated in the lee of the structural offsets (cf. section 3.2) at Durban and Port St Johns should be strongly reinforced by this seasonal wind pattern. Nevertheless, a consistent seasonal pattern for the flow of the Agulhas Current along the east coast of southern Africa has not yet been established. Similarly, any climatic effects on the nearshore circulation have not been quantified.

It should be noted that the frequent occurrence (60% p.a.) of gale force southwesterly winds (20 m/sec), especially in the late winter months (20%), produces a unique combination of factors which influence sedimentation on the continental shelf; for example, most of the rain on the escarpment falls at the same time as the wind generated surface waves and nearshore wind stress currents propagate counter to the Agulhas Current. Furthermore, the rain is of the intense, torrential type, falling in steep and easily eroded terraine, resulting in a large annual supply of sediment to the coast.

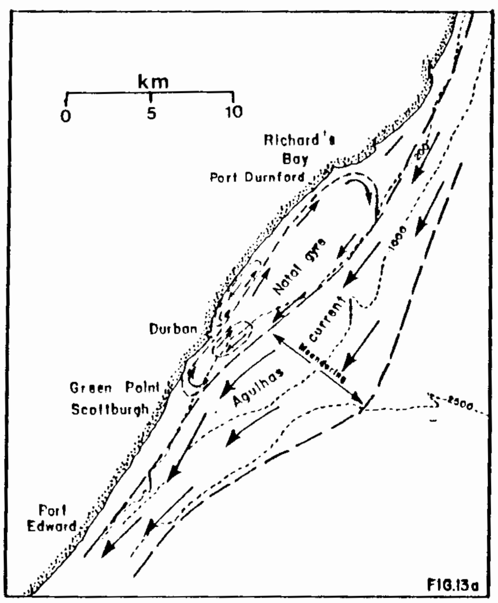
3.2 OCEANOGRAPHY

The study area is dominated by the Agulhas Current, although wind-driven currents and a high swell regime complete the picture. The behaviour of the Agulhas Current, both on a regional as well as a local scale, has been investigated, amongst others, by Darbyshire (1964, 1972), Grundlingh (1977), Pearce (1977), Harris (1978), Harris and van Foreest (1978), Grundlingh (1978), Pearce et al. (1978), Malan et al. (1979), Grundlingh and Lutjeharms (1979) and Schumann (1979). The main features of the regional flow pattern are summarized below, as they provide an essential basis for understanding sediment dispersal in the study area.

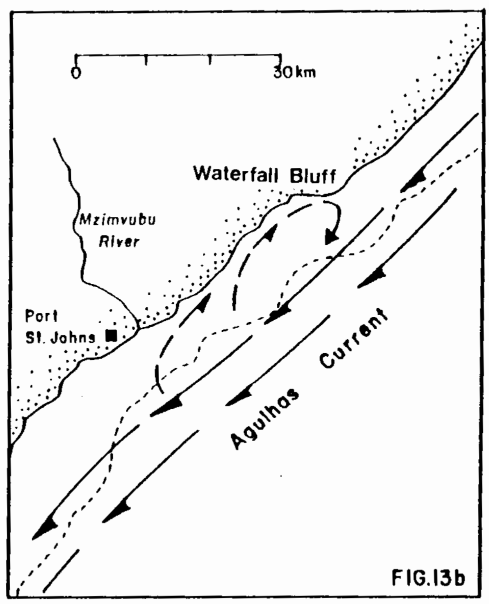
The Agulhas Current is part of the western boundary current system of the Southern Indian Ocean (Fig.12), receiving water from the South Equatorial Current which north of Madagascar, separates into the Mozambique Current and the East Madagascar Current. These currents unite to the east of Maputo to form the Agulhas Current (Duncan, 1974). The core of the Agulhas Current generally flows along the continental shelf break, exceeding speeds of 2 m/sec (4 knots) at times (Grundlingh et al., 1979; Bang et al., 1978). Whereas the surface temperatures vary from 22^{o}C to 27^{o}C (August to March resp.), there does not appear to be



Regional setting of the Agulhas Current (after Flemming, 1981).



The Natal Gyre System (after Moir, 1976, Harris, 1978).



The Port St Johns eddy (after Flemming, 1981).

a corresponding seasonal change in the core velocity (Pearce, 1975).

The core of the current is known to meander widely (Anderson, 1965; Snyman, 1969; Darbyshire, 1972; Bang et al., 1978). Off Durban, the core can be situated anywhere from 15 to 100 km offshore (Pearce, 1974). As a result the current is normally situated much further offshore between Port Durnford and Green Point than either to the north or the south. South of Scottburgh the shelf is very narrow (10 km) and the influence of the current on the shelf is therefore particularly strong. Velocity fluctuations on the shelf are thought to be the result of the combined effects of lateral migration of the current and local wind stress. The main flow of the Agulhas Current is separated from the inshore region by a narrow zone of intense horizontal shear and a strong surface temperature gradient (Pearce, 1975). As a result of frictional upwelling the water on the shelf is several degrees colder than in the core region (Pearce, 1973). This inshore zone is locally characterized by periodic counter currents which persist over a period of up to 6 days (see Table 2). Such regions of flow reversal are associated with eddy systems situated in the lee of structural offsets (Flemming, 1980, see also Fig.13a,b).

Stavropoulos and Duncan (1974) suggested that the northward flow off Durban is part of a large permanent eddy, approximately centred on $31^{o}15'$S and $33^{o}10'$E. Pearce et al. (1978), however, consider it to comprise a succession of eddies existing on a variety of scales which are generated by current shear and meteorological forcing. It has been pointed out that these eddy

TABLE 2 Variation in flow direction in the Natal Gyre System (after Harris, 1978, Schumann, 1979)

	Position	Dist. offshore	% North flowing	% South flowing	% No current
A	Durban	1 km	63	30	7
	Durban	1 - 5 km	45	36	19
			49	28	23
B	Durban	1 km	48	52	
	Amanzimtoti		60	40	
	Umkomaas		44	56	
C	Durban to Green Point	2 km	38	34	28
					Onshore
D	Umkomaas	1	42	51	7
		2	39	43	9,1
		3	47	50	1,5
		4	50	44	3,8
		5	40	50	7,1

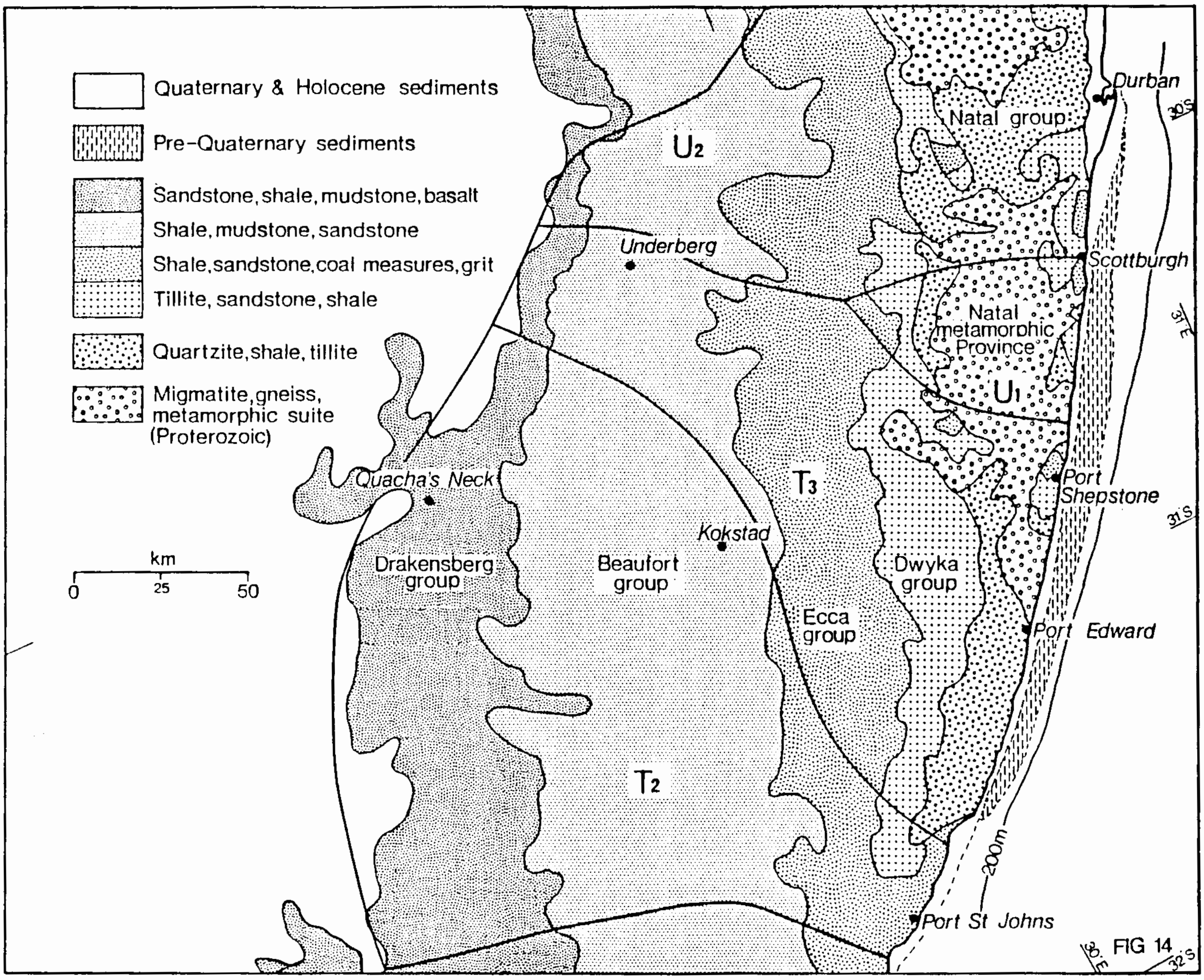
systems respond to the movement of the atmospheric low pressure systems which migrate in a northeasterly direction up the coast (Bang et al., 1978). In fact, Flemming (1980) has demonstrated that the onset of the return flow migrates alongshore over a certain distance in response to local weather conditions. Surface velocities in the Natal gyre system are reported to reach more than 100 cm/sec (Stavropoulos and Duncan, 1974; Schumann, 1979).

The eddy system situated in the lee of Waterfall Bluff has not been as well documented as the Natal gyre system. The offset in the continental margin is considerably smaller than that at Durnford (10 km as compared with 60 km), but the shelf to the north and south of Waterfall Bluff remains very narrow and the core of the Agulhas Current flows very close to the shelf break. Gill and Schumann (1979) have suggested that these return flow cells are probably due to the inherent vorticity structure of the Agulhas Current produced when moving across shallower shelf regions and thereby forcing water to move inshore and then northwards.

The influence of the Agulhas current on the regional distribution of shelf sediments along the east coast of Southern Africa has been qualitatively described by Flemming, (1978, 1980, 1981).

3.3 ONSHORE GEOLOGY AND PHYSIOGRAPHY

A simplified geological map of the catchment area between Durban and Port St Johns is presented in Fig.14. Greater detail may be found on the gravity edition southeastern sheet 1970 (1:2 000



Simplified geology of the hinterland between Durban and Port St. Johns taken from the gravity edition southeastern sheet, Geol. Surv., R.S.A., 197Ø.

000) of the Geological Survey, RSA. It will be noted that the offshore geology differs from that presented by Dingle and Siesser (1975, Marine Geoscience Series 2, 1977) as it was compiled from new seismic records which have in the meantime become available from the area. The new data suggests that the basement rocks are not exposed on the shelf except locally within a few hundred metres of the shoreline. The cross sections in Fig.15 show the geology of the hinterland in greater detail and also illustrate the relationship between geology, topography and drainage. As fluvial discharge is the prime source of terrigenous material along the east coast, the onshore geology is of particular interest with respect to the volumes of sediment supplied to different shelf sections, as well as the hydraulic properties of this material. Both are determined by the nature of the bedrock and its weathering products together with the annual sediment yield through erosion.

The most recent sediment yield budget for the east coast catchment areas is summarized in Table 3 (Flemming and Hay, 1983). The bedload component has been conservatively estimated at 5% of the total sediment yield. It may reach at least 15% in some cases, but no reliable figures are available at this stage. It should be noted that the catchment area U2 includes rivers to the north of Durban and the corresponding figures thus overestimate the supply to the northern sector of the study area. A recalculation, in which the area north of Durban has been excluded, reduces this figure to $3.093 \times 10^6 m^3$.

The rate of erosion is determined, amongst others, by the depth of weathering, the intensity, distribution and amount of

TABLE 3 Annual sediment yield along the east Coast of Southern Africa as a function of catchment area and local sediment production rates

Drainage Region	River System	Catchment area (km^2)	TOTAL ($x 10^6 m^3$)	TERRIGENOUS Susp. load ($x 10^6 m^3$)	TERRIGENOUS Bedload ($x 10^6 m^3$)	BIOGENIC Bedload ($x 10^6 m^3$)	Proportion of input %
T_2	Mzimvubu Umzimvubu Mtafufu Mtzintlava	20 186	5.587	5.308	0.279	0.042	4.20
T_3	Umzimkulu Umtamvuma Mtentu Mzumbe Msikaba Mzambe	14 659	3.512	3.336	0.176	0.026	2.64
U_1	Mpambanyoni Mtwalume	2 927	0.721	0.685	0.036	0.005	0.54
U_2	Umkomaas Illovu Mlazi	16 408	4.124	3.918	0.206	0.031	3.10
TOTAL			13.944	13.247	0.497	0.104	

N.B.

a) In calculating sediment volumes from masses a bulk density factor of 1.5 g/cm^3 has been used. To convert volumes to metric tons simply multiply by 1.5.

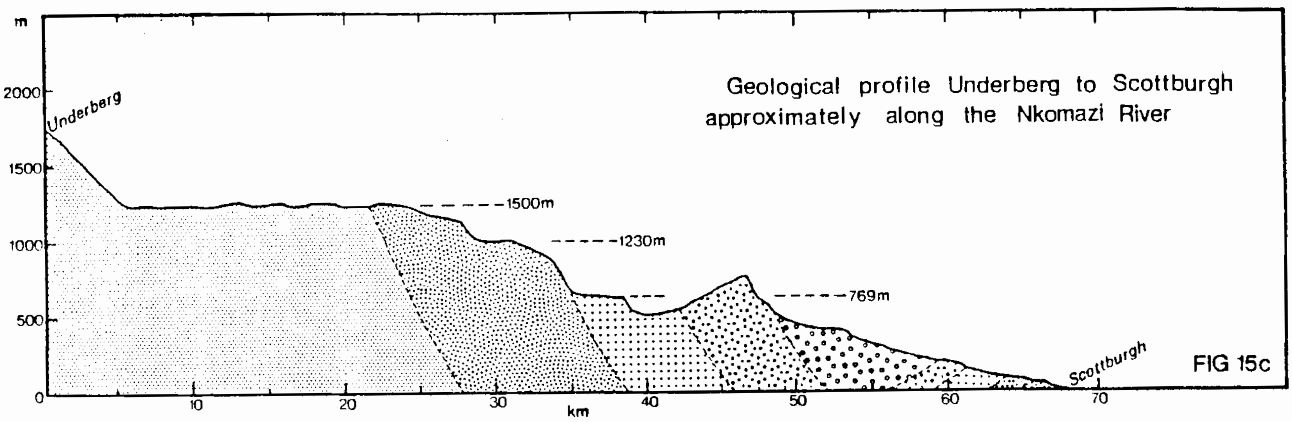
b) For practical purposes the bedload component has been conservatively estimated at only 5% of the total sediment yield. In individual cases it could be as high as 25%, but no reliable figures are available.

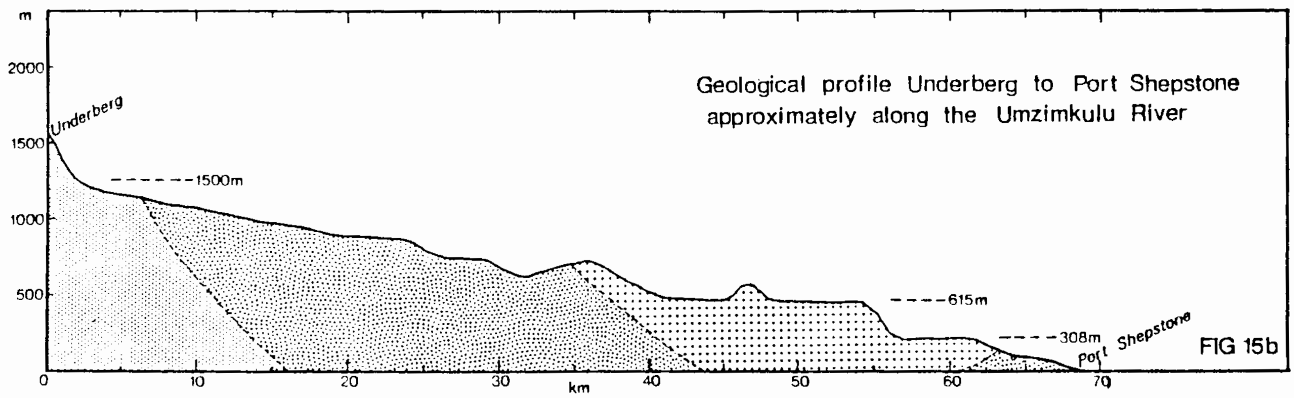
c) The biogenic input has been estimated at 15% of the bedload component, being equivalent to the regional carbonate content of nearshore sediments. This can however be as high as 20 - 40%. See Figures 22, 37, 50, 63.

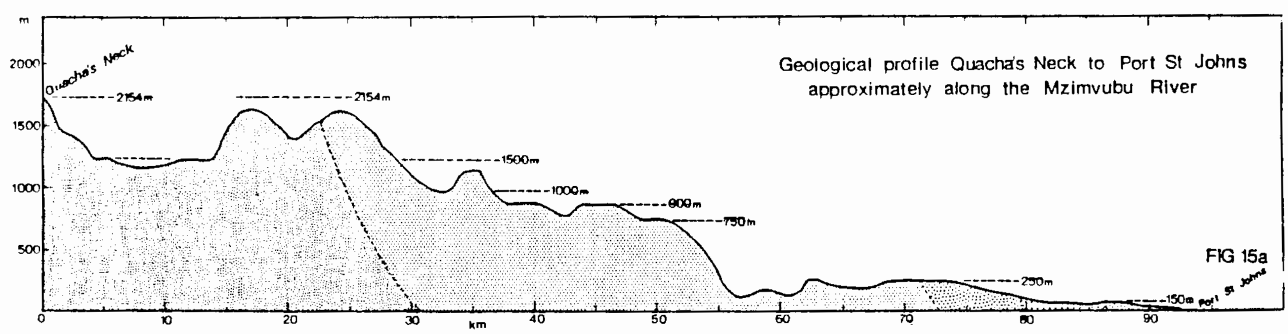
precipitation, the type and density of vegetation and the local topography. It is known that a steep slope erodes considerably faster than a low one. For example, by doubling the flow rate the eroding capacity of a stream is increased 60 times (Thompson, 1936). Thus the torrential summer rains on the escarpment and the highlands ensure a high discharge for the Mzimvubu, the Umzimkulu and the Nkomazi Rivers. On the other hand, the less seasonal and less intense precipitation on the lower, flatter and more densely vegetated coastal lowlands is much less effective. The difference in fluvial discharge is further influenced by the mineralogy and geology of the source rocks which determine the availability of various grain sizes, the topography, the distance between the sediment source and the river mouth and the transport capacity of the river.

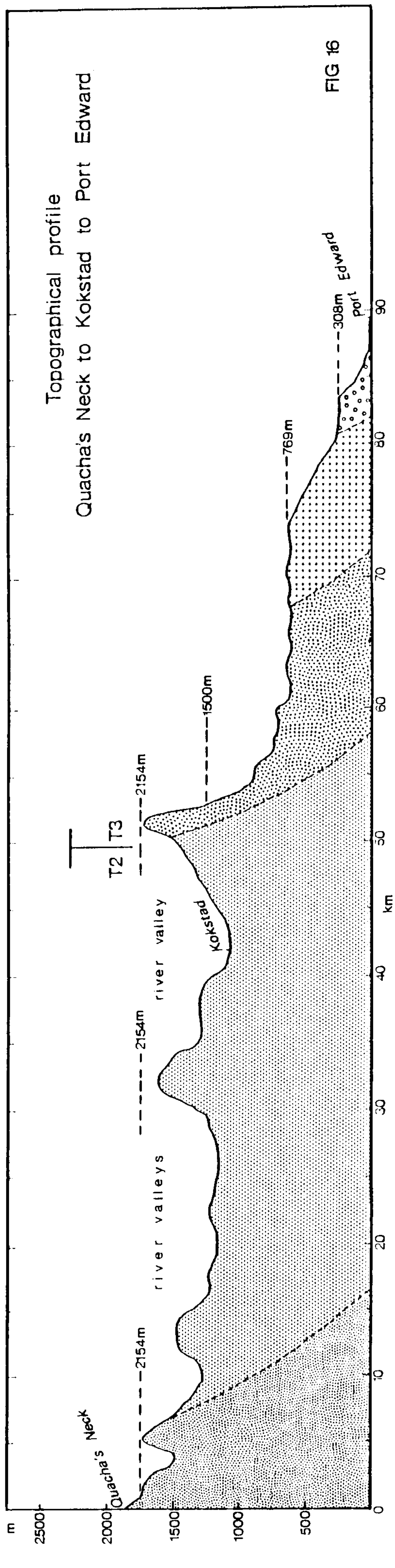
The cross sections in Figs.15 & 16 reveal three plateaux, defined at elevations of approximately 308 m, 769 m and 1500 m. The Drakensberg escarpment rises steeply at 2100 m, whereas the coastal plateau flattens out and broadens to the north and steepens and narrows to the south. Fig.17 illustrates the relationship between river drainage and topography. The three major rivers, the Nkomazi, the Umzimkulu and the Mzimvubu extend inland as far as the 2000 m hight contour. The Ilovu, the Umtamvuma and the Umtentu, on the other hand, barely reach beyond the 1000 m contour on the middle escarpment. The other lesser rivers have the origins along the lowest coastal escarpment, at elevations between 500 and 1000 m.

The topographical, as well as the geological, cross sections (Figs.15) follow the approximate courses of the Mzimvubu


Geological profile Underberg to Scottburgh
approximately along the Nkomazi River
m
2000
1500
1000
500
0
Underberg
1500m
1230m
769m
Scottburgh
10
20
30
40
50
60
70
km
FIG 15c


Geological profile Underberg to Port Shepstone
approximately along the Umzimkulu River
m
2000
1500
1000
500
0
Underberg
1500m
615m
308m
Port Shepstone
10
20
30
40
50
60
70
km
FIG 15b

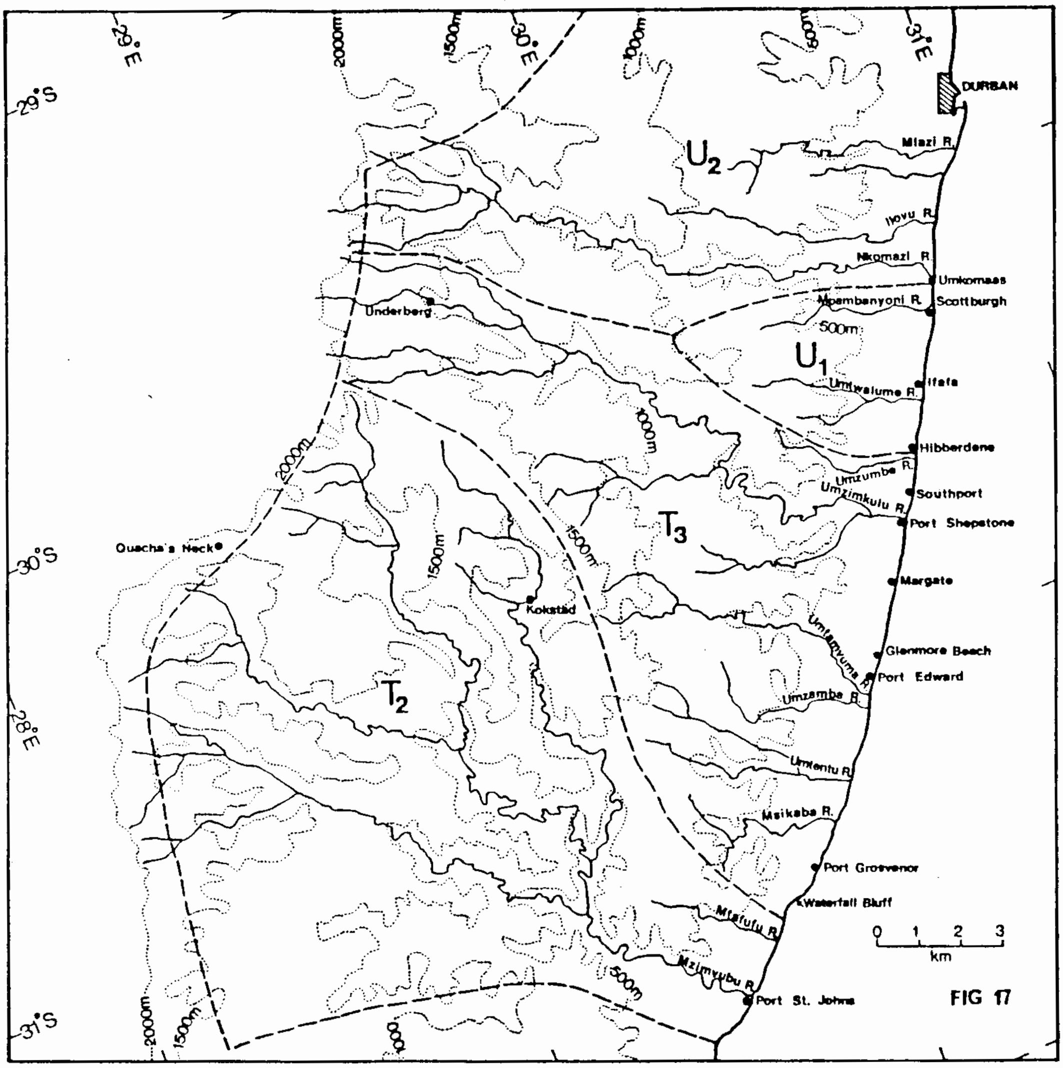

Geological profile Quacha's Neck to Port St Johns
approximately along the Mzimvubu River
m
2000
1500
1000
500
0
Quacha's Neck
2154m
2154m
1500m
1000m
800m
750m
250m
150m
Port St Johns
10
20
30
40
50
60
70
80
90
km
FIG 15a


Topographical profile
Quacha's Neck to Kokstad to Port Edward
FIG 16
Quacha's Neck
2154m
river valleys
2154m
river valley
Kokstad
T2
T3
2154m
1500m
769m
308m
port Edward
m
2500
2000
1500
1000
500
0
10
20
30
40
50
60
70
80
90
km

(drainage area T2), the Umzimkulu (drainage area T3) and the Nkomasi River (drainage area U2). The cross sections indicate the type of source material in conjunction with the topography. These three major river systems drain extensive areas of steep and undulating topography. The preferential sediment source areas consist of the easily eroded, fine-grained shales and mudstone of the Beaufort and Ecca groups. In its upper reaches the Mzimvubu also drains the sedimentary sequence of the Drakensberg Group. These comprise the largely argillaceous sequence known as the Molteno Red Beds and the Cave Sandstones. The latter is a very fine-grained sandstone with intercalated siltstone. Clearly, the bulk of the sediments being discharged into the sea by these rivers, especially the Mzimvubu, are predominantly fine to medium grained.

Those rivers which have their origin along the middle escarpment north of Port Shepstone, such as the Mlazi and the Ilovu, drain primarily the sandstones of the Natal Group (Cape Supergroup) and the Proterozoic granulite-gneiss schists of the Natal metamorphic and structural province. These rocks are mostly coarse grained and, being more resistant to erosion, form elevated plateaux. These rivers will have considerably lower sediment yields and the sediment supplied to the adjacent shelf areas will be largely medium to coarse grained.

South of Port Shepstone however, rivers like the Msikaba, Umzamba,Umtamvuma and the Umtentu drain the Ecca and Dwyka groups of the Karoo Supergroup as well as the Natal Group. Much of the sediment brought down by these rivers must be derived from the Ecca Group, more particularly the Middle Ecca and the Northern



Topography and river drainage on the hinterland between Durban and Port St. Johns (Topographical edition; Durban SE 31/28, Queenstown SE 33/66).

facies of the Upper Ecca (Truswell, 1970 and Tankard et al., 1982). These rocks are predominantly fine-grained shales and greywackes, interspersed with some coal measures. Such source rocks would yield a wide range of grain szes, which would inevitably become size-sorted before they reach the sea, especially along the larger and longer river sytems. The Umtamvuma near Port Edward and the Ilovu River north of Scottburgh drain the Beaufort group in their very upper reaches.

The other rivers referred to in Table 3 are rather short with very limited catchment areas. They flow across relatively flat terrains (cf. Fig.16), draining the harder and more resistant rocks of the Dwyka and the Natal Groups south of Port Shepstone and the Natal Group and the Natal metamorphic province north of this town. It should be noted that south of Waterfall Bluff even the smaller rivers drain sediments of the Ecca Group (cf. Fig.14).

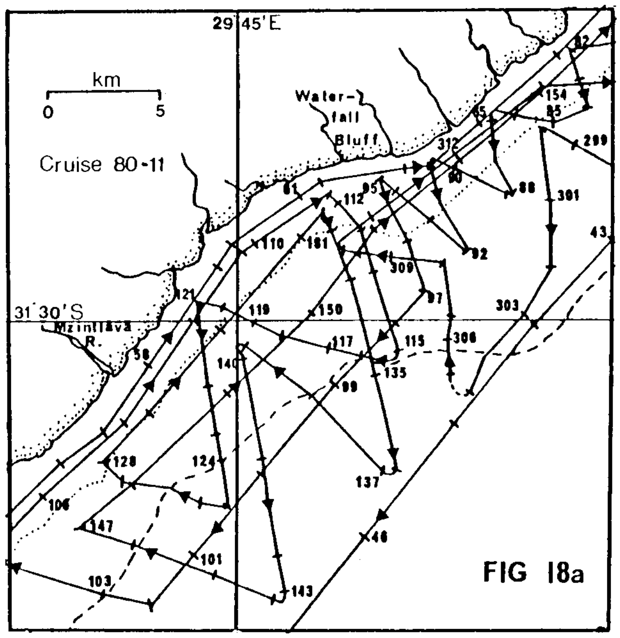
From the above it is clear that the shelf between Durban and Port St Johns should essentially have a bimodal, terrigenous sediment input in terms of both particle size and rate of supply. North of Ilovu Beach, between Scottburgh and Port Shepstone and between Port Shepstone and Port Edward, fluvial discharge should be considerably less and the actual sediment should be much coarser. Between Port Edward and Port St Johns the sediment supply should again be reduced, but the sediments should now be finer.

3.4 OFFSHORE GEOLOGY AND PHYSIOGRAPHY

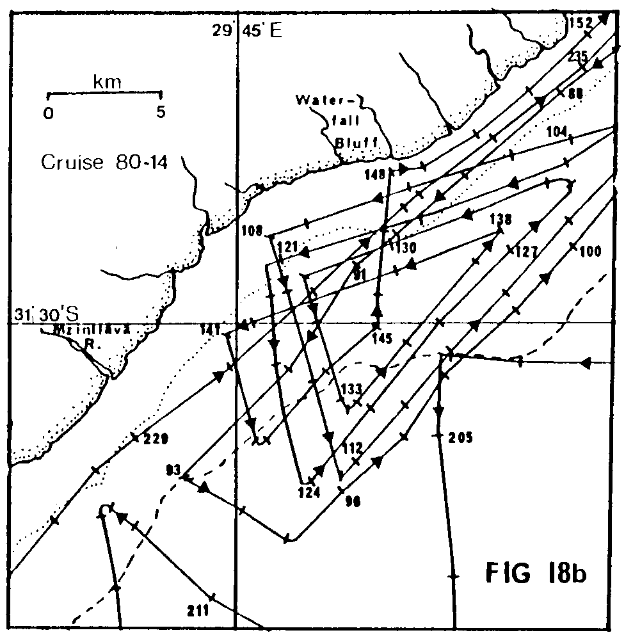
The bathymetry of the east coast has previously been compiled and described by Birch (1981). The bathymetric maps used in this study, however, were redrawn by contouring the South African Navy Fair Charts (SAN 23, 20, 21, 19, 18). Contrary to the approach followed by Birch (1981) the fathom soundings were first metricated and the contours were then drawn at 2 m intervals. These contours were smoothed and in cases of doubt cross-references were made to bathymetric records obtained on various cruises of the R.V. MEIRING NAUDE (24-79, 81-19, 82-19, 83-10). The isobaths between chart SAN 21 and Chart SAN 23, i.e. north and south of Waterfall Bluff, do not coincide. As already observed by Birch (1981), there is a 10 m discepancy along individual lines, possibly reflecting a base-level error in the data collection or conversion. To overcome this, the bathymetry in this area was contoured using recent bathymetric data. Track charts showing the extent of the bathymetric coverage are presented in Fig.18. The bathymetry has been divided up into four individual maps which are reproduced separately in Appendix IV. They are contoured at 2 m intervals on a chart scale of 1:150 000. The same sections are reproduced on a much smaller scale in Figs.20, 35, 48, 61.

3.4.1 Morphology of the continental margin

The general morphology of the continental shelf between Port St Johns and Durban has been described by Birch (1981, 1982) and Flemming (1981). Birch (1981) noted that the Durban-Waterfall Bluff section of the coastline is regular and sub-parallel to the



Seismic coverage in the
Waterfall Bluff area
(Cruise 8Ø-11; N.R.I.O.).



Seismic coverage in the
Waterfall Bluff area
(Cruise 8Ø-14; N.R.I.O.).

shelf break and that, over most of the study area, the shelf itself is of regular width, trending south to southeast. The shelf is exceptionally narrow (cf. Fig.1). In the study area the width varies between 4 km and 12 km (world average 75 km, Shepard, 1963). In addition the continental slope is very steep, reaching values of 6-16^{o}, which are up to 2 to 4 times that of the world average (3-4^{o}), whereas the shelf break at about 100 m is considerably shallower than the world average of 130 m.

Birch (1981) estimated the deviation of the coastline from a straight line drawn between two arbitrarily chosen end points and compared this with a second line drawn parallel and 10 km seawards of the shore, calculating the deviation of the shelf break from this line. This approach , however, cannot reflect the genetic origin of the coast. The shape and orientation of the continental shelf and slope is more probably the result of the separation process of the African plate from the South American plate by transform faulting along the Agulhas fracture zone (Scrutton, 1973, Martin et al., 1981 and numerous others). Such movement often results in a continental slope that is steep and regular. With the exception of the major offsets northeast of Durban and at Waterfall Bluff this feature is characteristic of the entire east coast.

As there is no evidence of Early Cretaceous compression along this part of the plate boundary (Martin et al., 1981; Smith, 1982), a smooth strike-slip motion is assumed to have occurred. Using the most recent best-fit model between the African and the South American plates presented by Martin et al. (1981), it can be demonstrated that the continental separation came about by rotation of 1,65^{o} about the pole 6^{o}N 2^{o}W, describing a small circle. The trend of the shelf break and the coastline closely parallels this small circle.

3.4.2 Morphology of the continental shelf

Birch (1981) distinguishes an inner shelf (0-50 m), a middle shelf (50-70 m) and an outer shelf (-70 m to the shelf break). Flemming (1981) divides the shelf platform into a nearshore and an offshore physiographic zone separated by a "drowned and partly reworked Pleistoceone sediment ridge" which lies at water depths of between 40 and 60 m (cf. Fig.19).

The positions of these isobaths relative to each other and relative to the shoreline, however, vary markedly and the topographic character of the shelf therefore changes considerably from place to place. Detailed aspects of the bathymetry have been described in the relevant subsections of Chapter 4, whereas the main topographic features and their influence on the Agulhas Current and sediment dispersal are outlined below.

The morphology of the shelf is strongly influenced by the presence or absence of surficial sediments. This is a function of sediment supply and sediment dispersal. A major control factor of sediment dispersal is the drowned coastal dune ridge on the central shelf (Birch, 1979, 1981; Flemming, 1980). It is interpreted by Flemming (1981) as representing the remains of an indurated coastal dune cordon. It reaches at least 25 m above the sea bed in places and is nearly continuous between Durban in the North and Port Grosvenor in the south; a distance of 195 km.

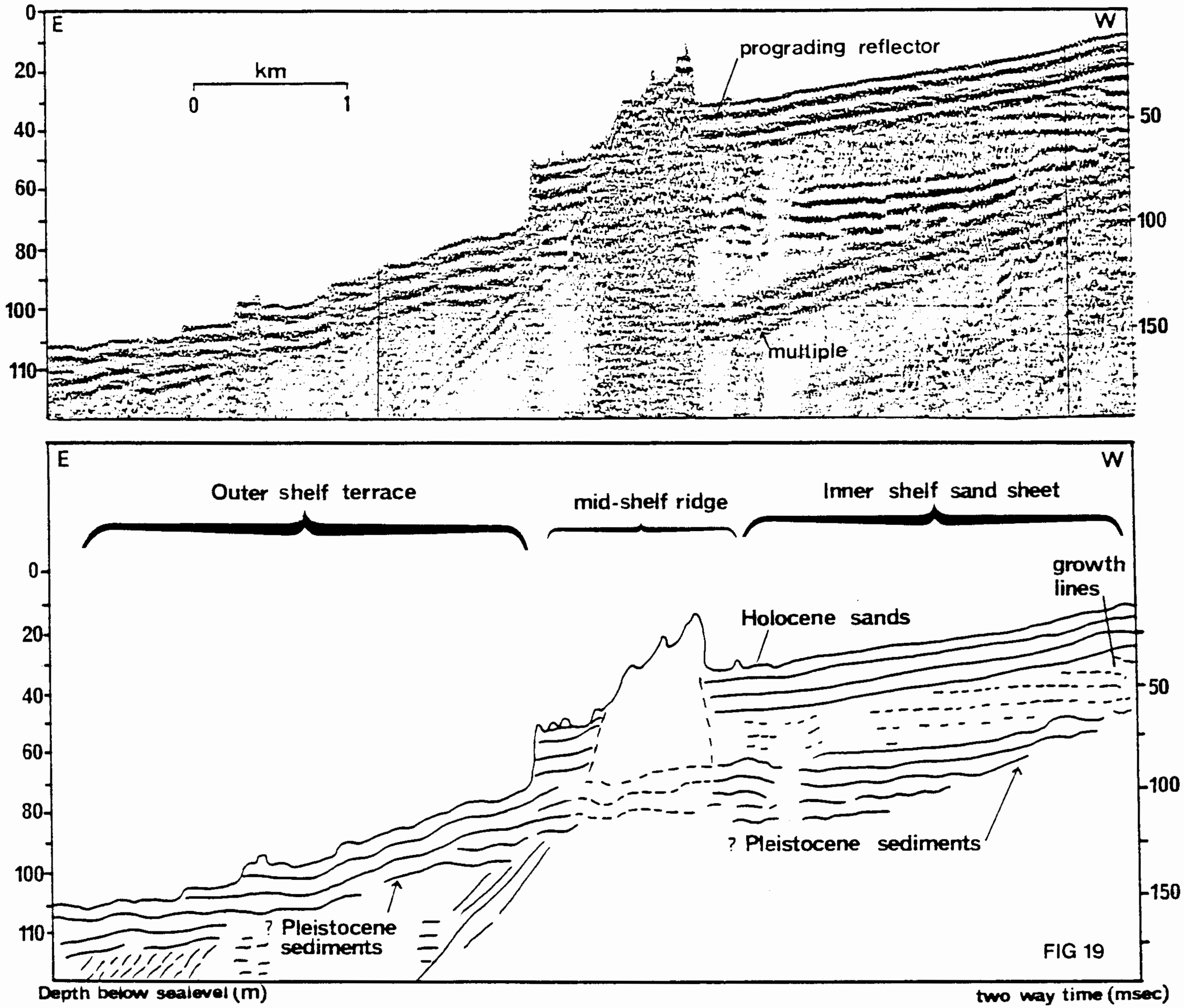


FIG 19

Seismic section across the shelf north of Port Shepstone (Cruise 8Ø-14; N.R.I.O.).

Locally, it forms an effective barrier to cross-shelf sediment dispersal, as well as limiting the influence of the fast flowing Agulhas Current on its shoreward side.

As a result of gradual sediment accumulation (4-25 m) on the shoreward side of the ridge since the last transgression, the inner shelf described by Birch (1981) is in general a gently undulating and uniformly sloping (0,5-1,5°) feature which is 1,9 to 6,0 km wide and lies above -40 to -50 m. Sediments of up to 25 m thick (Birch, 1979) have been trapped behind the ridge in places e.g. Ilova to Ifafa (see Fig.4.1, line 392/167, Birch, in press) and are known to have overtopped the dune cordon off Umzinto Bay. In such areas the sea floor is particularly smooth. Elsewhere, where the dune ridge is both wide and high and/or sediment supply is low, the inner shelf is very much narrower and the sea floor is rougher e.g. Hibberdene to Port Edward.

A prominent feature of the inner shelf in the northern sector is the broad, arcuate terrace between Ilovu and Scottburgh. It extends 5,2 km offshore at its widest point and is broadly outlined by the 30 m isobath. The Aliwal Shoals lie on the southern edge of this feature between -20 and -30 m, forming part of the reworked Pleistocene ridge (Flemming, 1981). Here the ridge rises 25 m above the sea bed.

The topographic expression of the ridge also dominates the middle shelf. The distance offshore, the width and the height above the seafloor of this feature varies considerably. It follows a curvilinear path, approximately parallel to the 60 m isobath from Durban, where it is 2,5 km distant from the Bluff, to 3-4 km offshore at Port Grosvenor, where it terminates beneath the nearshore sediment wedge. It is situated 8 km offshore between Margate and Port Shepstone in the central region. Here the ridge is particularly well developed and is exposed as the Protea Shoals. These are 25 m high and 4,1 km wide (Birch, 1979). The ridge also reaches a substantial height off the Msikaba River, rising 16 m above the sea bed.

Elsewhere the ridge has been overtopped by sediment or, as between Durban and Ilovo, off Port Shepstone and between Margate and the Umtentu rivers, it is seldom higher than 5 m and generally only between 2 and 4 km wide. In some places it is missing or strongly fragmented (e.g. south of Port Edward) or present only as a topographic irregularity. The importance which the ridge has on sediment dispersal is especially well demonstrated by the development of the sandwave system south of Port Edward where the ridge is entirely absent.

Birch (1981) has described a second discontinuous, 10-15 m high ridge situated near the shelf break between Scottburgh and Hibberdene and off Port Grosvenor. Its exact geological nature is still unclear and there are indications from elsewhere along the shelf that these elevated areas on the outer shelf are not superimposed features, but eroded parts of the underlying strata (Flemming, pers. comm.). As little sediment reaches the outer shelf in these areas, these outer shelf irregularities are unlikely to influence modern sediment dispersal. They might to some extent `channel` the flow of the Agulhas Current and the increased roughness of the seabed would certainly produce additional turbulence in the nearbottom flow.

The offshore distance of the main ridge system, however, clearly influences the width and character of the outer shelf. This physiographic zone is best developed in the form of two large arcuate-shaped terraces of uneven topography between Scottburgh and Port shepstone and from the Umtentu River to Waterfall Bluff. South of Waterfall Bluff, beyond the offset, the terraces are smaller and lie below 100 m, while to the north they lie between -70 and -100 m.

From Ifafa to Margate the dune ridge is generally well developed as it shifts gradually offshore leaving a major gap only before it joins up with Protea Banks to the east of Port Shepstone. Conversely, the outer shelf terrace narrows progressively from 4,8 km at Ifafa until it terminates abruptly against the Protea Banks off Port Shepstone.

South of the Msikaba River, below -70 m, the topography once more becomes irregular. This southern terrace reaches a maximum width of 5,9 km. It terminates abruptly at the structural offset in the shelf break. The smaller Mbotyi and St Johns terraces, situated to the south of the offset, are most likely a continuation of the same feature, being both offset to the west and deeply dissected by the Mbotyi, the Mzimvubu and the St Johns canyons.

It is here suggested that all of the terraces are an expression of strong current action which prevents sediment deposition in these areas. This conclusion is strongly supported by the fact that in places where there is little or no current action, there is also no evidence of terrace formation, for example to the north of Scottburgh where the Agulhas Current is known to be absent. To the south of Scottburgh, on the other hand, where sedimentary evidence (cf. section 4.2) points to renewed current influence, terraces can again be observed. Conversely, south of Ifafa where the Pleistocene ridge, particularly the Protea Banks, acts as an effective barrier to the flow of the Agulhas Current, the terrace is well developed. It is possibly terminated at the Protea Shoals as a result of the Agulhas Current being almost forced off the shelf altogether. South of the Protea Banks, as far as the Umtentu River, the outer shelf is topographically not markedly different from the inner and middle shelf regions, being only slightly more undulating and irregular. The nature of the outer shelf between Durban and Scottburgh is essentially similar. It is somewhat smoother, however, and seismic evidence suggests that unconsolidated sediment mantles the outer shelf (Birch, in press). The difference is probably due to the influence of the eddy systems on sediment dispersal in this area (cf. section 3.2 and 4.1).

North of Ifafa the shelf break is not interrupted by submarine canyons. Birch (1979), on the other hand, located and named nine canyons on the upper slope between Ifafa and Port St Johns. He related the Umzumbe, the Umzimkulu, the Protea, the Umtamvuma and the Umtentu canyons to the position of the Pleistocene dune cordon in these areas. The canyons, except for the Protea, have accordingly been given the names of the associated rivers. Birch furthermore suggested that the Egosa, the Mbotyi, the Mzimvubu and the St Johns canyons to the south are more likely related to large/scale onland faulting. The canyon heads north of Waterfall

Bluff do not penetrate as far onto the shelf as those to the south. Even so, Birch (1981) reports 5-10 m of sediment draped over these canyon heads. The position of the Mbotyi canyon immediately south of the Waterfall Bluff offset further decreases the possibility of sediment exchange across this natural, structurally controlled boundary.

4. SEDIMENTS

The data for the study area are presented and discussed in four separate sections. This approach was adopted simply because it made data presentation more convenient and practical, considering that the study area is over 400 km long but only 10 km wide. The divisions are entirely arbitrary and have no sedimentary relevance. It is emphasized, however, that all contours shown on various maps have been carefully matched across the areas. The individual shelf sectors are: 4.1 Durban to Scottburgh

4.2 Scottburgh to Port Shepstone

4.3 Port Shepstone to the Mtentu River

4.4 Umtentu River to Port St Johns.

Where necessary cross-references between these areas have been made in the text.

4.1 DURBAN TO SCOTTBURGH

4.1.1 Bathymetry (Fig.20)

Between Durban and the Ilovu River the inner shelf slopes gradually (1,4°) down to -40 m and the 40 m isobath itself runs parallel to the coastline. In the north of this sector, i.e. between Durban and the Mlazi River, the transition between the inner and the middle shelf (40-60 m) is marked by an increase in slope. At -60 m the slope gradient initially levels off, before sloping progressively down to the shelf break.

Between the Mlazi and the Ilovu Rivers on the other hand, the shelf levels off at -40 m, to form a relatively flat, arcuate embayment which reaches a maximum width of about 5 km. The

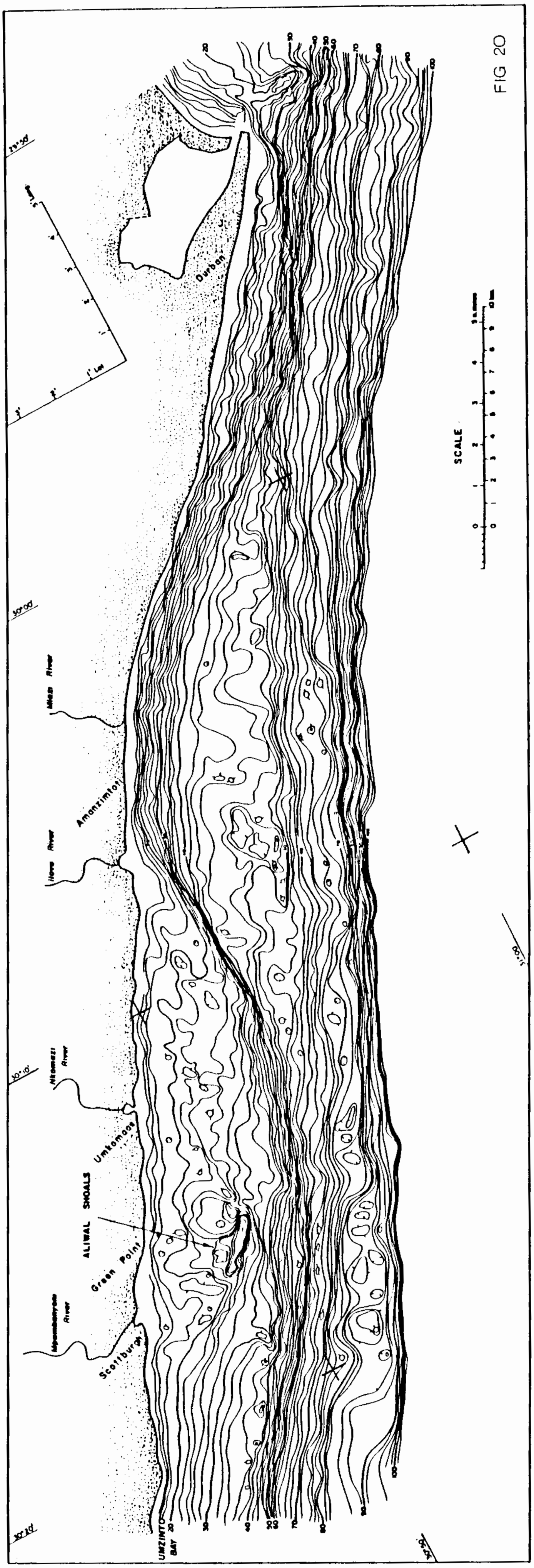


FIG 20

BATHYMETRIC MAP A - DURBAN TO UMZINTO BAY seaward margin of this terrace is situated at about -50 m and is characterised by low outcrops of aeolianites which form part of the relict coastal dune system described by Birch (1981) and Flemming (1981). From here there is a gradual slope (0,56°) down to -60 m, where the topography again becomes flatter (0,29°), marking the beginning of the outer shelf terrace. Along this section of the shelf the outer terrace is relatively narrow at 2 km, but both to the south and the north it is broader, more irregular in topography and better developed. The shelf break commences sharply between -90 and -100 m in the south, but it is less pronounced in the north, where the southern extension of the Tugela Cone is beginning to influence the topography.

The southern section of this shelf sector is characterised by an extensive shoal area which is centred around the Aliwal Shoals. The latter are situated due east of Scottburgh, rising from a depth of -15 to -30 m. In some places they reach up to a few metres below sea-level and thus form a serious shipping hazard. The inner shelf is characterised by a narrow zone which slopes gently seawards to a depth of -20 m. It is followed by a shallow terrace between -20 and -30 m that bulges out onto the shelf, beginning off the Ilovu River and continuing southwards past the Aliwal Shoals. It represents a massive, northeastwards prograding sand body. This topographic high is an almost inverse morphological feature to the deeper midshelf terrace immediately to the north. The seaward margin of the shoal area is marked by a sharp increase in slope gradients.

The shoal edge slopes upward from -40 m off Scottburgh to about -15 m off Ilovu, where it slopes down steeply towards the midshelf

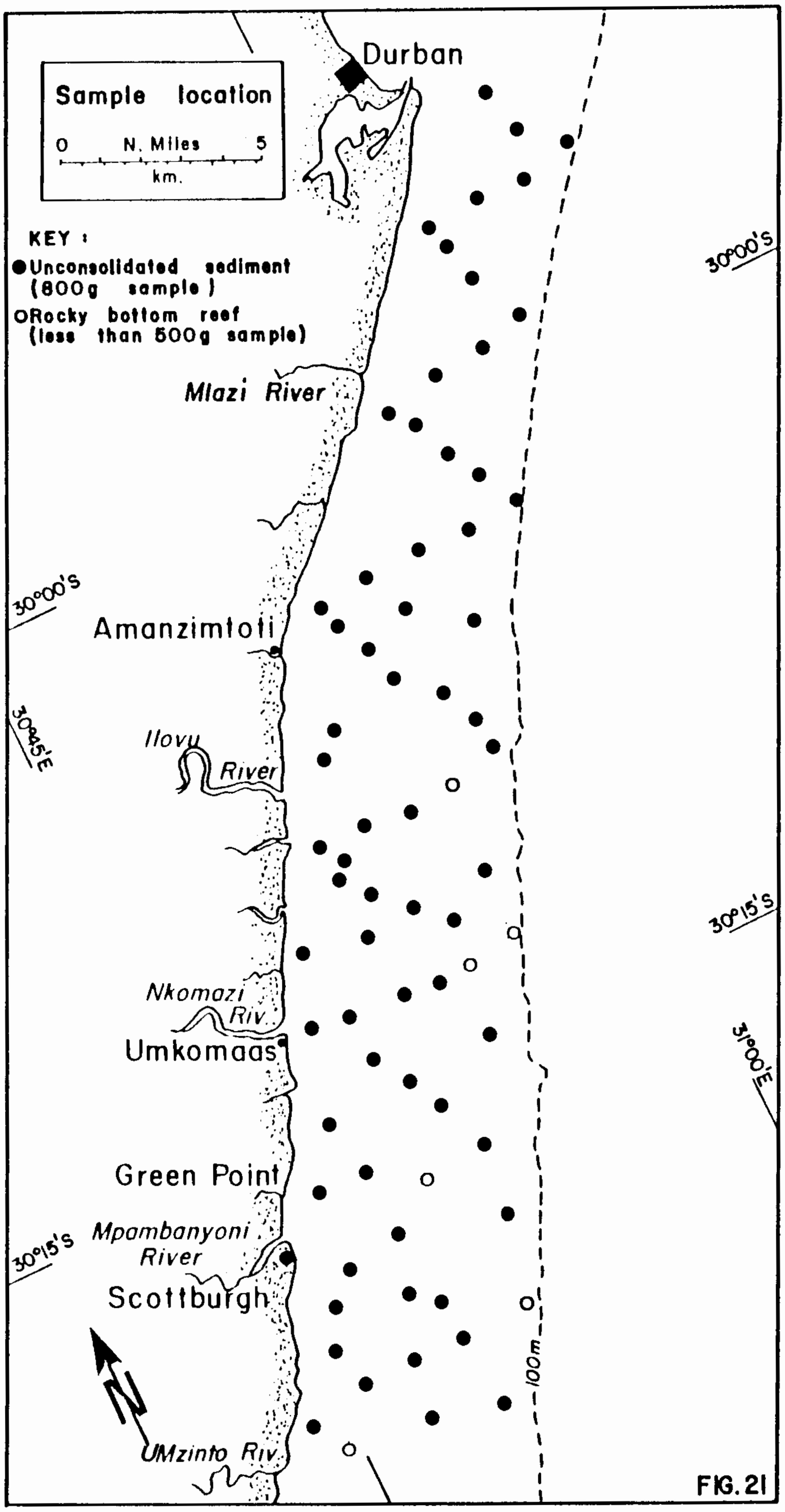

Sample location
0 N. Miles 5
km.
KEY :
●Unconsolidated sediment (800g sample)
○Rocky bottom reef (less than 500g sample)
Durban
Mlazi River
Amanzimtoti
Ilovu River
Nkomazi Riv.
Umkomaas
Green Point
Mpambanyoni River
Scottburgh
UMzinto Riv.
30°00'S
30°45'E
30°15'S
31°00'E
100m
N

FIG. 21

terrace which is situated between -30 and -50 m. Further to the south the slope is less steep and continues down to -60 m, where the slope gradient eases somewhat until at -80 m it merges with the outer shelf terrace.

4.1.2 Sediment Distribution Patterns

There are three main sources of sediment. Fluvial discharge from the Mpanbamyoni, Nkomazi, Ilovu and Mlazi Rivers supplies at least 0,721 x $10^6 m^3$ of sediment annually (Flemming and Hay, 1983; see also section 3.3). At least 5%, but possibly as much as 15% of this material is transported in bedload.

Modern biogenic production has been estimated as being equivalent to 15% of the terrigenous bedload (Flemming, 1981). In addition, relict biogenic material occurs on the outer shelf (Flemming, 1980). This coarse lag deposit continues shorewards beneath the midshelf sandstream and the nearshore sand sheet, where it is occasionally exposed in geological windows. A sample map for this area is presented in Fig.21.

Biogenic sediments (Fig.22)

Between Durban and Scottburgh there is a progressive offshore increase in the $CaCO_3$ content of the sediment, starting with 20% in shallow water and reaching over 50% on the outer shelf (Fig.22a). This trend is also illustrated when plotting carbonate content against water depth (Fig.22b). A regression curve fitted to this plot gives the equation: $Y=23.77+0.32X$, where Y is the $CaCO_3$ content and X is the water depth in metres

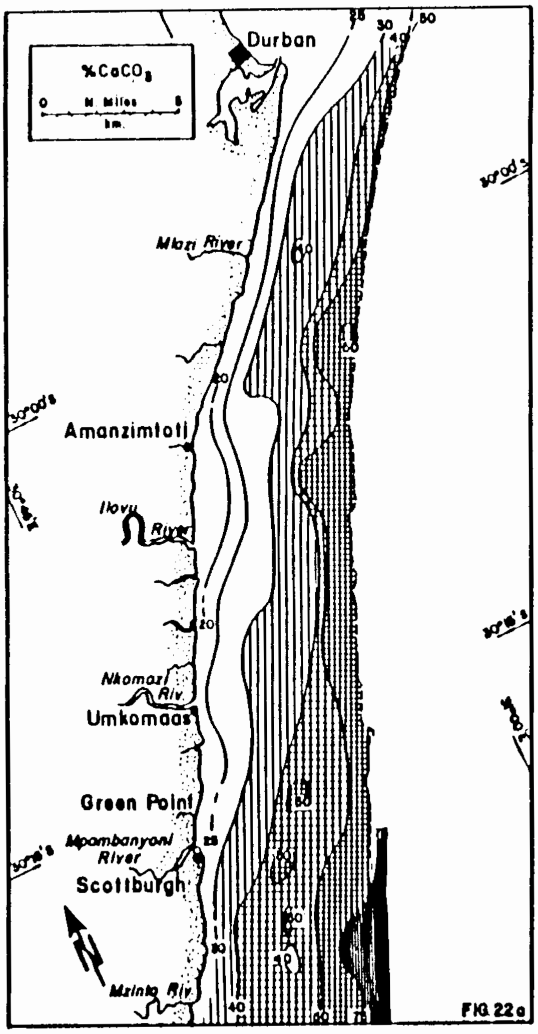


FIG 22a

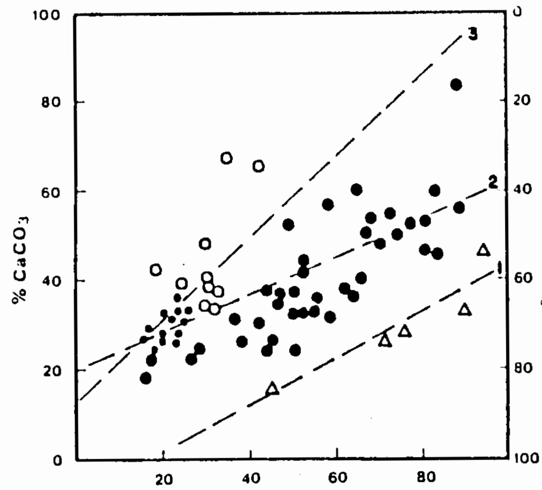


FIG.22b

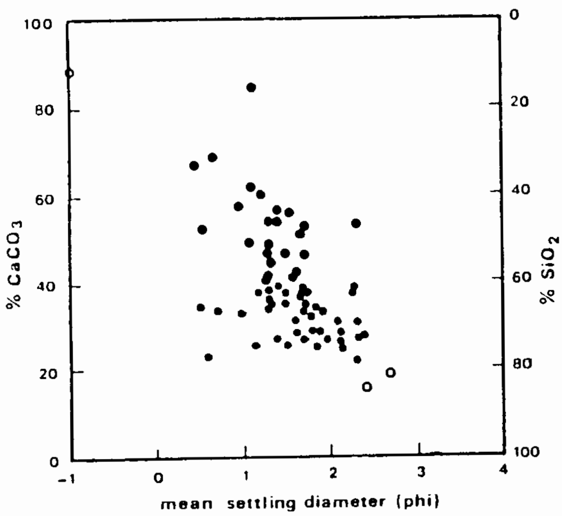


FIG 22c

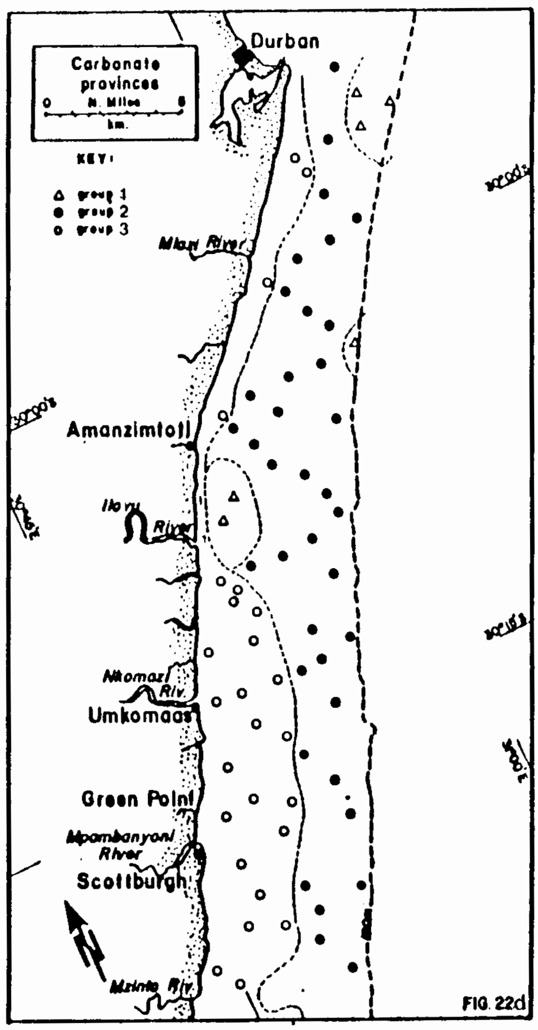


FIG. 22d

(r=0.55). The plot also indicates that the data can be grouped into several point clusters, each representing a distinctive carbonate province (Fig.22c). Each group follows a slightly different trend, reflecting the effects of varying terrigenous dilution. It should also be noted that the correlation coefficients of the individual groups are markedly better. Group 1 sediments lie on the inner to middle shelf between the Ilovu River and Scottburgh, but also in the nearshore zone near the northern boundary of the study area. This latter area shows the most rapid increase in $CaCO_3$ with water depth (Fig.22a). The calcium carbonate content comprises modern biogenic material and does not exceed 40% of the total sediment. The regression line fitted to the sample points gives the equation, Y=0.843X+13.2369 (r=0.74). The sediments which comprise group 2 were collected on the middle shelf and outer shelf between Durban and the Ilovu River, and from the outer shelf south of the Ilovu River. There is a more gradual increase in $CaCO_3$ content with water depth and the correlation coefficient is lower (r=0.59), where Y=0.45X+19.2. Group 3 is described by the regression line, Y=0.54X-10.245 (r=0.93). The samples consist of muddy fine sands and the carbonate content is mainly made up of modern microfauna. As expected there is a greater spread in the carbonate content, in the group 2 samples, viz. 20-60%. The biogenic material consists of both modern and relict lag deposits. To the south on the outer shelf, it is predominantly of relict origin.

There appears to be no marked correlation between carbonate content and topography as observed in other shelf sectors. The 40% contour broadly follows the 50 m isobath and off Scottburgh local highs in the $CaCO_3$ content reflect geological windows in the vicinity of the Aliwal Shoals. Such windows are exposed in areas where topographic highs in the subbottom rise above the equilibrium profile of modern sediments.

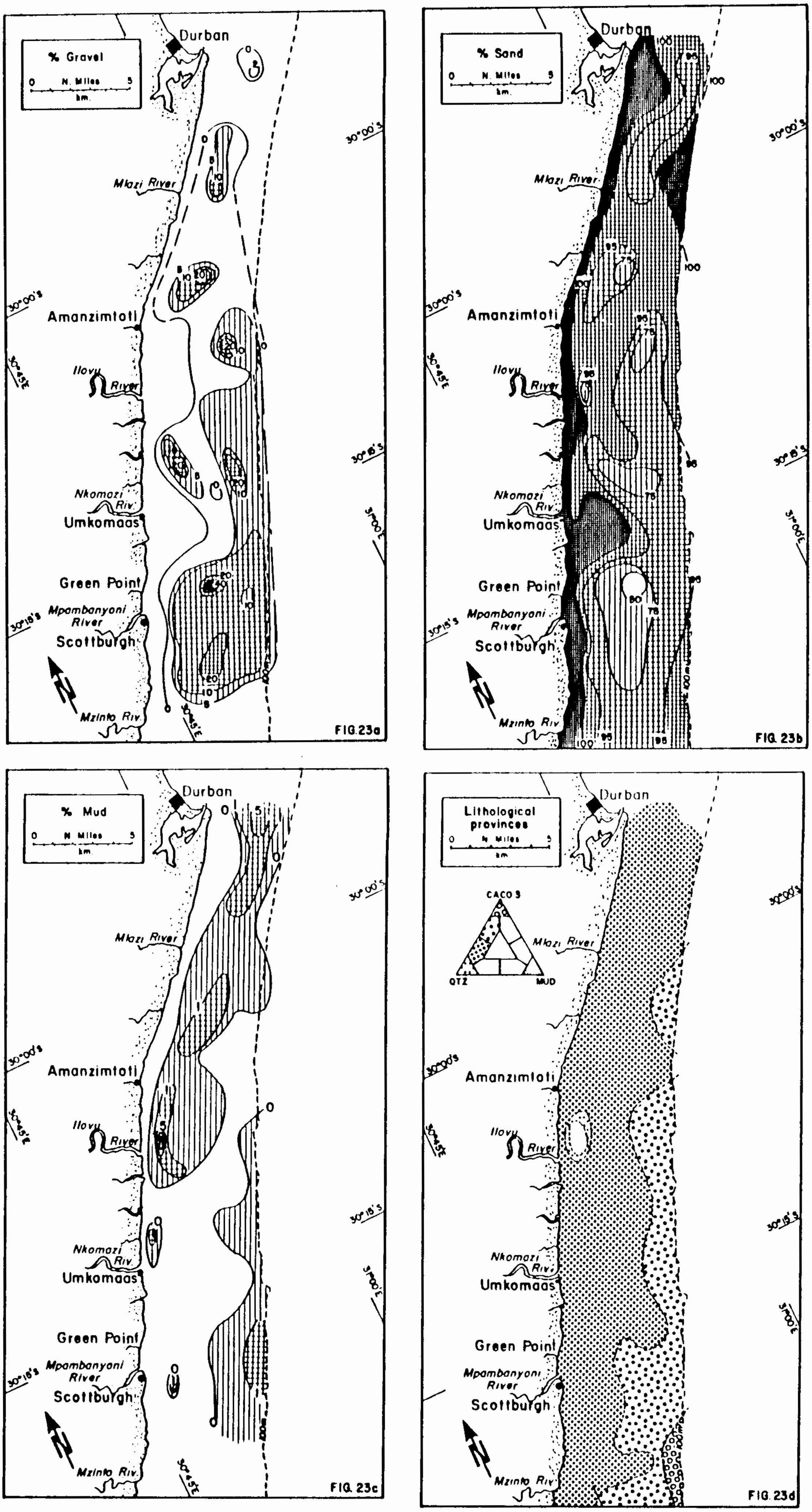
It is interesting to note that south of Scottburgh the 40% contour begins to move shoreward and the $CaCO_3$ content on the outer shelf increases to more than 75% of the total sediment (Fig.22a). This suggests a decrease in the supply of terrigenous material to the outer shelf in this area and possibly signals the renewed influence of the Agulhas Current on sediment dispersal.

Gravel, Sand and Mud (Fig.23)

The distribution of gravel (Fig.23) in the study area is characteristically associated with irregular topography, most notably the relict dune ridge on the middle shelf. Here, between 20 and 50% gravel is found in isolated patches. These areas also coincide with high biogenic content (cf. Fig.22a), especially off Scottburgh.

In general, however, gravel is not found in amounts exceeding 10% on the middle and outer shelves. North of Amanzimtoti there is no gravel on the outer shelf at all. On the middle shelf of this area there are three separate zones behind the dune ridge where gravel is recorded in amounts of up to 20%. A similar zone occurs in conjunction with the irregular topography of the inner shelf immediately south of the Ilovu River. Elsewhere it is altogether absent from the inner shelf.

Sand is by far the dominant component of the total sediment,


% Gravel
0 N. Miles 5
km.
Durban
30°00'S
Mlazi River
30°00'S
Amanzimtoti
30°45'E
Ilovu River
30°15'S
Nkomazi Riv.
Umkomaas
31°00'E
Green Point
30°15'S
Mpambanyoni River
Scottburgh
Mzinto Riv.
30°45'E
FIG.23a
% Sand
0 N. Miles 5
km.
Durban
30°00'S
Mlazi River
30°00'S
Amanzimtoti
30°45'E
Ilovu River
30°15'S
Nkomazi Riv.
Umkomaas
31°00'E
Green Point
30°15'S
Mpambanyoni River
Scottburgh
Mzinto Riv.
FIG. 23b
% Mud
0 N. Miles 5
km.
Durban
30°00'S
Mlazi River
30°00'S
Amanzimtoti
30°45'E
Ilovu River
30°15'S
Nkomazi Riv.
Umkomaas
31°00'E
Green Point
30°15'S
Mpambanyoni River
Scottburgh
Mzinto Riv.
30°45'E
FIG. 23c
Lithological provinces
0 N. Miles 5
km
CACO 3
QTZ
MUD
Durban
30°00'S
Mlazi River
30°00'S
Amanzimtoti
30°45'E
Ilovu River
30°15'S
Nkomazi Riv.
Umkomaas
31°00'E
Green Point
Mpambanyoni River
Scottburgh
Mzinto Riv.
FIG. 23d

reaching 100% in the nearshore zone and along the shelf break (Fig.23b). As expected, it shows an inverse distribution pattern to that of the gravel, since the latter is the only other significant sedimentary component. Only in a small area off the Ilovu River is the sand pattern substantially affected by mud which otherwise forms a very subordinate component. An important trend outlined by the sand pattern would appear to be a corridor which stretches across the shelf in the northern half of the study area, linking the inner shelf with the outer shelf. This feature will again emerge when discussing the distribution of individual size fractions.

As pointed out above, mud (Fig.23c) forms a very minor component of the sediments in this coastal sector. It barely exceeds 1% in places and only off the Ilovu River does the mud content exceed 50%. Significantly this locality is situated in the lee of the Ilovu Spit, just offshore from the Ilovu River. From this point a continuous belt of low but measurable mud content (1-5%) can be traced northeastward, running obliquely across the shelf in a manner not identical, but very similar to the sand corridor. Quite evidently this belt outlines a major route of fine sediment dispersal along the seabed. It will receive further attention when discussing the distribution patterns of fine and very fine sand. A second area exhibiting a continuous, albeit low mud content paradoxically coincides with coarse sediment depocentres on the outer shelf of the southern half of the study area. Mud content barely reaches 1%, suggesting a mechanism by which mud passes through this area in the form of a nearbottom nepheloid layer. In the course of this process some mud is trapped in the interstitial voids of the coarse sediment. This interpretation is also supported by the fact that much of the sediment in this area is bimodal.

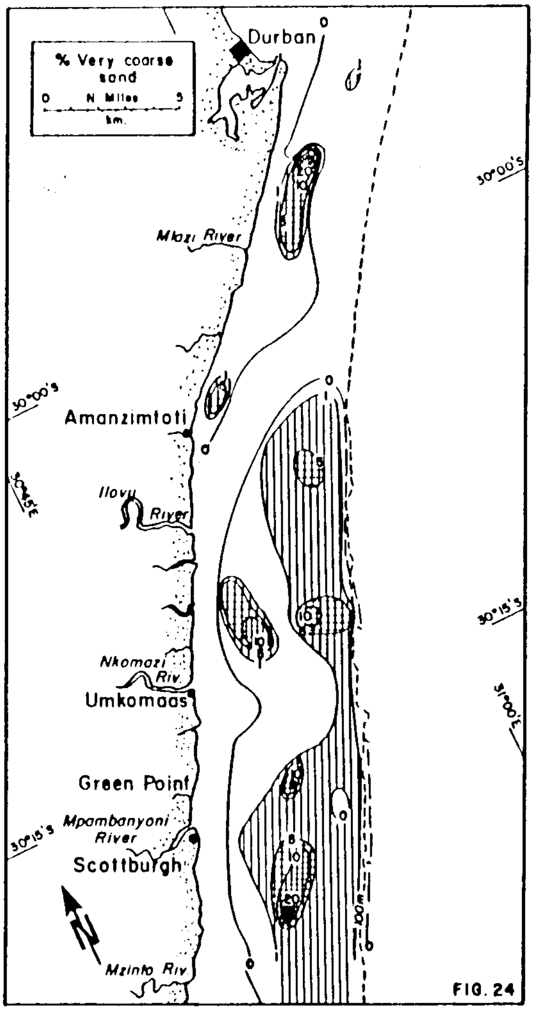
With two exceptions, the sediments mantling this sector of the shelf can be classified lithologically as calcareous quartzarenites. Only on the outer shelf, south of the Mlazi River, are quartzose calcarenites present, whereas the sediment in the region of the Illovu spit is pelitic (Fig.23d). Pure calcarenites and pelites do not occur.

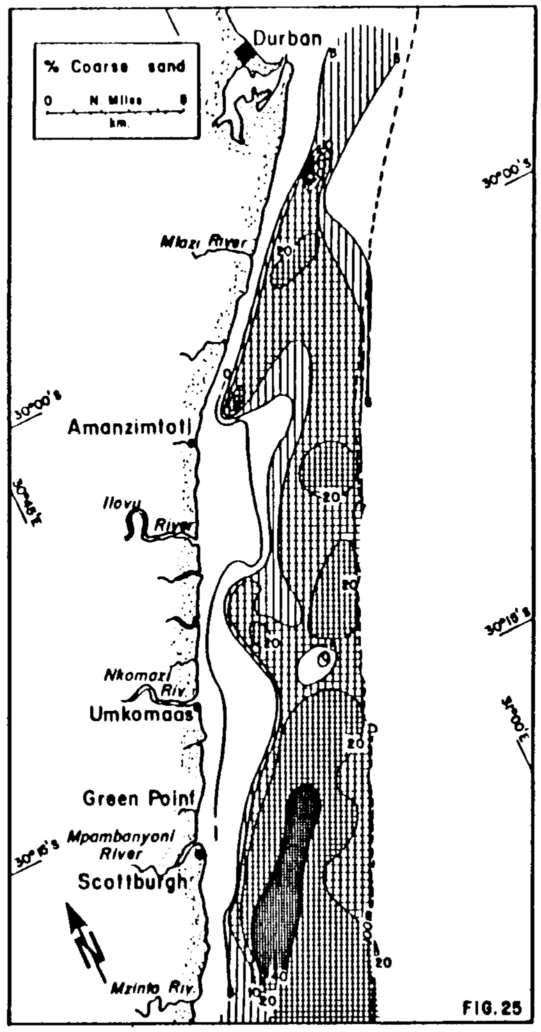
Very Coarse Sand (Fig.24)

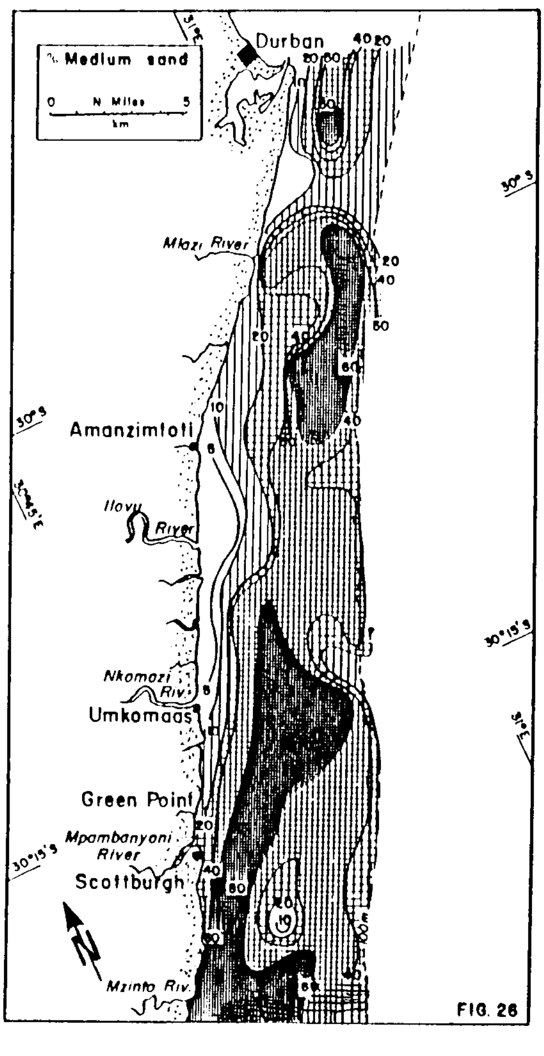
There is very little very coarse sand on the shelf of this coastal sector (Fig.24). Discreet patches of very coarse sand (5-20%) are found at the same localities where gravel reaches concentrations >5%. On the outer shelf south of Amanzimtoti small amounts (1-5%) of very coarse sand occur in almost all of the samples, but none is found in the nearshore zone. The exact opposite, however, holds true for the shelf section to the north of Amanzimtoti. Here a "normal" gradient is found with small amounts of very coarse sand on the inner shelf but none on the outer shelf. A corridor completely devoid of coarse material runs obliquely across the shelf at Amanzimtoti. This corridor coincides with the mud and sand belt described earlier.

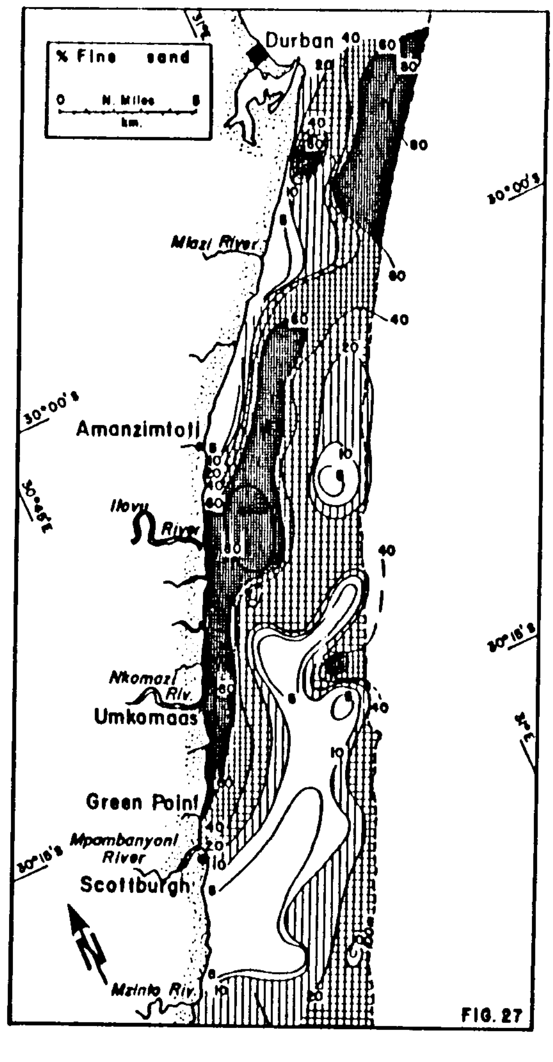
Coarse Sand (Fig.25)

The distribution of coarse sand (Fig.25) is essentially similar to that of very coarse sand and gravel, being concentrated in


% Very coarse sand
N. Miles
km.
Durban
Mlazi River
Amanzimtoti
Ilovu River
Nkomazi Riv.
Umkomaas
Green Point
Mpambanyoni River
Scottburgh
Mzinto Riv.
30°00'S
30°15'S
31°00'E
30°45'E
100m
FIG. 24


% Coarse sand
N. Miles
km.
Durban
Mlazi River
Amanzimtoti
Ilovu River
Nkomazi Riv.
Umkomaas
Green Point
Mpambanyoni River
Scottburgh
Mzinto Riv.
30°00'S
30°15'S
31°00'E
30°45'E
FIG. 25


% Medium sand
N. Miles
km
Durban
Mlazi River
Amanzimtoti
Ilovu River
Nkomazi Riv.
Umkomaas
Green Point
Mpambanyoni River
Scottburgh
Mzinto Riv.
30°S
30°15'S
31°E
30°45'E
100m
FIG. 26


% Fine sand
N. Miles
km.
Durban
Mlazi River
Amanzimtoti
Ilovu River
Nkomazi Riv.
Umkomaas
Green Point
Mpambanyoni River
Scottburgh
Mzinto Riv.
30°00'S
30°15'S
31°E
30°45'E
FIG. 27

larger amounts in a number of separate areas. Between Durban and Amanzimtoti concentrations above 20% are found in three patches on the inner to middle shelf, dropping off rapidly both towards the nearshore and the outer shelves. Conversely, between Amanzimtoti and Scottburgh coarse sand is predominantly concentrated on the middle and outer shelf. An exception to this general trend is observed locally on the nearshore spit-bar south of Ilovu. A similar deviation has been pointed out in the distribution pattern of very coarse sand and gravel. A visual inspection of the sample material suggests that the coarse material at this locality originates from "in situ" shells of small, modern bivalves. The material is therefore not in hydraulic equilibrium with the other sediment found at the same localities. The corridor of low coarse material observed in the very coarse sand and gravel patterns is less conspicuous in the coarse sand, although it can still be recognised in the contour lines.

