GEOMORPHOLOGY AND SEDIMENTOLOGY OF THE MOMBASA - DIANI AREA: IMPLICATIONS TO COASTAL ZONE MANAGEMENT

BY

PAMELA ATIENO W. ABUODHA.

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PAMELA ATIENO W. ABUODHA.

A thesis submitted in partial fulfilment for the degree of Master of Science in the University of Nairobi.

This thesis is my original work and has not been presented for a degree in any other University.

P. A. W. ABUODHA

This thesis has been submitted for examination with my knowledge as University Supervisor.

DR. E. O. ODADA.

ABSTRACT

The overall objective of this thesis was to identify coastal zone management problems within Mombasa-Diani area. The study of sedimentological processes and geomorphic features have been used to solve these problems. Other objectives included evaluating the effectiveness of the existing control measures and identifying response strategies for the affected areas.

The methods used were divided into field and laboratory methods. Sediments were investigated using grain size distribution analysis, carbonate content determination and microscopic study. Beach profiling, beach gradients and beach width measurements together with wave and current measurements and aerial photo interpretation facilitated the interpretation of geomorphic results.

The results of sedimentological work showed erosional beaches to occur at Kikambala, Kanamai, Mtwapa, Shanzu, Bamburi, Kenyatta and Black Cliff Point. Nyali, Tiwi, Galu and Kinondo were found to be stable beaches while Likoni, Diani and Gazi were considered depositional beaches given no induced erosion. Geomorphologically, coastal dunes and beach

ridges, cliffed coasts and backshore areas could be developed but with proper set back lines so as not to induce erosion. Coastal erosion, over development and lack of coastal zone management system, and construction of stabilizing structures along the beaches were identified as major problems within the project area.

From these results it is concluded that there is an urgent need for a coastal zone management system and to enact a legislation which would protect coastal resources and environment for their sustainability. Stabilizing structures should be constructed only for highly developed areas. Keeping in mind the future sea level rise, beach hotels should be put about 1 km landward of the shoreline.

ACKNOWLEDGEMENTS

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I gratefully acknowledge the help obtained from Dr. E. O. Okemwa, the Director, Kenya Marine and Fisheries Research Institute (KMFRI). I must mention Mr. K. Kalundu, a technician for help in collecting samples and beach profiling. Mr. S. Langat, a technician, assisted in taking photographs in the field and Messrs Z. M. Onsare and S. M. Kavoi, cartographers, for drawing the maps.

I would also like to record my great indebtedness to the German Academic Exchange Services (DAAD) for financing this work through the UoN., the Office of the President, for granting me permission to purchase maps and aerial photographs of my study area, the Commissioner of Mines and Geology, Mr. C. Y. Owayo, for offering me their laboratory for my sediment analysis in Nairobi, Prof. F. F. Ojany and Dr. I. J. Mwanje, both of the Department of Geography, UoN, for their advice and relevant literature. Special acknowledgement is made to those authors and publishers whose illustrations have been reproduced in this thesis; fuller acknowledgements of sources are made at appropriate places in the text.

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CHAPTER 1 GENERAL INTRODUCTION

1.1. Study objectives

The overall objective of this thesis is to study geomorphological features and sedimentological processes within the Mombasa-Diani coastal area and then relate these features and processes to the management of the coastal zone. The specific objectives of this study are therefore as follows:-

1. Identify major geomorphological features within the study area in order to determine the vulnerability of the coastline to sea level rise and impacts of coastal development.
2. Investigate nature and type of beach sediments in order to determine which sections of the beach are undergoing erosion, deposition or are stable.
3. Assess the vulnerability, response strategy, and requirements for the affected areas.

1.2. Study area

The study area is situated on the southern section of the Kenya coast (Fig. 1). It stretches over 70 km between latitudes 3°53'4" south and 4°26'5" south. To the west, the study area is bounded by dunes and cliffs and to the east by the western Indian Ocean. To the north the project area is bounded by Kikambala Beach, approximately 10 km from Mtwapa Creek, and to the south by Gazi Bay (Fig. 2). The

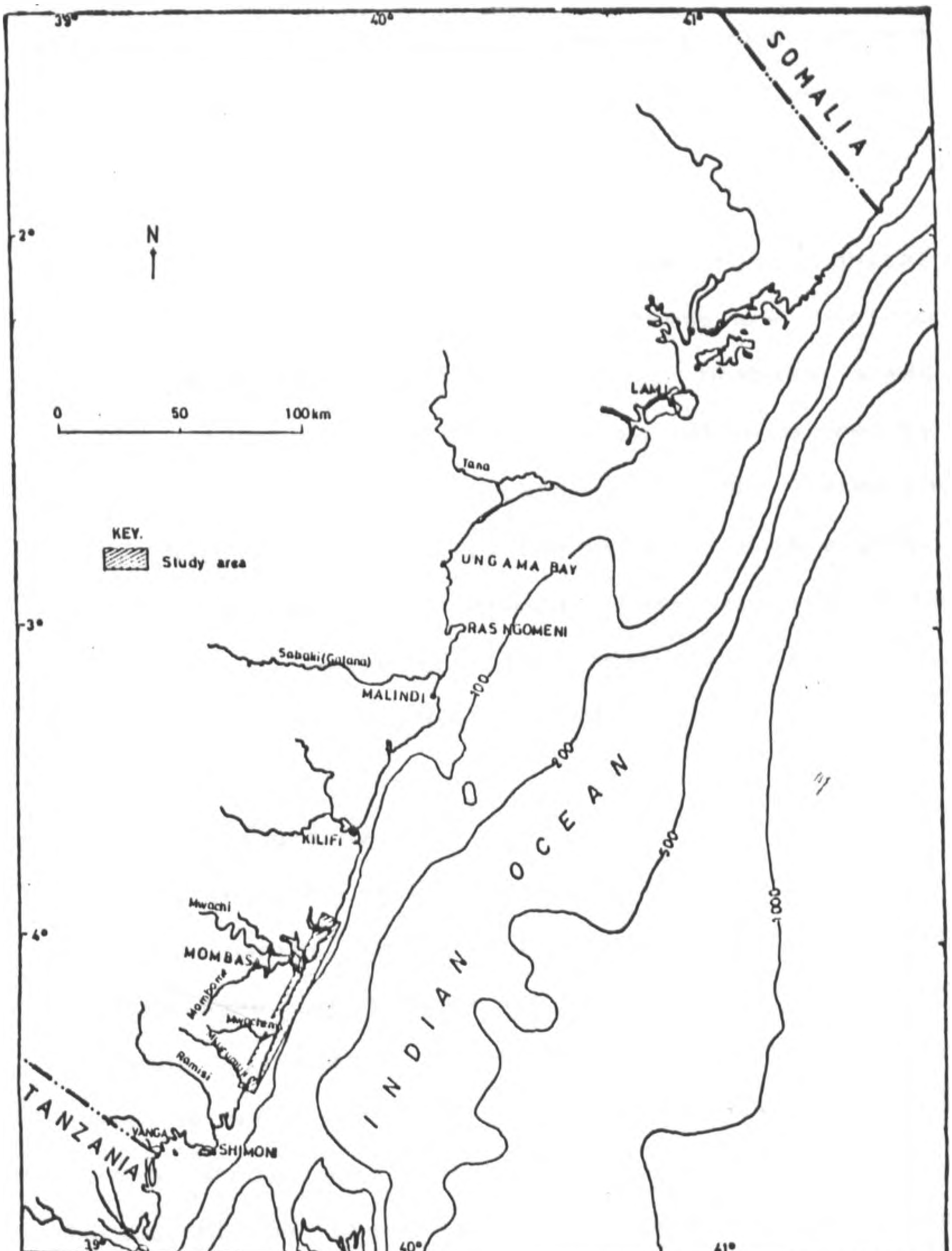


Fig. 1 shows map of Kenyan coast with the study area shaded (Source; Admiralty charts 667, 1980 and 6272, 1970).

investigated area embraces the southern sector of Kilifi district, the whole of Mombasa district and most of the Kwale district, all in the Coast Province of Kenya.

The study area is covered by four topographical sheets at a scale of 1:50,000. These are Vipingo sheet 198/4, Mazeras sheet 198/3, Mombasa sheet 201/1 and Ukunda sheet 201/3. It is also covered by aerial photographs at a scale of 1:12 500 taken in 1955. Bathymetric data of the study area is scanty. Limited coverage from Mtwapa Creek to Mwachema estuary is found on the admiralty chart of Approaches to Mombasa (Wyatt, 1948).

1.2.1. Physiography

The physiography of the study area include islands, bays, estuaries, reefs and beaches (Fig. 2). The islands occur at Mombasa and Chale. A narrow strip of land alternately being exposed and covered by tides or waves constitutes the present day shoreline in the study area. The bays occur around Mombasa Island, Mtwapa Creek and Gazi. Several rivers and streams enter these bays. In Mombasa, rivers Mwachi, Cha Shimba (Pemba), Mambone and Manjera discharge into the southern arm of the bay known as Port Reitz Creek while rivers Kombeni and Tsalu discharge into

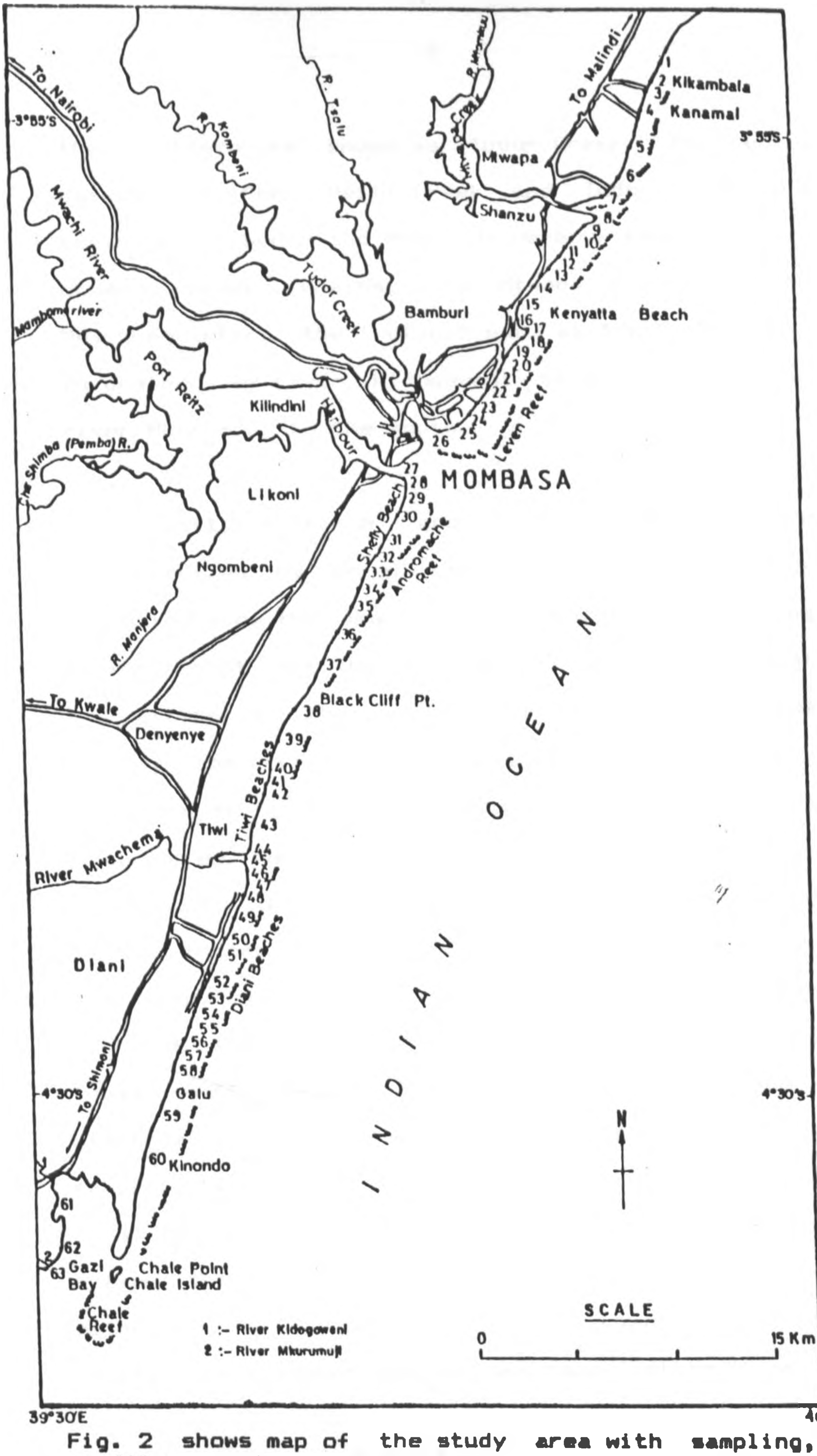


Fig. 2 shows map of the study area with sampling, profile locations and drainage.

the northern arm known as Tudor Creek. The narrow passages of Port Reitz Creek and Tudor Creek are Kilindini Harbour and Mombasa Harbour respectively. Mtomkuu river drains into Mtwapa Creek. River Mwachema enters the Indian Ocean at Tiwi. Gazi bay is drained by river Kidogoweni to the north and river Mkurumuji to the south.

The coastlines north and south of Mombasa are characterized by coral rocks and sandy beaches protected from the open Indian Ocean by the fringing reefs. Except for the interruption of the reefs at the creeks by the outflow of fresh water from rivers, the reefs run parallel to the entire shoreline at a distance of approximately 2 km in the study area. North of Mombasa, the shore platform extends 1-2 km offshore leaving a well protected lagoon inside. Small sand dunes and offshore bars are also characteristic features of the northern part of Mombasa. South of Mombasa the reefs are found mostly close to the shore and the shore platform is characterized by small stacks and cavities because the waves generally break on it and thus it is most of the time under strong wave action. The upper level of the shore•platform is either an area consisting of weathered undercut cliffs with frequent notches and caves (plate 1) or a sandy beach with sea walls (plate 2).

1.3. Climate

1.3.1. Temperature

Due to the equatorial position of the Mombasa-Diani area between 3° 53' S and 4° 26' S, seasonal variations in air temperature are small. The warmer period is from November to March (Table 1). The annual mean maximum temperature averages about 30.1° C while the annual mean minimum temperature is 22.4° C. The coldest months start from June to September. Diurnal temperature variations are within the range of 6.7-8.9°C.

1.3.2. Rainfall

The mean annual rainfall recorded in the Mombasa region is 1077 mm (Table 1). The long rains season occurs during April/May. Short rains occur from October to November. Minimum precipitation occurs in the dry warm season of January and February. The precipitation in this area is usually concentrated in short heavy showers.

1.4 Coastal processes

1.4.1 Surface Currents direction and speed

Wind intensity and direction have direct influence upon surface currents (table 2). These currents

Plate 1 shows a cliffed coast (c) with undercut notches (n) and a beach (b) adjacent to the cliffs at Nyali (September, 1990; Photo by P. Abuodha).

Plate 2 shows a beach (b) marked on the landward side by a seawall (s) along Bamburi beach (September, 1990; Photo by P. Abuodha).

Table 1: Annual long term average climatological data for the years 1946 to 1990 for Mombasa area. Moi Airport Meteorological station (from Kenya Meteorological Department, unpub. data).

Month	Air temperature (° C)			Rainfall (mm)
	Max.	Min.	Range	Mean
January	31.9	23.3	8.7	2.7
February	32.4	23.5	8.9	15
March	32.5	24.2	8.3	60
April	31.3	23.9	7.4	166
May	29.4	22.7	6.7	257
June	28.1	21.3	6.8	85
July	28.1	20.3	7.8	68
August	27.8	20.4	7.4	62
September	28.6	20.8	7.8	62
October	29.5	22.1	7.4	104
November	30.6	23.1	7.5	89
December	31.5	23.4	8.1	82
Annual mean	30.1	22.4	7.7	1077

are important in the open shallow waters in the bays, estuaries and as longshore currents which flow along the beaches north and south of Mombasa Island. The currents influence coastal processes such as erosion and deposition. The annual mean surface current direction is 113° while the speed is 1.2 m/s.

1.4.2 Wind direction, force and speed

There are 4 distinct wave regimes in the coastal region (Turyahikayo, 1987). They are conveniently referred to as:

1. NE monsoon regime (December-February),
2. transition regime (March/April),
3. SE monsoon regime (May-October) and
4. transition regime (November).

The NE monsoons represent the shorter and the warmer of the two monsoon seasons. The annual average wind speed at 0600 GMT is lower (3.1 m/s.) than at 1200 GMT (6.3 m/s) (Table 2). The annual mean wind force is 2.5. Beaufort force with negligible force in January and the annual mean wind direction is 138°. The winds of the SE monsoons are generally stronger than the NE monsoons.

1.4.3. Tides

Mombasa area is subject to an irregular semi-diurnal

Table 2: Coastal processes for Mombasa (Surface currents and winds from Kenya Meteorological Department, 1984 and tide level from KMFRI, 1979-1981 unpub. data).

	Surface currents		Wind		speed(m/s)		Tide
Month	dir. (°)	Speed (m/s)	dir. (°)	Force (BF)	0600 GMT	1200 GMT	Level (mm)
January	223	0.8	093	0.0	3.1	6.2	2008
February	220	0.8	061	3.0	2.6	6.7	1983
March	212	0.9	124	3.0	2.6	6.2	2034
April	044	1.3	184	4.0	3.1	6.2	2056
May	042	1.8	180	3.5	4.1	6.7	2075
June	038	1.5	180	3.8	4.1	6.7	2048
July	056	1.5	183	3.8	3.6	6.7	2011
August	032	1.4	170	2.7	3.6	6.7	1986
September	025	1.0	160	1.5	3.1	6.7	1996
October	051	1.0	168	2.4	2.6	6.2	2018
November	224	1.2	108	1.7	2.1	6.2	2011
December	194	0.9	044	1.0	2.6	5.7	1984
Ann. mean	113	1.2	138	2.5	3.1	6.3	2018

mesotidal to macrotidal regime in a lunar day. The tidal period is 12 h 25 min. Mean high water spring and neap tides occur at 3.4 m and 2.4 m respectively above datum while mean low water spring and neap tides occur at 0.3 m and 1.3 m respectively above datum (Wyatt, 1948). The average tidal range is about 2-3 m and the annual mean tide level is 2018 mm (Table 2).

1.5. Geological setting

The coastal belt of Kenya comprises of the following main topographical features which are closely related to the geological characteristics of the area;

1. Coastal Plain,
2. Foot Plateau,
3. Coastal Range and
4. The Nyika.

The width of the Coastal Plain varies between 8 km in the north and 15 km in the south but is absent on Mombasa Island (Fig. 3) and its altitude is generally less than 45 m above sea level. The Foot Plateau varies in width from 10 km in the north and is widest to the east of Mombasa Island but rapidly thins out in the south. Its altitude is about 60-140 m above sea level. The Rabai and Senawe Ranges form the Coastal Range within the study area, with a

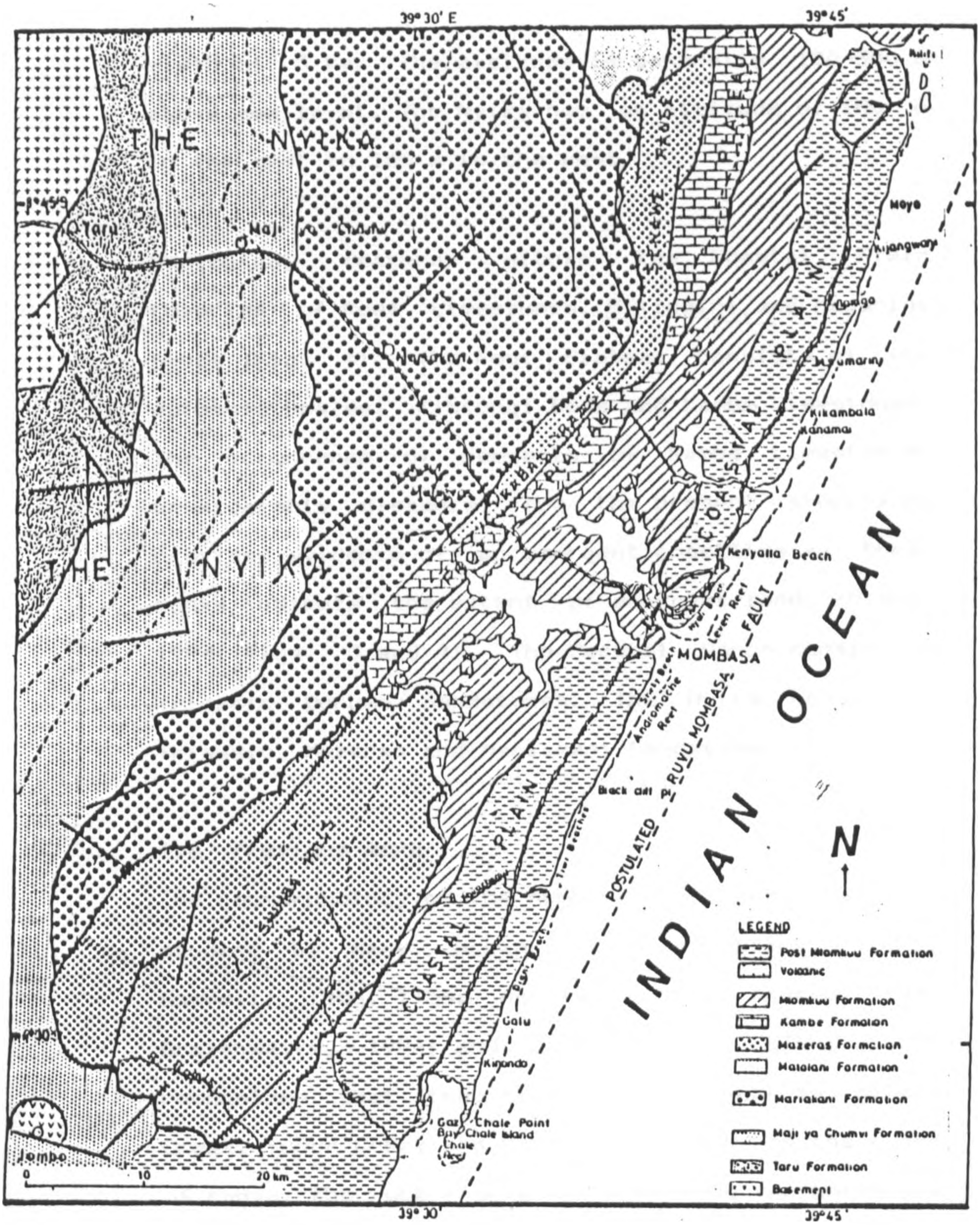


Fig. 3 shows generalised geological map of the southern portion of the Kenya Coastal Belt (Modified after Rais-Assa, 1987).

width of 5 km. The altitude is generally 180-300 m above sea level. The Nyika has an altitude of 180 m in the east to 300 m in the west.