Medium Sand (Fig.26)

Along the entire coast medium sand gradually increases in an offshore direction (Fig.26), reaching highest concentrations of over 60% in two extensive areas within a belt that stretches from the nearshore off Scottburgh obliquely north-northeastwards across the shelf to the outer shelf off Durban. Seaward of this belt concentration levels drop off rapidly towards the shelf break. Inshore, where the medium sand concentration is less than 40%, fine sand predominates. On the middle to outer shelves off the Ilovu River however, where between 40 and 60% medium sand is found, coarse and very coarse material is the secondary component.

Fine Sand (Fig.27)

The distribution of fine sand (Fig.27) follows an inverse trend to that described for the very coarse sand fraction (Fig.24). North and south of the Ilovu River on the inner to middle shelf two distinct trends are evident. To the north the amount of fine sand progressively increases in the offshore direction, reaching maximum values of above 60%. Between Durban and the Mlazi River fine sand extends across the entire shelf to the shelf break. Between the Mlazi River and the Ilovu River up to 80% fine sand is concentrated on the middle shelf terrace, whereas less than 40% is found on the outer shelf. This corridor which trends northeastwards obliquely across the shelf from the Ilovu River parallels the zone in which little coarse material was recorded (Fig.25).

The corridor continues into the nearshore zone towards the south. More than 40% fine sand is found on the inner shelf between Ilovu River and Scottburgh. A belt with less than 20% fine sand extends northwards across the shelf beginning at Scottburgh. It more or less covers the same area defined by discontinuous patches of very coarse and coarse material (Figs.24 and 25). The amount of fine sand increases both inshore as well as offshore from the central zone.

Very Fine Sand (Fig.28)

Very fine sand (Fig.28) is notable for its general paucity. Its

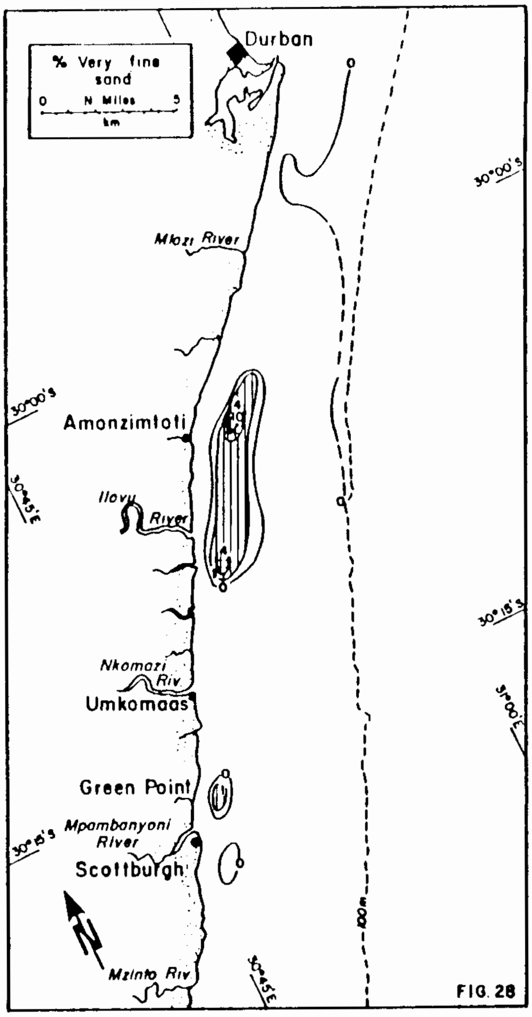


FIG. 28

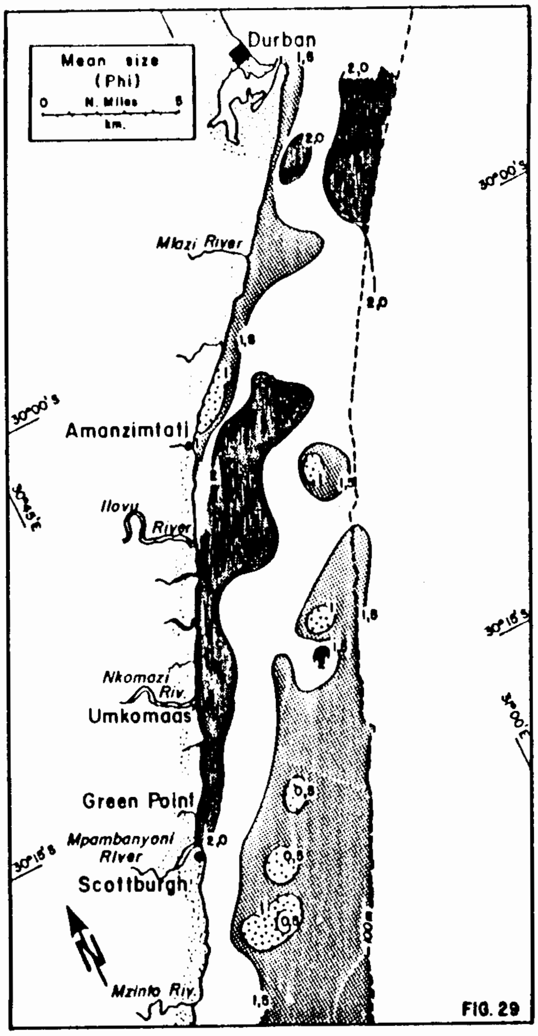


FIG. 29

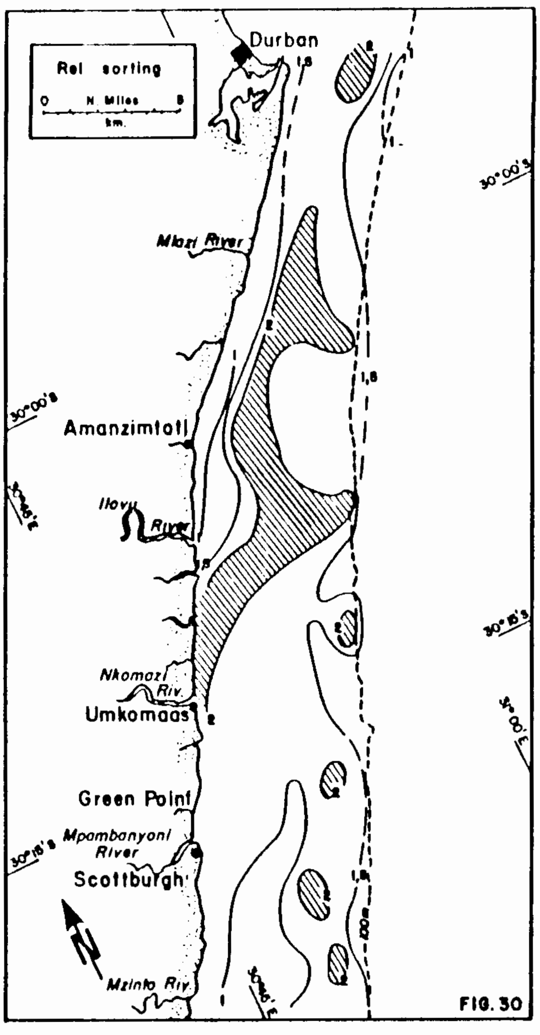


FIG. 30

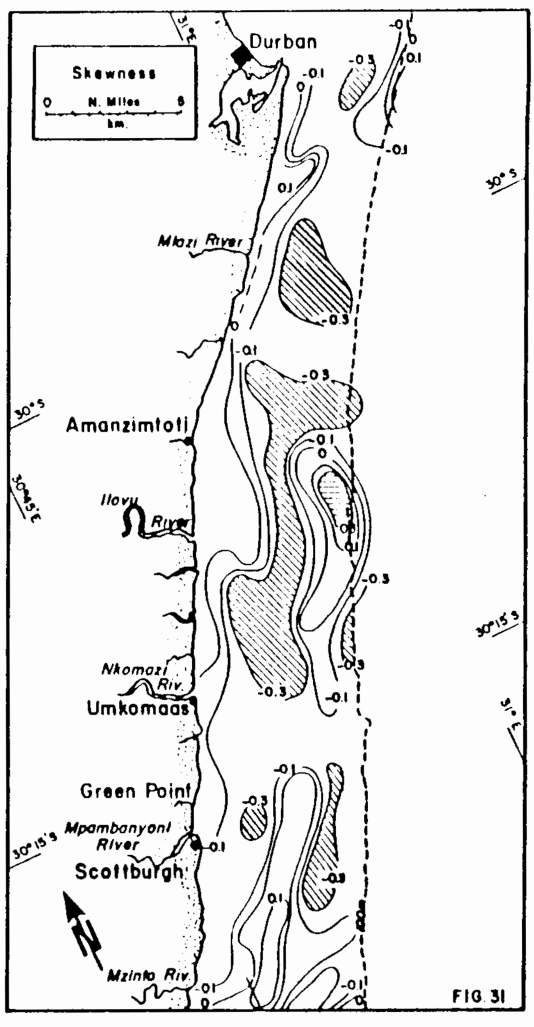


FIG. 31

distribution mirrors that of the mud, being concentrated (1-10%) in a narrow zone between -20 and -30 m immediately offshore and northeast of the Ilovu River. Very fine sand is also found in amounts of up to 1% on the outer shelf off Durban where mud occurs in amounts between 1 and 5%. Elsewhere very fine sand is absent, except for minor amounts off Scottburgh. The paucity of very fine sand and mud indeed suggests that all material less than about 125 microns (boundary between fine and very fine sand) must be regarded as true suspension, the bulk of which has been eliminated from this high-energy section of the shelf.

Mean Size (Fig.29)

The Mean Size distribution map (Fig.29) broadly summarizes the patterns described by the medium and the fine sand contours. Where more than 60% fine sand is found, the mean size is around 2 phi. Where medium sand is concentrated on the middle and outer shelves the mean size for the sediment is between 1.0 and 2 phi. In the south the 1.5 phi contour is similar in outline to the zone contained in the 10% fine sand contour. Similarly, the areas where the mean size is between 0 and 1.5 phi define a trend which is reflected in the 20-40% contour pattern of coarse sand.

Relative Sorting (Fig.30)

All the sediments in this sector of the shelf are well sorted (1.5 to 2.0 QH units). The nearshore belt north of Ilovu is extremely well sorted, whereas the fine sediment, extending obliquely north from the Nkomazi River, is the least well sorted. This diagonally cross-shelf movement of sediment is emphasized by tongues of more poorly sorted sediment which occupy the middle and outer shelves opposite the Ilovu and Mlazi Rivers. South of the Ilovu River isolated patches of sediment show poorer sorting (QH >2). These are areas of bimodal sediment, comprising coarse and fine sediment, whereas the former are mixtures of fine and medium-sized sand.

Skewness (Fig.31)

The skewness pattern reveals two distinct trends. North of Scottburgh a diagonal, cross-shelf trend of negatively skewed sediments is manifest. Between Amanzimtoti and Durban negatively skewed sediments extend across the outer shelf. South of Scottburgh a second, more subtle trend is observed. Here very slightly positively skewed sediments are found on the middle shelf, whereas negatively skewed sands are found on the inner and outer shelves. The latter are more negatively skewed than the former.

4.1.3 Discussion and Conclusions

The dominant trends revealed by the distribution patterns of the coarse, medium and fine sand fractions are summarized in the mean size map (Fig.29). It can be demonstrated that the general trend of fine, medium and coarse sand cross over on the middle to outer shelf off the Mlazi River. To the south of this point the sediment follows an inverse gradient across the shelf i.e. from fine to coarse, whereas to the north, a "normal" offshore fining trend is observed.

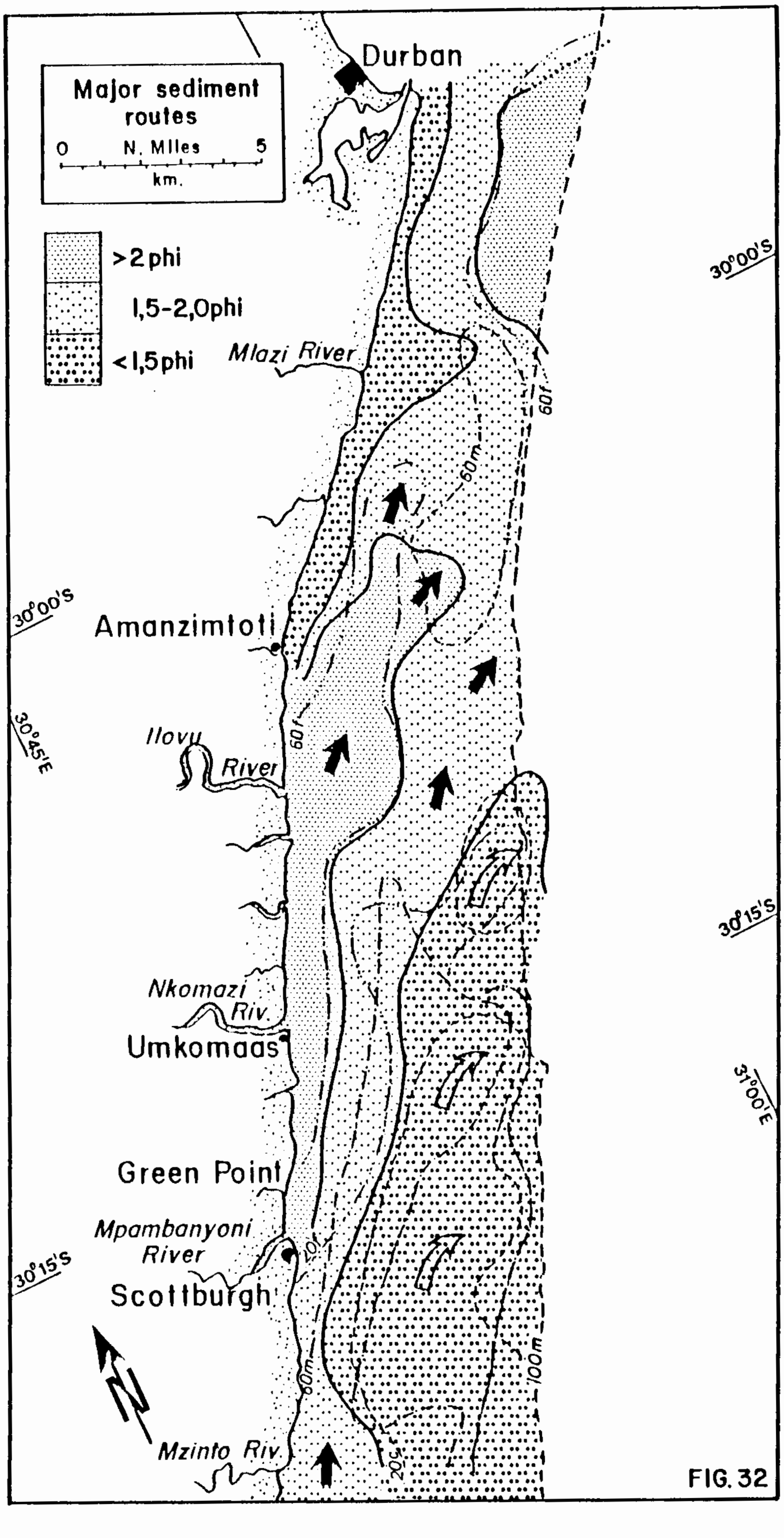

Major sediment routes
0 N. Miles 5
km.
>2 phi
1,5-2,0phi
<1,5phi
Durban
Mlazi River
Amanzimtoti
Ilovu River
Nkomazi Riv.
Umkomaas
Green Point
Mpambanyoni River
Scottburgh
Mzinto Riv.
30°00'S
30°15'S
30°45'E
31°00'E
60m
100m
N

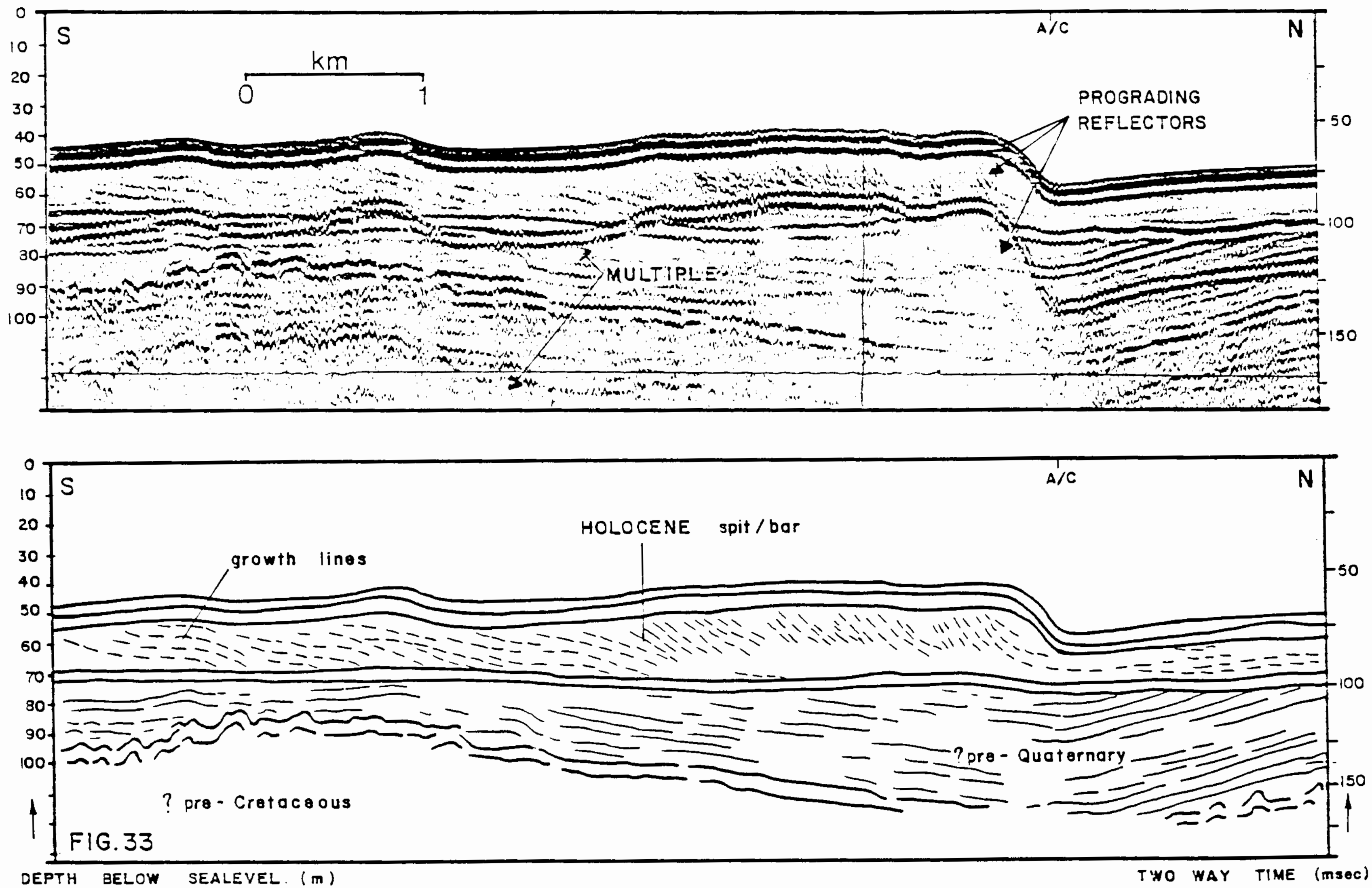
FIG. 32

The occurrence of coarse material is discontinuous and probably represents a current scoured modern or relict lag. In many cases these coarse-sediment deposits are associated with minor amounts of fine sediment under 2 phi in size, producing positively sheared bimodal distributions. It is possible that fine and very fine sands are being transported across the shelf towards the shelf break south of the Ilovu River. In the course of this process minor amounts ($^{+}/-10\%$) of fine sand are trapped interstitially, whereas very fine sand escapes across the shelf break. It is also possible, however, that most of this sediment originates on the Tugela Cone, being carried onto this shelf section by the Agulhas Current.

South of the Ilovu River the positions of the fine, medium and coarse sand contours, when compared with those of the mean diameter (Fig.32), show that the 60% fine sand contour closely parallels the 2 phi mean size contour. Furthermore, the 10% fine sand contour is similar in outline to the 1.5 phi mean size corridor. As might be expected, the mean size is coarser than 1.5 phi where more than 20% coarse sand is present. The high (60-80%) medium-sand corridor, on the other hand, lies on either side of the 1.5 phi mean size contour, but distinctly offset from the fine sand belt.

The medium sand (1.0-2.0 phi) is distributed obliquely across the shelf from south to north. It would appear, however, that only material finer than 1.5 phi is being transported northwards across the middle shelf towards the shelf break off the Mlazi River. The coarser medium sand fraction (1.5 to 1.0 phi), on the other hand, is being moved offshore and deposited on the outer shelf where it mixes with the coarse lag deposits. The above observation suggests that both size-sorting as well as sediment mixing are taking place, involving mainly medium sand. This material is supplied to the shelf by local rivers to the south of Scottburgh, initially being transported offshore by wave action, rip currents and possibly also by strong fluvial jets before being taken northwards by longshore drift and currents of the Natal Gyre.

The close proximity of the two distinct fine and medium sand corridors points towards different sediment sources. The main source of fine sand would appear to be the Nkomazi River, whose upper catchment area lies in the Beaufort and Drakensberg Group. These rocks comprise mainly fine sandstones, mudstones and shales. The rivers to the south, on the other hand, drain the Table Mountain Group quartzites and highly metamorphosed terrain of the Natal metamorphic and structural province. It would thus seem that there is a pronounced control over grain size in the source regions of the various fluvial supply systems. The fine-sand corridor originates in the nearshore just north of Scottburgh. From the Ilovu River this belt moves northwards across the inner shelf and onto the middle shelf. Only in a narrow zone to the north and south of the Mlazi River, does the fine sand overlap with the distribution pattern of the medium sand. The bulk of fine sand is moved northwards by the return-flow current of the Natal gyre system which is enhanced by a combination of southeasterly swells and nearshore wind stress currents generated by the frequent southwesterly gales (60% p.a., cf. Flemming, 1981).



Seismic section across the Ilovu Spit (N.R.I.O.; Cruise 80-14).

The fine sand found on the outer shelf in the south would thus appear to be recycled by the Agulhas Current once it spills over the shelf edge off the Mlazi River.

A particularly large concentration of fine sand (more than 80%), including the only occurrence of very fine sand (more than 4%), is found in very shallow water near the Ilovu Spit which appears to be building out southwards, as indicated on the bathymetry of Fig.20 (cf. also Chart A of Appendix IV). The spit-bar as a whole, on the other hand, progrades in a northeasterly direction as clearly documented on the seismic section of Fig.33. In fact, at $30^{o}10$\`S and $30^{o}52$\`E Flemming (1980) has reported dunes migrating northwards, thus confirming strong northerly flow some distance offshore.

The juxtaposition of two such distinctly different sediment transport directions suggests the presence of two opposing flow cells situated in close proximity to each other. One is formed by the main return flow of the gyre, which is situated farther offshore and which is responsible for the northward movement of medium and fine sand in their respective corridors. It also controls the northward progradation of the spit-bar as a whole. The other is a small inshore, anticlockwise eddy which is responsible for the southerly progradation of the shallow water spit. The only mud deposit of this shelf sector appears to be situated in the centre of this small inshore gyre (cf. Ferentinos et al. 1980). It should be noted that the inner shelf in this area is rather steep, being associated with a marked change in the orientation of the shoreline. Both features would favour the formation of a small topographically induced eddy.

On the middle and outer shelves off the Mlazi River the fine, medium and coarse sand corridors overlap. Relative sorting in this area is poor (Fig.30) and the sediments are negatively skewed (Fig.31), suggesting extensive mixing. The obliquely offshore directed current appears to have effectively removed much of the fine and all of the very fine sand, both of which are probably deposited on the southern margin of the Tugela cone, or are partly recycled by the Agulhas Current to reappear on the outer shelf terrace off Scottburgh.

The existence of another eddy off Durban (cf. Fig.13a) is generally accepted in the literature (Duncan and Stavropoulos, 1974; Pearce, 1977; Schumann, 1979). As no samples have been taken to the north of this areas it is not possible to define any trends adequately. The concentration of poorly sorted, negatively skewed fine sediment on the middle and outer shelves in this area does, however, suggest that an eddy is present and that sediment mixing is taking place between material supplied from the north and from the south by the different eddy systems. Fine sediment would be deposited in the centre of such an eddy where the energy is lowest, whereas coarse material should be found on the outside in the region of stronger flow. The "normal" offshore size gradient which has been described earlier would also support the idea of a clockwise gyre. The source of the fine material in this region is not entirely clear. However, the complexity of this northernmost sector suggests a strong influence of processes beyond the limits of the study area and no attempt will therefore be made to provide a solution.

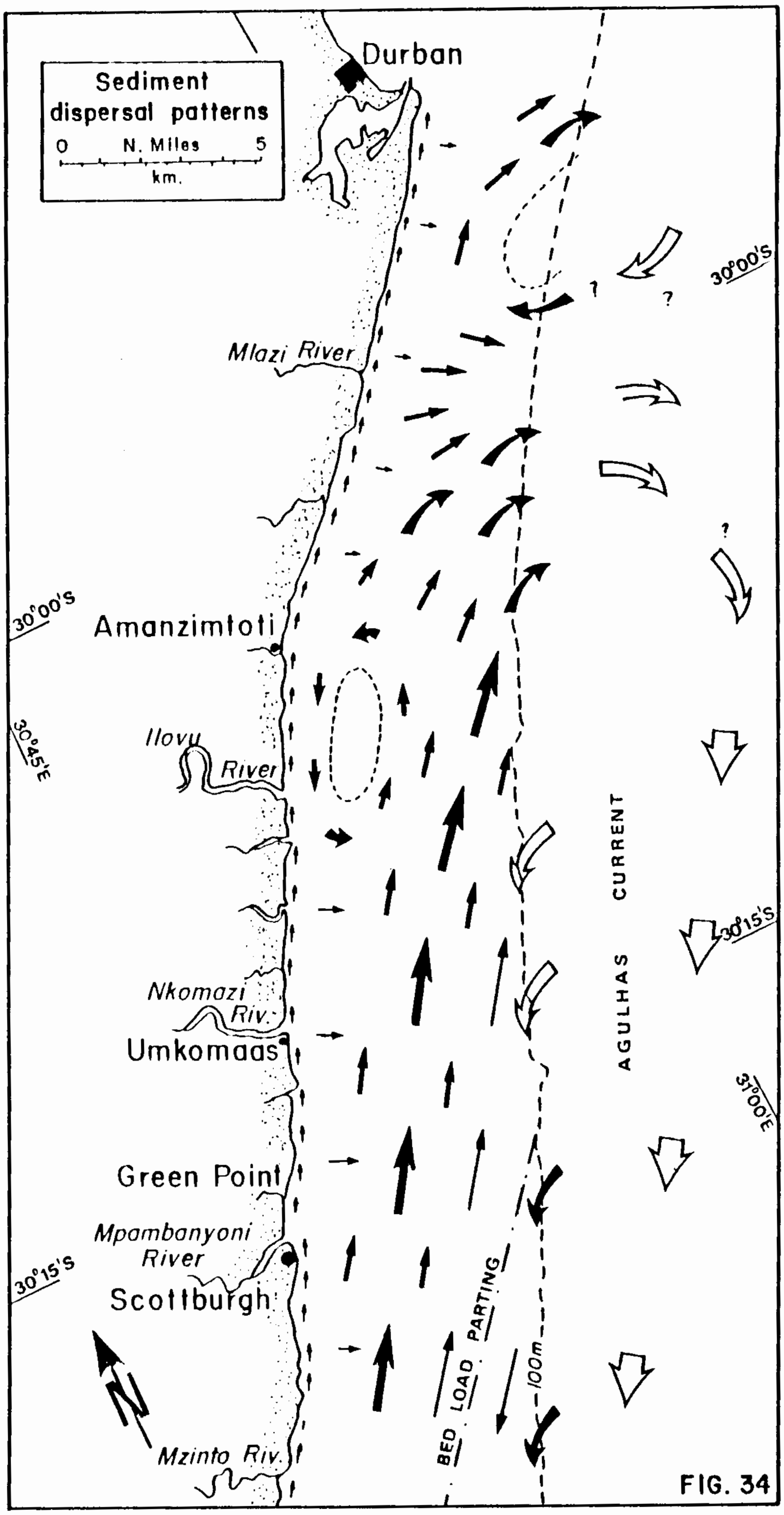

Sediment dispersal patterns
0 N. Miles 5
km.
Durban
Mlazi River
30°00'S
Amanzimtoti
30°45'E
Ilovu River
Nkomazi Riv.
Umkomaas
Green Point
Mpambanyoni River
Scottburgh
30°15'S
N
Mzinto Riv.
BED LOAD PARTING
100m
AGULHAS CURRENT
30°00'S
30°15'S
31°00'E

FIG. 34

The sediment dispersal patterns suggested by the sediment distribution on this sector of the shelf is summarised in Fig.34. It has already been noted that the sediment on the outer shelf, south of the Ilovu River, consists of gravel lag with interstitial coarse, medium and fine sand. This interstitial sand can only be remobilised under conditions which are able to move the coarse gravel lag that protects the finer grain sizes. It is unlikely, however, that the gravel itself will be mobilized by the peak flow expected in this area. On the other hand, wave action during severe storm events appears capable of forming ripple marks at water depths of at least 100 m (Flemming, 1980) and in such cases the finer material may be winnowed from the coarser lag material.

4.2 SCOTTBURGH TO PORT SHEPSTONE

4.2.1 Bathymetry (Fig.35)

The continental shelf between Scottburgh and Port Shepstone is almost of uniform width throughout, fluctuating between 11,8 km and 12,2 km. The shelf break is situated at a water depth of 90-100 m in the north, but closer to 80 m in the south. The southern half of the outer shelf is in addition disrupted by at least three major submarine canyons. The canyon heads reach at least 1 km onto the outer shelf terrace, which itself varies in width from about 2 km in the south, to about 6 km in the central sector, to 2 km in the north.

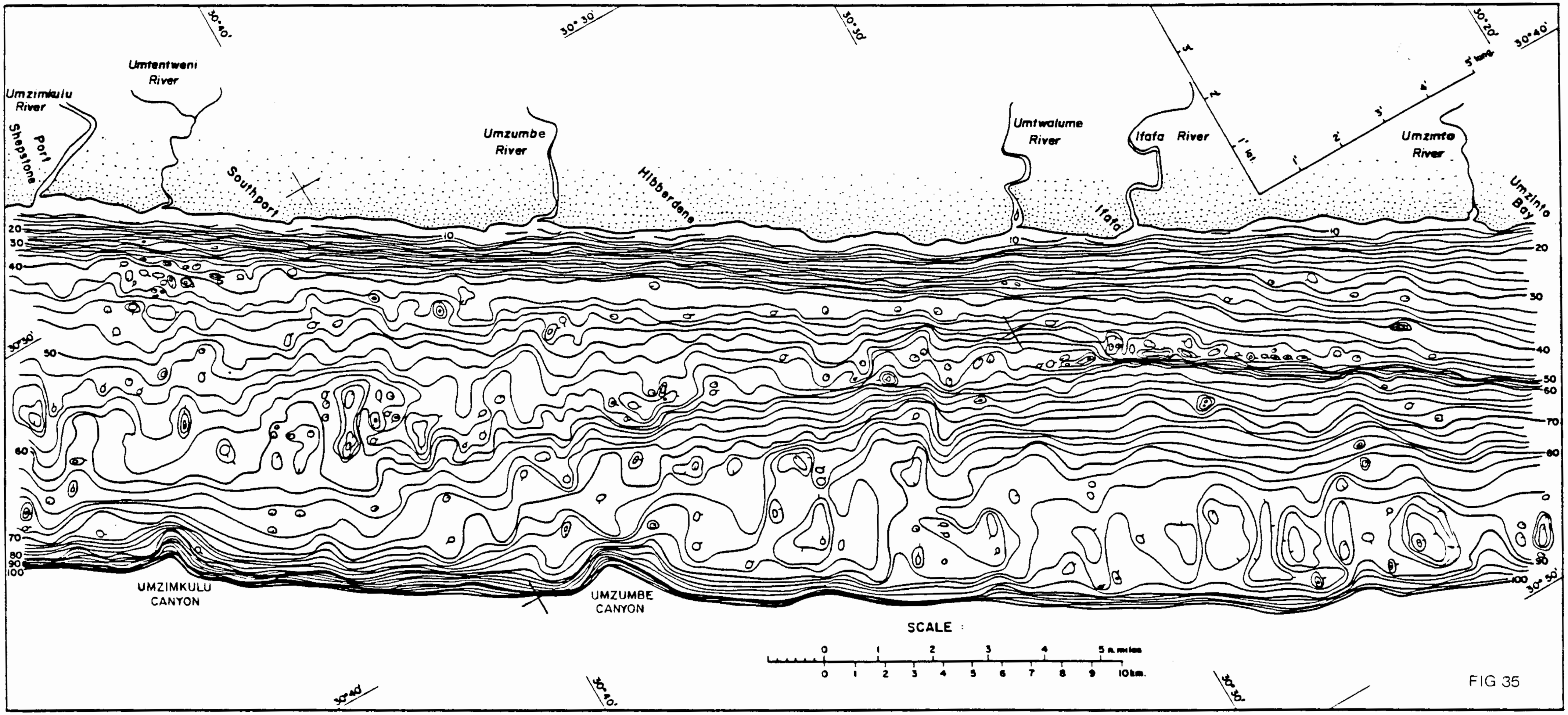


FIG 35

BATHYMETRIC MAP B · UMZINTO BAY TO PORT SHEPSTONE

The morphology of the shelf platform is quite evidently controlled by the size, continuity and position of the midshelf dune ridge. Off Scottburgh the seaward limit of the ridge is best defined by the 50 m isobath, being situated approximately in the middle of the shelf, some 6 km from the shoreline. Following the 50 m isobath southwards, the ridge gradually shifts closer to the shoreline, reaching an offshore distance of 4 km due east of Ifafa. At this point it changes direction and now follows the 60 m isobath until it reaches the Protea Banks, situated to the southeast of Port Shepstone, about 8 km offshore.

Between Scottburgh and Ifafa the shelf area shoreward of the dune ridge consists of a uniformly sloping, smooth sandy seabed. Off Ifafa, i.e. where the ridge changes direction, a new physiographic unit in form of a midshelf terrace, begins to develop adjacent to the dune ridge. The smoothly sloping nearshore sand wedge which abutts against the dune ridge to the north of Ifafa, now separates itself from the ridge and its seaward edge continues to gradually shift closer to the shoreline, reaching a width of only 3 km off Port Shepstone. At the same time the newly emerged midshelf terrace widens progressively, attaining a maximum width of about 6 km just north of the Protea Banks. It is interesting to note that the maximum depth of the nearshore sediment wedge remains almost constant at approximately -45 m, even where it abutts against the midshelf ridge in the north. Its gradient, on the other hand, increases from about 0.46^{o} in the north, to about 0.8^{o} in the south as it narrows from 6 km off Scottburgh to 3 km off Port Shepstone. The midshelf terrace slopes gradually (0.14^{o}) seawards from a depth of 45 m to about 60 m.

The dune ridge itself appears very narrow in the north, mainly because it is mostly buried in sediment with only its crestline penetrating in places. However, as it separates from the sediment wedge its actual height also decreases and it almost disappears before rising sharply into the Protea Banks.

The shelf beyond the dune ridge also comprises two physiographic features. There is the outer shelf terrace which has already been referred to and there is a second sediment wedge which hugs the midshelf dune ridge in the northern half of this shelf sector. It pinches out at a point approximately on a line joining Hibberdene with the Umzumbe Canyon head. The wedge is situated between the 60 m and the 80 m isobath, its toe shoaling slightly as it pinches out towards the south. The outer shelf terrace is situated between the 80 m isobath and the shelf break at about 90 m in the north, but also shoals towards the south as first the 80 m isobath and then the 70 m isobath shift closer to the shelf break to the south of Ifafa. The outer shelf terrace is thus situated 15-30 m lower than the midshelf terrace.

A potentially important feature, in terms of sediment dispersal, is the offset between the start of the midshelf terrace off Ifafa and the end of the outer shelf sediment wedge off Hibberdene. This offset covers a distance of at least 15 km. It suggests that whereas nearshore sediment is prevented from reaching the midshelf dune ridge to the south of Ifafa, possibly by a northward flowing current, it is carried further south seaward of the ridge by an obviously southward flowing current. It would thus appear that this area lies at the centre of the bedload

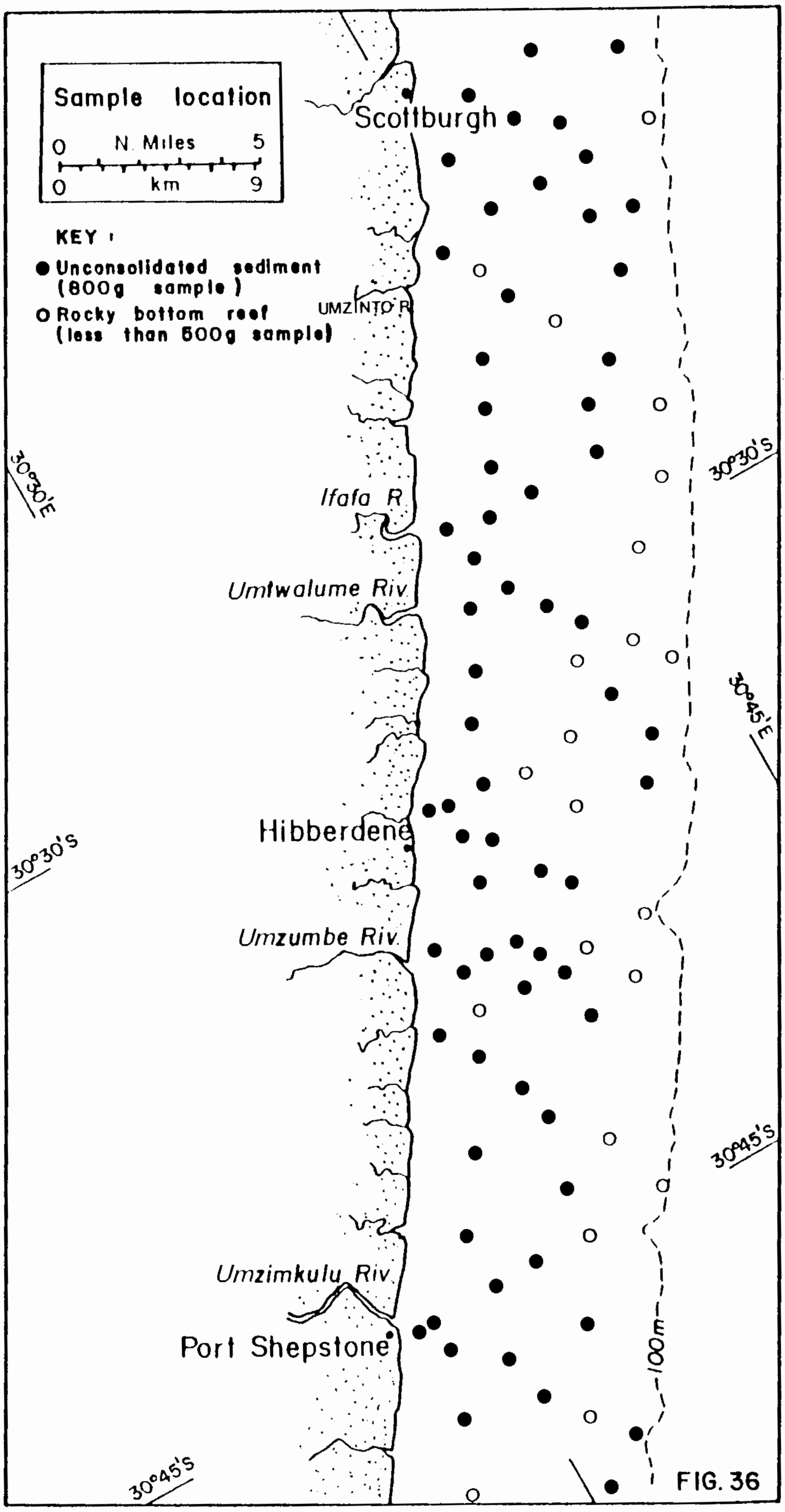

Sample location
0 N. Miles 5
0 km 9
KEY :
Unconsolidated sediment (800g sample)
Rocky bottom reef (less than 500g sample)
Scottburgh
UMZINTO R.
Ifafa R.
Umtwalume Riv.
Hibberdene
Umzumbe Riv.
Umzimkulu Riv.
Port Shepstone
30°30'E
30°30'S
30°45'E
30°45'S
100m

FIG. 36

parting postulated by Flemming (1980, 1981).

4.2.2 Sediments Distribution Patterns

The distribution patterns described below were contoured on the basis of the sample density shown in Fig.36.

Biogenic sediments (Fig.37)

Two major trends are apparent in the distribution of biogenic material on the shelf between Scottburgh and Port Shepstone, the division line being situated near Hibberdene. Between Scottburgh and Hibberdene the distinct shore parallel, offshore increase in $CaCO_3$ content observed in the northern sector becomes highly irregular. The 30% contour runs shore parallel between -20 and -30 m, whereas the 75% and 90% contours follow a similar trend at depths greater than -80 m. The 40% and 50% contours, however, criss-cross the middle and outer shelves irregularly, possibly in response to highly local terrigenous inputs (cf. pattern offshore the Mtwalume River) or the occurrence of carbonate-rich geological windows, especially along the dune ridge. It could also be a characteristic feature of the bedload parting region.

South of Hibberdene, on the other hand, the shore parallel zonation exhibited elsewhere is re-established. There is, however, less biogenic material on the inner shelf in this region than further to the north. Whereas the 20% contour is still situated relatively close to the shore, the 30% contour now lies beyond the 50 m isobath. The 40%, 50% and 75% contours are closely spaced between -60 and -70 m giving a high $CaCO_3$ gradient

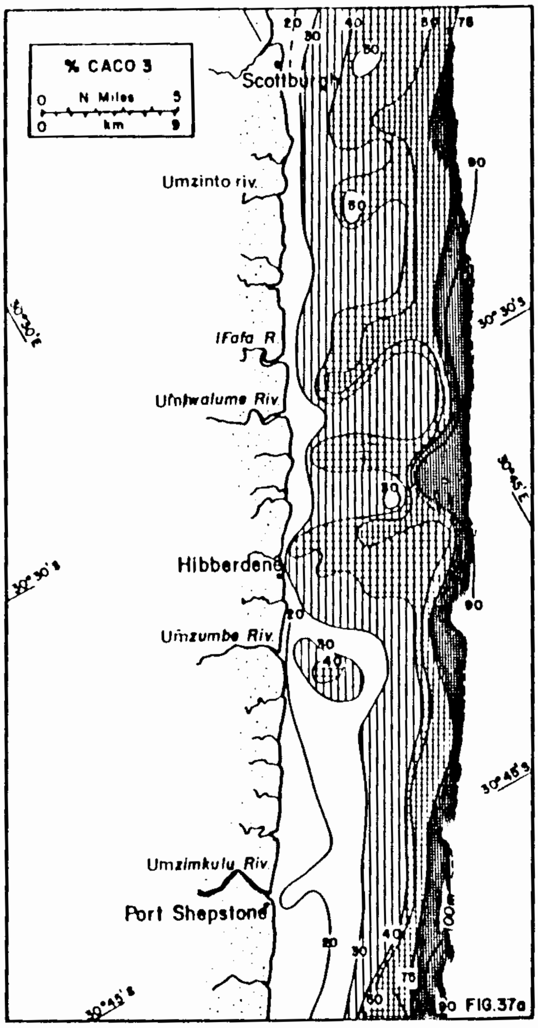


FIG.37a

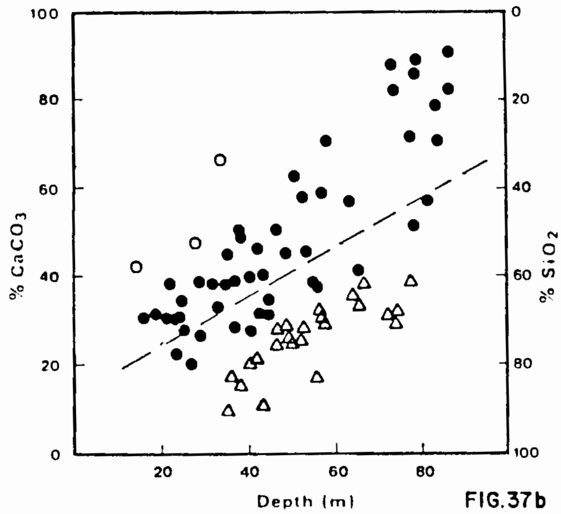


FIG.37b

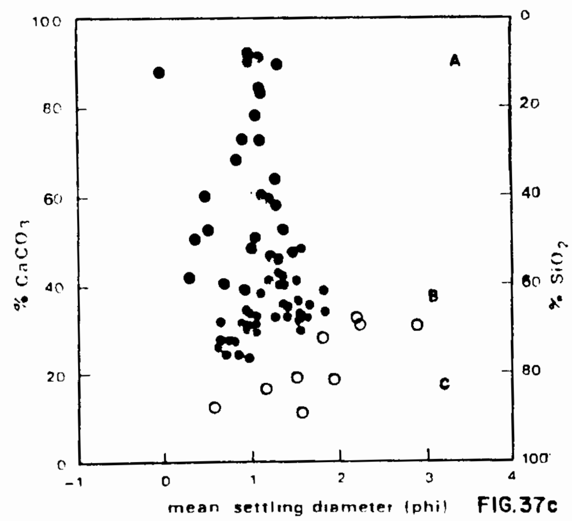


FIG.37c

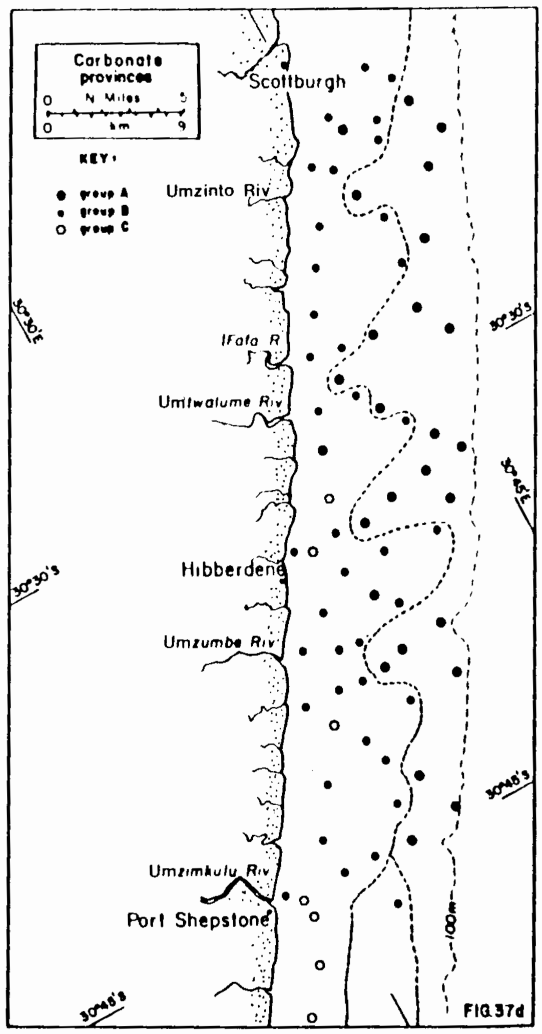


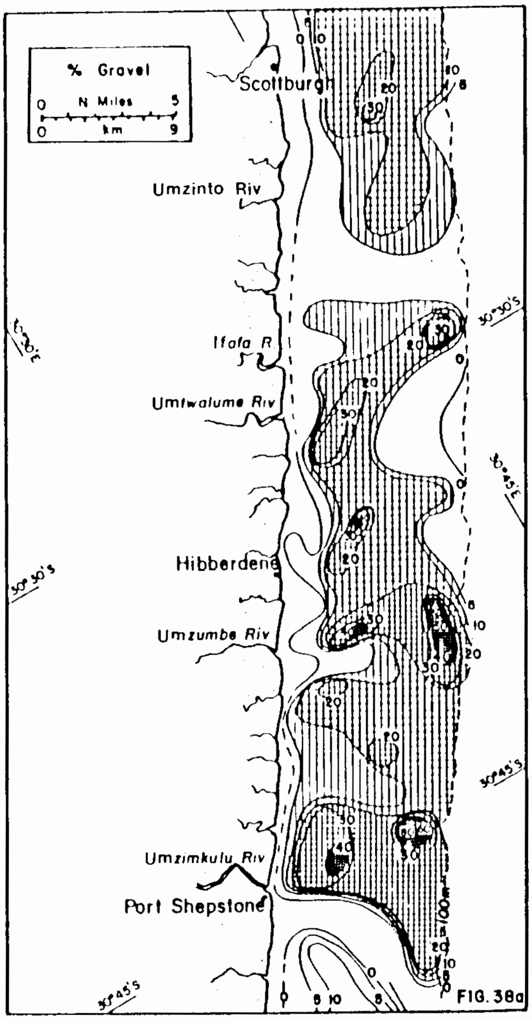
FIG.37d

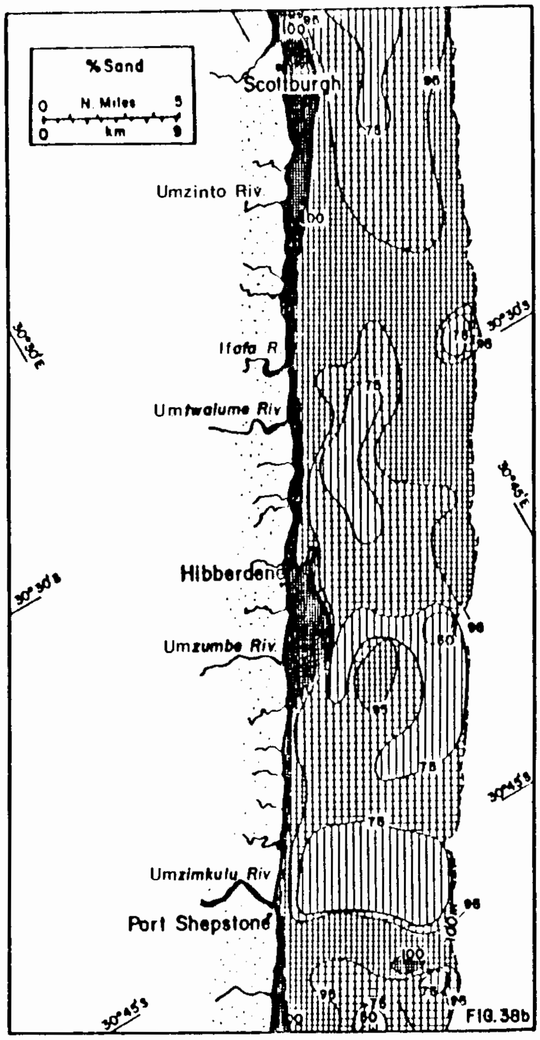
across the middle to outer shelf transition zone. More than 90% $CaCO_3$ is occasionally found near the shelf break. It is interesting to note that the 40% and 50% contours lie on the landward side of the Protea Banks, possibly indicating strong current action on that side of the Banks.

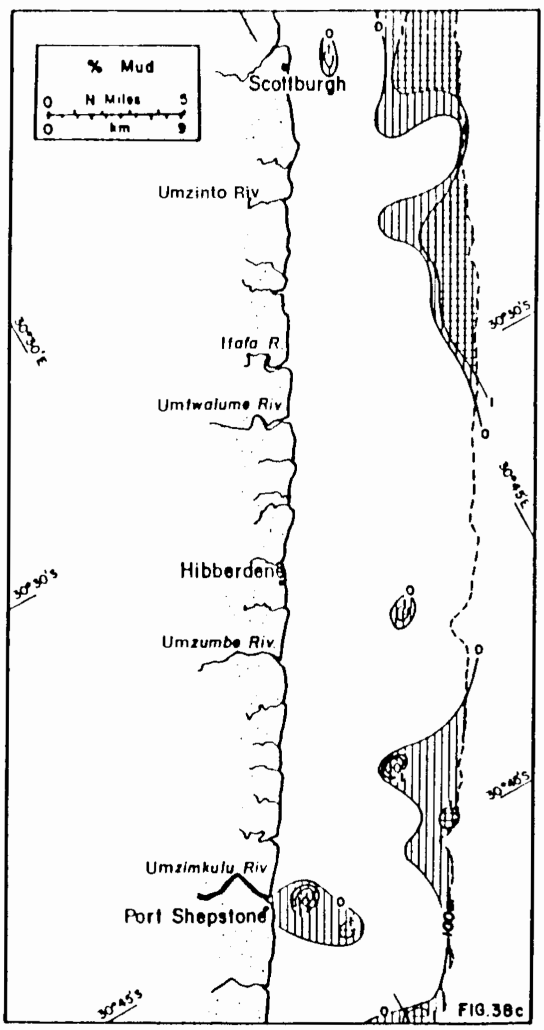
Both the $CaCO_3$ vs water depth plot (Fig.37b) and the $CaCO_3$ vs mean size (phi) (Fig.37c) indicate an overall increase in carbonate content with an increase in water depth and mean size, which is to be expected. Subgroups are not easily distinguished in either plot. Regression curves fitted to these plots give the equations $Y = 0{,}6157\ x + 12{,}0$ ($r = 0{,}5756$) and $Y = -7{,}09\ x + 52{,}16$ ($r = -0{,}1722$) where $Y = CaCO_3$ and x is equal to the depth and the mean size respectively. The increase in $CaCO_3$ with mean size is more regular than the relationship between $CaCO_3$ and water depth. The latter shows distinct changes in the $CaCO_3$ gradient across the shelf which are even better revealed by the % $CaCO_3$ contours.

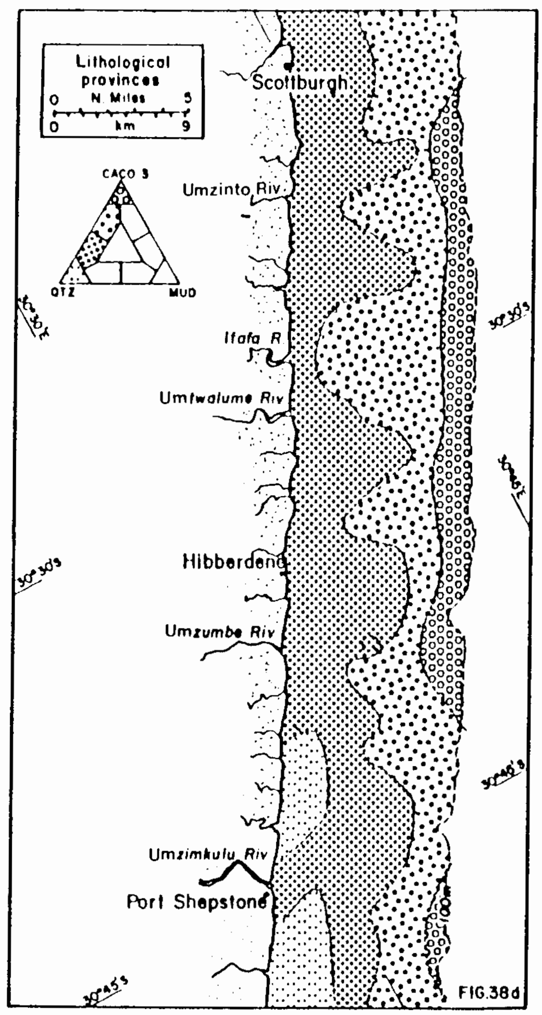
Gravel, Sand and Mud (Fig.38)

Gravel is generally a minor component of the total sediment. Amounts between 20% and 50% are only found in isolated patches in areas of uneven topography, notably the relict dune ridge on the middle shelf and on the outer shelf terrace (Fig.38a). In general, however, the gravel content increases towards the middle shelf (10-20%), but then decreases towards the shelf break (5-10%) except in places where the relict dune ridge has shifted onto the outer shelf. This is the situation between the Umzumbe and Umzimkulu Rivers. The overall pattern is interrupted by two


% Gravel
N. Miles
km
Scottburgh
Umzinto Riv
Ifafa R
Umtwalume Riv
Hibberdene
Umzumbe Riv
Umzimkulu Riv
Port Shepstone
FIG. 38a


% Sand
N. Miles
km
Scottburgh
Umzinto Riv
Ifafa R
Umtwalume Riv
Hibberdene
Umzumbe Riv
Umzimkulu Riv
Port Shepstone
FIG. 38b


% Mud
N. Miles
km
Scottburgh
Umzinto Riv
Ifafa R
Umtwalume Riv
Hibberdene
Umzumbe Riv
Umzimkulu Riv
Port Shepstone
FIG. 38c


Lithological provinces
N. Miles
km
CACO 3
QTZ
MUD
Scottburgh
Umzinto Riv
Ifafa R
Umtwalume Riv
Hibberdene
Umzumbe Riv
Umzimkulu Riv
Port Shepstone
FIG. 38d

cross-shelf corridors which have a low gravel content as, for example, off the Umzinto and Umzimkulu Rivers.

In this area there is no marked correlation between the gravel and the biogenic component on the middle shelf, as is the case on the outer shelf. It is therefore postulated that between Nkomazi and Port Shepsone the fluvial discharge is predominantly coarse grained (cf. section 3.3). Since much of the biogenic material consists of relict gravel lag deposits, the correlation observed elsewhere is in this case obscured by a high supply of coarse, terrigenous sediment.

As in the northern sector of the study area, sand is again the major component of the total sediment (Fig.38b). There is no gravel in the nearshore zone and even on the outer shelf the sediment frequently comprises more than 95% sand. As expected, the sand content has an inverse distribution pattern to that of the gravel. This is most obvious in the cross-shelf corridors, which are characterised by low gravel contents, as well as in the decrease of sand sized material on the outer shelf terrace between Ifafa and Port Shepstone, where the dune ridge shifts progressively farther offshore.

Mud is a very minor component in this shelf sector and significant quantities are restricted to two localized occurrences (Fig.38c). Off the Umzimkulu River the occurrence of mud on the outer shelf, although low, is nevertheless significant. Less than 1% mud is found on the outer shelf itself, but 1-3% mantles the shelf break. This trend is similar in outline to that of the 40% medium sand contour, a correlation which will be readdressed in the general discussion. Very minor amounts of mud (less than 0,5%) appear on the outer shelf to the south of the Umzumbe River. This area was previously noted for a decrease in the sand fraction and a relative increase in the gravel component. Again we thus find a strange correlation between mud and gravel, pointing towards interstitial entrapment.

Lithologically the sediments consist of calcareous quartzarenites in the nearshore sediment wedge and quartzose calcarenites on the outer shelf. Slightly quartzose calcarenites are found along the shelf break , whereas slightly calcareous quartzarenties are present in the nearshore north and south of the Umzimkulu River (Fig.38d).

<u>Very Coarse Sand</u> (Fig.39)

There is little (less than 1%) or no very coarse sand in the nearshore region of this shelf section, except for the area between the Umzumbe (Hibberdene) and the Umzimkulu (Port Shepstone) Rivers. Similarly, there is little very coarse sand along the shelf break. Most of it is therefore concentrated on the middle and outer shelves, reaching concentrations of up to 20% in some places. Two of these areas are found on the Ifafa Terrace. Other localised `highs` occur along the mid-shelf dune ridge. These latter localities correspond to areas where gravel is also found in appreciable amounts, whereas a similar correlation along the outer shelf would be tenuous. Here small patches of very coarse sand overlap with regions of low gravel content. The shelf between Hibberdene and Port Shepstone, however, is again a zone in which very coarse sand correlates

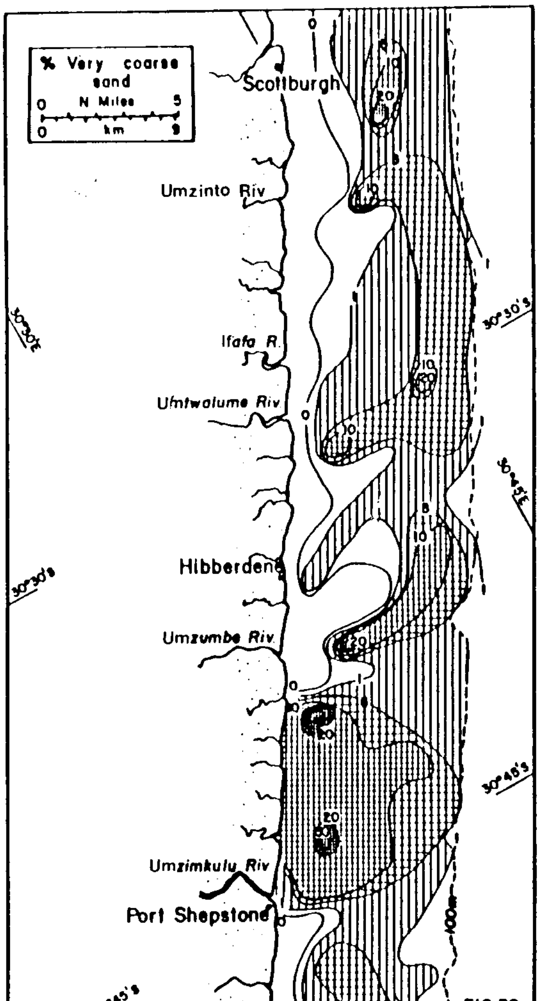


FIG. 39

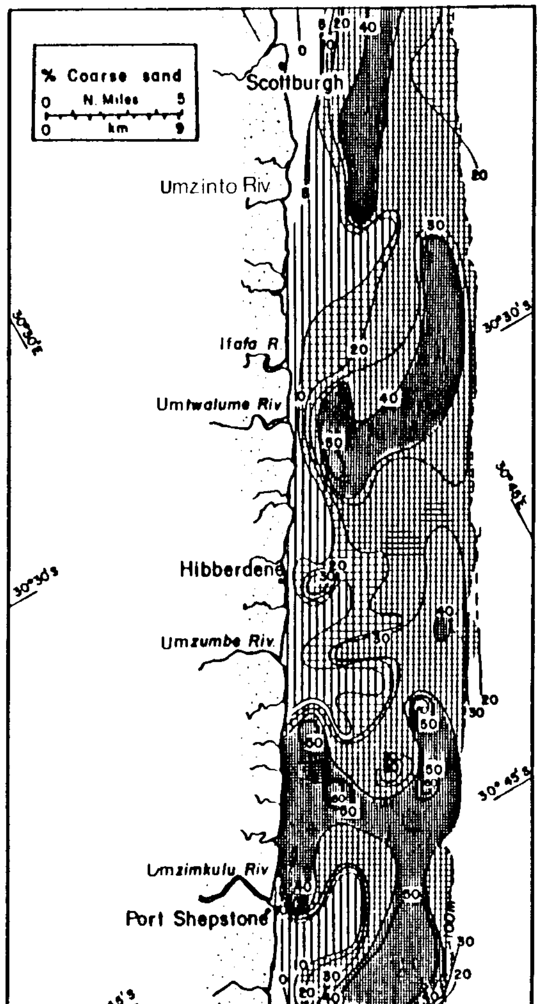


FIG. 40

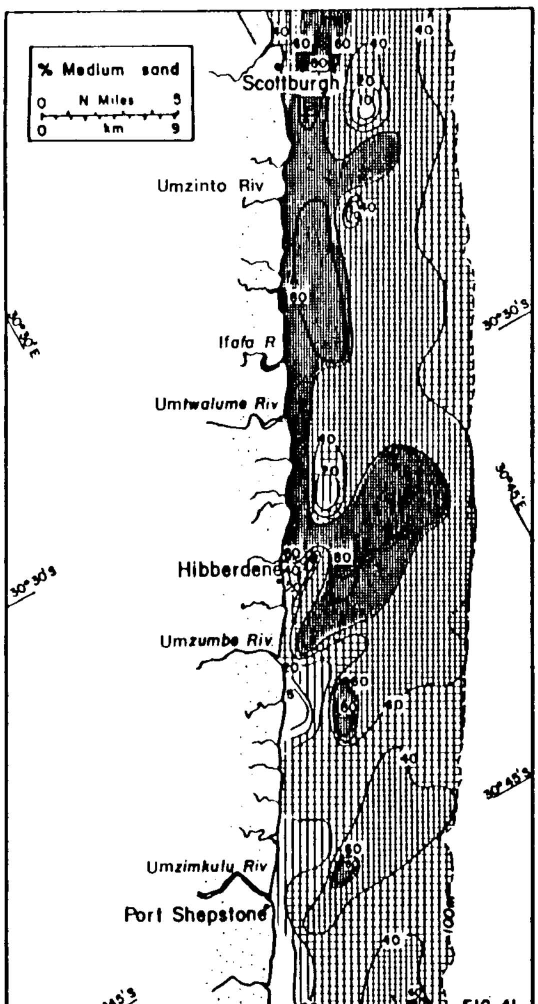


FIG. 41

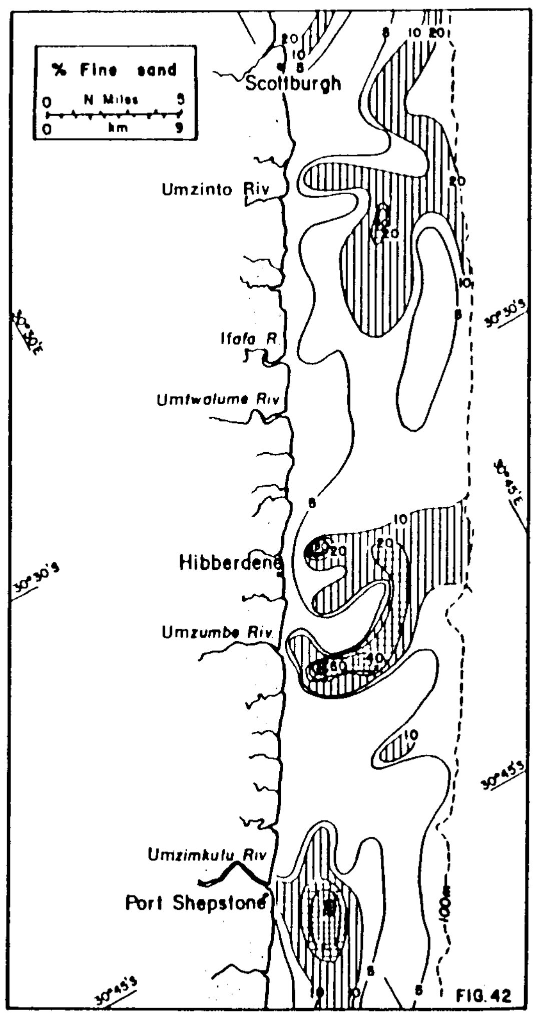


FIG. 42

with a relatively high gravel content.

Coarse Sand (Fig.40)

There is a general increase in coarse sand content of the sediment in an offshore direction, although the contours are very irregular. Close to the shelf break concentrations seem to decrease once more. Only between Hibberdene and Port Shepstone can coarse sand be found in larger concentrations on the inner shelf, locally reaching over 50%. Otherwise the 20% coarse sand contour follows a very similar trend as the 1% very coarse sand contour, both on the inner and on the outer shelf. Isolated patches of high coarse sand concentration coincide with high $CaCO_3$ content, suggesting that such concentrations comprise 'in situ' biogenic lag deposits which are not in dynamic equilibrium with the remainder of the sediment. This would also explain the irregularity of the contours. South of Hibberdene, on the other hand, the coarse sand distribution is more regular and continuous across the shelf. Highest concentrations, reaching more than 50% coarse sand, occur in discontinuous patches on the outer shelf and around the Protea Banks to the south of Port Shepstone.

On the whole there is a remarkable similarity between the distribution pattern of coarse sand and very coarse sand, especially where concentrations are relatively high. Since a similar correlation was observed between very coarse sand and gravel, this would suggest that much of the coarse suite of the size spectrum has a similar origin, being closely associated with the transgressional lag deposits exposed on many parts of the outer shelf of this region.

Medium Sands (Fig.41)

Two major trends can be observed in the distribution of medium sand. To the north of Hibberdene highest concentrations are found close to the shore, followed by a progressive offshore decrease reaching less than 40% near the shelf break. This trend is subparallel to the shore, with a slight cross-shelf component. Over 60%, and locally over 80%, of medium sand can be found on the inner shelf, whereas on the outer shelf it drops below 40%. It is by far the most dominent size component on this shelf sector. Lowest concentrations occur near the mid-shelf dune ridge where high concentrations of gravel, very coarse and coarse sand are found. The 60% contour appears to be a result of cross-shelf sediment dispersal in areas where the mid-shelf ridge has been overtopped. In fact, the 60% medium sand contour closely resembles that of the 20% contour for coarse sand, and both follow the curvilinear trend of the mid-shelf ridge.

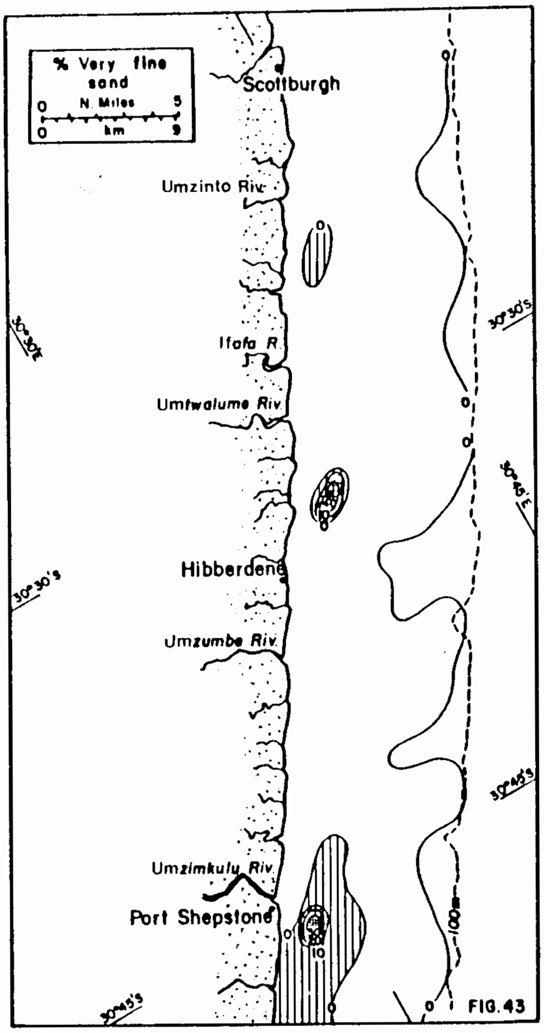
On the other hand, to the south of Hibberdene, the medium sand is mainly concentrated on the middle shelf, decreasing both seawards and shorewards. This trend is particularly well developed in the vicinity of the Protea Banks, although it tends to be discontinuous. Medium sand is conspicuously low in the nearshore zone where less than 20% is found. This obviously suggests that there is no input of medium sand to the south of Hibberdene in this area.

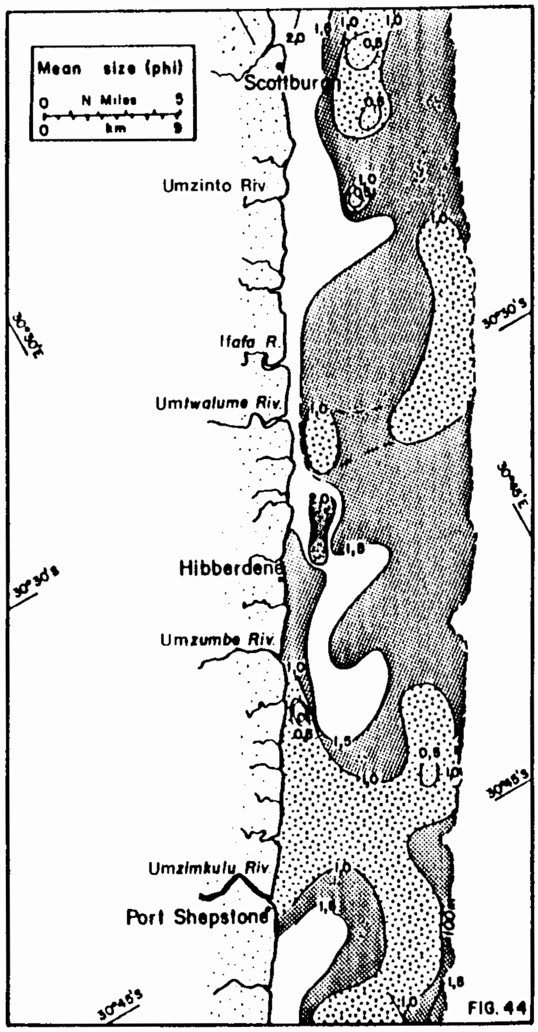
Fine Sands (Fig.42)

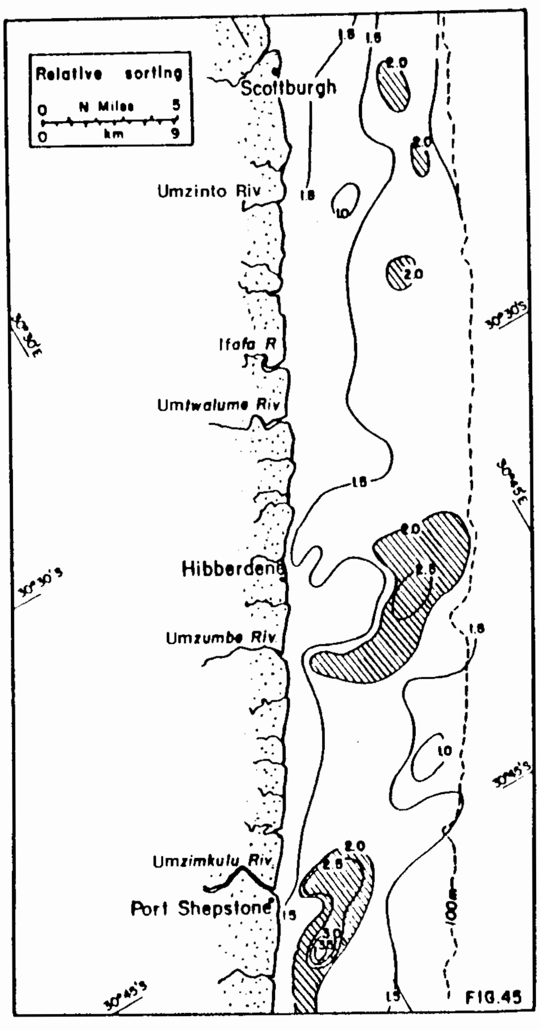
Contrary to the clearly defined trend of fine sand on the shelf sector between Durban and Scottburgh, no such trend can be recognised between Scottburgh and Port Shepstone. In addition, over most parts of this shelf sector the concentration of fine sand is very low, although there are a few localities where concentration levels exceed 20%, as for example off Hibberdene (more than 80%) and off Port Shepstone (more than 40%). Paradoxically, there is a slightly higher occurrence of fine sand on the outer shelf, i.e. near the high velocity core of the Agulhas Current, than there is in the nearshore zone. This would suggest that there is very little, and even then only a very localized input of fine sand, focussing on the Umzumbe and the Umzimkulu Rivers. There is certainly no independent fine sand population on any significant scale comparable to that in the northern sector. The fine sand more likely represents the fine tail of the predominantly medium-sized hydraulic population, which has undergone some degree of size-sorting on the shelf. As pointed out in the previous section, the slight increase of fine sand on the outer shelf might indicate that the Agulhas Current manages to entrain some fine sediment where the return flow in the north dumps its load onto the southern extension of the Tugela cone.

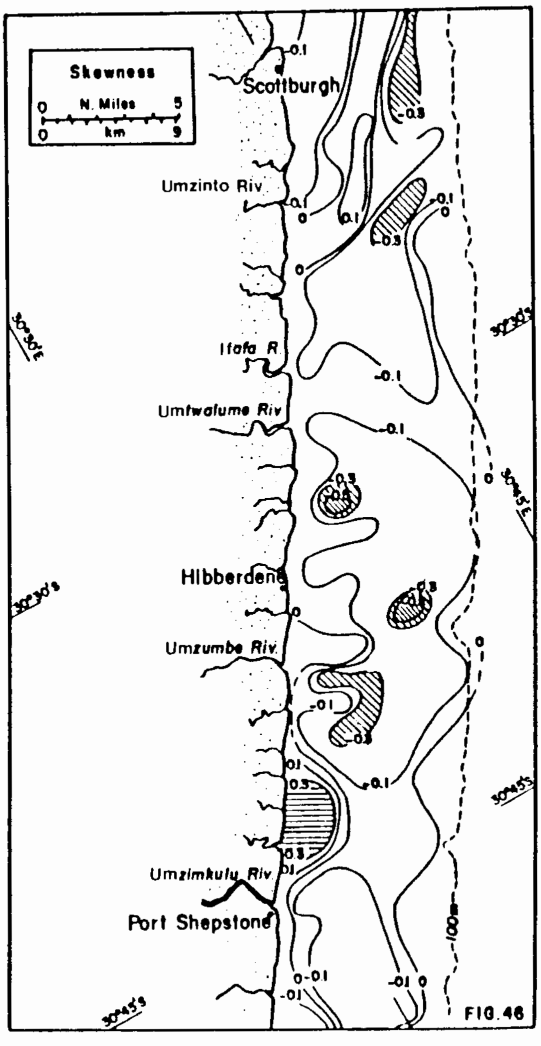
Very Fine Sand (Fig.43)

Very fine sand is even less conspicuous than fine sand, but follows the same general trend. Again local highs can be associated with local rivers and the slight increase along the shelf break must be related to the same mechanism responsible for


% Very fine sand
0 N. Miles 5
0 km 9
Scottburgh
Umzinto Riv.
Ifafa R.
Umtwalume Riv.
Hibberdene
Umzumbe Riv.
Umzimkulu Riv.
Port Shepstone
30°30'S
30°45'S
100m
FIG. 43


Mean size (phi)
0 N. Miles 5
0 km 9
Scottburgh
Umzinto Riv.
Ifafa R.
Umtwalume Riv.
Hibberdene
Umzumbe Riv.
Umzimkulu Riv.
Port Shepstone
30°30'S
30°45'S
100m
FIG. 44


Relative sorting
0 N. Miles 5
0 km 9
Scottburgh
Umzinto Riv.
Ifafa R.
Umtwalume Riv.
Hibberdene
Umzumbe Riv.
Umzimkulu Riv.
Port Shepstone
30°30'S
30°45'S
100m
FIG. 45


Skewness
0 N. Miles 5
0 km 9
Scottburgh
Umzinto Riv.
Ifafa R.
Umtwalume Riv.
Hibberdene
Umzumbe Riv.
Umzimkulu Riv.
Port Shepstone
30°30'S
30°45'S
100m
FIG. 46

the presence of fine sand in this region. If there is a fine to very fine sand population present at all, then it is volumetrically so small that it is obscured by the overwhelming dominance of the medium and coarse sand.

Mean Size (Fig.44)

The mean size distribution strongly reflects that of the coarse sand and to a lesser extent also that of the medium sand. Between Scottburgh and Hibberdene the 1.5 phi contour runs along the inner shelf, outlining a similar area defined by the 10-20% coarse sand contours. On the outer shelf the 1,0 phi mean diameter contour closely corresponds to the 40% coarse sand contour. This contour also roughly outlines the very coarse to coarse sand 'wedge' which extends across shelf between Hibberdene and Port Shepstone reaching as far south as the Protea Banks. South of Port Shepstone sediment finer than 1,5 phi is once more found on the inner shelf and along the shelf break, a trend which reflects the concentration of medium sand along the midshelf in this region. Considering the fact that medium sand is the dominant sediment on the shelf, it might seem surprising to observe a coarse sand overprint in the mean diameter map. However, since coarse sand is the next most dominant component the mean must obviously shift towards the coarse sand, especially if it is coupled with a slight bimodality in the distribution curves.