Geological features within the Coastal Plain comprise of Reef Limestones, Kilindini and Magarini Sands (Fig. 4). The Foot Plateau consists of the Jurassic Shales, Kibiongi Beds and Kambe Limestones. The occurrence of remnants of Kambe Limestones, considerable distance from the present shoreline, provides evidence of an emergent coastline as these rocks indicate the extent of emergent land (Ojany, 1984; Figs. 3 and 4). The Coastal Range consists of Triassic Duruma Sandstones. The Nyika consists of Triassic, Mazeras and Mariakani Sandstones.

1.6 Previous work

The geomorphology of the Mombasa-Diani area has been studied by many workers such as Sikes, 1930; Caswell, 1953, 1956; Ase 1978, 1981; Andrew, 1981; Braithwaite, 1984; and Oosterom 1988. Sikes (1930) recognized that the tidal creeks such as Mtwapa Creek, Tudor Creek and Port Reitz Creek on the coast of Kenya, the rock floors of which are far below sea level, originated as land valleys which are now "drowned". He also indicated that the sub-aerial erosion which produced or rejuvenated these valleys

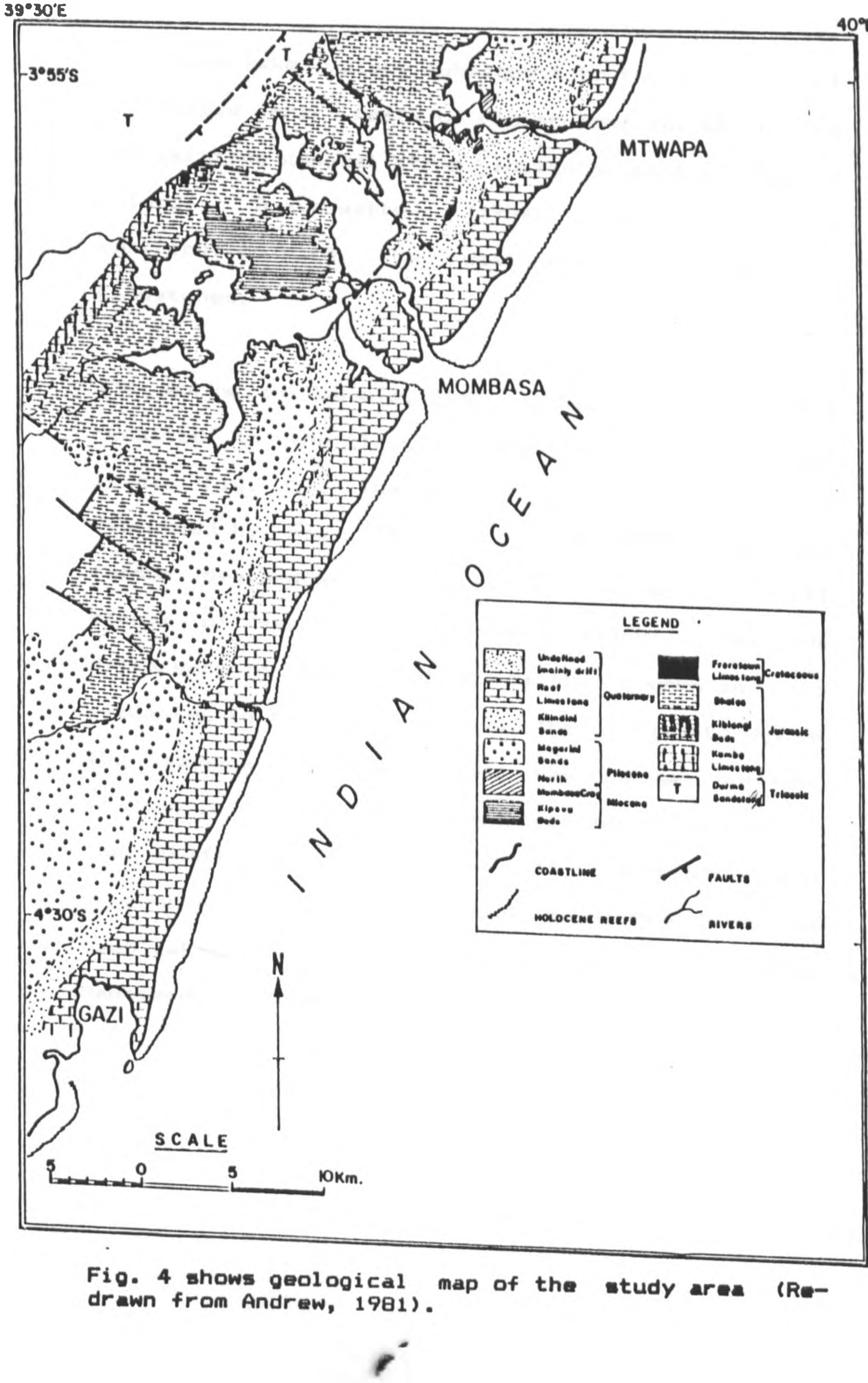


Fig. 4 shows geological map of the study area (Re-drawn from Andrew, 1981).

must have taken place subsequent to the formation of the raised coral reefs of Pleistocene age which form the existing coastal strip including most of Mombasa Island. Braithwaite (1984) gave available contribution to the weathering of the Reef Limestones.

The works of Caswell, 1953, 1956; and Andrew, 1981 resulted in the classification of coastal terrace levels (Fig. 5). The origin of these terraces is discussed by Ase (1978) who has shown that the raised beaches and terraces were formed at still stands of sea level. Oosterom (1988) gives the difference in configuration of the creeks and the estuaries in the project area. The sedimentology of the Mombasa-Diani beach sands has however not been studied in detail. The bathymetric morphology within the study area is unknown and sedimentological processes such as erosion and deposition have not been taken into consideration especially for better management of the coastal zone.

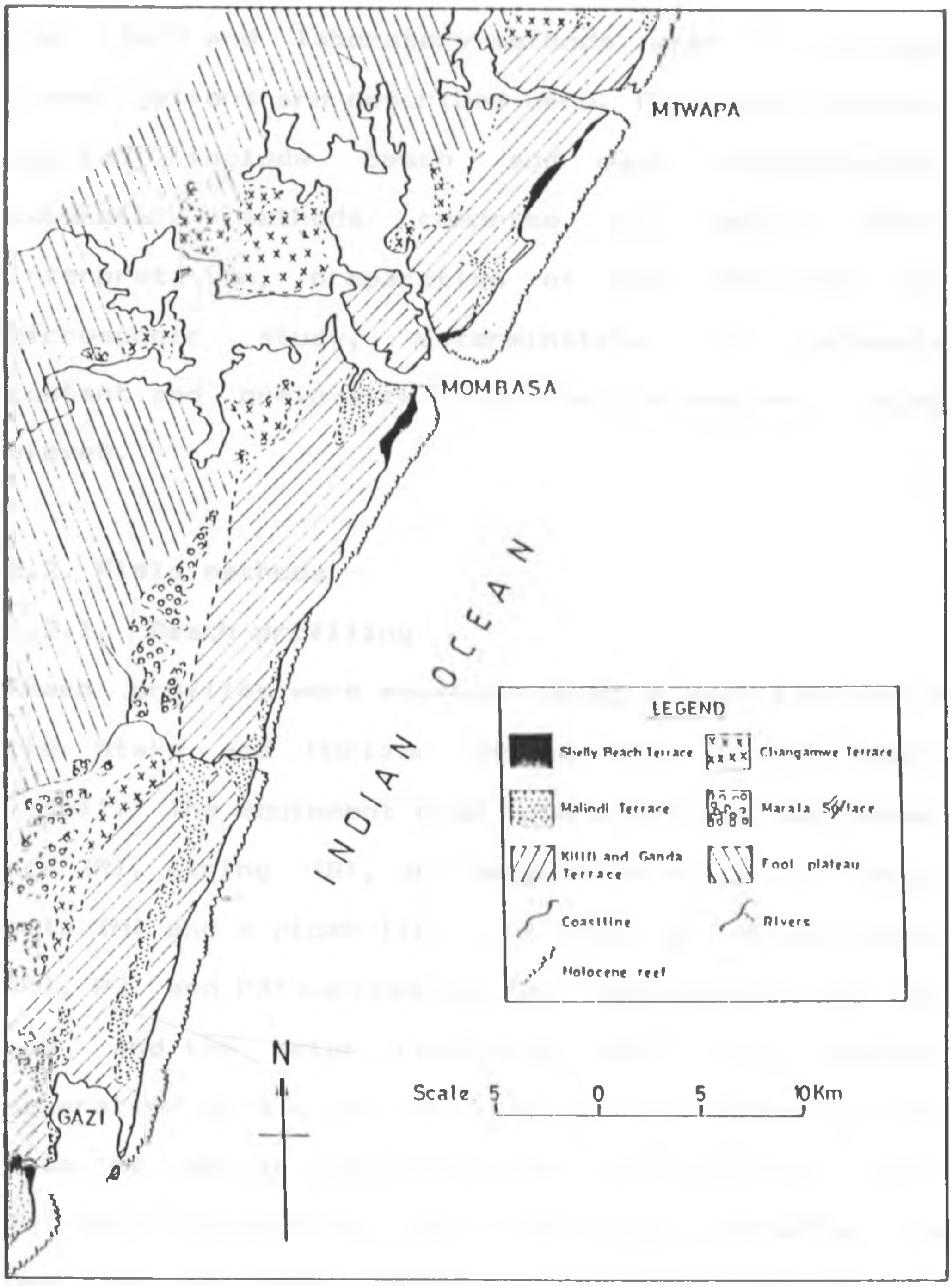


Fig. [illegible] shows terraces of the coastal zone (from Andrew, 1981).

CHAPTER 2 FIELD AND LABORATORY METHODS

2.1 Introduction

The field and laboratory methods used for various investigations are described here. The field methods applied include beach and wave measurements. Laboratory methods comprise of aerial photo interpretation, preparation of thin sections for microscopic study, determination of carbonate content and grain-size distribution analysis using sieves.

2.2. Field methods

2.2.1. Beach profiling

Beach profiles were measured using a modification of the Stake and Horizon method described by Emery (1961). The equipment used consisted of one wooden rod (R), string (S), an Abney's level (L), a meter rule (M) and a plumb-line (Q) (Fig. 6). Three people (P1, P2 and P3) carried out the beach-profiling. The rod and the meter rule were held at a constant separation of 5 m by the string. The rod was driven into the sand at high tide mark as a starting point (A) for the profile until the string rested on the beach by the first person, P1. At position (B), the third person, P3, ensured the meter rule was vertical by holding it against the plumb-line. The second person, P2, ensured the string was horizontal

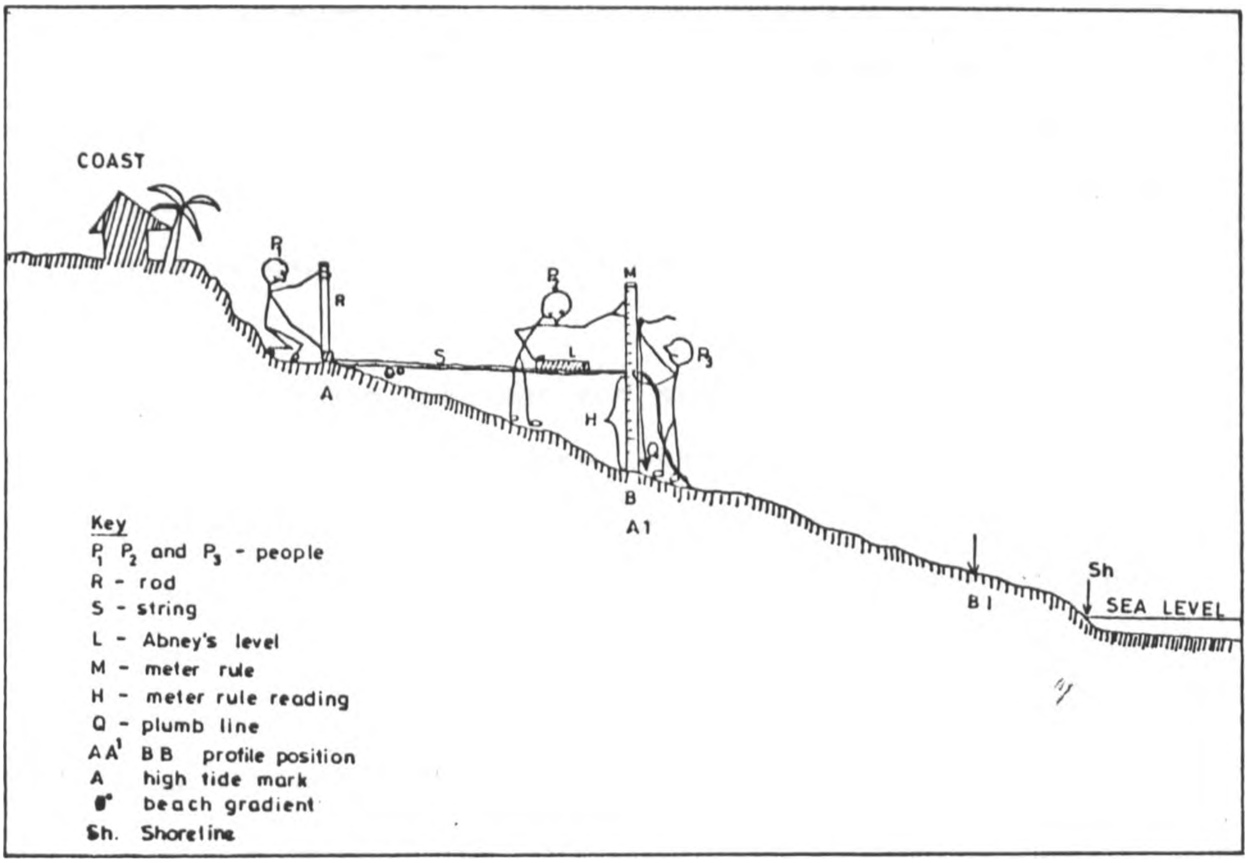


Fig. 6 shows schematic diagram for beach profiling with the aid of a level.

by checking against the Abney's level and noted down the meter rule reading (H). The profiling was done on a line perpendicular to the shore. When the first reading was complete, the first person moved from position A to A1 and the third person moved from position B to B1 and the profiling was repeated. For wide beaches (60 - 80 m), a string of 10 m instead of 5 m long was used. The profiling was completed at the shoreline (Fig. 6). Tide table of 1990 was used and the time for correction with tide position noted as is shown in figure 11 of Ase 1978.

2.2.2. Beach gradient and width measurements

Beach gradients were measured using an Abney's level. The level was placed on the beach at approximately the mid-tide level to give consistency in the measurements. It was then oriented at right angles to the shoreline and the level knob adjusted until the bubble comes to rest in the middle part. Beach gradients were then read off directly in degrees. Beach width was measured across the beach perpendicular to the shore using a string of known length.

2.2.3. Sediment sampling

Beach sediments were collected from mid-tide level to enable a consistent sampling for subsequent comparative analysis. The sampling stations are given in figure 2 and tabulated in Appendix I. The samples were obtained from the upper 1 - 5 cm of surface sediments using a cylindrical plastic corer. This is because wind effect and water movements across the beach is usually felt upto this depth. Visual description of the sediment samples was done in the field immediately after their recovery. The samples were then collected in labelled plastic bags, sealed and stored for detailed study at the University of Nairobi and Mines and Geological Departments Laboratories. On arrival in Nairobi the sediments were washed in distilled water to remove salts then oven-dried. During this field work photographs of prominent coastal features were also taken and are used in this thesis for more clarity.

2.2.4. Waves and currents measurements

Wave periods were measured with a stop clock used to record the time it takes successive wave crests to break at a particular point nearshore. Visual wave observations such as wave height and breaker type were carried out from the beach with the help of a pair of binoculars whilst the direction of wave propagation and longshore current was determined with the aid of a compass.

2.3 Laboratory methods

2.3.1 Aerial photo-interpretation

Before starting field work, a base map of the study area was prepared for use in the field. This was done by having aerial photographs covered with overlays and held firmly using cellulose tapes. Using the mirror stereoscope, a 3-dimensional, permanent and overall view of the ground was then obtained. These interpretations helped in planning of field work.

2.3.2. Bathymetric profiles

From the Mombasa admiralty chart (Wyatt, 1948), Bathymetric profiles were drawn along sections perpendicular to the shoreline (Fig. 7). At any point where the profile line intersects the contour line, two parameters were obtained. First, the length of the profile at that location was measured and converted into km by multiplying by a factor of 0.75 according to the linear scale. Secondly, the reading on the contour which is given in fathoms at that location was multiplied by 1.8 to convert the depth into m.

2.3.3 Grain size distribution analysis

Sediment samples were separated into different fractions using sieves of -1.0 to 4.0 Ø mesh sizes.

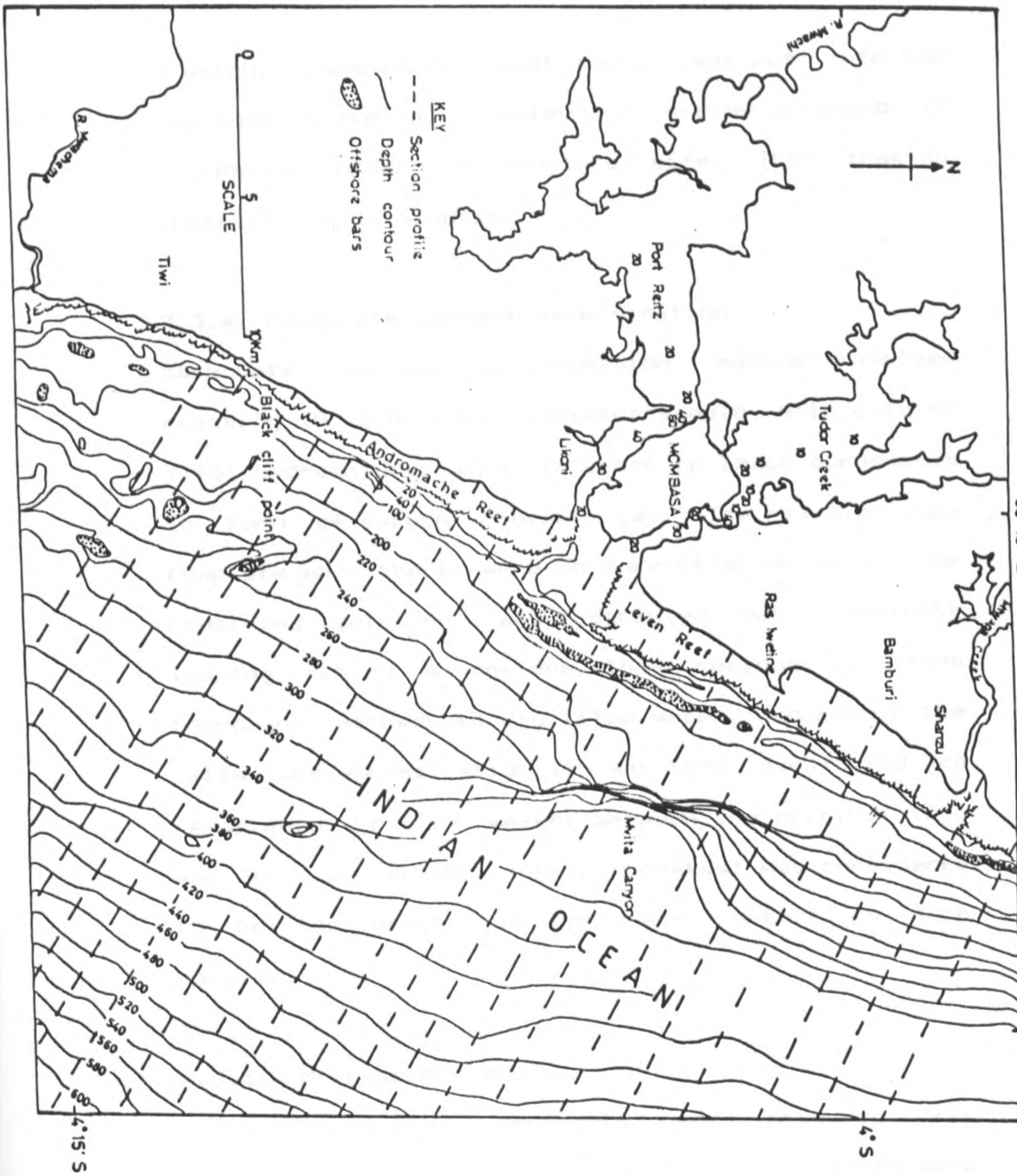


Fig. 7 shows bathymetric map of the Mombasa continental shelf indicating the location of submarine platforms, offshore bars and the Mvita Canyon.

A weighed sample of about 100 g, was put into the top most sieve in a system of sieves arranged in decreasing order of aperture size. The shaking interval was 15 minutes.

2.3.4. Carbonate content determination

Carbonate content determination method involved reacting 10 g of each sediment sample with diluted (1:3) hydrochloric acid in order to leach carbonates in form of carbon dioxide gas. The reaction was complete when there were no more effervescence. The remaining solution was decanted out carefully leaving behind a residue. This residue was then thoroughly washed in distilled water, to remove the salts and excess acid. It was then oven-dried and re-weighed. Loss in weight between the original 10 g and the new weight (non-carbonates) was considered to be the weight of carbonate content in each sample.