Relative Sorting (Fig.45)

Most of the sediments on the shelf are very well sorted when using the relative sorting scale. Within this category there is a general decrease in sorting towards the outer shelf in the north between Scottburgh and Hibberdene. Well sorted sediments with a QH value greater than 2 occur in isolated patches, but these nevertheless link up in a belt which commences on the outer shelf off Scottburgh and continues south towards the inner shelf off Port Shepstone. The shelf areas off the Umzumbe and the Umzimkulu Rivers, which are marked by a complex overlay of individual size fractions, coincide with the least well sorted sediments. As observed before, sorting appears to be directly related to the degree of mixing between sediments of different origin. This is also borne out by the skewness pattern discussed below.

Skewness (Fig.46)

Skewness reveals a remarkably consistent pattern over the entire study area and the shelf section between Scottburgh and Port Shepstone is no exception. All midshelf sediments are generally negatively skewed, whereas both nearshore and outer shelf sediments tend to be positively skewed. There are exceptions to this rule. For example, the entire shelf section between Ifafa and Hibberdene is negatively skewed, suggesting an absence of fine sediments, both in the nearshore as well as near the shelf break. This is in fact borne out by distribution map of fine sand (cf. Fig.42).

Another important deviation is observed immediately south of the Umzinto River where a tongue of positively skewed sediment stretches obliquely across the shelf towards the north, being flanked on both sides by negatively skewed sediments. Again this trend would be expected if one considers the overlap between the fine sand and the medium sand corridors discussed in section 4.1. The fine sand corridor in the nearshore should have a medium sand tail and hence be negatively skewed, whereas the medium sand corridor should display a fine tail, resulting in positive skewness.

South of the Umzumbe River the nearshore zone is positively skewed. In this case a very coarse to coarse sand poulation is diluted by medium sand. Since medium sands dominate the middle shelf, the negative skewness reflects a coarser tail, or a second mode, produced by the relatively high concentrations of coarse sand in this area. The outer shelf, on the other hand, comprises mainly coarse sediments and hence the small input of fine sediment discussed earlier would add a fine tail to the sediment.

4.2.3 Discussion and Conclusions

Three trends summarize the distribution patterns of the various size fractions on this sector of the shelf. Firstly, the dramatic decrease in fine sediment south of Scottburgh; secondly, the concentration of medium sand (more than 60%) on the inner shelf north of the Umtwalume River and to a lesser extent between this river and the Umzumbe River; thirdly, the difference in the distribution of coarse and very coarse sand on the inner and middle shelves north and south at Ifafa. Immediately offshore of Ifafa is an anomalous concentration of coarse sand which extends across the midshelf ridge to link up with a similar area on the middle shelf. The 40% $CaCO_3$ contour shifts seawards, outlining the same area which suggests a response to terrigenous dilution. South of the Umzumbe River coarse and very coarse sediments are mixed with lesser amounts of medium sand across the entire shelf.

The detailed distribution patterns clearly distinguish individual hydraulic populations which are dominated by particular size fractions. As a result sediment dispersal routes are well defined (cf. Swift et al., 1972). The population dominated by medium sand (1,5 to 2,0 phi, approximately 60%) is volumetrically the most important by far. The skewness trends indicate some mixing between this population and the finer-grained hydraulic population (finer than 2,0 phi), on the one hand, and the coarse and very coarse-grained population on the other. In addition, on the outer shelf, and especially along the shelf break, fine sediment mixes with coarse lag material. In this manner the main sediment pathways can be identified. These are outlined in more detail below.

Topographic detail often indicates sites of sediment accumulation, as well as sites of sediment starvation or erosion, both features reflecting the relative effect of the Agulhas Current. As has been outlined in Sections 3.3 and 4.1.3, the general paucity of fine sediment on this shelf sector is primarily due to a decrease in fluvial supply of this size class. The 5% fine sand contour suggests that the small amounts of fine sand, which enter the shelf regime north of the Umzumbe River, are carried northwards by the combined action of longshore drift and nearshore currents of the return flow cell. The sediments on the inner shelf are only very slightly negatively skewed, which is to be expected in a predominantly medium grained environment containing very small amounts of fine sand. It should be noted that the 5% fine sand contour shows an oblique northeastward cross-shelf trend immediately south of Scottburgh, which is identical to that of the 60% medium sand contour in the same area, although it is slightly offset from the latter. This trend will again be referred to in the discussion of the dynamics of the medium sized population. South of the Umzumbe River the 5% and the 10% fine sand contours suggest a southerly movement of fine sediment along the middle shelf.

The sediments on the outer shelf are predominantly positively skewed, reflecting interstitial entrapment of fine sand in coarser 'host' sands, frequently resulting in bimodal distribution. The source of this sediment is most likely the Tugela cone and to a lesser extent, the fine sediment on the outer shelf region to the north, which is entrained south by the Agulhas Current and re-deposited as it begins to impinge once more on the shelf. In some places, however, the outer shelf sands are negatively skewed, e.g. north of the Umzinto River and between the Umtwalume and Umzumbe Rivers, suggesting that the fine sand component is compensated and exceeded by a coarse sand tail at the other end of the size spectrum.

The bulk of the terrigenous material supplied to the shelf between Scottsburgh and Port Shepstone comprises medium to coarse-grained quartzose material (cf. Section 3.3). A sediment budget (Flemming and Hay, 1983) suggests that only $0{,}721 \times 10^6$ metric tons is supplied annually by the Umzinto, Umtwalume, Ifafa and other minor rivers. Relative to the areas to the north and south, this sector of the shelf is thus sediment starved. Birch (in press), however, notes that sediment overtops the midshelf ridge (which is up to 25 m above the sea floor) between Green Point and Ifafa so that up to 1 m of sediment has accumulated on the seaward side of the ridge. On the outer shelf, little (less than 4 m) or no sediment is present. The ridge thus forms an effective physical barrier by channelling the north flowing counter current and the movement as well as the accumulation of the medium sized hydraulic population north of the Umzumbe River. Accumulation of sediment shoreward of this ridge and on the outer shelf north of Ifafa has resulted in a smooth evenly sloping seabed. The limits of this oblique cross-shelf sediment corridor is revealed by the skewness patterns. Close to the shore the fine sand contains small amounts of very fine sand to produce a positively skewed sediment. Further offshore the fine sand overlaps with the medium sand belt and hence is negatively skewed (cf. Section 4.1.3). To the south of this corridor, medium sand forms the fine tail in a predominantly coarse sediment on the middle shelf,resulting in positive skewness.

The main zone of negative skewness continues southwards along the middle and outer shelves. Sediment accumulation indicated by the bathymetry south of the Umtwalume River (also the limit of the medium sand corridor) and the gradual increase in the width of the outer shelf terrace from as far north as Scottburgh reveals the renewed influence of the Agulhas Current. The coarse sediment on the outer shelf between Ifafa and the Umtwalume River consists of mixed relict and modern material. It would appear that medium to coarse sediment is being entrained south by the

Agulhas Current and is banked up against the seaward side of the ridge as it increasingly encroaches farther across the shelf. Calculations of the minimum flow velocities required to move this material in bedload indicate that the Agulhas Current must reach speeds above 60 m/sec on this part of the shelf. Conversely, south of Ifafa, the inner shelf sand wedge narrows rapidly. This is probably due to the combined effects of current erosion on the seaward side of the ridge, a reduced influence of the counter-current and a strongly reduced supply of medium-grained material by fluvial discharge to the area.

The regional bathymetry as well as seismic evidence (Birch, in press; Flemming, 1978, 1980) does not reveal large sediment accumulations between the Umtwalume River and Port Shepstone, This is alos indicated by the decrease in the amount of mobile medium sand south of the Umzumbe River. It is therefore postulated that the oblique bedload parting occupies the shelf area between the Umtwalume and the Umzumbe Rivers, where it occasionally migrates parallel to the shoreline in response to the intensity of the Natal Gyre System. Between these two rivers medium sand is either moved north in the counter-current or escapes across the shelf to be transported southwards by the Agulhas Current, depending on the local weather conditions. This interpretation is supported by two observations; firstly, by the anomalous northeasterly cross-shelf medium sand trend in an area where no sediment overtops the mid-shelf ridge and secondly, by the sudden paucity of medium sand between the Umzumbe River and Port Shepstone. In the former case the medium sand concentration pattern then continues southwards of the Umzumbe River on the mid-shelf, being negatively skewed, a trend which is to be

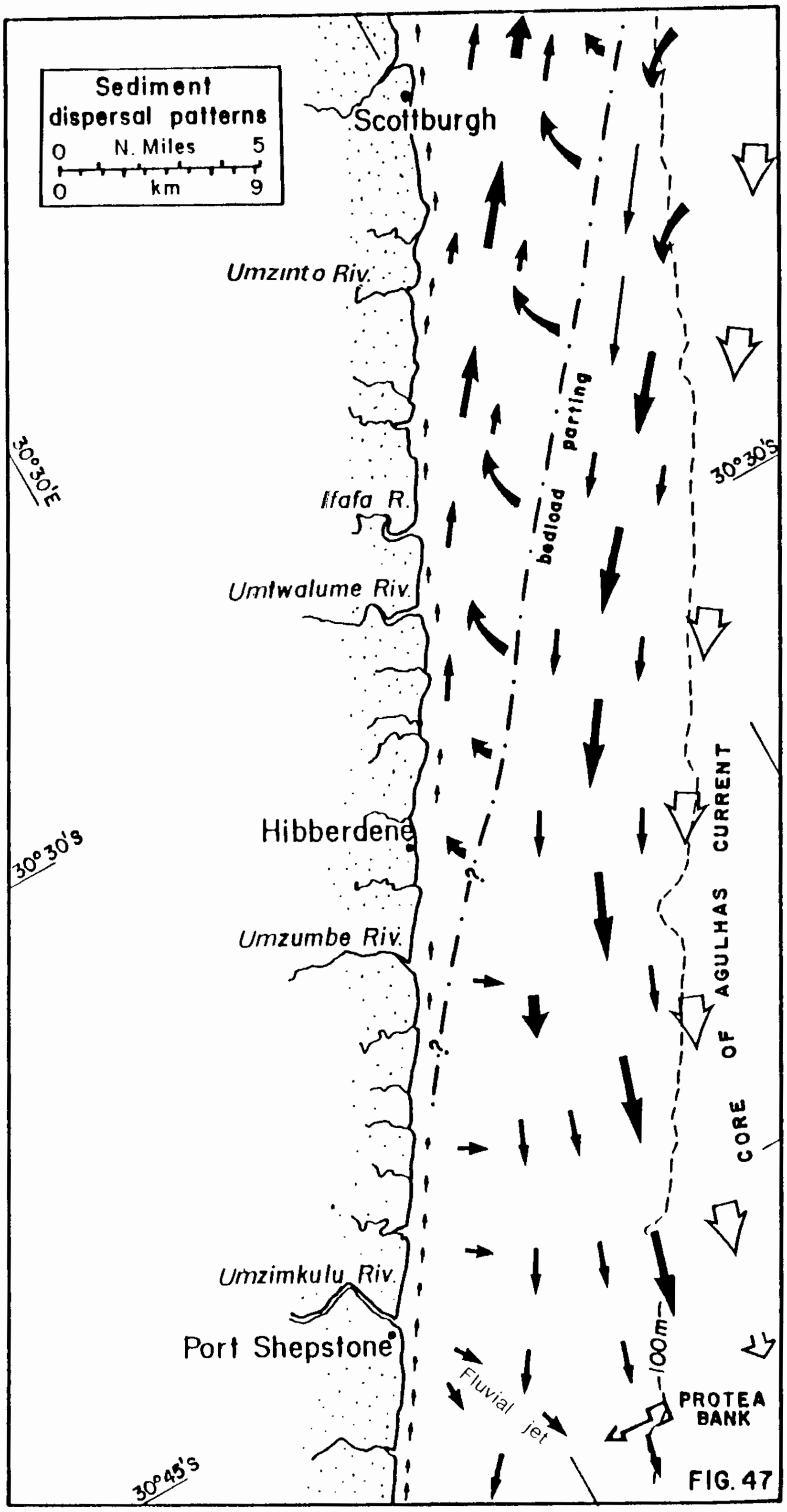

Sediment dispersal patterns
0 N. Miles 5
0 km 9
Scottburgh
Umzinto Riv.
Ifafa R.
Umtwalume Riv.
Hibberdene
Umzumbe Riv.
Umzimkulu Riv.
Port Shepstone
bedload parting
30°30'E
30°30'S
30°30'S
30°45'S
CORE OF AGULHAS CURRENT
100m
PROTEA BANK
Fluvial jet

FIG. 47

expected in accordance with the mobile mid-shelf sand stream concept outlined by Flemming (1980, 1981).

Given that there are only small rivers discharging onto the shelf in this area and that the Umtwalume and Umzumbe Rivers do not maintain a large supply of sediment to this sector of the shelf, it is furthermore probable that some of the sediment which is entrained by the Agulhas Current is subsequently exported via various submarine canyons, such as the Umzumbe Canyon, the Umzimkulu Canyon and the Protea Canyon. Birch (1981), for example, records up to 10 m of sediment mantling these canyon heads. The medium sand contours in fact indicate a progressive southward loss of sediment. Thus, whereas more than 40% medium sand lies along the Umzumbe and Umzimkulu Canyon heads, less than 40% occurs on the outer shelf off the Protea Canyon, decreasing to under 10% immediately to the south of this canyon in the vicinity of the Margate Canyon.

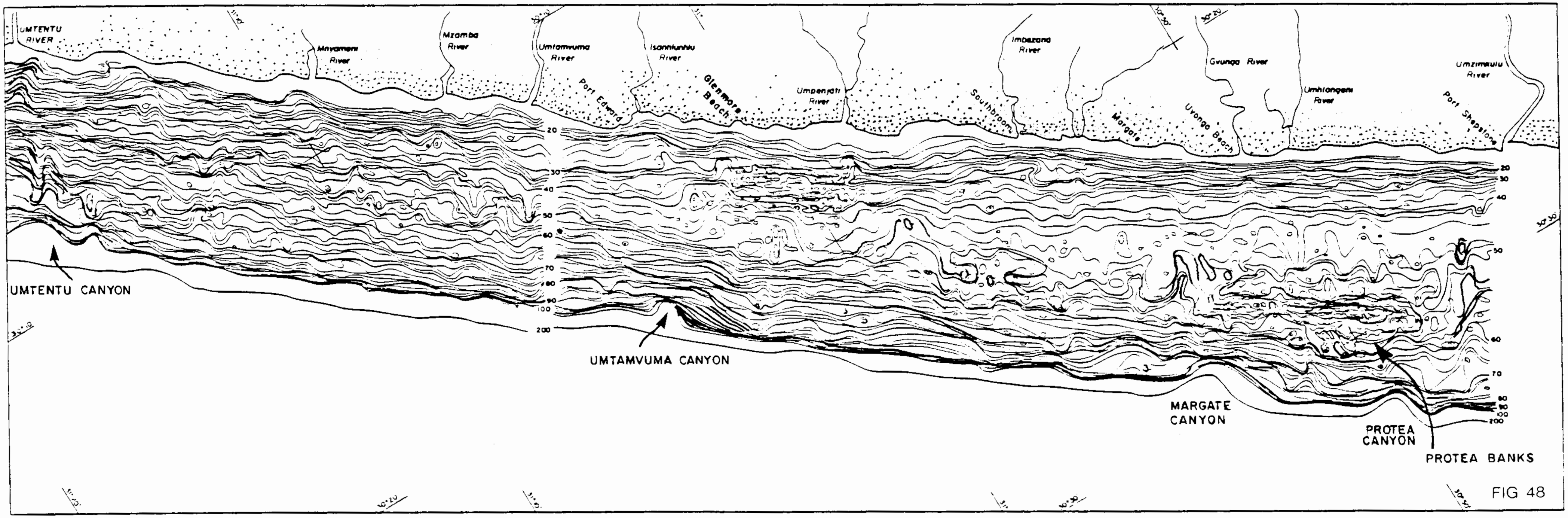
Although the above model may seem tenuous, it is nevertheless plausible if one accepts that the Agulhas Current is partially deflected offshore by the midshelf ridge. Bedforms on either side of the Protea Banks indicated that the current splits up and passes both inshore and offshore of this feature. In addition the $CaCO_3$ content is much higher on the seaward side. This again suggests a greater degree of erosion and loss of terrigenous material (Fig.47).

4.3 PORT SHEPSTONE TO THE UMTENTU RIVER

4.3.1 Bathymetry (Fig.48)

As in the previous section, the physiography of the shelf in this area is largely determined by the presence or absence of the midshelf dune ridge. The ridge is particularly prominent between Port Shepstone and Margate. It commences with a large shoal area, called the Protea Banks, which is situated between the 40 and 50 m isobaths southeast of Port Shepstone. The Banks are approximately 4 km wide and rise 15 m to 25 m above the surrounding seabed, some 8 km offshore. The ridge gradually decreases in height southwards and narrows as it once again moves closer to the shore, until south of Glenmore Beach it disappears completely. Slight topographic irregularities on the middle and outer shelves to the south of the Umzamba River may represent the eroded remnants of the ridge, although the ridge proper only reappears in the very south of this shelf sector off the Umtentu River.

The shelf itself gradually narrows from about 12 km off Port Shepstone to less than 9 km off the Umtentu River. Physiographicaly the shelf to the north of Glenmore Beach differs markedly from that in the south. Three provinces can be distinguished in the north. There is the characteristic nearshore sediment wedge which slopes at an average angle of 0,4^{o} and reaches a maximum width of about 4 km. At about -40 m it merges with the midshelf terrace which has a width of about 4 km in the north, but narrows progressively towards the south until it disappears approximately at the same locality as the midshelf ridge. The outer shelf slopes relatively smoothly down to the shelf break. An outer shelf terrace is not developed.



BATHYMETRIC MAP C - PORT SHEPSTONE TO MTENTU RIVER

To the south of Glenmore Beach the entire shelf is topographically undifferentiated and there is little difference in slope between the inner, the middle and the outer shelf. The slope angle on this sector averages around 0,57°. South of the Umtentu River the outer shelf terrace begins to reappear. This terrace, called the Waterfall Bluff Terrace, is fully discussed in the following section. Three major canyons, situated off the Protea Banks, off the Umtavuma River and the Umtentu River respectively, have been recorded.

4.3.2 Sediment Distribution Patterns

A map indicating the sample density and localities is presented n Fig.49.

Biogenic sediments (Fig.50)

The $CaCO_3$ content of the sediment increases in an offshore direction with the contours running subparallel to the shoreline (Fig.50a). In general 20-30% biogenic material is present on the inner shelf, but more than 50% is found on the outer shelf below a water depth of 50 to 60 m. In a number of isolated localities near the shelf break, for example seawards of the Protea Banks at -70 m and beyond the 80 m isobath between the Umtentu and the Msikaba Rivers, biogenic material comprises more than 90% of the total sediment.

Three subtrends are evident. Between Port Shepstone and Glenmore Beach, just north of Port Edward, the 40% contour follows the dune ridge along the boundary between the middle and the outer shelf. South of Glenmore Beach, however, this contour swings sharply towards the shore, before aligning itself with the 20 to 30 m isobaths. As a result there is a steep gradient across the inner shelf to the south of Glenmore Beach.

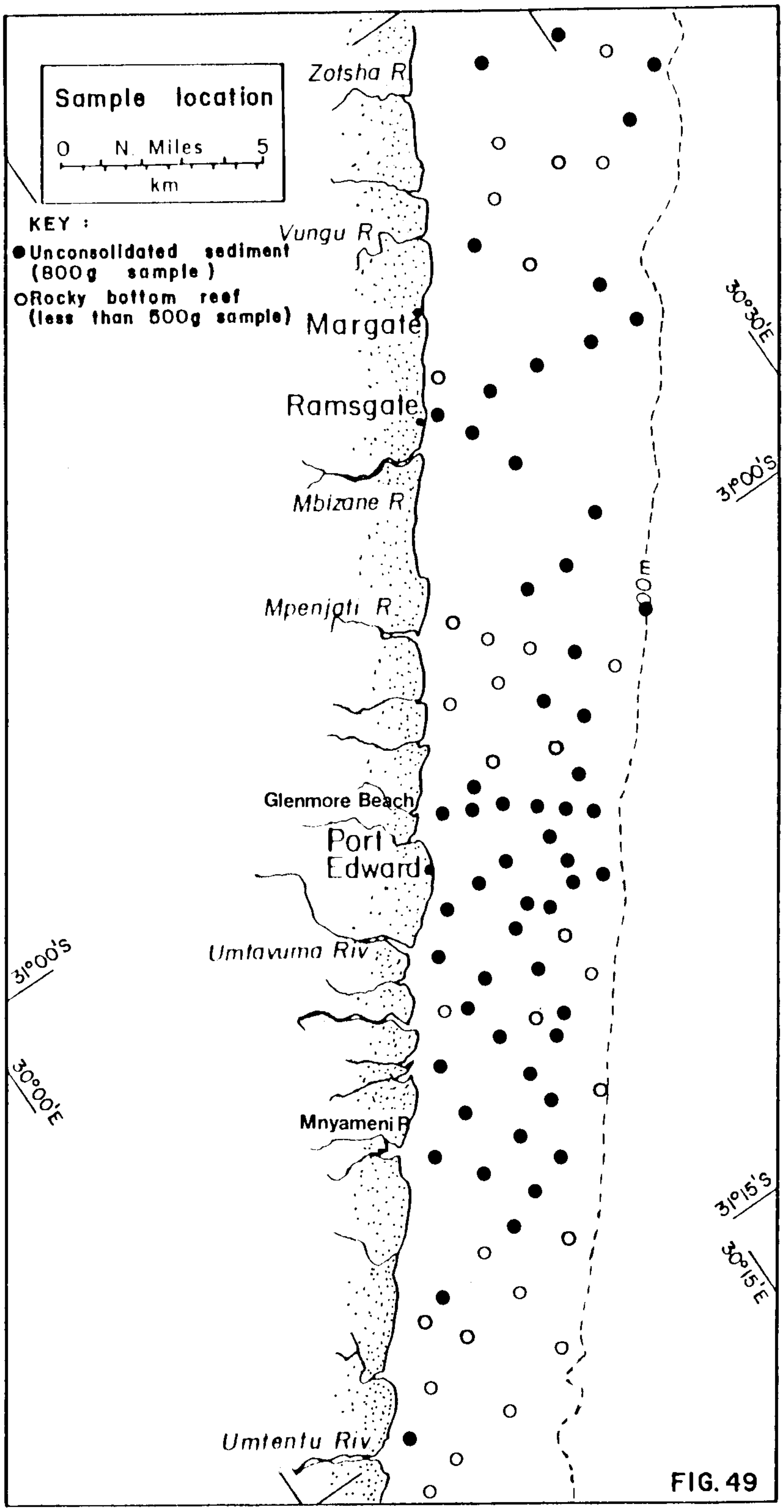

Sample location
0 N. Miles 5
km
KEY :
Unconsolidated sediment (800g sample)
Rocky bottom reef (less than 500g sample)
Zotsha R
Vungu R
Margate
Ramsgate
Mbizane R
Mpenjati R
Glenmore Beach
Port Edward
Umtavuma Riv
Mnyameni R
Umtentu Riv
30°30'E
31°00'S
31°15'S
30°15'E
30°00'E
100 m

FIG. 49

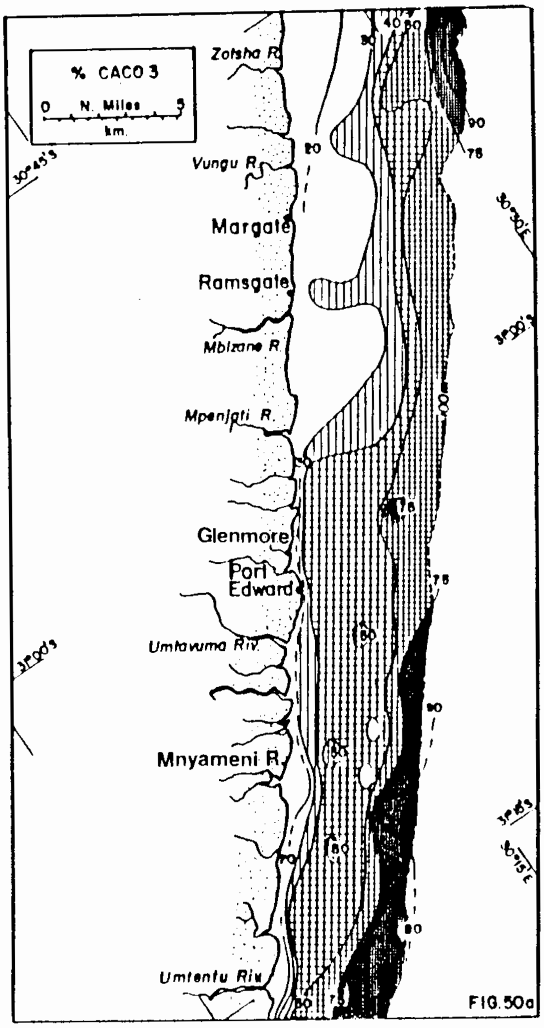


FIG.50a

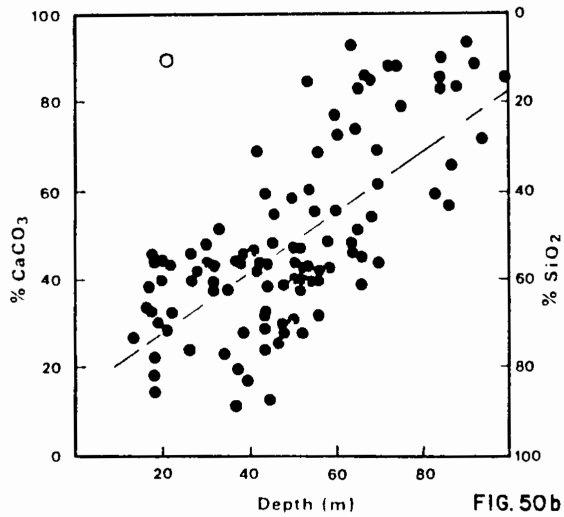


FIG. 50b

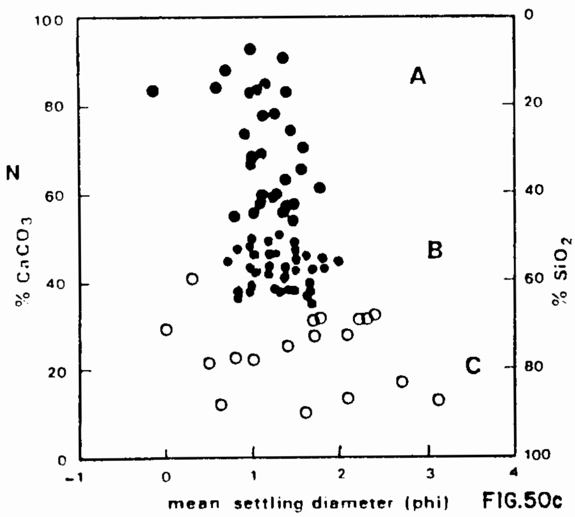


FIG.50c

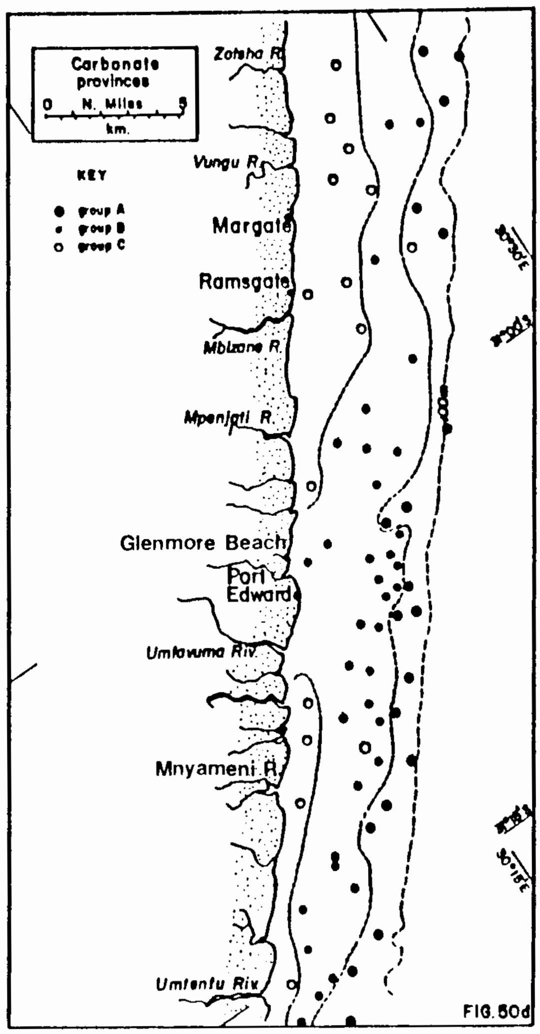


FIG. 50d

Similarly, starting off Port Edward, the 50% and the 75% contours gradually move across the middle shelf into shallower water. This displacement, especially of the 75% contour, is accompanied by a slight increase in the roughness of the outer shelf to the south of Port Edward.

A scatter plot of $CaCO_3$ vs water depth (Fig.50b) confirms the general offshore increase in $CaCO_3$ content, previously inferred from the carbonate distribution map of Fig.50a. The scatter is fairly wide as one would expect in cases where concentration lines cross bathymetric contours. The point cluster can be defined by the linear regression equation $Y = 0{,}6742\ x + 16{,}7$ with a correlation coefficient of $r = 0{,}6721$

When $CaCO_3$ is plotted against the mean diameter however, more subtle trends appear (Fig.50c). As along other parts of the study area, a number of distinct point groupings can be recognized, each of which corresponds to a specific area on the shelf. It would seem that the point clusters reveal mixing trends between low carbonate nearshore sediments and high carbonate offshore sediments, to produce intermediate populations, both with respect to size as well as carbonate content. It would thus appear that variations in the $CaCO_3$ content are largely the result of proportional mixing between the predominantly carbonate-rich relict material and the modern terrigenous material. High $CaCO_3$ values therefore imply that little terrigenous material (less than 40%) reaches or is retained on the central and outer shelf region. This compares well with the trend established by the 40% medium sand contour (Fig.54). Most of the sediments in the midshelf region comprise between 30% and 50% $CaCO_3$ and have a mean diameter ranging from 0,5 to 2,0 phi, with the bulk of the sediments falling in the 1,0 to 1,5 phi range. These sediments plot in a tight cluster at the centre of the mean size vs $CaCO_3$ scatter diagramme. They include all the samples from the area known as the Port

Edward dune field. The narrow range in the mean size and the carbonate content of this sample set suggests that they represent the least mixed sediment on this part of the continental shelf. Carbonate provinces distinguished in this manner are shown in Fig.5Ød.

Gravel, Sand and Mud (Fig.51)

In the northern half of this shelf sector, i.e. between Port Shepstone and Port Edward, there is a close relationship between the physiography of the shelf and the amount of gravel in the sediment (Fig.51a). Where the topography is smooth and the slope even, e.g. in the nearshore zone and beyond the midshelf ridge, little gravel is found, varying from Ø-5% or 1Ø%, reaching up to 6Ø% only locally along the midshelf ridge. Between the Umtavuma River and Waterfall Bluff, the trend of the northern shelf sector overlaps laterally with that of the southern shelf sector. A tongue of relatively higher gravel content extends from the midshelf terrace of the northern sector towards the inner shelf off the Mnyameni River. This tongue of high gravel content is separated from the southern shelf sector by a corridor in which gravel is absent. The corridor runs diagonally from the outer shelf off Port Edward towards the inner shelf off the Umtentu River. Seawards of the corridor the gravel content of the southern shelf sector increases progressively from Ø% to local maxima of over 5Ø%. Thus, while the gravel content of the northern shelf sector is mainly linked to physiographic features, concentrating around the midshelf terrace, that of the southern sector is mainly bathymetrically controlled, with some lateral overlap between the two areas. The high gravel content on the outer shelf of the southern sector in fact suggests that the outer shelf terrace extends all the way up to the Umtavuma Canyon Head, even though this is not clearly reflected in the bathymetry.

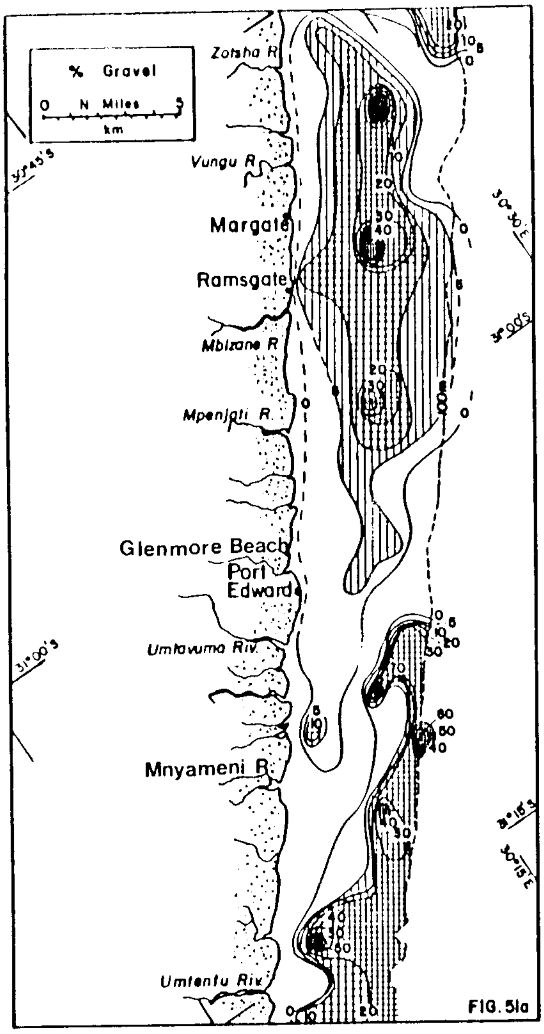


FIG. 51a

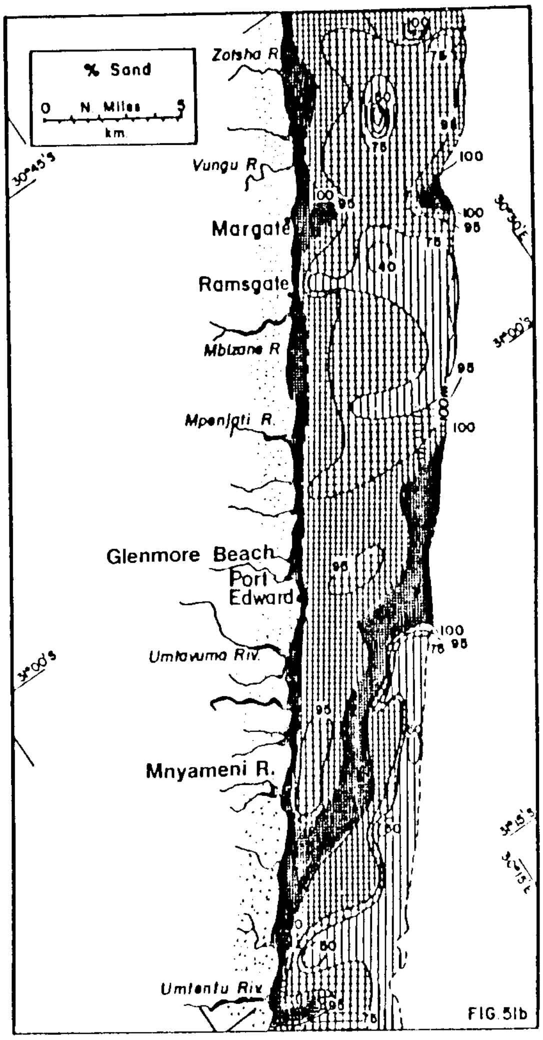


FIG. 51b

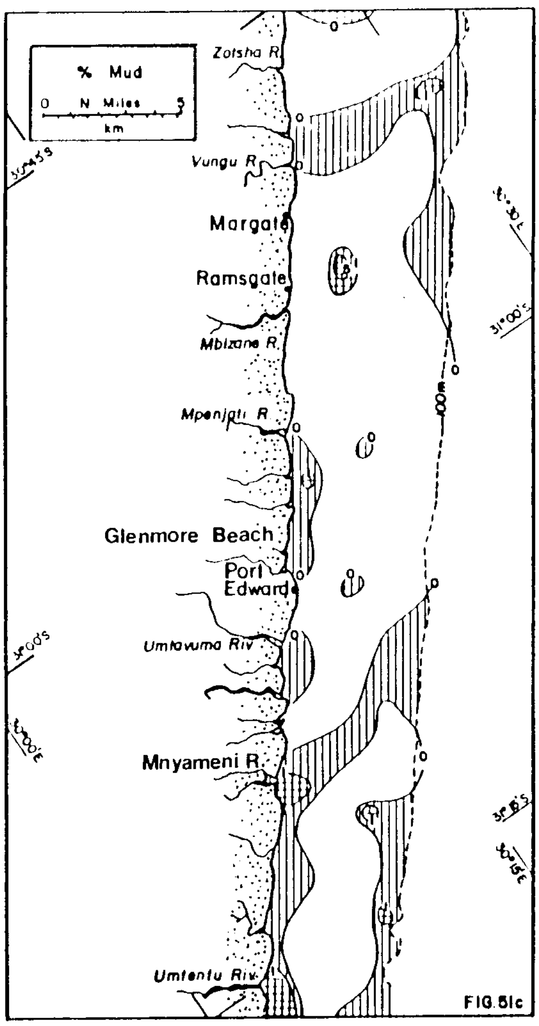


FIG. 51c

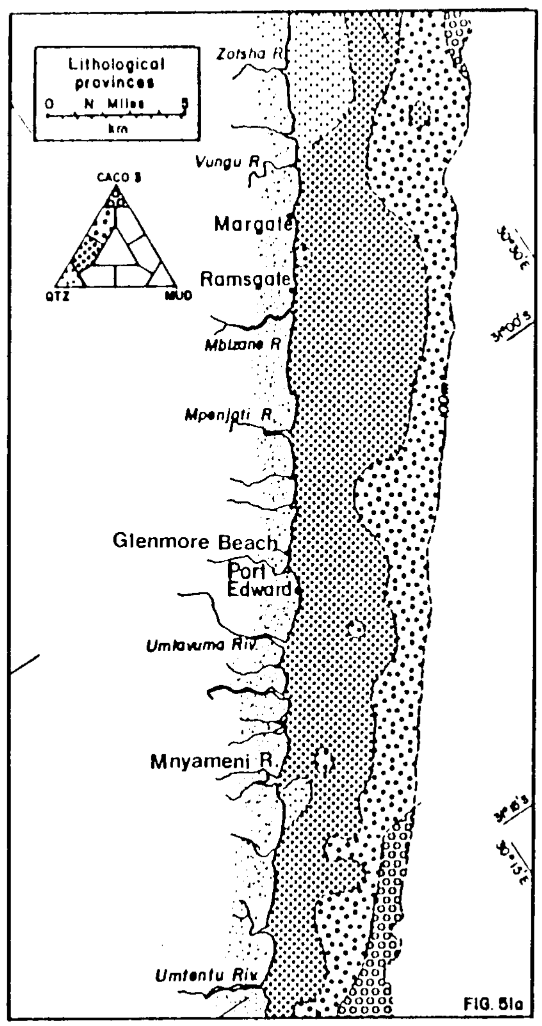


FIG. 51a

The sediments of this shelf sector consist at least of 50% sand-sized material and in many cases reach 100% (Fig.51b). Geological windows in the otherwise thin sediment cover account for discreet patches of high gravel concentrations. Since gravel is the second largest component and the mud content is negligible, it is not unexpected that the sand distribution pattern should display an inverse pattern to that of the gravel. Fig. 51b clearly outlines the two laterally overlapping provinces, separated by a narrow corridor consisting 100% of sand. In the northern sector sand is mainly concentrated on the inner shelf (more than 95%). Although the midshelf terrace has been identified as a high gravel province, sand-sized material is nevertheless the dominant component here,reaching more than 75% in some places. In the southern sector, on the other hand, there is a rapid offshore decrease in sand concentrations, dropping below 45% in some places on the outer shelf. The decrease in sand content corresponds to an increase of both gravel and carbonate, once again suggesting that most of the offshore gravels in this area compare biogenic lag material.

As mentioned above, mud is present only in very minor amounts (Fig.51c). This applies to the entire shelf, with the exception of a few localised patches as, for example, to the south of Margate where an isolated sample contained as much as 50% mud. A small number of samples with more than 1% mud can be found in the nearshore zone off some of the river mouths, especially to the south of Glenmore Beach, as well as along the shelf break. Except for a few localities mud is absent from the middle shelf. Two cross-shelf bands of very low mud content (less than 1%) are indicated, one off Margate and the other south of Port Edward. The latter is slightly offset from the sand corridor discussed earlier. It is difficult to attach any significance to these patterns due to the very small volumes involved. It is perhaps only the slight increase on the outer shelf and the patchy occurrence off some river mouths which fit into a consistent pattern when looking at the entire continental shelf of the study area (cf. Section 4.1).

Lithologically the sediments found on the inner and middle shelves can be classified as calcareous quartzarenites, whereas those on the outer shelf plot as quartzose calcarenites. Slightly quartzose calcarenites are found along the shelf break (Fig.51d).

Very Coarse Sand (Fig.52)

South of Port Shepstone there is a marked decrease in the amount of very coarse sand on the shelf. There is none at all in the nearshore zone. North of Port Edward small localized patches correlate with 'high' $CaCO_3$ and gravel distribution patterns which are concentrated on the mid-shelf terrace. South of the Umtavuma River there is a more regular increase in very coarse sand towards the outer shelf. Again there is a cross shelf corridor in which no very coarse sand is found. It is situated slightly to the south of the sand corridor discussed earlier, which must evidently comprise finer sediments.

Coarse Sand (Fig.53)

The distribution of coarse sand follows a similar, but more coherent pattern to that of the very coarse sand between Port Shepstone and Port Edward. It is mainly concentrated on the middle and outer shelves, reaching values of over 30% and locally over 50%. Less than 10% is present on the inner shelf and along parts of the shelf break. South of Port Edward, and as far as the Umtentu River, the pattern becomes more complicated by splitting up into two parallel belts of roughly equal

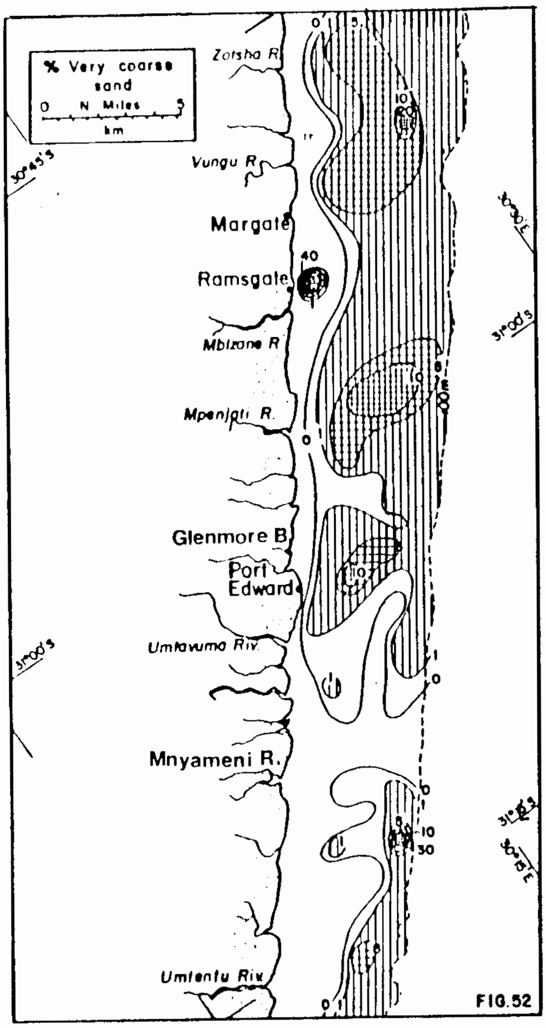


FIG.52

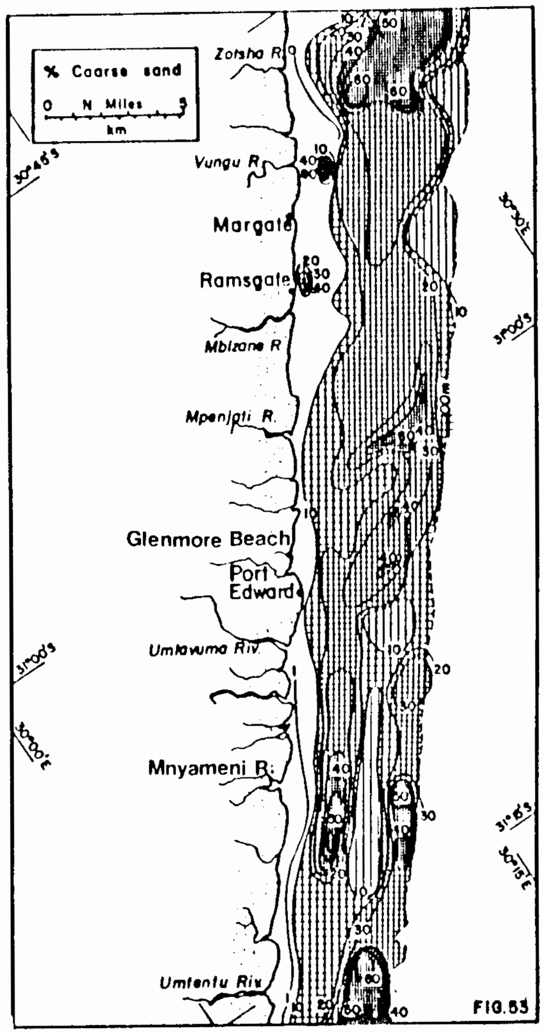


FIG.53

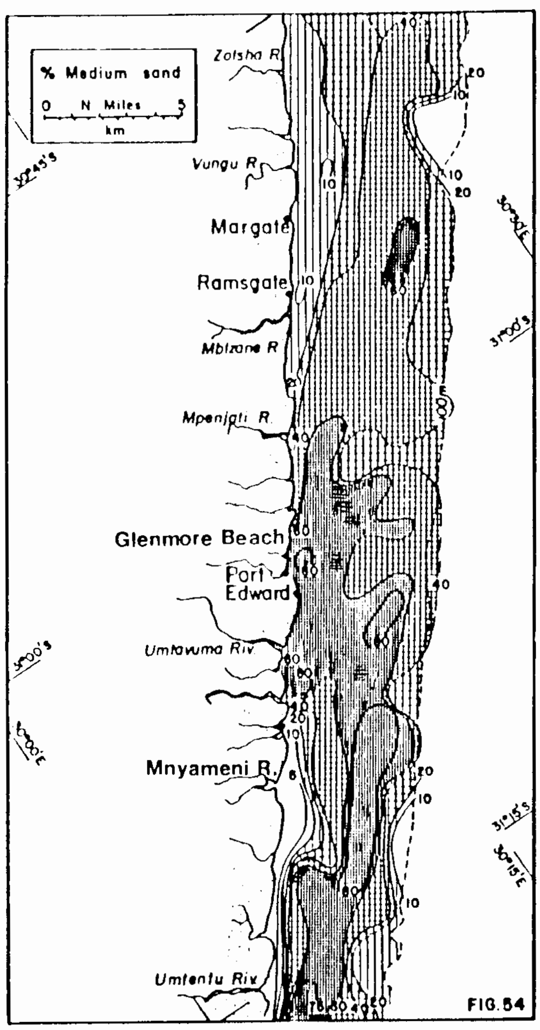


FIG.54

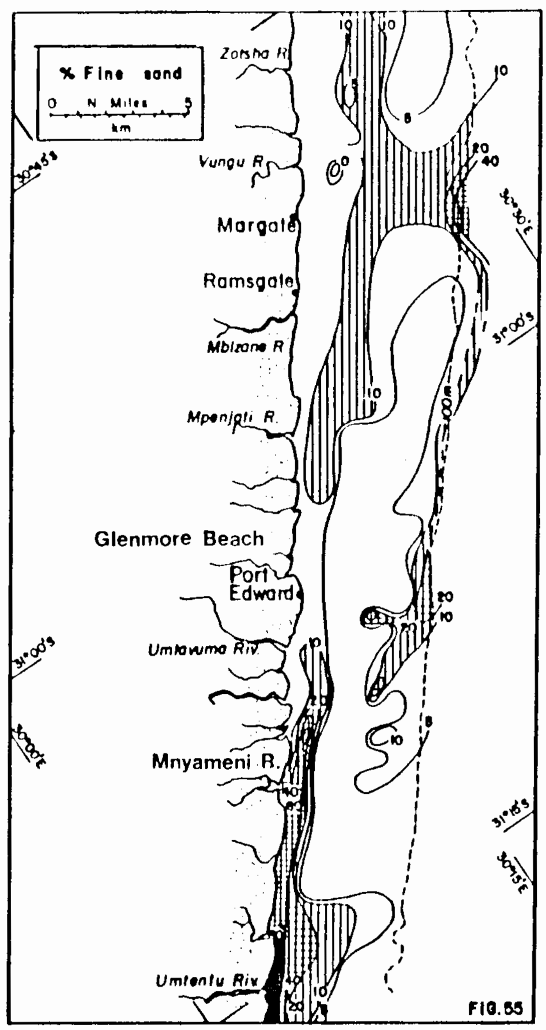


FIG.55

widths. One belt straddles the boundary between the inner and the middle shelf, whereas the other occupies the outermost parts of the outer shelf along the shelf break. They are separated by a corridor containing generally less than 10% coarse sand. As in the case of the gravel, therefore, the coarse sand distribution south of Port Edward is characterised by a similar, laterally offset overlap of two belts, a feature which is surprisingly not as clearly developed in the very coarse sand pattern. It should also be noted that the 30% coarse sand contours in this region are contained in the area oulined by the 95% sand and 10% very coarse sand contours.

Medium Sand (Fig.54)

Medium sand is concentrated mainly along the middle shelf reaching over 80% in places, but decreases both towards the shore as well as towards the shelf break. In general, there is less than 20% medium sand along the inner shore, and between 10% and 40% on the outer shelf. An exception is found off Port Edward where a zone of high medium sand concentration (40-80%) occupies almost the entire width of the shelf. Large amounts of medium sand appear to be supplied to the shelf in the vicinity of Port Edward, probably via the Umtavuma and other smaller rivers. Between 60% and 90% is recorded on the middle shelf between Glenmore Beach and the Umtentu River whereas only 40%-60% is recorded to the north of Glenmore Beach. The area of high medium sand concentration in the north overlaps with areas of high coarse sand (>20%) and gravel (>10%) concentration. Where there is more than 60% medium sand in the south, on the other hand, generally less than 20% coarse sand is found. This region was noted for its high sand content and as pointed out above, the coarse sand pattern more nearly parallels that of the gravel. South of the Umtentu River, however, high medium sand concentrations once again overlap with areas of high gravel content (more than 30%).

Fine Sand (Fig.55)

With the exception of the nearshore zone to the south of the Umtavuma River fine sand is a subordinate component of the sediment. In spite of this it follows a distinctive trend in its distribution. By and large it correlates negatively with medium sand, being concentrated in areas where the latter comprises less than 5-10%. Where there is less than 20% medium sand, more than 10% of fine sand is generally found. In this manner a semi-continuous belt of fine sand is found along the entire coastline, stretching from Port Shepstone to the Umtentu River, continuing southwards beyond this shelf sector.A second discontinuous belt occurs along the shelf break, with tongues of fine sand lapping onto the outer shelf off the Umtavuma River. Birch (in press) recorded 5-10 m of sediment mantling the Umtavuma and Margate Canyon heads. The nearshore belt seems to disappear off Port Edward, but this can be ascribed to dilution by medium sand entering the sea in this area (cf. Fig. 54). The fact that fine sand is found closer to the shore than medium sand would appear to be a significant feature, as it suggests very subtle hydrodynamic controls over cross-shelf sediment dispersal.

Very Fine Sand (Fig.56)

Very fine sand is generally absent from the middle shelf and is found in very small amounts (0-5%) on the inner shelf to the north of the Umtavuma River and along the shelf break. Following the fine sand distribution, it is concentrated in a narow nearshore belt south of the Umtavuma River, where it locally

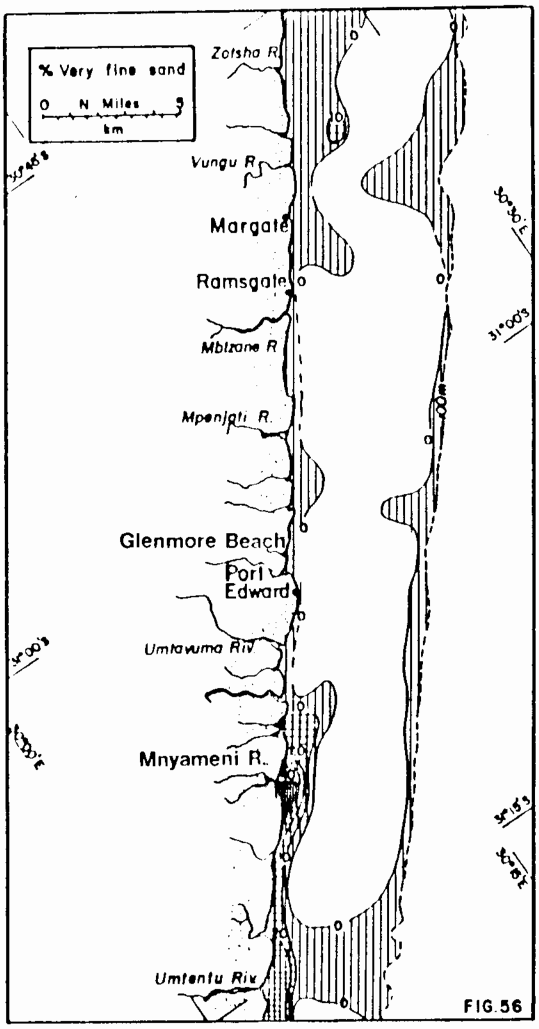


FIG.56

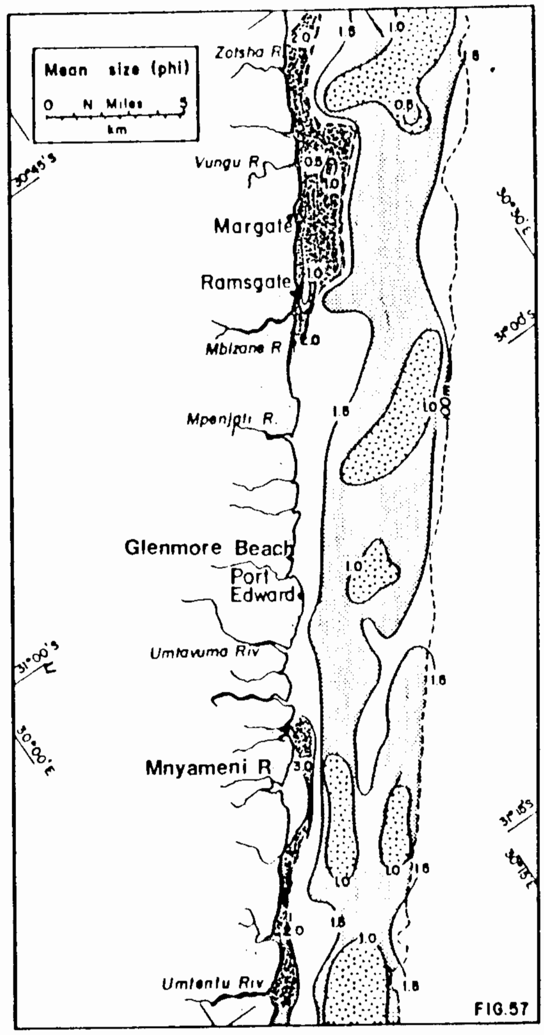


FIG.57

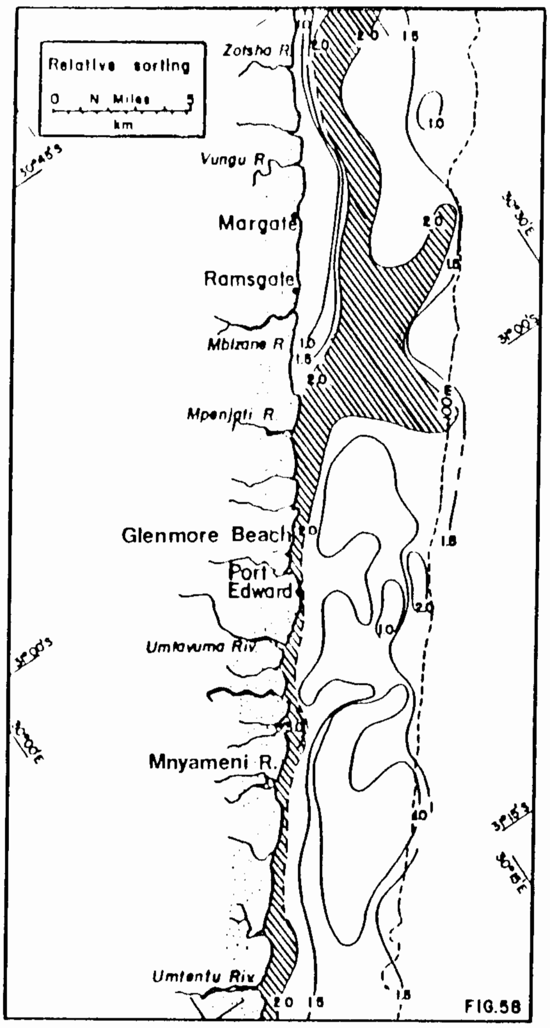


FIG.58

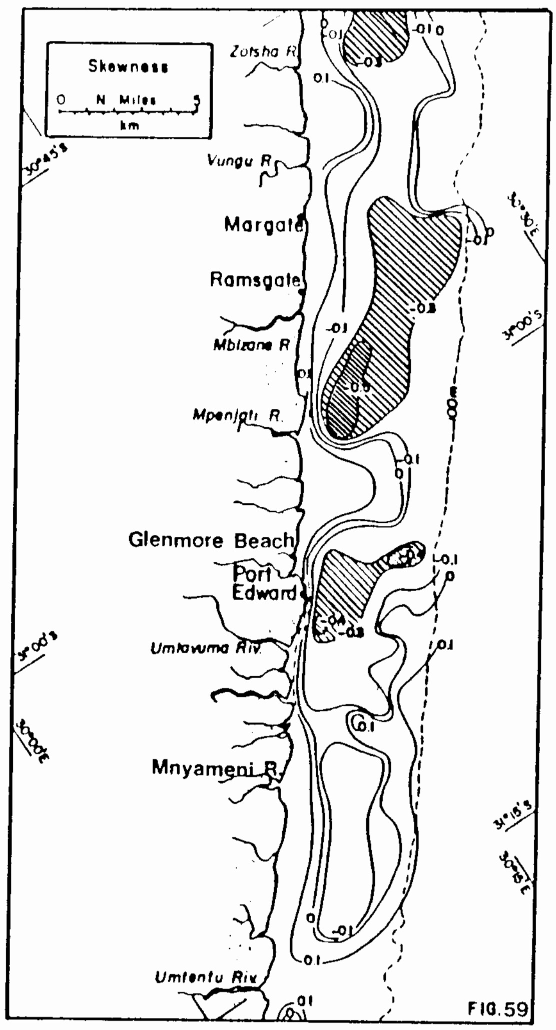


FIG.59

reaches over 40%. There is no indication of a similar belt to the north of the Umtavuma River indicating that, unlike the fine sand, there is no continuous supply of this size fraction. This suggests that very fine sand is supplied only by the Mnyameni and other rivers to the south. In fact, these rivers have their upper catchments within the shales and sandstones of the Ecca Group, whereas the rivers to the north drain a greater variety of geological formations.

<u>Mean Size</u> (Fig.57)

The greater part of this shelf sector is dominated by mean grain sizes larger than 1,5 phi. Sediment finer than 1,5 phi is found along the entire inner shelf and close to the shelf break north of Port Edward. A tongue of sediment with mean diameters between 1,5 and 1,8 phi traces the oblique cross-shelf sand corridor off the Umtavuma River. Sediment coarser than 1,5 phi thus occupies most of the middle and outer shelves. Patches of sediment with a mean size smaller than 1,0 phi are found around the Protea Banks and on the middle shelf to the south, coinciding with areas where coarse sand occurs in amounts greater than 40% and where medium sand correspondingly contributes less than 60%. The mean diameter map also reveals the new source of fine sediment with mean diameter finer than 2 phi in the nearshore zone to the south of the Mnyameni River. It does not resolve the fine sand belt to the north of the Umtavuma River nor the continuity of the medium sand belt on the middle shelf.

Relative Sorting (Fig.58)

Sorting clearly reflects the degree of overlap between different size fractions, especially the fine and medium sand. North of Port Edward the most poorly sorted sediment is found where fine sand, medium sand and coarse sand overlap on the middle to inner shelf section. This sediment, incidentally, has also the most strongly skewed distributions. It is outlined by the 10% fine sand, the 20-40% medium sand and the 10-20% coarse sand contours. South of Port Edward the midshelf region is mantled by exceptionally well sorted sediments. This area corresponds to the medium sand province emanating from the Port Edward area which contains more than 60% medium sand. It is, furthermore, only slightly negatively skewed (0,0 to -0,2), suggesting that these sediments are not significantly mixed with other populations and persist as an almost pure hydrodynamic population. Areas in which sorting lies between 1 and 2 QH units coincide with areas in which the sediments can either be positively or negatively skewed (-0,2 to 0,2), depending on the mean size of the dominant end member.

Skewness (Fig.59)

Skewness follows the same general trend observed on the other shelf sectors to the north. Between Port Shepstone and the Umtentu River the inner shelf sediments are positively skewed whereas all middle shelf sediments are negatively skewed. This suggests a medium to fine sediment with a very fine tail in the nearshore and a fine to medium sized sediment with a coarser tail on the middle shelf. Sediments on the outer shelf are generally positively skewed, again suggesting a coarse sediment with a fine tail. Between Margate and Port Edward negatively skewed sediments extend across the outer shelf, although the degree of negative skewness nevertheless decreases towards the shelf break. Conversely, the cross shelf pattern off the Umtentu River, described by the very fine and fine sand distributions, is shown to be positively skewed. The skewness pattern is consistent with the main sediment distribution patterns discussed earlier and its clear trend confirms that we are dealing with three main sediment populations namely, a fine, a medium and a coarse one.

4.3.3 Discussion and Conclusions

There is little overlap between the distribution patterns of the fine, medium and coarse sand fractions (Fig. 55,54,53). Since the sediments are skewed, however, the mean size map outlines only a very general north/south shore-parallel zonation. Sediment finer than 1,5 phi is deposited on the inner shelf and temporarily also along the shelf break. On the middle and outer shelves the sediment generally has mean diameters ranging from 1,0 to 1,5 phi. Localized patches on the middle and outer shelves north of the Umtentu River, for example, and also on the Protea Banks consist of sediments with mean sizes coarser than 1,0 phi. Such areas consistantly have sediments with a `high` gravel and very coarse sand content. The $CaCO_3$ distribution and the size frequency distributions of the terrigenous component indicate that these are areas of relict sediment, exposed in exposed in places of higher and irregular topography. More rarely they also occur on the midshelf which is thinly and unevenly covered by the modern mobile sand facies.

To the south of the Umtentu River sediment finer than 1,5 phi is not found on the outer shelf and the mean size of the sediment on the middle shelf gradually becomes coarser. This oblique cross-shelf trend in the nearshore parallels that established by the total sand (95-100%), coarse sand (20%), medium sand (60%) as well as the $CaCO_3$ (50 and 75%) contours. This indicates an increasing influence of the Agulhas Current on outer and middle shelf sediment dispersal, as well as a renewed inhibiting effect of the dune ridge on cross-shelf sediment dispersal.

The mean diameter map, however, does not reflect the strong cross-shelf trend of medium sand between Glenmore Beach and the Untamvuma River. This incidentally, questions the value of the mean diameter as a meaningful statistical measure in skewed sediments. Noting that strongly positively or negatively skewed sediments, as well as zero skewed but poorly sorted sediment suggest mixing, the following dispersal pattern can be reconstructed.

Whereas north and south of Glenmore Beach and Port Edward the nearshore sediments are positively skewed, they are negatively skewed between the two towns. Correspondingly, to the north of Glenmore Beach and as far as the Umzumbe River, the sediments are generally better sorted in the nearshore and near the shelf break than on the middle shelf. Off Port Edward the regional north/south-aligned skewness pattern, already observed on the other shelf sectors re-establishes itself. Sorting, on the other hand, improves progressively in an offshore direction as one moves southwards.

These variations suggest that the individual roles of sediment supply, bathymetric control and sediment dispersal mechanisms change from place to place, for example from the Umzumbe River to Glenmore Beach, from Glenmore Beach to Port Edward and from Port Edward to the Msikaba River.

The main rivers supplying terrigenous material to this shelf sector are the Umzumbe, the Unzimkulu, the Umtamvuma, the Umtentu and the Msikaba. Of these the Umzimkulu is by far the largest. The Umzumbe drains Namaqua-gneiss terraine whereas the others, with the exception of the Umzimkulu, drain Ecca and Dwyke sediments in their upper reaches, cutting deep valleys through the resistant Table Mountain sandstones before discharging onto the shelf. The Umzimkulu drains and predominantly erodes rocks belonging to the Drakensberg, Beaufort and Ecca groups of the Karoo Supergroup. Most of the sediment supplied to the shelf south of Port Shepstone is therefore very fine to medium grained. There are few rivers between Port Shepstone and Port Edward. The sediment yield for this catchment area (T3 in Flemming and Hay, 1983) is 3,512 x $10^6 m^3$ p.a., of which about 3,336 x $10^6 m^3$ is suspended load, whereby the rate and the amount of sediment supplied to the shelf decreases from Port Shepstone to the Msikaba. The sediment distribution patterns clearly suggest that the Umtamvuma, the Umtentu and the Msikaba Rivers have a proportionately higher discharge of finer sediments than the Umzimkulu River, but that their bedload components are as a result correspondingly lower.

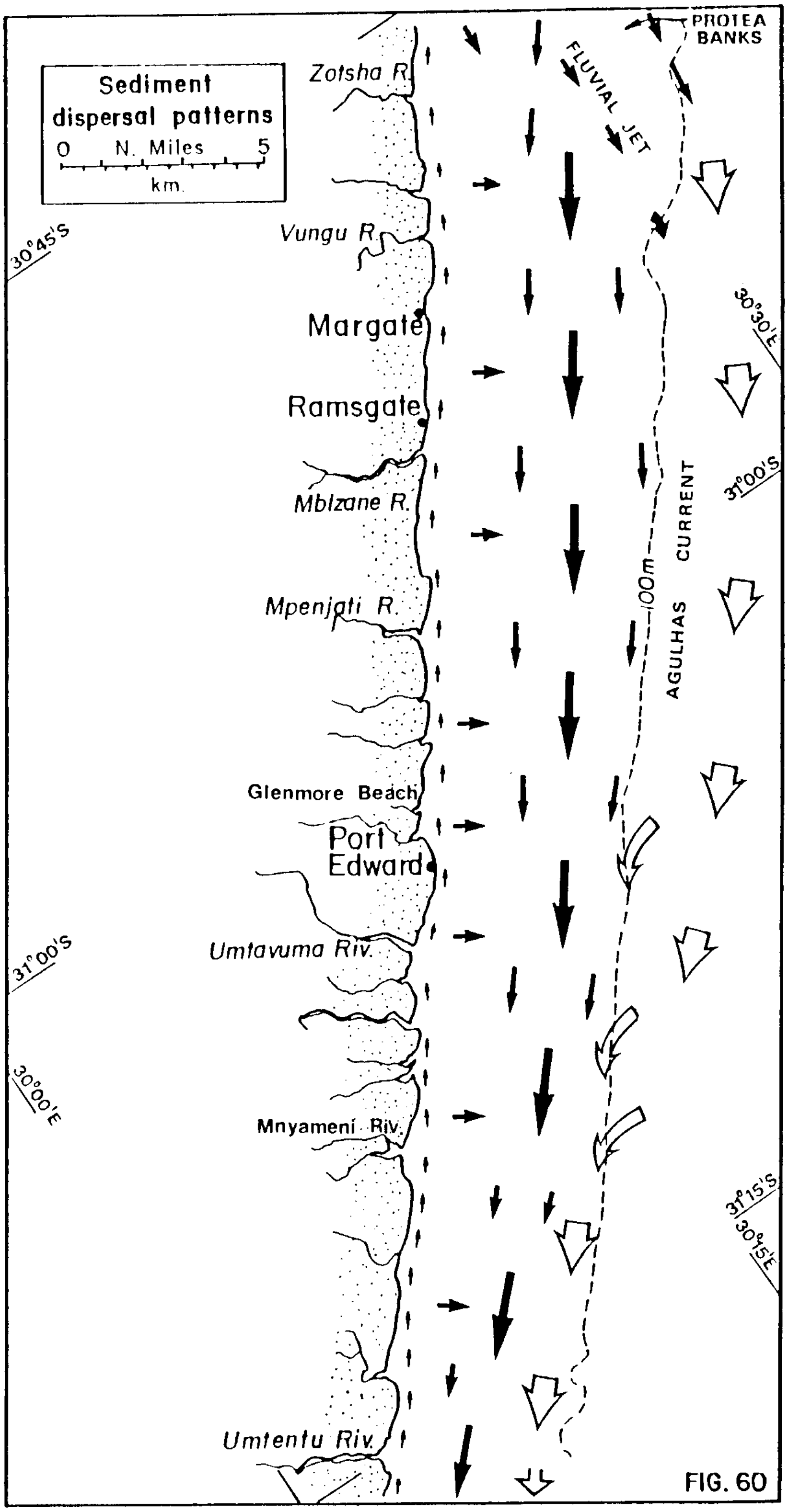
It is, therefore, surprising to find that the highest concentration of fine sand and mud lies in the nearshore zone between the Msikaba river mouth and the Umtamvuma River mouth, as well as on the outer shelf opposite the Port Edward region. Furthermore, the bulk of the medium sand is concentrated on the outer, middle and inner shelves opposite Port Edward and on the middle and inner shelves to the south (40-90%). Thus, despite the fact that approximately 25% of the entire suspended load as well as the bedload supplied to this area is discharged by the Umzimkulu River, the area between Port Shepstone and Port Edward is nevertheless sediment starved, with little or no sediment accumulation either in the inner or the middle shelf. Birch (in press) reports a dearth of sediment between South Port (cf. Fig.17) and the Msikaba River. Furthermore, off Port Shepstone the inner shelf sand sheet is only 700 m wide. In general less than 4 m of sediment have been recorded (the limit of seismic resolution) and this most frequently occurred in basement depresions. Between Palm Beach and Port Edward up to 6 m of unconsolidated sediment have accumulated (Birch, in press). Sediment accumulation is also revealed on the bathymetric chart. For instance, the shoreward trend of the mid-shelf ridge is closely paralleled by the seaward limit of the Port Edward sand corridor. Furthermore, as the ridge migrates shorewards, the outer shelf becomes increasingly rougher, whereas the inner and mid-shelf zones become more uniformly undulating and narrow.

From the evidence available it would appear that firstly, some of the fine sediment entering the shelf via the Umzimkulu River is almost immediately lost via submarine canyons or by remaining in suspension; secondly, that much of the remainder of the fine and medium-grained sediments discharged by the Umzimkulu River are moved south on the inner shelf and in the mid-shelf sandstream, and thirdly, that most of the medium, (1,0 to 1,5 phi) and fine (greater than 1,5 phi) sand discharged onto the shelf in the vicinity of Port Edward is carried out onto the shelf before being entrained southwards. The medium sand (1,0 - 1,5 phi) gets stabilised in the dune field on the middle to outer shelf off Port Edward (up to 90% of the total sand sized fraction is medium sand). The dune field therefore acts as a hydrodynamic sieve which retains the medium sand, but expels the fine sand. The dune field terminates some distance to the south of Port Edward, although medium sized sand (up to 80%) continues to be found as far south as the Msikaba River. This suggests that the disappearance of the dunes is not due to progressive sediment starvation, but more probably due to a change in flow regime, resulting in upper plane bed transport. This is strongly supported by the occurrence of sand ribbons.

In considering the processes responsible for sediment distribution, there are two major uncertainties. Firstly, the exact path of the Agulhas Current in this region has not been closely monitored and the sediment load and composition of the fluvial jets crossing the shelf is unknown. The re-appearance of the outer shelf terrace in the south also points to a stronger influence of the current. While the combination of wave action and wind-driven currents are responsible for the dispersal of material across the inner shelf along the entire coastline, the interaction between fluvial jets and the Agulhas Current is more localized.

It has been suggested in the previous section that the core of the Agulhas Current is gradually deflected offshore by the midshelf ridge between Ifafa and Port Shepstone. At the Protea Banks, where the ridge is up to 26 m high, thus occupying more than a third of the water column the current is diverted to either side. Although the ridge is again very much lower between the Umzumbe River and Port Shepstone, the current remains spread over a wider area. Bedforms on the shoreward side of the Protea Banks (Flemming, 1978) document that a southerly flow is in fact maintained in this region. This coincides with a marked decrease in the width of the inner shelf and the nearshore sand wedge (less than 700 m) south of the Umzumbe River as far as Glenmore Beach, suggesting erosion of the seaward toe of the wedge with subsequent entrainment south in the manner described by Flemming (1980).

As pointed out before, much of the fine sediment discharged by the Umzimkulu River appears to be transported far onto the shelf by the force of the fluvial jet during seasonal floods. The fine sand trend indicates that this jet is deflected south across the middle shelf by the Protea Banks. This cross-shelf removal of fine sediment in suspension by fluvial jets is in this case further facilitated by the position of the main flow of the



Sediment dispersal patterns
0 N. Miles 5
km.
Zotsha R.
Vungu R.
Margate
Ramsgate
Mbizane R.
Mpenjati R.
Glenmore Beach
Port Edward
Umtavuma Riv.
Mnyameni Riv.
Umtentu Riv.
PROTEA BANKS
FLUVIAL JET
100m
AGULHAS CURRENT
30°45'S
31°00'S
30°00'E
30°30'E
31°00'S
31°15'S
30°15'E

FIG. 60

current. As a result very little sediment is actually transported south on the sea-bed and the area between Margate and Port Edward is therefore sediment starved, both with respect to fine and medium sand. Between Port Shepstone and Glenmore Beach the classic shore parallel, offshore increase in mean diameter and $CaCO_3$-content, described by Flemming (1978, 1980, 1981), Swift (1970, 1971) and Emery (1968) and others, is once more established as additional sediment enters the system from the adjacent hinterland.

At Port Edward, the midshelf ridge is strongly eroded (Birch, in press) and the midshelf sand stream is sufficiently boosted by sediments supplied by the Umtamvuma River to maintain the Port Edward dune field described by Flemming (1978). The associated cross-shelf transport of suspended sediment is again clearly revealed by the distribution of fine sand, as well as the skewness and the relative sorting patterns. Sediment finer than 1,5 phi is moved across the shelf in suspension by the fluvial jet stream. Sediment coarser than 1,5 phi, on the other hand, moves across the inner shelf in bedload, before being trapped in the dune field. It is noteworthy that this dune field does not migrate beyond a certain position to the south. The abundance of medium sand clearly precludes sediment starvation as a prime cause of this phenomenon. It is therefore suggested that the deflected Agulhas Current begins, once again, to make itself felt, initially by sweeping the outer shelf clean of all `mobile` sediment, leaving a coarse, biogenic (>75% $CaCO_3$) predominantly gravel sized lag. The oblique movement inshore and across shelf of the Agulhas Current increases the flow velociies and thus

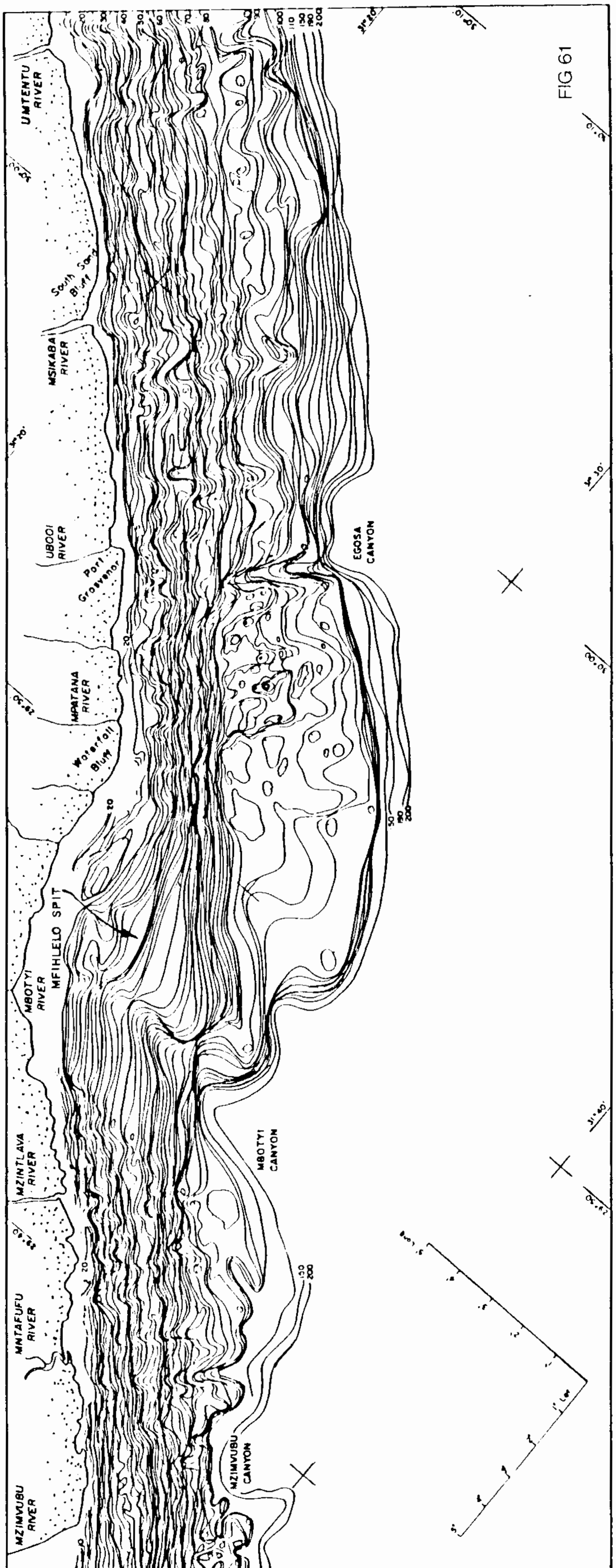


FIG 61

BATHYMETRIC MAP D - MTENTU RIVER TO PORT ST. JOHNS pushes its sediment transport capacity beyond the stability field of dunes towards upper plane bed transport. All fine, medium and possibly coarse sized sand is affected and this material is ultimately deposited on the upper slope to the south of the Waterfall Bluff offset. This process is also reflected by various other textural parameters. Thus, the distribution of fine sand suggests that some of this material(5-10%) on the outer shelf off Port Edward is moved slightly onshore farther to the south. The mean size map and medim sand distribution reflect a similar trend (cf. Pilkley et al., 1972; Southard et al., 1976). Simultaneously the coarse sand content increases on the outer shelf as the medium sand content decreases.

4.4 UMTENTU RIVER TO PORT ST JOHNS

4.4.1 Bathymetry (Fig. 61)

From the Umtentu River to Port St Johns the coastline is northeast - southwest aligned, with a major structural offset at Waterfall Bluff. The offset in the continental margin has been related to the onshore Egosa Fault (Dingle,1979;Birch, 1981). The shelf break is similarly offset to the west, but some 12 km further to the south, a feature that has not yet been explained structurally.

The major regional dimensions of the continental shelf in this area are summarised in Table IV. The area can be divided into a number of physiographic zones which appear to be related to

TABLE 4 a

Summary of major shelf features between the Msikaba River and Port St Johns.

PHYSIOGRAPHIC AREA	INNER SHELF			MIDDLE SHELF			OUTER SHELF			AVE
	Width	Slope	Bottom Depth	Width	Slope	Bottom Depth	Width	Slope	Bottom Depth	Shelf width
	(km)	degrees	(m)	(km)	degrees	(m)	(km)	degrees	(m)	(km)
Msikaba River to Port Grosvenor	3,2	1,0	-50	2,2	1,0	-90	3.7	0,15	-100	9,1
Port Grosvenor to Waterfall Bluff	3.0	0.78	-90				5,4	0.12	-100	8,4
Waterfall Bluff to Mzintlava River	5,8	0,55	-50	5,4	0,47	-90	6,0	0,21	-100	17,2
Mzintlava River to Port St. Johns	2,2	2,75	-95	1,4	0,23	-100	2,8	0,23	-110	6,4

TABLE 4 b

	Max. width (km)	N/S length (km)
Waterfall Bluff Terrace	5,9	13,2
Mbotyi Terrace	3,5	9,6
St. John's Terrace	2,8	6,5

TABLE 4 c

	Head distance from shore	Width of Shelf to N.	Width of Shelf to S.
Egosa Canyon	7,4 km	8,8 km	9,1 km
Mbotyi Canyon	6,6 km	8,8 km	8,1 km
Mzimvubu Canyon	4,0 km	8,1 km	7,6 km
St. Johns Canyon	4,9 km	6,6 km	6,6 km

dynamic processes active since the last major transgression (Flandrian). North and south of the Waterfall Bluff lineament, the inner and middle shelves differ, while the outer shelf remains a continuous feature.