2.3.5. Microscopic study

Thin-sections of sediments were prepared for microscopic study of the sediments. Sediments were ground, as explained below, to a uniform thickness of 30 μm which provides a standard on which to base interference colours, pleochroism, extinction and other optical properties. The sample was first impregnated with resin as an initial preparation for sectioning. One side was ground flat with coarse carborundum 200 grit on a lapping wheel, using soluble oil as lubricant. The specimen was washed thoroughly in distilled water to remove all the coarse grit. The process was then repeated using 600 grit, each time washing thoroughly in distilled water. The specimen was mounted, ground side down, on a glass slide with Lakeside Cement 70 and grinding was completed to a final thickness of 30 µm. The specimen was washed thoroughly in distilled water and dried. Pyrozelene dissolved in Amyl Acetate was applied and let to dry as it penetrates. Canada balsam was used for permanent mounting of cover slip. The thin section was cleaned and labelled.

CHAPTER 3 RESULTS ON SEDIMENTS

3.1. Introduction

The results on grain size distribution, sediment composition and coastal processes are presented and described in this chapter. An attempt is made to relate these results to the management of the coastal zone at the end of the chapter in the summary and discussion section.

3.2. Grain size distribution

In order to obtain the parameters required for describing the sediment sample most effectively, the results of grain size analysis (section 2.3.3.) were investigated using a grain size analysis computer package written by Dr. Mario Fay, University of Dar-es-Salaam, version of 10.07.1989 given in appendix II. The program calculates graphic measures after Folk and Ward (1957), which has been adapted for this work. It also gives sample description on grain size, sorting, skewness and kurtosis and these graphic measures have been described in the text for the samples collected. In addition the program can also be used to give an indication of the depositional environment such as good sorting, nearly symmetrical distribution or tail on the coarse-grained side are typical of beach sands. In this thesis, Folk and Ward's graphic measures have been used since they are the most efficient. Also, because of Folk and Ward's wide application in sedimentological studies, it is possible to compare these results with those obtained elsewhere. The cumulative graphs drawn from sample fractions in each sieve are presented in appendix III. Thus on the horizontal scale of the graph Ø units increase from left to right, which means that the finer sediments are at the right side of the scale. The vertical scale was used for the cumulative weight showing percentage finer particles increasing upwards. The Ø units are found by conversion from the mm scale where Ø is $-\log_2$ of the diameter in mm. The negative values of Ø units are the values coarser than 1 mm.As the Ø unit increases the size of the particle decreases (Table 3).

3.2.1. Gravel

Gravel beaches occur at Shanzu, Iwetine and Galu as shown in table 3 and appendix V. The gravel consist of boulders, pebbles and granules as shown in table 4. Gravel beaches were found to occur especially near eroding cliffs within the study area. Many tiny shell debris most of which are complete were observed at Kikambala beach. The shells are transported through the shore platform and deposited on the beach especially during high tide.

Table 3 shows predominant nature of sediments, grain size and process for the investigated area.

Location	Predominant Nature of sediments	Predominant grain size	Predominant process
Kikambala	carbonates	fine	erosion
Kanamai	carbonates	fine	erosion
Mtwapa	carbonates	medium	erosion
Shanzu	non-carbonates	fine	erosion
	non-carbonates	medium	erosion
	carbonates	gravel	erosion
Bamburi	carbonates	fine	erosion
Kenyatta beach	carbonates	fine	deposition
Iwetine	non-carbonates	gravel	erosion
Nyali	non-carbonates	very fine	stable
	carbonates	very fine	stable
	non-carbonates	fine	stable
Leven	non-carbonates	coarse	deposition
Mackenzie Point	non-carbonates	medium	deposition
Likoni	carbonates	coarse	erosion
	carbonates	medium	erosion
	carbonates	medium	erosion
Black Cliff Pt.	carbonates	coarse	erosion
	non-carbonates	coarse	erosion
	carbonates	coarse	erosion
Tiwi	carbonates	medium	stable
	non-carbonates	medium	stable
Mwachema	non-carbonates	coarse	deposition
	non-carbonates	medium	deposition
	non-carbonates	fine	deposition
Diani	carbonates	fine	erosion
	non-carbonates	fine	erosion
	carbonates	very fine	erosion
	non-carbonates	very fine	erosion
Galu	carbonates	fine	erosion
	carbonates	gravel	erosion
	carbonates	very fine	erosion
Kinondo	carbonates	fine	erosion
Gazi	non-carbonates	medium	deposition
	non-carbonates	fine	deposition

Shells were found to occur in abundance on particular beaches such as Mtwapa, Likoni and Kinondo but not in others. This has direct implications on aesthetic value of the beach and greater erosion potential. Pebble and cobbles derived from shore platform likewise imply high energy environment.

In Shanzu sub-rounded pebbles measuring 1-20 cm in diameter with very little sand are deposited at the foot of the cliff. The pebbles are poorly sorted. South of Iwetine and Galu the boulders and cobbles are sub-rounded with a diameter of 20-40 cm. The gravel consist of coral limestones, pumiceous material and shells. Some of the shells are intact while others are broken.

3.2.2. Coarse sands

Coarse sands have been taken here to comprise of 1 Ø to 0 Ø size fraction as shown in Table 4. Coarse grained sands occur at Leven, Likoni, Black Cliff Point and Mwachema Estuary (Table 3, Appendix IV). Leven sands are moderately sorted, positively skewed and leptokurtic while sands at Likoni are moderately well sorted, positively skewed and mesokurtic. Sands at Black Cliff Point are well sorted with nearly symmetrical distribution and leptokurtic. Mwachema

Table 4. The grain sizes for gravel, sand and mud found on beaches.

Wentworth size class	Unconsolidated sediments	Particle diameter (d)	Phi scale
Boulders		above 256 mm	below -8 Ø
Cobbles	Gravel	64 mm - 256 mm	-6 Ø to -8 Ø
Pebbles		4 mm - 64 mm	-2 Ø to -6 Ø
Granules		2 mm - 4 mm	-1 Ø to -2 Ø
Very coarse sand		1 mm - 2 mm	0 Ø to -1 Ø
Coarse sand	sand	1/2 mm - 1 mm	1 Ø to 0 Ø
Medium sand		1/4 mm - 1/2 mm	2 Ø to 1 Ø
Fine sand		1/8 mm- 1/4 mm	3 Ø to 2 Ø
Very fine sand		1/16 mm- 1/8 mm	4 Ø to 3 Ø
Silt	mud	1/256 mm - 1/16 mm	8 Ø to 4 Ø
Clay		below 1/256 mm	above 8 Ø

Note: The Ø (phi) scale is a logarithmic scale of particle diameters defined as the negative logarithm to base 2 of the particle diameter (d) in mm:

$Ø = -\log_2 d$.

sands are moderately well sorted with nearly symmetrical distribution and mesokurtic (Fig. 8). The southern bank of Mwachema estuary (Appendix IV), is however composed of medium grained sands. These sands at Mwachema come from the mainland and have not been reworked by the ocean waves for a long time. The sands are coarse grained because of the winnowing action of the waves, which removes fine grained sediments in suspension and deposits them offshore.

3.2.3. Medium sands

Medium sands range between 2 Ø to 1 Ø (Table 4). Medium grained sands occur at Mtwapa, Shanzu, Mackenzie Point, Likoni, Tiwi, Mwachema and Gazi (Table 3, Appendix IV). The sands at Mtwapa are moderately sorted, negatively skewed and platykurtic while those at Shanzu are moderately well sorted, negatively skewed and mesokurtic. Moderately sorted sands occur at Nyali with very negative skewness.

At Mackenzie Point and Likoni the sands are well sorted, very negatively skewed but mesokurtic and leptokurtic respectively. Tiwi sands are moderately sorted with nearly symmetrical grain size distribution and mesokurtic but at Mwachema the sands are moderately well sorted, nearly symmetrical

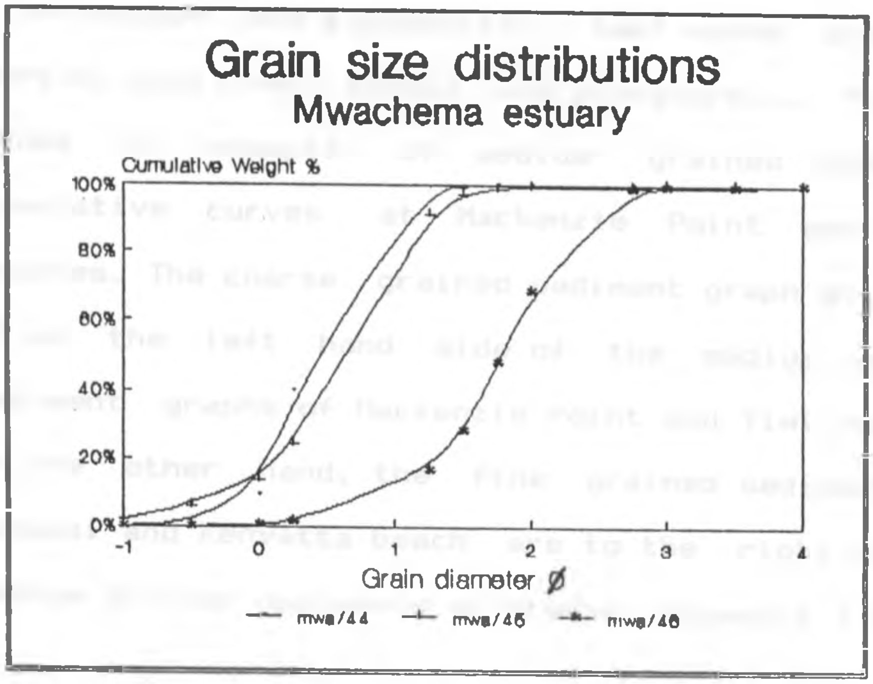


Fig. 8 shows cumulative graphs for coarse grained sands at MWA/44 and 45 and medium grained sands at MWA/46.

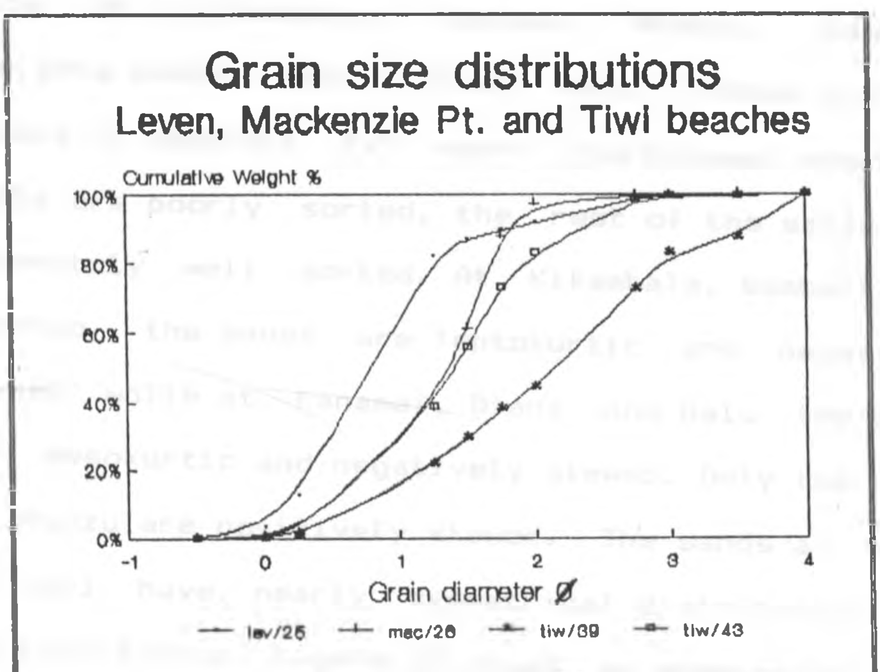


Fig. 9 shows cumulative graphs at LEV/25 for coarse sands and at MAC/26 and TIW/39 and TIW/40 for medium grained sands indicating the line of the graph shifted slightly right for the medium grained sands.

distribution and leptokurtic. Gazi sands are well sorted, positively skewed and platykurtic. Figure 9 shows an example of medium grained sediments cumulative curves at Mackenzie Point and Tiwi beaches. The coarse grained sediment graph at Leven is on the left hand side of the medium grained sediment graphs of Mackenzie Point and Tiwi beaches. On the other hand, the fine grained sediments at Kanamai and Kenyatta beach are to the right of the medium grained sediments at Mtwapa (Appendix III).

3.2.4. Fine sands

Fine sands range between 3 Ø to 2 Ø (Table 4) and occur at Kikambala, Kanamai, Shanzu, Bamburi, Kenyatta beach, Nyali, Diani, Galu, Kinondo and Gazi (Table 3, Appendix IV). Apart from Kanamai where the sands are poorly sorted, the rest of the sands are moderately well sorted. At Kikambala, Bamburi and Kinondo, the sands are leptokurtic and negatively skewed while at Kanamai, Diani and Galu the sands are mesokurtic and negatively skewed. Only the sands at Shanzu are positively skewed. The sands at Nyali and Gazi have nearly symmetrical distribution and are platykurtic. Figure 10 shows an example of fine grained sands cumulative curve at Galu, Kinondo and Gazi. At location gal/57 (Appendix III) the sands are fine grained thus the graph is to the left of

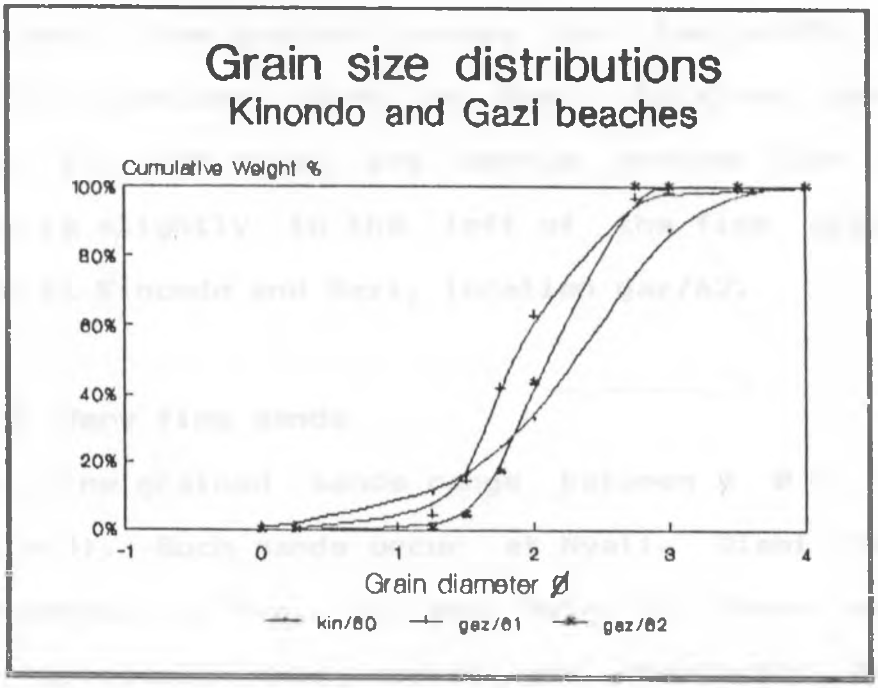


Fig. 10 shows cumulative curves at KIN/60 and GAZ/62 for fine grained sands and GAZ/61 for medium grained sands with the line of the graph shifted slightly to the right for the fine grained sands.

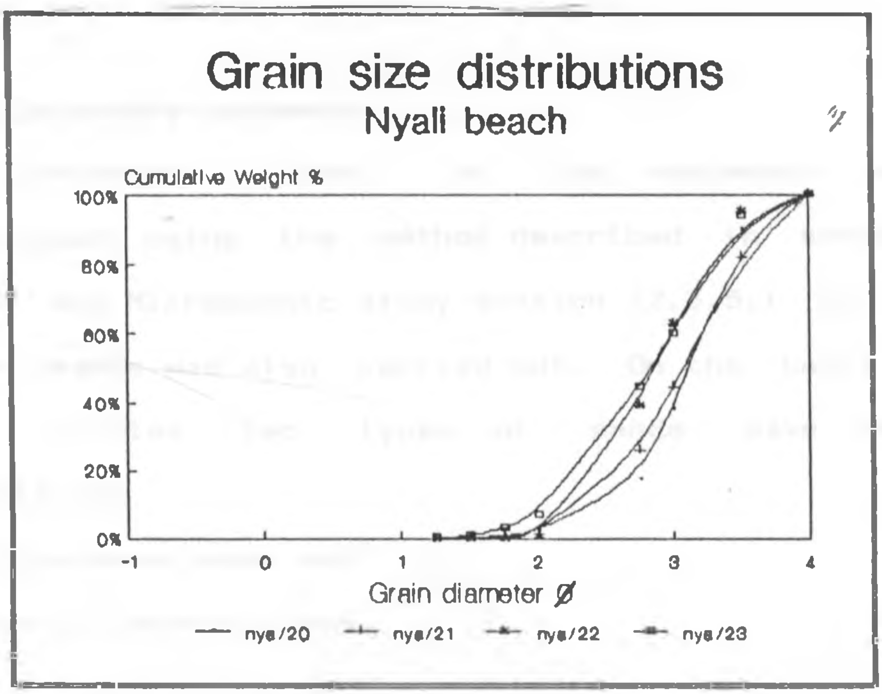


Fig. 11 shows cumulative graphs at NYA/20, 21, and 22 for very fine grained sands and NYA/23 for fine sands with the line of the graphs shifted to the right of the graph.

the very fine grained curves for the gal/58 and gal/59 locations. Also at Gazi, location gaz/61 (Fig. 10) the sands are medium grained thus the graph is slightly to the left of the fine grained sands at Kinondo and Gazi, location gaz/62.

3.2.5. Very fine sands

Very fine grained sands range between 4 Ø to 3 Ø (Table 4). Such sands occur at Nyali, Diani (Table 3, Appendix V, Fig. 11) and Galu. All these sands are moderately well sorted and mesokurtic. Apart from the Galu area where the sands have nearly symmetrical distribution, the rest of the sands at Nyali and Diani are negatively skewed.

3.3. Carbonate contents

The carbonate content of the sediments was determined using the method described in section 2.3.4 and Microscopic study section (2.3.5.) of the beach sands was also carried out. On the basis of this studies two types of sands have been identified;

1. Calcareous sands and
2. non-calcareous sands.

3.3.1. Calcareous sands

These are sands which were found to be predominantly carbonate with at least 50 % carbonates. Calcareous sands occur at Kikambala, Kanamai, Mtwapa, Shanzu, Bamburi, Kenyatta beach, Nyali, Likoni, Black Cliff Point, Tiwi, Diani, Galu and Kinondo (Table 3). The carbonate sand particles in general are fairly equidimensional and sub-angular or sub-rounded. On the low carbonate beaches like Gazi, the grains are well rounded and polished. The high carbonate content at Black Cliff Point (98 %) is due to the active cliff erosion in this area which provides immediate source of material for the beaches. At Kenyatta beach the percentage of non-carbonates and carbonates are almost the same (Q:C = 49:51) (Appendix IV). This could be due to river Bamburi supplying Kenyatta beach with terrigenous sand especially during flood tide as depicted from aerial photograph of figure 12.

3.3.2 Non-calcareous sands

Non-calcareous sands are sands which consist predominantly of non-carbonate sands. Such sands were found at Shanzu, Iwetine, Nyali, Leven, Mackenzie Point, Black Cliff, Tiwi, Mwachema, Diani and Gazi (Table 3). The non-carbonates within the sands were found to be mainly quartz. At Leven the quartz and carbonates are more or less equal in proportion (Q:C = 50:50) probably indicating an

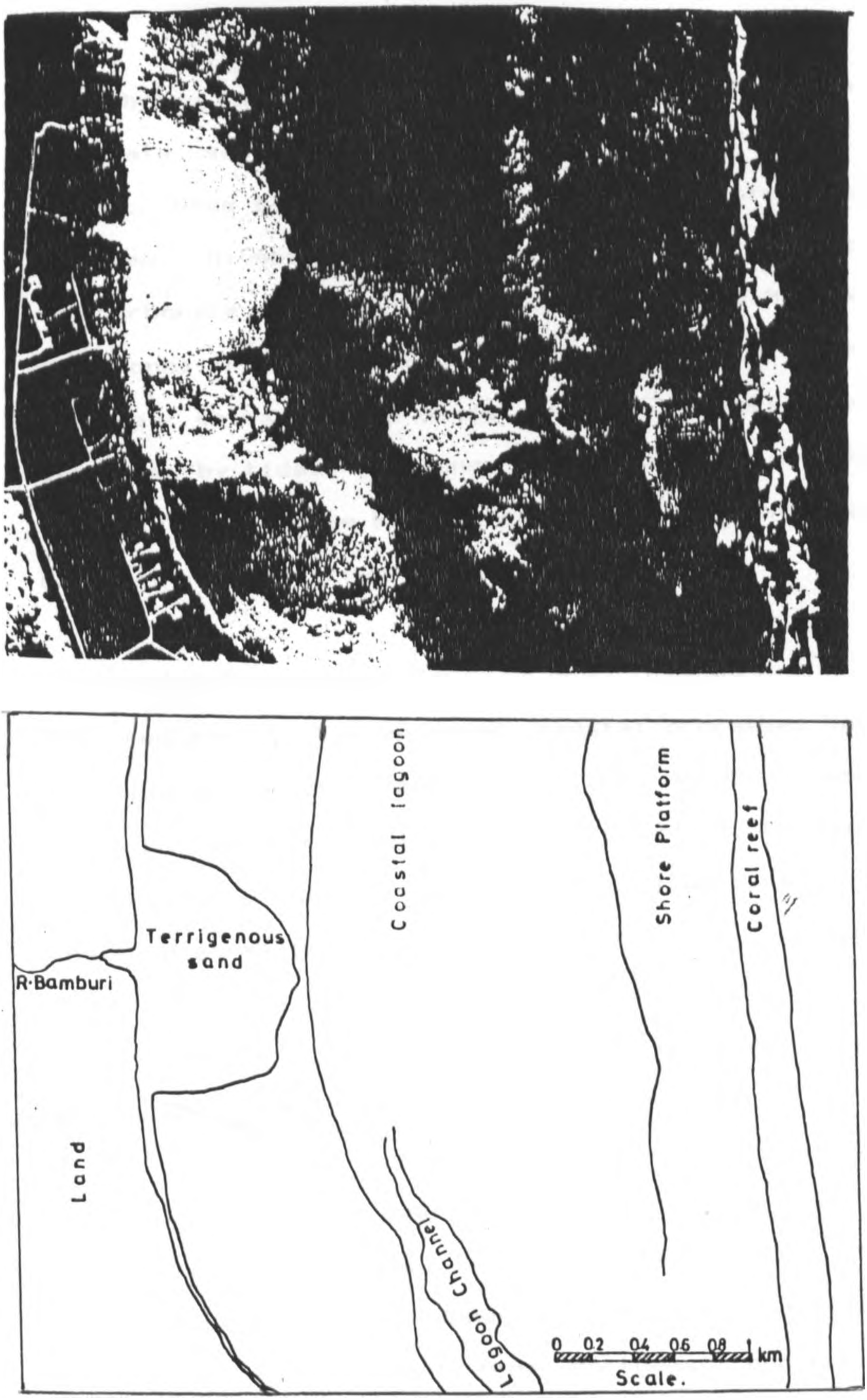


Fig. 12 shows aerial photograph with the large white circular spot as terrigenous material supplied by river bamburi on Bamburi and Kenyatta beaches.

equilibrium rate of mixing (Appendix IV). The non-carbonate sands consist of well rounded quartz grains. These sands are yellowish grey in colour at Mwachema. Rivers Kidogoweni and Mkurumuji transports non-carbonate sands derived from the nearby Mazeras Sandstones (Fig. 3) of the Shimba Hills into the Gazi bay entrance. The sands are then reworked and dispersed by tidal and longshore currents along the outer fringes of the bay as sandflats. Sediments at Gazi are reddish brown in colour.

3.4. Coastal processes

The results of the measured coastal processes have been summarized in Table 5. About 40-55 % were spilling breakers giving a mean of 47 %. Plunging breakers were slightly more than spilling breakers, their distribution ranging from 45 to 60 % and a mean of 53 %. The wave periods range from 7.4 to 20.2 s averaging 14.2 s. Wave heights were about 1-3 m during SE monsoon and less than 1 m during NE monsoon. Longshore currents direction was variable but with a slight NNE dominance, thus giving a northerly net direction of littoral drift (Fig. 13). Wave propagation is shown to be from southeast during SE monsoon and from northeast during NE monsoon (Fig. 13). Wind intensity and direction have considerable influence on currents. The wind induced

Table 5. Summary of coastal processes measured in the Mombasa-Diani area.

Parameter	mean	range
Breaker type		
spilling %	47	40 - 55
plunging %	53	45 - 60
Wave period (s)	14.2	7.4 - 20.2
Wave height (m)	1-3 m during southeast monsoon < 1 m during northeast monsoon	
Longhore current (m/sec)	Variable but with a slight NNE dominance	
Breaker angle	From SE during southeast monsoon From NE during northeast monsoon	
Tide height [m]		2-3
Springs: High water		3.4
Low water		0.3
Neaps: High water		2.4
Low water		1.3

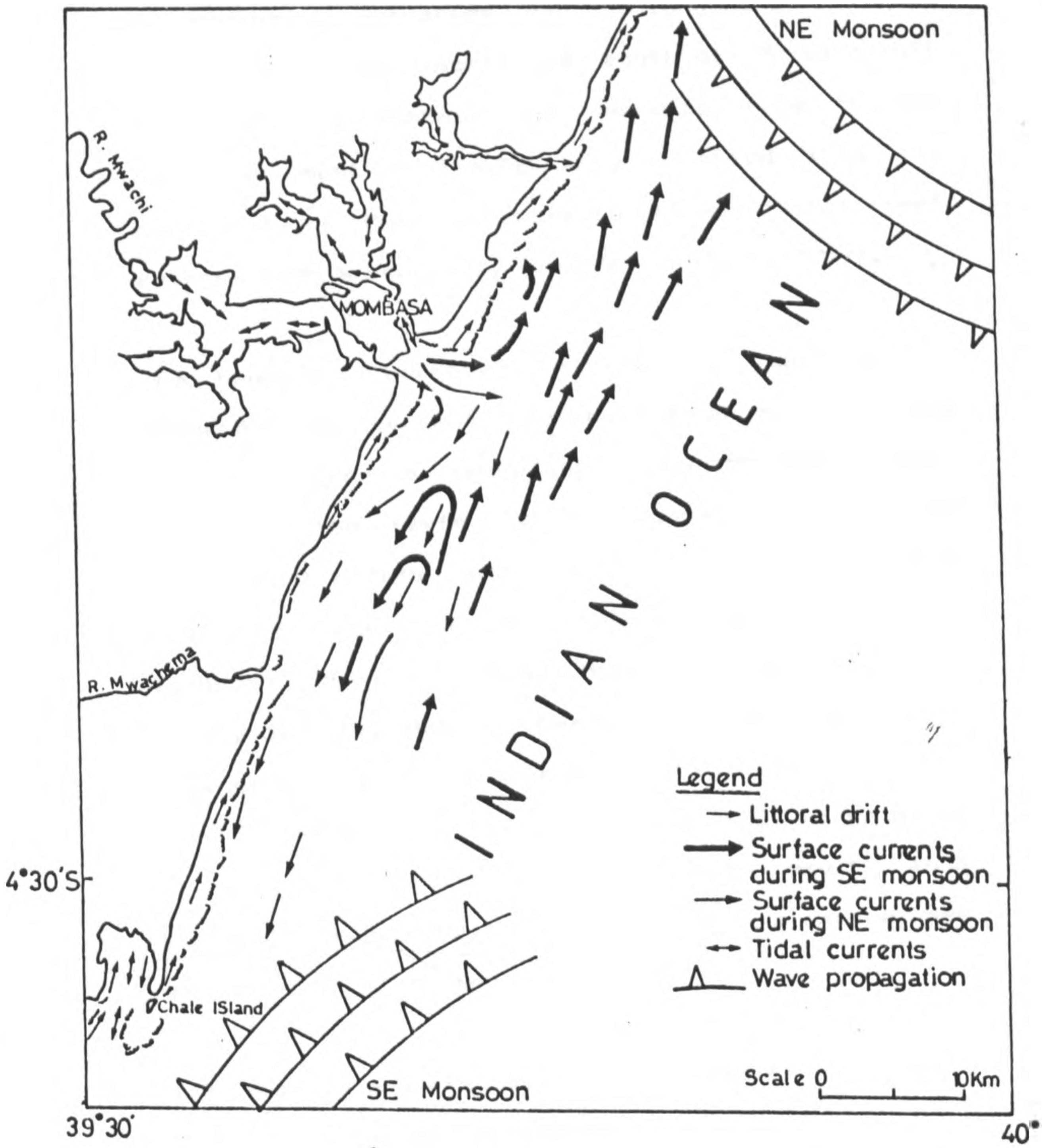


Fig. 13 shows littoral processes and surface current movements in the Mombasa-Diani area (Compiled from Norconsult, 1977 and KMFRI, unpub. data).

currents are important in the open shallow waters, in the bays, estuaries and as longshore currents along the beaches north and south of Mombasa. Off the coast of Mombasa the currents flow to the northeast most of the SE monsoon period (Fig. 13) but south of Mombasa, currents close to the reef reverse into a southerly flow (Norconsult, 1977).

The bending of current path is mainly caused by the onshore tidal currents. During the NE monsoon, the southerly currents sweep all along the outer reef. Although the reefs are irregularly shaped no significant eddies or reversing currents along the edge of the reef are observable during NE monsoons. Inshore currents around Mombasa Island, Mtwapa Creek, Gazi Bay and the Mwachema Estuary are almost exclusively caused by the tides (Fig. 13). The large water volumes accumulating in the upper, wider parts of the Tudor and Port Reitz Creeks result in a strong tidal current flushing through the narrow sea entrances at flood and ebb tides.

3.5. Summary and discussion on sediments

3.5.1. Grain size distribution

The coarse sands occur between Mackenzie Point and Mwachema estuary (Fig. 14) and mostly form the isolated beaches in this area. The origin of the isolated beaches, as at Leven, Mackenzie Point, Shanzu and Likoni (Appendix I) is still unclear, but possible explanations could be;

1. Areas of weakness along the extensive cliff face, either made up of softer rock or are zones of structural failure and
2. due to wave convergence at these specific areas which therefore experience higher littoral energy impact in comparison to the rest of the cliff extension.

The second theory is more acceptable since it also accounts for higher amount of coarse quartz in the sediments. The tidal currents play an important role in sediment transport and deposition (sorting) at the vicinity of Mtwapa and Tudor Creeks and Mwachema Estuary. Repeated movement of sand across beach and nearshore profiles results in sediment sorting. There is almost a strong correlation between the quartz content in sediments within the investigated area and phi sorting (Appendix V). The implication here is that the lithology of the sediments does not in any way affect their sorting. Sorting is an indication of effectiveness of hydrodynamic parameters to selectively transport and deposit sediments according to density and shape. Differential transport of coarse and fine, angular

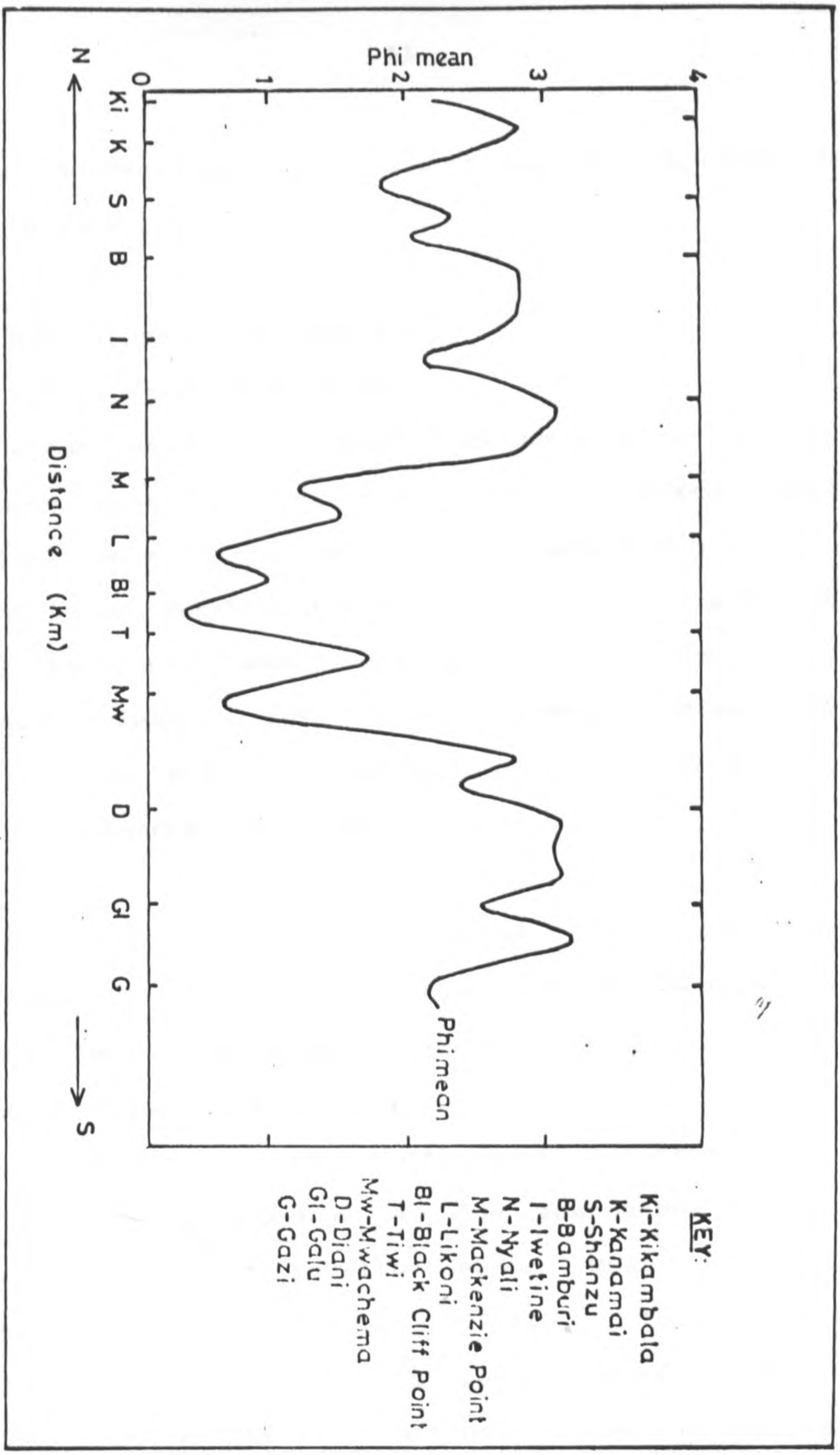


Fig. 14 shows phi mean along Mombasa-Diani area. Most of the grains are fine between Kikambala and Nyali and also between Diani and Gazi but are coarse grained between Mackenzie Point and Mwachema due to terrigenous sands brought into the creeks and the estuary.

and rounded, and light and heavy grains leads to selective deposition.

3.5.2. Types of sediments

3.5.2.1. Calcareous sands

The carbonate sands eroded from the adjacent cliffs, shore platforms and reefs due to constant wave attrition are deposited on the nearby beach after a short transport distance. The erosion is a product of combined chemical and physical weathering and once released into the littoral system, the particles are subjected to physical processes of the nearshore environment.

The high carbonate content at Black Cliff Point (Appendix IV) is due to the cliff erosion in this area which provides immediate material for the beaches and also to lack of river input. Sediments at Tiwi are calcareous in the north but become more and more terrigenous as one approaches Mwachema estuary. At a location along Nyali beach the sediments are calcareous (97 %) and this could be due to the erosion of the coral limestone that has been used for the construction of seawalls and also due to an isolated cliff nearby. The highest carbonate concentrations occur where there are no rivers, for example at Kikambala, Tiwi, Diani and

Kinondo (Appendix V). In conclusion, carbonate beaches along Mombasa-Diani area occur in areas which are undergoing erosion.

3.5.2.2. Non-calcareous sands

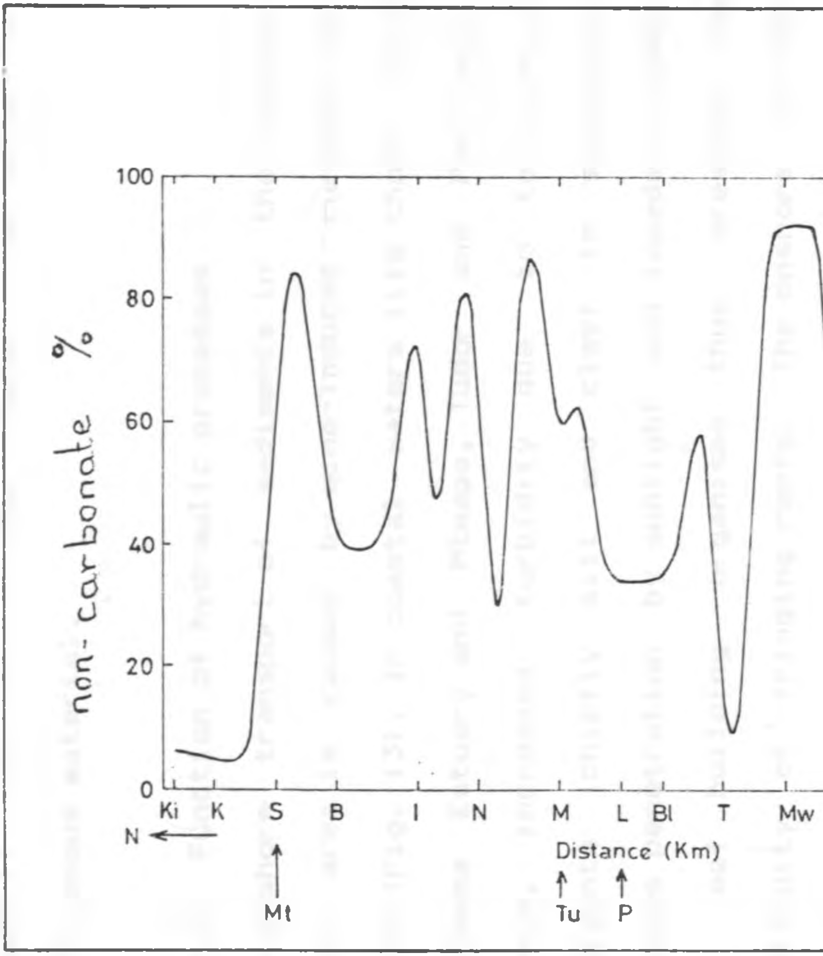
Non-carbonate sands are formed by accumulation of fragments derived from pre-existing rocks or minerals and mechanically transported as discrete particles by hydraulic and eolian processes to the places of deposition (Schroeder, 1974). The non-calcareous sands within the area of study were found to be mainly quartz, as is shown in section 3.3.2. The sands brought in through Mwachema estuary and Gazi bays nourish the immediate beaches directly. The sediments brought in through Mtwapa, Tudor and Port Reitz Creeks are first deposited on the river mouths opening into the creeks and latter carried offshore by tidal currents upon which they drift and nourish the beaches on either sides of the creek-mouths but especially to the north.

Apart from the estuary, bay and creeks, some non-calcareous sands were also found in localized areas at Black Cliff Point. These non-calcareous sands have been derived from erosion of some localized sandstone rock encountered near Black Cliff Point.

Most of the river-borne quartz grains at Mwachema and Gazi are rounded with smooth edges implying long distance of travel, but quartz grains found in localized areas such as Black Cliff Point are sub-rounded with some sharp edges implying short distance of travel or that the sands are derived in situ from the weathering of adjacent cliffs.

The sands at Mwachema are coarse-grained because of the winnowing action of the waves, which removes fine grained sediments in suspension and deposits them offshore. The high quartz content (86 %) at a particular location along Diani beach (Appendix V) may be due to some selective deposition of such materials on the beach. The sudden increase of quartz content to 49 % at the northern limit of Galu beach may be due to the erosion of some localized sandstones within the cliffs bordering the beach. Around Mombasa island, some of this sand is lost into the head of the Mvita submarine canyon.

In conclusion, beaches in which non-calcareous sands occur can be said to be undergoing deposition or are stable (Table 3) as they derive material from mainland, and as such are recommendable for development. Terrigenous sediments are predominant in the vicinity of Mtwapa, Tudor and Port Reitz


non - carbonate %
100
80
60
40
20
0
Ki
K
S
B
I
N
M
L
Bl
T
Mw
N
Distance (Km)
Mt
Tu
P

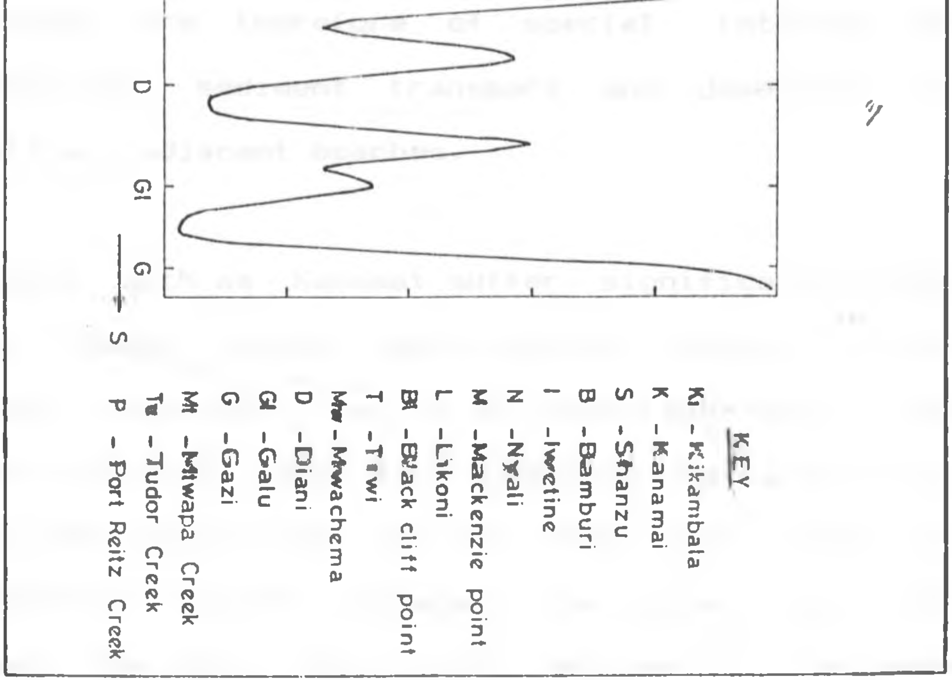


Fig. 15 shows non-carbonate (quartz) sands along Mombasa-Diani area to be associated with terrigenous material brought down by rivers into the creeks.

Creeks entrances but decreases rapidly further away (Fig. 15). Persistence of greater quartz content values is indicative of the downdrift direction of terrigenous material.

3.5.3. Function of hydraulic processes

The onshore transport of sediments in the Mombasa-Diani area is caused by wind-induced currents and waves (Fig. 13). In coastal waters like those along Mwachema Estuary and Mtwapa, Tudor and Port Reitz Creeks, increased turbidity due to terrigenous sediments (chiefly silt and clay) in suspension reduces penetration by sunlight and impedes growth of reef building organisms thus breaking the continuity of fringing reefs. The onshore surface currents are therefore of special interest for predicting sediment transport and deposition on reefs and adjacent beaches.

Beaches such as Kanamai suffer significant erosion when storms remove beach material within a short period. Such sand loss is of great importance if the beach does not have ready supply of sediments as is the case within most of the study area. Waves and longshore currents transport and deposit the sand along the shore which build beaches and longshore bars. In general, sandy beaches are supplied partly by;

1. material eroded from the adjacent parts of the coast,
2. partly by fluvial sediment and
3. partly by sand, carried shoreward from the continental shelf, the relative proportions being determined by local conditions such as wave activity.
4. In addition, quantities of sand may be blown seaward by offshore winds from the dunes.