From the Msikaba river mouth to Waterfall Bluff the inner and middle shelves narrow appreciably. Offshore of the Mfihlelo Spit the inner shelf merges with the middle shelf, creating a steep incline down to the almost flat Waterfall Bluff Terrace. The inner and middle shelf regions change markedly across the offset. To the south of Waterfall Bluff the inner shelf developes into a narrow, relatively steep zone as the middle shelf becomes exceptionally broad with a very gentle slope (0,47^{o}). At -90 m it flattens out into the southern half of the Waterfall Bluff Terrace. Further south the inner shelf continues to steepen and becomes even narrower. The middle shelf narrows in a similar fashion. It slopes evenly downwards, until at -100 m it levels out into the Mbotyi Terrace. South of the Mntafufu River, up to the head of the Mzimvubu Canyon, the inner and middle shelves assume a uniform slope which appears to be a continuation of the middle shelf immediately to the north. Between -90 and -100 m the slope decreases further still. The latter depth outlines the shoreward edge of the outer shelf terrace.

South of the Mzimvubu Canyon the inner and middle shelves can once more be distinguished as different physiographic units by their respective slopes and widths. Between the Mzimvubu and St Johns Canyons the inner shelf is relatively broad (2,2 km) with a gradual incline, whereas the middle shelf again becomes markedly steeper and narrower. Between the 90 m and the 100 m isobath there is once more a gentle incline down to the St Johns Terrace.

Whereas the physiography of the inner and middle shelves between the Msikaba River and Port St Johns has been shown to vary considerably, both parallel as well as perpendicular to the shoreline, the outer shelf remains remarkably constant in depth and slope, despite the major offset in the shelf break.

Between the Msikaba and Port Grosvenor the outer shelf slopes gradually from -80 m to the shelf break at -100 m. At the Egosa Canyon the shelf break swings shorewards for a short distance. As a result the outer shelf is narrower in this area. South of the Egosa Canyon the character of the outer shelf changes to a broad, flat (5,9 km) and rectangular-shaped terrace situated between the -90 and the -100 m isobaths. It extends for 13,2 km southwards before being abruptly terminated by the offset. The position of the Mbotyi Canyon enhances the sediment sink effect of this structural feature. The southern edge of this terrace at first has an unusually gentle slope, but steepens suddenly at -110 m. This feature is specifically pointed out in order to emphasise the fact that to the south of the Mbotyi Canyon the shelf break is also found at -110 m, whereas to the north it is consistently situated at -100 m.

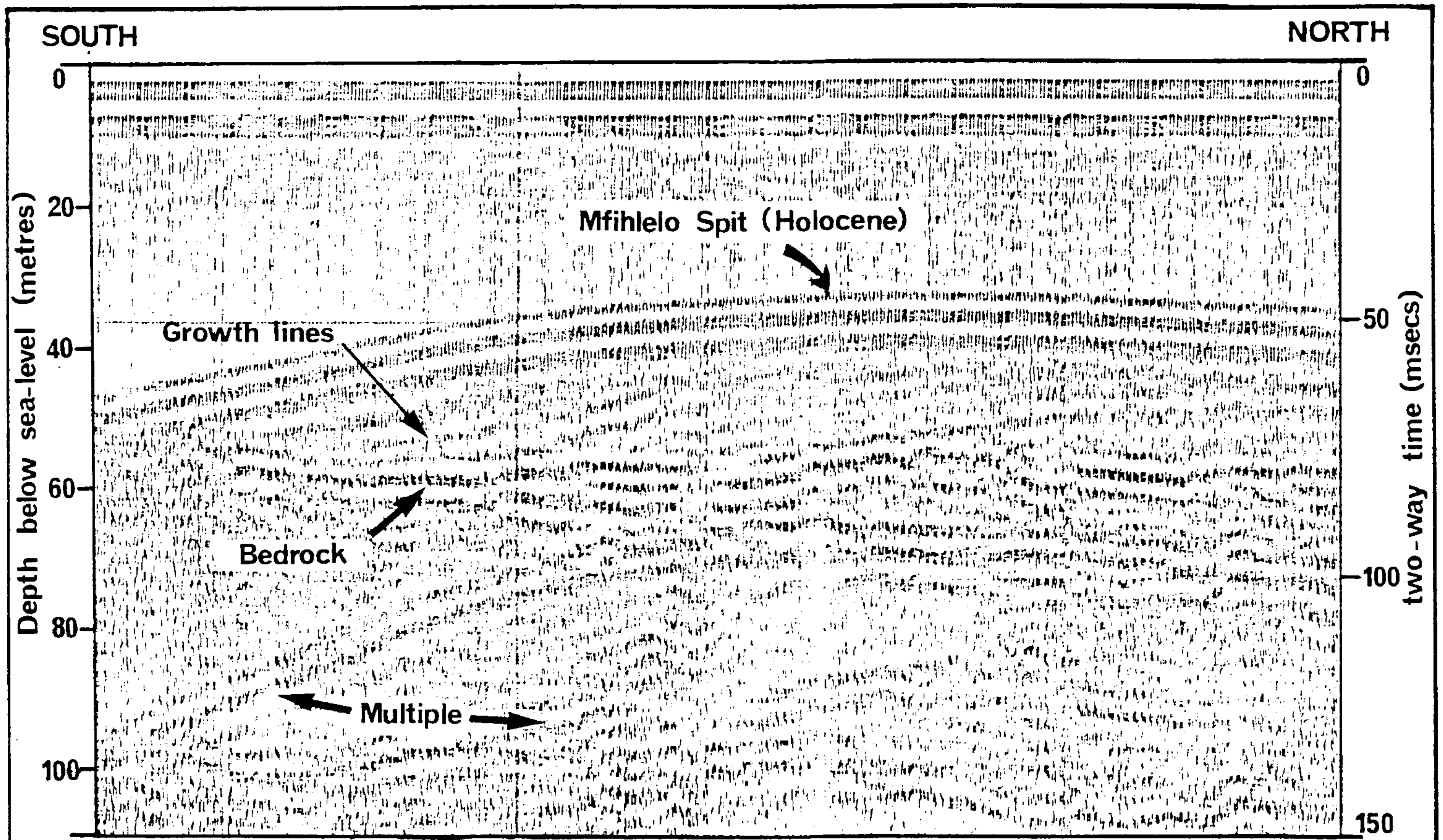


FIG. 61b

Seismic section across the Mfihlelo Spit (N.R.I.O.; Cruise 80-11)

This terrace-like character of the outer shelf continues southwards. The Mbotyi, Mzimvubu and St Johns Canyons define the northern and southern edges of the Mbotyi and St Johns Terraces respectively. These terraces are considerably smaller in size, being outlined by the 100 and 110 m isobaths. Were it not for the canyons the terraces would appear as a single, continuous physiographic feature extending southwards from the northern edge of the Waterfall Bluff Terrace. This suggests that there may possibly be some sediment exchange on the outer shelf between the two sedimentary compartments.

Two features are sufficiently prominent to be mentioned independently. These are the drowned Pleistocene(?) coastal dune ridge and the Mfihlelo Spit. The former is about 1,8 km wide, 12 to 25 m high and lies between 2 and 3,7 km offshore with a base level at -68 m. In this region the ridge is found between the Msikaba River and Port Grosvenor. It gradually decreases in height southwards as it is progressively drowned in younger sediments leading up to the Mfihlelo Spit. The spit extends 4 km southwards from the Bluff. It is about 800 m wide and has a thickness of about 20 m. Side scan sonar and shallow seismic records suggest that it is a prograding feature (Fig.61b). The spatial distribution of the medium, fine and very fine sand support this interpretation. These depositional characteristics have previously been documented by Flemming (1981) and Birch (1981).

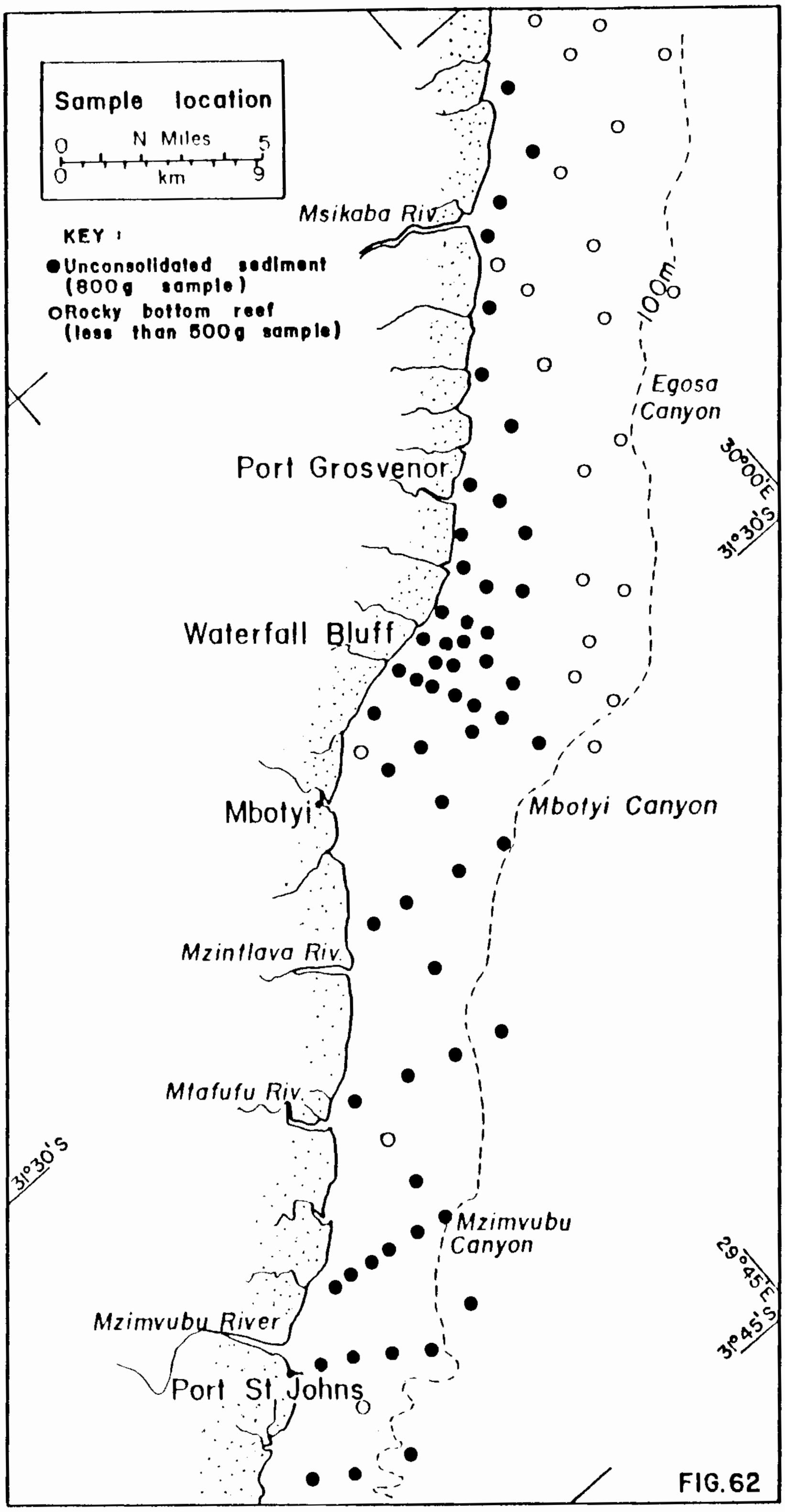

Sample location
0 N Miles 5
0 km 9
KEY :
● Unconsolidated sediment (800g sample)
○ Rocky bottom reef (less than 500g sample)
Msikaba Riv.
100m
Egosa Canyon
30°00'E
31°30'S
Port Grosvenor
Waterfall Bluff
Mbotyi
Mbotyi Canyon
Mzintlava Riv.
Mtafufu Riv.
31°30'S
Mzimvubu Canyon
29°45'E
31°45'S
Mzimvubu River
Port St Johns

FIG. 62

4.4.2 Sediment Distribution Patterns

The two main sources of sediment are fluvial discharge and biogenic production. The biogenic material consists predominantly of relict material which forms a lag deposit on the outer shelf (Flemming, 1978). The main rivers supplying sediment to the area are the Mzimvubu and the Msikaba. The amount of material has been estimated by Flemming (1981) and Flemming & Hay (1983). If one assumes that the two rivers dominate the supply, then a total of about 8 x $10^6 m^3$ are being supplied annually, i.e. 5.6 x $10^6 m^3$ to the south and about 2.4 x $10^6 m^3$ to the north of Waterfall Bluff, respectively. At least 90-95% of the total sediment from the rivers is transported as suspended load and only 5-10% as bedload. Modern biogenic input is estimated at 15% of the terrigenous bedload.

A map indicating the sample density and localities is presented in Fig.62. It is noted that there is some discontinuity in the contours of the biogenic material (Fig.63a), the coarse sand (Fig.66), the medium sand (Fig.67) and the fine sand (Fig. 68). This was done to better outline the distribution patterns of these parameters to the south of the Umtentu River and in no way does it alter the regional trends.

Biogenic sediments (Fig. 63)

The relationship between terrigenous and biogenic material on the shelf is reflected in the distribution of $CaCO_3$ (Fig. 63a).

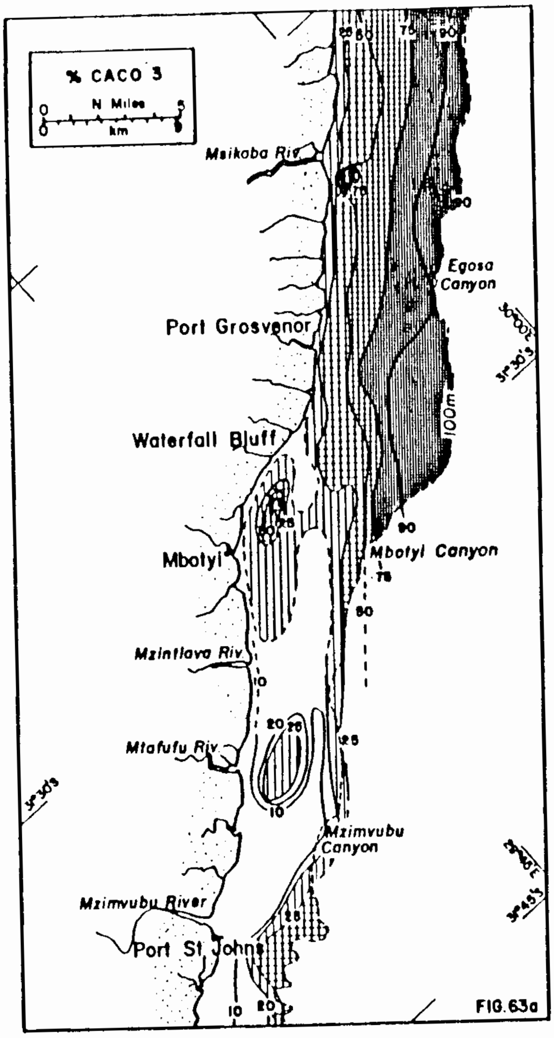


FIG.63a

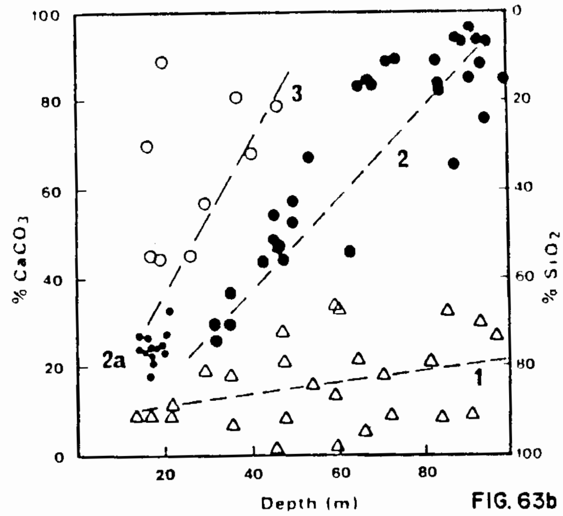


FIG. 63b

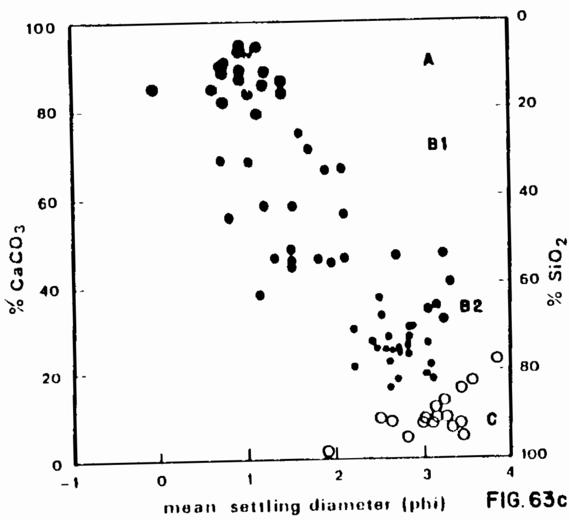


FIG. 63c

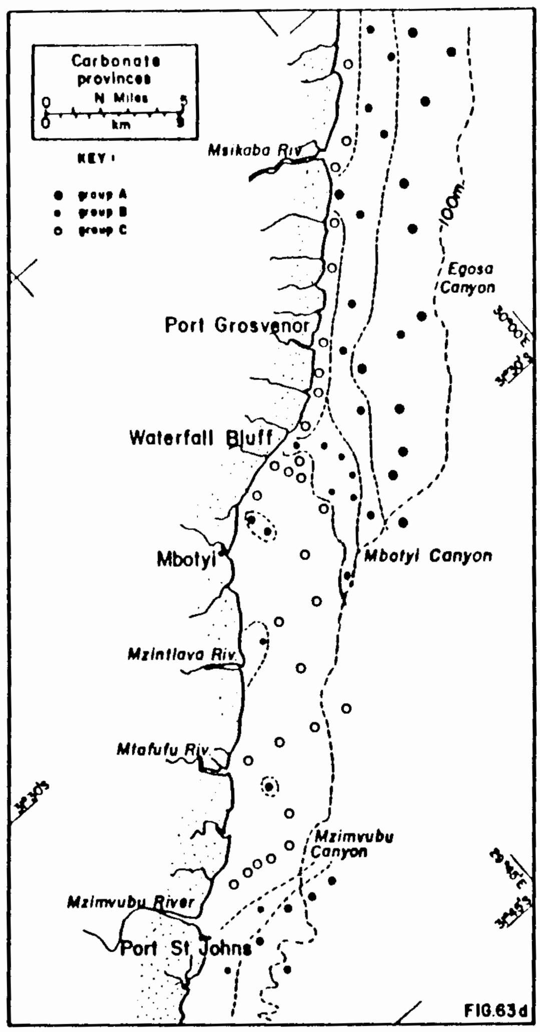


FIG.63d

North of Waterfall Bluff, the $CaCO_3$ content follows a shore-parallel trend. From the Msikaba River to the offset there is a progressive increase of biogenic material with water depth. Thus, at -30 m the $CaCO_3$ content is about 25%, whereas at -60 m in the north and -100 m in the south it has increased to 75%. North of Port Grosvenor the 75% contour runs parallel to the outer edge of the middle shelf as defined by Flemming (1980). To the south of this point the boundary coincides more closely with the 50% contour. The position of the contours appear to be physiographically controlled as they are strongly influenced by the presence or absence of the drowned Pleistocene dune ridge.

South of the Mbotyi Canyon a uniform increase in $CaCO_3$ with water depth is observed only on the outer shelf. The 50% contour lies approximately parallel to the shelf break at -100 m, whereas concentrations of 75% or greater do not occur on the shelf beyond the offset. Here the 25% contour is situated close to the shelf break, running parallel to the -100 to -110 m isobaths. North of the offset, passing on the seaward side of the Mfihlelo Spit, this contour swings shorewards at an oblique angle until it reaches a depth of about 20 m before alinging itself more or less parallel to the shoreline.

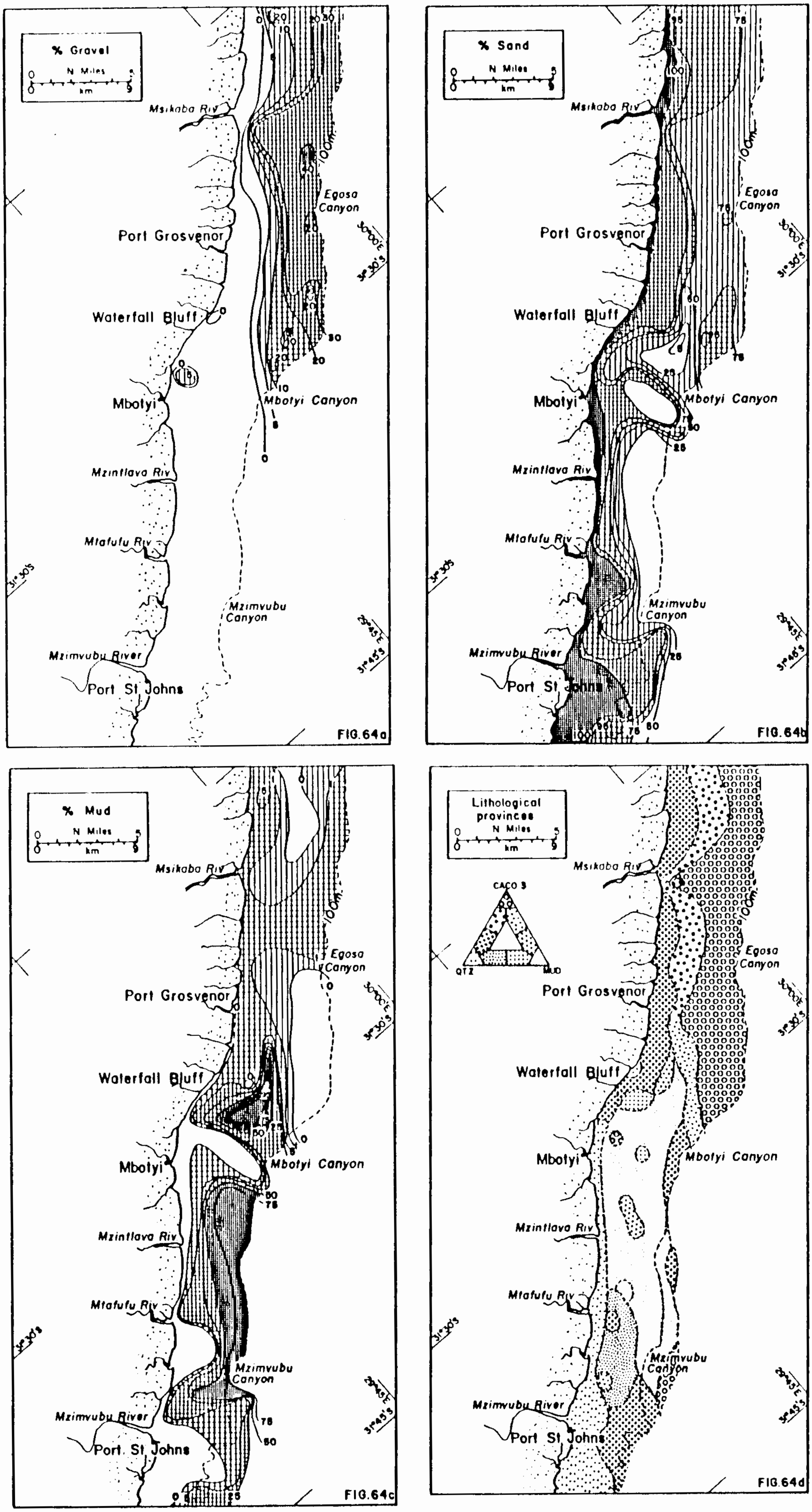
The 20% contour has been added in order to increase the resolution to the south of Waterfall Bluff. At first it outlines the spit and then continues southwards parallel to the coast and close inshore at depths of -30 to -40 m as far as the Mtzinlava

River. Here it moves offshore in a large northerly loop before continuing southwards close to the 25% contour on the middle to outer shelves. The 10% contour is not generally resolved as it is situated too close to the shoreline. However, just north of the Mzimvubu River it encompases almost the entire shelf width. To the south it at first runs obliquely across the shelf before aligning itself parallel to the shoreline along the 40-50 m depth contour on the middle shelf.

Small discreet areas of high $CaCO_3$ content occur on the middle shelf south of Waterfall Bluff. Such areas represent `windows` which indicate that the coarse carbonate-rich basal palimpsest facies found on the outer shelf extends shorewards below the terrigenous sediment wedge. The sampling of such windows is purely coincidental and one should therefore expect the phenomenon to be more common than indicated on Fig. 63a.

The $CaCO_3$ vs water depth diagram (Fig. 63b) shows three interesting trends. Sediments in the nearshore zone above -24 m contain 20 to 30% $CaCO_3$ (group 3). Only 2 samples from this group contain more than 60% biogenic material. An examination under the binocular microscope has left no doubt that it comprises modern shell material, which is concentrated in the coarse size fraction. A second trend can be expressed by the equation $Y = 0{,}92x + 7{,}4$; $r = 0{,}9195$ (group 2). It shows a gradual increase of $CaCO_3$ with increasing water depth, but also reveals an interesting subtrend. This minor trend is defined by the equation Y = 1,361x + 17,9 with r = 0,9116 and comprises all samples located shallower than 50 m (group 2a). The tight point cluster reveals a much steeper gradient than that which defines the group 2 cluster. It is also very prominent in the $CaCO_3$ distribution map (Fig. 63a), where it outlines the inner to middle shelf transition and the position of the midshelf ridge. The third trend (Group 1) is found south of Waterfall Bluff and on the edges of the Mfihlelo Spit. These sediments show very little increase in $CaCO_3$ content with depth. They plot along the line Y = 9,12x + 0,12 with r = 0,3373.

$CaCO_3$ vs mean diameter, on the other hand, shows a regular and progressive increase in size with an increase in $CaCO_3$ content, even though the scatter is quite large (cfd. Fig.63c). This is described by the line Y = -26,11x + 100,09 with r = -0,8277. Sediment samples with a mean diameter below 2 phi and with less than 40% $CaCO_3$ plot in a bimodal cluster at one end and sediments with a mean diameter between 1,5 and 0,5 phi and more than 80% $CaCO_3$ form a cluster at the other end. When those sample points are contoured the individual trends described above in fact produce coherent point groupings which define specific areas of the shelf as indicated in Fig. 63d. This suggests that there is up to 40% modern biogenic material in the fine sediment of the nearshore zone. The gradual increase of $CaCO_3$ content as a function of water depth, as well as mean diameter, is therefore most likely the result of lateral mixing processes between the modern terrigenous fine to medium grained material and the coarse biogenic relict material found on the outer shelf.


% Gravel
N Miles
km
Msikaba Riv
Egosa Canyon
Port Grosvenor
Waterfall Bluff
Mbotyi
Mbotyi Canyon
Mzintlava Riv
Mtafufu Riv
Mzimvubu Canyon
Mzimvubu River
Port St Johns
100m
31°30'S
FIG.64a
% Sand
N Miles
km
Msikaba Riv
Egosa Canyon
Port Grosvenor
Waterfall Bluff
Mbotyi
Mbotyi Canyon
Mzintlava Riv
Mtafufu Riv
Mzimvubu Canyon
Mzimvubu River
Port St Johns
100m
FIG.64b
% Mud
N Miles
km
Msikaba Riv
Egosa Canyon
Port Grosvenor
Waterfall Bluff
Mbotyi
Mbotyi Canyon
Mzintlava Riv
Mtafufu Riv
Mzimvubu Canyon
Mzimvubu River
Port St Johns
100m
FIG.64c
Lithological provinces
N Miles
km
CACO 3
QTZ
MUD
Msikaba Riv
Egosa Canyon
Port Grosvenor
Waterfall Bluff
Mbotyi
Mbotyi Canyon
Mzintlava Riv
Mtafufu Riv
Mzimvubu Canyon
Mzimvubu River
Port St Johns
100m
FIG.64d

Gravel, Sand and Mud (Fig. 64)

Gravel dominates the outer shelf north of Waterfall Bluff (Fig. 64a). It is absent from the inner shelf to the north of Waterfall Bluff and from the entire shelf to the south of the offset. In the north the gravel content increases progressively from 0% at the transition from the inner to the middle shelf to 30% on the outer shelf, reaching up to 40% in isolated patches. The gradient is markedly steeper and the contours are closer to the shore just south of the Msikaba River. To the north between 10 and 20% gravel can be found on the middle shelf, whereas to the south less than 5% is present.

Three trends are apparent in the distribution of sand (Fig. 64b). Between the Mtentu River and Waterfall Bluff there is an offshore decrease in the sand content which closely parallels the increase in the gravel component described above. Accordingly, in the inner shelf more than 95% of the total sediment is sand sized, whereas it drops to less than 60% in some places on the outer shelf. At the offset in the continental shelf, immediately south of Waterfall Bluff, these contours swing sharply towards the shore. The 75% and 95% contours outline a roughly triangular area of very low sand content (less than 10%). A second area of low sand content (<2%) lies on the outer shelf further south, being separated from the first one by a corridor of very high sand content. Inshore of this low sand reach, i.e. between the Mbotyi River and the Mzimkulu River more than 75% sand is found. south of the Mzimkulu River a second high sand corridor stretches across the shelf, possibly revealing the occurrence of another fluvial jet stream in this area.

There is little mud on the continental shelf to the north of Waterfall Bluff (Fig. 64c). From the Bluff southwards the mud distribution pattern is almost a mirror image of that described by the sand, except that concentration levels follow an inverse gradient. The high concentration of mud in the Waterfall Bluff area forms a triangular area with concentric contours, one corner of which is draped over the shelf break in the corner of the offset. At its centre over 94% of mud is recorded. Mud is thus preferentially deposited in a narrow belt along the lower seaward margin of the Mfihlelo Spit, and on the lower leeward slope. From here it extends southeastwards into the Mbotyi Canyon head, where concentrations have dropped to under 50% indicating dilution by coarser material. A second depocentre occurs on the middle and outer shelves between the Mbotyi and the St Johns Canyon. This area is separated from the Mfihlelo Spit by a narrow southeastwards facing corridor comprising pure sand. Another sand corridor straddles the entire width of the continental shelf off the Mzimkulu River, as mentioned above. South of Port St Johns the low sampling density does not facilitate the reconstruction of a clear trend, although a third depocentre of mud on the outer shelf seems to be indicated. Lithoogically the sediments are very variable. They differ markedly north and south of Waterfall Bluff. To the north slightly quartzose calcarenites are found on the outer shelf with calcareous quartzarenites and quartzose calcarenites on the inner to midshelf respectively. South of Waterfall Bluff slightly argillaceous quartzarenites are found on the inner shelf grading across shelf into slightly quartzose argillite. South of Port St Johns the regional trend found north of Waterfall Bluff is re-established.

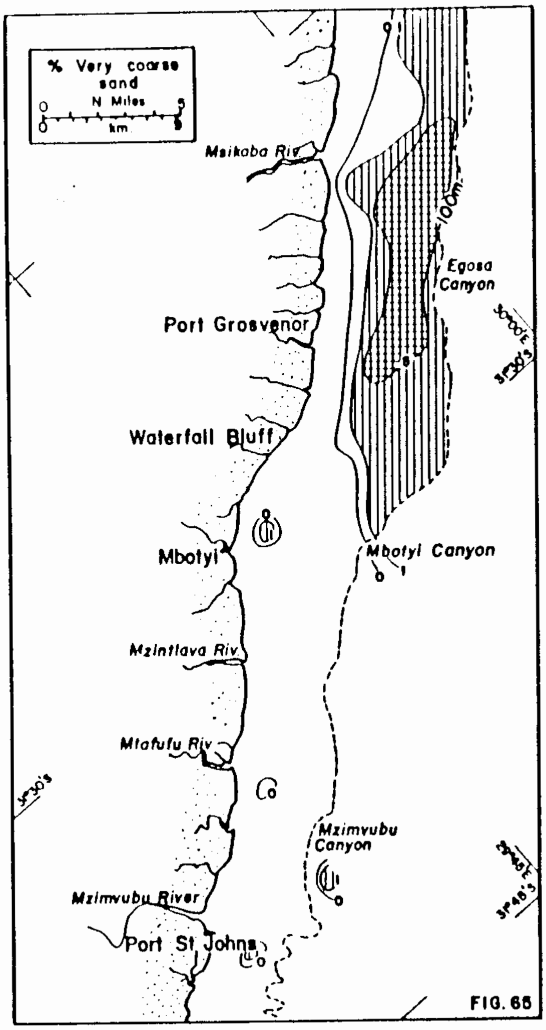


FIG. 65

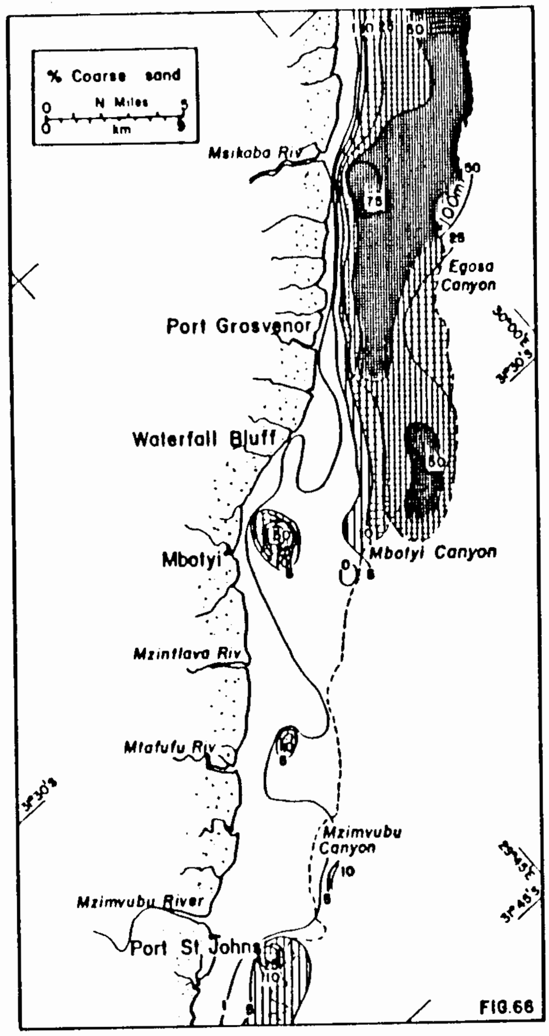


FIG. 66

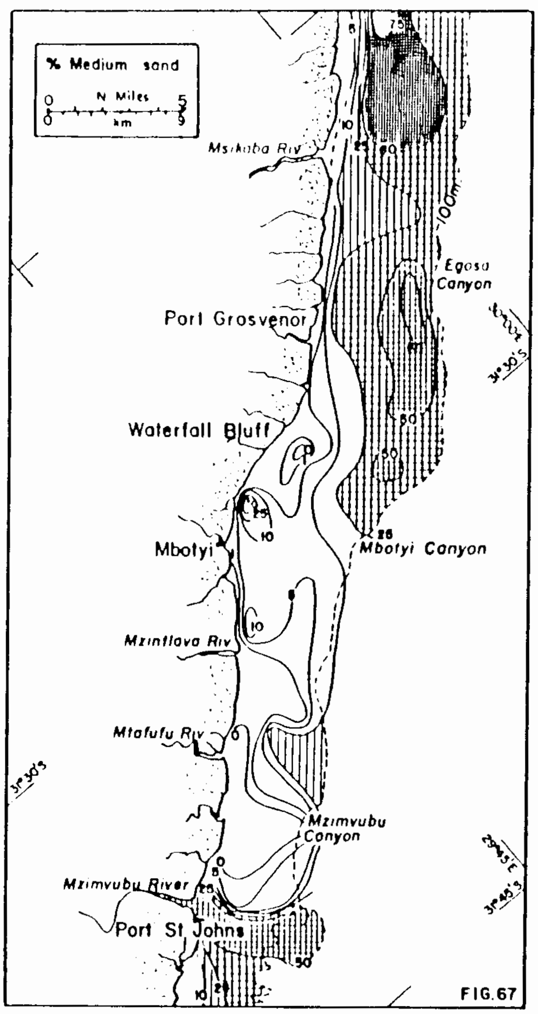


FIG. 67

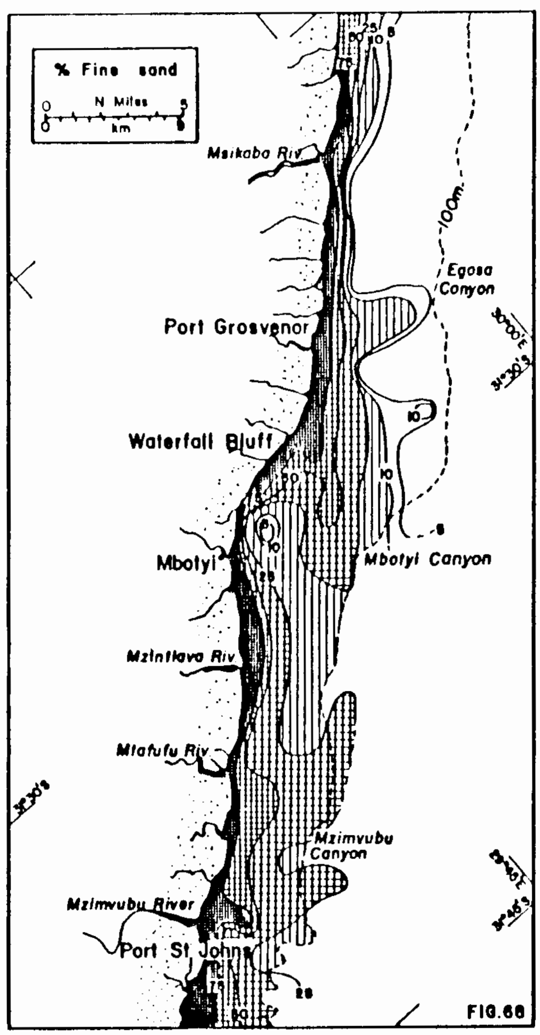


FIG. 68

Very coarse sand (Fig. 65)

Very coarse sand occurs in small amounts only. On the middle and outer shelf to the north of the offset it reaches concentrations of just over 5%. South of the offset, on the other hand, very coarse sand is found only in a number of small patches which probably mark the centres of isolated geological windows.

Coarse Sand (Fig.66)

In comparison with very coarse sand there is a marked increase in the proportion of coarse sand, although the distribution of coarse sand essentially follows the same regional trend as that of the very coarse sand. To the north of Waterfall Bluff concentrations increase rapidly with distance from the shore, the 50% contour being situated at about -40 m. East and south of Waterfall Bluff the contours gradually shift across the shelf towards the shelf break along the offset. The highest concentrations of coarse sand, locally reaching up to 80%, are found on the middle and outer shelves to the north of the offset, but concentrations appear to decrease towards the shelf break. The 5, 10 and 25% contours all terminate at the southern edge of the terrace, whereas the 1% contour moves persistently southwards along the midshelf zone, meandering between -60 and -100 m, as far as Port St Johns. Patches of coarse sediment in amounts greater than 5% are occasionally recorded on the outer shelf terraces in this region. Immediately to the south of Port St Johns the 1% contour moves inshore again. Here beween 1% and 5% coarse sand is found on the inner and middle shelves, with 5 to 10% recorded on the outer shelf.

Medium Sand (Fig. 67)

The medium sand fraction has a similar regional distribution to that described by the coarse and very coarse sand and surprisingly does not occur in greater concentrations than the former, except off the Mzimkulu River. Off the Waterfall Bluff the 25% contour moves offshore and terminates at the offset, whereas the 5% and 10% contours gradually turn around the Mfihlelo Spit to continue southwards along a rather irregular path until they terminate along the northern margin of the medium sand corridor off the Mzimvubu River. To the north of Waterfall Bluff on the other hand, concentrations are mostly below 25%. At Port St Johns, however, a belt of medium sand stretches across the shelf to the St Johns canyon head. On either side of this corridor the medium sand content decreases. To the north it drops rapidly to zero, whereas to the south it decreases more gradually to below 20%. Higher amounts are recorded in isolated geological windows which have already been referred to earlier. Elsewhere on the middle shelf there is less than 5% medium sand in the sediment.

A comparison between distribution patterns of medium sand, coarse sand and very coarse sand suggests a close association of these fractions over most of the study area. This means that the localised high concentrations of medium sand on the inner shelf between the Mntafufu and Mbotyi rivers might also originate in the geological windows situated slightly further offshore along the inner edge of the middle shelf. The $CaCO_3$ map, in fact, supports this interpretation. An exception would be the medium sand corridor off Port St Johns which appears to have its source in the Mzimvubu River.

Fine Sand (Fig. 68)

With the exception of the Port St Johns area, the fine sand component has an inverse relationship to the trends described for the coarser sediments. The amount of fine sand comprises up to 75% of the total sediment in the nearshore region (-20 to -30 m). It decreases rapidly to less than 5% on the middle to outer shelves north of the offset. Between the Msikaba River and Port Grosvenor the concentration gradient is particularly steep. Already at -40 m the proportion of fine sand has dropped to less than 5%. At Port Grosvenor the contours again shift seawards. The 25% contour now follows the outer limit of the middle shelf (-90 m) with a progressive decrease to less than 5% at approximately -95 m, whereas the 50% and 75% contours remain between -20 and -30 m. The central shelf sandstream in this area thus carries at least a 25% proportion of fine sand.

In the lee of Waterfall Bluff the 75%, 50% and 25% concentration lines faithfully contour the Mfihlelo Spit and then continue southwards along the inner shelf. Between 25% and 50% of fine sand occurs on the middle and outer shelves of this region. In general, areas with high concentration of fine sand correspond to areas of low concentration in medium and coarse sand, the only exception being the corridor off Port St Johns and some degree of overlap with the medium sand province in the north.

Very Fine Sand (Fig. 69)

Two distinct trends emerge from the distribution of very fine sand. North of Waterfall Bluff the proportion of very fine sand

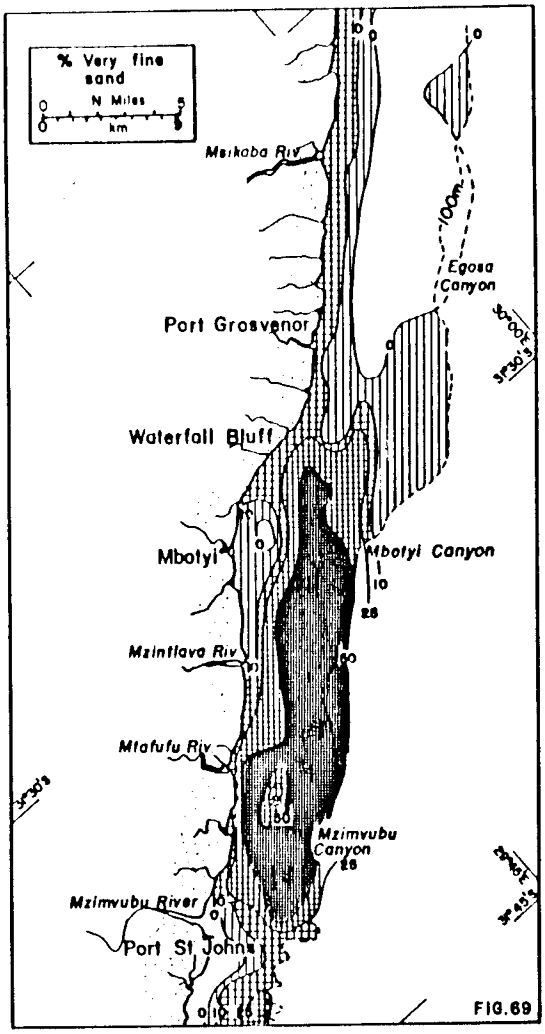


FIG.69

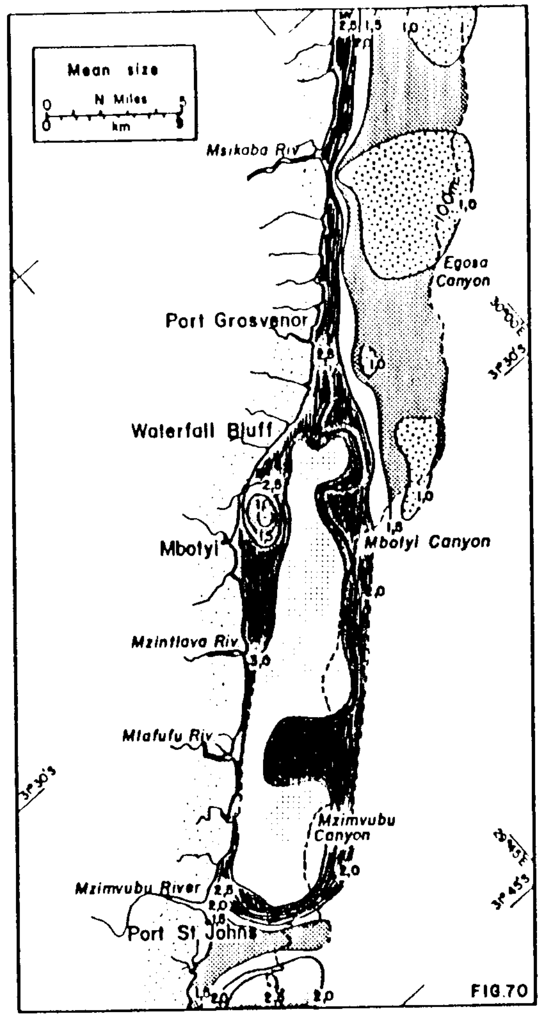


FIG.70

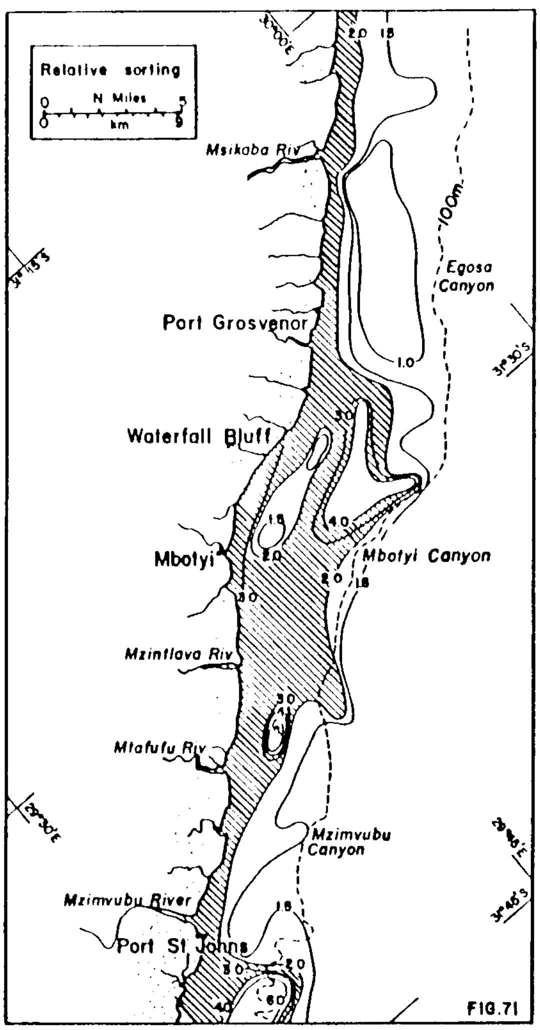


FIG.71

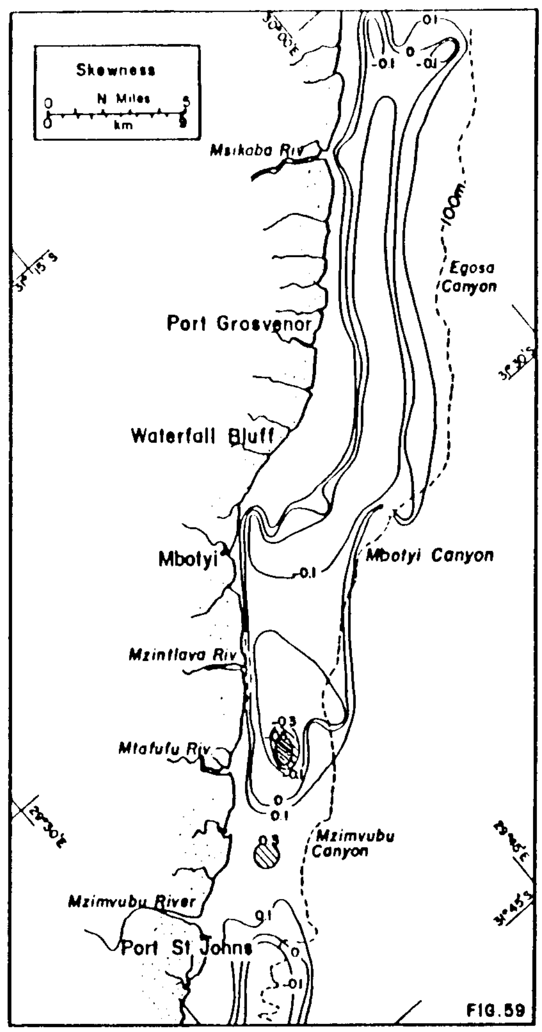


FIG.59

decreases rapidly with water depth. Very fine sand is absent on the outer shelf of this region, except on the shoreward side of the Waterfall Bluff Terrace where it is associated with the eddy. South of Waterfall Bluff the exact reverse is found. Very fine sand now increases with water depth and is mostly concentrated on the middle to outer shelves (50-75%). Off Port St Johns the corridor occupied by medium sand is clearly enhanced by the very fine sand distribution pattern, but now as an area of low concentration. The very fine sand depocentre on the middle and outer shelves south of the offset is probably situated at the centre of a large eddy.

Mean (Fig. 70)

North of Waterfall Bluff the mean diameter map reflects the distribution of medium coarse and very coarse sand, whereas to the south of Waterfall Bluff, as far as Port St Johns, it is more indicative of the fine and very fine sand populations. South of Port St Johns it retraces the trend of the medium sand. Due to the better separation of the individual size populations and the relatively small overlap between them, the mean diameter map provides a clearer picture of the major sedimentological trends than in the other sections of the shelf.

Thus, north of Waterfall Bluff the mean sediment size decreases offshore. Sediments finer than 1,5 phi are found on the inner shelf and material with a mean size coarser than 1,5 phi is present on the middle and outer shelves. Larger areas of very coarse (less than 1,0 phi) sediment are exclusively found on the outer shelf to the north and east of Waterfall Bluff.

Between Waterfall Bluff and Port St Johns the finest sediment (more than 3,0 phi) is found in the region of the Mfihlelo spit and on the middle to outer shelves to the south. Shoreward of the Mfihlelo Spit (approx. -30 m) the mean size increases slightly (2,5 to 3,0 phi). The cross-shelf corridor of high medium sand content off Port St Johns is reflected in a similar zone of sediment with a mean diameter of 1 to 2 phi.

Relative Sorting (Fig. 71)

The sorting pattern of sediments on this shelf sector undergoes a pronounced change off Waterfall Bluff. To the north the sediments are generally well sorted in the nearshore (QH = 2-4) but improve in sorting towards the middle and outer shelf, where large patches of extremely well sorted sediments are found (QH<1). Sorting once more decreases slightly towards the shelf break. Significantly, the areas of extremely good sorting do not correlate with any particular size fraction, indicating that the boundaries of the size fractions do not coincide with the size spectrum of individual hydraulic populations. The best sorted sediments to the north of Waterfall Bluff would seem to be either predominantly coarse grained (more than 50%) or coarse to medium grained (more than 50%) whereas the least well sorted sediments on the inner shelf consist of fine to very fine sands.

South of Waterfall Bluff the general level of sorting is considerably lower than that to the north. There are no extremely well sorted sediments (QH >1) and by far the largest area comprises well sorted sediments with sorting values similar to those found in the nearshore zone to the north of Waterfall

Bluff. Poorest sorting is found in areas of large-scale sediment mixing, between different populations, e.g. in the mud depocentre at the foot of the Mfihlelo spit. Off Port St Johns sediment sorting seems to resume a pattern more like that in the northern part of the shelf sector.

Skewness (Fig. 72)

The skewness pattern follows a very similar trend to that observed along the other coastal sectors. Again the inner shelf and the outer shelf are positively skewed, whereas the midshelf sediments are negatively skewed. The positively skewed cross-shelf corridor off the Umtentu River has already been pointed out in the previous section. A second positively skewed corridor of this type is found off Port St Johns. In both cases the trend is ascribed to the activity of fluvial jets carrying medium and fine sand across the shelf, whereas coarser bedload material, if it exists at all, already drops out near the mouth. In the case of the Umtentu it is the particularly fine sand which adds a fine tail to the otherwise medium sand on the shelf, whereas in the case of the Mzimvubu, medium and fine sand are supplied together. The entire spit/bar off Waterfall Bluff is positively skewed, consisting predominantly of fine and very fine sand.

As in previous cases, the skewness pattern suggests the presence of several major sediment populations which mix in different proportions at different localities on the shelf. In some places it is fine sand mixing with some very fine sand to produce positive skewness, as in the nearshore zone. On the middle shelf north of Waterfall Bluff it is fine to medium sand which is diluted by medium to coarse sand resulting in negative skewness, whereas on the outer shelf medium to coarse sand mixes with small amounts of finer sediment to produce positive skewness. South of Waterfall Bluff the midshelf depocentre of very fine sand and mud is invaded by smaller amounts of fine sand to produce negative skewness.

4.4.3 Discussion and Conclusions

On the basis of the sediment distribution patterns described above a model of sediment dispersal on the continental shelf between the two adjacent sedimentary compartments can be constructed.

To the north of the offset, medium sand, with greatest concentrations on the middle and outer shelf, appears to form the main bedload component of the central-shelf sand stream. All of this sediment, including any finer sediment, is eventually funneled onto the upper continental slope at the offset as the current overshoots the shelf break (Flemming, 1980). On the other hand, the distribution patterns of coarse and very coarse sand of the same region do not suggest much southerly movement. They forms a pavement of mostly relict lag material deposited during the Flandrian transgression.

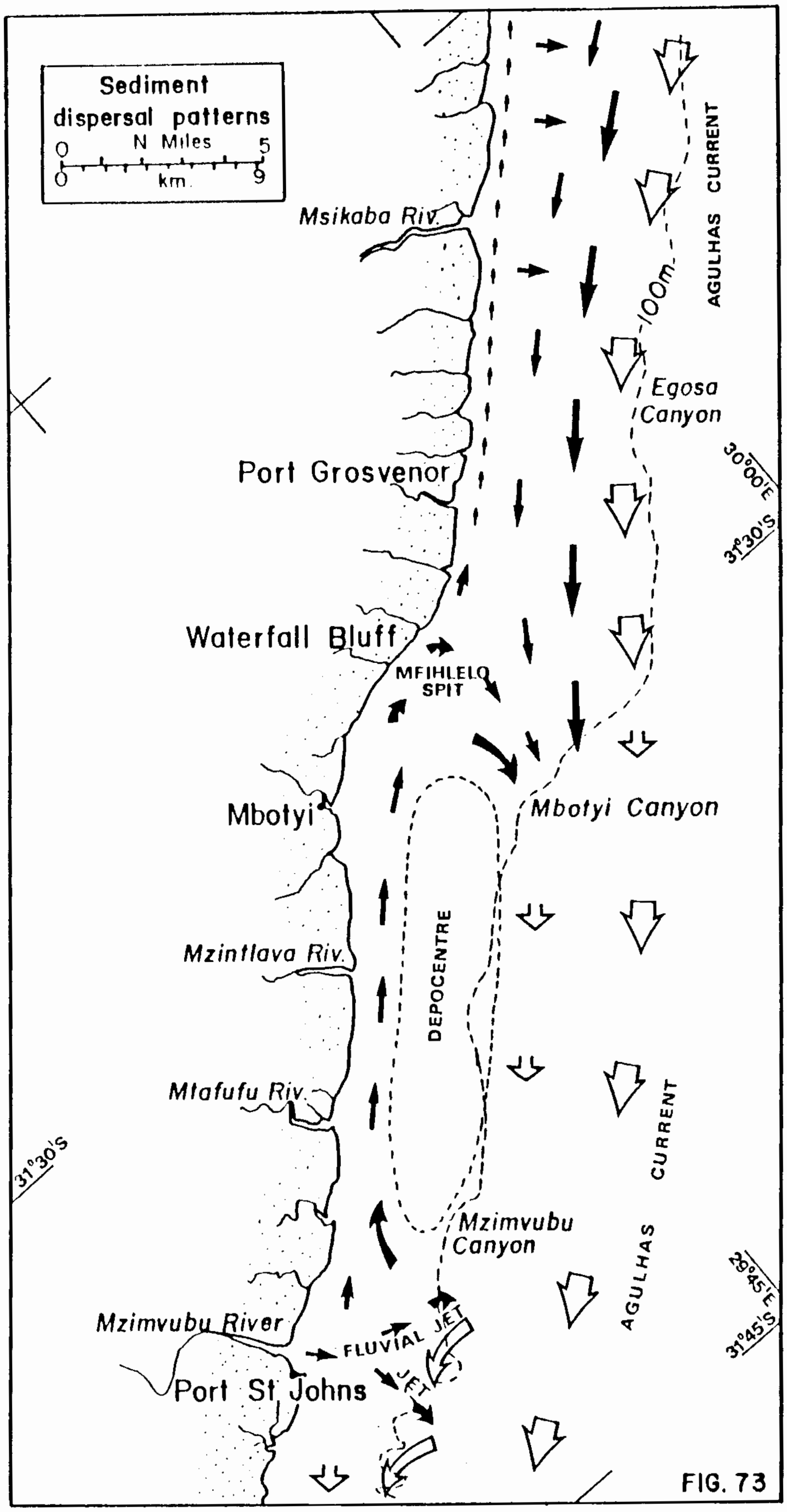
Fine and very fine sand is concentrated in the nearshore zone of the northern shelf sector, where a deposit of considerable thickness has accumulated in the Mfihlelo Spit. The origin of some of this material has been traced to the rivers entering the sea to the south of the Msikaba River. Another source of fine sand feeding the Spit may also originate to the south of the offset, being carried northwards by the eddy current discussed earlier. This conclusion is reached on the basis of the corresponding distribution patterns of individual size fractions on the shelf to the south of Waterfall Bluff.

Between Port St Johns and Waterfall Bluff the presence of medium, coarse and very coarse sand in appreciable amounts is limited to isolated occurrences on the middle shelf and at the shelf break. The former has been interpreted as representing windows of similar relict material extensively found on the outer shelf to the north of the offset. The presence of coarser, carbonate-rich material on the outer shelf terraces in this region suggests a marginal influence of the Agulhas Current as it sweeps the shelf edge. Fine sand in this area is concentrated in a narrow zone on the inner shelf, whereas very fine sand mantles the middle and outer shelves shoreward of the current-swept terraces, being trapped in the centre of the eddy system.

The distribution of the coarse, medium, fine and very fine sand fractions off the Mzimvubu River is substantially different from the regional pattern described above. Across the shelf towards the head of the St Johns Canyon a corridor of high medium sand concentration overlaps with a corridor low in very fine sand. South of this belt medium sand is concentrated in amounts between 20% and 50% of the total sediment. Little medium sand occurs to the north. This means that a large proportion of the medium sized fraction supplied by the Mzimvubu River is being carried across the shelf and lost down the head of the St Johns Canyon. It is suggested that when the Mzimvubu River is in full flood, the strength of the flow is sufficient to transport medium-sized material in suspension across the shelf, where some may escape down the St Johns Canyon. The remainder is entrained by the Agulhas current and carried southward. The renewed influence of the current is supported by the fact that the coarse sand component increases rapidly across the shelf to the south of this corridor.

In analogy to the distribution pattern of medium sand, much of the fine sand is also transported across the shelf, this time both towards the Mzimvubu and the St Johns Canyon. The remainder, together with a very fine fraction is carried northwards by the eddy flow induced by the Agulhas Current in the lee of the offset. This northerly movement of sediment is reinforced by the frequent (60% p.a.) occurrence of southwesterly gales which generate surface waves and nearshore wind-stress currents counter to the Agulhas current. Since rain, and hence floods, are associated with strong southwesterly winds, it is not difficult to understand why the present distribution of sediment has persisted through time. Birch (1981) reports up to 34 m of sediment across the shelf off the Mzimvubu river and up to 5 and 10 m of material draped over the canyon heads.

As the sediment is moved north the finer sediment is deposited in the nearshore zone, while the very fine material moves into the centre of the eddy to cover the middle and marginal outer shelves. In the lee of the bluff the fine grained material is mainly fed into the spit, although some may also be moved north by littoral drift before it is fed into the nearshore stream of fine sand moving southwards on the innter shelf. Very little



Sediment dispersal patterns
0 N Miles 5
0 km 9
Msikaba Riv.
AGULHAS CURRENT
100m
Egosa Canyon
30°00'E
31°30'S
Port Grosvenor
Waterfall Bluff
MFIHLELO SPIT
Mbotyi
Mbotyi Canyon
DEPOCENTRE
Mzintlava Riv.
Mtafufu Riv.
31°30'S
CURRENT
Mzimvubu Canyon
AGULHAS
29°45'E
31°45'S
Mzimvubu River
FLUVIAL JET
JET
Port St Johns

FIG. 73

very fine sand is found north of the bluff. Part of this material settles out on the seaward edge of the Mfilelo spit, whereas some is dumped in the head of the Mbotyi canyon. The largest portion, however, appears to recirculate in the eddy, being deposited on the middle shelf and on the inner edges of the outer shelf terraces to the south of Waterfall Bluff where the energy is lowest.

The above pattern of sediment dispersal, which is summed up by the mean diameter map of Fig.70, therefore draws a complex picture of regional separation and local mixing of different populations. The major sediment dispersal routes outlined above and the corresponding flow path of the Agulhas Current are summarised in Fig.73. It has already been noted that the areas of net deposition correspond to areas of poorest sorting, e.g. the Mfihlelo Spit, the middle shelf between Waterfall Bluff and Port St Johns and the outer shelf and shelf break to the south of Port St Johns in the vicinity of the Port St Johns Canyon. The contrast between the distribution of mud and sand suggests that separation between these size fractions occurs to the south of the Mfihlelo Spit. This means that fine sand progrades across a base of mud and very fine sand, thereby producing an upward coarsening depositional sequence.

5. SYNTHESIS AND CONCLUSIONS

5.1 Process-Response Models for Shelf Sediment Dispersal

The present study has, on the whole, confirmed the validity of the dynamic model proposed by Flemming (1980, 1981). Nevertheless, the large amount of additional information evaluated above has locally led to a considerable refinement of the model. It has been demonstrated that the textural variations found in the shelf sediments are determined by a combination of factors such as sediment sources, local bathymetry and hydrodynamic conditions. The distinct distribution patterns of the various size fractions, e.g. fine, medium and coarse sand, suggest that the different energy regimes along and across the shelf act as hydrodynamic filters or even as barriers (cf. Figs. 25-27, 40-42, 53-55, 66-68).

It has been demonstrated that the coarse, medium and fine sand fractions in general show less than 20% overlap, although it has also been recognised that the hydraulic populations do not strictly correspond to the arbitrarily defined size fractions. It is this overlap, however, which suggests that some degree of lateral mixing occurs between adjacent populations and which determines both local sorting and skewness in the size frequency distribution patterns (cf. Figs. 30/31, 45/46, 58/59, 71/72). Thus, in the nearshore positively skewed sediments are invariably fine grained, whereas on the outer shelf they are coarse grained. The most negatively skewed sediments are those which show the greatest degree of overlap between the medium and coarse sand fractions. Best sorting occurs where individual hydraulic

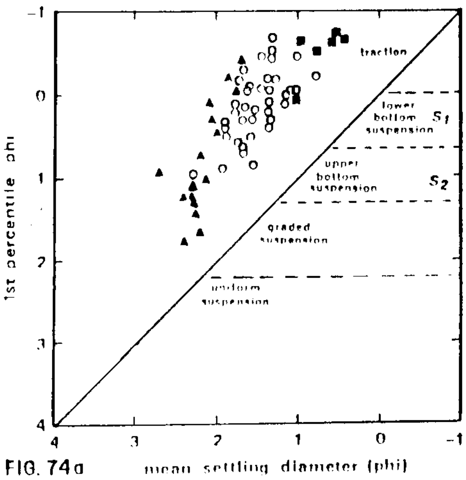


FIG. 74a

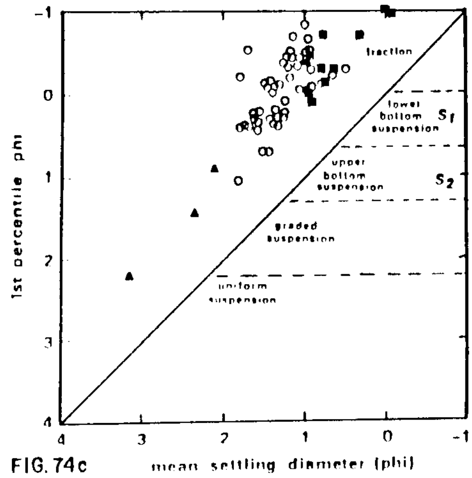
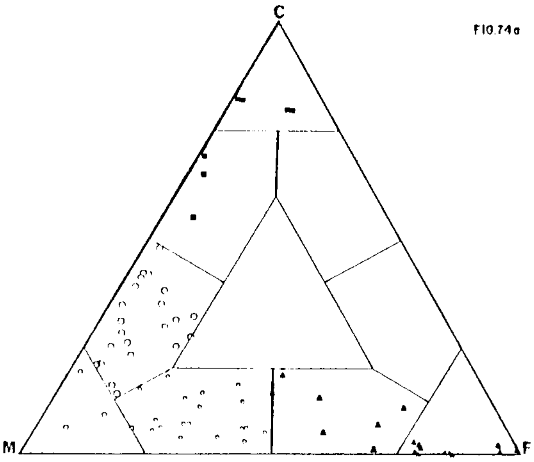
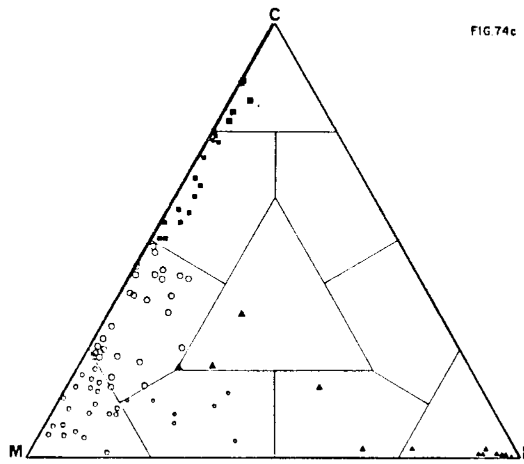


FIG. 74c





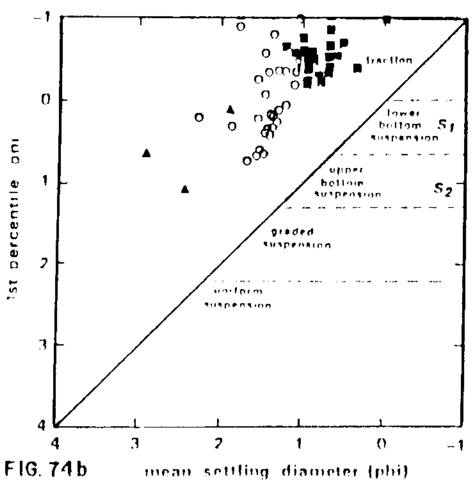


FIG. 74b

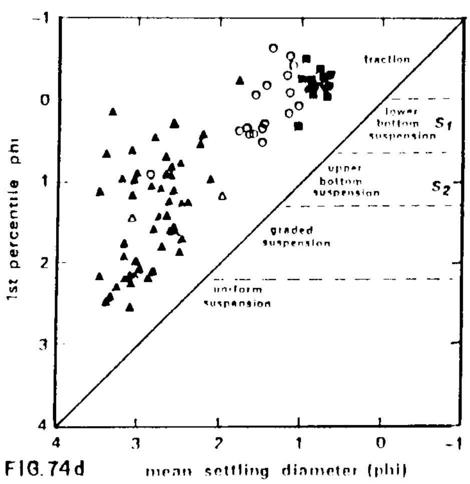
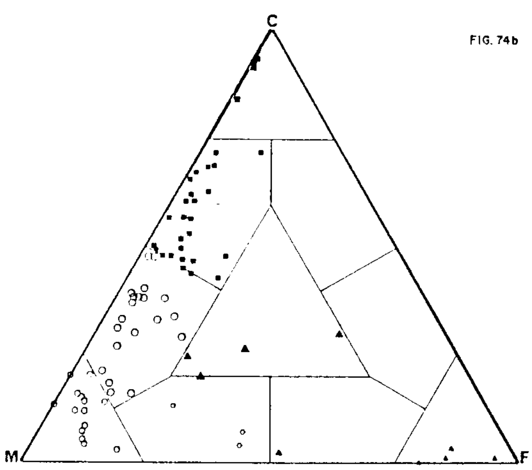
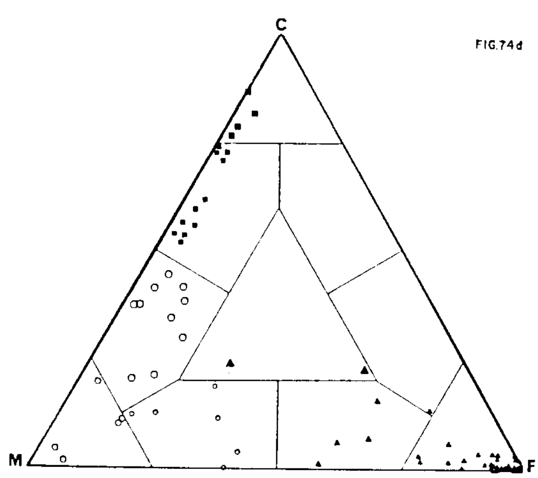


FIG. 74d

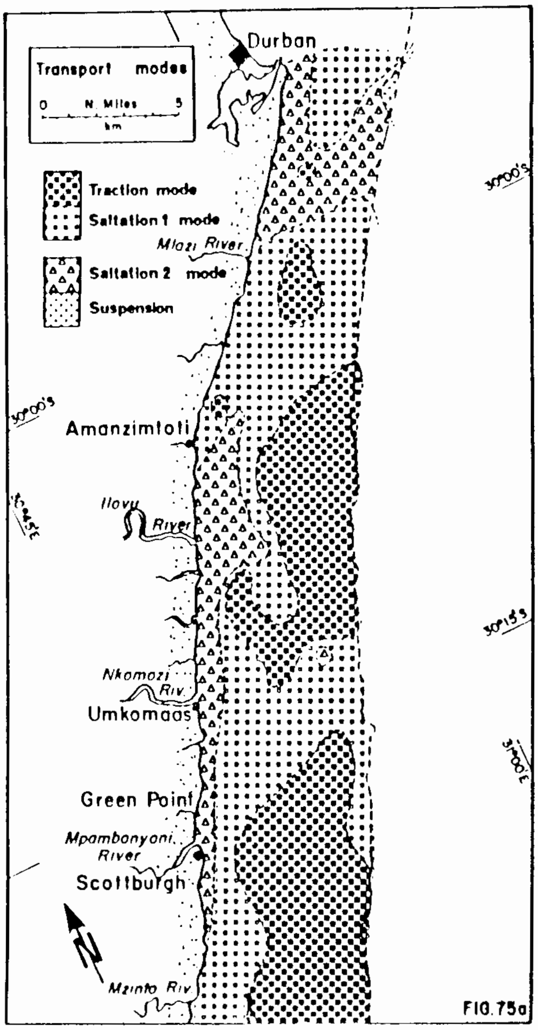




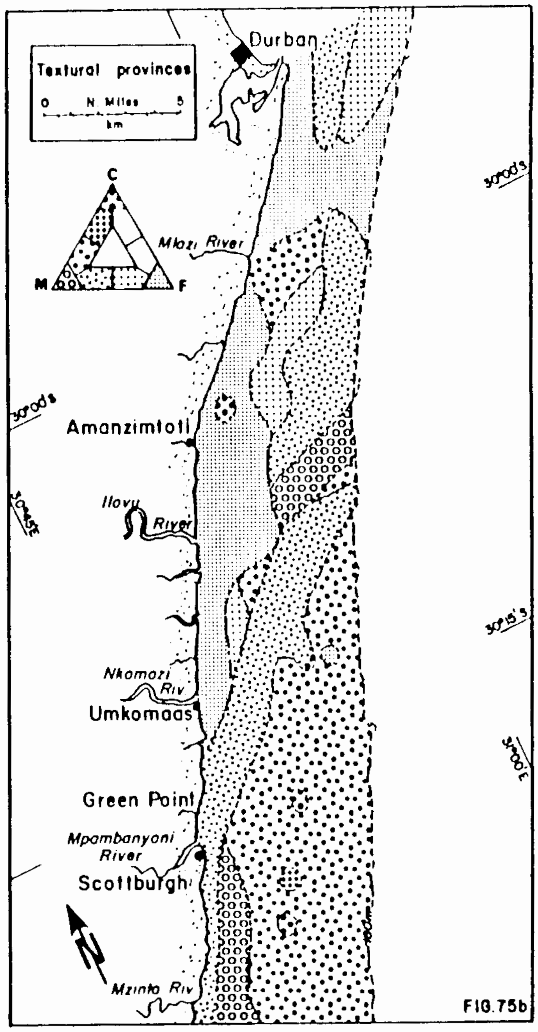
populations show the smallest degree of overlap with adjacent ones, whereas zero skewness occurs where the contribution of the overlap population happens to cancel the inherited skewness of the parent population. Both skewness and sorting are therefore primarily a function of the combined effect of source-inherited texture and subsequent mixing between different populations in the marine environment.

For purposes of comparison between the mean sediment size and the prevailing energy regime CM diagrams (Passega 1957) were plotted and the results contoured (Figs.74 & 75). The data indicate similar energy gradients to that described by the size fraction contours, thereby strongly supporting the general validity of the CM-approach. Sediments with mean diameters between 1,5 - 2,Ø phi are invariably moved in upper bottom suspension (S2), whereas sands with mean diameters between 1,5 and 1,Ø phi are transported either in lower bottom suspension (S1) or in traction. Sediments with a mean diameter coarser than 1,Ø phi are invariably transported in traction, provided it is not too coarse to be transported at all under the prevailing energy conditions.

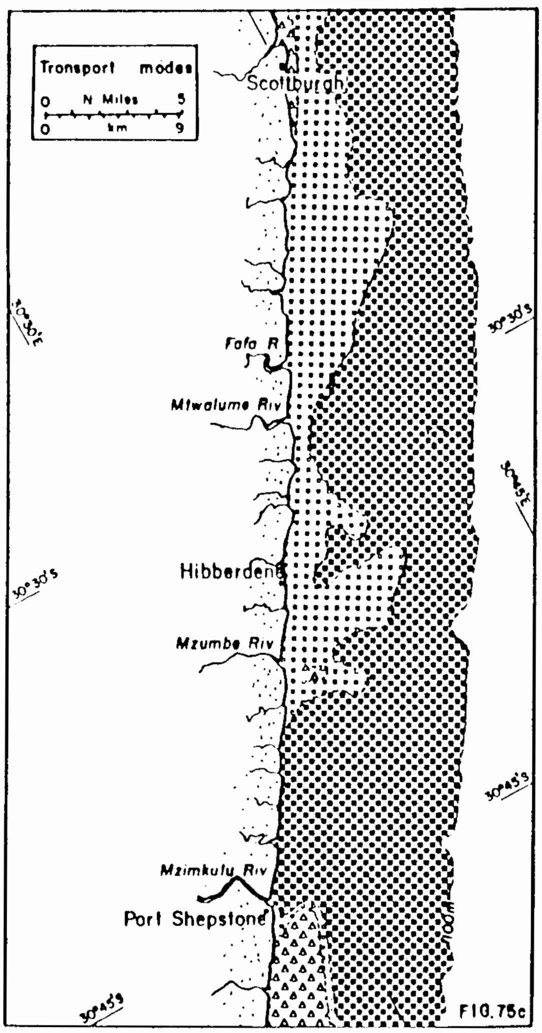
Most sediments which move in the S2 mode or in true suspension are generally positively skewed and well sorted on the relative sorting scale. The S1 populations, on the other hand, are always negatively skewed and they include the best sorted sediments found on the shelf, being very well to extremely well sorted. They would thus appear to be the least mixed sediments. Traction load are either strongly positively or strongly negatively skewed, depending on whether the bulk of the population is medium grained or coarse grained, respectively.



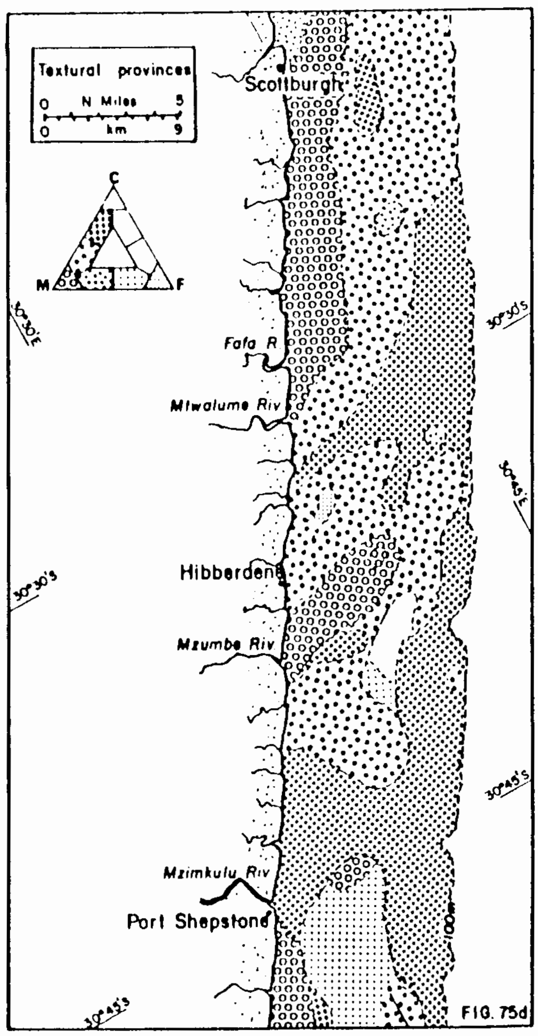
Durban
Transport modes
0 N. Miles 5
km
Traction mode
Saltation 1 mode
Mlazi River
Saltation 2 mode
Suspension
30°00'S
Amanzimtoti
Ilovu River
30°15'S
Nkomazi Riv.
Umkomaas
Green Point
Mpambanyoni River
Scottburgh
N
Mzinto Riv
FIG. 75a



Durban
Textural provinces
0 N. Miles 5
km
C
M
F
Mlazi River
30°00'S
Amanzimtoti
Ilovu River
30°15'S
Nkomazi Riv
Umkomaas
Green Point
Mpambanyoni River
Scottburgh
N
Mzinto Riv
FIG. 75b



Transport modes
0 N. Miles 5
0 km 9
Scottburgh
30°30'S
Fafa R
Mtwalume Riv
Hibberdene
30°30'S
Mzumbe Riv
30°45'S
Mzimkulu Riv
Port Shepstone
100m
30°45'S
FIG. 75c



Textural provinces
0 N. Miles 5
0 km 9
Scottburgh
C
M
F
30°30'S
Fafa R
Mtwalume Riv
Hibberdene
30°30'S
Mzumbe Riv
30°45'S
Mzimkulu Riv
Port Shepstone
100m
30°45'S
FIG. 75d

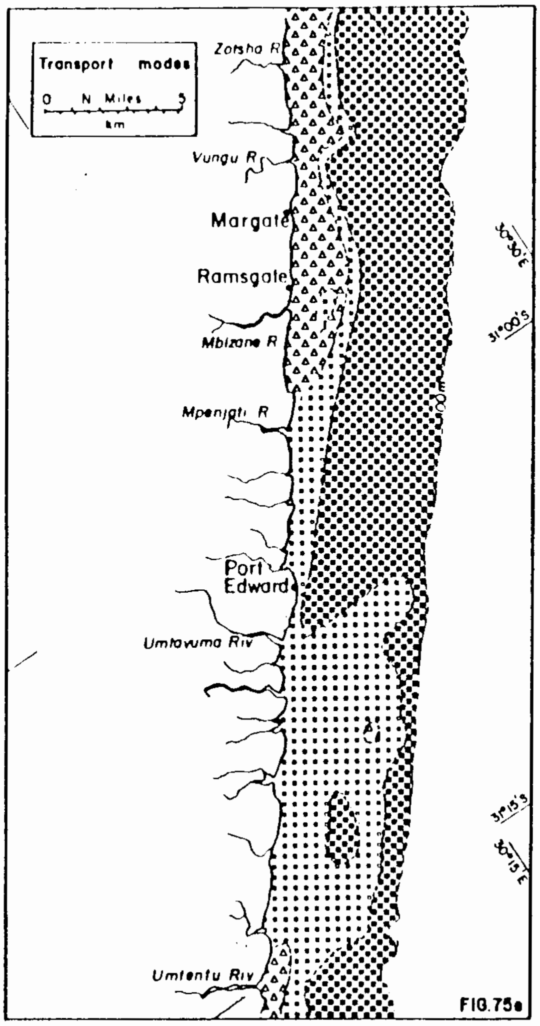


FIG. 75e

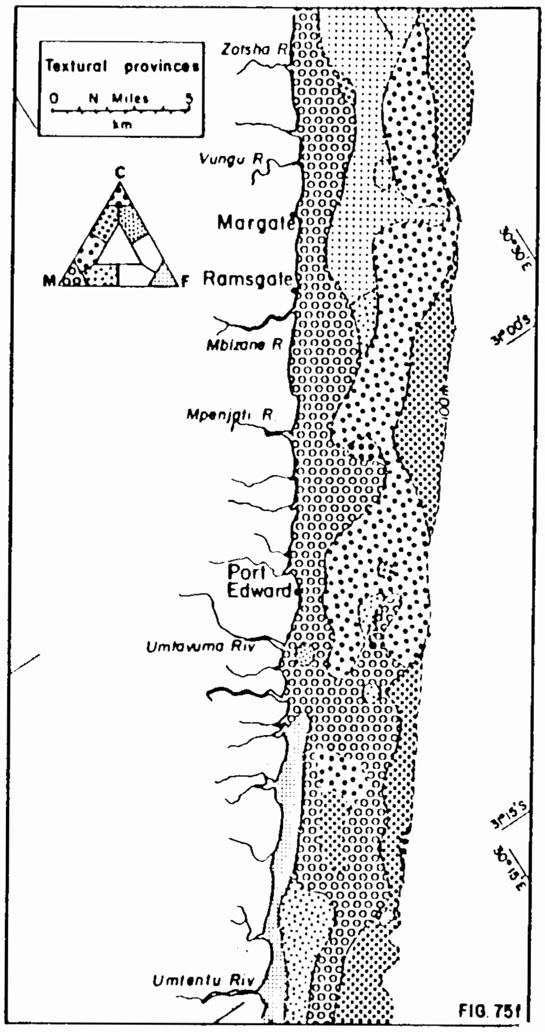


FIG. 75f

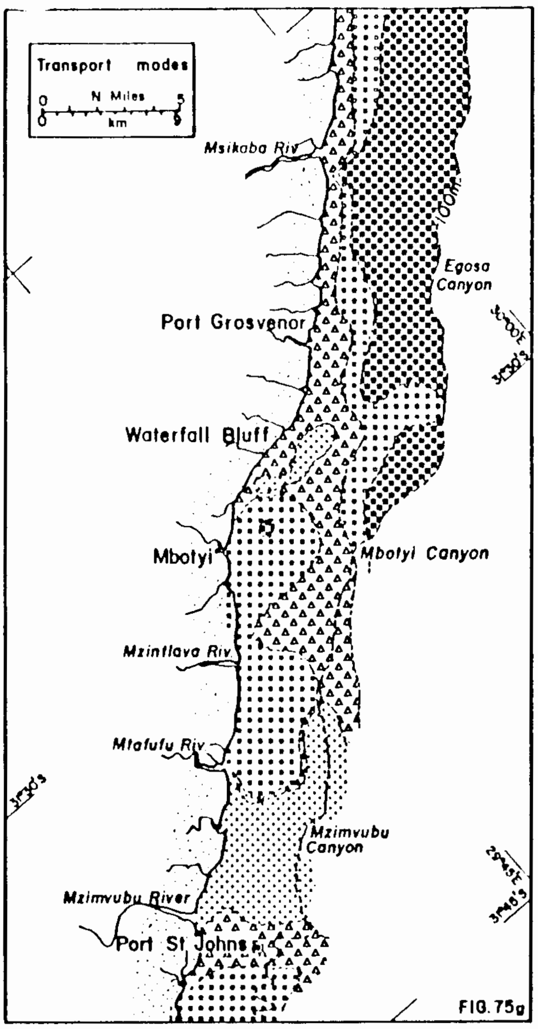


FIG. 75g

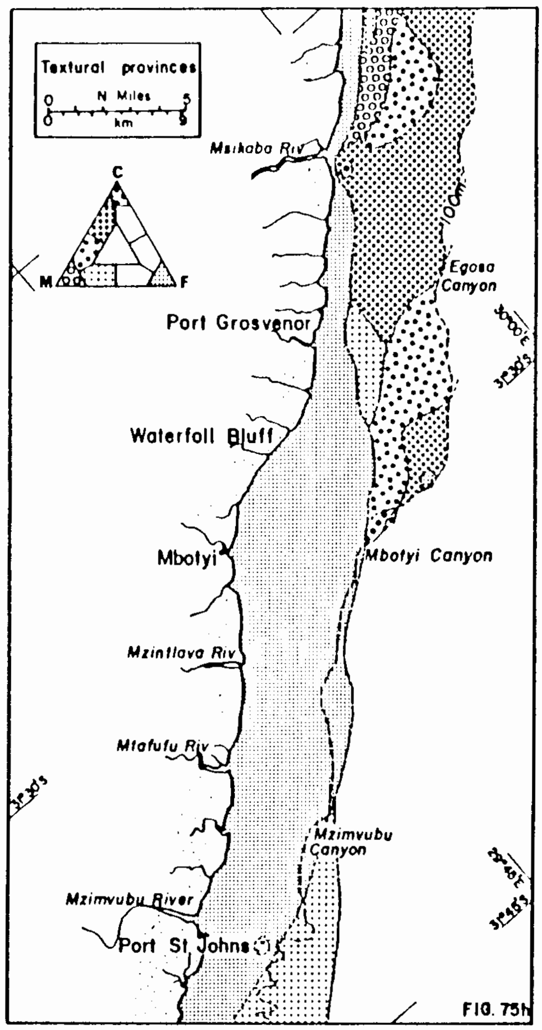


FIG. 75h

The above results clearly distinguish between the S1 and the S2 modes of transport, even though one might argue that the chosen boundaries are to some extent arbitrary. The sediments moved in the S2 mode are positively skewed through the addition of a fine tail which in turn is the result of progressive deposition from true suspension. Similarly the negative skewness of the S1 population indicates a close association with material moved in the traction mode.

Flemming (1977) successfully used the Passega (1957) model as a sequential indicator of energy levels in a lagoonal environment. The evidence rpesented in this study also supports this approach. It further validates the Passega method as an indicator of the prevailing energy regimes. It would appear that the mode of transport is a function of the excess shear stress or excess velocity available over and above that which is required to initiate transport together with the size of the sediment to be moved. In the case of this study the transition from bedload to suspended load transport would seem to fall between the S1 and S2 categories described by Flemming (1977). This classification of transport modes, based on the mean diameter and the first percentile, therefore defines the lower limit of transport within any one of the different modes. Thus, individual sediment populations which are moving simultaneously are in actual fact being transported by different modes and that progressive intermittent deposition of opposite tail members of such hydraulic populations results in the so-called mixed sediments that are eventually sampled.

A summary of the above textural classification of the shelf sediments is presented in Fig. 75. The triangular diagrams of the textural data illustrate the tolerance of the CM diagram for variations in the relative proportions of the different size fractions which in turn are a function of mixing between the different hydraulic populations. The more they are mixed, the poorer is their sorting and the further they plot away from the diagonal centre line (see also Flemming, 1977). It is noted that most mixing takes place in the S2 population and the coarser end members of the S1 population, as is to be expected. It would appear that the mid-shelf sand-stream facies described by Flemming (1980, 1981) consists mostly of negatively skewed S1 sediments. The inner shelf sand sheet, on the other hand, comprises predominantly positively skewed fine/grained S2 sediments which grade offshore into negatively skewed, medium-grained S1 sediments. Similarly, the outer-shelf palimpsest facies is characterised by positively skewed coarse sands, with negatively skewed fine to medium sand occurring intermittently along the shelf break.

A second approach in gaining some qualitative insight into the dynamic behaviour of the shelf sediments of the study area makes use of threshold criteria for bedload and suspension. Critical velocities have been calculated for the initiation of both bedload and suspension transport (Fig.76). They are expressed in terms of the minimum surface flow velocities required to initiate such movement. Two methods have been used to evaluate the results obtained in this manner. However, before proceeding it should also be noted that surface velocities of at least 100 cm/sec have locally been recorded on the shelf (Pearce, 1977, 1978; Schumann and Gill, 1979). If one assumes that this velocity is regularly attained, then the local difference between this "maximum" velocity and the calculated threshold velocities should give some idea of the excess velocity (and hence excess shear stress) locally available for sediment transport. The same excess velocity, for example, would obviously result in a greater sediment flux in finer sediments than in coarser sediments (cf. Figs. OPEN UNI. SERIES 11). Furthermore, finer sediments are more likely to be moved in the S2 and suspension modes than in the S1 and traction modes, whereas the opposite would hold true for coarser sediments, provided that the same amount of excess shear stress was available.

A similar rationale has been used when comparing the CSVB*1 with the CSVS*2. The coarser the sediments, the greater the difference between the two (cf. Fig. 6). A sharp gradient in the CSVB velocities should therefore result in a sharp separation between adjacent hydraulic populations, whereas a sharp gradient in the CSVS contours indicates a sudden increase in the amount of coarse material present. The gradient of the CSVS contours observed on the shelf, as well as sharp gradients in the CSVB contours, may then be viewed as indicators of changes in major transport modes or be indicative of the relative speed at which discreet hydraulic populations are being moved along the seabed.

Secondly, by correlating the mode of transport inferred from the CM diagrams with the minimum flow velocities, it may be assumed

*1 CSVB critical surface velocities required for bedload motion

*2 CSVS critical surface velocities required for suspension motion.

that where a CM diagram indicates suspension or S2 mode transport, the minimum velocities required for suspension of the sediment are probably frequently attained and exceeded. Similarly, where an S1 populatin is present, the minimum velocities required to initiate bedload motion must be exceeded. With respect to the traction mode, however, consideration of critical velocities for bedload transport is not quite as straightforward. In areas where gravel is present in appreciable amounts, the topography generally indicates extensive erosion, or at least non-deposition. This suggests that the gravel fraction and most likely also the very coarse sand fraction (including the 1st percentile in the sand distribution!) represent lag deposits which are largely immobile. Very coarse sand, however, is generally absent from the shelf and the mean size of the coarser grained sediment paralells that of coarse sand distribution pattern. Thus, the critical velocity for bedload motion in such cases would predict the lowest level of expected real-time surface velocities, whereas the CSVS value predicts a conservative upper limit. In places where traction mode is indicated but little gravel is present, one can merely conclude that the CSVB values must be exceeded. In this manner, reasonable estimates can be made of the approximate surface velocities that may be expected over the shelf.

The flow patterns inferred from sediment distribution trends confirm and delineate quasi-permanent, north-flowing eddies near the northern and southern boundaries of the study area. These areas are discussed separately from the regional shelf trend.

From Fig.76bit is clear that the north-flowing counter current of the Natal gyre system must regularly attain speeds between 60 and

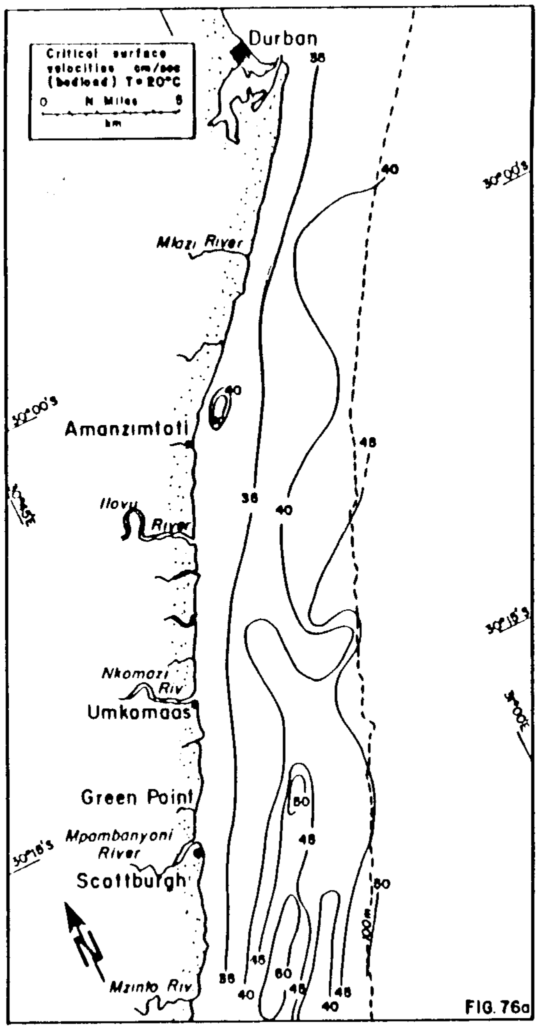


FIG. 76a

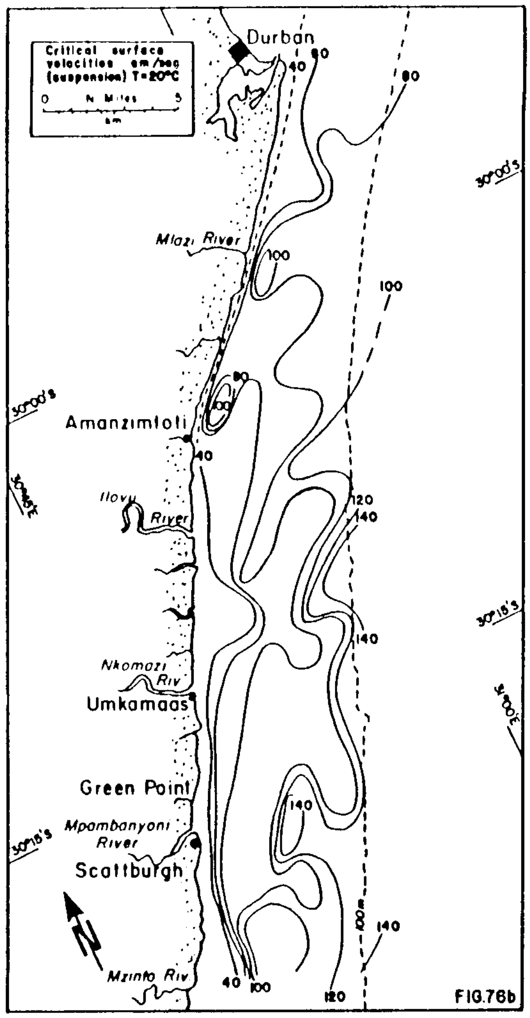


FIG. 76b

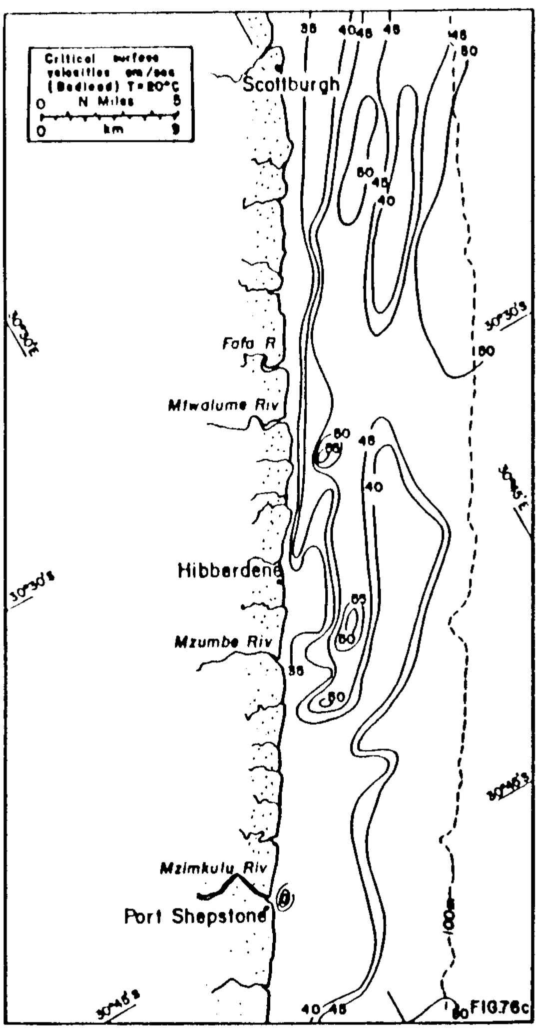


FIG. 76c

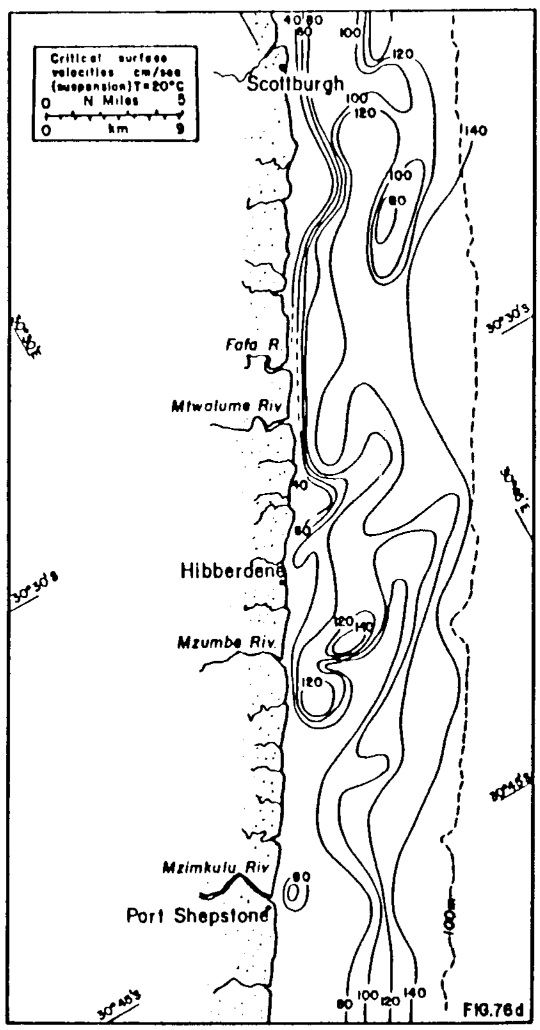


FIG. 76d

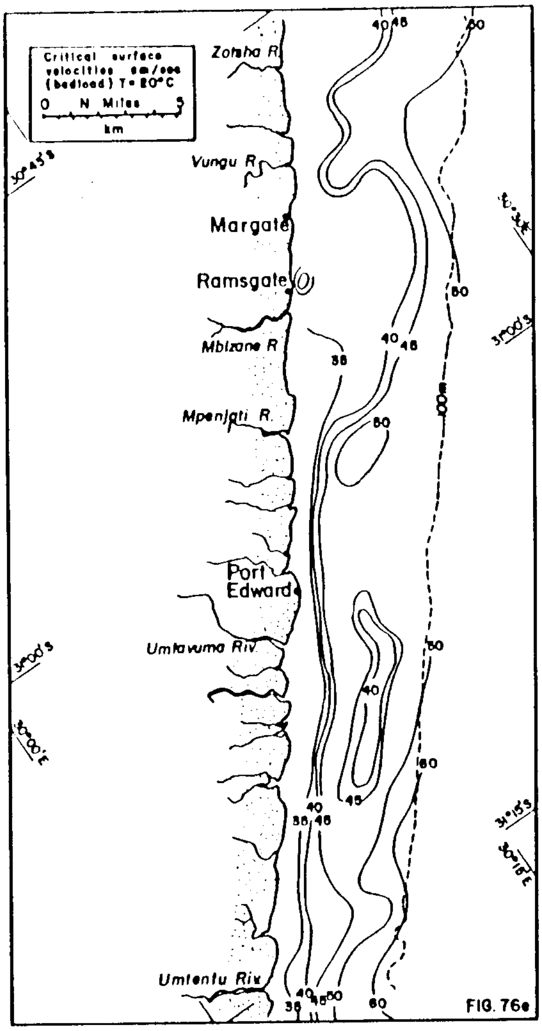


FIG. 76e

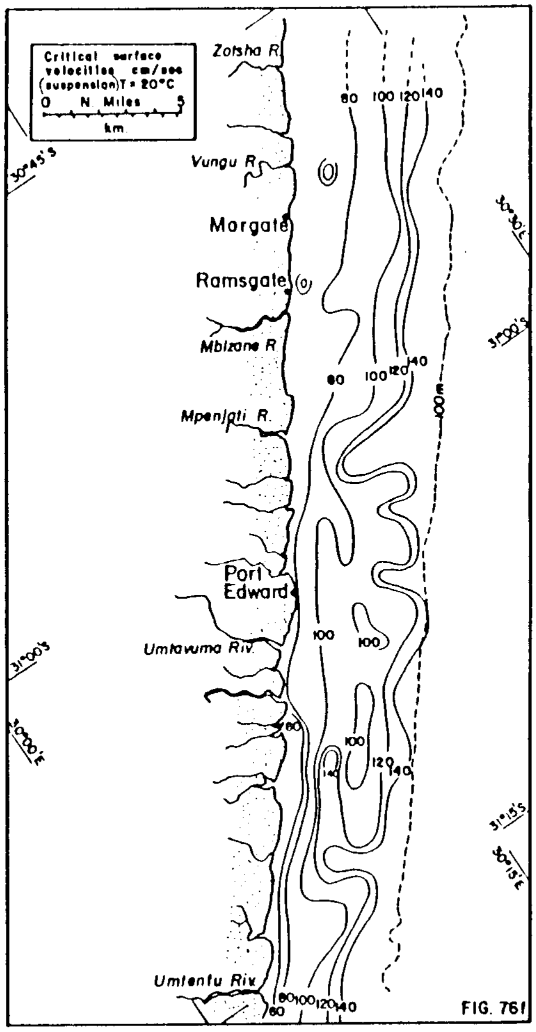


FIG. 76f

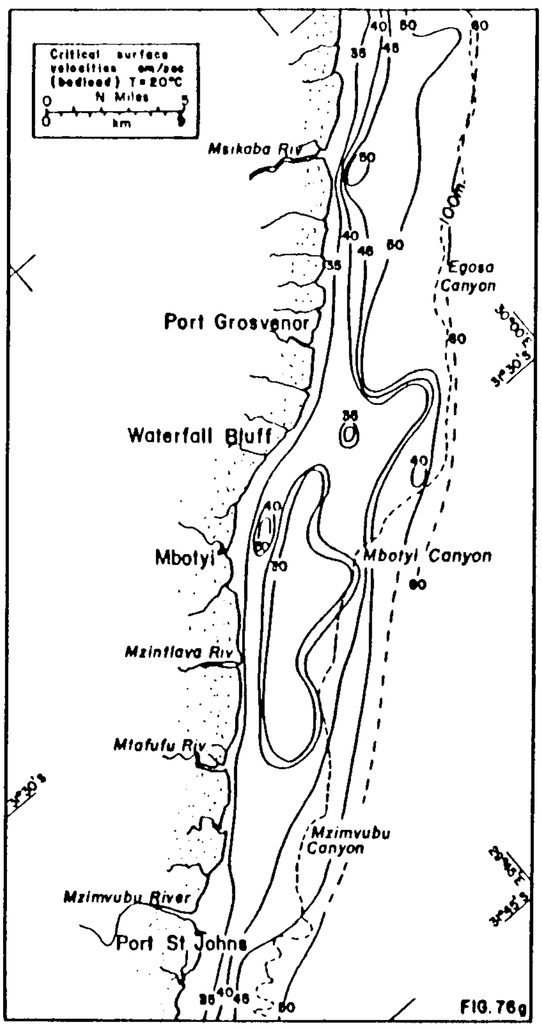


FIG. 76g

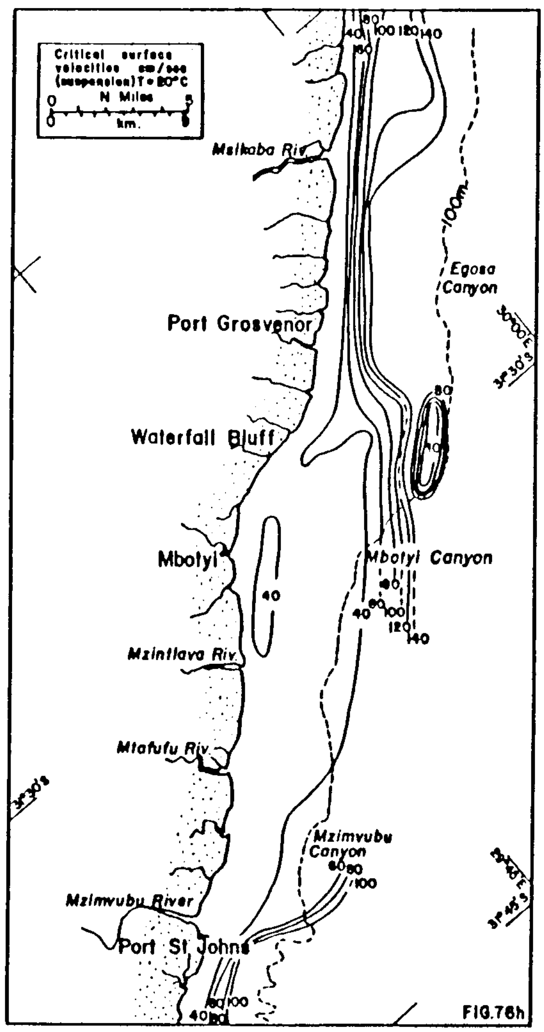


FIG. 76h

80 cm/sec (1,2 - 1,6 knots) on the inner and middle shelves north of Scottburgh. To the south the velocity is expected to decrease as the eddy progressively weakens, controlling sediment dynamics only on the inner shelf. There is some overlap between the high fine sand corridor and the S2 transport mode inferred from the CM plots. If one assumes that within a particular transport mode fine sand should always move faster than medium sand, then the major hydraulic populations outlined above are composed of a number of subpopulations which are essentially defined by the degree of mixing and which move at different rates along the same dispersal route, or that there is simply a progressive increase in sediment flux from the medium sand population to the fine sand populations. As it is highly unlikely that coarse sands are moved in the suspension mode the diagonal trend from the outer shelf to the midshelf ridge, described by the close juxtaposition of the 100, 120, 140 cm/sec contours (CSVS)(Fig.76), indicate the increasing influence of the main flow of the Agulhas Current on the outer shelf from as far north as the Ilovu River.

The eddy system south of Waterfall Bluff appears to be somewhat weaker than its northern counterpart (Fig. 76g,h). Surface velocities in the counter-current are probably less than 50-60 cm/sec and less than 30-40 cm in the centre of the eddy as well as on the Mphilelo Spit, where deposition is evident. It would appear questionable whether these sediments could be transported at all without the help of surface waves to attain and exceed the critical threshold stresses.

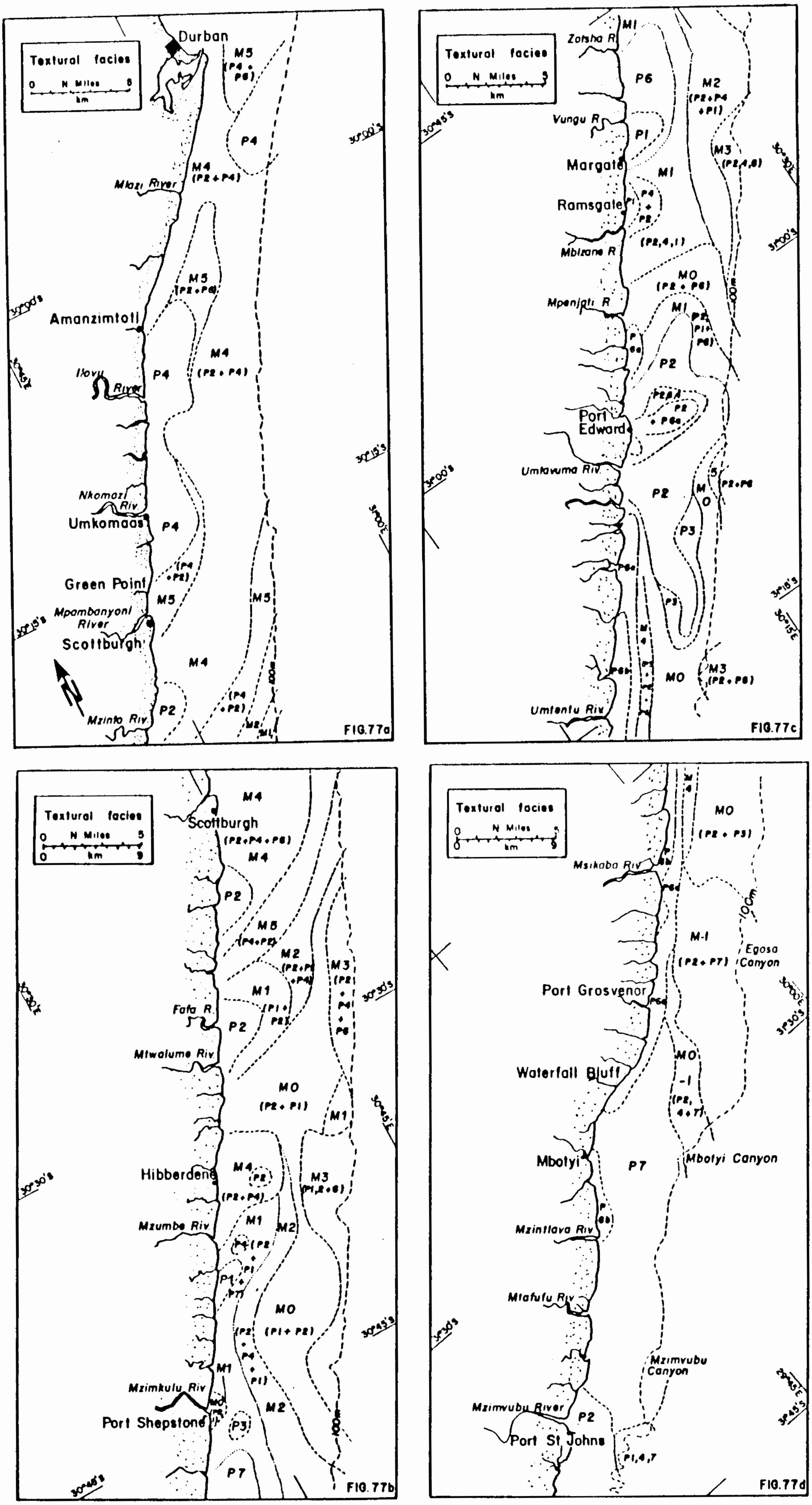
A steep gradient along the middle shelf south of the Msikaba River and on the seaward side of the Mphilelo Spit delineates the influence of the Agulhas Current on the outer shelf. A similar gradient is suggested by the CM gradient (Fig.75h) which outlines the limits of the S2 and traction transport modes. Significantly, this area is characterised by a lack of medium sand (normally a S1 population) and the absence of the midshelf ridge south of Port Grosvenor.

On the remainder of the shelf the critical surface velocities required for bedload transport follow a similar pattern throughout. The assumed boundary between predominantly bedload and suspension transport is, however, positioned further offshore and runs parallel to the trend of the outer midshelf boundary. The cross-shelf gradient of the critical velocities required for suspension, on the other hand, is much more gradual. The bedload criterion highlights the role of the ridge as a physical barrier to the influence of the Agulhas Current on the inner to middle shelves, whereas the suspension criterion again suggest the presence of subpopulations in the mobile sandstream which are being transported south in bedload, but at different speeds. In fact the area from Glenmore Beach to just south of the Mzamba River provides an interesting case study which outlines the regional cross-shelf energy variations (Fig.76e,f).

In this area the ridge is absent and this facilitates cross-shelf transport. A sharp increase in the gradient of the bedload criterion outlines the inner limit of the Port Edward dune field. The seaward limit of this feature, on the other hand, is outlined by a similarly steep gradient of the suspension criterion. It is therefore suggested that the inner gradient separates the nearshore zone, which is dominated by longshore drift and wave action, from the current controlled mid-shelf sand stream, whereas the outer gradient separates the sand stream from the outer shelf gravel pavement. Thus the S1 population occupies almost the entire width of the shelf, with the CSVS gradient marking the transition to the traction population as it shifts obliquely inshore to the south. This transition is also paralleled by the 50 m/sec CSVB contour and the re-establishment of an outer shelf terrace to the south, (cf. Msikaba to Waterfall Bluff). These observations support the assertion (cf. section 4.3.3) that the dunes off Port Edward are formed in response to a local reduction in the influence of the Agulhas Current on the middle and outer shelf, probaly produced by the offshore deflection of the current at the Protea Banks further north.

It would appear that a threshold of 45-60 cm/sec is a reasonable estimate for the minimum surface velocity of the Agulhas Current in these regions where the midshelf sand stream is maintained as evidenced by the bedform patterns described and catalogued by Flemming (1980, 1981). In these areas maximum current velocities, on the other hand, cannot frequently exceed 120 cm/sec (CSVS), since at these velocities the material would go into suspension and thereby destroy any transverse bedforms. Where erosion is evident, as for example on the outer shelf, surface current speeds above 120 to 140 cm/sec are to be expected since the relative absence of sand in these areas suggests removal by suspension transport.

The distinct across-shelf energy gradients discussed above are a strong indications that initial size-sorting of the fresh terrigenous material supplied to the shelf, takes place very


Textural facies
Durban
M5
(P4 + P6)
P4
M4
(P2 + P4)
Mlazi River
M5
(P2 + P6)
Amanzimtoti
M4
(P2 + P4)
Ilovu River
P4
Nkomazi Riv
Umkomaas
P4
(P4 + P2)
Green Point
M5
Mpambanyoni River
Scottburgh
M4
Mzinto Riv
P2
(P4 + P2)
100m
FIG.77a
Textural facies
Scottburgh
M4
(P2+P4+P6)
M4
P2
M5
(P4+P2)
M2
M3
M1
(P1 + P2)
Fafa R
P2
Mtwalume Riv
MO
(P2 + P1)
M1
Hibberdene
M4
(P2+P4)
M3
M1
M2
Mzumbe Riv
MO
(P1 + P2)
M1
Mzimkulu Riv
Port Shepstone
M2
P3
P7
100m
FIG.77b
Textural facies
Zotsha R
M1
P6
M2
(P2+P4 +P1)
Vungu R
P1
M3
Margate
M1
Ramsgate
Mbizane R
(P2,4,1)
MO
(P2 + P6)
Mpenjati R
M1
P2
Port Edward
Umtavuma Riv
P2
P3
MO
M3
(P2 + P6)
Umtentu Riv
FIG.77c
Textural facies
MO
(P2 + P3)
Msikaba Riv
100m
M-1
(P2 + P7)
Egosa Canyon
Port Grosvenor
MO
-1
(P2, 4+7)
Waterfall Bluff
Mbotyi
P7
Mbotyi Canyon
Mzintlava Riv
Mtafufu Riv
Mzimvubu Canyon
Mzimvubu River
P2
Port St Johns
P1,4,7
FIG.77d

close to the shoreline, possibly even in the surf zone. The distinction between the middle and outer shelf sand populations, however, is not as clear as in the nearshore zone since the hydraulic separation occurs closer to the gravel/sand cut-off, which is arbitrary for purely analytical reasons. Lateral mixing between these size and/or energy selected populations, which move independently and in different modes, can be observed. Additional size sorting and mixing can then take place downstream, since the mobile sand stream acts both as a conduit and as a temporary sink for bedload sediments (eg. dunes).

More specific mixing patterns have been identified by comparing and grouping size frequency curves. The cumulative curve groups were selected at 0,5 phi intervals in preference to the conventional 1,0 phi interval used to plot the size data. These are considered to be more sensitive, particularly to slight mixing between apparently distinct hydraulic populations. Clearly, such groupings automatically reveal both skewness and sorting in addition to size. Thus, when plotted and contoured, the group areas reflect both cross-shelf and downstream variations in the sediment In addition it highlights both the mobile sand stream which grades offshore into a coarse palimpsest gravel lag facies and the oblique cross-shelf bedload parting zone to the north of Hibberdene. Fine sand is intermittently found in the nearshore and along the shelf break. The local effect of fluvial supply to the shelf is clearly illustrated. Variations in the supply of terrigenous material to the shelf are discussed in section 3.3.

5.2 General Conclusions

Discussions and conclusions about the meaning of specific phenomena observed in the course of this investigation have been dealt with at the end of each shelf section presented in Chapter 4. The purpose of these general conclusions, therefore, is to assess the main objectives of the study and to provide some answers to the key questions posed in the introduction.

On the basis of the existing sample density the study has, on the whole, achieved a coherent and consistent description of sediment distribution on the continental shelf between Durban and Port St Johns. Locally, e.g. on the Illovu Spit/bar, a greater sample density could have led to a better resolution of the textural relationships between adjacent sand streams. There is no reason to believe, however, that a greater sample density would have resulted in a drastically different interpretaion of the major trends outlined in this study.

The results clearly corroborate the dynamic model proposed by Flemming (1978, 1980, 1981), which was based entirely on qualitative side-scan sonar data. On the other hand, it is equally clear that this study has enabled a considerable refinement of the model, particularly with respect to local detail. In addition, it has added a new dimension to the general bedload dispersal model by resolving its textural structure.

It has been demonstrated that grain size analysis of sediments can be successfully used for the elucidatin of dispersal patterns, especially if the various textural parameters are first resolved and then integrated in the course of the interpretation. This approach has facilitated the recognition of major sediment sources and their transport pathways. In conjunction with new and previously published geophysical data, such as echo soundings, side-scan sonar records and sub-bottom profiling, it has also been possible to identify `en route` depositional products (e.g. bedforms), major sediment sinks (e.g the Illovu and Mfihlelo Spit/bars) and/or sediment escape routes (e.g. the export of suspended material and sediment spill-over via submarine canyons and at the offset).

Sedimentary facies and subfacies have been identified using several lines of evidence. For example, it could be shown that it was possible to combine the purely descriptive compositional and textural classification schemes, based on triangular diagrams, with process-response models, based on CM-diagrams and cumulative curve groupings, to produce a dynamic classification of depositional environments and facies.

It has furthermore been demonstrated that, within limits, it should be possible to predict minimum and maximum current velocities, flow patterns and specific transport modes using threshold criteria in combination with textural data and CM-diagrams. With some additional information on related volume transport this approach could eventually lead to a quantification of sediment transport and depositional processes through time.

Finally, the results of this study should in themselves answer the daunting question posed by the provocative and challenging editorial of Robert Ehrlich which was quoted in the introduction.

Perhaps the title of an appropriate reply should read "Robert Ehrlich wears no clothes

or

Has his moment come and gone?"

6. REFERENCES

Allen,J.R. 1970. Physical processes of sedimentation. Unwin University Books, London: 248pp.

Bang,N.D. and Pearce,A.F. et al., 1978. Ecology of the Agulhas current region: An assessment of biological responses to environmental parameters in the South-West Indian Ocean. (ed. Heydorn,A.E.F.). Trans. Roy. Soc. S. Afr., 43(2): 151-191.

Birch,G.F. 1979-1980. The bathymetry and geomorphology of the continental shelf and upper slope between Durban and Port St Johns. Tech. Rep. No.12. Mar. Geosc. Unit Jt. GSO/UCT.

Birch,G.F. 1981. The bathymetry and geomorphology of the continental shelf and upper slope between Durban and Port St Johns. Ann. geol. Surv. S. Afr., 15(1): 53-62.

Birch,G.F. (In press). Sedimentological and geophysical investigations of a major sediment exit point on the southeast African continental margin (vicinity of Port St Johns). Geol Surv. S. Afr. Bul.

Birch,G.F. (In press). Geophysical and sedimentological investigation between Cape Vidal and Cape Padrone (east coast of southern Africa).

Blatt,H., Middleton,G. and Murray,R. 1978. Origin of sedimentary rocks. Prentice-Hall, New York. 634pp.

Carter,L. and Schafer,C.T. 1983. Interaction of the western boundary undercurrent with the continental margin off Newfoundland. Sedimentology 30:

Creager,J.S. and Sternberg,R.W. 1972. Some specific problems in understanding bottom sediment distribution and dispersal on the continental shelf. In: Swift, Duane, Pilkey (eds.). Shelf Sediment Transport. Dowden, Hutchinson and Ross, Inc. Stroudsberg, Pennsylvania. 656pp.

Darbyshire,J. 1964. A hydrological investigation of the Agulhas current area. Deep-Sea Research 11: 781-815.

Darbyshire,J. 1972. The effect of bottom topography on the Agulhas current. Rev. Pure and Applied Geophysics 101: 208-220.

Davies,J.L. 1972. Geographical variation in coastal development. Oliver and Boyd, Edinburgh. 204pp.

Dingle,R.V. 1979. Sedimentary basins and basement structures on the continental margin of southern Africa: a review. Geol. surv. Bull., 63: 29-45.

Duncan,C.P. 1970. The Agulhas current. Thesis, Univ. Hawaii, Honolulu (unpubl.).

Ferentinos,A. and Collins,M. 1980. Effects of shoreline irregularities on a rectilinear tidal current and their significance in sedimentation processes. J. Sed. Petr. 50(4): 1081-1094.

Flemming,B.W. 1977. Depositional processes in Saldanha Bay and Langebaan Lagoon. Prof. Res. Series No.2. N.R.I.O. (CSIR).

Flemming,B.W. 1978. Underwater sand dunes along the southeast African continental margin - observations and implications. Mar. Geol. 26: 177-198.

Flemming,B.W. 1980. Sand transport and bedform patterns on the continental shelf between Durban and Port Elizabeth (Southeast African continental margin). Sed. Geol. 26: 179-205.

Flemming,B.W. 1981. Factors controlling shelf sediment dispersal along the southeast African continental margin. Mar. Geol. 42: 259-277.

Flemming,B.W. and Hay,E.R. 1983. On the bulk density of South African marine sands. Joint GSO/UCT Mar. Geosc. Tech. Rept. No.14: 171-177.

Folk,R.L. 1966. A review of grain-size parameters. Sedimentology 6: 73-93.

Folk,R.L. 1968. Petrology of sedimentary rocks. Humphills,Austin. 170pp.

Folk,R.L. and Ward,W.C. 1957. Brazos River bar: A study in the significance of grain size parameters. J. Sed. Petro. 27: 3-26.

Fortuin,H. 1983. The running of a Univac computer program for processing size data from the Marine Geoscience settling tube. Jt Geol. Surv./UCT Tech. Rept.No.14: 240-244.

Gill,A.T. and Schumann,E.H. 1979. Topographically induced changes in the structure of an inertial coastal jet: Application to the Agulhas current. Int. Phys. Oceanog. 9(5): 975-991.

Graf,W.H. and Acaroglou,E.R. 1966. Settling velocities of natural grains. Bull. Int. Ass. Sci. Hydrol., 11: 27-43.

Grundlingh,M.L. 1977. Drift observations from Nimbus VI satellite-tracked buoys in the Southwestern Indian Ocean. Deep-Sea Res. 24: 903-913.

Grundlingh,M.L. 1978. Drift of a satellite-tracked buoy in the southern Agulhas current and Agulhas return current. Deep-Sea Res. 25: 1209-1224.

Grundlingh,M.L. and Lutjeharms,J.R.E. 1979. Large-scale flow patterns of the Agulhas current system. S. Afr. Jnl. Sci. 75: 269-270.

Harris,T.F.W. 1978. Review of coastal currents in southern African waters. S. Afr. Nat. Sci. Prog. Rep. No.30. August.

Harris,T.F.W., Legeckis,R. and Van Foreest,D. 1978. Satellite infra-red images in the Agulhas current system. Deep-Sea Res. 25: 543-548.

Harris,T.F.W. and Van Foreest,D. 1978. The Agulhas current in March 1969. Deep-Sea Res. 25: 549-561.

Inman,D.L. 1949. Sorting of sediments in the light of fluid mechanics. J. Sed. Petr. 19: 51-70.

Jackson,S.P. and Tyson,P.D. 1971. Aspects of weather and climate over southern Africa. The Standard Encyclopaedia of Southern Africa 3: 258-269. Nason Ltd. Cape Town.

Komar,P.D. 1976. The transport of cohesionless sediments on continental shelves. In: Stanley,D.J. and Swift,D.J.P. (eds). Marine sediment transport and environmental management. Wiley-Interscience, New York. 602pp.

Komar,P.D. and Miller,M.C. 1973. The threshold of sediment movement under oscillatory water waves. J. Sed. Petr. 43: 1101-1110.

Koopman,B.J., Lees,A., Piessons,P. and Sarnthein,M. 1979. Skeletal carbonate sands and wind-derived silty marls off the Saharan coast: Baie du leurier, Arguin Platform, Mauritania. "Meteor" Forsch-Ergebnisse 3(39): 15-57.

Krumbein,W.C. 1934. The probable error of sampling for mechanical analysis. Ann. J. Sci. 27: 204-214.

Loring,D.H. and Nota,D.J.G. 1973. Morphology and sediments of the Gulf of St Lawrence. Bull. Fish. Res. Board Canada. No.182.

Lundie,G.S.H. 1977. An analysis of fluctuations in atmospheric pressure and wind over areas of Natal, Transkei and Southeast Cape. NRIO (S.Afr.) Int. Rep. SCAIR 7907: 69p.

Mallory,J.K. 1977. Abnormal waves on the south-east coast of South Africa. Inst. Oceangr. Univ. Cape Town, Occas. Rep. 77/1 18p.

Martin,A.K., Hartnady,C.J.H. and Goodlad,S.W. 1981. A revised fit of South America and South Central Africa. Earth & Plan, Sci. Lett. 54: 293-305.

McCave,I.N. 1972. Transport and escape of fine-grained sediment from shelf areas. In: Swift, Duane, Pilkey (eds). Shelf sediment transport. Dowden, Hutchinson & Ross, Inc. Stroudsberg, Pennsylvania. 656pp.

Meade,R H. 1972. Sources and sinks of suspended matter on continental shelves. In: Swift, Duane, Pilkey (eds). Shelf sediment transport. Dowden, Hutchinson & Ross, Inc. Stroudsberg, Pennsylvania. 656pp.

Menard,H.W. 1950. Sediment movement in relation to current velocity. J. Sed. Petr. 20: 148-160.

Milliman,S.D. and Emery,K.O. 1968. Sea-levels during the last 35000 years. Science 162: 1121-1123.

Moir,G.J. 1976. Preliminary textural and compositional analyses of surficial sediments from the upper continental margin between Cape Recife (34°S) and Ponto do Ouro (27°S), South Africa. Jt. GSO/UCT Mar. Geol. Prog. Tech. Rep. 8. 68-75.

Nair,R.R., Hashimi,N.H. and Purnachandra,Ras,V. 1982. On the possibility of high velocity tidal streams as dynamic barriers to longshore sediment transport: evidence from the continental shelf at the Gulf of Kutch, India. Mar. Geol. 47: 77-86.

Nota,D.J.G. 1958. Sediments of the Western Guiana Shelf. Doctoral thesis, Univ. of Utrecht.

Page,H.G. 1955. Phi-millimetre conversion table. J. Sed. Petr. 25: 258-292.

Passega,R. 1957. Texture as characteristic of clastic deposits. AAPG Bull. 41: 1952-1984.

Passega,R. 1964. Grain size presentation by CM patterns as a geological tool. J. Sed. Petr. 34: 830-847.

Passega,R. 1977. Significance of CM diagrams of sediments deposited by suspension. Sedimentology 24: 723-733.

Passega,R. and Byramjee,R. 1969. Grain-size image of clasic deposits. Sedimentology 13: 233-252.

Passega,R., Rizzini,A. and Berghetti,G. 1967. Transport of sediment by waves, Adriatic coastal shelf, Italy. AAPG Bull. 51: 1304-1319.

Pearce,A.F. 1977. The shelf circulation off the east coast of South Africa. Proff. Res. Series No.1 NRIO, S. Af.

Pearce,A.F., Schumann,E.H. and Lundie,G.S.H. 1978. Features of the shelf circulation off the Natal coast. S. Afr. Jnl. Sci. 74: 328-331.

Pettijohn,F.J. 1957. Sedimentary rocks. Harper and Row, New York. 718pp.

Pierce,J.W. 1976. Suspended sediment transport at the shelf break and over the outer margin. In: Stanley,D.J. and Swift,D.J.P. (eds). Marine sediment transport and environmenral management. Wiley-Interscience, Yew York. 602pp.

Pilkey,O.H. and Field,M.E. 1972. Onshore transportation of continental shelf sediment: Atlantic Southeastern United States. In: Swift, Duane, Piley (eds). Shelf sediment transport. Dowden, Hutchinson and Ross, Inc. Stroudsberg, Pennsylvania: 656pp.

Potter,P.E. 1959. Facies model Conference. Science 129: 1292-1394.

Reiche,P. 1950. A survey of weathering processes and products. Univ. New Mexico Publ. Geol. 3: 1-95.

Reinecke,H.-E. and Singh,I.B. 1973. Depositional Sedimentary Environments. Springer-Verlag, Berlin. 439pp.

Schubel,J.R. and Okubo,A. 1972. Comments on the Dispersal of suspended sediment across the continental shelves. In: Swift, Duane, Pilkey (eds). Shelf sediment transport. Dowden, Hutchinson and Ross, Inc. Stroudsberg, Pennsylvania. 656pp.

Schulze,B.R. 1965. Climate of South Africa, Part 8. General Survey, Weather Bureau 28, Govt. Printer and Weather Bureau, Pretoria. 330pp.

Schumann,G. 1979. Agulhas current structure and subtidal fluctuations off Natal. Ph.D. Thesis, Dept. of Phys., Univ. Natal.

Schumann,E.H. and Malan,O.G. 1979. Natal shelf circulation revealed by landsat imagery. S. A. J. Sci. 75: 136-137.

Scrutton,R.A. 1973. Structure and evolution of the sea floor south of South Africa. Earth Planet. Sci. Lett., 19: 250-256

Seibold,E. 1963. Geological investigation of nearshore sand transport. In: Scars,M. (ed). Progress in Oceanography 1: 1-70.

Shepard,F.P. 1954. Nomenclature based on sand-silt-clay ratios. J. Sed. Petr. 24: 151-158.

Shields,A. 1936. Anwending der Ahnlich keitsmechanik und der Turbulenz forschung auf die geschiebebewegung: Mitterlangen der Preuss. Versuch anst. P. Wasserban u. Schiffban. Berlin 26: 1-26.

Siesser,W.G. and Rogers,J. 1970. An investigation of the suitability of four methods in routine carbonate analysis of marine sediments. Deep-Sea Res. 18: 135-139.

Smith,A.G. 1982. Late Cenozoic uplift of stable continents in a reference frame fixed to South America. Nature 296(April):

Smith,A.J. 1961. Meteorological aspects, especially surface winds and associated weather along the Natal coast. Marine studies off the Natal Coast. CSIR Symp. 52: 10-17 (Durban, 16 March)

Southard,J.B. 1975. Bed configurations. In: Harris et al (eds.). Depositinal environments as interpreted from primary sedimentary structures and stratification sequences. SEPM, Short Course Lecture Notes 2: 5-43.

Southard,J.B. and Stanley,D.J.P. 1976. Shelf break processes and sedimentation. In: Stanley,D.J. and Swift,D.J.P. (eds). Marine sediment transport and environmental management. Wiley-Interscience, New York 602pp.

Spencer,D.W. 1963. The interpretation of grain size distribution curves of clastic sediments. J. Sed. Petr. 334: 180-190.

Stavropoulis,C.C. and Duncan,C.P. 1974. A satellite tracked buoy in the Agulhas current. J. Geophys. Res. 79: 2744-2746.

Sternberg,R.W. 1972. Predicting initial motion and bedload transport of sediment particles in shallow marine environment. In: Swift, Duane, Pilkey (eds). Shelf sediment transport. Dowden, Hutchinson and Ross, Inc. Stroudsberg, Pennsylvania 656pp.

Swift,D.J.P. 1970. Quaternary shelves and the return to grade. Mar. Geol. 8: 5-30.

Swift,D.J.P. 1972. Implications of sediment dispersal from bottom current measurements; some specific problems in understanding bottom sediment distribution and dispersal on the continental shelf - a discussion of two papers. In: Swift, duane, Pilkey (eds). Shelf sediment transport. Dowden, Hutchinson and Ross, Inc. Stroudsberg, Pennsylvania. 656pp.

Swift,D.J.P. 1976. Coastal sedimentation. In: Stanley,D.J. and Swift,D.J.P. (eds). Marine sediment transport and environmental management. Wiley-Interscience, New York. 602pp.

Swift,D.J.P. 1976. Continental shelf sedimentation. In: Stanley,P.J. and Swift,D.J.P. (eds). Marine sediment transport and environmental management. Wiley-Interscience, New York. 602pp.

Swift,D.J.P. and Ludwick,J.C. 1976. Substrate response to hydraulic process: grain-size frequency distribution and bedforms. In: Stanley,P.J. and Swift,D.J.P. (eds). Marine sediment transport and environmental management. Wiley-Interscience, New York. 602pp.

Swift,D.J.P., Ludwick,J.C. and Boehmer,R.W. 1972. Shelf sediment transport: a probability model. In: Swift, Duane, Pilkey (eds). Shelf sediment tranport. Dowden, Hutchinson and Ross, Inc. Stroudsberg, Pennsylvania. 656pp.

Swift,D.J.P., Stanley,D.J. and Curray,J.R. 1971. Relict sediments on continental shelves: a reconsideration. J. Geol. 79: 322-346.

Teleki,P.G. 1972. Wave boundary layers and their relation to sediment transport. In: Swift, Duane, Pilkey (eds). Shelf sediment transport. Dowden, Hutchinson and Ross, Inc. Stroudsberg, Pennsylvania. 656pp.

Tankard,A.J., Jackson,M.P.A., Eriksson,K.A., Hobday,D.K., Hunter,D.R. and Minter,W.E.L. 1982. Crustal evolution of Southern Africa: 3.8 Billion years of Earth History. Springer-Verlag. N.Y., Heidelberg, Berlin. 523pp.

Thompson,B.R. 1936. Moisture and farming in South Africa. S. Afr. Agric. Ser. 266p.

Truswell,J.F. 1970. An introduction to the historical geology of South Africa. Purnell, Cape Town, S.A. 167pp.

Tyson,P.D. 1969. Atmospheric cirulation and precipitation over South Africa. Occ. Pap. Dept. Geogr. Univ. Witwatersrand 2: 1-22.

Tyson, P.D. and Dyer, T.G.J. 1975. Mean annual fluctuations of precipitation in the summer rainfall region of South Africa. S. Afr. Geogr. J. 57(2): 105.

Tyson, P.D. 1980. Temporal and spatial variation of rainfall anomalies in Africa south of latitude 22^{o} during the period of meteorological record. Climatic Change 2(4): 363pp.

Van Andel, Tj.H. and Veevers, J.J. 1967. Morphology and sediments of the Timor Sea. Dept. of Nat. Development, Bureau of Mineral Resources, Geology and Geophysics, Bull. 63: 173pp.

Wilson, J.B. 1982. Shelly fauna associated with temperate offshore tidal deposits. In. A.H.Stride (ed.). Offshore tidal sands. Chapman and Hall: 126-171.

7. APPENDIX 1

7.1.1 Sample localities (Cruise 80-19)

STATION NO.	WATER DEPTH (m)	GEOGRAPHIC COORDINATES Latitude deg.	min.	Longitude deg.	min.
19 - 01	15	31	37,0	29	24,9
- 02	23		37,0		35,4
- 03	36		37,3		36,2
- 04	48		37,3		36,8
- 05	72		37,5		37,8
- 06	91		37,6		38,6
- 07	66		36,5		38,7
- 08	46		35,3		38,8
- 09	22		34,0		38,8
- 10	48		34,3		40,5
- 11	84		34,8		42,0
- 12	98		35,1		43,5
- 13	60		32,8		43,2
- 14	48		30,9		42,8
- 15	48		30,1		43,9
- 16	70		28,7		45,7
- 17	86		31,5		47,2
- 18	54		30,3		47,2
- 19	38		31,8		46,0
- 20	46		28,4		47,2
- 21	65		28,8		48,7
- 22	95		29,7		50,0
- 23	82		29,1		49,6
- 24	60		28,5		49,1
- 25	46		27,9		49,0
- 26	36		27,4		48,5
- 27	32		27,0		48,4
- 28	18		26,5		48,2
- 29	15		26,9		46,7
- 30	18		27,3		45,8
- 31	17		26,3		49,4
- 32	18		26,1		50,3
- 33	20		25,5		51,6
- 34	17		24,9		52,2
- 35	17		24,2		53,3
- 36	17		22,2		5,7
- 37	16		21,0		57,1
- 38	21		20,4		58,2
- 39	18		19,7		58,6
- 40	22		19,2		59,4
- 41	72		21,7	30	0,3
- 42	102		23,4		1,0
- 43	84		23,0	29	59,2
- 44	50		23,0		57,3
- 45	91		25,9		57,2
- 46	86		25,8		56,0
- 47	74		25,9		53,7
- 48	88		27,0		52,6
- 49	88		27,9		53,9
- 50	92		28,8		54,6
- 51	94		29,2		52,9
- 52	96		30,7		52,2

STATION NO.	WATER DEPTH (m)	GEOGRAPHIC COORDINATES Latitude deg.	min.	Longitude deg.	min.
- 53	96		31,2		51,0
- 54	94		29,6		51,8
- 55	93		28,6		50,6
- 56	60		27,7		50,4
- 57	36		27,3		49,5
- 58	30		27,0		49,2
- 59	25		26,7		49,8
- 60	36		27,1		50,2
- 61	48		26,3		51,9
- 62	47		24,9		53,7
- 63	47		23,7		55,4
- 64	41		21,6		58,1
- 65	43		17,7	30	1,2
- 66	21		17,0		1,7
- 67	30		16,5		3,4
- 68	18		15,2		3,6
- 69	18		14,3		5,0
- 70	20		13,0		5,9
- 71	46		12,1		8,5
- 72	64		13,5		8,7
- 73	84		15,3		8,8
- 74	68		15,8		6,5
- 75	18		9,6		8,8
- 76	17		7,7		10,4
- 77	44		8,0		12,3
- 78	17		6,4		11,6
- 79	37		6,6		12,9
- 80	17		5,4		12,2
- 81	19		4,6		13,2
- 82	38		4,4		15,4
- 83	22		2,4		14,8
- 84	40		2,1		17,0
- 85	18		0,2		16,8
- 86	38		0,6		18,3
- 87	32	30	59,4		18,8
- 88	18		58,6		18,1
- 89	54	31	19,8		1,1
- 90	84		20,0		3,2
- 91	50		17,8		3,5
- 92	46		16,1		4,5
- 93	40		14,0		6,9
- 94	27		12,7		6,8
- 95	33		9,1		10,3
- 96	27		6,8		12,1
- 97	44		6,0		14,5
- 98	32		4,4		14,5
- 99	30		2,4		15,9
-100	44		0,2		19,7
-101	58		1,0		20,7
-102	76		1,8		21,5
-103	46		1,6		19,2
-104	70		2,4		19,9
-105	56		2,7		18,7
-106	66		3,6		18,7
-107	86		4,6		18,5
-108	60		4,1		18,5

STATION NO.		WATER DEPTH (m)	GEOGRAPHIC COORDINATES Latitude deg.	min.	Longitude deg. min.
-109		50		3,7	17,2
-110		52		4,4	17,0
-111		70		5,2	16,9
-112		87		6,0	17,6
-113		70		5,8	16,8
-114		48		6,0	15,8
-115	A	52		5,6	15,2
	B	50			
-116	A	66		6,8	15,6
	B				
-117		54		7,2	14,4
-118		75		7,9	15,6
-119		65		8,4	14,4
-120	1.	51		8,2	13,6
	2.	52			
-121		64		8,9	13,7
-122		92		10,6	13,8
-123		56		9,3	12,4
-124		65		10,1	12,6
-125		52		10,4	11,1
-126		74		11.5	11.9
-127		64		11,8	10,6
-128		40		10,7	9,7
-129		54		12,1	9,4
-130		68		13,2	10,8
-131		66		17,7	4,7
-132		90		19,3	5.4
-133		26	30	44,8	27,2
-134		38		45,5	28,8
-135		48		46,6	30,0
-136		52		47,8	30,2
-137		56		48,7	31,3
-138		88		49,7	32,3
-139		60		50,6	30,7
-140	A	42		51,1	29,4
-140	B				
-141	A	54		50,4	28,4
-141	B				
-142		44		50,3	26,2
-143		34		51,0	24,9
-144		46		52,2	25,9
-145		83		54,9	27,6
-147		55		54,7	26,1
-148		44		54,4	24,5
-149		39		54.3	22.9
-150		17/15		53,3	21,8
-151		19		54,0	21,1
-152		32		54,9	21,7
-153		44		56,2	22,3
-154		66		58,4	23,5
-155		100	31	1,0	23,2
-156		58	30	59,1	22,0
-157		50		59,0	20,6
-158		40		44,7	28,6
-159		48		44,7	30,8
-160		50		44,7	32,0

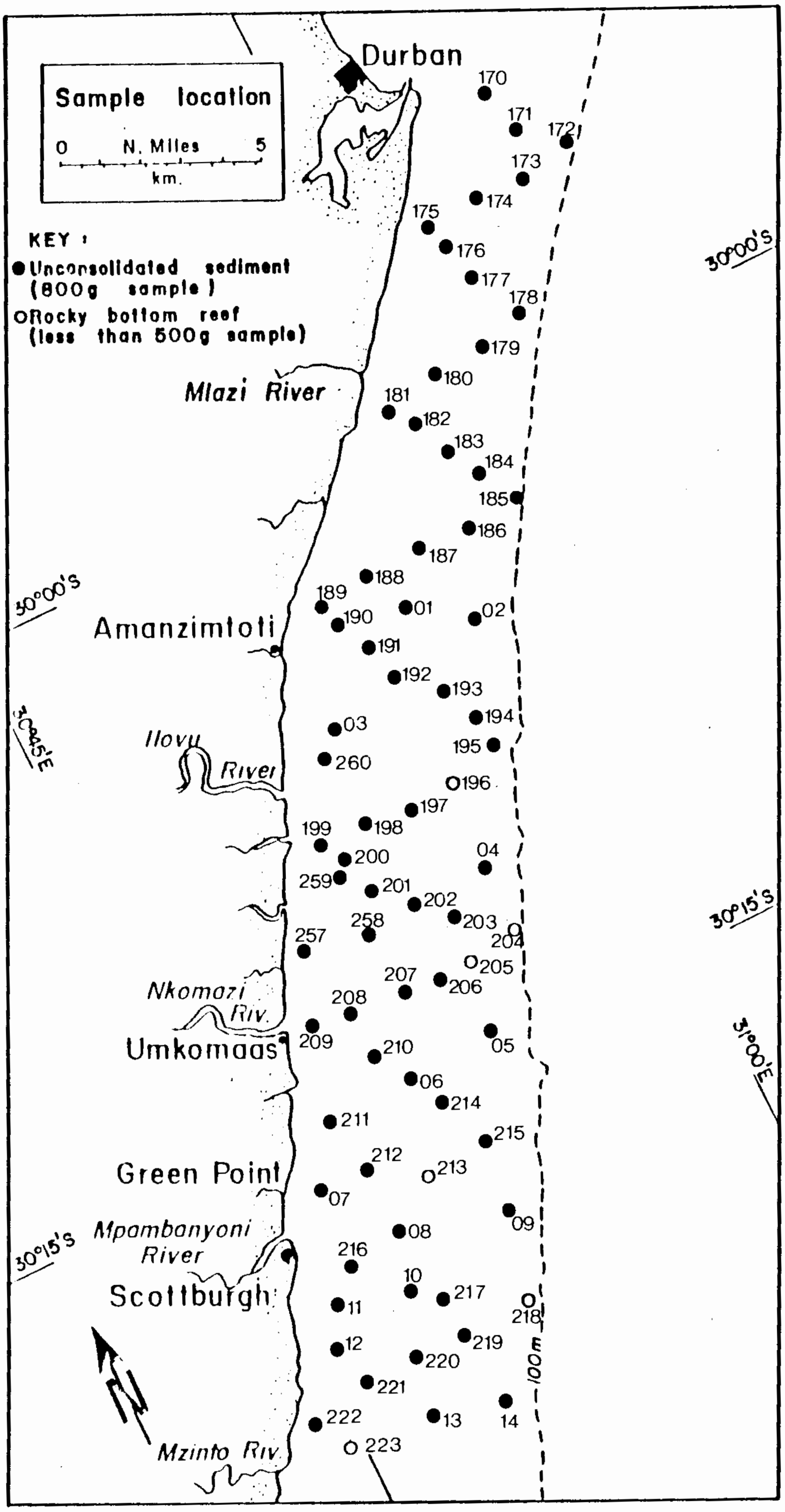
STATION NO.	WATER DEPTH (m)	GEOGRAPHIC COORDINATES Latitude deg. min.		Longitude deg. min.
-216	23		18,2	46,9
-217	66		20,0	48,8
-218	84		21,0	51,1
-219	80		21,1	48,8
-220	48		21,1	47,4
-221	30		21,0	45,8
-222	20		21,5	43,9
-223	30		22,3	44,5
-224	40		23,2	45,0
-225	66		24,4	45,7
-226	86		25,8	46,7
-227	77		27,5	47,4
-228	79		27,8	45,0
-229	65		27,8	42,7
-230	45		27,9	41,3
-231	23		27,6	39,9
-232	40		28,6	40,3
-233	54		29,7	40,8
-234	65		30,6	41,6
-235	76		31,4	42,2
-236	82		32,3	43,0
-237	80		33,2	43,8
-238	80		33,4	42,0
-239	72		33,6	40,2
-240	52		33,9	38,5
-241	44		33,7	37,3
-242	26		33,7	36,2
-243	16		33,7	35,6
-244	37		34,6	36,1
-245	47		35,2	36,9
-246	50		36,3	37,6
-247	67		37,0	38,2
-248	74		38,3	39,6
-249	66		38,6	37,8
-250	57		38,2	36,5
-251	28	31	2,6	15,6
-252	35		3,0	16,4
-253	18	30	36,7	33,7
-254	37		37,6	34,2
-255	48		37,5	35,1
-256	52		37,6	36,0
-257	16		10,7	49,6
-258	22		10,9	51,5
-259	20		9,3	51,5
-260	36		6,4	52,7

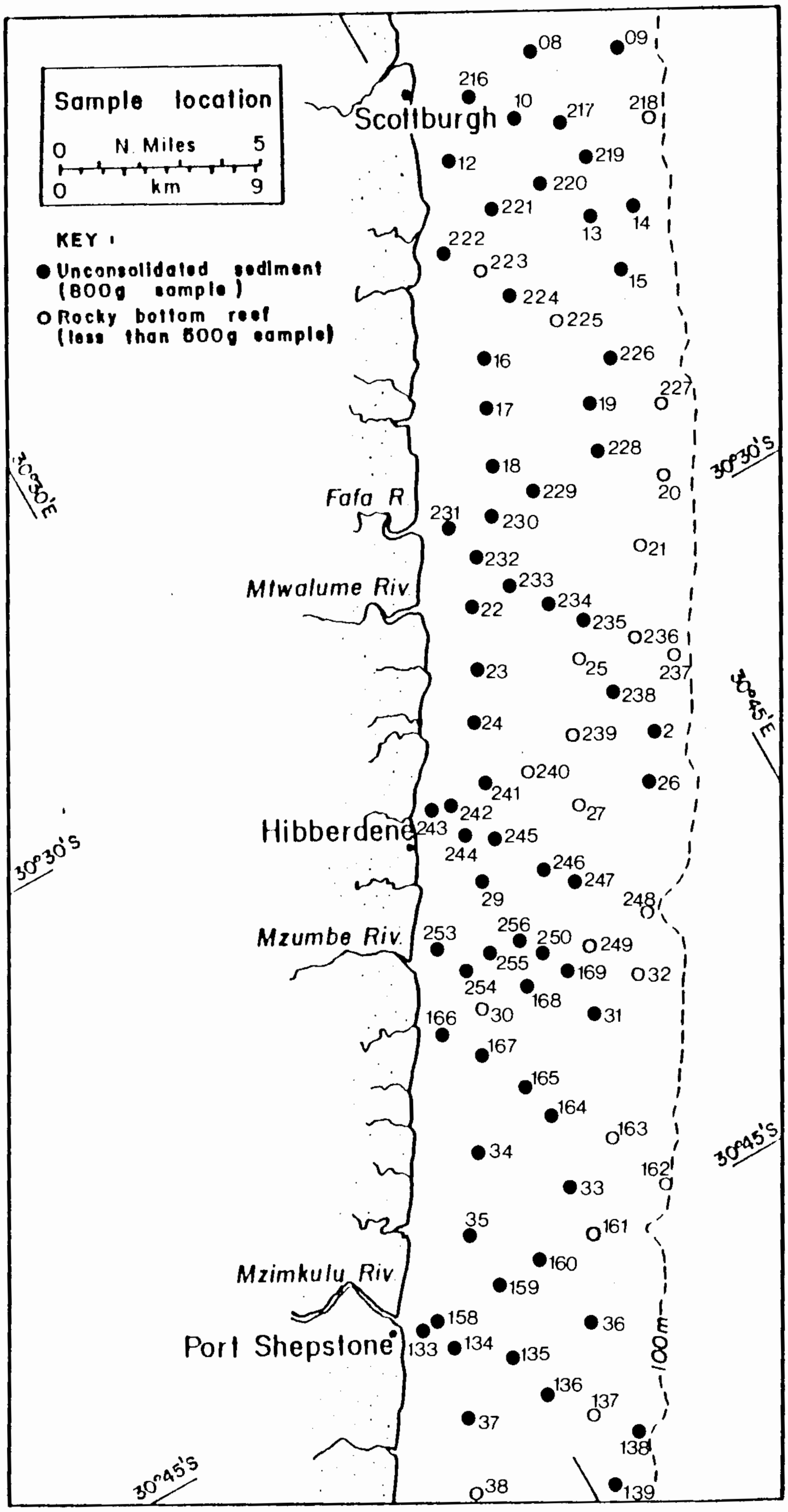
7.1.2 Sample localities (Cruise 83-10)

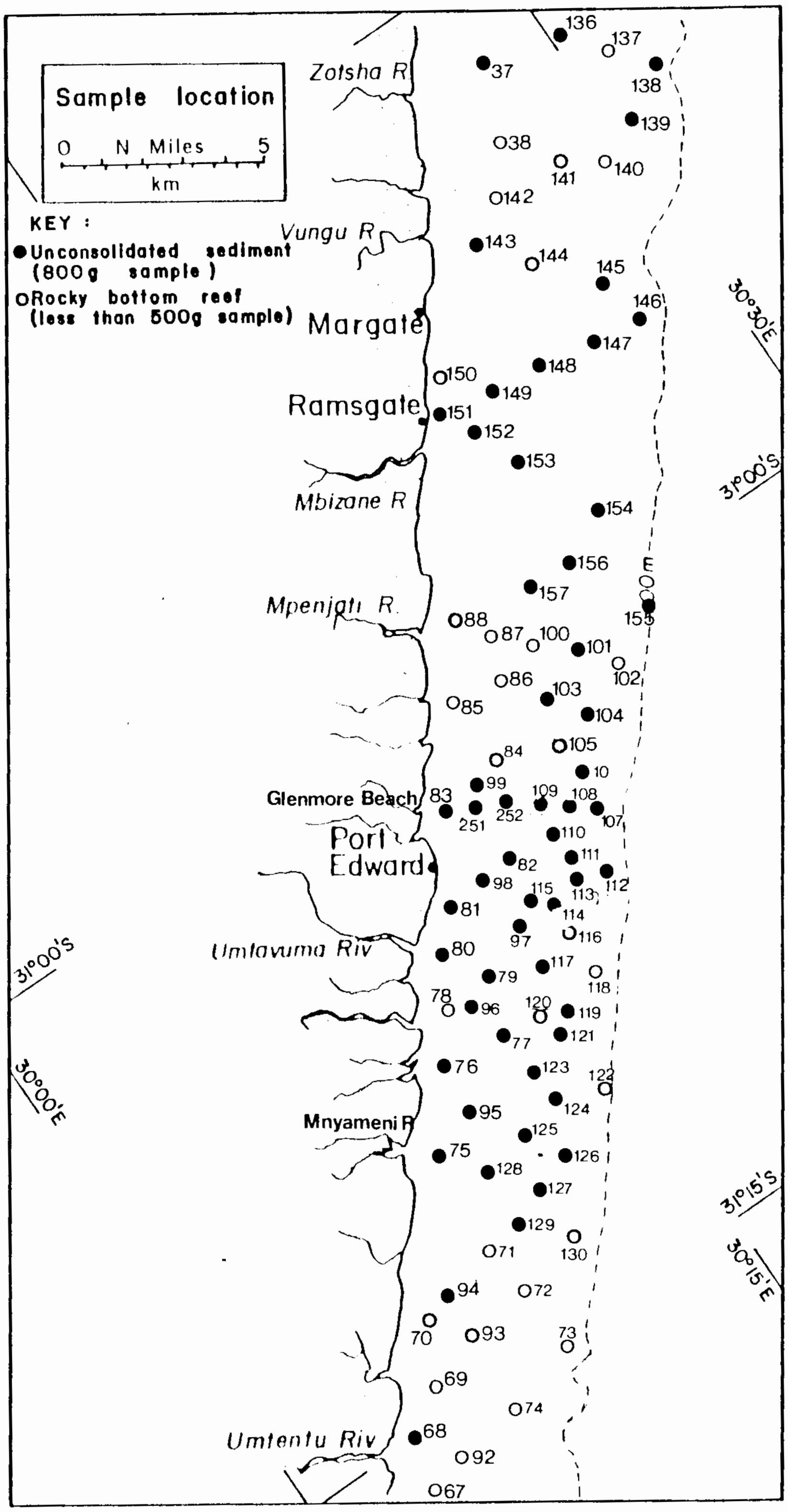
STATION NO.	WATER DEPTH (m)	GEOGRAPHIC COORDINATES Latitude deg. min.	GEOGRAPHIC COORDINATES Longitude deg. min.
10 - 01	46	30 03,8	30 56,5
- 02	18	05,3	58,7
- 03	45	06,1	53,9
- 04	65	10,5	55,7
- 05	70	14,6	53,1
- 06	32	14,8	50,5
- 07	23	16,1	46,9
- 08	30	17,6	48,4
- 09	82	19,0	51,2
- 10	35	19,2	48,1
- 11	25	19,0	46,3
- 12	24	20,3	46,3
- 13	58	22,4	46,8
- 14	55	23,4	47,9
- 15	83	24,7	47,3
- 16	27	23,1	43,3
- 17	27	25,2	41,9
- 18	33	26,9	41,1
- 19	79	26,6	45,3
- 20	85	29,0	45,8
- 21	77	30,25	42,9
- 22	30	29,4	39,4
- 23	38	30,0	38,9
- 24	38	32,6	37,8
- 25	67	31,8	41,0
- 26	75	35,0	41,8
- 27	75	35,4	39,8
- 28	58	34,8	37,9
- 29	38	35,8	35,6
- 30	48	38,8	39,3
- 31	53	40,4	36,1
- 32	75	40,9	38,7
- 33	52	43,3	33,4
- 34	44	41,4	32,2
- 35	45	43.4	30,6
- 36	57	46,9	31,8
- 37	37	46,4	28,1
- 38	43	48,1	27,7

7.1.3 Sample localities (Cruise 79-24)

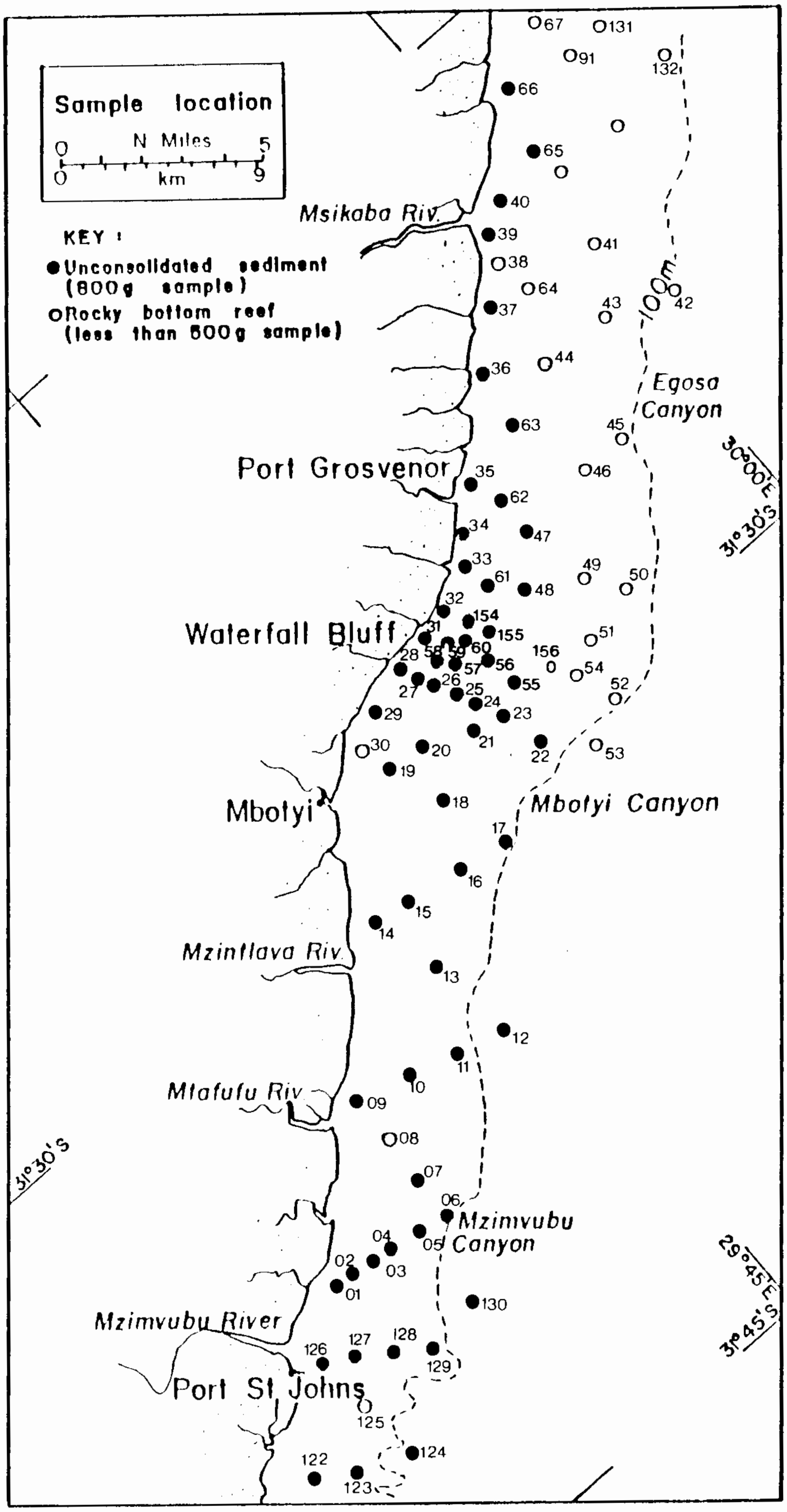
STATION NO.	WATER DEPTH (m)	GEOGRAPHIC COORDINATES Latitude deg.	min.	Longitude deg.	min.
122	31	31	40,2	29	31,35
123	74		40,85		32,5
124	99		41,4		34,15
125	44		39,4		33,85
126	9		38,15		33,8
127	34		38,5		34,6
128	71		39,1		35,6
129	95		39,7		36,7
130	112		39,4		38,4
154	41	32	26,8	29	50,8
155	83		27,7		51,4
156	95		28,55		51,8


Sample location
0 N. Miles 5
km.
KEY :
● Unconsolidated sediment (800g sample)
O Rocky bottom reef (less than 500g sample)
Durban
Mlazi River
Amanzimtoti
Ilovu River
Nkomazi Riv.
Umkomaas
Green Point
Mpambanyoni River
Scottburgh
Mzinto Riv.
30°00'S
30°15'S
30°45'E
31°00'E
100 m
170
171
172
173
174
175
176
177
178
179
180
181
182
183
184
185
186
187
188
189
190
01
02
191
192
193
194
03
195
260
196
197
198
199
200
04
259
201
202
203
258
204
257
205
207
206
208
209
210
05
06
214
211
215
212
213
07
09
08
216
10
217
11
218
12
219
220
221
222
13
14
223


Sample location
0 N. Miles 5
0 km 9
KEY :
● Unconsolidated sediment (800g sample)
O Rocky bottom reef (less than 800g sample)
Scottburgh
Fafa R
Mtwalume Riv.
Hibberdene
Mzumbe Riv.
Mzimkulu Riv.
Port Shepstone
100m
30°30'E
30°45'E
30°30'S
30°45'S
08 09 216 10 217 218 12 219 220 221 13 14 222 223 15 224 225 16 226 17 19 227 228 18 20 229 231 230 21 232 233 22 234 235 236 237 23 25 238 24 239 2 240 26 241 242 27 243 245 244 246 247 29 248 253 256 250 249 255 169 32 254 168 30 31 166 167 165 164 163 34 162 33 35 161 160 159 158 36 133 134 135 136 137 37 138 38 139