The main processes along the shores are transportation of material by tidal currents and/or waves and deposition of the material as the velocity of currents decreases. Vegetation promotes deposition by acting as roughness elements thus reducing rate of sediment removal near the surface. Climate influences these processes since precipitation and runoff modify sediment supply and the ability of wind to transport beach sands to the dunes. These investigations revealed that sediments are transported for short distances along the shores of the study area, and deposited mainly at the nearest beaches.

CHAPTER 4 RESULTS ON MORPHOLOGY

4.1. Introduction

Data on beach profiles, beach widths and submarine platforms are presented, described and discussed in this chapter. Major morphological features are then described at the end of the chapter.

4.2. Beach profiles and beach scarps

After the completion of beach profile measurements using the method described in section 2.2.1., the data obtained were plotted graphically as shown in figure 16 for Bamburi and appendix VI for the rest of the study area. As shown in figure 16 the horizontal scale represents the distance in m from high tide mark while the vertical scale indicates the height in m above datum. The high tide mark was indicated on wide beaches by the debris marking the highest swash mark (Plate 3). On narrow beaches however, the high tide mark was either marked by a beach ridge, a cliffed coast (Plate 4) or a seawall. During most of the high tides, the backshore area where the beach hotels have been constructed gets flooded.

In figure 17 for Mackenzie Point, high tide mark in October (O) was found to be higher than that in September (S). This suggests more water covers the

Plate 3 shows debris marking the highest swash mark along Bamburi beach (September, 1990; Photo by P. Abuodha).

Plate 4 shows high tide mark marked by a weathered cliffed coast and a seawall (September, 1990; Photo by P. Abuodha).

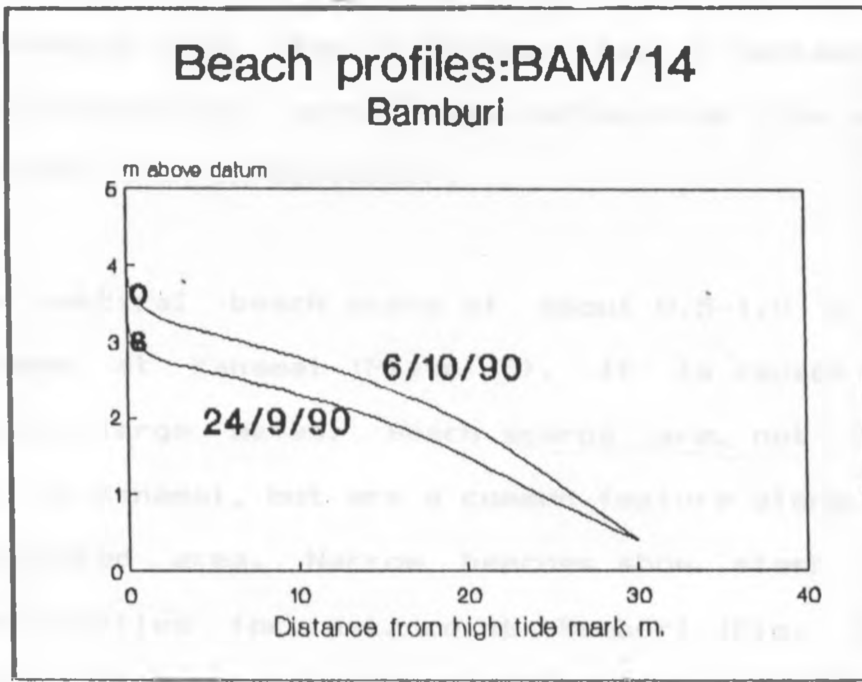


Fig. 16 shows high tide mark in October (O) to be higher than that in September (S) suggesting more water covers the beach during high tide in October than in September along Bamburi.

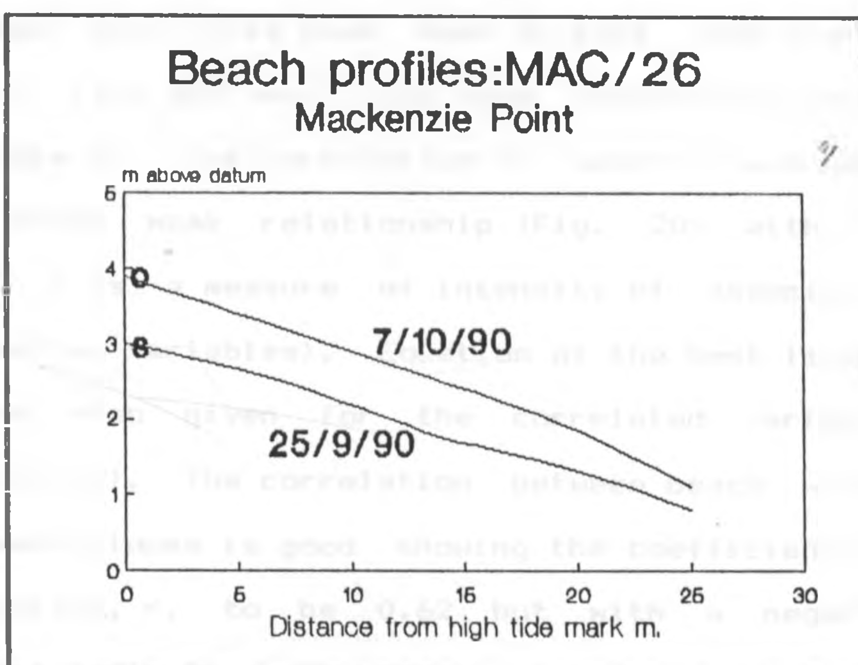


Fig. 17 shows high tide mark in October (O) to be higher than that in September (S) suggesting more water covers the beach during high tide in October than in September along Mackenzie Point.

beach during high tide in October than in September. As such erosion is more likely during high tide mark in October than in September.

A near-vertical beach scarp of about 0.5-1.0 m has developed at Kanamai (Plate 5). It is caused by unusually large waves. Beach scarps are, not only found at Kanamai, but are a common feature along the investigated area. Narrow beaches show steep but smooth profiles for instance at Bamburi (Fig. 16). Beaches with wide widths exhibit an undulating profile as at Diani as shown in figure 18.

4.3. Slope of beach face and beach width

The mean grain size have been divided into coarse, medium, fine and very fine sand respectively (Fig. 19, Table 4). The correlation of quartz % and beach slope shows weak relationship (Fig. 20) with r = 0.32 (r is a measure of intensity of association between two variables). Equation of the best line of fit is also given for the correlated variables (appendix V). The correlation between beach widths and beach slopes is good showing the coefficient of correlation, r, to be 0.62 but with a negative gradient indicating the beach width increases with decreasing beach slope (Fig. 21). On the basis of these results, it can be concluded that shore areas

Plate 5 shows a 1 m beach scarp (bs), slanting coconut tree (c) and remnants of a seawall (s) at Kanamai as the results of wave action during a flood tide (September, 1990; Photo by J. Abuodha).

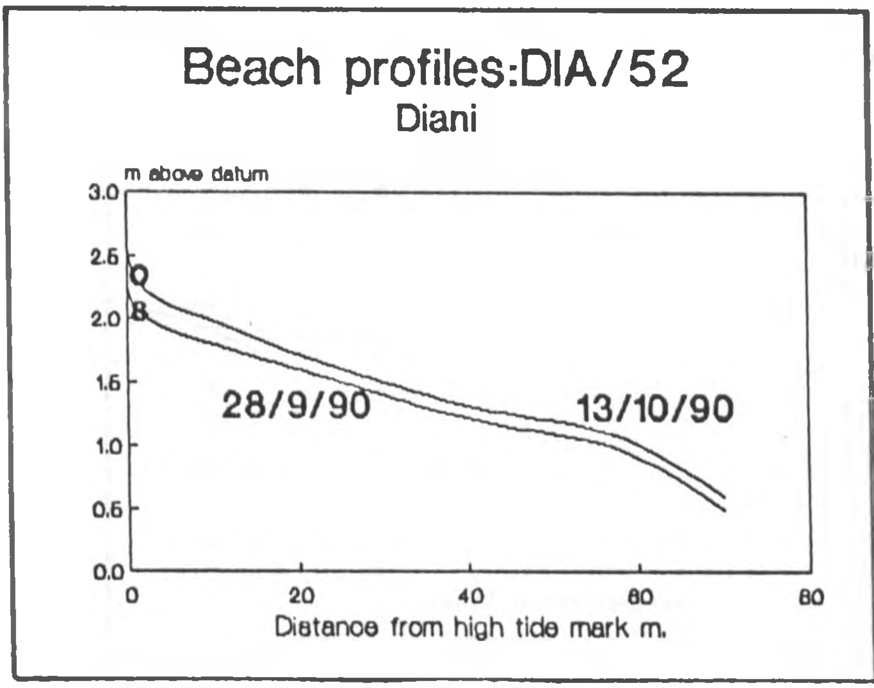


Fig. 18 shows undulating profiles for wide beaches as at Diani.

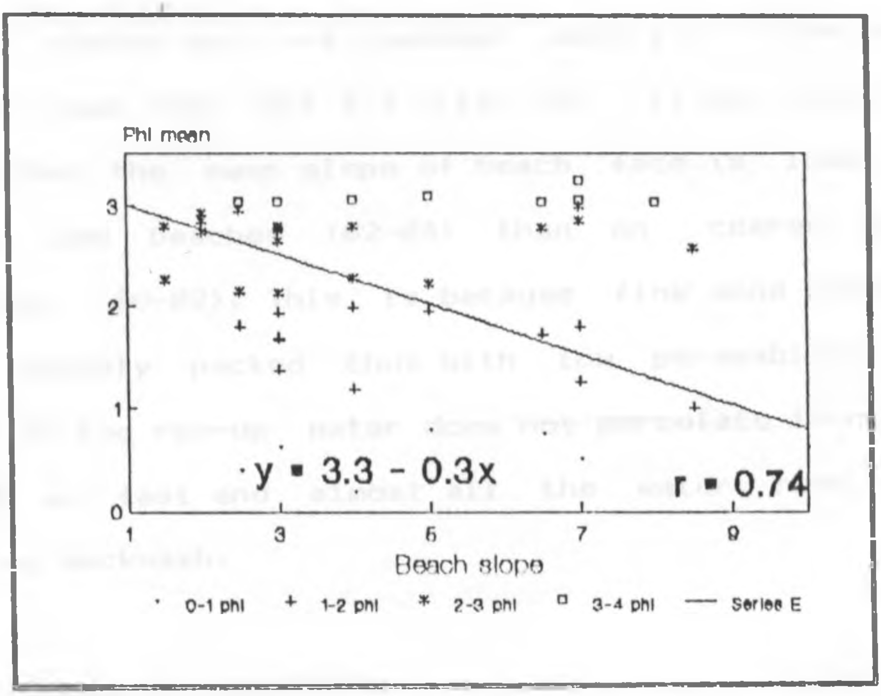


Fig. 19 shows good correlation (r = 0.74) between mean grain size and beach slope. It can be noted beach slope increases with grain size.

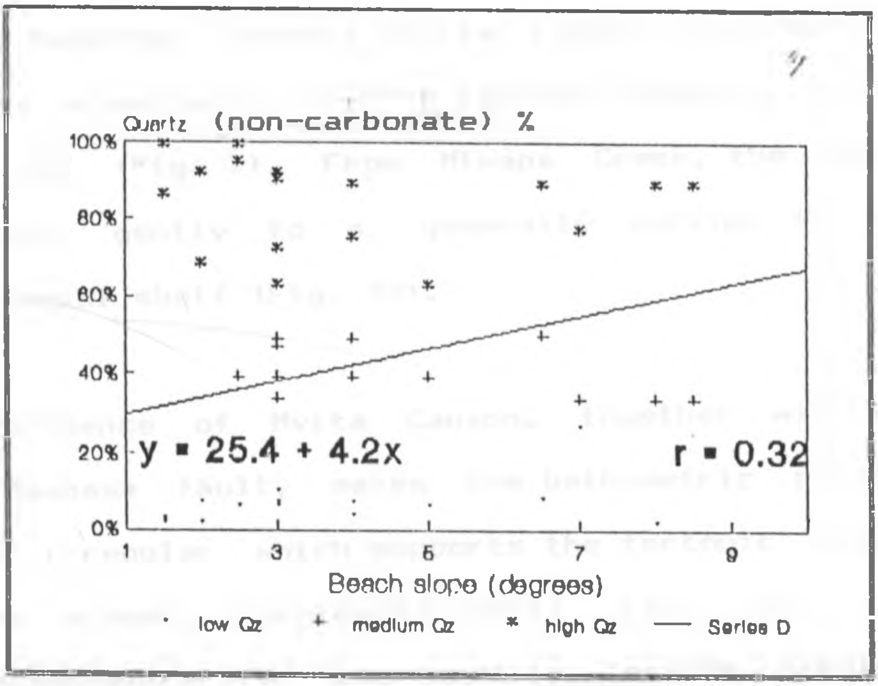


Fig. 20 shows a weak correlation between non-carbonate (quartz) % and beach slope.

with a low mean slope of beach face have wide mean beach widths and are composed mainly of fine sand which range from phi 2-3 (Fig. 19). It can also be seen that the mean slope of beach face is lower on fine sand beaches (Ø2-Ø4) than on coarse sand beaches (ØO-Ø2). This is because fine sand beaches are densely packed thus with low permeability so that during run-up water does not percolate into the sand as fast and almost all the water runs back during backwash.

4.4. Submarine platforms

Submarine platforms were identified from the bathymetric profile measurements described in section 2.3.2. The bathymetric map of the Mombasa continental shelf extending from Mtwapa Creek to River Mwachema reveals Mvita Canyon northeast of Mombasa Island and offshore bars off Mombasa Island and Tiwi (Fig. 7). From Mtwapa Creek, the coast descends gently to a generally narrow (2 km) continental shelf (Fig. 22).

The presence of Mvita Canyon, together with the Ruvu-Mombasa fault, makes the bathymetric profile appear irregular which supports the tectonic origin of the present continental shelf (Fig. 23). The characteristics of the profile include straight walls, trough-shaped transverse profiles and

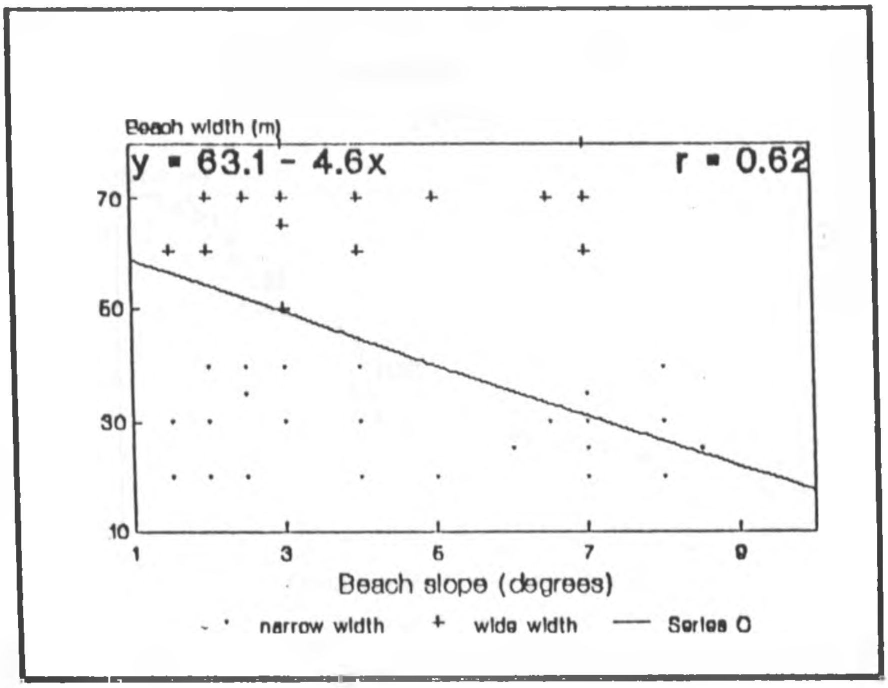


Fig. 21 shows good correlation of slope of beach face and beach width indicating that beach slope increases as beach width decreases.

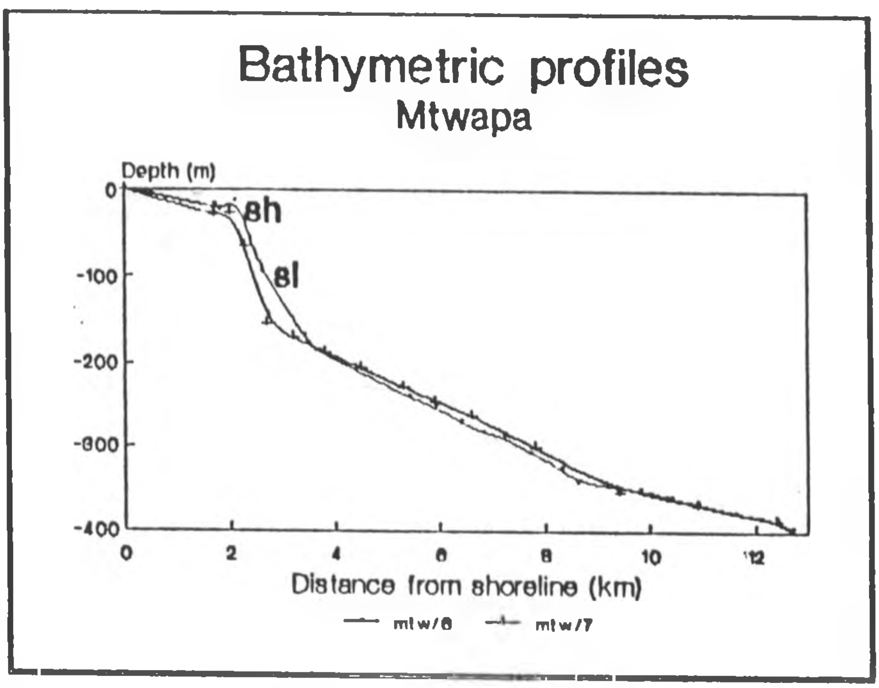


Fig. 22 shows a narrow continental shelf (sh) and a steep slope (sl) enhanced by the Ruvu-Mombasa fault off Mtwapa.

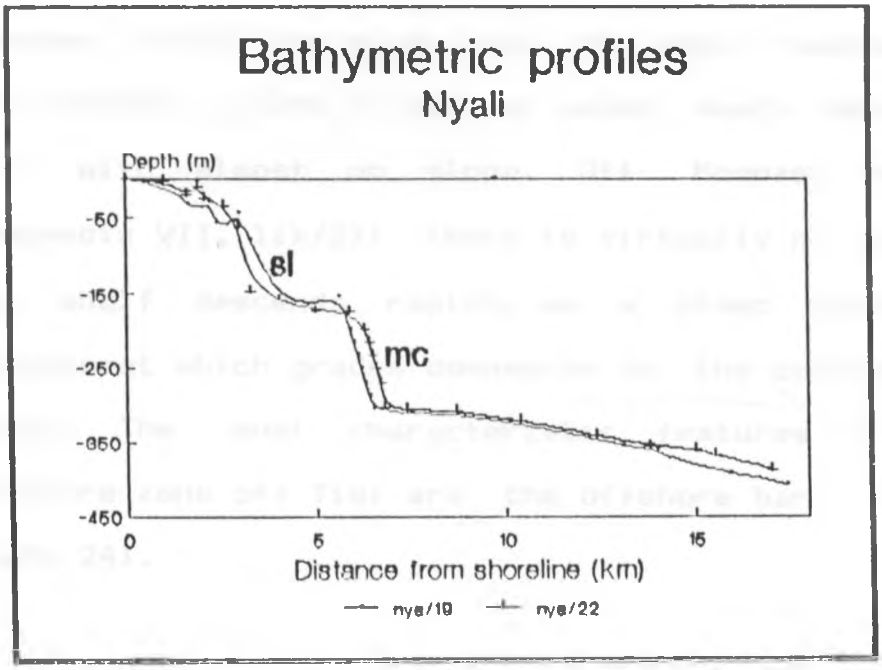


Fig. 23 shows a terraced bathymetry across Mvita canyon and Ruvu-Mombasa fault off Nyali.

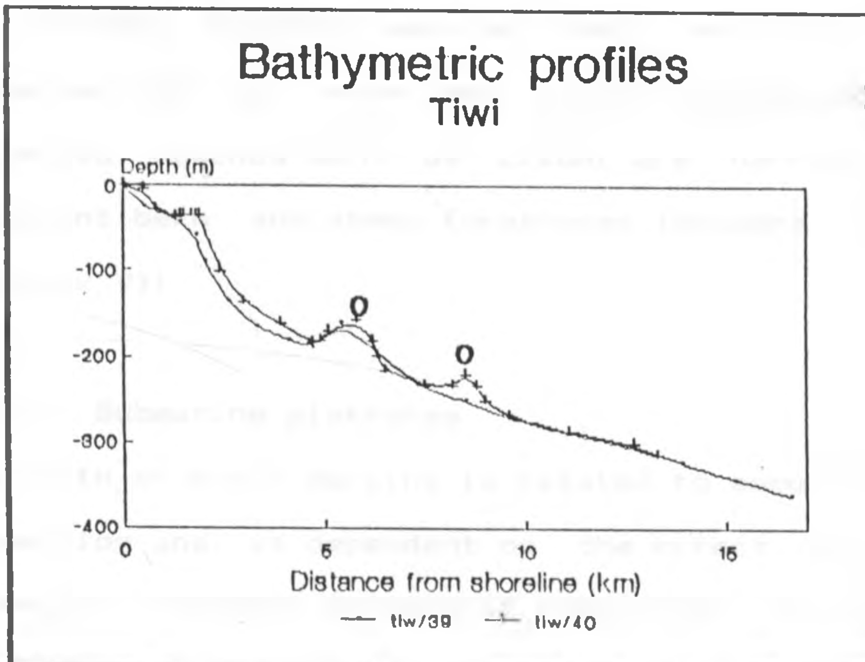


Fig. 24 shows offshore bars (ob) which are the most characteristic features off Tiwi.

termination in basin depressions at its lower reaches. Within the study area, the shelf reaches its greatest width (3 km) at Leven Beach (Appendix VII) with almost no slope. Off Mombasa Island (Appendix VII, lik/27) there is virtually no shelf. The shelf descends rapidly as a steep submarine escarpment which grades downwards to the continental slope. The most characteristic features of the offshore zone off Tiwi are the offshore bars (Figs. 7 and 24).