Sample location
0 N Miles 5
km
KEY :
● Unconsolidated sediment (800g sample)
O Rocky bottom reef (less than 500g sample)
Zotsha R
Vungu R
Margate
Ramsgate
Mbizane R
Mpenjati R.
Glenmore Beach
Port Edward
Umtavuma Riv
Mnyameni R
Umtentu Riv
30°30'E
31°00'S
30°00'E
31°15'S
30°15'E



Sample location
N Miles
0 5
0 km 9
KEY :
● Unconsolidated sediment (600g sample)
○ Rocky bottom reef (less than 600g sample)
Msikaba Riv.
Port Grosvenor
Waterfall Bluff
Mbotyi
Mzintlava Riv.
Mtafufu Riv.
Mzimvubu River
Port St Johns
Egosa Canyon
Mbotyi Canyon
Mzimvubu Canyon
100m
30°00'E
31°30'S
29°45'E
31°45'S

STATION NO.	WATER DEPTH (m)	GEOGRAPHIC COORDINATES Latitude deg.	min.	Longitude deg.	min.
-161	60		44,8		33,8
-162	80		44,5		36,1
-163	59		42,8		35,5
-164	58		41,8		34,5
-165	58		40,8		34,2
-166	29		38,7		32,8
-167	43		39,8		33,5
-168	58		38,7		35,5
-169	62 (1)				
	63 (2)				
-170	50	31	53,1	31	5,5
-171	71		54,4		5,9
-172	90		55,2		6,9
-173	75		55,5		5,4
-174	55		55,4		3,9
-175	24		55,5		2,2
-176	29		56,2		2.5
-177	62		57,2		2,7
-178	84		58,5		3,6
-179	63		58,8		2,2
-180	52		58,9		0,7
-181	28		59,2	30	58,9
-182	44		59,7		59,4
-183	55	30	0,9		59,9
-184	74		1,7	31	0,6
-185	94		2,6		1,1
-186	72		2,8	30	59,6
-187	46		2,7		57,9
-188	42		2,7		56,1
-189	26		2,9		54,5
-190	38		3,5		54,8
-191	45		4,4		55,3
-192	47		5,4		55,6
-193	58		6,3		56,6
-194	68		7,3		57,1
-195	76-80		8,0		57,3
-196	56		8,5		55,7
-197	50		8,6		54,3
-198	44		8,4		52,9
-199	17		8,4		51,4
-200	15		9,0		51,9
-201	20		10,0		52,2
-202	52		10,8		53,1
-203	57		11,5		54,0
-204	88		12,6		55,3
-205	67		12,8		53,8
-206	50		12,8		52,7
-207	30		12,6		51,8
-208	23		12,4		50,0
-209	16		12,3		48,9
-210	36		13,7		50,1
-211	18		14,7		48,2
-212	23		16,2		48,5
-213	42		17,0		50,0
-214	52		15,6		51,3
-215	80		16,9		51,8

7.2.1 Statistical summary of the total sandsized sediment

CRUISE 81 - 19

Sample No.	Mean	QD	QH	Skew	Kurt	1%	50%	99%
19 - 01	3.00	0.46	2.21	0.22	1.09	1.99	2.93	4.21
02	3.03	0.36	1.68	0.25	1.09	2.27	2.98	4.09
03	3.25	0.38	1.53	0.22	1.04	2.30	3.19	4.23
04	3.10	0.33	1.49	0.30	1.05	2.52	3.04	4.06
05	3.32	0.41	1.55	0.24	0.95	2.37	3.25	4.27
06	3.34	0.45	1.69	0.13	0.82	2.44	3.30	4.27
07	3.12	0.30	1.30	0.17	1.04	2.20	3.09	3.87
08	2.65	0.44	2.42	-0.14	2.30	0.22	2.63	3.72
09	3.11	0.47	2.09	0.16	1.00	2.12	3.06	4.19
10	2.55	1.09	6.09	-0.51	0.83	0.25	2.99	4.03
19 - 11	3.43	0.48	1.68	0.00	0.92	2.15	3.43	4.43
12	2.98	0.77	3.68	-0.12	1.25	0.90	2.99	4.28
13	3.40	0.59	2.10	-0.10	1.08	0.64	3.39	4.37
14	2.42	0.38	2.12	-0.10	1.45	1.25	2.44	3.56
15	3.05	0.58	2.68	-0.09	1.04	1.16	3.05	3.96
16	3.47	0.65	2.16	-0.08	1.06	1.12	3.45	4.54
17	3.18	0.41	1.72	0.13	1.02	1.85	3.14	4.14
18	3.13	0.70	3.07	-0.31	1.62	0.65	3.18	4.17
19	0.73	0.47	1.00	0.17	1.14	-0.17	0.71	2.44
20	3.57	0.55	1.69	-0.08	1.03	1.47	3.57	4.53
19 - 21	2.57	0.78	4.37	0.08	1.21	0.80	2.51	4.22
22	1.57	0.87	3.11	0.14	1.11	-0.12	1.51	3.70
23	3.35	0.64	2.36	-0.21	1.64	0.17	3.35	4.36
24	3.22	0.69	2.83	-0.09	1.23	1.00	3.20	4.50
25	3.05	0.57	2.61	0.15	1.17	1.43	2.96	4.30
26	3.14	0.44	1.89	0.19	0.93	2.15	3.09	4.27
27	2.83	0.51	2.62	0.24	1.45	1.06	2.74	4.17
28	2.61	0.37	2.07	0.16	1.23	1.56	2.57	3.83
29	2.69	0.44	2.39	0.28	0.99	1.80	2.60	4.12
30	1.57	0.67	2.43	0.32	0.87	0.44	1.42	3.21
19 - 31	2.59	0.38	2.10	0.14	1.12	1.23	2.55	3.76
32	2.62	0.39	2.16	0.14	1.14	1.61	2.59	3.84
33	2.55	0.38	2.14	0.13	1.23	1.61	2.53	3.96
34	2.45	0.34	1.87	0.09	1.30	1.23	2.44	3.68
35	2.66	0.37	2.00	0.18	1.40	0.91	2.62	3.77
36	2.64	0.39	2.15	0.24	1.43	1.37	2.58	3.71
37	2.62	0.40	2.21	0.21	1.68	0.88	2.57	3.85
38	0.69	0.37	0.77	0.26	1.37	-0.04	0.64	3.24
39	2.83	0.55	2.85	-0.01	1.40	0.89	2.79	3.88
40	2.54	0.49	2.74	0.22	2.25	1.10	2.49	3.98
19 - 41	0.93	0.62	1.48	0.07	1.05	-0.47	0.91	2.42
42	0.87	0.54	1.25	0.11	1.03	-0.26	0.84	2.42
43	0.71	0.48	1.01	0.13	1.04	-0.20	0.68	1.99
44								
45	1.38	0.53	1.69	-0.11	1.24	-0.19	1.41	2.72
46	1.33	0.73	2.25	-0.21	1.03	-0.64	1.44	2.99
47	0.73	0.53	1.12	0.05	1.09	-0.36	0.73	2.18
48	1.91	1.14	5.13	-0.22	0.93	-0.28	2.14	3.89
49	1.06	0.50	1.30	0.07	1.13	0.07	1.06	2.74
50	1.18	0.56	1.57	0.30	1.69	0.15	1.11	3.04
19 - 51	0.91	0.44	1.04	0.07	1.15	-0.03	0.90	2.42
52								
53	0.94	0.45	1.09	-0.08	1.07	-0.27	0.96	2.19
54	1.22	0.69	1.97	-0.17	0.97	-0.28	1.31	2.89
55	2.82	0.92	4.80	-0.26	1.37	0.47	2.94	4.15
56	3.11	0.50	2.21	0.02	0.96	1.00	3.09	4.11
57	2.90	0.36	1.81	0.18	0.95	2.10	2.87	3.93
58	3.03	0.47	2.19	0.28	0.91	2.12	2.94	4.09
59								
60	2.49	0.25	1.40	0.13	1.11	1.83	2.47	3.21
61								
62	2.12	0.48	2.43	0.03	0.98	0.96	2.11	3.18
63	1.06	0.44	1.14	0.29	1.07	0.31	0.98	2.27
64	0.70	0.40	0.83	-0.10	1.08	-0.23	0.74	2.20
65	1.52	0.50	1.73	-0.08	1.64	0.34	1.56	3.00
66	2.82	0.42	2.19	0.28	1.10	1.62	2.74	3.85
67	1.54	0.44	1.55	-0.15	1.61	0.41	1.59	2.56
68	2.73	0.42	2.26	0.20	1.19	1.42	2.67	3.72
69	1.78	0.68	2.78	0.06	1.31	0.42	1.77	3.65
70								
19 - 71	0.77	0.39	0.85	-0.11	1.13	-0.22	0.80	1.99
72	1.48	0.23	0.79	-0.12	1.28	0.53	1.49	2.17
73	1.15	0.63	1.72	0.08	1.04	-0.53	1.12	2.73
74	0.64	0.52	1.04	0.23	1.14	-0.29	0.57	2.21
75	3.13	0.42	1.84	0.18	0.94	2.22	3.07	3.99
76	2.38	0.55	3.06	0.13	1.23	0.73	2.33	3.85
77	1.20	0.34	0,97	-0.10	1.34	0.03	1.22	2.07
78	1.66	0.30	1.14	-0.13	1.32	0.37	1.67	2.37
79	1.24	0.38	1.10	-0.21	1.10	0.12	1.30	2.19
80	1.61	0.42	1.54	-0.18	1,69	0,24	1,65	2.67

Sample No.	Mean	QD	QH	Skew	Kurt	1%	50%	90%
19 - 81	1.48	0.47	1.61	-0.46	1.40	-0.05	1.61	2.22
82	0.96	0.62	1.51	-0.37	0.98	-0.66	1.10	1.91
83	1.59	0.37	1.33	-0.26	1.46	0.48	1.64	2.54
84								
85	1.58	0.61	2.20	-0.25	1.07	0.28	1.73	3.59
86	0.80	0.59	1.29	0.19	0.81	-0.29	0.71	2.09
87	1.14	0.59	1.60	-0.50	1.07	-0,47	1,35	2.15
88	1.34	0.44	1.37	-0.40	1,45	-0,07	1,43	2.10
89	1.02	0.41	1.05	-0.24	1,34	-0.03	1.09	2.23
90	1.42	0.56	1.84	-0,10	1,10	0,14	1,46	2.69
19 - 91	1.17	0.52	1.45	-0.46	0,72	-0.01	1.35	2.15
92	1.49	0.44	1.51	0.17	1.30	0.27	1.43	2.67
93	1.63	0.50	1.85	-0.21	1.46	0.34	1.70	2.74
94	1.30	0.37	1.12	0.08	0.97	0.41	1.27	2.28
95	0.97	0.40	0.98	-0.12	1.35	0.06	1.01	2.00
96								
	1.25	0.66	1.93	-0.06	0.91	-0.02	1.31	3.15
97	1.26	0.40	1.18	-0.25	1.00	0.24	1.34	2.27
98	1.24	0.48	1.39	-0.30	1,24	-0.33	1,32	2.12
99	1.27	0.38	1.11	-0.26	1.62	-0.09	1.32	2.50
100	0.65	0.39	0.79	0.02	1.11	-0.23	0.66	1.88
19 -101	0.98	0.55	1.36	-0.06	1.03	-0.34	1.00	2.19
102								
103	1.36	0.38	1.18	0.01	1.16	0.40	1.35	2.27
104	1.14	0.63	1.71	-0.14	0.94	-0.50	1.20	2.54
105	1.08	0.53	1.40	o.00	1.09	-0.06	1.09	2.56
106	1.18	0.37	1.03	-0.22	1.20	0,10	1.23	2.17
107	o.43	0.70	2.32	-0.30	1.07	-0.62	1.57	2.66
108	1.02	0.56	1.43	-0.44	0.99	-0.38	1,20	2.06
109	0.97	0.62	1.52	-0.20	0.96	-0.49	1.05	2.11
110	0.96	0.53	1.29	-0.13	1.00	-0.44	1.01	2.18
19 -111	1.23	0.34	0.98	-0.02	1.15	0.29	1.24	2.18
112	1.56	0.66	2.37	-0.24	1.00	-0.05	1.67	2.77
113	1.44	0.26	0.87	0.07	1.39	0.70	1.44	2.36
114	1.40	0.29	0.92	0.06	1.11	0.71	1.40	2.25
115	1.69	0.46	1.81	-0.27	1.08	0.41	1.78	2.63
116	1.53	0.56	1.96	-0.22	1.39	-0.11	1.60	2.66
117	1.45	0.40	1.32	-0.06	1.08	0.34	1.47	2.41
118	1.19	0.69	1.94	0.04	1.22	-0.29	1.22	3.67
119	0.93	0.42	0.99	0.11	1.42	0.01	0.92	2.26
120	1.77	0.44	1.82	-0.18	1.48	0.37	1.80	2.71
19 -121	1.36	0.29	0.90	-0.30	1.50	0.21	1.40	2.03
122	1.31	0.50	1.53	0.10	1.18	0.23	1.28	2.84
123	1.79	0.24	1.01	0.04	1.36	1.03	1.78	2.71
124	1.31	0.33	1.00	-0.27	1.35	0.31	1.36	2.12
125	1.62	0.34	1.28	-0.17	1.30	0.24	1.65	2.49
126	0.74	0.41	0.87	0.06	1.16	-0.12	0.75	1.92
127	1.44	0.23	0.78	-0.06	1.19	0.67	1.44	2.07
128	0.93	0.34	0.82	-0.17	1.09	0.0	0.97	1.90
129	1.39	0.32	1.04	-0.16	1.52	0.0	1.40	2.19
130	-0.06	0.65	0.85	-0.04	1.21	-1.98	-0.05	1.45
19 -131	0.99	0.53	1.32	0.09	1.11	-0.26	0.95	2.23
132	0.90	0.49	1.17	-0.01	1.05	-0.13	0.91	2.09
133	0.89	0.50	1.16	0.08	1.04	-0.29	0.86	2.25
134	1.99	0.36	1.72	-0.09	1.35	0.80	2.00	2.86
135	1.89	0.53	2.34	-0.48	2.08	-0.12	2.02	2.79
136								
137	0.97	0.43	1.05	-0.07	1.00	0.04	0.99	2.19
138	0.96	0.53	1.28	0.14	1.15	-0.11	0.91	2.32
139	1.48	0.38	1.28	-0.15	1.19	0.44	1.51	2.44
140	0.31	0.44	0.73	0.04	1.04	-0.69	0.31	1.46
19 -141	1.12	0.61	1.65	-0.27	1.03	-0.34	1.23	2.41
142	2.33	0.44	2.42	0.26	1.43	1.43	2.24	3.37
143	0.47	0.35	0.62	-0.02	1.07	-0.28	0.48	1.44
144	1.41	0.78	2.52	-0.39	0.73	-0.30	1.65	2.67
	1.35	.84	2.63	-0.25	0.86	-0.46	1.50	3.17
145	1.25	0.61	1.79	0.07	1.08	-0.35	1.20	2.66
146	1.79	0.71	2.95	-0.45	1.29	-0.19	2.01	3.06
147	1.45	0.48	1.61	-0.30	1.12	-0.11	1.54	2.35
148	1.22	0.65	1.86	-0.36	0.82	-0.44	1.40	2.45
149	2.12	0.41	2.09	-0.12	1.32	0.90	2.15	3.08
150								
19 -151	0.0	0.68	0.93	0.03	0.98	-1.17	0.02	1.61
152	1.37	0.38	1.20	-0.05	1.61	0.39	1.40	2.56
153	1.69	0.64	2.49	-0.49	1.55	-0.51	1.86	2.73
154	0.74	0.48	1.03	-0.19	1.09	-0.67	0.80	2.01
155	1.62	0.64	2.38	-0.22	1.03	-0.02	1.72	3.18
156	1.03	0.79	2.02	-0.34	0.92	-0.84	1.20	2.27
157	1.16	0.83	2.29	-0.39	0.78	-0.67	1.39	2.48
158	1.20	0.89	2.51	-0.30	0.75	-0.64	1.43	3.17
159	1.12	1.06	2.87	-0.94	8.20	-1.42	1.90	2.00
160	0.97	0.78	1.93	-0.08	0.90	-0.74	1.00	2.39

Sample No.	Mean	QD	QH	Skew	Kurt	1%	50%	99%
19 - 161	1.07	0.70	1.83	0.02	0.98	-0.52	1.06	2.75
162	0.97	0.64	1.07	0.0	1.08	-0.57	0.98	2.55
163	0.48	0.55	1.00	0.03	1.05	-0.70	0.48	1.85
164	1.13	0.75	2.04	-0.42	0.09	-0.40	1.38	4.44
165	1.07	0.63	1.66	-0.26	0.94	-0.34	1.19	2.10
166	-0.05	0.46	0.60	-0.19	0.98	-1.16	0.01	0.79
167	1.78	0.41	1.70	-0.68	7.66	-0.88	1.81	1.90
168	1.88	0.50	2.21	-0.43	1.32	0.12	2.01	2.73
169								
170	1.90	0.44	1.94	-0.15	1.23	0.31	1.93	2.81
19 - 171	2.09	0.47	2.33	-0.31	1.89	0.14	2.14	2.97
172	2.17	0.17	0.90	0.10	1.12	1.64	2.17	2.76
173	2.13	0.27	1.37	-0.02	1.21	1.00	2.12	2.85
174	1.74	0.41	1.63	-0.25	1.18	0.56	1.80	2.65
175	2.27	0.34	1.84	-0.17	1.18	1.22	2.30	2.99
176								
	1.48	0.54	1.85	-0.43	1.14	-0.21	1.61	2.31
177	2.27	0.34	1.85	-0.16	1.18	1.21	2.30	2.99
178								
179	1.72	0.39	1.57	-0.18	1.07	0.60	1.76	2.52
180	1.33	0.68	2.10	-0.30	0.99	-0.42	1.46	2.52
19 - 181	1.14	0.47	1.29	-0.01	0.97	0.10	1.14	2.20
182	1.75	0.56	2.28	-0.49	1.09	-0.02	1.94	2.64
183	1.84	0.63	2.67	-0.49	1.07	-0.19	2.03	2.72
184	1.66	0.52	1.98	-0.34	1.13	0.13	1.76	2.46
185	1.72	0.51	2.05	-0.23	1.12	0.32	1.79	2.66
186	1.55	0.53	1.90	-0.24	0.92	0.23	1.63	2.50
187	1.68	0.44	1.71	-0.12	1.01	0.60	1.72	2.59
188	2.06	0.67	3.29	-0.54	1.24	0.30	2.31	3.10
189	0.60	0.48	0.93	0.03	1.19	-0.64	0.60	2.13
190								
	1.42	0.55	1.79	-0.09	1.04	0.14	1.46	2.70
19 - 191	2.21	0.39	2.07	-0.29	1.42	0.70	2.26	2.95
192	1.76	0.53	2.16	-0.46	1.26	-0.23	1.90	2.50
193	0.96	0.70	1.70	0.03	0.89	-0.63	0.93	2.38
194	1.26	0.62	1.83	-0.46	0.91	-0.48	1.46	2.19
195	1.68	0.61	2.38	-0.33	0.98	-0.09	1.81	2.67
196								
197	1.67	0.59	2.29	-0.44	1.36	-0.25	1.81	2.56
198	2.24	0.25	1.31	0.04	1.22	1.45	2.24	2.92
199	2.30	0.39	2.12	-0.01	1.18	0.93	2.30	3.29
200	1.49	0.51	1.73	-0.32	1.29	-0.10	1.57	2.42
19 - 201								
	1.59	0.54	1.96	0.26	1.18	-0.21	1.68	2.61
202	1.87	0.40	1.75	-0.33	1.33	0.41	1.94	2.59
203	0.74	0.69	1.47	0.03	0.94	-0.50	0.73	2.14
204	1.44	0.68	2.26	-0.37	0.93	-0.46	1.59	2.48
205	2.30	0.09	0.46	-0,02	0.99	1.07	2.30	2.49
206	1.81	0.39	1.62	-0.33	1.47	0.08	1.87	2.54
207	1.35	0.49	1.53	-0.32	1.22	-0.20	1.45	2.20
208	1.88	0.35	1.55	-0.20	1.37	0.47	1.91	2.62
209	1.79	0.60	2.49	-0.41	1.59	-0.10	1.92	2.64
210	1.82	0.36	1.53	-0.18	1.32	0.60	1.85	2.63
19 - 211	1.90	0.41	1.81	-0.27	1.48	0.25	1.94	2.74
212	1.55	0.45	1.58	-0.28	1.05	0.29	1.63	2.36
213	0.45	0.62	1.10	0.06	1.12	-0.70	0.45	2.03
214	1.41	0.52	1.68	-0.25	0.91	0.19	1.50	2.43
215	1.45	0.63	2.17	-0.40	0.87	-0.14	1.63	2.50
216	1.34	0.50	1.56	-0.28	0.98	-0.05	1.43	2.23
217	1.27	0.81	2.40	-0.42	0.95	-0.67	1.51	2.55
218	-1.92	1.06	2.49	0.09	0.88	-3.69	-1.99	0.71
219	1.36	0.69	2.17	-0.31	0.78	-0.15	1.52	2.44
220	0.47	0.82	1.47	0.29	1.30	-0,75	0.35	2.44
19 - 221	1.04	0.50	1.29	0.06	0.91	0.01	1.03	2.17
222	1.69	0.39	1.52	-0.14	1.10	0.57	1.72	2.50
223	1.55	0.40	1.42	-0.06	0.98	0.52	1.57	2.38
224	0.34	0.40	0.66	0.12	1.29	-0.37	0.34	1.85
225	1.86	0.43	1.86	-0.33	1.33	0.31	1.93	2.59
226	0.88	0.67	1.55	0.0	0.95	-0.57	0.87	2.21
227								
228								
229	1.27	0.64	1.90	-0.12	0.93	-0.33	1.30	2.39
230	1.37	0.37	1.15	-0.03	1.22	0.35	1.37	2.33
19 - 231	1.45	0.36	1.21	-0.15	1.31	0.42	1.48	2.39
232	1.15	0.36	1.00	0.11	1.25	0.25	1.14	2.37
233	1.12	0.58	1.56	-0.09	0.94	-0.19	1.16	2.29
234								
235	0.98	0.62	1.53	-0.10	1.03	-0.41	1.03	2.28
236	1.91	0.38	1.70	-0.18	1.58	0.73	1.95	2.88

CRUISE 81 - 19 (continued)

Sample No.	Mean	QD	QH	Skew	Kurt	1%	50%	99%
19 - 237	1.08	0.72	1.89	-0.01	0.89	-0.38	1.09	2.54
238	1.13	0.46	1.24	-0.08	1.03	-0.07	1.16	2.32
239	1.11	0.88	2.36	0.10	0.84	-0.73	1.05	3.21
240	1.28	0.52	1.56	-0.02	0.93	0.12	1.28	2.32
19 - 241	1.45	0.47	1.57	-0.07	1.15	-0.07	1.46	2.38
242	0.16	0.43	1.20	0.05	1.33	0.16	1.14	2.29
243	1.39	0.45	1.45	-0.04	1.10	0.37	1.40	2.40
244	1.21	0.66	1.89	-0.13	0.86	-0.35	1.26	2.39
245	1.52	0.36	1.27	-0.03	1.25	0.64	1.53	2.46
246	1.32	0.40	1.24	-0.13	1.11	0.25	1.36	2.20
247	1.43	0.86	2.82	-0.63	0.96	-0.57	1.82	2.60
248	1.05	0.64	1.65	-0.02	0.94	-0.45	1.04	2.29
249	1.06	0.81	2.11	-0.05	0.79	-0.50	1.10	2.90
250	1.56	0.65	2.31	-0.22	1.01	-0.25	1.63	2.69
19 - 251	1.21	0.46	1.30	-0.33	1.35	-0.16	1.30	2.14
252	1.44	0.46	1.53	-0.27	1.26	-0.15	1.49	2.25
253	1.42	0.43	1.40	0.14	1.24	0.37	1.39	2.56
254	2.43	.40	2.21	-0.34	1.22	1.09	2.51	3.15
255	0.67	0.74	1.50	0.07	0.78	-0.65	0.63	2.03
256	1.93	0.91	4.12	-0.22	0.79	0.17	2.10	3.7
257	(2.70)	(0.41)	(2.21)	(0.06)	(1.23)	(0.93)	(2.67)	(3.61)
	0.92	0.65	1.56	0.04	1.39	-1.39	0.88	2.50
258	0.98	0.70	1.73	-0.35	0.82	-0.45	1.17	2.17
259	1.70	0.73	2.85	-0.53	1.46	-0.42	1.93	2.75
260	MUD	MUD	MUD	MUD	MUD	MUD	MUD	MUD

CRUISE 83-10

Sample No.	Mean	QD	QH	Skew	Kurt	1%	50%	99%
10 - 01	1.98	0.40	1.87	-0.37	1.56	0.43	2.05	2.75
02	1.59	0.52	1.88	-0.40	1.27	-0.12	1.71	3.16
03	2.38	0.22	1.24	0.07	1.11	1.74	2.37	3.22
04	1.11	0.53	1.42	0.02	1.00	-0.07	1.10	2.37
05	1.33	0.42	1.31	-0.09	1.07	0.26	1.35	2.34
06	1.34	0.52	1.62	-0.24	0.95	0.04	1.44	2.47
07	1.95	0.40	1.82	-0.02	1.24	0.84	1.95	3.06
08	1.27	0.60	1.79	-0.39	0.98	0.19	1.44	2.34
09	1.26	0.58	1.71	-0.01	0.82	0.09	1.26	2.39
10	0.76	0.51	1.10	0.08	0.95	-0.24	0.74	1.95
10 - 11	1.54	0.33	1.16	-0.13	1.01	0.71	1.56	2.34
12	1.35	0.38	1.18	-0.19	1.02	0.36	1.39	2.13
13	1.16	0.46	1.27	-0.09	1.10	-0.05	1.17	2.15
14	1.10	0.53	1.42	-0.10	0.96	-0.10	1.13	2.17
15	1.17	0.73	2.02	-0.27	0.88	-0.35	1.31	2.62
16	1.53	0.35	1.24	00	1.14	0.61	1.53	2.42
10 - 17	1.61	0.32	1.16	-0.07	1.18	0.66	1.62	2.38
18	1.41	0.36	1.17	-0.06	1.24	0.14	1.42	2.29
19	1.29	0.68	2.03	-0.19	0.82	-0.26	1.38	2.48
20	0.95	0.67	1.61	0.05	1.01	-0.51	0.94	3.23
21	0.72	0.79	1.66	-0.13	0.90	-0.87	0.79	2.30
22	0.96	0.52	1.28	-0.14	0.94	-0.14	1.03	2.16
23	0.73	0.63	1.34	0.07	1.06	-0.38	0.71	2.38
24	2.96	0.38	1.83	-0.83	12.38	0.63	3.03	3.10
25	1.36	0.45	1.43	-0.17	1.01	0.26	1.41	2.33
26	1.30	0.53	1.59	-0.23	1.05	0.01	1.38	2.47
27	1.08	0.81	2.13	-0.17	0.74	-0.37	1.19	2.65
28	1.62	0.54	2.00	-0.13	1.08	0.21	1.66	2.83
29	1.73	0.32	1.29	-0.10	1.17	0.72	1.74	2.44
30	1.45	0.56	1.86	-0.07	1.49	-0.33	1.44	2.54
10 - 31	0.85	0.56	1.28	0.24	0.91	-0.19	0.74	1.99
32	1.13	0.60	1.62	-0.13	1.08	-0.19	1.18	2.43
33	0.84	0.62	1.39	-0.05	0.80	-0.35	0.86	2.01
34	0.75	0.68	1.45	0.35	0.91	-0.39	0.56	2.20
35	0.62	0.94	1.85	0.58	0.71	-0.55	0.21	2.82
36	0.92	0.55	1.31	0.13	1.09	-0.25	0.86	2.27
37	1.60	0.97	3.55	-0.47	0.71	-0.30	1.99	3.45
38	0.98	0.59	1.45	0.29	1.14	-0.15	0.84	2.37

CRUISE 79 - 24

Sample No.	Mean	QD	QH	Skew	Kurt	1%	50%	99%
24 - 122	2.50	0.63	3.51	0.17	0.95	0.77	2.42	3.91
123	2.63	1.20	6.59	-0.15	0.66	0.70	2.88	4.56
124	2.23	0.80	4.24	-0.10	0.79	0.56	2.29	3.60
125	1.07	0.54	1.47	-0.12	1.10	-0.45	1.11	2.62
126	1.93	0.32	1.44	0.09	1.18	1.17	1.92	2.94
127	2.80	0.28	1.45	0.17	1.17	2.10	2.77	3.62
128	3.16	0.39	1.65	0.17	1.06	1.73	3.13	3.98
129	3.28	0.42	1.64	-0.01	0.98	1.89	3.27	4.07
130	2.11	1.03	5.20	-0.31	1.07	-0.34	2.35	3.97
24 - 154	2.46	0.27	1.51	0.12	1.34	1.70	2.45	3.53
155	3.52	0.37	1.18	0.03	1.19	2.03	3.49	4.26
156	MUD	MUD	MUD	MUD	MUD	MUD	MUD	MUD

7.2.2 Grain size parameters and calcium carbonate content

CRUISE 81 - 19

Sample No.	% GRAV	% MUD	% VCS	% CS	% MS	% FS	% VFS + SILT	% $CaCO_3$
19 - 01	0.0	8.1	0.0	0.0	1.03	54.92	44.05	9.3
02	0.0	8.3	0.0	0.0	0.01	52.85	47.14	9.3
03	0.0	7.0	0.0	0.0	0.42	26.13	73.46	6.7
04	0.0	25.0	0.0	0.07	0.39	44.36	53.51	8.0
05	0.0	45.0	0.0	0.0	0.21	21.88	77.91	8.0
06	0.0	84.0	0.0	0.0	0.0	26.56	73.44	8.0
07	0.0	0.0	0.0	0.0	0.61	36.71	62.68	5.2
08	80.0	4.0	0.34	3.07	4.52	77.86	14.20	46.7
09	1.0	8.0	0.0	0.0	0.41	45.04	54.55	10.7
10	24.0	40.0	0.22	13.13	12.79	24.55	49.31	28.0
19 - 11	0.0	86.0	0.0	0.0	0.64	19.11	80.25	8.0
12	0.0	76.0	0.0	1.69	10.87	37.86	49.57	26.7
13	0.0	80.0	0.25	1.63	2.67	19.45	76.00	12.8
14	0.0	1.0	0.02	0.41	12.11	81.44	6.02	29.5
15	0.0	73.0	0.0	0.58	5.74	40.75	52.88	20.5
16	1.03	85.0	0.26	0.48	3.77	17.14	58.33	17.9
17	0.0	2.75	0.0	0.0	1.66	34.39	63.96	32.6
18	0.0	3.23	0.0	3.75	7.68	26.02	62.55	16.3
19	9.0	1.0	3.01	69.83	23.89	3.27	0.0	82.1
20	12.6	0.0	0.0	0.27	2.66	11.54	85.53	0.0
19 - 21	0.0	89.0	0.0	2.75	16.86	53.77	26.61	21.8
22	23.0	33.0	1.85	22.59	48.06	19.99	7.52	76.9
23	0.0	94.0	0.63	2.85	3.21	17.28	76.04	20.5
24	0.0	9.56	0.0	1.00	6.03	31.39	61.58	34.0
25	0.0	61.0	0.0	0.0	4.64	48.44	46.92	0.0
26	0.0	48.0	0.0	0.19	0.55	41.96	57.29	17.9
27	0.0	10.0	0.09	0.72	4.25	67.66	27.28	25.6
28	0.0	1.0	0.0	0.15	4.28	81.35	14.01	20.5
29	0.0	9.0	0.0	0.0	2.95	74.63	22.42	24.1
30	39.0	0.0	0.0	19.14	52.67	25.31	2.89	71.3
19 - 31	0.5	0.5	0.0	0.73	4.36	80.64	14.28	9.1
32	0.0	1.45	0.0	0.34	4.03	79.22	16.41	21.5
33	0.0	2.0	0.0	0.14	5.53	82.41	11.92	25.3
34	0.0	2.3	0.0	0.62	6.61	86.00	6.67	26.6
35	0.4	2.0	0.0	1.30	3.25	79.68	15.77	25.3
36	0.9	2.8	0.0	0.49	4.46	78.08	16.97	24.1
37	0.5	2.8	0.0	1.30	3.96	80.17	14.56	26.6
38	39.4	0.4	1.40	80.81	14.00	2.23	1.56	89.9
39	0.0	1.4	0.0	1.58	6.27	59.95	32.20	21.5
40	0.0	0.8	0.0	0.83	6.98	78.28	13.90	32.9
19 - 41	31.3	1.0	5.84	50.36	38.44	5.36	0.0	88.6
42	37.9	3.6	3.97	57.87	34.38	3.77	0.0	86.1
43	40.0	1.3	5.29	68.70	25.15	0.86	0.0	89.6
44				no data				
45	19.7	0.0	2.17	18.92	68.75	10.16	0.0	86.1
46	36.4	0.0	4.93	25.05	53.91	14.91	0.92	0.0
47	5.5	0.8	7.55	63.57	26.41	2.47	0.0	89.9
48	4.3	53.6	4.08	19.11	20.59	39.80	16.41	65.8
49	29.6	0.0	0.56	44.42	49.69	4.87	0.46	95.00
50	8.7	0.0	0.17	38.35	49.76	10.52	1.20	96.7
19 - 51	14.5	0.0	1.21	58.45	37.04	2.96	0.53	95.4
52				no data				
53	15.8	0.0	3.31	50.28	44.46	1.70	0.25	95.5
54	0.0	0.0	4.63	30.17	54.53	9.96	0.70	88.8
55	4.6	90.2	0.0	5.77	11.81	36.39	46.03	30.4
56	0.0	2.66	0.44	0.56	3.11	40.73	55.15	27.6
57	0.0	0.0	0.0	0.0	0.61	62.39	37.0	27.0
58	0.0	12.0	0.0	0.0	0.53	53.95	45.52	19.0
59				no data				
60	0.0	2.3	0.0	0.0	2.75	93.19	4.06	36.7
19 - 61				no data				
62	0.0	2.4	0.0	1.21	40.89	53.96	3.94	46.2
63	0.0	0.2	0.0	52.14	43.94	3.92	0.0	79.5
64	29.1	0.6	4.89	73.67	19.57	1.86	0.0	69.3
65	1.4	1.9	0.0	13.31	72.67	13.03	0.99	43.6
66	0.0	7.6	0.0	0.31	2.82	68.93	27.95	28.2
67	28.2	1.4	0.0	11.28	75.93	12.79	0.0	57.7
68	0.0	4.6	0.0	0.63	3.64	72.66	23.07	17.9
69	55.5	0.0	0.0	11.64	56.38	26.37	5.61	46.1
70								

CRUISE 81 - 19

Sample No.	% GRAV	% MUD	% VCS	% CS	% MS	% FS	% VFS + SILT	% $CaCO_3$
19 - 71	4.5	0.0	3.81	68.94	26.31	0.94	0.0	55.1
72	4.3	0.0	0.0	5.12	92.44	2.43	0.0	46.2
73	25.0	1.3	3.79	38.17	48.25	9.69	0.10	86.1
74	21.1	0.0	8.43	68.53	20.72	2.20	0.13	85.1
75	0.0	6.4	0.0	0.0	0.45	43.04	58.50	13.9
76	10.4	0.0	0.0	2.29	20.35	63.77	13.60	22.5
77	0.0	0.0	0.81	22.31	75.39	1.49	0.0	43.8
78	0.0	0.4	0.0	4.81	85.62	9.57	0.0	32.9
79	0.0	0.0	0.48	23.82	73.12	2.58	0.0	44.3
80	1.1	0.1	0.25	9.67	78.45	11.63	0.0	38.0
19 - 81	1.2	0.0	1.32	15.32	77.25	6.11	0.0	40.5
82	7.9	0.5	9.99	33.73	56.07	0.20	0.0	44.3
83	3.5	0.1	0.0	9.44	82.20	8.36	0.0	43.0
84				no data				
85	5.5	1.6	0.0	19.10	59.86	17.57	3.47	40.7
86	8.3	0.0	6.08	58.01	34.16	1.75	0.0	45.7
87	4.1	0.0	6.32	23.90	67.38	2.40	0.0	39.2
88	3.5	0.0	1.69	17.19	78.94	2.18	0.0	39.2
89	0.0	0.1	1.27	36.55	59.67	2.51	0.0	68.4
90	18.9	0.0	0.20	21.68	64.67	13.30	0.15	84.4
19 - 91	10.4	0.0	1.09	36.99	59.95	1.93	0.03	57.7
92	0.0	0.0	0.0	10.27	77.10	12.42	0.21	47.7
93	24.5	0.0	0.0	12.79	67.98	19.23	0.0	0.0
94	0.0	0.4	0.04	19.78	76.51	3.67	0.0	45.6
95	3.3	0.3	0.07	48.82	50.15	0.96	0.0	50.6
96	2.4	0.0	1.15	34.45	52.65	10.04	1.71	40.5
97	6.6	0.0	0.18	25.00	71.66	3.16	0.0	59.5
98	2.2	0.0	3.45	22.18	72.21	2.17	0.0	43.00
99	2.8	0.0	1.63	16.87	77.81	3.69	0.0	44.3
100	0.60	0.0	0.28	15.70	79.17	4.84	0.00	43.6
19 - 101	6.7	0.0	4.87	45.41	46.69	3.03	0.0	49.4
102				no data				
103	0.6	0.0	0.28	15.70	79.17	4.84	0.0	43.6
104	0.0	0.0	4.69	35.81	53.05	6.45	0.00	69.6
105	2.8	0.0	1.54	41.37	51.79	5.01	0.29	85.1
106	3.9	0.0	0.43	26.38	70.96	2.24	0.0	49.6
107	0.0	0.0	4.72	20.66	55.95	18.67	0.0	56.7
108	8.8	0.0	6.73	34.97	56.92	1.38	0.00	55.7
109	10.3	0.0	7.93	38.80	50.90	2.37	0.0	40.3
110	3.7	0.0	4.72	44.74	48.11	2.43	0.0	46.8
19 - 111	0.0	0.0	0.25	22.32	74.88	2.55	0.0	44.2
112	0.0	0.0	1.21	19.59	52.64	26.45	0.12	66.3
113	0.0	0.0	0.0	4.89	90.54	4.57	0.0	61.7
114	0.0	0.0	0.0	6.78	89.54	3.68	0.0	39.0
115	0.0	0.0	0.07	9.61	65.01	25.31	0.0	42.9
116	31.7	0.3	1.72	14.15	68.34	15.79	0.0	39.0
117	0.0	0.0	0.28	12.42	79.74	7.56	0.0	42.9
118	38.3	0.7	3.34	33.96	51.12	8.06	3.51	77.9
119	3.6	0.1	0.94	59.13	36.43	3.49	0.0	74.00
120	71.0	0.8	0.0	7.54	66.29	26.17	0.0	44.2
19 - 121	1.8	0.0	0.55	11.89	86.32	1.24	0.0	48.1
122	63.8	0.0	0.0	25.58	64.24	9.89	0.29	88.8
123	0.0	0.1	0.0	0.83	83.47	15.70	0.0	31.6
124	1.8	0.0	0.0	16.31	81.78	1.91	0.0	50.6
125	0.0	0.0	0.32	6.15	84.39	9.15	0.0	38.0
126	23.8	0.0	2.33	72.58	24.66	0.43	0.0	88.6
127	48.4	2.2	0.0	5.08	93.22	1.70	0.0	92.4
128	0.0	0.0	0.96	52.63	45.83	0.58	0.0	46.8
129	4.4	0.0	0.97	10.31	85.77	2.95	0.0	40.5
130	35.6	0.8	53.26	41.11	5.63	0.0	0.0	84.8
131	16.1	0.5	3.44	50.24	42.22	4.11	0.0	83.5
132	36.0	1.4	3.14	54.05	40.93	1.88	0.0	93.7
133	3.8	0.0	3.66	58.42	35.32	2.60	0.0	24.1
134	0.0	0.2	0.0	2.41	47.14	50.45	0.0	19.2
135	3.3	0.0	1.69	9.41	36.39	52.16	0.35	27.5
136				no data				
137	0.0	0.0	0.39	50.51	47.12	1.89	0.08	68.8
138	24.8	0.5	2.11	55.12	38.33	4.45	0.0	93.6
139	9.6	0.0	0.05	12.01	81.35	6.42	0.17	77.5
140	8.0	0.0	23.94	69.06	7.00	0.0	0.0	42.3

CRUISE 81 - 19

Sample No.	% GRAV	% MUD	% VCS	% CS	% MS	% FS	% VFS + SILT	% $CaCO_3$
19 - 141	99.3	0.0	6.21	31.84	57.06	4.90	0.0	60.3
142	11.4	0.2	0.0	0.0	19.79	69.46	10.76	32.1
143	5.6	0.1	8.74	84,46	6.80	0.0	0.0	23.1
144 A	21.7	0.0	3.98	29.34	40.16	26.47	0.04	26.1
144 B	8.9	0.0	8.16	27.66	39.55	22.91	1.72	66.7
145	0.0	0.0	3.31	30.11	55.31	11.02	0.25	59.2
146	8.2	0.7	2.40	13.75	33.18	49.19	1.48	61.5
147	30.9	0.0	1.70	16.16	74.00	8.13	0.0	56.4
148	65.2	0.0	4.61	31.15	57.76	6.48	0.0	32.1
149	16.1	5.0	0.0	1.81	30.76	65.60	1.83	28.2
150			no data					
19 - 151	36.1	0.0	49.12	42.77	8.21	0.0	0.0	29.5
152	3.0	0.0	0.0	14.47	78.54	6.99	0.0	38.5
153	15.3	0.0	4.64	10.48	51.72	33.16	0.0	28.2
154	8.9	0.0	8.10	60.54	30.33	1.03	0.0	44.9
155	5.0	0.0	1.08	17.02	51.83	28.04	2.03	70.6
156	24.7	0.0	13.15	28.87	52.54	5.43	0.0	41.6
157	41.1	0.0	12.43	28.69	47.39	11.50	0.0	46.8
158	34.7	16.4	11.52	31.11	39.25	16.35	1.76	16.7
159	41.7	0.0	18.50	0.99	8.52	0.0	0.0	29.5
160	25.7	0.0	12.32	37.74	42.51	7.44	0.0	30.8
19 - 161	96.2	0.2	6.28	40.88	43.95	8.82	0.06	73.1
162	18.5	2.1	6.80	44.87	42.47	5.86	0.0	88.5
163	15.2	0.1	18.84	64.59	16.17	0.41	0.0	61.0
164	26.1	0.0	10.46	23.99	57.95	7.59	0.0	30.1
165	10.3	0.0	6.69	32.37	57.62	3.32	0.0	32.5
166	14.2	0.0	49.50	50.50	0.0	0.0	0.0	22.1
167	12.5	0.0	12.11	0.98	86.91	0.0	0.0	28.6
168	3.7	0.0	0.55	8.93	39.48	51.03	0.0	33.8
169			no data					
170	0.1	1.8	0.04	5.05	53.00	41.91	0.0	24.7
19 - 171	2.4	6.3	0.63	6.53	25.01	67.09	0.75	27.3
172	0.0	0.6	0.0	0.37	12.91	86.60	0.12	35.8
173	0.0	2.3	0.0	1.01	28.87	69.79	0.33	28.6
174	0.0	0.0	0.0	6.30	68.39	25.31	0.0	33.8
175	0.0	0.1	0.0	0.30	19.53	79.25	0.92	30.8
176	5.0	0.0	2.81	16.25	70.45	10.49	0.0	34.6
177	1.4	3.9	0.0	0.36	19.51	79.25	0.88	38.5
178			no data					
179	0.0	0.2	0.0	5.53	70.01	23.66	0.0	38.5
180	13.0	0.3	4.82	24.36	57.43	13.39	0.0	44.9
19 - 181	1.40	0.2	0.51	37.97	58.14	3.38	0.0	25.6
182	3.4	0.0	1.08	12.89	43.33	42.70	0.0	38.5
183	1.8	2.3	2.00	11.14	34.40	52.46	0.0	35.9
184	2.3	0.6	0.42	13.00	60.74	25.84	0.0	51.3
185	1.7	0.2	0.0	10.66	59.18	30.15	0.0	47.4
186	2.1	0.0	0.0	17.63	62.54	19.83	0.0	56.4
187	26.1	1.0	0.0	7.29	69.43	23.29	0.0	36.6
188	10.4	1.8	0.0	10.98	17.85	69.04	2.13	31.2
189	4.22	0.0	9.27	72.78	16.03	1.79	0.0	23.4
190	5.8	0.0	0.55	21.83	64.40	13.23	0.0	27.3
19 - 191	0.0	0.9	0.0	2.85	20.09	76.50	0.55	26.0
192	3.0	0.8	2.03	10.16	49.38	38.43	0.0	36.6
193	27.1	1.6	8.85	45.95	39.17	6.03	0.0	58.4
194	9.4	0.0	4.97	25.67	64.77	4.60	0.0	54.5
195	3.5	0.3	1.51	14.53	48.86	35.09	0.0	53.2
196			no data					
197	9.2	0.1	3.17	11.33	56.28	29.22	0.0	37.7
198	0.0	2.2	0.0	0.0	13.63	86.08	0.29	24.7
199	0.0	0.3	0.14	1.01	19.00	75.26	4.59	22.1
200	2.5	0.0	1.78	14.72	73.56	9.94	0.0	27.3
19 - 201	1.6	0.0	2.02	13.13	64.50	20.35	0.0	28.6
202	2.5	0.10	0.10	5.63	52.68	41.59	0.0	33.8
203	21.4	0.2	15.29	50.05	31.99	2.66	0.0	33.8
204	6.7	0.1	5.12	21.96	53.25	19.67	0.0	57.1
205	26.2	0.0	0.78	0.21	98.81	0.0	0.0	51.9
206	0.0	0.1	0.88	5.62	64.12	29.38	0.0	33.8
207	5.9	0.0	2.38	18.69	73.93	4.99	0.0	35.1
208	0.0	0.0	0.18	4.09	59.18	36.55	0.0	28.6
209	0.8	0.0	1.90	11.45	45.89	40.77	0.0	28.6
210	0.0	0.0	0.0	4.38	66.11	29.51	0.0	32.5

CRUISE 81 - 19

Sample No.	% GRAV	% MUD	% VCS	% CS	% MS	% FS	% VFS + SILT	$CaCO_3$
19 - 211	0.0	0.0	0.12	5.69	51.98	42.21	0.0	25.00
212	27.1	0.0	0.20	13.54	74.30	11.96	0.0	36.8
213	50.6	0.2	21.97	60.15	16.53	1.35	0.0	67.1
214	0.7	0.0	0.09	22.71	67.65	9.55	0.0	43.4
215	15.8	0.1	2.01	23.57	56.63	17.79	0.0	47.4
216	11.6	0.0	1.35	23.21	70.38	5.07	0.0	34.2
217	20.0	2.6	10.48	20.82	53.46	15.24	0.0	40.8
218	78.93	0.0	95.49	3.45	0.43	0.0	0.0	88.7
219	14.8	0.7	2.75	29.27	49.86	18.11	0.0	53.9
220	31.5	0.1	28.94	51.35	7.02	12.68	0.0	52.6
19 - 221	11.7	0.0	0.87	47.37	48.94	2.81	0.0	48.7
222	0.0	0.0	0.0	5.89	74.78	19.33	0.0	32.9
223	1.2	0.0	0.0	8.67	78.97	12.37	0.0	40.8
224	9.6	0.0	16.56	75.72	7.56	0.17	0.0	51.3
225	15.4	0.4	0.22	6.78	52.01	40.98	0.0	38.2
226	9.4	1.3	9.68	47.82	38.85	3.65	0.0	73.7
227			no data					
228			no data					
229	8.6	0.0	3.98	29.40	55.44	11.18	0.0	59.2
230	1.2	0.0	0.17	14.40	80.56	4.87	0.0	42.1
19 - 231	1.2	0.0	0.0	12.33	82.18	5.49	0.0	32.9
232	2.5	0.0	0.12	31.46	64.86	3.56	0.0	44.7
233	29.0	0.0	2.95	37.27	54.59	5.19	0.0	30.3
234			no data					
235	4.7	0.0	6.18	41.58	47.75	4.49	0.0	34.2
236	0.0	0.0	0.0	3.60	54.02	41.70	6.68	35.9
237	0.0	1.1	5.88	39.37	45.21	9.54	0.0	92.1
238	0.0	0.0	1.52	35.58	59.28	3.62	0.0	90.6
239	0.0	0.8	8.46	39.58	34.56	15.31	2.09	29.8
240	47.3	0.0	0.61	29.53	61.81	8.05	0.0	64.9
19 - 241	0.8	0.0	1.36	14.60	73.72	10.32	0.0	48.1
242	0.0	0.0	0.43	32.27	63.23	4.07	0.0	32.5
243	6.3	0.0	0.11	18.65	72.68	8.55	0.0	44.2
244	4.8	0.0	4.44	33.54	52.16	9.87	0.0	46.8
245	21.1	0.0	0.0	8.50	82.68	8.82	0.0	32.5
246	16.9	0.0	0.0	20.26	75.73	4.01	0.0	46.8
247	21.7	1.2	10.58	15.80	41.86	31.72	0.04	35.1
248	67.0	0.0	6.12	41.98	46.43	5.47	0.0	79.2
249	30.9	0.0	10.53	35.99	42.19	10.66	0.63	28.0
250	4.5	0.0	3.04	16.77	54.34	25.85	0.0	19.5
19 - 251	4.1	0.0	2.36	22.15	73.07	2.42	0.0	41.6
252	2.9	0.0	1.96	14.23	77.32	6.49	0.0	37.7
253	0.0	0.0	0.0	13.58	76.16	10.26	0.0	32.5
254	0.0	0.0	0.0	0.56	14.53	81.90	3.02	40.3
255	36.8	0.0	21.47	44.47	32.44	1.33	0.0	26.0
256	69.7	0.0	0.0	20.39	25.66	43.90	9.84	27.5
257	2.40	1.2	8.35	50.38	35.32	5.95	0.0	27.3
258	24.9	0.0	11.57	30.44	55.04	2,96	0.0	32.5
259	14.6	0.0	5.08	12.44	39.26	43.23	0.0	26.00
260	MUD	100	MUD	MUD	MUD	MUD	MUC	MUD

CRUISE 83 - 10

Sample No.	% GRAV	% MUD	% VCS	% CS	%MS	% FS	% VFS + SILT	$CaCO_3$
10 - 01	3.9	0.0	0.11	4.87	36.93	58.09	0.0	28.2
02	5.2	0.0	1.88	12.86	69.36	14.66	1.24	42.9
03	0.0	1.9	0.0	0.09	4.05	93.17	2.70	16.0
04	7.1	0.0	1.57	40.09	53.74	4.59	0.0	61.4
05	6.7	0.0	0.20	20.55	74.29	4.96	0.0	48.9
06	2.9	0.0	0.73	25.23	65.93	8.11	0.0	38.0
07	0.0	0.0	0.0	2.36	53.82	42.57	1.25	27.00
08	10.9	0.0	3.47	24.35	66.38	5.81	0.0	39.0
09	6.3	1.1	0.44	34.91	55.91	9.65	0.0	46.4
10	18.6	0.0	4.93	64.07	30.41	0.60	0.0	68.9
10 - 11	0.0	0.0	0.0	6.50	87.46	5.98	0.0	32.6
12	0.0	0.0	0.15	18.39	79.05	2.41	0.0	39.9
13	8.3	0.0	1.36	33.12	63.04	2.48	0.0	38.3
14	4.1	0.0	2.10	38.56	56.30	3.04	0.0	84.5
15	15.3	0.8	7.94	29.68	52.98	9.39	0.01	60.3
16	0.7	0.0	0.19	6.98	83.95	8.82	0.06	36.2
17	2.4	0.0	0.0	4.89	85.70	9.32	0.1	29.8
18	5.0	0.0	0.36	11.73	83.02	4.89	0.0	39.8
19	2.9	0.0	3.77	30.26	52.37	13.61	0.0	40.8
20	38.9	1.6	6.35	46.89	40.46	4.48	1.82	91.6
10 - 21	4.2	0.0	20.23	40.46	35.64	3.67	0.0	31.7
22	1.9	0.0	2.71	44.88	49.98	2.43	0.0	29.2
23	37.7	0.0	12.43	56.45	27.59	3.53	0.0	40.5
24	0.9	0.0	0.0	3.53	11.78	8.18	76.51	31.6
25	2.3	0.0	0.06	21.19	72.72	6.03	0.0	42.3
26	11.3	1.0	0.84	25.45	67.44	6.15	0.12	90.8
27	2.2	1.5	10.90	33.29	44.03	11.54	0.25	32.8
28	17.9	0.0	3.8	12.80	63.31	23.18	0.32	47.8
29	0.0	0.0	0.0	3.49	78.92	17.59	0.0	34.0
30	25.5	0.0	3.46	13.21	69.86	13.47	0.0	35.4
10 - 31	11.0	0.0	4.08	63.16	31.82	0.93	0.0	27.3
32	40.1	0.0	4.0	33.53	56.54	5.91	0.0	84.6
33	8.4	0.0	9.02	48.37	41.59	1.03	0.0	27.6
34	6.4	0.0	10.71	60.98	25.18	3.14	0.0	24.3
35	31.5	0.0	34.66	37.00	16.16	11.99	0.19	12.5
36	28.8	0.0	4.60	56.87	35.33	3.20	0.0	39.6
37	11.1	0.0	6.08	23.87	20.97	45.27	3.81	11.2
38	3.8	0.0	2.72	60.16	31.54	5.56	0.03	23.9
CRUISE 79 - 24								
24 - 122	0.0	0.0	0.0	1.89	20.06	55.92	22.13	10.00
123	0.0	13.14	0.03	7.23	27.59	21.84	44.31	31.6
124	0.0	0.0	0.0	5.99	35.32	40.71	17.98	50.6
125	0.0	0.0	4.54	37.14	53.98	3.87	0.47	38.0
126	0.0	0.0	0.0	0.28	61.42	37.48	0.81	0.0
127	0.0	0.0	0.0	0.0	0.61	78.42	20.97	0.0
128	0.0	0.0	0.0	0.0	2.23	33.50	64.28	46.8
129	0.0	2.45	0.0	0.05	1.34	24.55	74.06	40.8
130	0.0	0.0	3.68	12.56	21.50	46.13	16.13	84.8
24 - 154	0.0	0.0	0.0	0.0	4.16	90.44	5.40	59.0
155	0.0	8.7	0.0	0.0	0.87	7.58	91.54	0.0
156			no data					

APPENDIX 3

7.3.1 Programme for size transformation of settling tube data

```
                            ------

                            LINE-PRINTER:

                            MODULE  (I)    :  DATA DISTRIBUTION TABLE,
                                              STATISTICAL AND TEXTURAL
                                              INFORMATION
                                    (II)   :  INITIALIZATION OF PLOT ARRAYS
                                    (III)  :  GRAPH PLOTS OF NORMAL AND
                                              CUMULATIVE FREQUENCY DISTRIBUTIONS


                            MAGNETIC DISC:

                            MODULE  (I)    :  DATA FOR STATISTICAL PACKAGES
                                    (II)   :  DATA FOR PHIPLOTTER PROGRAM

          SECTION  V
                   -

                            (TERMINATION ROUTINES)
                            ----------------------

                            MODULE  (I)    :  EOF FLAGS ON DISC OUTPUT
                                    (II)   :  INFORMATION SUMMARY TABLE
                                              FOR ALL SAMPLES
                                    (III)  :  END  STATEMENT



                            PROGRAM COMPILATION:
                            --------------------

                                                   THE COMPILATION AND COLLECTION
                                                   PROCESSING  REQUIRED  THE
                                                   FOLLOWING  RUNSTREAM :

      @RUN # HEPROG,R0218-7105/HENRI,GEOMARINE,5,90
      @PASSWD # FIALGI
      @ASG,A  # PROGFILE.
      @ASG,AX # RELOCFILE.
      @ASG,AX # ABS.
      @FIN,EAKS # PROGFILE.SETTLEPROG/TOTAL, RELOCFILE.SETTLEPROG/TOTAL
      @MAP,IS # TPF$.DUM, ABS.SETTLEPROG/TOTALSTATS
      IN # RELOCFILE.SETTLEPROG/TOTAL
      LIB # SYS$*FINLIB$
      @FIN

      N.B.    EACH LINE IN THE ABOVE RUNSTREAM REPRESENTS ONE CARD .
              MANDATORY BLANKS ARE REPRESENTED BY THE '#' CHARACTER .

    N.N.B.    SINCE  15 NOVEMBER 1982, THE PREFERRED   F O R T R A N
              COMPILER AT U.C.T. IS THE   ASCII FORTRAN (FIN)  10R1A
              LEVEL, WHICH IS COMPATIBLE WITH STANDARD ASCII
              F O R T R A N  77; AND IS NOT TOTALLY COMPATIBLE WITH


SETTLEPROG/TOTALSTATS
              THIS PROGRAM AS IT IS PRESENTLY WRITTEN UNDER LEVEL 8R1A,
              WHICH CONFORMS TO STANDARD  ASCII   F O R T R A N   66.

              THE FOLLOWING RUNSTREAM WILL THEREFORE DO THE REQUIRED
              COMPILATION AND COLLECTION PROCESS AS FROM 15 NOV. 1982.


      @RUN,/NP # HEPROG,R0218-7105/HENRI,GEOMARINE,5,80
      @PASSWD # FIALGI
      @ASG,AX # PROGFILE.
      @ASG,AX # ABS.
      @FIN*FD1.FIN,EAKS # PROGFILE.SETTLEPROG/TOTALSTATS,TPF$.TOTALSTATS
      @MAP,IS # TPF$.DUM, ABS.SETTLEPROG/TOTALSTATS
      IN # TPF$.TOTALSTATS
      LIB # FIN8R1.
      @FIN

              THE OPTIONS ON THE '@FIN, ..' CARD RESULT IN THE
              FOLLOWING:

                        'E' : 'ONE-STEP WALKBACK' -- IF A NONFATAL I/O
                              ERROR OCCURS, THEN , AFTER THE I/O ERROR
                              MESSAGE, THE LINE NUMBER AND THE NAME OF
                              THE PROGRAM UNIT WHERE THE ERROR OCCURRED
                              ARE LISTED

                        'A' : 'ERR' MODE IS NOT ENTERED WHEN SERIOUS
                              ERRORS OCCUR. WITHOUT THIS OPTION, CERTAIN
                              ERRORS (SUCH AS I/O ERRORS) RESULT IN AN
                              >ERR> TERMINATION  I.E. THE PROGRAM VERY
                              SINCERELY  'BOMBS OUT' !

                        'K' : THE UPDATE (CURRENT) AND INPUT (BASE) LINE
                              NUMBERS, AS WELL AS THE SIR CORRECTION
                              LINES TO THE FIN SOURCE LISTING,  ARE
                              PRINTED

                        'S' : ONLY THE SOURCE LISTING AND THE ERROR
                              MESSAGES (IF ANY) ARE LISTED


      A TYPICAL RUNSTREAM:


      @RUN # HEPROG, R0218-7105/HENRI, GEOMARINE, 2, 50
      @PASSWD # FIALGI
      @ASG,AX # DATA.
      @ASG,A  # ABS.
      @ASG,T  # 11.
      @ASG,T  # 12.
      @ELT,IL # TPF$.SETTLEPROG/INPUT
      RICHARD'S BAY SEDIMENTS, APRIL 1981.                 (TITLE CARD)
      175.0                                 (HEIGHT OF SETTLING COLUMN)
      @ADD,P  # DATA.RICHARDSBAY/SETTLE
      @HDG,XN # Y,M,66,0,0
      @XQT,F  # ABS.SETTLEPROG/TOTALSTATS
      @ADD,P  # TPF$.SETTLEPROG/INPUT
      @ELT,IL # DATA.RICHARDSBAY/STATSINPUT
      @ADD,P  # 11.
      @ELT,IL # DATA.RICHARDSBAY/PHIPLOTTER
      @ADD,P  # 12.
      @FIN
```

```
*       N.B.     EACH LINE IN THE RUNSTREAM ABOVE REPRESENTS ONE CARD .
*                MANDATORY BLANKS ARE REPRESENTED BY THE '#' SYMBOL .
*                ALL CARD PUNCHING STARTS IN COLUMN 1 (ONE)
*
*
*
*       REFERENCES:
*       -----------
*
*                    FLEMMING, B.W., 1977.
*                           DEPOSITIONAL PROCESSES IN SALDANHA
*                           BAY  AND  LANGEBAAN LAGOON.
*
*                                NRIO  (S.A.).  CSIR  RESEARCH
*                                                 REPORT  362.
*
*                    FLEMMING, B.W.  &  THUM, A.B., 1978.
*                           THE  SETTLING  TUBE  --  AN HYDRAULIC
*                           METHOD FOR GRAIN SIZE ANALYSIS OF SANDS
*
*                                KIELER MEERESFORCHUNGEN,
*                                SONDERHEFT 4: 82-95.
*
*                    GIBBS, R.J., MATTHEWS, M.D. & LINK, D.A., 1971.
*                           THE RELATIONSHIP BETWEEN SPHERE SIZE
*                           AND SETTLING VELOCITY.
*
*                                J. SED. PETR.  41:7-18.
*
*                    BREZINA, J., 1979.
*                           PARTICLE SIZE AND SETTLING RATE
*                           DISTRIBUTIONS OF SAND-SIZED MATERIALS.
*
*                                PARTIKEL TECHNOLOGIE NUERNBERG  (PAR TEC):
*                                2ND EUROPEAN SYMPOSIUM ON
*                                PARTICLE CHARACTERISATION:
*                                PAPER  SESSION   1,
*                                TUESDAY,    25  SEPTEMBER  1979.
*
*
*
*************************************************************************


*             DECLARATION OF VARIABLES:
*             -------------------------
*
*                                    ALL ARRAYS ARE DECLARED IN THE
*                                    TYPE DECLARATION, DATA TYPES
*                                    ARE GROUPED TOGETHER.
*
*
      REAL             SETVEL( 101 )
     &                 / 44.9062, 42.9762, 40.9773, 39.1562,
     &                   37.2947, 35.4200, 33.7254, 32.0359,
     &                   30.5131, 29.0062, 27.5318, 26.0412,
     &                   24.6451, 23.3393, 22.0255, 20.8122,
     &                   19.5782, 18.4512, 17.3605, 16.3152,
     &                   15.3221, 14.3483, 13.4507, 12.5860,
     &                   11.6258, 11.0128, 10.2405,  9.5505,
     &                    8.8769,  8.2230,  7.6445,  7.0624,
```

SETTLEPROG/TOTALSTATS

```
     &                    6.5261,  6.0241,  5.5410,  5.0926,
     &                    4.6739,  4.2977,  3.9157,  3.5741,
     &                    3.2510,  2.9564,  2.6806,  2.4270,
     &                    2.1902,  1.9743,  1.7758,  1.5925,
     &                    1.4262,  1.2745,  1.1379,  1.0115,
     &                    0.8985,  0.7973,  0.7055,  0.6237,
     &                    0.5493,  0.4850,  0.4269,  0.3755,
     &                    0.3297,  0.2892,  0.2535,  0.2221,
     &                    0.1943,  0.1700,  0.1486,  0.1298,
     &                    0.1134,  0.0990,  0.0864,  0.0754,
     &                    0.0657,  0.0573,  0.0500,  0.0436,
     &                    0.0380,  0.0331,  0.0288,  0.0251,
     &                    0.0219,  0.0191,  0.0166,  0.0145,
     &                    0.0126,  0.0110,  0.0095,  0.0083,
     &                    0.0072,  0.0063,  0.0055,  0.0048,
     &                    0.0042,  0.0036,  0.0032,  0.0028,
     &                    0.0024,  0.0021,  0.0018,  0.0016,
     &                    0.0014                                   /
      REAL             SD   ( 50 )
     &                 /0.0071, 0.0112, 0.0161, 0.0231, 0.0331,
     &                  0.0474, 0.0680, 0.0975, 0.1398, 0.2005,
     &                  0.2875, 0.4123, 0.5912, 0.8477, 1.2155,
     &                  1.7430, 2.4993, 3.5838, 5.1389, 7.3687,
     &                  10.5661,15.1507,21.7248,31.1515,44.6684,
     &                  2540.0000                                  /
      REAL             DENS ( 21 )
     &                 /0.99973,0.99961,0.99959,0.99945,0.99920,
     &                  0.99905,0.99889,0.99871,0.99855,0.99836,
     &                  0.99817,0.99795,0.99778,0.99758,0.99746,
     &                  0.99713,0.99690,0.99660,0.99638,0.99607,
     &                  0.99567                                    /
      REAL             VISC( 21 )
     &                 /0.01307,0.01271,0.01235,0.01202,0.01169,
     &                  0.01139,0.01109,0.01081,0.01053,0.01027,
     &                  0.01002,0.00978,0.00955,0.00933,0.00911,
     &                  0.00890,0.00871,0.00851,0.00833,0.00815,
     &                  0.00798                                    /
      REAL             FACTOR( 6 )
     &                 /0.200, 0.500, 1.000, 2.000, 3.000, 6.000 /
      REAL             CUMPLY( 16 )
     &                 /99.990, 99.950, 99.900, 99.500,
     &                  99.000, 95.000, 90.000, 70.000,
     &                  30.000, 10.000,  5.000,  1.000,
     &                   0.500,  0.100,  0.050,  0.010             /
      REAL
     &                 UPPHI
      REAL
     &                 30F   ( 51 )
     &                 /1.200, 1.150, 1.100, 1.050, 1.000,
     &                  0.950, 0.910, 0.870, 0.825, 0.780,
     &                  0.735, 0.690, 0.650, 0.615, 0.580,
     &                  0.545, 0.515, 0.480, 0.455, 0.425,
     &                  0.400, 0.375, 0.355, 0.330, 0.310,
     &                  0.290, 0.273, 0.255, 0.240, 0.225,
     &                  0.210, 0.200, 0.190, 0.185, 0.180,
     &                  0.178, 0.180, 0.185, 0.190, 0.200,
     &                  0.210, 0.225, 0.240, 0.260, 0.280,
     &                  0.305, 0.335, 0.365, 0.400, 0.430,
     &                  0.470                                      /
      REAL
     &                 DIST( 2,30 ),   AR( 4,200 ),   SEC( 30 ),
     &                 CUMFREQ( 3 ),   CALVEL( 30 ),  DIAM( 30 ),
```

```
     R              RADIUS( 30 ),   PHI( 30 ),      HALF1( 10 ),
     R              HAFF1( 9 ),     HALF2( 10 ),     HAFF2( 9 ),
     R              TOT1( 10 ),     TOT2( 10 ),     IFPEQX( 11 ),
     R              X( 4 ),         Y( 4 ),         S( 5 ),
     R              AMIDPH( 100 ), REYNOL( 100 ), PERC( 100 ),
     R              PCTILE( 100 ), DEC( 10 ),      MOMIMU( 100 ),
     R              MOMTOD( 100 ), MOMIDP( 100 ), MOMISK( 100 ),
     R              MOMIKT( 100 ), MEDIAF( 100 ),
     R              GRAFMU( 100 ), GRAFRD( 100 ), GRAFOH( 100 ),
     R              GRAFSK( 100 ), GRAFKT( 100 ), DRAG( 100 )
      REAL
     R              DIV1( 9 )
     R                  / -1.5, -0.5, 0.5, 1.5, 2.5,
     R                    3.5, 4.5, 5.5, 6.5                            /,
     R              DIV2( 9 )
     R                  / -1.0, 0.0, 1.0, 2.0, 3.0,
     R                    4.0, 5.0, 6.0, 7.0                            /
      REAL
     R              FOLEAN,         MU3D,           MODE,           MOSKEW,
     R              DSKEW1,         MOKUR1,         MKUR11,         MED,
     R              MUD
*
*                               =============
*
      INTEGER
     R              FYDIVF 6 )
     R                  / 1 , 11, 21, 31, 41, 51                        /
      INTEGER
     R              CYDIVF 16 )
     R                  / 2, 7, 9, 13, 15, 19, 21, 24,
     R                    28, 31, 33, 37, 39, 43, 45, 50                /
      INTEGER
     R              ICORD / 04 /, ILNP1 / 05 /,
     R              IDS11 / 11 /, IDS12 / 12 /
      INTEGER
     R              ISAMP /0/,
     R              ZERO /00/,      ONE /01/,       TWO /02/
      INTEGER
     R              SELACT( 3 ), IDEC( 9 ), IFPEQY( 6 ), CUMULX( 11 ),
     R              TEMP, FLOTOP
*
*                               =============
*
      CHARACTER*4  TITLE ( 20  )
      CHARACTER*4  SAMPL( 4 )
      CHARACTER*4  SAMP( 100,4 )
      CHARACTER*101 GRID( 51 )
      CHARACTER*30 TXTEXT( 100 )
      CHARACTER*30 FKTEXT( 100 )
      CHARACTER*24 FKSORT( 100 )
      CHARACTER*22 FLSORT( 100 )
      CHARACTER*29 FKSKEW( 100 )
      CHARACTER*22 FKKURT( 100 )
      CHARACTER*30 MEANTY
      CHARACTER*30 FOLKTY
      CHARACTER*24 FOLKST
      CHARACTER*22 FLFEST
      CHARACTER*20 FOLKSK
      CHARACTER*22 FOLKKT
      CHARACTER*4  PERCENT( 9 )
     R              / '  1 ',' 5 ',' 16 ',' 25 ',' 50 ',
     R                ' 75 ',' 84 ',' 95 ',' 99 '                     /


SETTITLEPROG/TOTALSTATS

      CHARACTER*4  DECILE( 9 )
     R              / ' 10 ',' 20 ',' 30 ',' 40 ',' 50 ',
     R                ' 60 ',' 70 ',' 80 ',' 90 '                     /
      CHARACTER*4  HALPHI( 9 )
     R              / '-1.5', '-0.5', '+0.5', '+1.5', '+2.5',
     R                '+3.5', '+4.5', '+5.5', '+6.5'                  /
      CHARACTER*4  HAPPHI( 9 )
     R              / '-1.0', '+0.0', '+1.0', '+2.0', '+3.0',
     R                '+4.0', '+5.0', '+6.0', '+7.0'                  /
      CHARACTER*4  PHIINT( 9 )
     R              / 'GRV ', 'VCS ', 'CS  ', 'MS  ', 'FS  ',
     R                'VFS ', 'C7  ', 'M7  ', 'F7  '                  /
*
*                               =============
*
      LOGICAL       GRGE20,  GRLT20,  GRGE30,  GRLT30,  GRGE5,
     R              GRLT5 ,  GRGE01,  GRLT01,  GRGE00
      LOGICAL       SMGE9 ,  SMLT9 ,  SMGE1 ,  SMLT1 ,  SMGE11,
     R              SMLT11,  SMGT00
      LOGICAL       MUL000,  SAE000
      LOGICAL       00LT35,  RD3550,  LD5070,  RD7001,  UD0102,
     R              UD0204,  UDGT04
      LOGICAL       UD0001,  CU0102,  UU0204,  UU0408,  UU0816,
     R              UU1632
      LOGICAL       SKVNEG,  SKNEG,   SKESYM,  SKPOS,   SKVPOS
      LOGICAL       KTVPLT,  KTPLAT,  KTMESO,  KTLEPT,  KTVLPT,
     R              KTELPT


***********************************************************************


*         FORMATTING:
*         ----------
*
*
*                     THE INPUT AND OUTPUT FORMATS ARE GROUPED AS
*                     FOLLOWS:
*
*                           INPUT -- 1000 SERIES LABELLED STATEMENTS
*                           -----
*
*                           OUTPUT -- 2000+ SERIES LABELLED STATEMENTS
*                           ------
*
*                     MORE SPECIFICALLY, THE GROUPING IS:
*
*                           1000 SERIES    --    CARD READER INPUT DATA
*
*                         /2000    ''      --    VALIDATION ERROR MESSAGES
*                        : 3000    ''      --    DATA DISTRIBUTION TABLES
*                       .: 4000    ''      --    GRAPH PLOTS
*                       /  7000    ''      --    INFORMATION SUMMARY FOR
*         LINE-PRINTER  <                        ALL SAMPLES IN THE RUN
*                       \  8000    ''      --    ERROR-FREE TERMINATION
*                        :                       MESSAGES
*                        :9000     ''      --    TITLE FOR THE RUN
*                        \
*
*         MAGNETIC DISC   <  6000    ''      --    OUTPUT FOR PHIPLOTTER
*                         <                      AND STATISTICAL PACKAGES
*
```

```
PROGRAM-ID       :   SETTLEPROG/TOTALSTATS
----------
AUTHOR           :   M.H.G. FORTUIN
------
DATE-WRITTEN     :   DECEMBER  1980.
------------
DATE-COMPILED    :   MAY        1981.
-------------
SOURCE COMPUTER:     UNIVAC  1108
---------------
OBJECT COMPUTER:     UNIVAC  1108
---------------
INSTALLATION     :   UNIVERSITY OF CAPE TOWN
------------
LANGUAGE USED    :   ASCII  FORTRAN  --  LEVEL 8R1.
-------------
OBJECT OF PROGRAM:
------------------

        THIS PROGRAM COMPUTES GRAIN SIZE DATA AT
        DOWN TO 0.10 PHI INTERVALS FROM THE SETTLING
        VELOCITIES OF SEDIMENT PARTICLES. PROVISION
        IS MADE, THROUGH THE PHIDIV INPUT VARIABLE,
        FOR THE PHI INTERVAL EITHER TO BE SMALLER OR
        LARGER THAN  0.10  PHI. HOWEVER, NO GRAPH
        OUTPUT IS POSSIBLE IF THE 'PHIDIV' VARIABLE
        IS LESS THAN  0.10  PHI,  DUE TO THE
        HARDWARE CONSTRAINTS OF THE COMPUTER SYSTEM.


PROGRAM HISTORY:
----------------
                          THE HISTORY OF THIS PROGRAM PRIOR
                          TO 1974 IS NOT KNOWN.

                          DR. G.J. MOIR OBTAINED A VERSION
                          OF THIS PROGRAM FROM THE
                          UNIVERSITY  OF  SOUTHERN
                          CALIFORNIA IN 1974. THE PROGRAM
                          WAS SUBSEQUENTLY IMPROVED AND
                          ADAPTED FOR USE WITH A PROTOTYPE
                          SETTLING TUBE  ( WHICH HAD BEEN
                          DEVELOPED WITHIN THE  MARINE
                          GEOSCIENCE UNIT, U.C.T. )  WITH
                          THE HELP OF, INTER ALIA, DRS.
                          A.R. DUNCAN, D.L. REID, J.M.
                          MARCHANT, R.M. FLEMMING  AND
                          MR. J.G.K. GLASS  DURING  THE
                          PERIOD  1974-1979.

                          IT WAS DECIDED THAT THE PROGRAM
                          NEEDED RESTRUCTURING AND TO BE
                          MADE MORE FLEXIBLE.ITS CONVERSION
```

SETTLEPROG/TOTALSTATS

```
                          FROM FORTRAN V TO ASCII FORTRAN
                          ALSO FACILITATED THE USE OF
                          STRUCTURED PROGRAMMING TECHNIQUES.


PROGRAM OVERVIEW:
----------------
                          THE PROGRAM HAS BEEN GROUPED INTO
                          FIVE SECTIONS  WHICH,  IN  THEIR
                          TURN,   ARE   SUBDIVIDED  INTO
                          MODULES, EACH OF WHICH PERFORMS A
                          SPECIFIC AND INDEPENDENT TASK OR
                          FUNCTION.

PROGRAM  DESIGN:
---------------

  SECTION  I  :
           -
                 MODULE  (I)   :  DECLARATION OF VARIABLES
                                            AND CONSTANTS.
                         (II)  :  FORMATS OF INPUT AND
                                            OUTPUT DATA.
                         (III) :  INITIALIZATION OF VARIABLES.

  SECTION  II  :
           --
               (INPUT)
                -----
                 MODULE  (I)   :  READING IN OF CARD IMAGES
                         (II)  :  VALIDATION OF INPUT DATA

  SECTION  III :
           ---
               (PROCESS OR 'DRIVER')
                -------     ------
                MODULE   (I)    :  SETTLING TIMES
                         (II)   :  SETTLING DIAMETERS (PHI)
                         (III)  :  PHI DISTRIBUTION
                         (IV)   :  SETTLING VELOCITIES, NORMAL  &
                                   CUMULATIVE FREQUENCY PERCENTAGES
                         (V)    :  TEXTURAL DISTRIBUTION
                         (VI)   :  MOMENT STATISTICS
                         (VII)  :  CALCULATING SELECTED PERCENTILES
                         (VIII) :  FOLK'S  GRAPHIC STATISTICS
                         (IX)   :  CALCULATING THE DECILES
                         (X)    :  TEXTURAL DESCRIPTION
                         (XI)   :  TEXTURAL CLASSIFICATION

  SECTION  IV  :
           --
               (OUTPUT)
```

```
*

 1000 FORMAT( 4A4, 1X, I2, 1X, 3( I1, 1X, F5.2, 1X ), F4.3, 1X, I2, 1X,
     &           2( F7.2 ), 2( F5.2 ), F4.2 )
 1001 FORMAT( 16F5.2 )
 1002 FORMAT( 14F5.2 )
 1003 FORMAT( 20A4 )
 1004 FORMAT( F7.2 )

*                              =============

 2000 FORMAT(1H1, 20X, ' CHECK  TEMP.  VALUE  FOR  SAMPLE  ', 4A4, //,
     &               50X, ' PROGRAM  TERMINATED  ABNORMALLY ! ',/,
     &               50X, '                      --           ' )
 2001 FORMAT(1H1, 20X, ' CHECK  PHI  INTERVAL  VALUE  FOR  SAMPLE  ',
     &                   4A4, //,
     &               50X, ' PROGRAM  TERMINATED  ABNORMALLY ! ',/,
     &               50X, '                      --           ' )
 2002 FORMAT(1H1, 20X, ' CHECK  SPEED  FACTOR  VALUES  FOR  SAMPLE  ' ,
     &                   4A4, //,
     &               50X, ' PROGRAM  TERMINATED  ABNORMALLY ! ',/,
     &               50X, '                      --           ' )
 2003 FORMAT(1H1, 20X, ' CHECK THAT YOUR INPUT DATA CARDS HAVE NOT BEEN
     &INADVERTENTLY INVERTED,',/,20X,'OR THAT ZEROES HAVE NOT BEEN ERRON
     &EOUSLY TYPED IN FOR SAMPLE  ', 4A4, //,
     &               53X, ' PROGRAM  TERMINATED  ABNORMALLY ! ',/,
     &               53X, '                      --           ' )
 2004 FORMAT(1H1, 20X, ' CHECK  SETTLING  COLUMN  LENGTH  VALUE  FOR  SA
     &MPLE  ',           4A4, //,
     &               50X, ' PROGRAM  TERMINATED  ABNORMALLY ! ',/,
     &               50X, '                      --           ' )
 2005 FORMAT(1H1, 20X, ' CHECK THAT THE INPUT DATA IS OF THE CORRECT TYP
     &E OR HAS BEEN PUNCHED CORRECTLY FOR SAMPLE  ', 4A4, //,
     &               50X, ' PROGRAM  TERMINATED  ABNORMALLY ! ',/,
     &               50X, '                      --           ' )
 2006 FORMAT(1H1, 20X, ' CHECK  THE  NUMBER  OF  CARDS  IN  THE  DATASET
     &  FOR  SAMPLE  ', 4A4, //,
     &               50X, ' PROGRAM  TERMINATED  ABNORMALLY ! ',/,
     &               50X, '                      --           ' )

*                              =============

 3000 FORMAT(1H , 14X, 48HDATA  FOR  OBTAINING  DISTRIBUTION  CURVES  FO
     &R  ,                 4A4, 2X, 15HX CO-ORDINATE: , F6.2,
     &                          2X, 15HY CO-ORDINATE: , F6.2, //,
     &          3X, 12HPHI INTERVAL, 2X, 9HREYNOLD'S, 3X, 4HDRAG, 5X,
     &              8HSETTLING, 3X, 8HSETTLING, 9X, 3HPHI, 6X, 9HFREQUENCY,
     &          4X, 10HCUMULATIVE, 5X, 9HFREQUENCY, 4X, 10HCUMULATIVE, /,
     &          5X, 8HMIDPOINT, 5X, 6HNUMBER, 4X, 6HCOEFF., 4X,
     &              8HDIAMETER, 3X, 8HVELOCITY, 6X, 8HINTERVAL, 5X,
     &              7HPERCENT, 6X, 7HPERCENT, 8X, 7HPERCENT, 6X, 7HPERCENT,
     &      /, 21X, 9H( LOG10 ), 9X, 6H( MM ), 4X, 8H( CM/S ), 16X,
     &              13H( SAND SIZE ), 13H( SAND SIZE ), 1X,
     &              14H(TOTAL SAMPLE), 14H(TOTAL SAMPLE), /,
     &          3X, 12H------------, 2X, 17H-----------------, 4X,
     &              8H--------, 3X, 8H--------, 6X, 8H--------, 4X,
     &              9H---------, 4X, 10H----------, 3X,
     &              12H------------, 2X, 12H------------, //,
     & /, 1H ,   17X, 14HAT  20  DEG. C, 15X, 12HAT 20 DEG. C,
     &           41X, 18H'SIEVED  GRAVEL': , F5.2, /,
     &          100X, 18H'SETTLED GRAVEL': , F5.2, // )
```

SETTLEPROG/TOTALSTATS

```
 3001 FORMAT(1H ,6X, F5.2, 6X, F5.2, 5X, F5.2, 5X, F7.5, 5X, F6.3,
     &              8X, F5.2, 5X, F6.2, 7X, F6.2, 9X, F6.2, 7X, F6.2 )
 3002 FORMAT(1H1,40X,40HSTATISTICAL   AND   DESCRIPTIVE   PARAMETERS,///
     &/)
 3003 FORMAT(1H , 20X, 17HMOMENT STATISTICS, 5X,
     &                 25HFOLK'S GRAPHIC STATISTICS, 30X, 7HDECILES, /,
     &            21X, 17H------ ----------, 5X,
     &                 25H------- ------- ----------, 30X, 7H-------, //,
     & 3X, 4HMEAN, 20X, F5.2, 19X, F5.2, /,
     & 3X, 12HSTD. SORTING, 12X, F5.2, 19X, F5.2, 20X, 9( A4, 2X ), /,
     & 3X, 12HMEL. SORTING, 12X, F5.2, 19X, F5.2, 19X, 9( F5.2, 1X ), /,
     & 3X, 8HSKEWNESS, 16X, F5.2, 2H *, 5X, F5.2, 2H *, 5X, F5.2, /,
     & 3X, 8HKURTOSIS, 16X, F5.2, 2H *, 5X, F5.2, 2H *, 5X, F5.2, 40X,
     & 11HPERCENTILES, /, 3X, 6HMEDIAN, 18X, F5.2, 19X, F5.2,  40X,
     & 11H----------- )
 3004 FORMAT(1H , 1HS, /, 2X, 33HAFTER FRIEDMAN & SANDERS   (1978),
     & /,        1H , 1H*, 70X, 9( A4, 2X ), /,
     &           1H , 1X, 33HAFTER KRUMBEIN & PETTIJOHN (1938),
     &           40X, 9( F5.2, 1X ), // )
 3005 FORMAT(1H , 20X, 22HTEXTURAL  DISTRIBUTION, 32X,
     &                 44HCUMULATIVE  PERCENT  AT  0.5  PHI  INTERVALS,/
     &            21X, 22H--------  ------------, 32X,
     &                 44H----------  -------  --  ---  ---  ---------,//
     & , 21X, 4HSAND, 13X, 5HTOTAL, 56X, 4HSAND, 10X, 5HTOTAL, /,
     &  ( 15X, A4, 17X, F5.2, 10X, F5.2, /, 3X, A4, 13X, F5.2, 13X, F5.2,
     & 35X, A4, 17X, F5.2, 10X, F5.2, / ), /// )
 3006 FORMAT(//, 1H , 56X, 20HTEXTURAL  CLASSIFICATION, /,
     &                 57X, 20H--------  --------------, // )
 3007 FORMAT(1H , 10HTEXTURE : , A30, 3PH, IN A TOTAL SEDIMENT CLASSIFIE
     &D AS A ,A30, 15H-- FOLK (1968), , //,
     &        1H , 10HSORTING : , A24, 7X, 22H-- FOLK & WARD (1957), ,10X
     &,                        A22, 9X, 16H-- FLEMMING (1977), ,//,
     &        1H , 10HSKEWNESS: , A24, 11X, 22H-- FOLK & WARD (1957), ,
     &5X, //,1H , 10HKURTOSIS: , A22, 9X, 22H-- FOLK & WARD (1957).,///)
 3008 FORMAT(1H , /, 3X, 21HSAND/MUD  RATIO  IS  , F5.2 )
 3009 FORMAT( /, 1H , 99X, 18H'SETTLED     MUD': , F5.2,
     &           /, 1H , 99X, 18H'SIEVED      MUD': , F5.2 )

*                              =============

 4000 FORMAT(1H , 10X, 53HFREQUENCY  DISTRIBUTION  CURVE  ( SAND  SIZE )
     &  FOR  ,           4A4, 2X, 15HX CO-ORDINATE: , F6.2,
     &                        2X, 15HY CO-ORDINATE: , F6.2, // )
 4001 FORMAT(1H , 27X, I2, 1X, A101 )
 4002 FORMAT(1H , 10X, 17HFREQUENCY PERCENT, 2X, A101 )
 4003 FORMAT(1H , 30X, A101 )
 4004 FORMAT( /, 1H , 27X, 10( F5.2, 5X ), F5.2, / )
 4005 FORMAT(1H , 67X, 27HSETTLING  DIAMETER  ( PHI ) )
 4010 FORMAT(1H ,  9X, 54HCUMULATIVE  DISTRIBUTION  CURVE  ( SAND  SIZE
     & )  FOR  ,         4A4, 2X, 15HX CO-ORDINATE: , F6.2,
     &                        2X, 15HY CO-ORDINATE: , F6.2, // )
 4011 FORMAT(1H , 24X, F5.2, 1X, A101 )
 4012 FORMAT(1H , 10X, 10HCUMULATIVE, 4X, 5H50.00, 1X, A101 )
 4013 FORMAT(1H , 10X, 7HPERCENT, 13X, A101 )
 4014 FORMAT(1H , 30X, A101 )
 4015 FORMAT(/, 1H , 29X, 10( I2, 8X ), I2, / )
 4016 FORMAT(1H , 67X, 27HSETTLING  DIAMETER  ( PHI ) )
 4020 FORMAT(1H ,  8X, 55HCUMULATIVE  DISTRIBUTION  CURVE  ( TOTAL SAMPL
     &E )  FOR  ,        4A4, 2X, 15HX CO-ORDINATE: , F6.2,
     &                        2X, 15HY CO-ORDINATE: , F6.2, // )
 4021 FORMAT(1H , 24X, F5.2, 1X, A101 )
 4022 FORMAT(1H , 10X, 10HCUMULATIVE, 4X, 5H50.00, 1X, A101 )
```

```
 4023 FORMAT(1H , 10X, 7HPERCENT, 13X, A10 )
 4024 FORMAT(1H , 30X, A10 )
 4025 FORMAT(/, 1H , 50X, 10( I2, 8X ), I2, / )
 4026 FORMAT(1H , 67X, 27HSETTLING  DIAMETER  ( PHI ), /,
     &                60X, 10H> 2PH % = , F5.2, 5X, 17H< 63 MICRONS % = ,
     &                      F5.2 )

*                                   =============


 6000 FORMAT( 4A4, 1X, 13( F5.2, 1X ),/,
     &                1X,  9( F5.2, 1X ),
     &                     4( F5.1, 1X ) )
 6001 FORMAT( 4A3, 1X, I3, 3( 1X, F4.1 ) )
 6002 FORMAT( F5.2, F8.4, F9.4 )
 6003 FORMAT( 17X, I3 )
 6004 FORMAT( ///, 1H , 67HTHE DATA ABOVE IS LISTED, FOR EACH SAMPLE, IN
     & THE FOLLOWING ORDER :, //,
     & 1X, 85HFIRST LINE:  MEAN, STD. SORTING, REL. SORTING, SKEWNESS,
     &KURTOSIS  (MOMENT MEASURES), /,
     &15X, 73HMEAN, STD. SORTING, REL. SORTING, SKEWNESS, KURTOSIS,  (GR
     &APHIC MEASURES), /,
     &15X, 66HFIRST PERCENTILE, MEDIAN DIAMETER, NINETY-NINTH PERCENTILE
     &  (PHI), , /,
     &1X, 75HSECOND LINE:  GRV, VCS, CS, MS, FS, VFS, CZ, MZ, FZ
     & (SIZE ANALYSIS), /,
     &15X, 70H                 GRAVEL, SAND, MUD, CARBONATE    (LABORATORY
     &WET SIEVING), / )
 6005 FORMAT( 17X, I3 )

*                                   =============

 7000 FORMAT(1H , 40X, 38HSTATISTICS  SUMMARY  FOR  ALL  SAMPLES, ////,
     &                24X, 4HMEAN, 19X, 2HSD, 20X, 2HSK, 17X, 8HSKEWNESS,
     &                     14X, 8HKURTOSIS, 9X, 6HMEDIAN, /,
     &                24X, 4H----, 19X, 2H--, 20X, 2H--, 17X, 8H--------,
     &                     14X, 8H--------, 9X, 6H------, //,
     &                18X, 5( 1X, 6HMOMENT, 4X, 7HGRAPHIC, 4X ), /,
     &                18X, 5( 8HMEASURES, 3X, 8HMEASURES, 3X ), // )
 7001 FORMAT( /, 1H , 4A4, 1X, 5( 1X, F5.2, 6X, F5.2, 5X ), F4.2 )
 7002 FORMAT(/, 133(1H-), /////, 49X, 22HTEXTURAL   DESCRIPTION, /,
     &                         49X, 22H---------  -----------, ////)
 7003 FORMAT(1H , 4A4, 1H , 10HTEXTURE : , A30, 19H  FRACTION  OF  A  ,
     &                A30, 15H-- FOLK(1968), , //, 18X,
     &                     10HSORTING : , A24, 7X, 22H-- FOLK & WARD (1957),,
     & 2X,            A22, 2X, 19H-- FLEMMING (1977), , //, 18X,
     &                     10HSKEWNESS: , A20, 11X, 22H-- FOLK & WARD (1957),
     & , //, 18X,          10HKURTOSIS: , A22, 9X, 22H-- FOLK & WARD (1957),
     & , //, 33X, 33( 2H-- ), /// )

*                                   =============

 8000 FORMAT(1H1, /,/, 50X, 'PROGRAM   TERMINATED   NORMALLY', ///,
     &                 50X, 'TOTAL  NUMBER  OF  SAMPLES  PROCESSED  =  '
     &,  I4, /,/,/,/, ' LAST SAMPLE PROCESSED WAS: ',  4A4 )

*                                   =============

 9000 FORMAT(1H1, 27X, 20A4, // )


*********************************************************************
```

SETTLEPROG/TOTALSTATS

```
*           INITIALIZATION SECTION
*           ----------------------
*
*           LOCAL VARIABLES USED:
*
*               SN           --    ORDINATE CONSTANTS FOR THE
*                                  NORMAL PROBABILITY SCALE USED IN
*                                  PLOTTING THE CUMULATIVE FREQUENCY
*                                  DISTRIBUTION  VS  SETTLING DIAMETER
*
*             DIS(1,1)       --    30 INTERVALS ON THE NOMOGRAM USED
*                 :                FOR SAMPLING THE INPUT DATA POINTS
*                 :                THIS IS THE FIRST ROW OF A TWO-
*             DIS(1,30)      --    DIMENSIONAL ARRAY NAMED  <DIS>
*
*               K            --    LOOP VARIABLE COUNTER
*
*
      DO  10   K = 1,25
          SN( 25+K ) = ( 100.0 ) - ( SN( 26-K ) )
   10 CONTINUE


        DIS(1,1) = 0.0
        DIS(1,2) = 0.5
        DIS(1,3) = 1.0

      DO  20   K = 4,15
          DIS(1,K) = DIS(1,K-1) + 4.
   20 CONTINUE

      DO  30   K = 16,30
          DIS(1,K) = ( 100. ) - ( DIS(1,31-K) )
   30 CONTINUE


*********************************************************************


*           INPUT  SECTION:
*           --------------
*
*
*           READ MODULE:
*                      THE DATA IS INPUT VIA THE CARD READER AND IS
*                      ORDERED AS FOLLOWS:
*
*                      (I) TITLE CARD     (20A4 I.E. 80 CHARACTERS)
*                      (II)HT CARD        (F7.2 I.E. 7 NUMERIC DIGITS)
*                                          REPRESENTING THE HEIGHT OF
*                                          THE SETTLING COLUMN
*
*                       (III)DATA CARDS IN GROUPS OF 3 PER SAMPLE
*
*                    EXAMPLE OF DATA CARD IMAGE INPUT:
*                    --------------------------------
*
*       CARD 1:
*             88-110101[illegible]/24/1////////2/F123./3/R062./0.10/
*               10/101.25F102.75E5.10E2.75*77.0
```

```
      CARD 2: 20.#033.#400.#497.#609.5#102.#110.5112.# -- ETC.

      CARD 3: 154.#160.#165.#171.5180.# -- ETC.

      EXPLANATION:
      ------------
                               DESCRIPTION          FORMAT   TYPE     VARIABLE NAME

      98-010101                SAMPLE NUMBER        8A8      ALPHA    SAMPL
      20  /                    TEMPERATURE OF THE   I2       INTEGER  TEMP
                               MEDIUM ( WATER)
      1                        AN INITIAL SPEED     I1       INTEGER  SPFACT(1)
                               FACTOR,REPRESENTING
                               THE PAPER FEED RATE
                               OF THE PEN RECORDER.
                               6 PAPER FEED RATES
      2                        ARE USED, AND ARE    I1       INTEGER  SPFACT(2)
                               CODED AS:
                               1 -- 300MM/MIN.
                               2 -- 1200MM/MIN.
                               3 --  600MM/MIN.
                               4 --  300MM/MIN.
                               5 --  200MM/MIN.
                               6 --  100MM/MIN.
      123.                     AN EXAMPLE OF THE    F5.2     REAL     CHANGE(2)
                               DISTANCE IN MM. FROM
                               THE STARTING POINT AT
                               WHICH THE PAPER FEED
                               RATE WAS CHANGED FROM
                               300MM/MIN TO 1200MM/MIN
      3                                             I1       INTEGER  SPFACT(3)
      462.                     N.B. IF A RUN IS     F5.2     REAL     CHANGE(3)
                               STARTED AT A SPEED
                               FACTOR 2 OR 3, THEN
                               THESE TAKE THE POSITION
                               OF SPEED FACTOR 1 ON
                               THE CARD I.E. SPEED
                               FACTORS ARE ALWAYS
                               LEFT-JUSTIFIED
      0.10                     PHI INTERVAL AT      F4.3     REAL     PHIDIV
                               WHICH THE
                               THE DATA IS TO
                               BE PRESENTED
      0                        OPTION FOR           I2       INTEGER  PLOTOP
                               PRINTING THE
                               GRAPHS :
                               0 -- ALL GRAPHS
                               1 -- NO  GRAPHS
      101.55                   LINE OF LONGITUDE    F7.2     REAL     XCOORD
      102.75                   LINE OF LATITUDE     F7.2     REAL     YCOORD
      5.10                     PERCENTAGE (SILT     F5.2     REAL     MUD
                               + CLAY) FRACTION
                               WHICH PASSES
                               THROUGH A 63
                               MICRON SIEVE.
      2.75                     PERCENTAGE GRAVEL    F5.2     REAL     GRAVEL
                               FRACTION LEFT
                               BEHIND ON A 2MM

SETTLEPROG/TOTALSTATS

                               SIEVE
      77.0                     WEIGHT LOSS AFTER    F4.2     REAL     CARB
                               SEDIMENT HAS
                               UNDERGONE ACID
                               DIGESTION

    N.B. '#' REPRESENTS MANDATORY BLANKS BETWEEN FIELDS ON CARD
         '/' REPRESENTS OPTIONAL BLANKS WITHIN FIELDS ON CARD

      DATACARDS 2 & 3:

                               SECOND ROW OF        F5.2     REAL     DIS(2,1)
                               TWO-DIMENSIONAL                            !
                               ARRAY -- THE                               :
                               DISTANCES IN MM.                           :
                               BETWEEN THE STARTING                       :
                               LINE AND THE                               :
                               RECORDED CURVE.                            :
                               THESE 30 SAMPLED                           :
                               PERCENTILES OF THE                         :
                               RECORDED SETTLING                          :
                               CURVE ARE                                  :
                               DISTRIBUTED AS                             V
                               FOLLOWS:                               DIS(2,30)

      CARD 2:        0%, 0.5%, 1%, 5%, 9%, 13%, 17%, 21%, 25%,
                     29%, 33%, 37%, 41%, 45%, 49%, 51%,
      CARD 3:        55%, 59%, 63%, 67%, 71%, 75%, 79%,
                     83%, 87%, 91%, 95%, 99%, 99.5%, 100%

      READ ( ICORD,1003 ) TITLE
      READ ( ICORD,1004 ) CI

   40 CONTINUE

      READ ( ICORD,1000, ERR=900, END=920 )  SAMPL, TEMP,
     &                                     ( SPFACT( K ),
     &                                       CHANGE( K ),  K=1,3 ),
     &                                       PHIDIV, PLOTOP,
     &                                       XCOORD, YCOORD,
     &                                       MUD, GRAVEL, CARB
      READ ( ICORD,1001, ERR=900, END=910 ) ( DIS( 2,K ), K=1,16 )
      READ ( ICORD,1002, ERR=900, END=910 ) ( DIS( 2,K ), K=17,30 )
                                                    # TALLY OF
            ISAMP    =    ISAMP  +  1               # NO. OF SAMPLES
                                                    # READ IN

                                ==============

          VALIDATION MODULE:
                          THE DATA INPUT IS CHECKED FOR
                          REASONABLENESS, AND PRINTS OUT
                          INFORMATIVE ERROR MESSAGES AS
                          AND WHEN ERRORS ARE ENCOUNTERED.
                          THE PROGRAM IS THEN TERMINATED.
```

```
*
*
*
      IF   (TEMP.EQ.0.0)  THEN
                WRITE (ILNPT,2000) SAMPL
                STOP
      ENDIF

      IF   (PHIDIV.LE.0.0001)  THEN
                WRITE (ILNPT,2001) SAMPL
                STOP
      ENDIF

      IF   (SPFACT(1).EQ.0.0)  THEN
                WRITE (ILNPT,2002) SAMPL
                STOP
      ENDIF
      DO   50  K = 1,30
           IF  ( DIS( 2,K ) .EQ. 0.0 )  THEN
                WRITE ( ILNPT,2003) SAMPL
                STOP
           ENDIF
   50 CONTINUE



************************************************************************

*         PROCESS SECTION:
*         ----------------
*
*         (I)  CALCULATING SETTLING TIMES:
*
*              LOCAL VARIABLES USED:
*
*                 S(1-3)          --    CORRECTED CUMULATIVE DISTANCE
*                                       TRAVELLED BY THE RECORDED CURVE
*                                       WHEN VARYING PAPER FEED RATE IS
*                                       USED
*                 SPFACT(1-3)     --    CODE FOR SPECIFYING WHICH PAPER
*                                       FEED RATE HAS BEEN USED
*                 CHANGE(1-3)     --    POINT AT WHICH THE PAPER FEED
*                                       RATE WAS CHANGED ( IF AT ALL)
*                 FACTOR(1-3)     --    FACTOR FOR CONVERTING ALL PAPER
*                                       RATES TO A SPEED OF 60 MM/MIN
*                 SEC(1-30)       --    CALCULATED SETTLING TIME AT EACH
*                                       POINT PICKED OFF THE RECORDED
*                                       CURVE
*
*                 K               --    LOOP VARIABLE COUNTER
*
*
*

              S(1) = 0.0


      IF   (SPFACT(2).EQ.0.0)  THEN

SETTLEPROG/TOTALSTATS

              DO   60  K = 1,30
                  SEC(K) = ( DIS(2,K) )* ( FACTOR(SPFACT(1)) )
   60         CONTINUE

      ENDIF

      IF   (SPFACT(2).NE.0.0.AND.SPFACT(3).EQ.0.0)  THEN

              S(2) = ( CHANGE(2) )*( FACTOR(SPFACT(1)) )

              DO   70  K = 1,30

                   IF   (DIS(2,K).LE.CHANGE(2))  THEN
                        SEC(K) = (DIS(2,K) )*( FACTOR(SPFACT(1)) )
                   ENDIF

                   IF   (DIS(2,K).GT.CHANGE(2))  THEN
                        SEC(K)=(DIS(2,K) - CHANGE(2))*(FACTOR(SPFACT(2)))
                        SEC(K) = ( SEC(K) ) + S(2)
                   ENDIF

   70         CONTINUE

      ENDIF

      IF   (SPFACT(2).NE.0.0.AND.SPFACT(3).NE.0.0)  THEN

              S(2) = ( CHANGE(2) )*( FACTOR(SPFACT(1)) )
              S(3) = ( ( CHANGE(3)-CHANGE(2) )*( FACTOR(SPFACT(2)) ) )
              S(3) = ( S(3) ) + S(2)

              DO   80  K = 1,30

                   IF   (DIS(2,K).LE.CHANGE(2))  THEN
                        SEC(K) = ( DIS(2,K) )*( FACTOR(SPFACT(1)) )
                   ENDIF

                   IF   (DIS(2,K).GT.CHANGE(2).AND.DIS(2,K).LE.CHANGE(3))
     &               THEN
                        SEC(K)=(DIS(2,K) - CHANGE(2))*(FACTOR(SPFACT(2)))
                        SEC(K) = ( SEC(K) ) + S(2)
                   ENDIF

                   IF   (DIS(2,K).GT.CHANGE(3))  THEN
                        SEC(K)=(DIS(2,K) - CHANGE(3))*(FACTOR(SPFACT(3)))
                        SEC(K) = ( SEC(K) ) + S(3)
                   ENDIF

   80         CONTINUE

      ENDIF


*                           =============
*
*         (II) CALCULATING SETTLING DIAMETERS (PHI):
*
*
*              LOCAL VARIABLES USED:
*
```

```
*                    FALVEL(1-30)   --   UNCORRECTED INTERMEDIATE SETTLING
*                                        VELOCITY
*                    PL             --   FALL HEIGHT OF THE SETTLING TUBE
*                                        I.E. THE DISTANCE IN CM. BETWEEN
*                                        THE WATER SURFACE AT SAMPLE ENTRY
*                                        AND THE COLLECTING PAN
*                    SEC(1-30)      --   CALCULATED SETTLING TIME FOR EACH
*                                         SAMPLED POINT ON THE RECORDED
*                                         CURVE
*                     TEMP           --   TEMPERATURE OF THE SETTLING MEDIUM
*                     I              --   SUBSCRIPT INDEX FOR TEMP USED IN
*                                         DENS AND VISC ARRAYS
*                     DENS(1-21)     --   DENSITY OF WATER (SETTLING MEDIUM)
*                                         FOR TEMPERATURE RANGE 10-30 C
*                     VISC(1-21)     --   VISCOSITY OF WATER BETWEEN 10
*                                         AND 30 DEGREES CELSIUS
*                     RADIUS(1-30)   --   SETTLING RADIUS OF THE
*                                         PARTICLE IN CM
*                     DIAM(1-30)     --   SETTLING DIAMETER OF THE
*                                         PARTICLE IN MM
*                     PHI(1-30)      --   SETTLING DIAMETER IN PHI UNITS
*                                         OF PARTICLE
*
*                     K              --   LOOP VARIABLE COUNTER
*
*
*
*               LOCAL CONSTANTS USED:
*
*                     2.65           --   DENSITY OF QUARTZ SPHERES
*                     980.66         --   FORCE EXERTED BY GRAVITY
*                     (0.500)        \    THESE CONSTANTS ARE USED IN THE
*                     -0.055804      :    SETTLING EQUATION OF THE ORIGINAL
*                                     >   PROGRAM. THEIR SIGNIFICANCE AND
*                     -2.25          :    HISTORY ARE EXPLAINED BY GIBBS,
*                     0.004353       /    ET AL, 1971.
*
*
*

      DO  90  K = 1,30

          FALVEL( K ) = ( PL )/( SEC( K ) )

              I = ( TEMP - 9 )
              A = ( 0.500 )*( 2.65 - DENS( I ) )*( 980.66 )
              B = ( -0.0558040 )*( DENS(I) )*( FALVEL(K)**2 )
              C = ( -2.250 )*( ( VISC(I) )*( DENS(I) ) )*( FALVEL(K) )
              C = ( C ) - ( ( 0.098353 )*( DENS(I) )*( FALVEL(K)**2 ) )
         RADIUS(K) = ( (-1)*( B ) + ( DSQRT(B**2 - 4*A*C) ) ) / ( 2*A )

      DIAM( K ) = ( RADIUS( K ) )*( 20. )
      PHI ( K ) = ( (-1)*( DLOG10( DIAM(K) ) ) ) / ( DLOG10( 2. ) )


   90 CONTINUE


*                              =============

*          (III)CALCULATING PHI DISTRIBUTION AT
*               SPECIFIED PHI INTERVALS:
*
*
```



```
*               LOCAL VARIABLES USED:
*
*                     A, B, C        --   INCREMENTAL INTERMEDIATE VARIABLES
*                                         FOR FINDING INITIAL PHI INTERVAL
*                     INENET         --   PHI INTERVAL OVER WHICH THE
*                                         RUNNING MEANS ARE COMPUTED
*                     PHIDIV         --   SPECIFIED PHI INTERVAL AT WHICH
*                                         THE DATA DISTRIBUTION IS PRESENTED
*                     NM(3,..)(9,..)--    SETTLING DIAMETER (PHI)
*                     NM(1,..)       --   SETTLING DIAMETER (MM.)
*                     VALUE          --   TEMPORARY INTERMEDIATE VARIABLE
*                     L              --   TOTAL NUMBER OF PHI CLASSES
*                     IDIFF          --   FLAG WHICH INDICATES WHETHER THE
*                                         SMOOTHED AND RAW CURVE START AT
*                                         THE SAME POINT OR NOT
*
*                     K              --   LOOP VARIABLE COUNTER
*
*


          INENET  =  0.05

          A  =  -5.0
          B  =  -5.0

  100 CONTINUE

          A  =  ( A ) + INENET
          B  =  ( B ) + PHIDIV
          C  =  ( B ) - ( A )
          IF  ( (A) .LE. PHI(1) )  THEN

              IF  ( (C) .GT. 0.0001 )  THEN
                  B  =  ( B ) - PHIDIV
              ENDIF

              GO  TO  100

          ENDIF
          A  =  ( A ) - ( (INENET)*(2.) )
          B  =  ( B ) - ( (PHIDIV)*(2.) )
          K  =  0

  110 CONTINUE

          A  =  ( A ) + INENET
          B  =  ( B ) + PHIDIV
          K  =  ( K ) + 1


                          NM(3,K) = B
                          NM(9,K) = A


                  VALUE = ( DLOG10( 2. ) )*( B )
                  VALUE = ( - ( ( DLOG( 10. ) )*( ( VALUE ) ) ) )
                          NM(1,K) = ( DEXP( VALUE ) )

        IF  ( (A).LT.PHI(30) .AND. (K).LT.200 )    GO TO    110
```

```
          L = K

          IDIFF = 1

          IF  ( ( ABS( NM(3,2) - NM(9,2) ) ) .LE. 0.0001 )  THEN
              IDIFF = 2
          ENDIF

*
*                          ==============
*
*           (IV) CALCULATING NORMAL AND CUMULATIVE FREQUENCY
*                PERCENTAGES FOR BOTH SAND SIZE AND TOTAL SEDIMENT,
*                AND SETTLING VELOCITY OVER THE WHOLE DISTRIBUTION:
*                WHERE THE CUMULATIVE CURVE IS SMOOTHED AT 0.05
*                PHI INTERVALS WITH TWO SUCCESSIVE RUNNING MEANS.
*
*
*                LOCAL VARIABLES USED:
*
*                    NM(2,1-..)      --   STANDARD SETTLING VELOCITY OF THE
*                                         PARTICLE AT 18 DEGREES CELSIUS
*                    NM(4,1-..)      --   WEIGHT PERCENTAGE PER CLASS
*                                         INTERVAL (PHI) FOR SAND SIZE ONLY
*                    NM(5,1-..)      --   CUMULATIVE WEIGHT PERCENTAGE PER
*                                         ON SAND SIZE DISTRIBUTION CURVE
*                    NM(6,1-..)      --   WEIGHT PERCENTAGE PER CLASS
*                                         INTERVAL (PHI) FOR TOTAL SEDIMENT
*                    NM(7,1-..)      --   CUMULATIVE WEIGHT PERCENTAGE PER
*                                         PHI ON TOTAL DISTRIBUTION CURVE
*                    NM(8,1-..)      --   SMOOTHED MEAN WEIGHT PERCENTAGE
*                                         PER CLASS INTERVAL AT 1/20 PHI
*                    NM(9,1-..)      --   1/20 PHI INTERVALS
*                    SETGRV          --   PERCENTAGE GRAIN SIZES WHICH
*                                         HYDRAULICALLY BEHAVE LIKE 'GRAVEL'
*                    SETMUD          --   PERCENTAGE GRAIN SIZES WHICH
*                                         HYDRAULICALLY BEHAVE LIKE 'MUD'
*                    GRAVEL          --   THAT PROPORTION OF THE TOTAL
*                                         SEDIMENT (IN PERCENT) WHICH DOES
*                                         NOT PASS THROUGH A 2MM. SIEVE SCREEN
*                    MUD             --   THAT PROPORTION OF THE TOTAL
*                                         SEDIMENT (IN PERCENT) WHICH PASSES
*                                         THROUGH A 63 MICRON SIEVE SCREEN
*                    TOTGRV          --   THAT PROPORTION (IN PERCENT) OF
*                                         THE TOTAL SEDIMENT WHICH BEHAVES
*                                         LIKE GRAVEL SIZED PARTICLES
*                    TOTMUD          --   THAT PROPORTION (IN PERCENT) OF
*                                         THE TOTAL SEDIMENT WHICH BEHAVES
*                                         LIKE MUD SIZED PARTICLES
*                    SAND            --   THAT PROPORTION (IN PERCENT) OF
*                                         THE TOTAL SEDIMENT WHICH REMAINS
*                                         AFTER WET SIEVING WITH THE 2 MM.
*                                         AND 63 MICRON SIEVE SCREENS
*                    COSAND          --   THAT PROPORTION (IN PERCENT) OF
*                                         THE SAND SIZED SEDIMENT WHICH DOES
*                                         NOT HYDRAULICALLY BEHAVE LIKE
*                                         EITHER GRAVEL OR MUD
*                    SETVEL(..-..) --     TABLE OF SETTLING VELOCITIES WHICH
*                                         HAVE BEEN STANDARDIZED AT 20
*                                         DEGREES CELSIUS
```



```
*                    REYNOL(..-..) --     REYNOLD'S NUMBER PER CLASS
*                                         INTERVAL EXPRESSED AS THE LOG
*                                         TO THE BASE TEN (DLOG10)
*                    DRAG( ..-.. ) --     DRAG COEFFICIENT FOR THE SPHERES
*                                         HAVING THE SAME SETTLING
*                                         VELOCITIES AS THE ACTUAL
*                                         PARTICLES AND ASSUMING A SHAPE
*                                         FACTOR  ( SF' )  OF  1.2
*                                         ( I.E. SMOOTH GLASS SPHERES ),
*                                         EXPRESSED AS LOG, BASE TEN.
*                    INM             --   INTEGERIZED PHI INTERVAL VALUE
*                    IPHI            --   TEST INTEGER IN RANGE -20 TO 101
*                    RATIO           --   TEMPORARY RATIO VARIABLE
*                    CVINT           --   AVERAGE INTERVAL ON THE RECORDED
*                                         CURVE BETWEEN TWO OF THE SAMPLED
*                                         PERCENTILE POINTS
*                    RUMEN5          --   SUM OVER FIVE CLASS INTERVALS
*                    RUMEN3          --   SUM OVER THREE CLASS INTERVALS
*                    IREM            --   REMAINDER OF EQUATION: ( L/2 )
*
*                    IGRV, IMUD      --   VARIABLE COUNTERS
*                    I, K, L         --   LOOP VARIABLE COUNTERS
*
*

                                  SETGRV  = 0.00
                                  SETMUD  = 0.00


                                  NM(4,1) = 0.00
                                  NM(5,1) = 0.00
                                  NM(6,1) = 0.00
                                  NM(7,1) = 0.00
                                  NM(8,1) = 0.00

         DO  120  I = 2,L

             DO  115  K = 2,30

                 IF  ( PHI(K) .GT. NM(9,I) )  THEN
                     RATIO = ( NM(9,I)-PHI(K-1) ) / ( PHI(K)-PHI(K-1) )
                     CVINT = ( DIS(1,K) - DIS(1,K-1) )
                                  NM(5,I) = ( RATIO*CVINT ) + ( DIS(1,K-1) )
                                  NM(4,I) = NM(5,I) - NM(5,I-1)
                                  NM(8,I) = NM(4,I)

                                  GO  TO  120

                 ENDIF

 115         CONTINUE

 120 CONTINUE

             IF  ( NM(9,L) .GE. PHI(30) )  THEN
                                  NM(5,L) = 100.0
                                  NM(4,L) = 100.0 - NM(5,L-1)
                                  NM(8,L) = NM(4,L)
             ENDIF

          DO  130  K = 4,(L-2)
```

```
                RUMEN5 = NM(4,K-2) + NM(4,K-1) + NM(4,K) +
     &                   NM(4,K+1) + NM(4,K+2)
                NM(8,K)= (RUMEN5)/(5.000)
 130    CONTINUE

        DO  140  K = 4,(L-2)
            NM(4,K)= NM(8,K)
 140    CONTINUE

        DO  150  K = 3,(L-1)
            RUMEN3  = NM(4,K-1) + NM(4,K) + NM(4,K+1)
            NM(8,K) = (RUMEN3)/(3.000)
            NM(5,K) = NM(8,K) + NM(5,K-1)
 150    CONTINUE

            NM(5,L) = NM(4,L) + NM(5,L-1)
            RATIO   =  ( 100.00 )/( NM(5,L) )

        DO  160  K = 2,L
            NM(4,K) = ( NM(8,K) )*( RATIO )
            NM(5,K) = NM(4,K) + NM(5,K-1)
            NM(8,K) = 0.00
 160    CONTINUE


          IREM      =  MOD( L ,2 )
          L         =  ( L/2 ) + IREM


          IGRV      =  1
          IMUD      =  ( L ) + 1


        DO  170  K = 2,L
            NM(5,K) = NM(5,(2*K-IDIFF))
            NM(4,K) = NM(5,K) - NM(5,K-1)

            IF  ( NM(3,K) .LT. -0.9999 )  THEN
                SETGRV = SETGRV + NM(4,K)
                IGRV   = IGRV + 1
                NM(6,K)= 0.00
                NM(7,K)= 0.00
            ENDIF
            IF  ( NM(3,K) .GT. +4.0001 )  THEN
                SETMUD = SETMUD + NM(4,K)
                IMUD   = IMUD - 1
                NM(6,K)= 0.00
                NM(7,K)= 0.00
            ENDIF
 170    CONTINUE
          IF  ( ( IDIFF .EQ. TWO ) .AND. ( IREM .EQ. ZERO ) )  THEN
              L        =    ( L ) + 1
              IDIFF    =    ( IDIFF )
              IMUD     =    ( IMUD ) + 1

              NM(5,L) = NM(5,( 2*L-IDIFF ))
              NM(4,L) = NM(5,L) - NM(5,L-1)

              IF  ( NM(3,L) .GT. +4.0001 )  THEN
                NM(6,L) = 0.00
                NM(7,L) = 0.00
```

SETILEPROG/TOTALSTATS

```
                SETMUD  = SETMUD + NM(4,L)
                IMUD    = IMUD - 1
              ENDIF

          ENDIF

          IF  ( ( IDIFF .EQ. TWO ) .AND. ( IREM .EQ. ONE ) )  THEN
              L        =    ( L ) + 1
              IDIFF    =    ( IDIFF ) + 1
              IMUD     =    ( IMUD ) + 1

              NM(5,L) = NM(5,( 2*L-IDIFF ))
              NM(4,L) = NM(5,L) - NM(5,L-1)

              IF  ( NM(3,L) .GT. +4.0001 )  THEN
                NM(6,L) = 0.00
                NM(7,L) = 0.00
                SETMUD  = SETMUD + NM(4,L)
                IMUD    = IMUD - 1
              ENDIF

          ENDIF

          IF  ( ( IDIFF .EQ. ONE ) .AND. ( IREM .EQ. ZERO ) )  THEN
              L        =    ( L ) + 1
              IDIFF    =    ( IDIFF ) + 1
              IMUD     =    ( IMUD ) + 1

              NM(5,L) = NM( 5,( 2*L-IDIFF ))
              NM(4,L) = NM(5,L) - NM(5,L-1)

              IF  ( NM(3,L) .GT. +4.0001 )  THEN
                NM(6,L) = 0.00
                NM(7,L) = 0.00
                SETMUD  = SETMUD + NM(4,L)
                IMUD    = IMUD - 1
              ENDIF

          ENDIF

          IF  ( ( IDIFF .EQ. ONE ) .AND. ( IREM .EQ. ONE ) )  THEN
              L        =    ( L )
              IDIFF    =    ( IDIFF )

              NM(5,L) = ( NM(5,L) )
              NM(4,L) = ( NM(4,L) )

              IF  ( NM(3,L) .GT. +4.0001 )  THEN
                NM(6,L) =    0.00
                NM(7,L) =    0.00
                SETMUD  = ( SETMUD )
                IMUD    = ( IMUD )
              ENDIF

          ENDIF


              TEMP      =    20
              VISCOS    =    ( VISC( TEMP-9 ) )*( 10.000 )

        DO  180  I = 2,L
```

```
              INM = ( NM(3,I) )*( 10 )
              IPHI =  -20

         DO  175  K = 1,101

              IF  ( INM .EQ. IPHI )  THEN

                        NM(2,I) = SEIVEL(K)
                        REYNOL(I) = ( NM(2,I) )*( PH(1,I) )/( VISCOS )

                          COEFF1 = ( 23.963 )/( REYNOL(I) )
                          COEFF2 = ( 4.059 )/( DSQRT( REYNOL(I) ) )
                          COEFF3 =    0.379679

                         DRAG(I) =  COEFF1 + COEFF2 + COEFF3
                         DRAG(I) = DLOG10( DRAG(I) )
                       REYNOL(I) = DLOG10( REYNOL( I ) )

                           GO  TO  180
              ENDIF

              IPHI = IPHI + 1

  175     CONTINUE

  180 CONTINUE


                           SAND     = ( 100.00 ) - ( GRAVEL + MUD )
                           COSAND   = ( 100.00 ) - ( SETGRV + SETMUD )


                           SETGRV   = ( SETGRV/100.00 )*( SAND )
                           SETMUD   = ( SETMUD/100.00 )*( SAND )


                           TOTGRV = GRAVEL + SETGRV
                           TOTMUD = MUD    + SETMUD

                           SAND     = ( 100.00 ) - ( TOTGRV + TOTMUD )

                           NM(6,IGRV+1) = NM(4,IGRV+1)*(100.00/COSAND)
                           NM(6,IGRV+1) = NM(6,IGRV+1)*( SAND/100.00 )
                           NM(7,IGRV+1) = NM(6,IGRV+1)  +  TOTGRV

              DO  190  K = ( IGRV+2 ), ( IMUD-1 )

                           NM(6,K) = ( NM(4,K) )*( 100.00/COSAND )
                           NM(6,K) = ( NM(6,K) )*( SAND / 100.00 )
                           NM(7,K) =    NM(6,K)  +  NM(7,K-1)

  190         CONTINUE



*                          =============

*        (V)  CALCULATING THE TEXTURAL DISTRIBUTION:
```

SETTLEPROG/TOTALSTATS

```
*
*
*              LOCAL VARIABLES USED:
*
*                   DIV1(1-9)       --    CUTOFF POINTS AT -1.5, -0.5,
*                                         0.5, 1.5, ..., 6.5
*                   DIV2(1-9)       --    CUTOFF POINTS AT -1.0, 0.0,
*                                         1.0, 2.0, ..., 7.0
*                   HALF1(1-9)      --    SUBTOTALS AT 'DIV1' INTERVALS
*                                         FOR SAND SIZE
*                   HARF1(1-9)      --    SUBTOTALS AT 'DIV1' INTERVALS
*                                         FOR TOTAL SAMPLE
*                   HALF2(1-9)      --    SUBTOTALS AT 'DIV2' INTERVALS
*                                         FOR SAND SIZE
*                   HARF2(1-9)      --    SUBTOTALS AT 'DIV2' INTERVALS
*                                         FOR TOTAL SAMPLE
*                   TOT1(1-9)       --    SUBTOTALS AT ONE PHI INTERVALS
*                                         FOR SAND SIZE SEDIMENT
*                   TOT2(1-9)       --    SUBTOTALS AT ONE PHI INTERVALS
*                                         FOR TOTAL SAMPLE
*                   TOTAL1,TALLY1 --      RUNNING CUMULATIVE TOTAL FOR
*                                         SAND SIZE SAMPLE
*                   TOTAL2,TALLY2 --      RUNNING CUMULATIVE TOTALS FOR
*                                         TOTAL SAMPLE
*
*                   ICOUNT,JCOUNT --      LOOP VARIABLE COUNTERS
*                   K, L            --    LOOP VARIABLE COUNTERS
*
*
                           TOTAL1   = 0.0
                           TOTAL2   = 0.0
                           TALLY1   = 0.0
                           TALLY2   = 0.0


              ICOUNT   =  1
              JCOUNT   =  1

       DO   200   K = 1,9
              HALF1( K ) = 0.00
              HALF2( K ) = 0.00
              HARF1( K ) = 0.00
              HARF2( K ) = 0.00
              TOT1( K )  = 0.00
              TOT2( K )  = 0.00
  200 CONTINUE

       DO   210   K = 2,L
                           TOTAL1   = ( TOTAL1 ) + ( NM(4,K) )
                           TOTAL2   = ( TOTAL2 ) + ( NM(6,K) )
                           TALLY1   = ( TALLY1 ) + ( NM(4,K) )
                           TALLY2   = ( TALLY2 ) + ( NM(6,K) )

            DO   204   ICOUNT = 1,9
              IF   ( ( ABS( NM(3,K)-DIV1(ICOUNT) ) ) .LE. 0.0001 )
     &           THEN
                   HALF1( ICOUNT ) = TOTAL1
                   HALF2( ICOUNT ) = TOTAL2
                   HARF1( ICOUNT ) = TOT1(ICOUNT) - HALF1(ICOUNT)
                   HARF2( ICOUNT ) = TOT2(ICOUNT) - HALF2(ICOUNT)
                   TOTAL1 = 0.0
```

```
                        TOTAL2 = 0.0
                        GO TO  210
                    ENDIF
      204       CONTINUE
                DO  206   JCOUNT = 1,9
                    IF  ( ( ABS( WR(3,K)-DIV2(JCOUNT) ) ) .LE. 0.0001 )
     &               THEN
                        TOT1(JCOUNT) = TOTAL1 + HALF1(JCOUNT)
                        TOT2(JCOUNT) = TOTAL2 + HALF2(JCOUNT)
                        TOT1(JCOUNT + 1) = 100.0 - TALLY1
                        TOT2(JCOUNT + 1) = SAND - TALLY2
                        HALF1(JCOUNT) = TOTAL1
                        HALF2(JCOUNT) = TOTAL2
                        HALF1(JCOUNT + 1) = TOT1(JCOUNT + 1)
                        HALF2(JCOUNT + 1) = TOT2(JCOUNT + 1)
                        TOTAL1 = 0.0
                        TOTAL2 = 0.0
                        GO TO  210
                    ENDIF
      206       CONTINUE

      210 CONTINUE



*                                  =============

*
*           (VI) CALCULATING MOMENT STATISTICS:
*
*
*                   LOCAL VARIABLES USED:
*
*                       AMIDNM(1-..)    --    MIDPOINTS OF THE CLASS INTERVALS
*                       SUM             --    SUMMED WEIGHT PERCENTAGES OVER THE
*                                             PHI CLASS INTERVALS
*                       X(1-4)          --    FIRST TO FOURTH MOMENTS ABOUT THE
*                                             TRUE MEAN
*                       Y(1-4)          --    FIRST TO FOURTH MOMENTS ABOUT THE
*                                             ASSUMED MEAN
*                       WR(4,1-..)      --    WEIGHT PERCENTAGES PER PHI CLASS
*                                             INTERVAL
*                       MOMEAN          --    MEAN SETTLING DIAMETER (PHI)
*                       MOSD            --    STANDARD SORTING
*                       MOOR            --    RELATIVE SORTING: FLEMMING (1977)
*                       MOSKEW          --    SKEWNESS AS DEFINED BY FRIEDMAN
*                                             AND SANDERS (1978)
*                       MSKEW1          --    SKEWNESS AS DEFINED BY KRUMBEIN
*                                             AND PETTIJOHN (1938), AND WHICH
*                       QDE(1-51)       --    REFERENCE TABLE OF ELEMENTARY
*                                             SORTING VALUES USED IN THE
*                                             CALCULATION OF RELATIVE SORTING
*                                             AS DEFINED BY FLEMMING (1977)
*                       QDPHI           --    INTERMEDIATE CUTOFF POINT
*
*                       K, I            --    LOOP VARIABLE COUNTERS
*
*
          DO  220  K = 1,L
              AMIDNM(K) = ( WR(3,K) - ( (PHIDIV)/(2.) ) )
      220 CONTINUE
```

SETTLEPROG/TOTALSTATS

```
            SUM = 0.0

          DO  230  K = 1,L
              SUM = ( SUM )  +  ( WR( 4,K ) )
      230 CONTINUE

          DO  240  K = 1,4
              X( K ) = 0.0
              Y( K ) = 0.0
      240 CONTINUE

          DO  250  I = 1,4

              DO  245  K = 2,L
                  Y(I) = ( Y(I) + ( ( WR(4,K) )*( AMIDNM(K)**I ) )/(SUM) )
      245         CONTINUE

      250 CONTINUE


          X(1) = Y(1)
          X(2) = ( Y(2) ) - ( ( Y(1) )**2 )
          X(3) = Y(3) - ( 3*( Y(2)*Y(1) ) ) + ( 2*( Y(1)**3 ) )
          X(4) = Y(4) + Y(1)*( ( -4*Y(3) )+( 6*Y(1)*Y(2) )-( 3*Y(1)**3 ) )

          MOMEAN = X(1)
          MOSD   = ( SQRT( X(2) ) )
          MOKURT = ( X( 4 ) )/( X( 2 )**2 )
          MKURT1 = ( X( 4 ) )/( X( 2 )**2 ) - ( 3.0 )
          MOSKEW = ( X( 3 ) )/( ( SQRT( X( 2 ) ) )*( X( 2 ) ) )
          MSKEW1 = ( X( 3 ) )/( ( 2.0 )*( ( SQRT( X( 2 ) ) )*( X( 2 ) ) ) )

              QDPHI  =  -1.0


          DO  260  K = 1,51
              IF  ( ( ABS( MOMEAN - QDPHI ) ) .LE. 0.000001 )  THEN
                  MOOR  =  ( MOSD )/( QDE( K ) )
              ENDIF

              IF  ( (MOMEAN .GT. QDPHI) .AND. (MOMEAN .LT. (QDPHI + 0.10)) )
     &          THEN
                  VALUE   =  ( MOMEAN - QDPHI )/( 0.10 )
                  RATIO   =  ( VALUE  )*( QDE( K+1 ) - QDE( K ) )
                  MOOR    =  ( MOSD )/( QDE( K ) + RATIO )
              ENDIF
              QDPHI   =  ( QDPHI )  +  ( 0.10 )
      260 CONTINUE


*                                  =============

*           (VII)CALCULATING SELECTED PERCENTILES:
*
*
*                   LOCAL VARIABLES USED:
*                       PCTILE(1-9)     --    CONVENTIONAL PERCENTILE VALUES
*                                             USED IN CALCULATIONS FOR GRAIN
*                                             SIZE STATISTICS
*                       PERC(1-100)     --    SETTLING DIAMETER (PHI) VALUES
```

```
*                                              AT 1% INTERVALS FROM 1%-100%
*                      START           --      PHI VALUE ON FREQUENCY CURVE
*                                              AT WHICH THE CALCULATION STARTS
*                      RATIO           --      TEMPORARY RATIO VARIABLE
*                      PCINT           --      PROPORTIONED CLASS INTERVAL
*                      PHIDIV          --      SPECIFIED WIDTH OF CLASS INTERVAL
*
*                      I, K, L         --      LOOP VARIABLE COUNTERS
*
*

      DO  270  K = 1,100
          PERC(K) = 0.00
  270 CONTINUE

      PCTILE(1) = 1.
      PCTILE(2) = 5.
      PCTILE(3) = 16.
      PCTILE(4) = 25.
      PCTILE(5) = 50.
      PCTILE(6) = 75.
      PCTILE(7) = 84.
      PCTILE(8) = 95.
      PCTILE(9) = 99.

      DO  280  I = 1,9

          DO  275  K = 1,L

              IF  ( NH(5,K).GT.PCTILE(I) )  THEN
                  START=( NH(3,1) + (K-2)*(PHIDIV) )
     *            RATIO=( PCTILE(I)-NH(5,K-1) )/( NH(5,K)-NH(5,K-1) )
                  PCINT=( RATIO )*( PHIDIV )
                  PERC(I) = ( START ) + ( PCINT )
                  GO  TO  280
              ENDIF

  275     CONTINUE

  280 CONTINUE


*                               =============
*
*         (VIII)CALCULATING THE GRAPHIC STATISTICS:
*
*
*                 LOCAL VARIABLES USED:
*
*                      GRMEAN          --      MEAN SETTLING DIAMETER (PHI)
*                                              ACCORDING TO FOLK & WARD (1957)
*                      GRSD            --      STANDARD SORTING ACCORDING TO
*                                              FOLK & WARD (1957)
*                      GRSH            --      RELATIVE SORTING AS DEFINED BY
*                                              FLEMMING (1977) AND ACCORDING
*                                              TO FOLK & WARD (1957)
*                      GRSKEW          --      SKEWNESS : FOLK & WARD (1957)
*                      GRKURT          --      KURTOSIS : FOLK & WARD (1957)
*                      QDE(1-51)       --      REFERENCE TABLE FOR ELEMENTARY
*                                              SORTING VALUES : FLEMMING (1977)
*                      QDPHI           --      INTERMEDIATE CUTOFF POINT
```

SETTLEPROG/TOTALSTATS

```
*                      TERM1, TERM2 --        TEMPORARY INTERMEDIATE VARIABLES
*                      PERC(2-8)       --      PERCENTILE VALUES REQUIRED BY
*                                              FORMULAE OF FOLK & WARD (1957)
*
*                      K               --      LOOP VARIABLE COUNTER
*
*
*                 LOCAL CONSTANTS USED:
*
*                      3.0, 4.0, 2.0 --       FROM THE GRAPHICS STATISTICS
*                      2.44, 6.6       --      EQUATIONS AS DEFINED BY FOLK
*                                              & WARD (1957 )
*
*

      GRMEAN = ( PERC(3) + PERC(5) + PERC(7) ) / ( 3. )
      GRSD   = ( ( PERC(7) - PERC(3) ) / ( 4. ) )
      GRSD   = ( GRSD )  +  ( ( PERC(8) - PERC(2) ) / ( 6.6 ) )
       TERM1 = ( PERC(3)+PERC(7) - 2*PERC(5) )/( 2*( PERC(7)-PERC(3) ) )
       TERM2 = ( PERC(8)+PERC(2) - 2*PERC(5) )/( 2*( PERC(8)-PERC(2) ) )
      GRSKEW = ( TERM1 )  +  ( TERM2 )
      GRKURT = ( PERC(8) - PERC(2) ) / ( (2.44)*( PERC(6) - PERC(4) ) )

          QDPHI  =  -1.0
      DO  290  K = 1,51
          IF  ( ( ABS( GRMEAN - QDPHI ) ) .LE. 0.000001 )  THEN
              GRSH  =  ( GRSD )/( QDE( K ) )
          ENDIF

          IF  ( (GRMEAN .GT. QDPHI) .AND. (GRMEAN .LT. (QDPHI + 0.10)) )
     &        THEN
              VALUE  =  ( GRMEAN - QDPHI )/( 0.10 )
              RATIO  =  ( VALUE  )*( QDE( K+1 ) - QDE( K ) )
              GRSH  =  ( GRSD )/( QDE( K ) + RATIO )
          ENDIF
          QDPHI  =  ( QDPHI )  +  ( 0.10 )
  290 CONTINUE


*                               =============
*
*         (IX) CALCULATING DECILES:
*
*
*                 LOCAL VARIABLES USED:
*
*                      IDEC(1-9)       --      SPECIFIED DECILE INTERVALS
*                      DEC(1-9)        --      PHI VALUES AT SPECIFIED
*                                              DECILE VALUES
*                      START           --      PHI VALUE ON CUMULATIVE
*                                              FREQUENCY CURVE AT WHICH THE
*                                              CALCULATION STARTS
*                      RATIO           --      TEMPORARY RATIO VARIABLE
*                      DECINT          --      PROPORTIONED CLASS INTERVAL
*                      PHIDIV          --      SPECIFIED WIDTH OF THE CLASS
*                                              INTERVAL (USUALLY 0.10 PHI)
*                      A               --      INTERMEDIATE VARIABLE
*                      MED             --      MEDIAN SETTLING DIAMETER (PHI)
*
*                      I, K, L         --      LOOP VARIABLE COUNTERS
*
*
```

```
      DO  300  I = 1,9
          A        = ( I )*10.
          IDEC(I) = A

          DO  295  K = 1,I

              IF   ( NM(5,K).GT.( A ) )  THEN
                     START = ( NM(5,1) ) + ( (PHIDIV)*(K-2) )
                     RATIO = ( A - NM(5,K-1) ) / ( NM(5,K) - NM(5,K-1) )
                     DECINT = ( RATIO )*( PHIDIV )
                     DEC(I) = ( START ) + ( DECINT )
                     GO  TO  300
              ENDIF

  295     CONTINUE

  300 CONTINUE

          MED  =  DEC(5)


*                                 =============

*         (X)  TEXTURAL DESCRIPTIONS
*
*              LOCAL VARIABLES USED:
*
*                   SMRATIO         --  %SAND TO %MUD RATIO
*
*                   GRGE80-GRGE00  :   LOGICAL VARIABLES WHICH SET A
*                                  :   'TRUE' FLAG WHENEVER THE
*                                   >  CONDITIONS ON THE RIGHT-HAND
*                                  :   SIDE OF THE EQUATION ARE
*                   SMGE9-SMGT00   :   SATISFIED
*
*                   TXTEXT,         --   CHARACTER STRINGS CONTAINING
*                   FKTEXT          --   THE DESCRIPTIONS
*
*
          IF   ( MUD .LE. 0.001 )   THEN
                 MUD = 0.0000001
          ENDIF

          SMRATIO   =    ( SAND ) / ( MUD + SETMUD )

          IF   ( MUD .LE. 0.0001 )   THEN
                 MUD = 0.000000
          ENDIF

          GRGE80   =   ( GRAVEL  .GE.  80.0 )
          GRLT80   =   ( GRAVEL  .LT.  80.0 )
          GRGE30   =   ( GRAVEL  .GE.  30.0 )
          GRLT30   =   ( GRAVEL  .LT.  30.0 )
          GRGE5    =   ( GRAVEL  .GE.  05.0 )
          GRLT5    =   ( GRAVEL  .LT.  05.0 )
          GRGE01   =   ( GRAVEL  .GE.  0.01 )
          GRLT01   =   ( GRAVEL  .LT.  0.01 )
          GRGE00   =   ( GRAVEL  .GE.  0.00 )



SETTLEPROG/TOTALSTATS

          SMGE9    =   ( SMRATIO .GE. 9.0 )
          SMLT9    =   ( SMRATIO .LT. 9.0 )
          SMGE1    =   ( SMRATIO .GE. 1.0 )
          SMLT1    =   ( SMRATIO .LT. 1.0 )
          SMGE11   =   ( SMRATIO .GE. 0.1111 )
          SMLT11   =   ( SMRATIO .LT. 0.1111 )
          SMGT00   =   ( SMRATIO . GT. 0.0 )

          SAEQ00   =   ( SAND .EQ. 0.0 )
          MUEQ00   =   ( MUD .EQ. 0.0 )



          FKTEXT( ISAMP )  =  '                              '

      IF   ( (GRGE80) .AND. ( (SAEQ00) .OR. (MUEQ00) ) )  THEN
                 FKTEXT( ISAMP ) = '              GRAVEL           '
      ENDIF
      IF   ( (GRGE30) .AND. (GRLT80) .AND. (SMGE9) )  THEN
                 FKTEXT( ISAMP ) = '          SANDY GRAVEL         '
      ENDIF
      IF   ( (GRGE30) .AND. (GRLT80) .AND. (SMGE1) .AND. (SMLT9) )  THEN
                 FKTEXT( ISAMP ) = '      MUDDY SANDY GRAVEL       '
      ENDIF
      IF   ( (GRGE30) .AND. (GRLT80) .AND. (SMLT1) )  THEN
                 FKTEXT( ISAMP ) = '          MUDDY GRAVEL         '
      ENDIF
      IF   ( (GRGE5) .AND. (GRLT30) .AND. (SMGE9) )  THEN
                 FKTEXT( ISAMP ) = '         GRAVELLY SAND         '
      ENDIF
      IF   ( (GRGE5) .AND. (GRLT30) .AND. (SMGE1) .AND. (SMLT9) )  THEN
                 FKTEXT( ISAMP ) = '      GRAVELLY MUDDY SAND      '
      ENDIF
      IF   ( (GRGE5) .AND. (GRLT30) .AND. (SMLT1) )  THEN
                 FKTEXT( ISAMP ) = '         GRAVELLY MUD          '
      ENDIF
      IF   ( (GRGE01) .AND. (GRLT5) .AND. (SMGE9) )  THEN
                 FKTEXT( ISAMP ) = '   SLIGHTLY GRAVELLY SAND      '
      ENDIF
      IF   ( (GRGE01) .AND. (GRLT5) .AND. (SMGE1) .AND. (SMLT9) )  THEN
                 FKTEXT( ISAMP ) = ' SLIGHTLY GRAVELLY MUDDY SAND '
      ENDIF
      IF   ( (GRGE01) .AND. (GRLT5) .AND. (SMGE11) .AND. (SMLT1) )  THEN
                 FKTEXT( ISAMP ) = ' SLIGHTLY GRAVELLY SANDY MUD  '
      ENDIF
      IF   ( (GRGE01) .AND. (GRLT5) .AND. (SMGT00) .AND. (SMLT11) )  THEN
                 FKTEXT( ISAMP ) = '   SLIGHTLY GRAVELLY MUD      '
      ENDIF
      IF   ( (GRGE00) .AND. (GRLT01) .AND. (SMGE9) )  THEN
                 FKTEXT( ISAMP ) = '              SAND             '
      ENDIF
      IF   ( (GRGE00) .AND. (GRLT01) .AND. (SMGE1) .AND. (SMLT9) )  THEN
                 FKTEXT( ISAMP ) = '           MUDDY SAND          '
      ENDIF
      IF   ( (GRGE00) .AND. (GRLT01) .AND. (SMGE11) .AND. (SMLT1) )  THEN
                 FKTEXT( ISAMP ) = '           SANDY MUD           '
      ENDIF
      IF   ( (GRGE00) .AND. (GRLT01) .AND. (SMGT00) .AND. (SMLT11) ) THEN
                 FKTEXT( ISAMP ) = '              MUD              '
      ENDIF
```

```
            TXTEXT( ISAMP )  =  '

      IF  ( ( MOMEAN .GE. -2.00 ) .AND. ( MOMEAN .LT. -1.00 ) )  THEN
                  TXTEXT(ISAMP ) = '          VERY FINE GRAVEL     '
      ENDIF
      IF  ( ( MOMEAN .GE. -1.00 ) .AND. ( MOMEAN .LT. +0.00 ) )  THEN
                  TXTEXT(ISAMP ) = '          VERY COARSE SAND     '
      ENDIF
      IF  ( ( MOMEAN .GE. +0.00 ) .AND. ( MOMEAN .LT. +1.00 ) )  THEN
                  TXTEXT(ISAMP ) = '             COARSE SAND       '
      ENDIF
      IF  ( ( MOMEAN .GE. +1.00 ) .AND. ( MOMEAN .LT. +2.00 ) )  THEN
                  TXTEXT(ISAMP ) = '             MEDIUM SAND       '
      ENDIF
      IF  ( ( MOMEAN .GE. +2.00 ) .AND. ( MOMEAN .LT. +3.00 ) )  THEN
                  TXTEXT(ISAMP ) = '             FINE   SAND       '
      ENDIF
      IF  ( ( MOMEAN .GE. +3.00 ) .AND. ( MOMEAN .LT. +4.00 ) )  THEN
                  TXTEXT(ISAMP ) = '             VERY FINE SAND    '
      ENDIF




*                            ==============

*         (XI) TEXTURAL CLASSIFICATION:
*
*
*              LOCAL VARIABLES USED:
*
*                   QDLT35-QDGT04 --   LOGICAL VARIABLES WHICH SET
*                   QH0001-QH1632 --   A 'TRUE' FLAG WHENEVER THE
*                   SKVNEG-SKVPOS --   CONDITIONS ON THE RIGHT-HAND
*                   KTVPLT-KTELPT --   SIDE ARE SATISFIED
*
*                   FKSORT,FLSORT --   CHARACTER STRINGS CONTAINING
*                   FKSKEW,FKKURT --   THE TEXTURAL CLASSIFICATIONS
*
*
          QDLT35  =     ( GROD .LT. 0.35 ) .AND. ( GROD .LT. 0.50 ) )
          QD3550  =  (  ( GROD .GE. 0.35 ) .AND. ( GROD .LT. 0.50 ) )
          QD5070  =  (  ( GROD .GE. 0.50 ) .AND. ( GROD .LT. 0.70 ) )
          QD7001  =  (  ( GROD .GE. 0.70 ) .AND. ( GROD .LT. 1.00 ) )
          QD0102  =  (  ( GROD .GE. 1.00 ) .AND. ( GROD .LT. 2.00 ) )
          QD0204  =  (  ( GROD .GE. 2.00 ) .AND. ( GROD .LE. 4.00 ) )
          QDGT04  =     ( GROD .GT. 4.00 )

          QH0001  =  (  ( GROH .GE. 0.00 ) .AND. ( GROH .LT. 1.00 ) )
          QH0102  =  (  ( GROH .GE. 1.00 ) .AND. ( GROH .LT. 2.00 ) )
          QH0204  =  (  ( GROH .GE. 2.00 ) .AND. ( GROH .LT. 4.00 ) )
          QH0408  =  (  ( GROH .GE. 4.00 ) .AND. ( GROH .LT. 8.00 ) )
          QH0816  =  (  ( GROH .GE. 8.00 ) .AND. ( GROH .LT. 16.0 ) )
          QH1632  =  (  ( GROH .GE. 16.0 ) .AND. ( GROH .LT. 32.0 ) )

          SKVNEG  =  (  (GRSKEW.GE.-1.00) .AND. (GRSKEW.LT.-0.30) )
          SKNEG   =  (  (GRSKEW.GE.-0.30) .AND. (GRSKEW.LT.-0.10) )
          SKNSYM  =  (  (GRSKEW.GE.-0.10) .AND. (GRSKEW.LT.+0.10) )
          SKPOS   =  (  (GRSKEW.GE.+0.10) .AND. (GRSKEW.LT.+0.30) )
          SKVPOS  =  (  (GRSKEW.GE.+0.30) .AND. (GRSKEW.LT.+1.00) )

          KTVPLT  =     (GRKURT .LT. 0.67)
```

SETTLEPROG/TOTALSTATS

```
          KTPLAT  =  (  (GRKURT .GE. 0.67) .AND. (GRKURT .LT. 0.90) )
          KTMESO  =  (  (GRKURT .GE. 0.90) .AND. (GRKURT .LT. 1.11) )
          KTLEPT  =  (  (GRKURT .GE. 1.11) .AND. (GRKURT .LT. 1.50) )
          KTVLPT  =  (  (GRKURT .GE. 1.50) .AND. (GRKURT .LE. 3.00) )
          KTELPT  =     (GRKURT .GT. 3.00)



          FKSORT( ISAMP )  =  '                          '
          FLSORT( ISAMP )  =  '                          '
          FKSKEW( ISAMP )  =  '                          '
          FKKURT( ISAMP )  =  '                          '



      IF  ( QDLT35 )  THEN
                  FKSORT( ISAMP ) = '     VERY WELL SORTED     '
      ENDIF
      IF  ( QD3550 )  THEN
                  FKSORT( ISAMP ) = '        WELL SORTED       '
      ENDIF
      IF  ( QD5070 )  THEN
                  FKSORT( ISAMP ) = ' MODERATELY WELL SORTED '
      ENDIF
      IF  ( QD7001 )  THEN
                  FKSORT( ISAMP ) = '    MODERATELY SORTED    '
      ENDIF
      IF  ( QD0102 )  THEN
                  FKSORT( ISAMP ) = '       POORLY SORTED      '
      ENDIF
      IF  ( QD0204 )  THEN
                  FKSORT( ISAMP ) = '    VERY POORLY SORTED    '
      ENDIF
      IF  ( QDGT04 )  THEN
                  FKSORT( ISAMP ) = ' EXTREMELY POORLY SORTED'
      ENDIF

      IF  ( QH0001 )  THEN
                  FLSORT( ISAMP ) = ' EXTREMELY WELL SORTED'
      ENDIF
      IF  ( QH0102 )  THEN
                  FLSORT( ISAMP ) = '    VERY WELL SORTED    '
      ENDIF
      IF  ( QH0204 )  THEN
                  FLSORT( ISAMP ) = '       WELL SORTED      '
      ENDIF
      IF  ( QH0408 )  THEN
                  FLSORT( ISAMP ) = '  MODERATELY SORTED  '
      ENDIF
      IF  ( QH0816 )  THEN
                  FLSORT( ISAMP ) = '      POORLY SORTED     '
      ENDIF
      IF  ( QH1632 )  THEN
                  FLSORT( ISAMP ) = '   VERY POORLY SORTED   '
      ENDIF

      IF  ( SKVNEG )  THEN
                  FKSKEW( ISAMP ) = 'VERY NEGATIVE SKEWED'
      ENDIF
      IF  ( SKNEG  )  THEN
                  FKSKEW( ISAMP ) = '    NEGATIVE SKEWED   '
      ENDIF
```

```
      IF  ( SKNSYM )  THEN
                FKSKEW( ISAMP ) = ' NEARLY SYMMETRICAL '
      ENDIF
      IF  ( SKPOS  )  THEN
                FKSKEW( ISAMP ) = '   POSITIVE SKEWED  '
      ENDIF
      IF  ( SKVPOS )  THEN
                FKSKEW( ISAMP ) = 'VERY POSITIVE SKEWED'
      ENDIF

      IF  ( KTVPLT )  THEN
                FKKURT( ISAMP ) = '   VERY PLATYKURTIC   '
      ENDIF
      IF  ( KTPLAT )  THEN
                FKKURT( ISAMP ) = '      PLATYKURTIC     '
      ENDIF
      IF  ( KTMESO )  THEN
                FKKURT( ISAMP ) = '      MESOKURTIC      '
      ENDIF
      IF  ( KTLEPT )  THEN
                FKKURT( ISAMP ) = '      LEPTOKURTIC     '
      ENDIF
      IF  ( KTVLPT )  THEN
                FKKURT( ISAMP ) = '   VERY LEPTOKURTIC   '
      ENDIF
      IF  ( KTELPT )  THEN
                FKKURT( ISAMP ) = ' EXTREMELY LEPTOKURTIC'
      ENDIF

*****************************************************************
*
*         OUTPUT SECTION:
*         ---------------
*
*         (I)  DATA DISTRIBUTION TABLES AND TEXTURE INFORMATION:
*
*              LOCAL VARIABLES USED:
*
*                   MEANTX,FOLKTX --   CHARACTER STRINGS CONTAINING
*                   FOLKSI,FLEMSI --   TEXTURAL INFORMATION FOR THE
*                   FOLKSK,FOLKKT --   CURRENT SAMPLE
*
*


                    MEANTX = TXTEXT( ISAMP )
                    FOLKTX = FKTEXT( ISAMP )
                    FOLKSI = FKSORT( ISAMP )
                    FLEMSI = FLSORT( ISAMP )
                    FOLKSK = FKSKEW( ISAMP )
                    FOLKKT = FKKURT( ISAMP )

      WRITE ( ILNPT,9000 ) TITLE
      WRITE( ILNPT,3000 ) SAMPL, XCOORD, YCOORD, GRAVEL, SETGRV

          DO  310  K = 2,L
            WRITE ( ILNPT,3001 ) AMIDUM( K ),
     &                               REYNOL( K ),
     &                                 DRAG( K ),
     &                                   ( NM( J,K ), J=1,7 )
  310     CONTINUE
```

SETILEPROG/TOTALSTATS

```
      WRITE( ILNPT,3009 ) SETMUD, MUD

      WRITE ( ILNPT,3002 )
      WRITE( ILNPT, 3003 ) MOMEAN, GRMEAN,      MOMD, GRMD,
     &                     ( DECILE( K ), K=1,9 ),
     &                     MOCP  , GRCP
     &                     ( DEC( K ), K=1,9 ),
     &                     MOSKEW, MSKEW1, GRSKEW,
     &                     MOKURT, MKURT1, GRKURT,
     &                     MED, MED
      WRITE( ILNPT,3004 ) ( PERCEN( K ), K=1,9 ), ( PERC( K ), K=1,9 )
      WRITE( ILNPT,3005 ) (  HALPHI( K ), HALF1( K ), HALF2( K ),
     &                       PHIINT( K ), TOT1( K ), TOT2( K ),
     &                       HARPHI( K ), HARF1( K ), HARF2( K ), K=1,9)
      WRITE( ILNPT,3006 )
      WRITE( ILNPT,3007 ) MEANTX, FOLKTX,
     &                    FOLKSI, FLEMSI,
     &                    FOLKSK, FOLKKT
      WRITE( ILNPT,3008 ) SEPAID



*                                 =============


*         (II) INITIALIZATION OF PLOT VARIABLES:
*
*
*              LOCAL VARIABLES USED:
*
*                   TFREQX(1-11)   --   ABSCISSA VALUES FOR NORMAL
*                                       FREQUENCY PLOT
*                   CUMULX(1-11)   --   ABSCISSA VALUES FOR CUMULATIVE
*                                       FREQUENCY PLOT
*                   TFREQY(1-6)    --   ORDINATE VALUES FOR NORMAL
*                                       FREQUENCY PLOT
*                   GRID(1-51)     --   ARRAY OF 101-CHARACTER STRINGS
*                                       INTO WHICH THE GRAPH CO-ORDINATES
*                                       ARE MAPPED
*                   IFLAG          --   FLAG POINTER FOR IMPLEMENTING THE
*                                       MULTI-BRANCHED 'GO TO'  I.E. THE
*                                       CASE MECHANISM
*
*                   K, KK          --   LOOP VARIABLE COUNTERS
*
*



              IFLAG = 1


                   IF     ( PLOTOP )  800, 320, 800


  320 CONTINUE

          CUMULX( 1 ) = -2.0
          TFREQX( 1 ) = -2.05
          TFREQY( 1 ) = 0.0
```

```
          DO  330  K = 1,10
               CUMULX( K+1 ) = CUMULX( K ) + 1.0
               IFREQX( K+1 ) = IFREQX( K ) + 1.0
 330      CONTINUE

          DO  340  K = 1,5
               IFREQY( K+1 ) = IFREQY( K ) + 5
 340      CONTINUE


 350 CONTINUE

          DO  360  K = 1,51
               DO  355  KK = 1,101
               SUBSTR( GRID( K ), KK, 1 ) = ' '
 355           CONTINUE
 360      CONTINUE

          DO  370  K = 1,51
               SUBSTR( GRID( K ), 1, 1 )   = ':'
               SUBSTR( GRID( K ), 101, 1 ) = ':'
 370      CONTINUE

          DO  380  K = 1,101
               SUBSTR( GRID( 1 ), K, 1 )    =  '-'
               SUBSTR( GRID( 51 ), K, 1 )   =  '-'
 380      CONTINUE

          DO  390  K = 1,51,10
               DO  385  KK = 1,101,10
               SUBSTR( GRID( 1 ), KK, 1 )   =  '+'
               SUBSTR( GRID( 51 ), KK, 1 )  =  '+'
 385           CONTINUE

               SUBSTR( GRID( K ), 1, 1 )  =  '+'
               SUBSTR( GRID( K ), 101, 1 )=  '+'

 390      CONTINUE

          DO  400  K = 1,51,2
               SUBSTR( GRID( K ), 11, 1 ) = ':'
               SUBSTR( GRID( K ), 61, 1 ) = ':'
 400      CONTINUE


                    GO  TO  ( 410, 440, 480, 800 )        IFLAG


*                                  =============
*
*         (III)PLOT OUTPUT OF THE FREQUENCY DISTRIBUTION CURVES:
*
*
*                   LOCAL VARIABLES USED:
*
*                        FX                --    ABSCISSA VALUE TO BE PLOTTED
*                        M                 --    INTEGERIZED ABSCISSA VALUE WHICH
*                                                SPECIFIES COLUMN OUTPUT OF
*                                                CHARACTER STRING GRID
*                        FY                --    ORDINATE VALUE TO BE PLOTTED
*                        N                 --    INTEGERIZED ORDINATE VALUE WHICH

SFTITLEPROG/TOTALSTATS

*                                                SPECIFIES ROW OUTPUT OF ARRAY GRID
*
*                        FYDIV, CYDIV      --    LINES AT WHICH THE Y-LABEL IS
*                                                TO BE PRINTED
*                        J, K, KK          --    LOOP VARIABLE COUNTERS
*
*
*                   LOCAL CONSTANTS USED:
*
*                        2.05, 2.0         --    THIS IS NECESSARY AS THE ABSCISSA
*                                                SCALE STARTS AT -2.05 OR -2.0
*                        1.5               --    FACTOR USED IN INTEGERIZING
*                        51.0              --    NUMBER OF ORDINATE LINES ON GRAPH
*                        2.0               --    THIS ENABLES THE 0% - 25% RANGE TO
*                                                FIT INTO 51 PRINTED LINES
*
*

 410 CONTINUE


          DO  420  K = 2,I
               FX  =  ( ( AVIDNM(K) + 2.05 )/( PHIDIV ) ) + 1.5
               M   =  ( FX )
               FY  =  ( 51.0 ) - ( NF(4,K)*( 2.0 ) )
               N   =  ( FY )
                      SUBSTR( GRID( N ), M, 1 )  =  '*'
 420      CONTINUE
      WRITE ( ILNPT,9000 ) TITLE
      WRITE ( ILNPT,4000 ) SAMPL, XCOORD, YCOORD
          J  =  1
          DO  430  K = 1,51
               IF ( K .EQ. FYDIV( J ) )  THEN
                  KK = ( K/10 )
                  KK = ( 6 ) - ( KK )
                  WRITE ( ILNPT,4001 ) IFREQY( KK ), GRID( K )
                  JJ  =  J
                  J   =  J + 1
               ENDIF
               IF  ( K .EQ. 26 )  THEN
                  WRITE ( ILNPT,4002 ) GRID( K )
               ENDIF
        IF    ( ( K .NE. 26 ) .AND. ( K .NE. FYDIV(JJ) ) )  THEN
                  WRITE ( ILNPT,4003 ) GRID( K )
          ENDIF
 430      CONTINUE
          WRITE( ILNPT,4004 ) ( IFREQX( K ), K=1,11 )
          WRITE ( ILNPT,4005 )
               IFLAG  =  IFLAG + 1

                                                       GO TO    350

 440 CONTINUE

          DO  460  K = 2,I
               FX  =  ( ( NN( 3,K ) + 2.0 )/( PHIDIV ) ) + 1.5
               M   =  ( FX )
               DO  450  KK = 2,51
               IF   ( (NN(5,K).GT.0.007) .AND. (NN(5,K).LE.SD(KK)) )
     *             THEN
                   N  =  ( 52 ) - ( KK )
                   SUBSTR( GRID( N ), M, 1 )  =  '*'
```

```
                         GO TO  460
                         ENDIF
                    CONTINUE
      460     CONTINUE

      WRITE ( ILNPT,9000 ) TITLE
      WRITE ( ILNPT,4010 ) SAMPL, XCOORD, YCOORD
           J  =  1
           DO  470   K = 1,51
                 IF   ( K .EQ. CYDIV( J ) )  THEN
                       WRITE ( ILNPT,4011 ) CUMULY( J ), GRID( K )
                       JJ  =  J
                       J   =  J + 1
                 ENDIF
                 IF   ( K .EQ. 26 )  THEN
                       WRITE ( ILNPT,4012 ) GRID( K )
                 ENDIF
                 IF   ( K .EQ. 27 )  THEN
                       WRITE( ILNPT,4013 ) GRID( K )
                 ENDIF
             IF  ( ( K .NE. 26 ) .AND.
     &             ( K .NE. 27 ) .AND.
     &             ( K .NE. CYDIV(JJ) ) )  THEN
                       WRITE ( ILNPT,4014 ) GRID( K )
             ENDIF
      470     CONTINUE
              WRITE( ILNPT,4015 ) ( CUMULX( K ), K=1,11 )
              WRITE ( ILNPT,4016 )
                IFLAG  =  IFLAG + 1

             IF   ( ( GRAVEL .LE. 0.00 ) .AND. ( MUD .LE. 0.00 ) )  THEN
                IFLAG = IFLAG + 1
             ENDIF

                                                        GO TO    350

      480 CONTINUE

           DO  500   K = 2,L
                 FX  =  ( ( NM( 3,K ) + 2.0 )/( PHIDIV ) ) + 1.5
                 M   =  ( FX )
                 DO  490  KK = 2,51
                   IF   ((NM(7,K) .GT. .007) .AND. (NM(7,K) .LE. SD(KK)))
     &               THEN
                         N  =  ( 52 ) - ( KK )
                         SUBSTR( GRID( N ), M, 1 )  =  '*'
                   GO TO  500
                   ENDIF
                    CONTINUE
      490
      500     CONTINUE
      WRITE ( ILNPT,9000 ) TITLE
      WRITE ( ILNPT,4020 ) SAMPL, XCOORD, YCOORD
           J  =  1
           DO  510   K = 1,51
                 IF   ( K .EQ. CYDIV( J ) )  THEN
                       WRITE ( ILNPT,4021 ) CUMULY( J ), GRID( K )
                       JJ  =  J
                       J   =  J + 1
                 ENDIF
                 IF   ( K .EQ. 26 )  THEN
                       WRITE ( ILNPT,4022 ) GRID( K )
                 ENDIF
```

SFILEPROG/TOTALSTATS

```
                 IF   ( K .EQ. 27 )  THEN
                       WRITE ( ILNPT,4023 ) GRID( K )
                 ENDIF
             IF  ( ( K .NE. 26 ) .AND.
     &             ( K .NE. 27 ) .AND.
     &             ( K .NE. CYDIV(JJ) ) )  THEN
                       WRITE ( ILNPT,4024 ) GRID( K )
             ENDIF
      510     CONTINUE
              WRITE( ILNPT,4025 ) ( CUMULX( K ), K=1,11 )
              WRITE( ILNPT,4026 ) TOTGRV, TOTMUD
                IFLAG  =  IFLAG + 1

                                                        GO TO    350

      800 CONTINUE
*                                     =============

              SAND( ISAMP,1 ) = SAMPL( 1 )         @  \   STORING
              SAND( ISAMP,2 ) = SAMPL( 2 )         @   :
              SAND( ISAMP,3 ) = SAMPL( 3 )         @   :
              SAND( ISAMP,4 ) = SAMPL( 4 )         @   :  STATISTICAL
              MOMTMN( ISAMP )  =   MOMEAN          @   :
              MOMTMD( ISAMP )  =   MOOD            @   :  AND
              MOMTQH( ISAMP )  =   MOQH            @   :  TEXTURAL
              MOMTSK( ISAMP )  =   MOSKEW          @   >  INFORMATION
              MOMTKT( ISAMP )  =   MOKURT          @   :  INTO
              GRAFMN( ISAMP )  =   GRMEAN          @   :  SAMPLE
              GRAFMD( ISAMP )  =   GRMD            @   :
              GRAFQH( ISAMP )  =   GRQH            @   :  SUMMARY
              GRAFSK( ISAMP )  =   GRSKEW          @   :
              GRAFKT( ISAMP )  =   GRKURT          @   :  TABLE
              MEDIAN( ISAMP )  =   MED             @  /
      WRITE ( IDST1,6000 )( SAMPL(K), K=1,4),
     &                        MOMEAN, MOMD, MOQH, MOSKEW, MOKURT,
     &                        GRMEAN, GRMD, GRQH, GRSKEW, GRKURT,
     &                        PERC( 1 ), MED, PERC( 9 ), ( TOT1(K),K=1,9 ),
     &                        GRAVEL, SAND, MUD, CARB


      INOPHI = L - 1
      WRITE ( IDST2,6001 ) ( SAND( ISAMP,K ), K=1,4 ), INOPHI,
     *                           MOMEAN, MOMD, MOSKEW

      DO  850  K = 2,L
      WRITE ( IDST2,6002 ) AMIDNM( K ), ( NM( KK,K ), KK=4,5 )
  850 CONTINUE



******************************************************************
*
*                 GO         TO         40       @  READ  NEXT  SAMPLE
*                                                   ----  ----  ------
*
*
******************************************************************


*            TERMINATION ROUTINES:
*            --------------------
```

SETILEPROG/TOTALSTATS

```
*
*

  900 CONTINUE
      WRITE ( ILNPT,2005 ) SAMPL
      GO TO    950
  910 CONTINUE
      WRITE ( ILNPT,2006 ) SAMPL
      GO TO    950

  920 CONTINUE
      WRITE ( ILNPT, 9000 ) TITLE
      WRITE ( ILNPT,7000 )
      DO  930  K = 1,ISAMP
         WRITE ( ILNPT,7001 ) ( SAND( K,KK ), KK =1,4 ),
     &                          MOMIMN( K ),    GRAFMN( K ),
     &                          MOMIOD( K ),    GRAFOD( K ),
     &                          MOMIOH( K ),    GRAFOH( K ),
     &                          MOMISK( K ),    GRAFSK( K ),
     &                          MOMIKT( K ),    GRAFKT( K ),
     &                          MEDIAN( K )
  930 CONTINUE
      WRITE ( ILNPT,7002 )
      DO  940  K = 1,ISAMP
         WRITE ( ILNPT,7003 ) ( SAND( K,KK ), KK = 1,4 ),
     &                          TXTEXT( K ),    FKTEXT( K ),
     &                          FKSORT( K ),    FLSORT( K ),
     &                          FKSKEW( K ),    FKKURT( K )
  940 CONTINUE
      WRITE ( ILNPT,8000 ) ISAMP, SAMPL


         IDSEOF = 999


      WRITE( IDS11,6003 ) IDSEOF                          @  WRITE
      WRITE( IDS11,6004 )                                 @  END-OF-FILE   (EOF)
      WRITE( IDS12,6005 ) IDSEOF                          @  MARKERS


  950 CONTINUE
      STOP

************************************************************************

      END
```

7.3.2 RUNSTREAM

```
1.  @RUN,Z/NR b run-id, accnt. no./userid,GEOMARINE,time,pages
2.  @PASSWD b ABS.
3.  @ASC,A b ABD.
4.  @ASG,AX b DATA.
5.  @ELT,IL b DATA.elementname/SETTLEPROG

    input data typed up appropriately

6.  @HDG,XN b X.M,66,Ø,Ø
7.  @XQT,F b ABS.SETTLEPROG/TOTALSTATS
8.  @ADD,P b DATA.elementname/SETTLEPROG
9.  @FIN
```

run-id, accnt. no., userid, password, elementname, will all vary from user to user.

allow five pages per sample in determining the no. of "pages" on card 1, and allow these "times" per no. of pages:

5Ø	pages	--	2 minutes
8Ø	"	--	5 minutes
25Ø	"	--	1Ø minutes

This input data is structured as set out below:

1. Title card (8Ø alphanumeric characters)
2. Fall height of settling tube (4 numbers, 1 point) e.g. 18Ø.Ø
3. First data card, first sample
4. Second data card, first sample
5. Third data card, first sample

6.
7. data cards, second sample
8.