4.5. Summary and discussion on morphology

4.5.1 Beach profiles and beach scarps

Beach slopes are steeper where the sediment is coarse-grained than where it is fine grained (Fig. 19). Exposed beaches such as Nyali and Diani are characterized by wide and broad foreshores but protected beaches such as Likoni are narrow with prominent berm and steep foreshores (Abuodha, 1989; Appendix VI)

4.5.2. Submarine platforms

The depth of shelf margins is related to amount of deposition and is dependent on the effect of ocean currents, in either preventing deposition or eroding the bottom. Narrow shelf has the effect of allowing waves to break at the coast at greater angles because the waves do not shoal or refract as much. Thus the wave-sediment transport capacity is much higher. Another implication of the narrow shelf is the likelihood that sediment carried from the shore is lost more easily to deeper waters especially in periods of high hydrodynamic activity. The geometric resemblance of submarine canyons to fluvial channels on land provides a strong argument that at least the heads of the former were originally cut by rivers. Turbidity current erosion of canyons are at least an active contributing cause of submarine canyons and certainly keep them open. The heads of the canyons act as channels down which sediment, carried along by longshore and rip currents is channelled and lost to the deep sea.

4.6. Major morphological features

4.6.1. Cliffed coasts

Limestone cliffs were observed at Kanamai, Shanzu, Iwetine, Nyali, Likoni (Fig. 25) and at Black Cliff Point as well as Tiwi (Fig. 26). The height of these cliffs (Plate 6) was estimated to be 10-15 m above sea level. The cliffs are near vertical with pronounced wave-cut notches (Plate 6) at 4 m above sea level (Ase, 1978). The notch is deepest where dynamic pressures are highest (Carter, 1988). The notch is evidently not only an abrasion notch but is

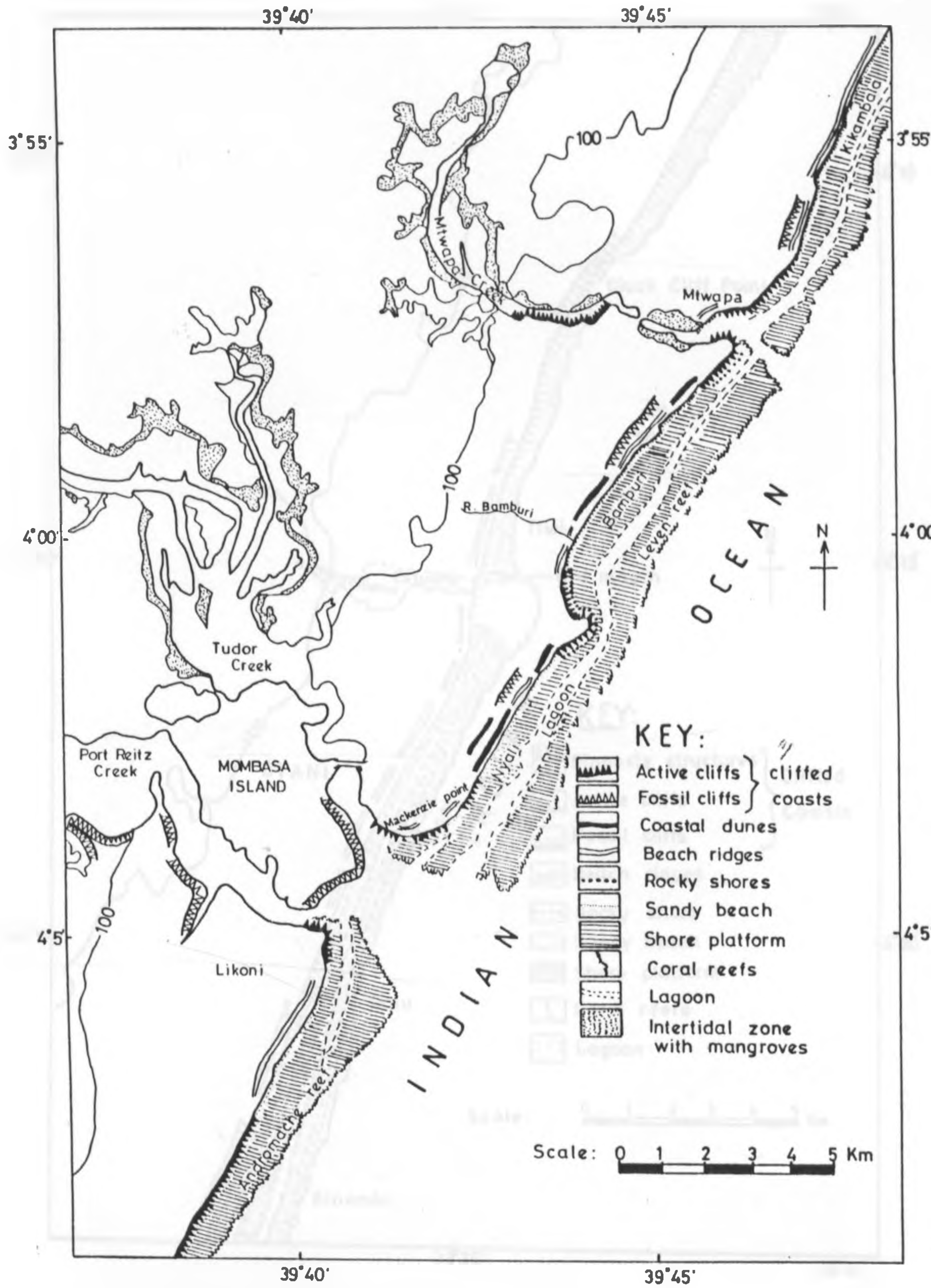


Fig. 25 shows the geomorphology of Mombasa area.

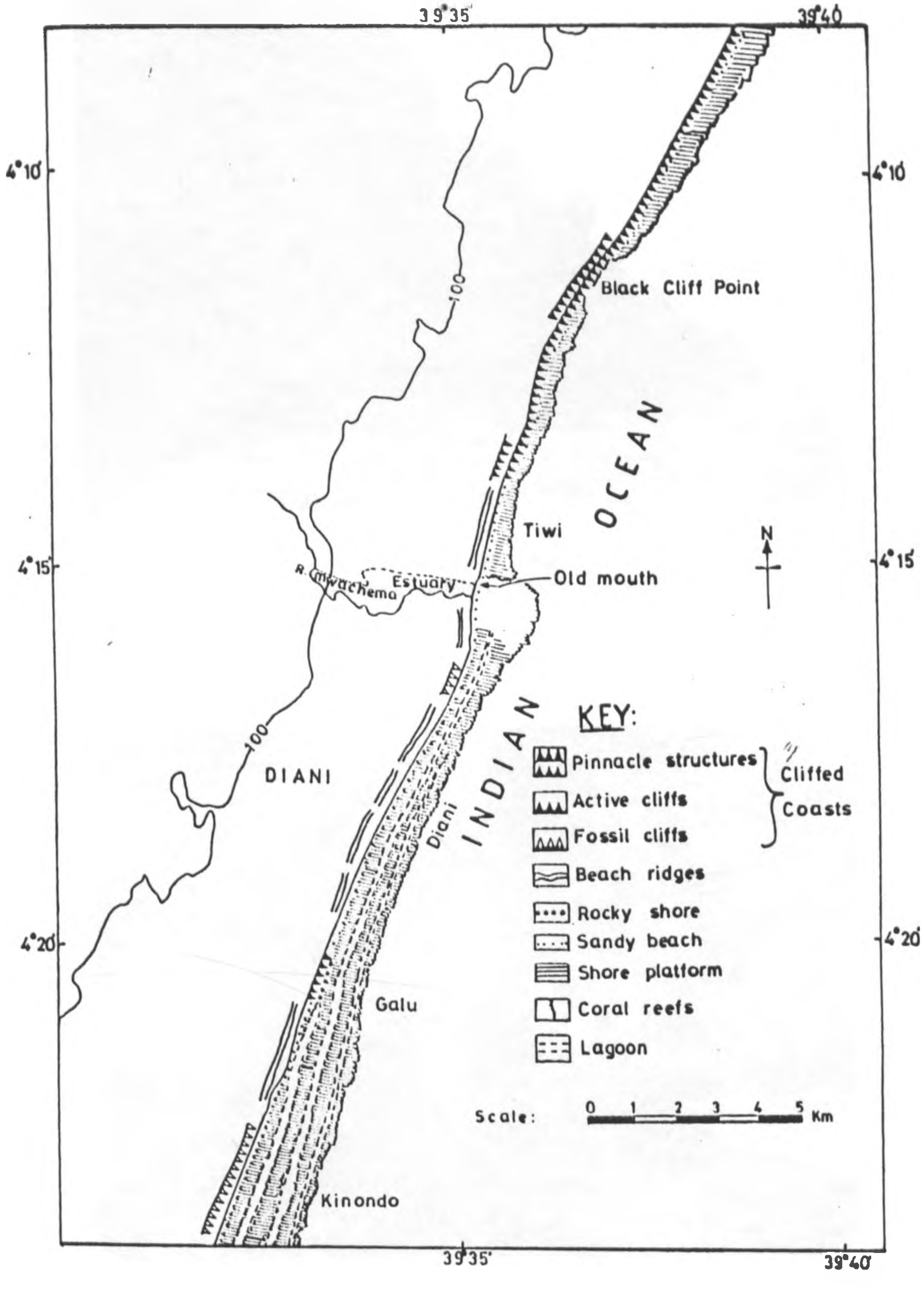


Fig. 26 shows the geomorphology of Diani area.

Plate 6 shows fallen cliff (fc) due to wave erosion at Mtwapa (September, 1990; Photo by P. Abuodha).

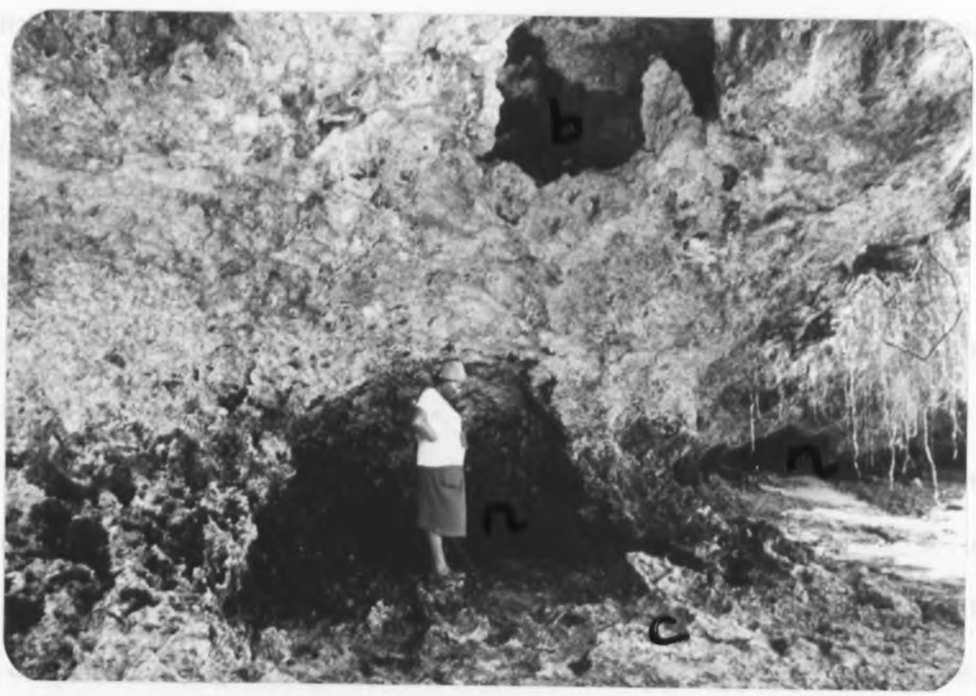


Plate 7 shows a notch (n), a blow out (b) and rugged bottom cavities (c) (September, 1990; Photo by J. Abuodha).

essentially the outcome of solution process. The base of the notch is mostly smoothened and polished by the movement of sand caused by waves. Notch-development will continue until the overburden fails (Plate 6). A tendency for the cliff to bulge seaward or even fail is created by negative pressures which occur between wave crests. When a wave impacts a cliff, the pressure distribution varies across the cliff face, some areas being far more affected than others.

Where the forces produced by the action of waves and the compression of trapped air puncture the roof of a cave or an overhanging cliff, water and spray are driven up through blow outs observed at Kanamai (Plate 7). The blow outs may also have formed during the last sea level rise during late Pleistocene (Ase, 1981) when the waves completely eroded a softer formation within the coral limestones. A cave, 20 m in length and 100 m from the shoreline occurs within the high cliffs at Shanzu (Plate 8). This cave was probably eroded by a late Pleistocene sea level approximately 6 m above the present sea level (Ase, 1981). Kenyatta beach is bound on the landward side by low cliffs of 1-2 m (Plate 9). These cliffs have been severely eroded by waves forming wide notches. It appears that the notches

Plate 8 shows a cave at Shanzu (September, 1990; Photo by P. Abuodha).

Plate 9 shows notches (n) beneath a sea wall (sl) at Kenyatta. Also note the exposed rocky shore (r) with little sand (s) (September, 1990; Photo by P. Abuodha).

have formed immediately below a seawall that has been constructed to protect the property behind.

Wave scour has even exposed the tree roots thus the seawall and the tree will finally collapse. These cliffs at Kenyatta form irregular, highly reflective wave barriers. The resistance of a cliff to wave attack varies according to its "strength" that is the compressive, tensile and cohesive properties with the likely recession rate of limestone being 1- 10 mm/yr (Carter, 1988). Erosion of such a cliff is proportion to the wave forces applied to it. The cliffs gradually increase in height towards the Iwetine headland attaining a 4 m maximal.

From Likoni (Fig. 26), as far as Black Cliff Point (Fig. 25) the shoreline is bordered on the landward side by cliffs (Plate 10). The base of the cliff is sparingly covered by sand. The cliffs in this area are generally low 2-4 m high above sea level but may be as high as 10-12 m above sea level in some places. These cliffs are undercut at the bottom forming cavities, notches, and sea arches (Plate 11). From Black Cliff Point (Fig. 26), cliffs extend for a distance of 6 km upto Tiwi beaches with heights of 3-4 m above sea level. Further south at

Plate 10 shows general view of a cliffed coast (cc) at Black Cliff Point with notches (n), sea arch (a), and a rugged shoreline (September, 1990; Photo by F. Abuodha).

Plate 11 shows a sea arch at Black Cliff Point (September, 1990; Photo by F. Abuodha.

Plate 12 shows severe limestone weathering which has resulted in pinnacle structures (p) at Tiwi (September, 1990; Photo by P. Abuodha).

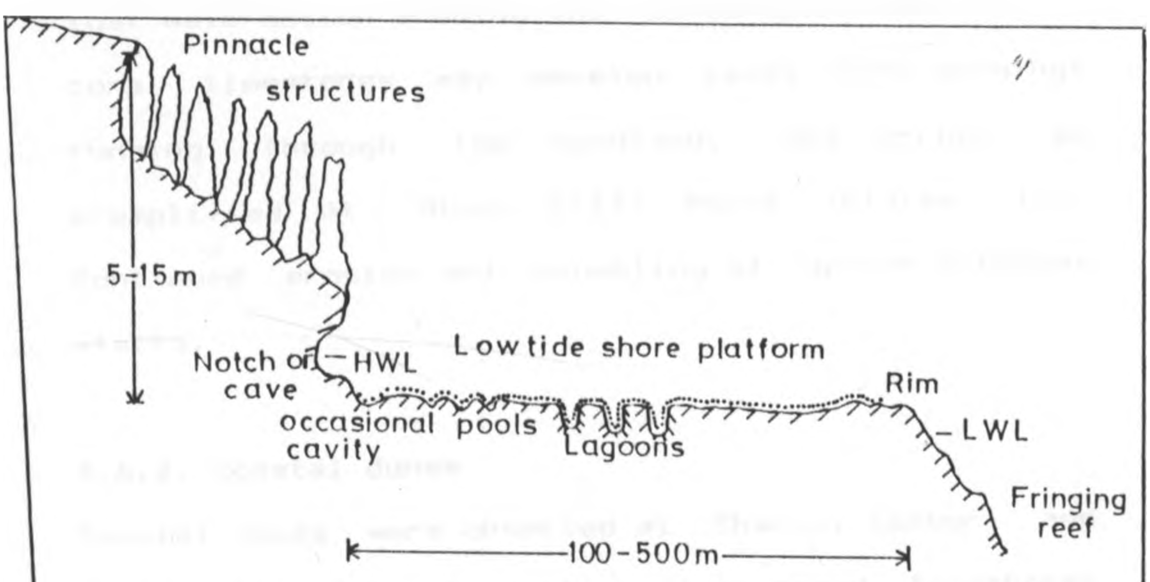


Fig. 27 shows vertical section of a pinnacle structure and the fringing reef in the Diani area.

Tiwi a karst topography forming a rugged shoreline due to its weathering style has formed a pinnacle structure (Plate 12). This structure occurs in severely dissected areas. A cross section of pinnacle structures is shown in figure 27. Besides this mechanical corrosion, biological weathering is very active. The subtidal zone is characterized by biological erosion from boring organisms.

From these observations, it can be seen that wave action on cliffs has two effects. First, there is the direct undercutting and erosion of the face and secondly, the removal of detritus products from the toe. Accumulation of eroded products at the cliff toe halts cliff recession. It has also been observed that wave action eroding the softer portions of the coral limestones may develop caves into openings running through the headland, sea arches as exemplified at Black Cliff Point (Plates 10). Continued erosion and crumbling of arches produces stacks.

4.6.2. Coastal dunes

Coastal dunes were observed at Shanzu, Bamburi and Nyali (Fig. 25). Sand blown from broad foreshores exposed at low tide is build up as dune topography extending inland from high tide mark. The dunes within the Mombasa-Diani area are of limited and local extent. This could be due to the fact that these beaches are narrow and the prevailing dampness of beach sands impedes deflation and backshore dune development. In Shanzu and Bamburi, low dunes are present in the backshore area, their height about 1-2 m and width about 2-5 m. The dunes cover an area of about 30 m^2 at Shanzu and 50 m^2 at Bamburi. These dunes are being stabilized by vegetation but the sediments underneath remain unlithified. The dunes cover an area of about 50 m^2. Two dune ridges were observed at Nyali. One ridge is 1 m in height while the other is 5 m. These two series of dunes have their ridges running parallel to each other with a separation of about 15 m and partially stabilized by vegetation. 1 km southwards, the separate dune ridges merge into one with a height of about 3 m.

The dunes in the study area are located close to the shoreline thus they form a buffer stock of sediments, that can be reshaped by the swell and can influence the equilibrium of adjacent beaches. These sands are usually not moved often as is indicated by the large trees that grow on them and often by the accumulation of beer cans and other human artifacts. Dunes protect the low-lying sand behind them and they are both of modern and subrecent origin.

4.6.3. Beach ridges

Beach ridges were observed at Kikambala, Kanamai, Mtwapa, Bamburi, Kenyatta beach, Nyali, Mackenzie Point, Leven and Likoni (Fig. 25). They were also observed at Tiwi, Mwachema, Diani and Kinondo (Fig. 26). Where there are buildings along Kikambala to Kanamai, the beach is marked on the landward side by seawalls but where there are no such structures, a beach ridge has developed (Plate 13). This is a low lengthy ridge of beach material piled up by storm waves landward of the berm. It consists of coarse sands, gravel or shells unlike dune ridges that form particularly where the sand is fine and resemble beach ridges. At Diani the beach is bordered on landward side by low cliffs and beach ridges (Plate 14) and seaward side by raised shore platform which acts as a natural breakwater. Two beach ridges 0.5 m and 1 m respectively occur parallel to the shoreline and are separated by 20 m.

4.6.4. Islands

Two islands occur within the study area namely Mombasa (Fig. 25) and Chale (Fig. 2). Mombasa island is larger than Chale island. Coral limestones (Fig. 4) occur on the eastern side of Mombasa forming a cliffed coast. These cliffs are as high as 10-15 m above sea level. Jurassic Shales occur to the west

Plate 13 shows high tide mark indicated by low beach ridges (br) at Kikambala (June, 1991; Photo by S. Langat).

Plate 14 shows high tide mark indicated by swash mark level (l) at Diani (September, 1990; Photo by P. Abuodha).

of Mombasa forming a low lying ground composed of muddy shores and mangroves (Fig. 4). Chale island is found south of Chale Point surrounded by a shore platform (Fig. 27). It is separated from Chale Point by a distance of 270 m. Two fault lines depicted on aerial photographs at Chale Island indicate possible faulting of the reef in the recent times.

4.6.5. Sandy beaches

The term beach (Plate 13) is applied to sediment seaward of the coastline through the surf zone that is in motion along the shore and within the surf zone (Thurman, 1975). The upper edge of the beach is formed by the landward limit of effective wave action often marked by a cliff base (Plate 15), dune, or beach ridge (Plate 13) while the lower edge is marked by the shore platform (Plate 16).

In the study area, the isolated beaches are present between small headlands. Extended beaches occur continuously for hundreds of metres. This shows that their position is determined by factors such as protection against wave action and the predominant direction of longshore currents of the ocean water (Oosterom, 1981).

Extended beaches occur north of Mtwapa Creek at

Plate 15 shows notches (n) and a crack (c) on a cliffed coast, a precursor to a major slab failure along Nyali (September, 1990; Photo by J. Abuodha).

Plate 16 shows a narrow beach (b) and a shore platform (rp) exposed during low tide at Kikambala (June, 1991; Photo by S. Langat).