9.
1Ø.data cards, third sample
11.
ETC.

The data cards are punched in the following manner:

FIRST CARD:

Columns	Description	Format
1 - 16	Sample name of number (alphanumeric)	4A4
17	one blank	1X
18 - 19	water temperature (integer)	I2
20	one blank	1X
21	1st speed factor (integer)	I1
22 - 28	seven blanks	7X
29	2nd speed factor (integer)	I1
30	one blank	1X
31 - 35	distance in mm. of 1st speed change (real)	F5.2
36	one blank	1X
37	3rd speed factor (integer)	I1
38	one blank	1X
39 - 43	distance in mm. of 2nd speed change (real)	F5.2
44	one blank	1X
45 - 48	phi interval (real)	F4.3
49	one blank	1X
50 - 51	plot option (integer)	I2
52	one blank	1X
53 - 59	X - co-ordinate (real)	F7.2
60 - 66	Y - co-ordinate (real)	F7.2
67 - 71	mud percentage (real)	F5.2
72 - 76	gravel percentage (real)	F5.2
77 - 80	carbonage percentage (real)	F4.2

SECOND CARD:

1 - 5	distance in mm. to 0%	(real)	F5.2
6 - 10	" " " " 0.5%	(real)	F5.2
11 - 15	" " " " 1%	(real)	F5.2
16 - 20	" " " " 5%	(real)	F5.2
	:		
	:		
	:		
	:		
76 - 80	" " " " 51%	(real)	F5.2

THIRD CARD:

1 - 5	" " " " 55%	(real)	F5.2
	:		
	:		
	:		
66 - 70	" " " " 100%	(real	F5.2

Note 1. the distance in mm. is obtained from the cumulative settling curve.

2. speed factors:

2mm/sec	--	2
1mm/sec	--	3
0,5mm/sec	--	4
20mm/min	--	5
10mm/min	--	6

3. plot option:

graphs printed -- ØØ (i.e. leave blank)
no graphs printed -- Ø1

For example, the relevant cards for a sample which has been settled down a tube with a fall height of 178 cm, water temp. 2Ø°C, and three chart speeds (1mm/sec; Ø,5mm/sec, and 1Ømm/sec, and 1Ømm/min) on the chart recorder, are produced below.

```
1.  @RUN,Z/NRbERHAY,BØ218-Z1Ø5/HENRI,GEOMARINE,2,5Ø
2.  @PASSWDbETALGT
3.  @ASG,AbABS.
4.  @ASG,AXbDATA.
5.  @ELT,ILbDATA.AGULHAS/SETTLEPROG
6.  CRUISE 83-1Ø : TOTAL SAMPLE SEDIMENT DISTRIBUTION
7.  178.Ø
8.  TOTAL SAND-Ø1     17 2     3 211.Ø 6 12Ø,Ø Ø.1Ø1.Ø  3.9 5.1
9.  22.  29.  32.  49.  6Ø.  71.  81.  91.  99. 1Ø5. 1Ø9. 112.
*118. 12Ø. 122.
1Ø. 125. 127. 129. 133. 136. 139. 143.5  147. 154. 163. 181. 223.
   *251. 265.
11. @XQT,FbABS.SETTLEPROG/TOTALSTATS
12. @ADD,PbDATA.AGULHAS/SETTLEPROG
13. @FIN
```

NOTE:
b means a blank space.
* continues the line above.

An example of the print-out obtained for one such sample is reproduced below:

CRUISE [illegible] TOTAL [illegible] SAND DISTRIBUTIONS GROUP [illegible]

DATA FOR OBTAINING DISTRIBUTION CURVES FOR 24-130 X CO-ORDINATE: .00 Y CO-ORDINATE: .00

PHI INTERVAL MIDPOINT	REYNOLD'S NUMBER (LOG10)	DRAG COEFF.	SETTLING DIAMETER (MM)	SETTLING VELOCITY (CM/S)	PHI INTERVAL	FREQUENCY PERCENT (SAND SIZE)	CUMULATIVE PERCENT (SAND SIZE)	FREQUENCY PERCENT (TOTAL SAMPLE)	CUMULATIVE PERCENT (TOTAL SAMPLE)
	AT 20 DEG. C			AT 20 DEG. C				'SIEVED GRAVEL': .00 'SETTLED GRAVEL': .00	
-.65	2.52	-.17	1.51572	22.226	-.60	.12	.12	.12	.12
-.55	2.47	-.16	1.41421	20.812	-.50	.25	.37	.25	.37
-.45	2.41	-.14	1.31951	19.579	-.40	.34	.70	.34	.70
-.35	2.36	-.12	1.23114	18.451	-.30	.53	1.23	.53	1.23
-.25	2.30	-.10	1.14870	17.261	-.20	.74	1.97	.74	1.97
-.15	2.24	-.08	1.07177	16.313	-.10	.85	2.82	.85	2.82
-.05	2.18	-.06	1.00000	15.[illegible]	.00	.86	3.68	.86	3.68
.05	2.13	-.05	.93303	15.322	.10	.90	4.58	.90	4.58
.15	2.10	-.03	.87055	14.346	.20	1.00	5.57	1.00	5.57
.25	2.04	-.01	.81225	13.451	.30	1.09	6.67	1.09	6.67
.35	1.98	.02	.75786	12.535	.40	1.14	7.80	1.14	7.80
.45	1.92	.05	.70711	11.826	.50	1.21	9.01	1.21	9.01
.55	1.86	.07	.65975	11.013	.60	1.32	10.33	1.32	10.33
.65	1.80	.10	.61557	10.247	.70	1.40	11.72	1.40	11.72
.75	1.74	.14	.57435	9.551	.80	1.44	13.16	1.44	13.16
.85	1.68	.17	.53589	8.877	.90	1.49	14.65	1.49	14.65
.95	1.61	.21	.50000	8.224	1.00	1.59	16.24	1.59	16.24
1.05	1.55	.24	.46652	7.645	1.10	1.81	18.05	1.81	18.05
1.15	1.49	.28	.43528	7.062	1.20	2.07	20.12	2.07	20.12
1.25	1.42	.32	.40613	6.526	1.30	2.22	22.34	2.22	22.34
1.35	1.36	.36	.37893	6.024	1.40	2.31	24.65	2.31	24.65
1.45	1.29	.40	.35355	5.541	1.50	2.39	27.03	2.39	27.03
1.55	1.22	.45	.32988	5.093	1.60	2.38	29.42	2.38	29.42
1.65	1.16	.49	.30779	4.674	1.70	2.29	31.70	2.29	31.70
1.75	1.09	.54	.28717	4.290	1.80	2.13	33.83	2.13	33.83
1.85	1.02	.59	.26794	3.916	1.90	1.99	35.82	1.99	35.82
1.95	.95	.65	.25000	3.574	2.00	1.92	37.74	1.92	37.74
2.05	.88	.70	.23326	3.251	2.10	2.01	39.75	2.01	39.75
2.15	.81	.76	.21764	2.956	2.20	2.58	42.32	2.58	42.32
2.25	.73	.82	.20306	2.687	2.30	4.52	46.85	4.52	46.85
2.35	.66	.87	.18946	2.427	2.40	6.77	53.61	6.77	53.61
2.45	.59	.94	.17678	2.190	2.50	7.45	61.06	7.45	61.06
2.55	.51	1.00	.16494	1.974	2.60	6.35	67.41	6.35	67.41
2.65	.44	1.07	.15389	1.775	2.70	5.26	72.67	5.26	72.67
2.75	.36	1.13	.14359	1.593	2.80	4.50	77.16	4.50	77.16
2.85	.28	1.20	.13397	1.426	2.90	3.73	80.89	3.73	80.89
2.95	.20	1.27	.12500	1.274	3.00	2.98	83.87	2.98	83.87
3.05	.12	1.34	.11663	1.138	3.10	2.39	86.26	2.39	86.26
3.15	.04	1.42	.10882	1.012	3.20	1.90	88.16	1.90	88.16
3.25	-.04	1.49	.10153	.899	3.30	1.59	89.76	1.59	89.76
3.35	-.12	1.57	.09473	.797	3.40	1.56	91.31	1.56	91.31
3.45	-.21	1.64	.08839	.705	3.50	1.62	92.93	1.62	92.93
3.55	-.29	1.72	.08247	.624	3.60	1.58	94.51	1.58	94.51
3.65	-.37	1.80	.07695	.549	3.70	1.39	95.90	1.39	95.90
3.75	-.46	1.89	.07179	.485	3.80	1.22	97.11	1.22	97.11
3.85	-.54	1.96	.06699	.427	3.90	1.14	98.25	1.14	98.25
3.95	-.63	2.05	.06250	.374	4.00	1.00	99.25	1.00	99.25
4.05	-.72	2.13	.05831	.33[illegible]	4.10	.73	99.98	.00	.00
4.15	-.80	2.21	.05441	.289	4.20	.02	100.00	.00	.00

'SETTLED MUD': [illegible]
'SIEVED MUD': [illegible]

STATISTICAL AND DESCRIPTIVE PARAMETERS

	MOMENT STATISTICS	FOLK'S GRAPHIC STATISTICS	
MEAN	2.10		2.11
STD. SORTING	1.01		1.03
REL. SORTING	5.07		5.20
SKEWNESS	-.51 $	-.26 *	-.31
KURTOSIS	2.71 $	-.29 *	1.07
MEDIAN	2.35		2.35

DECILES	10	20	30	40	50	60	70	80	90
	.58	1.19	1.63	2.11	2.35	2.49	2.65	2.88	3.32

PERCENTILES	1	5	16	25	50	75	84	95	99
	-.34	.14	.98	1.41	2.35	2.75	3.01	3.64	3.97

$ AFTER FRIEDMAN & SANDERS (1978)

* AFTER KRUMBEIN & PETTIJOHN (1938)

TEXTURAL DISTRIBUTION

	SAND	TOTAL
GRV	.00	.00
VCS	3.66	3.66
CS	12.56	12.56
MS	21.50	21.50
FS	46.13	46.13
VFS	15.38	15.38
CZ	.75	.75
MZ	.00	.00
FZ	.00	.00

CUMULATIVE PERCENT AT 0.5 PHI INTERVALS

	SAND	TOTAL
-1.5	[illegible]	[illegible]
-1.0	.00	.00
-0.5	.37	.37
+0.0	3.32	3.32
+0.5	[illegible]	[illegible]
+1.0	7.23	7.23
+1.5	[illegible]	[illegible]
+2.0	[illegible]	[illegible]
+2.5	[illegible]	[illegible]
+3.0	22.81	22.81
+3.5	[illegible]	9.06
+4.0	6.32	6.32
+4.5	[illegible]	[illegible]
+5.0	[illegible]	[illegible]
+5.5	[illegible]	[illegible]
+6.0	[illegible]	[illegible]
+6.5	[illegible]	[illegible]
+7.0	.00	[illegible]

TEXTURAL CLASSIFICATION

TEXTURE : FINE SAND , IN A TOTAL SEDIMENT CLASSIFIED AS : SAND -- FOLK (1968).

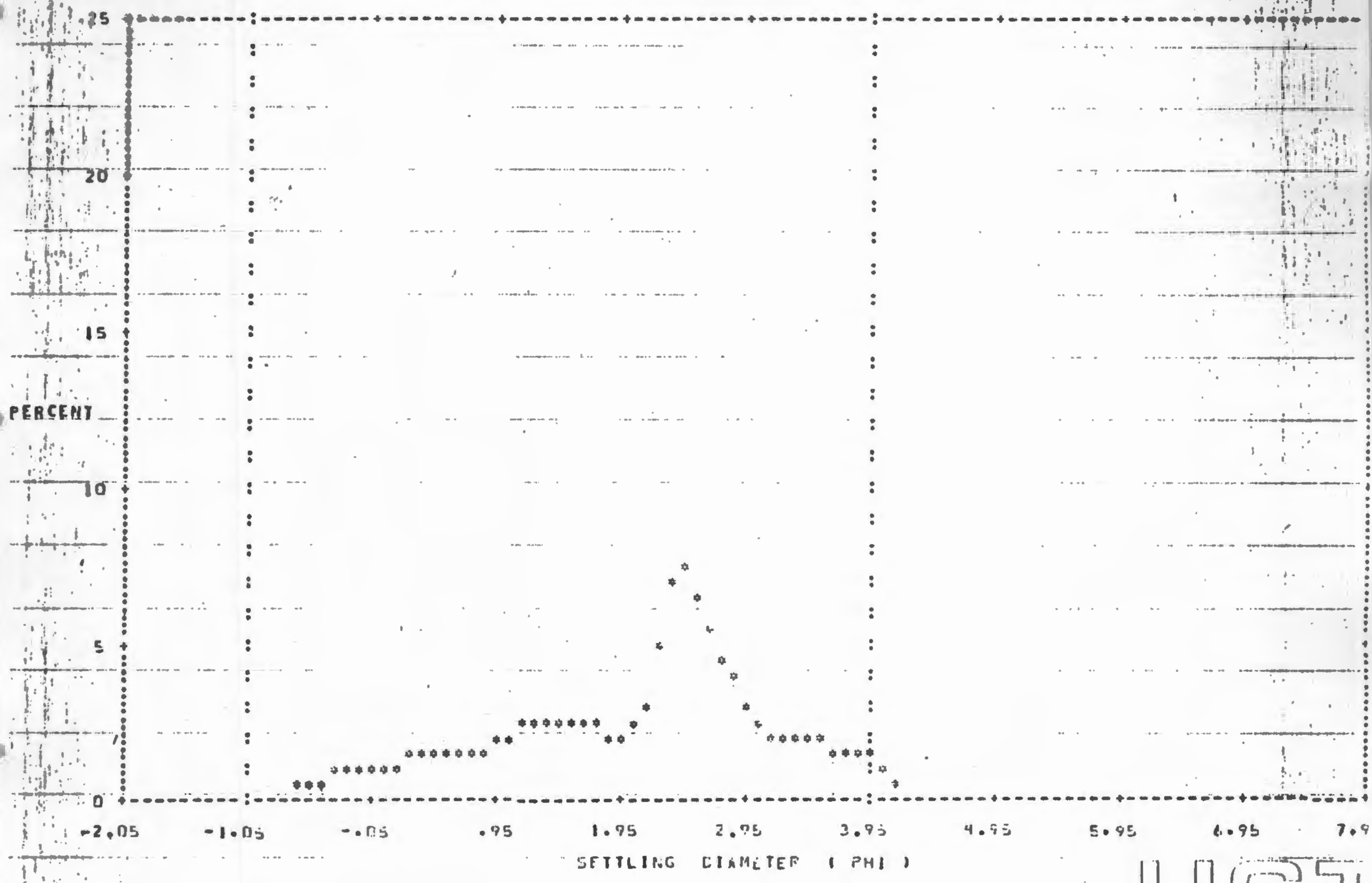
SORTING : POORLY SORTED -- FOLK & WARD (1957). MODERATELY SORTED -- FLEMMING (1977).

SKEWNESS: VERY NEGATIVE SKEWED -- FOLK & WARD (1957).

KURTOSIS: MESOKURTIC -- FOLK & WARD (1957).

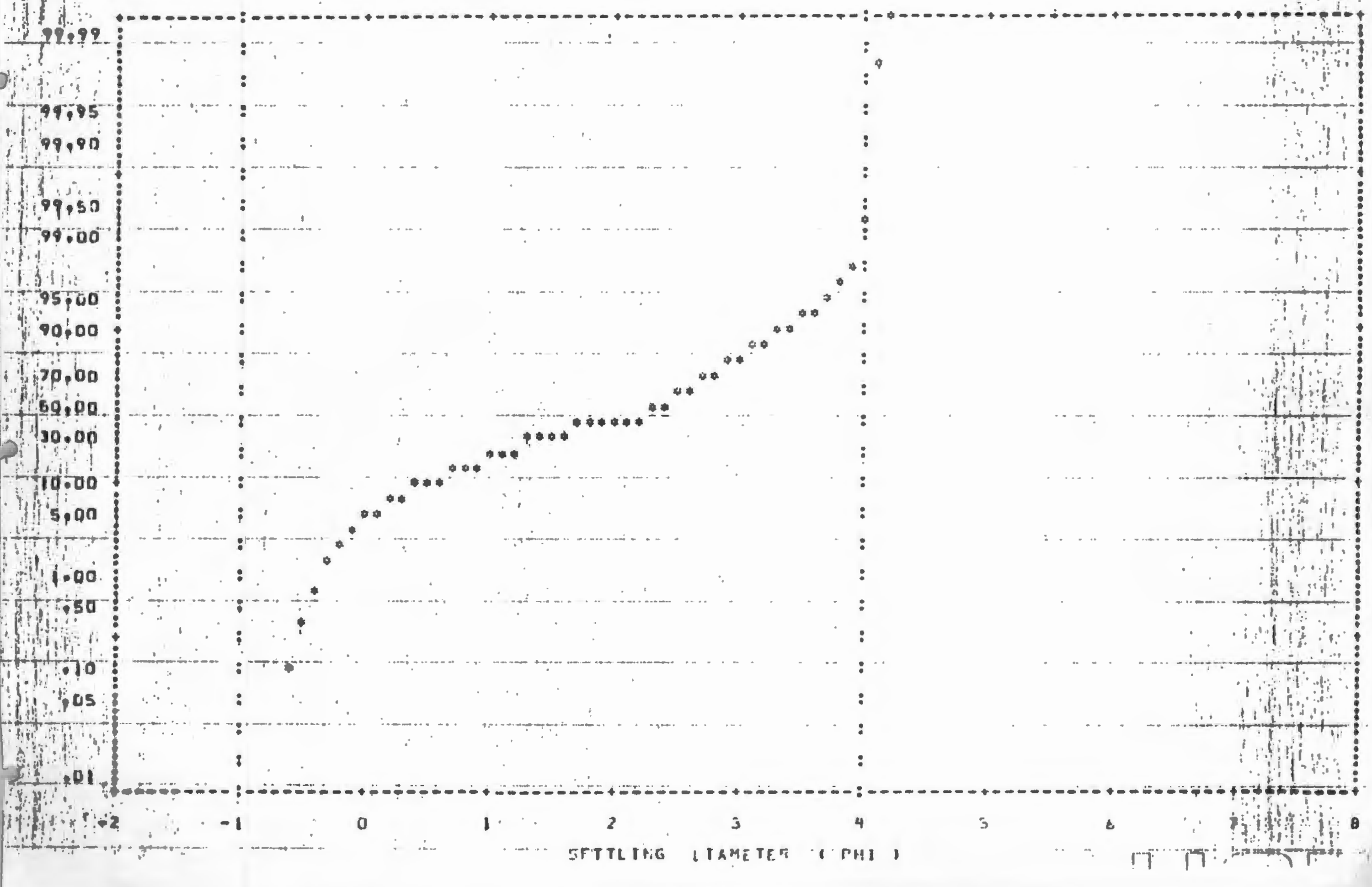
CRUISE BO-90 TOTAL & TERRIG. SAND DISTRIBUTIONS GROUP X0

DISTRIBUTION CURVE (SAND SIZE) FOR 24-130 X CO-ORDINATE: .00 Y CO-ORDINATE: .00



CRUISE BO-90 TOTAL & TERRIG. SAND DISTRIBUTIONS GROUP X0

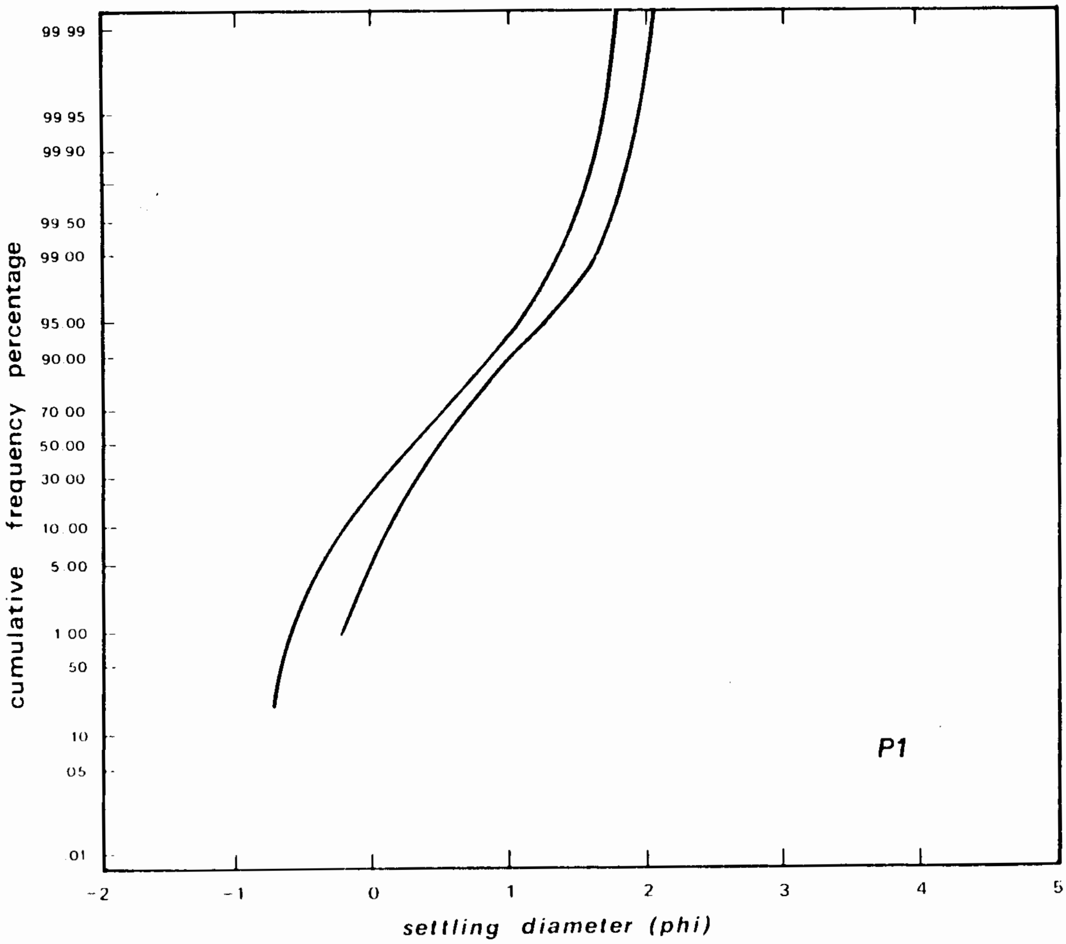
DISTRIBUTION CURVE (SAND SIZE) FOR 24-13C X CO-ORDINATE: .00 Y CO-ORDINATE: .00

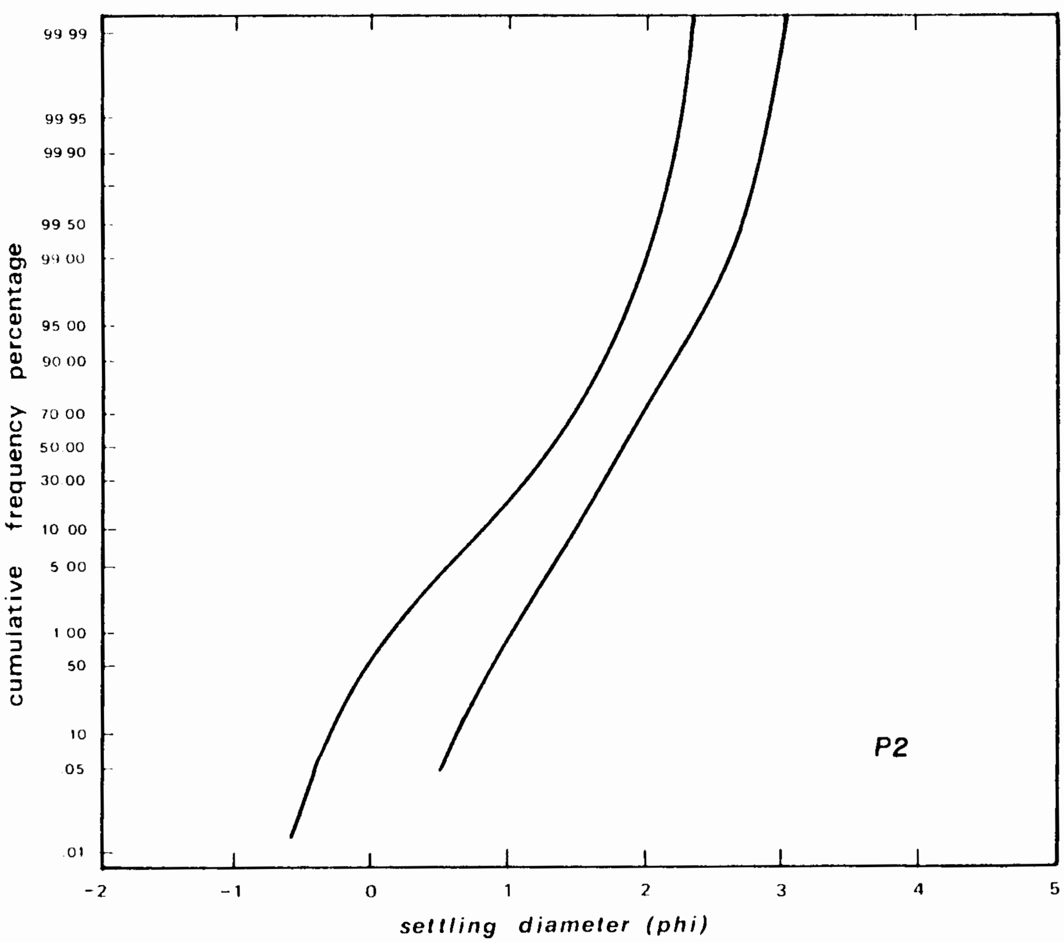


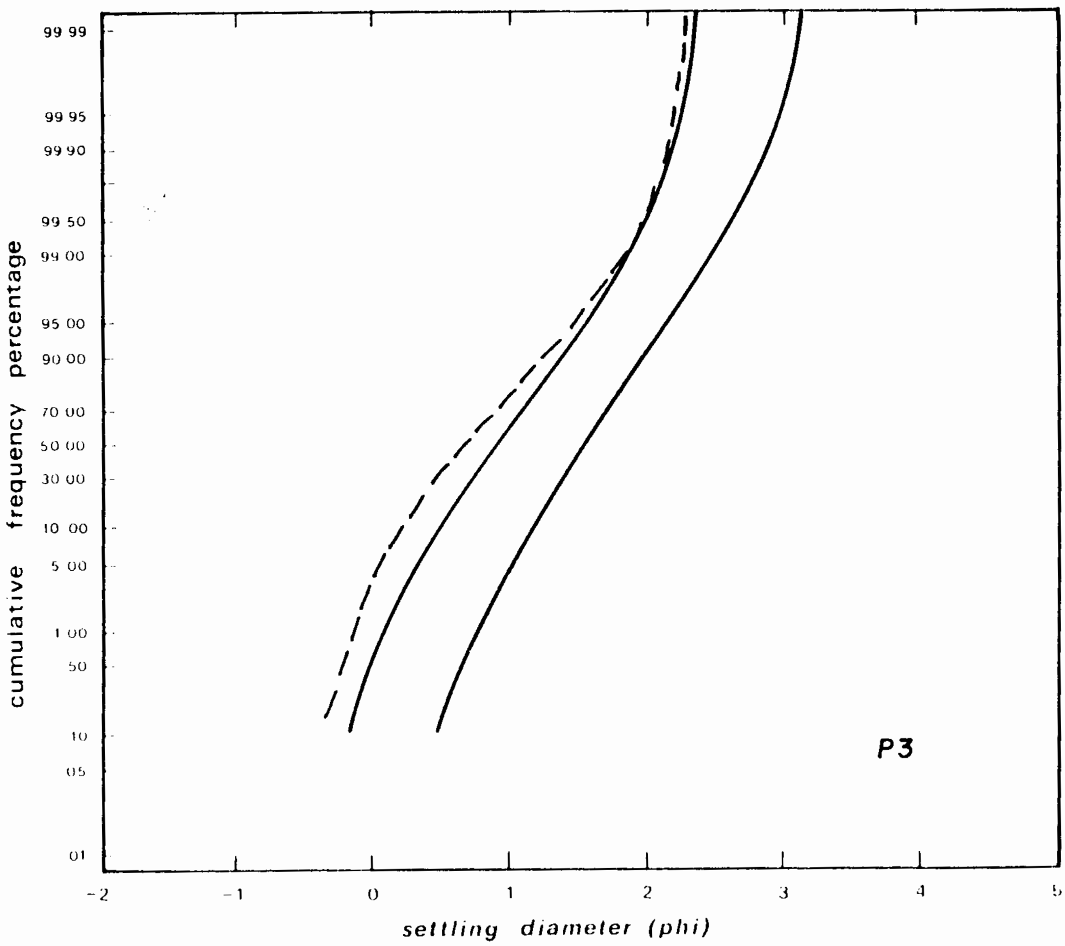
APPENDIX 4

7.4.1 Cumulative curve groupings

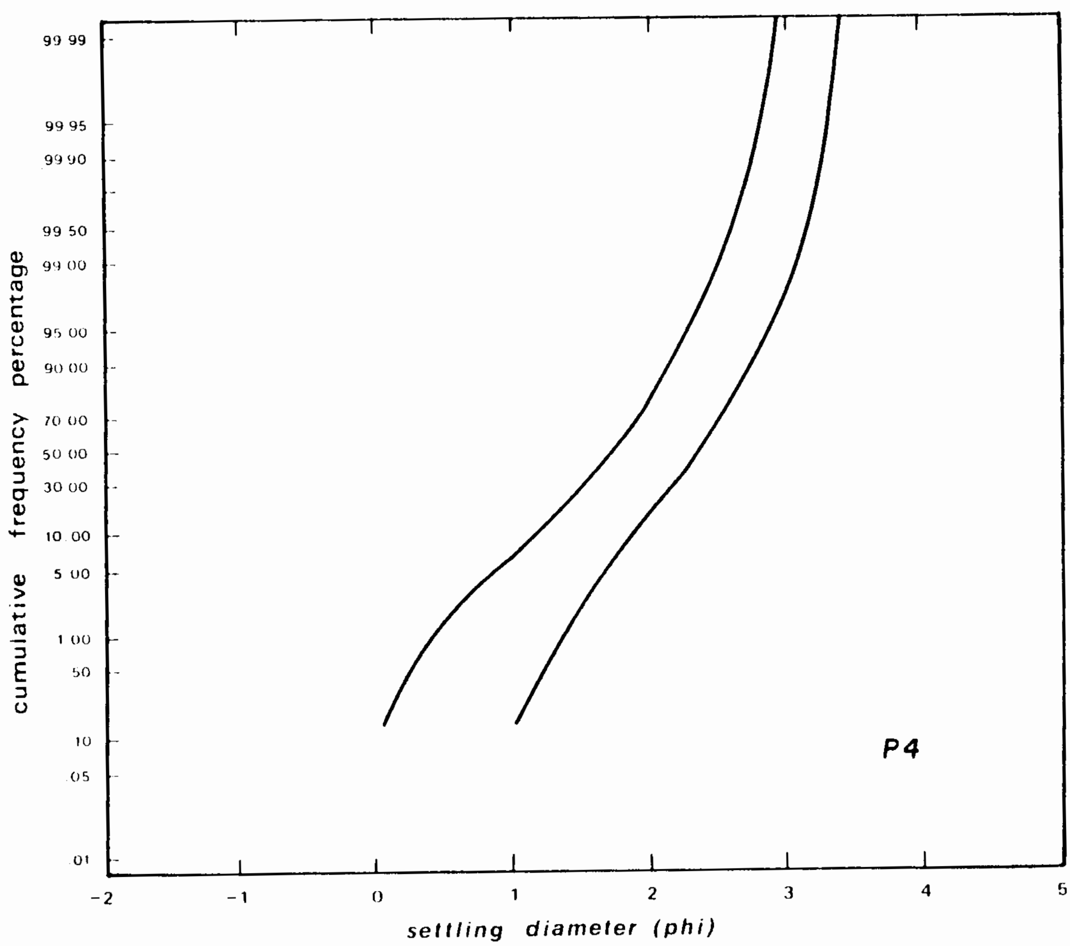
4.1 Cumulative curve groupings (unmixed populations)



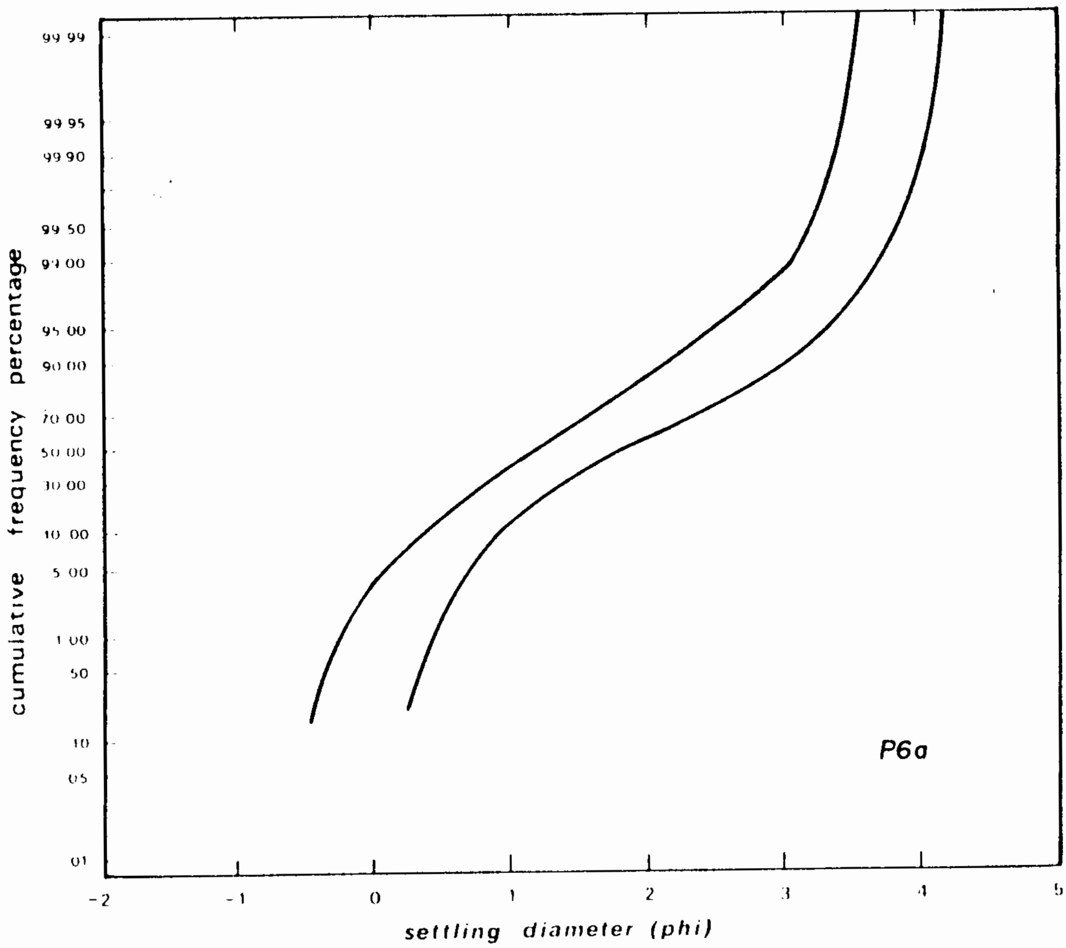




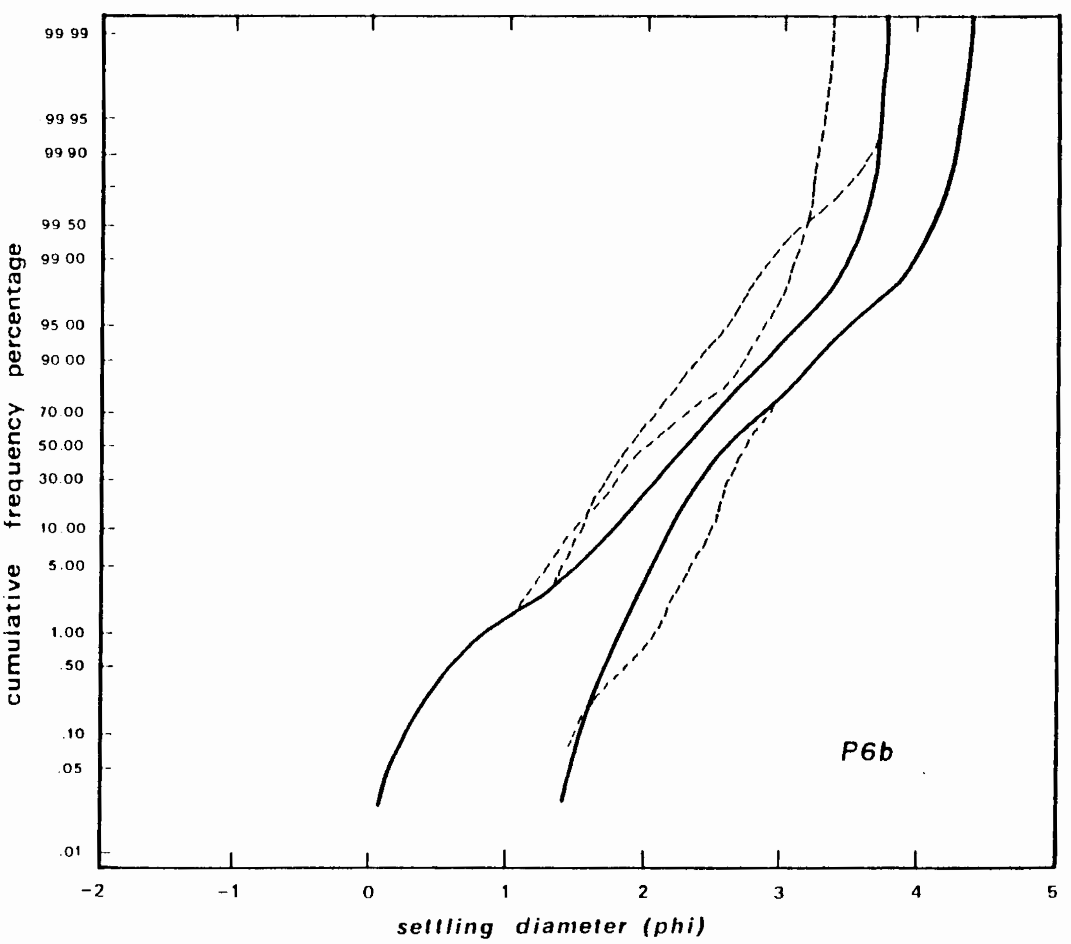
99 99
99 95
99 90
99 50
99 00
95 00
90 00
70 00
50 00
30 00
10 00
5 00
1 00
50
10
05
01
cumulative frequency percentage
-2
-1
0
1
2
3
4
5
settling diameter (phi)
P3



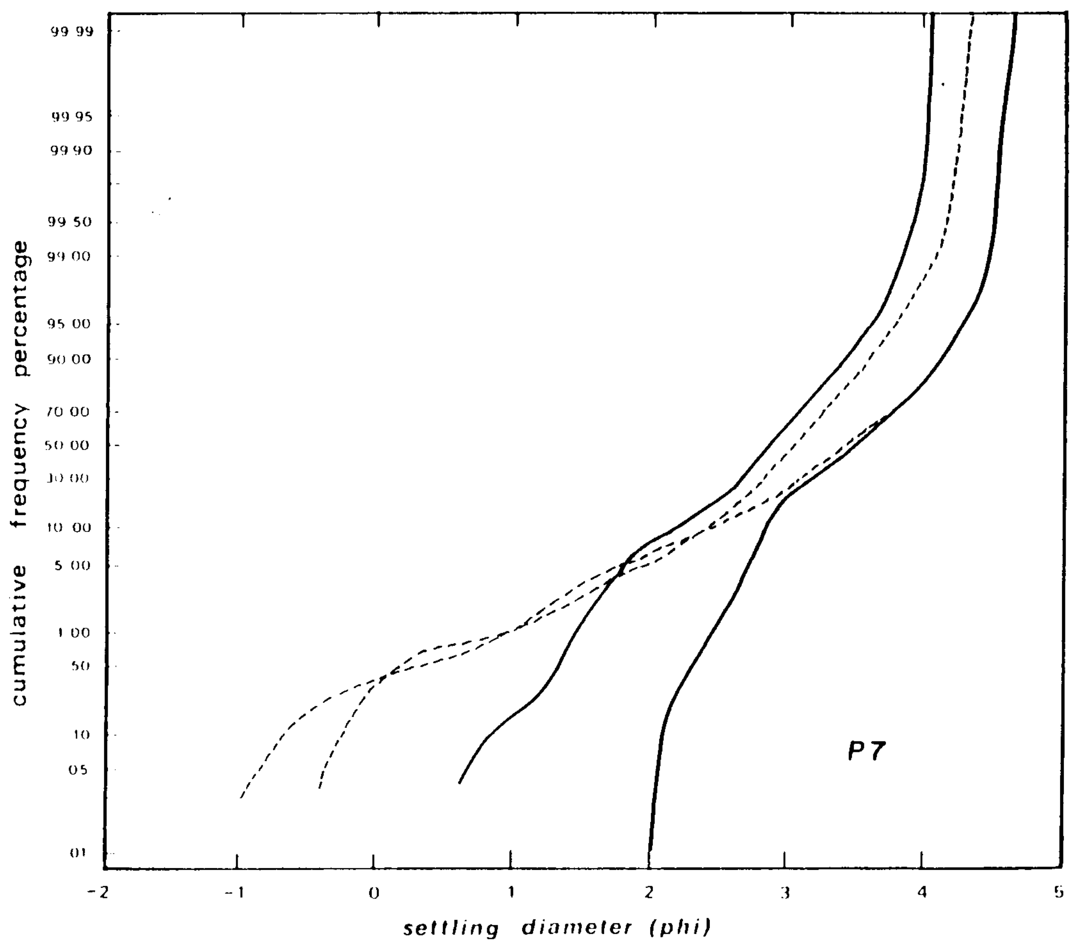
99 99
99 95
99 90
99 50
99 00
95 00
90 00
70 00
50 00
30 00
10 00
5 00
1 00
50
10
.05
.01
cumulative frequency percentage
-2
-1
0
1
2
3
4
5
settling diameter (phi)
P4



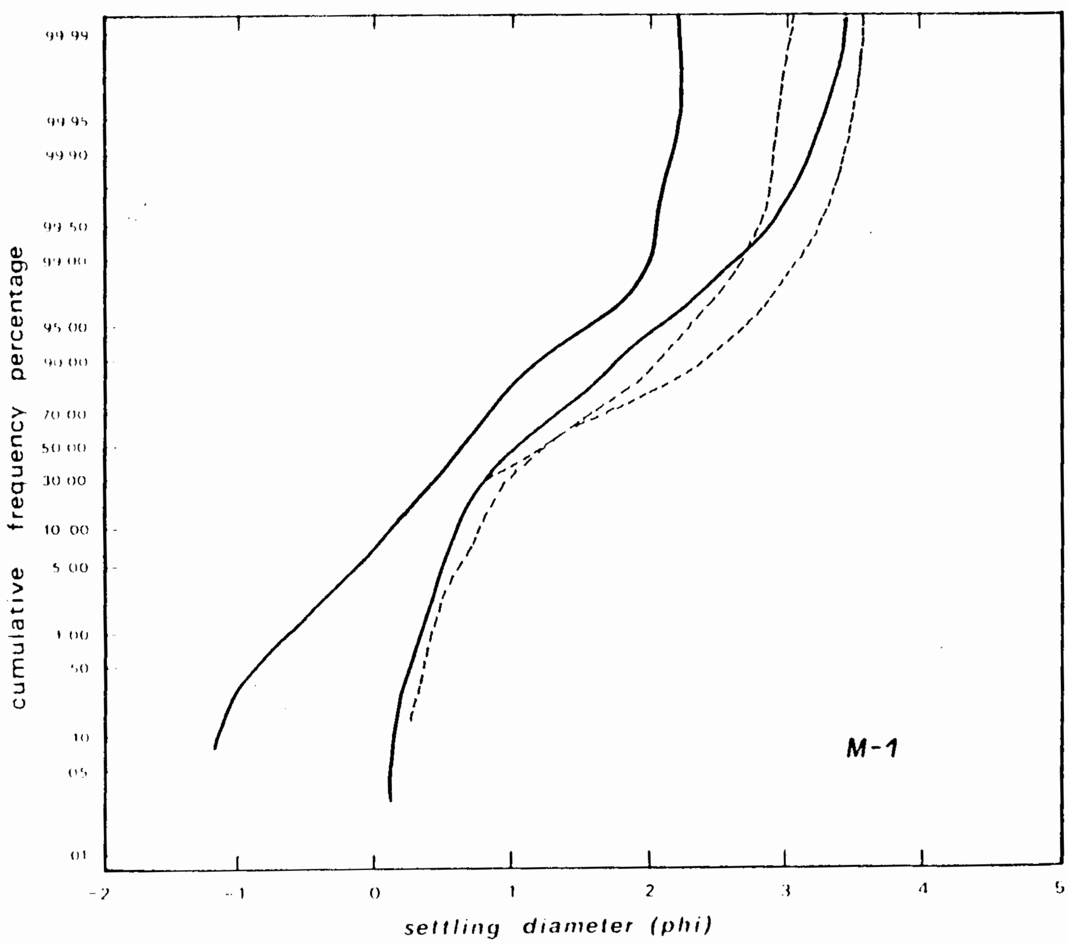
99 99
99 95
99 90
99 50
99 00
95 00
90 00
70 00
50 00
30 00
10 00
5 00
1 00
50
10
05
01
cumulative frequency percentage
-2
-1
0
1
2
3
4
5
settling diameter (phi)
P6a

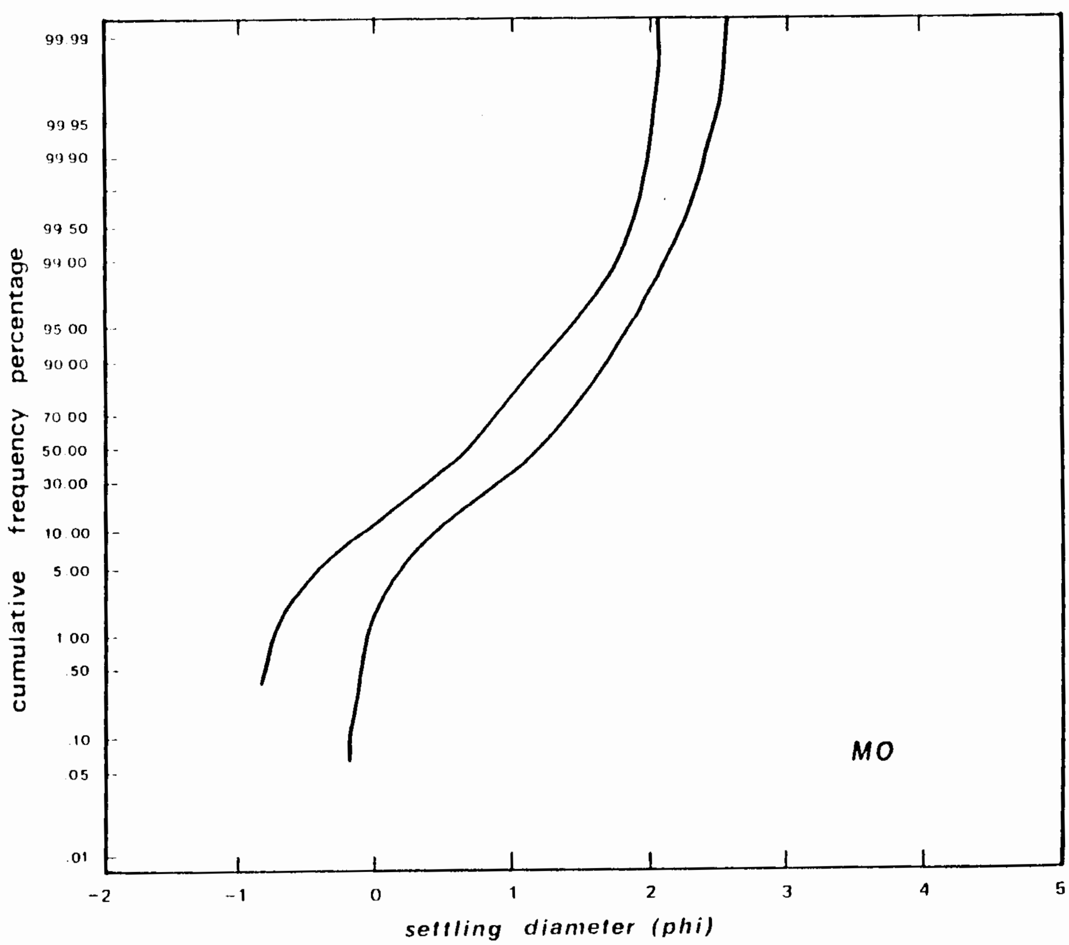


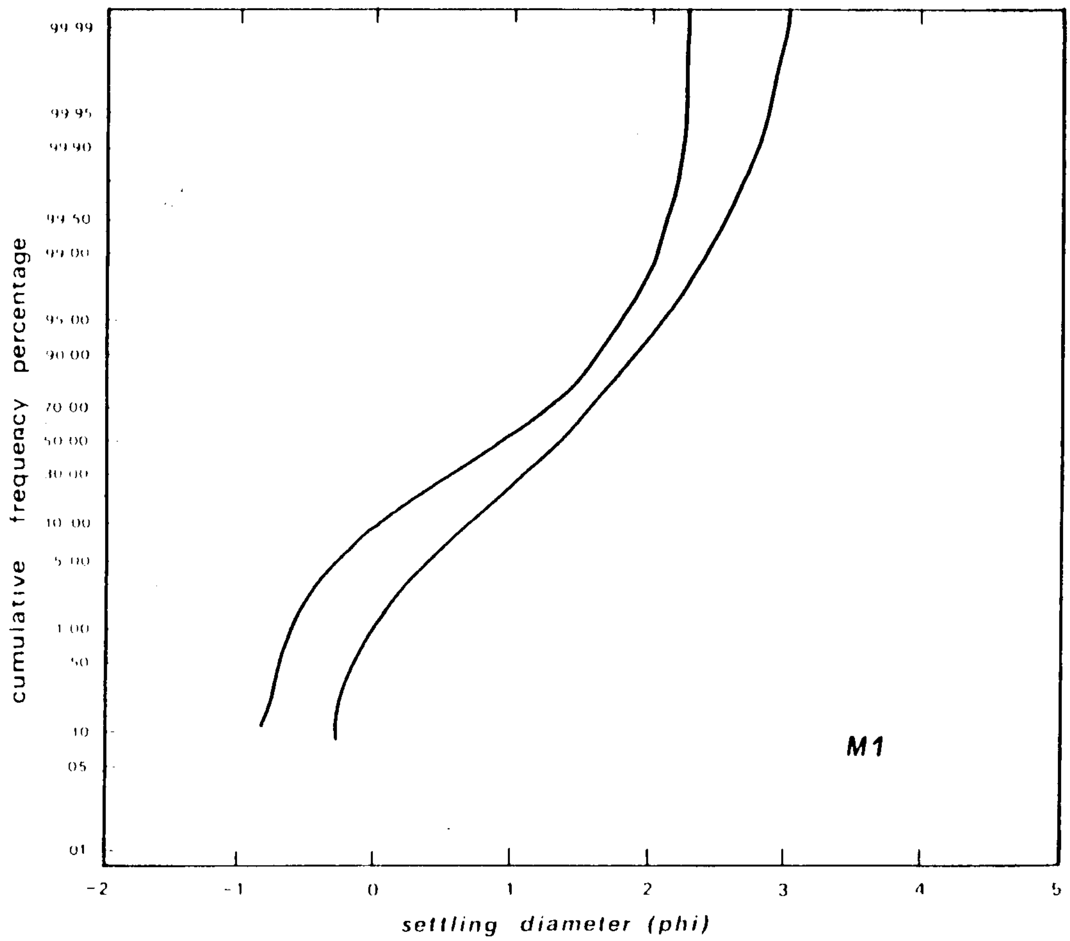
99 99
99 95
99 90
99 50
99 00
95 00
90 00
70 00
50.00
30.00
10.00
5.00
1.00
.50
.10
.05
.01
cumulative frequency percentage
-2
-1
0
1
2
3
4
5
settling diameter (phi)
P6b

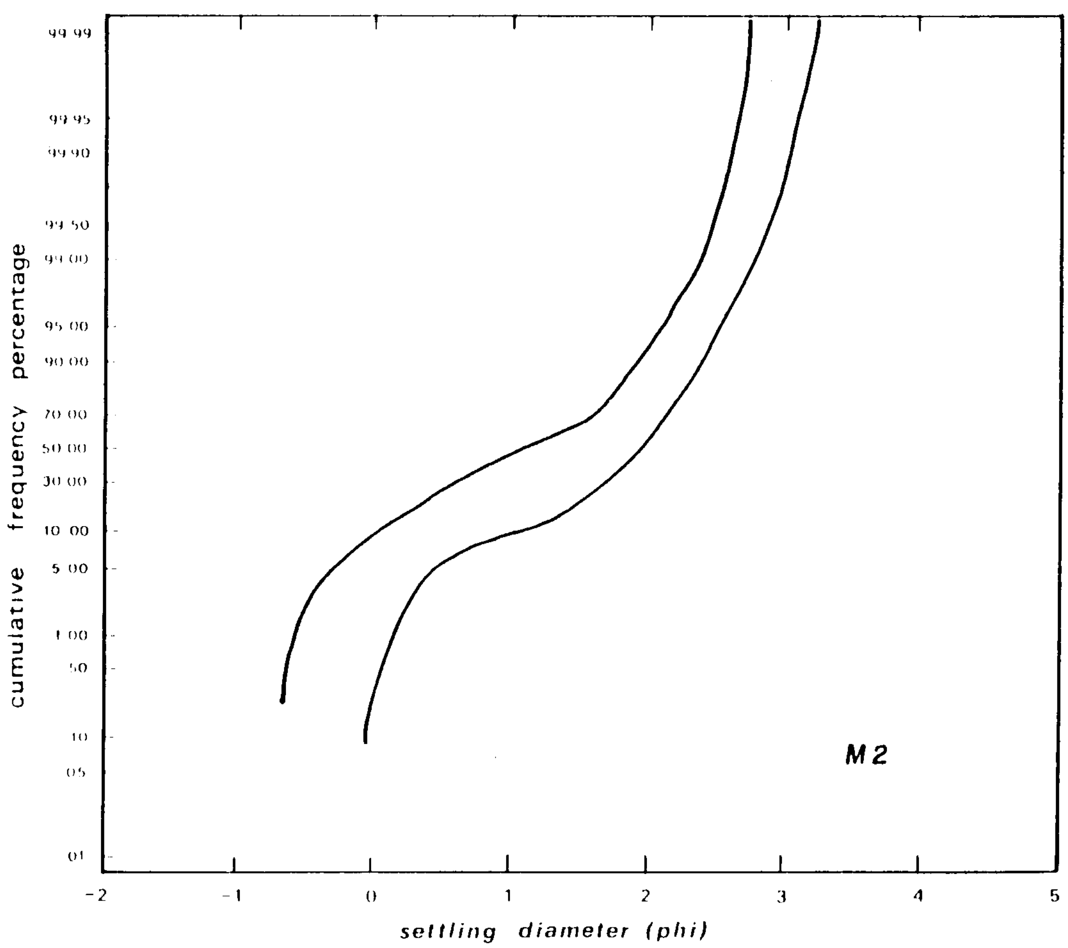

99 99
99 95
99 90
99 50
99 00
95 00
90 00
70 00
50 00
30 00
10 00
5 00
1 00
50
10
05
01
cumulative frequency percentage
P7
-2
-1
0
1
2
3
4
5
settling diameter (phi)

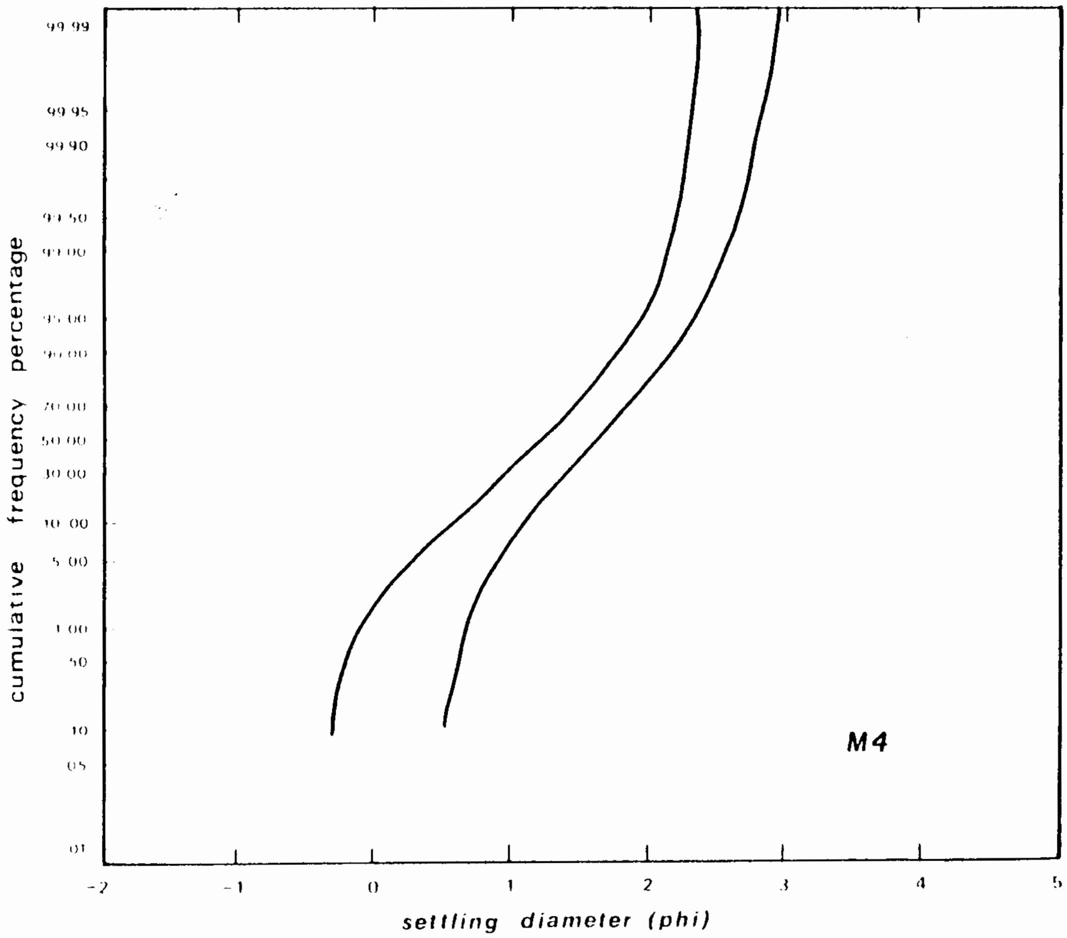
4.1.1 Cumulative curve groupings (mixed populations)

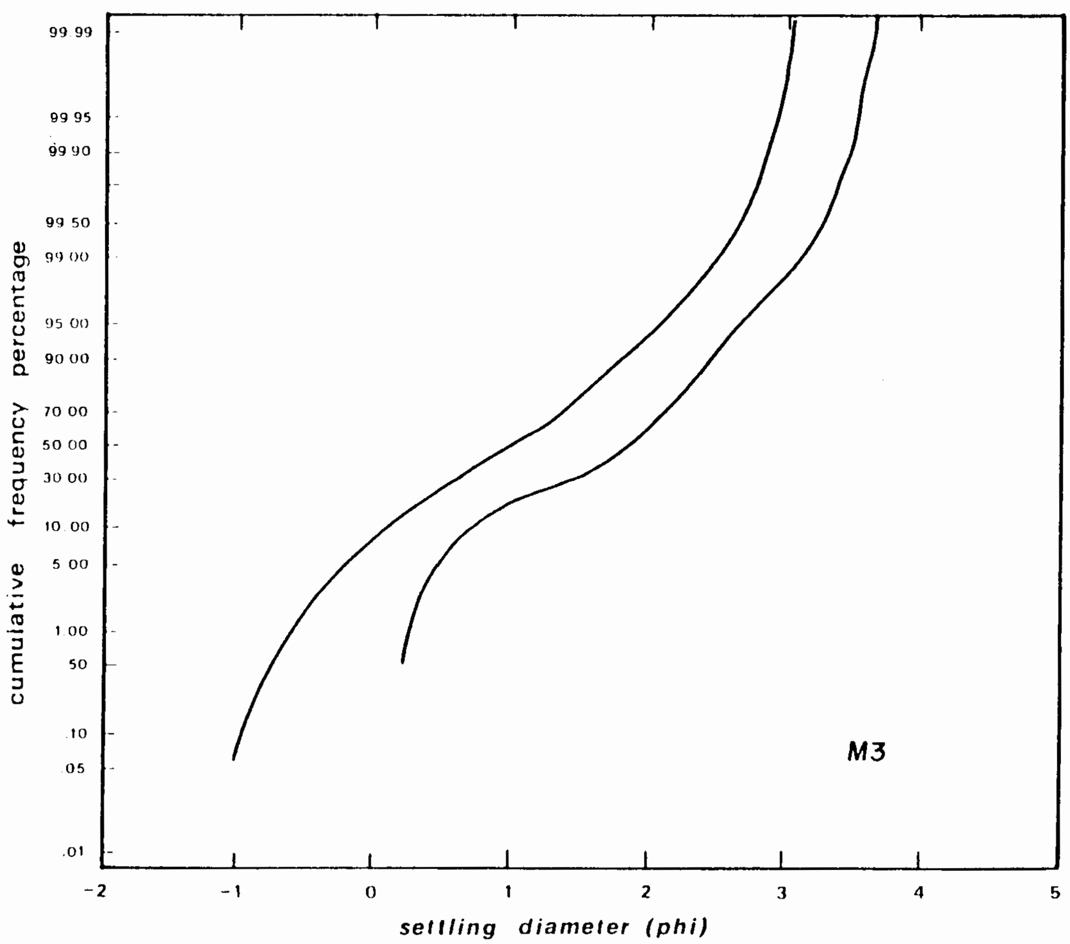


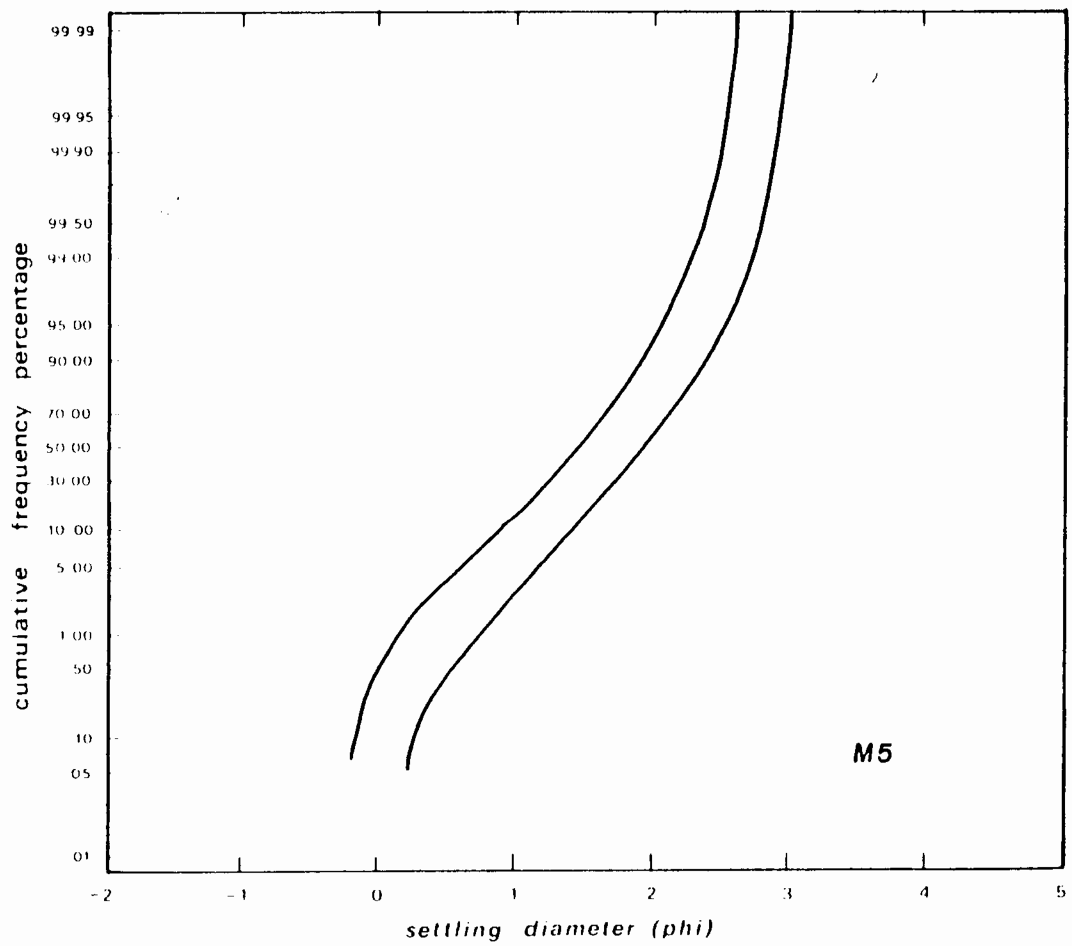


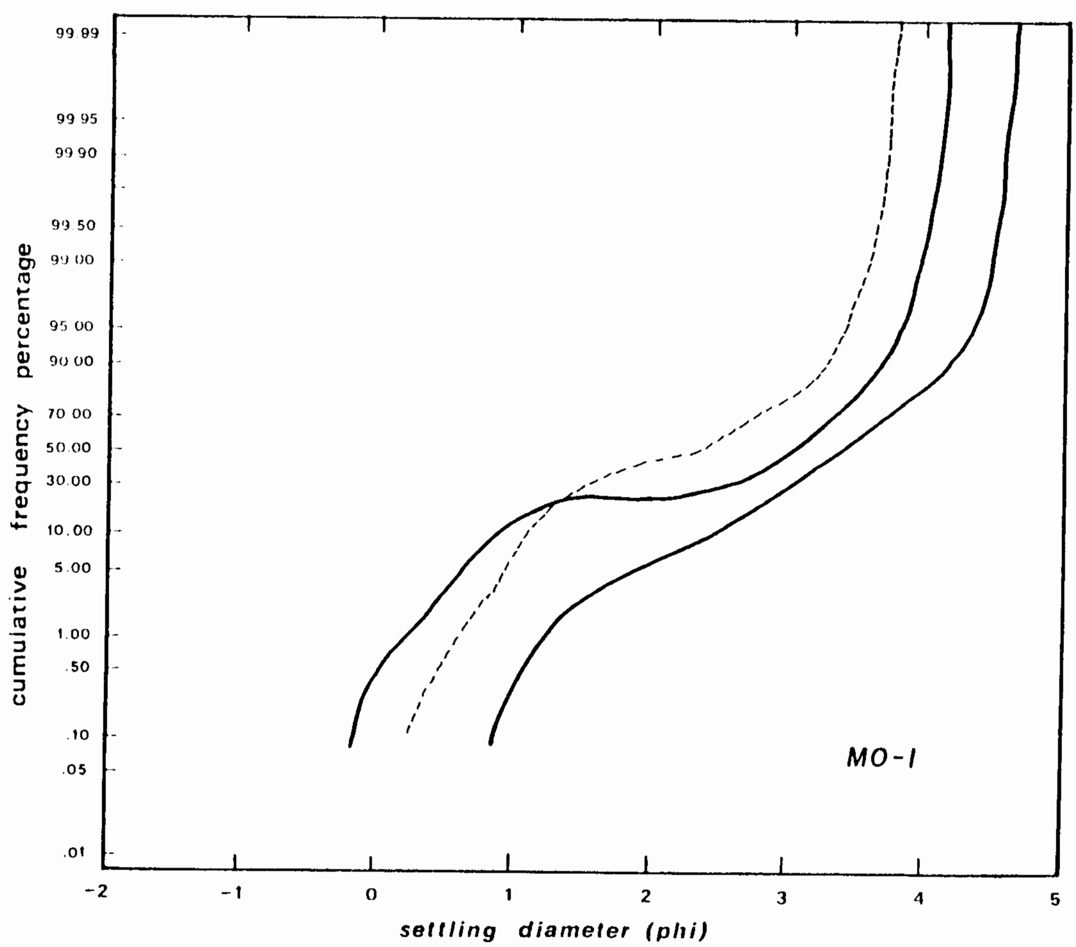

cumulative frequency percentage
99.99
99.95
99.90
99.50
99.00
95.00
90.00
70.00
50.00
30.00
10.00
5.00
1.00
.50
.10
.05
.01
-2
-1
0
1
2
3
4
5
settling diameter (phi)
M1


cumulative frequency percentage
99.99
99.95
99.90
99.50
99.00
95.00
90.00
70.00
50.00
30.00
10.00
5.00
1.00
.50
.10
.05
.01
-2
-1
0
1
2
3
4
5
settling diameter (phi)
M2

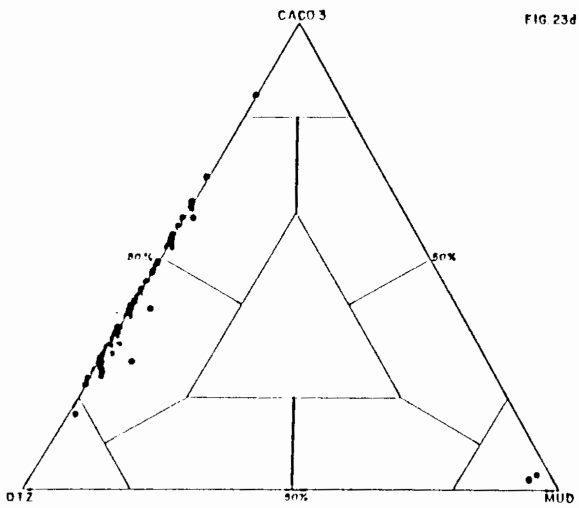

M4
cumulative frequency percentage
settling diameter (phi)
-2
-1
0
1
2
3
4
5


M3
cumulative frequency percentage
99.99
99.95
99.90
99.50
99.00
95.00
90.00
70.00
50.00
30.00
10.00
5.00
1.00
50
.10
.05
.01
settling diameter (phi)
-2
-1
0
1
2
3
4
5

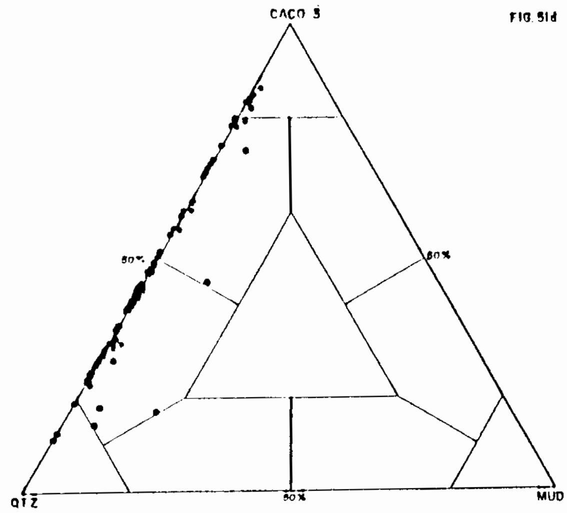

cumulative frequency percentage
99.99
99.95
99.90
99.50
99.00
95.00
90.00
70.00
50.00
30.00
10.00
5.00
1.00
.50
.10
.05
.01
-2
-1
0
1
2
3
4
5
settling diameter (phi)
M5


cumulative frequency percentage
99.99
99.95
99.90
99.50
99.00
95.00
90.00
70.00
50.00
30.00
10.00
5.00
1.00
.50
.10
.05
.01
-2
-1
0
1
2
3
4
5
settling diameter (phi)
MO-I

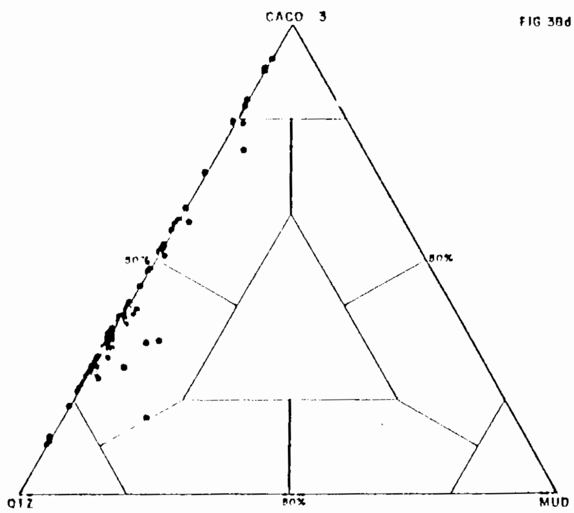
4.2 CACO3-QTZ-MUD PLOTS



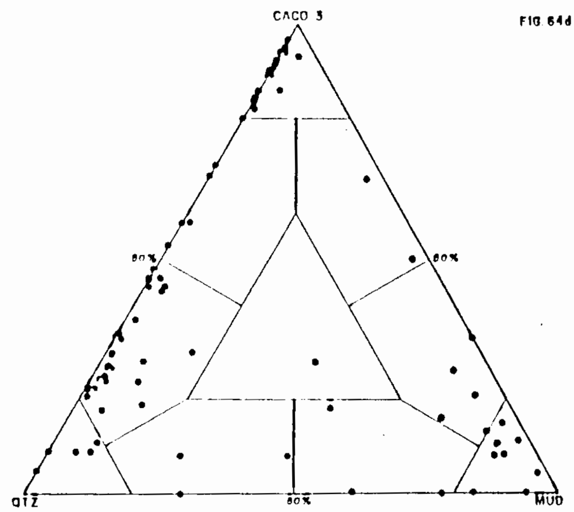
Durban to Scottburgh



Port Shepstone to Mtentu River

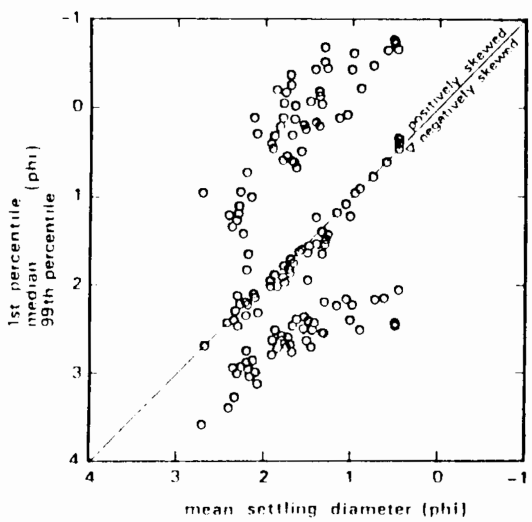


Scottburgh to Port Shepstone

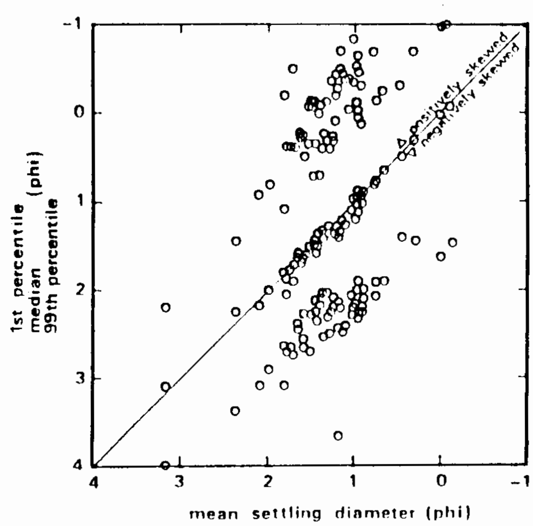


Mtentu River to Port St Johns

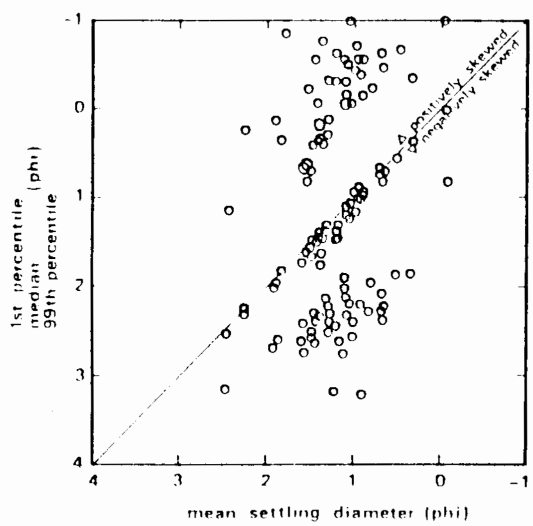
4.3 Grain size images



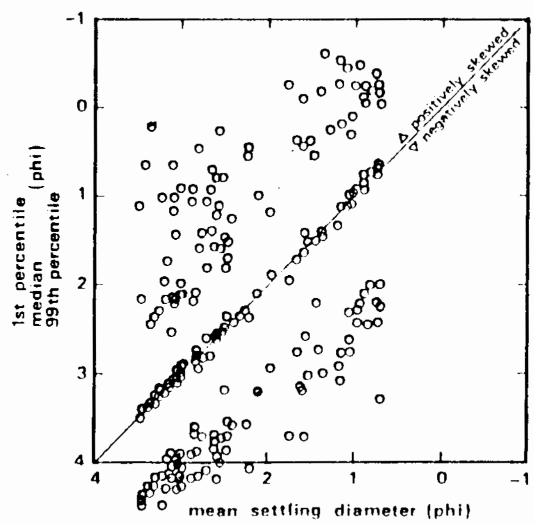
Durban to Scottburgh



Port Shepstone to Mtentu River



Scottburgh to Port Shepstone



Mtentu River to Port St Johns

BATHYMETRIC MAP A : DURBAN TO UMZINTO BAY

BATHYMETRIC MAP

BATHYMETRIC MAP B : UMZINTO BAY TO PORT SHEPSTONE

BATHYMETRIC MAP C : PORT SHEPSTONE TO MTENTU RIVER

BATHYMETRIC MAP D : MTENTU RIVER TO PORT ST. JOHNS