Kikambala and Kanamai, and north of Tudor Creek at Bamburi-Kenyatta and Nyali (Fig. 25). They also occur at Tiwi and Diani (Fig. 26). In general, extended beaches form many of the long and straight or slightly curved beaches. The extended beaches are generally characterized by a low gradient about 1-3^0 C and a wide surf zone.

Isolated beaches occur at Mtwapa, Shanzu, Leven, Likoni (Fig. 25) Black Cliff Point (Fig. 26) Galu, Kinondo and Gazi. These beaches are invariably steep. Likoni beach is the longest isolated beach in the Mombasa-Diani area. Small isolated beaches occur between the many numerous headlands at Black Cliff Point. In general, isolated beaches are short and crescentic in form.

4.6.6. Rocky shores

The term rocky is applied to a shore where no appreciable amount of sediment exists (Shepard, 1973). Within the study area such shores are found beneath cliffs of Pleistocene limestone at Shanzu, Kenyatta, Iwetine (Fig. 25) and Galu (Fig. 26). At Shanzu the rocky shore is uneven with sediments on its lower portions (Plate 17). Along Kenyatta beach, the rocky shore has a width of approximately 600 m. Grooved channels have resulted in a lot of

Plate 17 shows a rocky shore platform (r) marking the lower edge of the beach at Shanzu (June, 1991; Photo by S. Langat).

Plate 18 shows jagged surface of the rocky shore (r) at Iwetine (September, 1990; Photo by J. Abuodha).

sediments sporadically distributed on the shore platform of Iwetine headland, the rocky shore is well characterized by extremely jagged surface and numerous pits and pans indicating the weathering style of the limestones (Plate 18). These rocky shores are also characterized by a spur and groove structure developed perpendicular to the cliffs (Plate 19). The grooves act as channels for water and sediments and are thus vital to the dissipation of the wave energy incident on the cliffs. It is possible to envisage that a cliff notch (Plate 7) may turn into a rocky shore (Carter, 1988). The relatively level abraded surface is initiated at the base of the cliff by plunging waves, and then widened by spilling waves, probably armed with abrasive clasts.

4.6.7. Shore platforms

Shore platforms extend across the surf zone with gentle slopes which are not always uniform. These platforms are evidently developed and widened as the cliffs recede, and shaped by the action of waves and other marine processes. They extend from the lower ends of the beaches and rocky shores to a level below and beyond low tide mark, in the nearshore zone (Fig. 28). Low tide shore platforms may be defined as horizontal or almost horizontal platforms

Plate 19 shows a groove structure (g) developed perpendicular to the cliffs and a gravel beach (gb) at Galu (September, 1990; Photo by P. Abuodha).

Plate 20 shows sand distributed on the shore platform (p) exposed during low tide at Kikambala (June, 1991; Photo by B. Langat).

exposed only for a relatively brief period of time when the sea falls below mean mid-tide level (Bird, 1969).

Kikambala sand is sporadically distributed on the shore platform with one major sand bar extending upto the coral reef (Plate 20). The bar is exposed during low tide and is oriented perpendicular to the shoreline. Along Nyali, the shore platform is well developed and acts as a natural breakwater. In places the platform is perforated resulting in the formation of a notch immediately opposite the perforated shore platform (Plate 21). The most typical feature at Nyali beach, from aerial photographs (Fig. 29) is the lack of sediment distribution on the shore platform. It can therefore be concluded from this observation that Nyali is a stable beach.

At Likoni (Fig. 30), the sediment transport on the shore platform is in the SE direction controlled in the main by the tidal currents. Several disconnected channels occur on this platform. From these observations on the aerial photograph of figure 30, Likoni beach is being eroded faster than the other beaches within the study area.

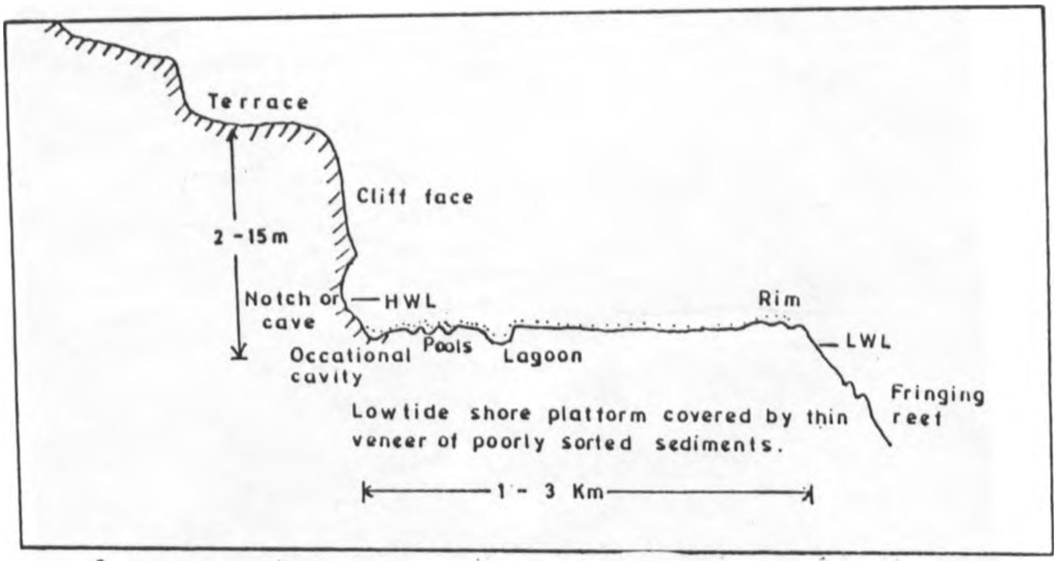


Fig. 28 shows vertical section of a cliff and the fringing reef in the Mombasa-Diani area.

Plate 21 shows a raised shore platform (p) at Nyali. Note notch (n) formation immediately opposite the perforated shore (September, 1990; Photo by P. Abuodha).

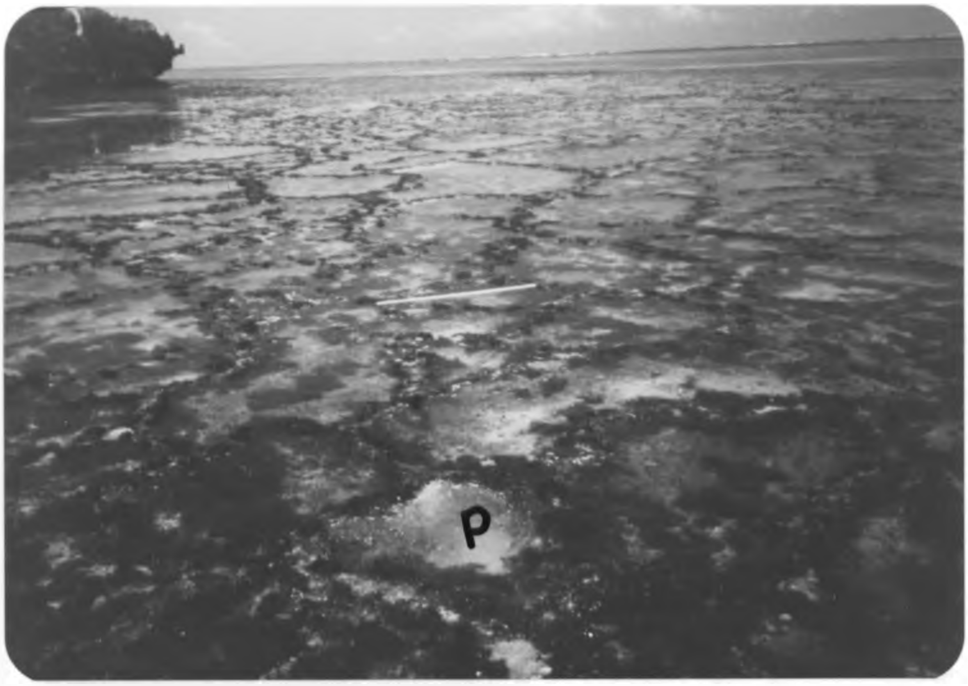


Plate 22 shows softer portions of the shore platform at Black Cliff Point scoured out as pools (p) (September, 1990; Photo by P. Abuodha).

Plate 23 shows coastal lagoon (l) at Diani located between the beach (b) and the raised shore platform (p) (June, 1991; Photo by S. Langat).

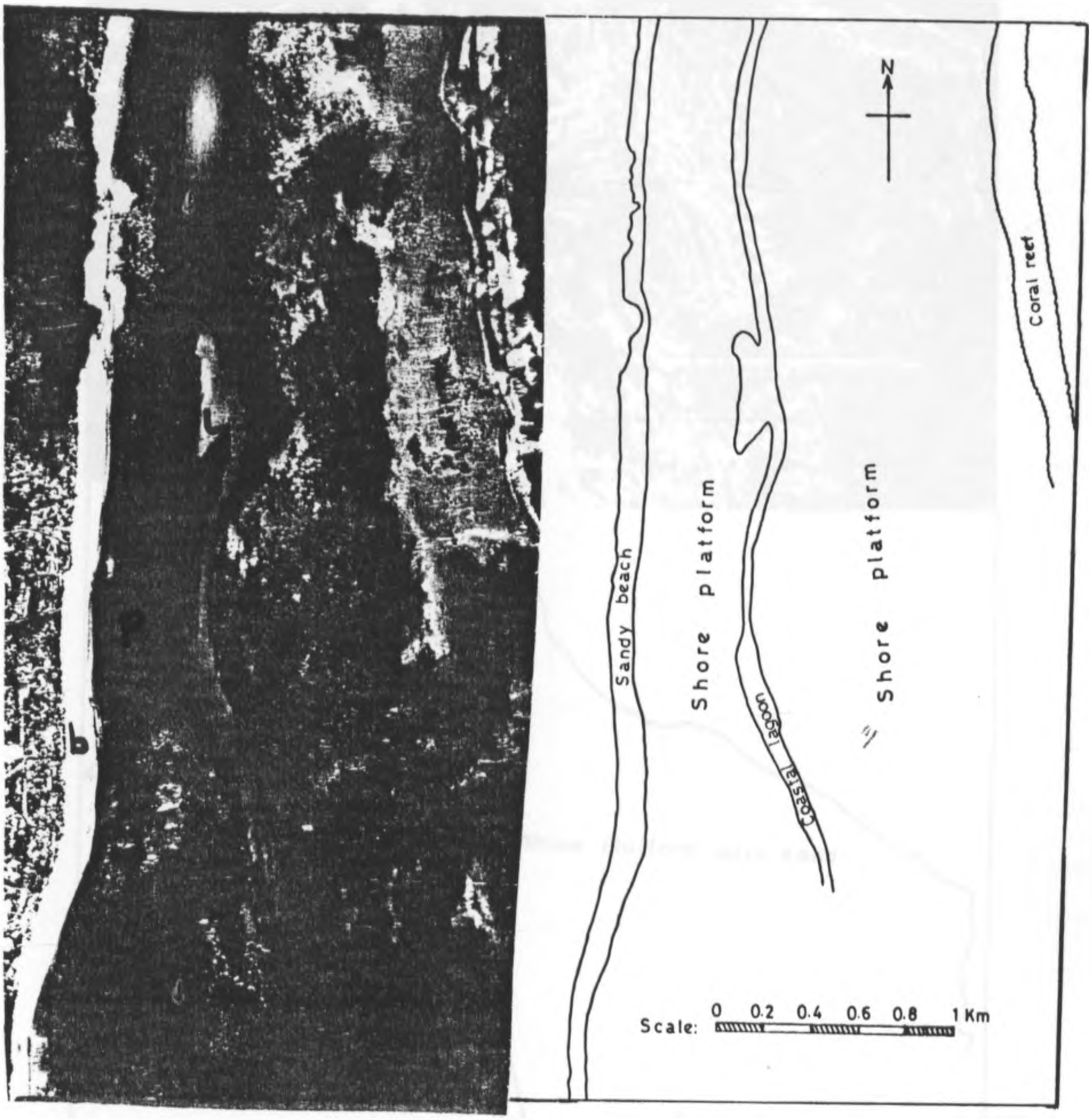


Fig: 29 shows beach (b), the shore platform (p) with no sand and the coastal lagoon (l) running parallel to the beach.

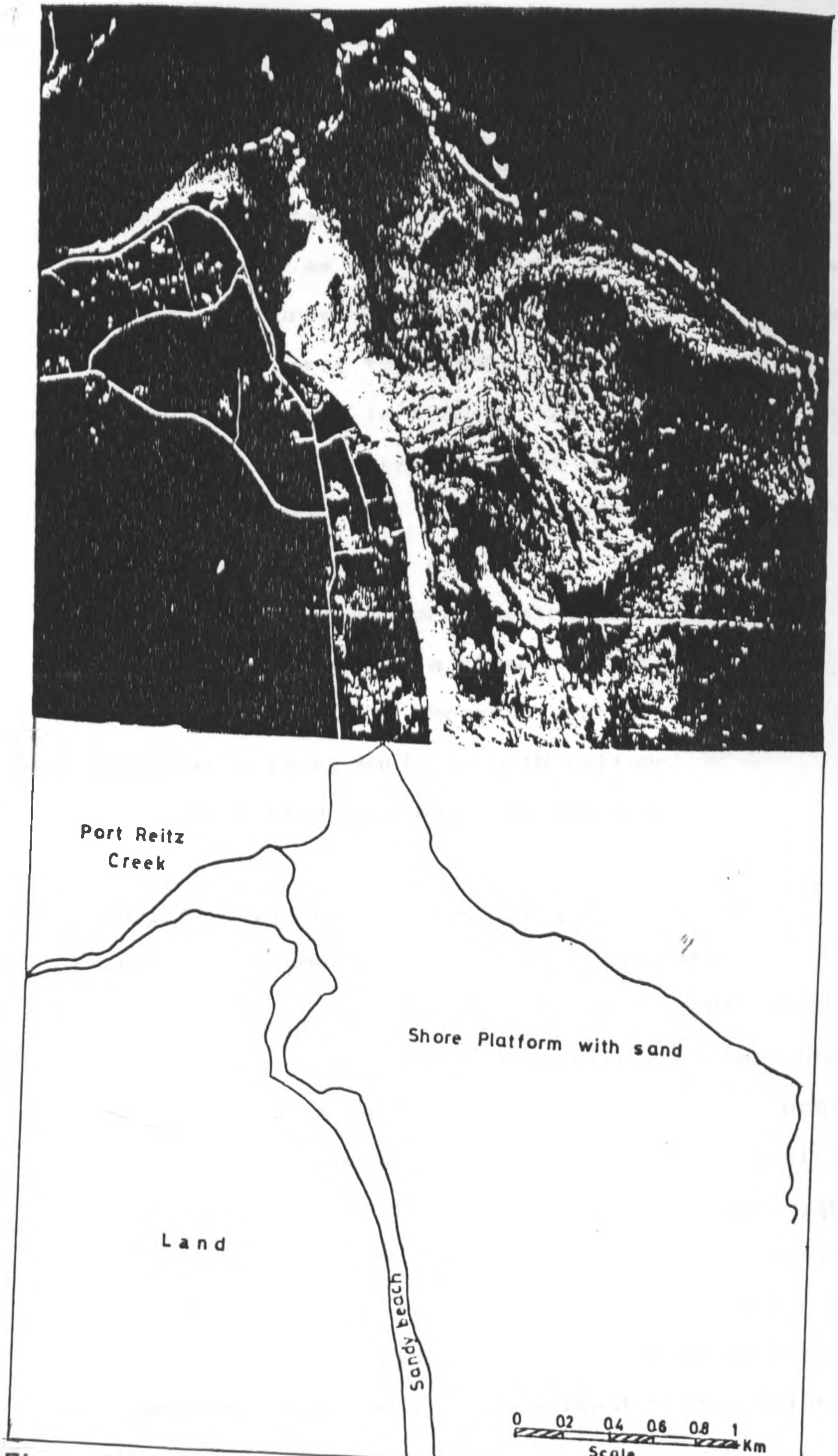


Fig. 30 shows sand (white spots) sporadically distributed on the shore platform.

Evidence of wave abrasion can be observed on shore platforms where the more resistant elements of rock persist as stacks and intervening areas have been scoured out as pools (Plate 22). Pools are very common features of the platform in the study area forming a karst topography. Across section of the pools is shown in figures 27 and 28. The rock fragments that become trapped in a crevice on a shore platform may be repeatedly moved by wave action in such a way as to excavate circular potholes, smoothly-worn basins containing smoothed and rounded pebbles- a clear evidence of the potency of waves armed with abrasive debris. At Mtwapa Creek there is a karst surface with cylindrical pits upto 1 m deep filled with hard red sediment.

An influx of water from the bottom can be observed when these pools are emptied, indicating a mutual subsurface connection. Braithwaite (1984) described these pools as (coalescing) pits on the present shore platform and attributes them to possible subaerial erosion at a time of lower sea-level after the formation of the shore platform. The various stages of this process and the scouring mill-stones can be observed in many places on the shore platform. As low tide shore platform is developed on limestone formations, it is evident that a solution of limestone (chiefly calcium carbonate) by water, in the presence of carbon dioxide, is an important factor in their formation. The dissolving of limestone is represented by the equation;

$$CaCO_{3(s)} + H_2O_{(l)} + CO_{2(g)} = Ca(HCO_3)_{2(s)}$$

where s, l and g represent solid, liquid and gas respectively. The rock limestone passes into solution as calcium bicarbonate, $Ca(HCO_3)_2$.

4.6.8. Mangrove swamps

Within the study area, mangrove swamps are found mainly at Gazi bay, but also occur within the intertidal zone along Mtwapa, Tudor and Port Reitz Creeks (Fig. 25). The mangroves form the pioneer community, spreading from the shores of Mwachema estuary and colonizing mudbanks of the creeks exposed at low tide. Mangrove encroachment is impeded by strong wave action or tidal scour, so that mangrove swamps become most extensive in sheltered areas, and only reach the sea on low wave energy sectors of the coast. The Gazi bay comprises three major landforms (Fig 31);

1. At the northern part of the bay there is intertidal zone with mangroves which occupy about 50 % of the bay. Within this zone there are tidal channels.

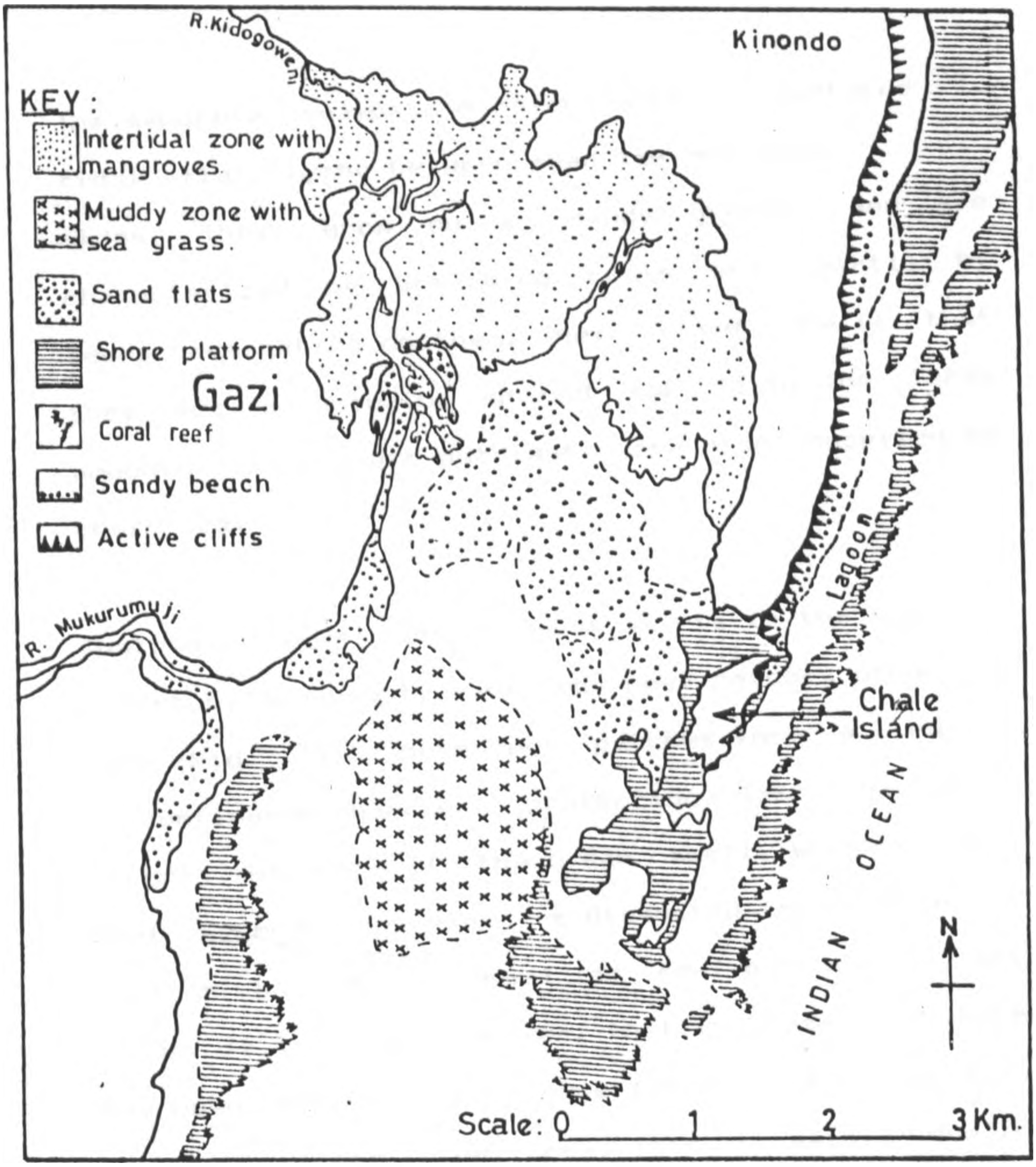


Fig. 31 shows the geomorphology of Gazi Bay and Chale Island (modified from The Dutch-Kenya Expedition, 1990-1995)

2. In the centre of the bay and on the banks of River Mkurumuji are sand flats which form the beaches.

3. The southern part of the bay in the centre is covered by muddy zone with sea grass.

The mangrove swamps are essentially a vegetated tidal flat, lying between mean low and high tides. They grow on a sandy ground and are characterized by breathing roots and partly by seeds germinating on them. Their chief role is that they act as breeding ground for fish. The large amounts of organic nutrients are also supplied by their leaf fall.

Instead of major reef segments as is in the rest of the study area, only isolated reef patches occur at Gazi (Fig. 31). These reef patches form a kind of discontinuous barrier protecting Gazi bay from direct influence of the ocean swell. Whether these reef segments represent a dissected former fringing reef or have been formed as reef patches is not clear. It is clear, however, that in Gazi, the shore has been subjected to a more intense dissection than the rest of the study area. This is mainly due to the absence of protecting coral reef (Oosterom, 1988). To what extent tectonic factors may have played a role is not clear.

Rivers Kidogoweni and Mkurumuji supply sediments on the western edge of Gazi (Fig. 31). The sediments are distributed along the beaches as sand flats. The sand flats are constituted by the barren tracts of land covered by water only at high tide. Tidal channels are constituted by the relatively small inlets in the mangrove swamps. Mangroves in Gazi are threatened by various activities. They are extensively cut for poles, cleared for more coconut plantations, firewood and charcoal, construction materials and timber for boats and dhows. Mangroves are also threatened by siltation from rivers which degrades protective reefs and exposes the shore to increased erosion. In summary, mangrove areas are threatened throughout the region by over-exploitation, deforestation for development sites and pollution by among others, agricultural chemicals. There is urgent need to conserve mangrove forests along these areas.

4.6.9. Coastal lagoons

Coastal lagoons were marked from aerial photographs. Along the shoreline of the study area, lagoons are located;

1. within the shore platform (Fig. 29) and
2. between the beaches and cliffs, and the raised shore platform (Plate 23).

Although the depth of the lagoon is generally less than 5 m, there is a narrow channel within Leven Reef situated close to the shore with a depth of 5-10 m (Andrew, 1981). Along Diani to Kinondo (Fig. 26), there are smaller isolated lagoons located at variable distances from the shore. Across section of these lagoons is shown in figure 27. At Bamburi the lagoon has a general width of about 1 km but the lagoon channel is not defined (Fig.). The channel has been filled up with sediments from the beach.

In general, the lagoon is 400-800 m wide but narrows to 300 m at Iwetine. The strength of lagoonal tidal currents gradually increases during the onset of flood tide reaching maximum velocities at the end of tidal phase. The strongest localized tidal currents associated with lagoonal channels are exemplified at the nearshore areas north of Mombasa (Fig. 25) where there is one major lagoon. At the south coast (Fig. 26) where the lagoons are generally of smaller dimensions, there are weaker tidal currents. The development of lagoons can be attributed to longshore currents. The waves and currents transport much fine carbonate sediment from the reefs, and the limestone cliffs. This has resulted in most of the lagoons within the study area being filled up.

4.6.10. Creeks

The creeks in the study area are Mtwapa in the north and Tudor and Port Reitz which surround the Mombasa Island (Fig. 25). In terms of water volume and depth, Mtwapa Creek has the least followed by Tudor and then Port Reitz. Kilindini Harbour undergoes dredging to maintain depth and alignment of navigable approach channels about 4 times a year as it is the passage for ships into the harbour. All these creeks are characterized by a wide enclosed water body with narrow passage towards the Indian Ocean (Fig. 25).

The origin of these creeks is considered to be drowned river valleys (Sikes, 1930). Ase (1981) referred to the creeks as rias which means branched inlets formed by partial submergence of river valleys. Alluvial scouring through the reef complex is most likely to have played an important role in creek formation although subsurface solution following the lowering of sea level may also have been involved in their formation. The typical configuration of these creeks is related to the type of the surrounding rocks as the broad water bodies are found at places where the Jurassic Shales occur while the narrow channels are found at places where the more resistant rocks of the Pleistocene reef complex are present (Fig. 4).

4.6.11. Estuaries

Estuaries are the mouths of rivers, widening as they enter the sea (Bird, 1969). Within the study area, Mwachema river is the only large river forming an estuary (Fig. 26). Other rivers, found at Gazi, are Kidogoweni and Mkurumuji (Fig. 31). The Mwachema channel is about 200 m wide and has been displaced southwards for about 400 m. Mwachema channel is 1 m deep at low tide.The outlets of the estuaries are different in plan to those of the creeks in that they are;

1. smaller in size,
2. lacking a broad water body and
3. basically have narrow tidal channels which are more or less funnel shaped (Oosterom, 1988).

The difference in shape is related to the size of the drainage areas of the estuaries and the creeks. Relatively large drainage areas of the Voi and Mwatate rivers are connected with the creeks whereas the small drainage areas of the Mwachema, Mkurumuji and Kidogoweni rivers are connected with the estuaries. These rivers with their limited discharge rates apparently have little potential to erode broad valleys in the shales and marl present behind the Pleistocene reef complex (Fig. 4).

4.6.12. Coral reefs

The coral reefs along the study area are fringing reefs meaning that they are directly attached to the shore (Thurman, 1975). Coral reefs are structures build by organisms with a framework strong enough to withstand the attacks of ordinary wind waves by a buffer effect (Schroeder, 1974). Within the study area, coral reefs grow at varying distances from the shoreline. They build upwards and outwards in the ocean and consist of a platform at low tide level (section 4.6.7). The reef that occur between Mtwapa and Tudor Creeks is called Leven (Fig. 25). The absence of the reef around Mombasa Island may be due to the fresh water flow from rivers draining into Tudor and Port Reitz Creeks and also due to pollution from petrochemical industries such as Bamburi Portland Cement and ships entering into the Kilindini Harbour. Andromache reef occurs south of Port Reitz Creek (Fig. 25). It is furthest (2 km) from the shoreline at Likoni but gradually extends near the shoreline and finally outcrops on the shore at Black Cliff Point (Fig. 31). From Black Cliff Point, it maintains a constant distance from the shoreline of about 500 m. A further displacement occurs at Mwachema estuary due to fresh water flow into the ocean from the river. At Diani it maintains a distance of about 1 km from the shoreline, increasing gradually to about 2 km from the shoreline at Kinondo. At Gazi the reef is not well developed. In this study, the coral reef has been taken to be located where the waves break during low tide and its position is marked by breakers on aerial photographs (Fig. 29). Where the reef is discontinuous the waves pass without breaking and gets distorted within the lagoon.

The growth of a coral reef creates a new living environment which gives shelter, protection and food to a variety of living organisms. The reef itself is a protecting barrier against the force of the sea. Coral reefs are threatened by siltation of nearshore marine areas due to terrestrial erosion. Deforestation of mangroves and environmentally destructive agricultural practices inland cause large quantities of silt to be carried to the sea where it smothers the reefs. Reefs are also exposed to low-level oil pollution in some areas, especially in the vicinity of Kilindini harbour.

CHAPTER 5 COASTAL ZONE MANAGEMENT

5.1. Introduction

Coastal Zone Management (CZM) is necessary for sustainable development and utilization of coastal resources. The coastal zone has four main functions:

1. Basic functions such as food production, water and energy supplies.
2. Social functions including housing and recreation.
3. Economic functions such as transport, mining and industrial development and
4. public functions which comprise of public transport and defence.

Man has turned to the beach as a break from the hectic pressures of modern life. The beaches are, without doubt, the most important tourist attractions at the Kenyan coast as a whole, and within the study area in particular. The beach provides a restful setting for picnics, walks along the shore, sun bathing and also encourages more vigorous sports including swimming, jogging, surf casting, and surfboard riding. The cool sea breeze and nearby water make the beach an alternative place to enjoy a seaside vacation.

Coastal problems in the study area were identified to be;

1. Lack of coastal zone management system,
2. coastal erosion and
3. degradation of beaches.

These problems are presented and discussed in this chapter.

5.2. Coastal problems in the study area

5.2.1 Lack of coastal zone management system

Lack of coastal zone management system was identified to be the major coastal management problem. Public awareness can easily eradicate problems such as ash-tray filling of sediments from the beaches, sweeping of the beaches, games on the beaches and mining of grinding stones from the shore platform. Human interferences are having major impacts on the coastal zone. There is, therefore, increasing acceptance of the need to protect the marine environment and its resources.

5.2.2. Coastal erosion

Erosion is a prevalent phenomenon along the Mombasa-Diani coast. In many places, the rate of coastline retreat and the resulting environmental degradation and economic loss is on such a scale as to be alarming (Plate 24). Most of the beaches are being eroded due to lack of major rivers which would

Plate 24 shows reinforcement of a hanging cliff (c) at Nyali. (September, 1990; Photo by J. Abuodha).

Plate 25 shows coastline retreat in front of Kanamai beach leaving a coconut stump (s) 50 m from the present coastline (September, 1990; Photo by P. Abuodha).

have compensated for the sand lost from longshore current action and this explains the obvious absence of prominent depositional features such as coastal dunes in most of the area. Apparently, the erosion is so widespread that it also affects the undeveloped coasts, which are beyond the direct influence of man (Plate 10). It seems therefore, that the main factor causing this erosion is the global sea level rise.

At Kanamai, an indentation into the coastline proves that erosion has significantly taken place in this area (Plate 25). A coconut tree stump located 50 m from the present shoreline in this area is another proof of erosion. The estimated annual retreat at Kanamai between 1971 and 1991 is therefore 2.5 m. At Shanzu, beach erosion is exemplified by slumped cliffs (Plate 26) resulting in the accumulation of pockets of sand. The slumped cliffs act as objects for starting sand accumulation. The 15th century staircase at Shanzu is suspended 4 m above the present shoreline giving a rate of cliff retreat of 8 mm/yr. At Iwetine, intense cliff erosion occurs at the edge of a retreating cliff. On the Mombasa island, two tunnels and a staircase have been left 4 m from the present shoreline giving a rate of erosion for the last 20 years as 20 cm/yr (Plate

Plate 26 shows slab (s) failure has cut off the only bridge (b) access to the sea at Shanzu (September, 1990; Photo by P. Abuodha).

Plate 27 shows hanging staircase (s) and tunnels (t) on a cliff at Mombasa Island (September, 1990; Photo by P. Abuodha).

27), while at Galu, on a undeveloped coast, exposure of tree roots by 1.5 m is an indication of intense erosion along this coast (Plate 28).

5.2.3. Degradation of beaches

5.2.3.1. Constructions beyond high tide mark

From Kikambala to Mtwapa, several beach hotels, cottages and private houses have been built along the shoreline or just a few metres landward. At Kikambala, a private residential area has been deserted due to cliff erosion. At Kanamai, a residential structure built close to the high tide mark has boulders placed at the house front in an attempt to protect the house from erosion (Plate 29). Approaching Mtwapa, more private houses have been constructed on eroding cliff tops. Beach hotels have been constructed at the edge of retreating cliffs at Shanzu and caves are already forming beneath these beach hotels and the sand on the beach has been completely eroded (Plate 30). Along Bamburi and Kenyatta, beach hotels have been constructed only 20 m from the shoreline and during high tide, most of these hotels get flooded.

In some areas along Nyali beach, development has been extended beyond the shoreline by sand infilling into a structure built on the beach (Plate 31). The

Plate 28 shows exposed tree roots (r) at Galu due to erosion (September, 1990; Photo by P. Abuodha).

Plate 29 shows limestone boulders (b) placed against a house to protect it from flooding during flood tide at Kanamai (June, 1991; Photo by S. Langat).

sand is obtained from the adjacent beach or the dunes along the shore. After sand-infilling, the structure is stabilized by a pavement on seaward side. The outcome of this project is the acceleration of beach erosion due to no exchange of sand between dunes and the beach.

A private house built along the shoreline on a retreating cliff at Nyali is being reinforced using pillars as erosion has caused undercutting below it (Plate 24). However, it was surprising to note that this house is still inhabited. This was evident from the garbage at the foot of the pillar and a dry carton that must have been dropped onto the beach after water receded during low tide. A few metres southward of this location, a private house stands at the edge of a retreating cliff. A 1 m scarp has formed as a result of landward adjustment of shoreline (Plate 32). At Leven manifestation of intense cliff erosion has resulted in a slab failure which has formed a crack on the wall above. It can be clearly seen that when finally this slab falls due to hydrostatic pressure of waves, it will move with part of the house (Plate 33). At the entrance to Tudor Creek, a resort for show members has been build with an extension into the creek and supported with pillars (Plate 34). Although the resort is

Plate 30 shows notches (n) developed beneath a beach hotel at Shanzu (September, 1990; Photo by P. Abuodha).

Plate 31 shows sand infilling (i) from the lower beach (b) at Nyali to built a protection structure (September, 1990; Photo by P. Abuodha).

Plate 32 shows property on a cliff. Note stack (s) on the right and a beach scarp (bs) on the left of the plate at Nyali (September, 1990; Photo by P. Abuodha).

Plate 33 shows slab failure (f) leading to crack (c) on house wall at Leven. Note the exposed rocks (r) beneath (September, 1990; Photo by J. Abuodha).

still under construction, the pillars have already started showing signs of decay upto 1.5 m above sea level. There is completely no beach at the entrance of Tudor Creek and even during low tide, a thin film of water still remains on the shore platform. Slightly inland along Tudor Creek entrance, a construction has been built along the shoreline (Plate 35). A residence built beyond the high tide mark at Tiwi has splash water marks above its door (Plate 36). This is probably a new house or it was recently renovated. Despite the splash water marks, no damage can be detected on the house.

In general, the coastline is subject to natural fluctuations due to variations in sediment transport, both in terms of quantities and direction. The construction of buildings very close to the shoreline often interferes with these natural fluctuations. This leads to decreased sediment supply to the shore and consequently erosion is either induced or accelerated. Thus, the present problems are therefore primarily caused by man through constructions on the beaches.

5.2.3.2. Sweeping of the beaches

Beach erosion is accelerated by the property owners themselves who employ workers to sweep (Plate 23)

Plate 34 shows construction of property at the entrance to Tudor Creek. Note level (l) of high tide mark on the pillars (September, 1990; Photo by P. Abuodha.)

Plate 35 shows property constructed at the entrance to Tudor Creek standing risks of erosion in the near future (June, 1991; Photo by S. Langat).

and bury seaweeds brought onto the beach during high tides (Plate 37). Sweeping of the seaweeds off the beaches has two serious effects on the beach:

1. By sweeping off the seaweeds from the beach with a rake, sand is not only exposed but also loosened. During high tide, therefore, more sediments are likely to be eroded and
2. by loosening the sand, the waves easily erode the loosened sand from the beach into the lagoons or onto the shore platforms.

Vegetation cover plays a very important role in the protection of coastal sediments by physically binding them. Increased clearing of coastal vegetation increases surface run-off and makes the exposed area more vulnerable to mass movement and to erosion by winds, currents and waves.

5.2.3.3. Aesthetic activities on the beaches

Playing games on the beaches like volley ball and the building of castles, which are a common practice on all the beaches also enhances beach erosion in the same manner in which sweeping of the beaches does, as explained above.

5.2.3.4. Beach mining

Another common practice by the inhabitants of the

Plate 36 shows splash water marks (m) above house door at Tiwi (June, 1991; Photo by S. Langat).

Plate 37 shows collected seaweeds at Diani. This disturbs the sediments thus enhancing erosion. Note games in the background (June, 1991; Photo by S. Langat).

coastal area is to mine limestone from the shore platform. The mining is done so systematically that the sites can be mistaken for building foundations. The sites were observed at Mtwapa and Shanzu. The mined limestones are used to make traditional grinding stones. One effect of the mining of grinding stones along the shore platforms is the deepening of the platform which allows waves to travel further up the beach thereby increasing the chances of erosion. It also alters the pattern of wave refraction and may cause a refocussing of wave energy which probably leadsto the acceleration of erosion around Mtwapa and Shanzu.

The beach hotels in the study area, utilize sand from the shoreface in ash trays for use by the visitors. This sand extraction although is small in quantity but in the long run enhances beach erosion. The extraction of sand from the shore for this purpose is a practice and is done regularly in all the beach hotels, cottages and private homes which deprive beaches of sediment and thus likely to cause disequilibrium.

5.2.3.5 Discharge of waste waters

Pollution is another adverse effect of coastal development along the shoreline. Nearly all the

Plate 38 shows games on the beach at Diani. This disturbs sediments and enhances sand depletion from the beach during flood tide (June, 1991; Photo by S. Langat).

Plate 39 shows liquid waste disposal (d) on the beach at Kikambala. It has formed a depression (de) of about 50 cm into the sands (June, 1991; Photo by S. Langat).

beach hotels within the study area dispose of their wastes, especially from the swimming pools directly into the sea (Plate 39). This results in volumes of sand being eroded from the beach which has formed 50-100 cm depressions into the beaches. The eroded sediments finally reach the coral reefs which they smother and thus the growth of the coral reefs is hindered, which in turn enhances beach erosion as the waves will now be breaking on the shore. These liquid wastes not only affect the marine life but is also dangerous to the health of swimmers along the beaches, not to mention the children who play in them.

CHAPTER 6 GENERAL DISCUSSION

6.1. Introduction

The data presented in the foregoing sections provide information on the sedimentology and geomorphology of the Mombasa-Diani area. More specifically, they provide information on implications of coastal morphology and sediment movement such as erosion and deposition, to the coastal zone management. To curb the erosion problem, for example, various sedimentological and geomorphological factors need to be studied in detail. Sedimentological factors such as those studied in this work would help in the identification of areas undergoing erosion, deposition and those which are stable (that is, erosion and deposition are balanced).

The generally poor performance of engineering structures to stabilize beaches emanates from the non-cognizance of the distinct peculiarities of beaches such as their morphology, surf zone dynamics as well as wave-current interactions. It is emphasized that construction activities in the coastal zone should only be undertaken after the consideration of these distinct peculiarities. In order to institute realistic research and management of coastal areas, it is important to understand the biophysical processes operating within the littoral environment. For instance, the movement and supply of sediments along the shoreline is an important phenomenon in coastal geomorphology. Indeed the coastal zone is a complex environment in which the physical human interaction culminates into a dynamic environment within which some of the most rapidly operating geomorphological processes occur. Geomorphological factors would include studies on the low, transitional and raised areas.

6.2. Sedimentological factors

Within the study area, it was difficult to isolate which areas are stable or undergoing deposition, as signs of erosion were observed almost everywhere. Serious erosion occurred in the 1970's resulting in the shore platform being exposed at Likoni (Dr. Odada, personal communication). As a result, the tourists avoided the area and Shelly Beach Hotel (Appendix I) was eventually closed because of lack of tourists. Minimal human interference with this beach for the last 20 yrs has resulted in deposition taking place here. But no sooner did beaches appear here than tourists started coming back and a seawall has now been constructed as the beach is undergoing induced erosion. The distance of Andromache reef (Figs. 25 and 30) from Likoni (2 Km) is also an added advantage to this beach as by the time the waves reach the beach, their strength is greatly reduced. Tiwi beaches (Fig. 26), on the other hand, have the disadvantage that Andromache reef is very close (0.5 km) to the shoreline, but despite this, the beach is relatively stable because there are no large beach hotels, only beach cottages and bungalows which are widely spaced and seasonally occupied by tourists. The reason for the low population on this beach is mainly due to the fact that Tiwi beach is almost inaccessible and very far (5 km) from the main road (Fig. 2). Compared to beaches such as Bamburi or Diani where a lot of activities by tourists go on (Plate 37), Tiwi beaches are relatively free of such activities, only a few people walk the beach.

Diani beach has the advantage that the shore platform is exposed above the water at low tide and thus acts as a natural breakwater (Plate 23). Breakwaters dissipate the energy of approaching waves and form a protected shadow zone on their landward sides. Unfortunately, this natural breakwater has been damaged in several places by fishermen in order to allow for passage of boats onto the offshore zone.

Very large indentations into the cliffs occur at Diani. In some areas, erosion has proceeded 5 m inland for the last 50 yrs giving an annual retreat rate of 10 cm. Gazi has the advantage that it occurs within a sheltered bay from the strong and direct attacks of currents and waves but induced erosion is now occurring in numerous parts of this bay due to the exploitation of the mangroves. In summary, Tiwi and Nyali can be considered stable beaches while Leven, Mackenzie Point, Mtwapa, Kenyatta beach, Likoni, Mwachema, Diani and Gazi are depositional beaches given no induced erosion. Kikambala, Kanamai, Shanzu, Bamburi, Iwetine, Black Cliff Point, Galu and Kinondo are erosional beaches.

6.3. Geomorphological factors

Geomorphologically, the study area can be divided into low, transitional areas and highly placed areas. Features which occur well above the high tide mark fall under raised areas and consist of features like cliffed coasts, coastal dunes, beach ridges and islands. Transitional areas fall within the intertidal zone in that they are generally exposed during low tide but are partly or completely covered with water during high tide. Features such as beaches, rocky shores, shore platforms and mangrove swamps form the transitional areas. Low lying areas are areas which are below low water mark such as coastal lagoons, creeks, estuaries and coral reefs.

Constructions can only go up in raised and transitional areas. In a transitional area like Gazi bay, where there is low relief, any elevation in the ocean surface close to shore would manifest as a landward translation of the shoreline many orders of magnitude compared to the vertical rise. The land surface close to shore is thus degraded and shoreline retreat occurs. Any constructions in the transitional areas should be placed with appropriate set back line and caution must be taken in order not to disturb the beach. The required set back must be carefully evaluated because of the considerable expense of moving a building if the set back latter appears to be insufficient. Hotels should be clustered in highly elevated areas. This will have the advantage of sharing common facilities such as water supply, electricity, roads and many others. All these constructions, however, should be temporary.

6.4. Coastal protection measures

6.4.1. Present practice in Kenya

A brief reconnaissance of other places outside study area revealed that coastal protection measures is a common practice along the Kenyan coast as a whole. To protect an eroding coastline the following corrective measures, subdivided according to their operating principles, have been used in Kenya;

1. Structures to prevent waves from reaching erodible materials such as seawall and revetments and they are constructed parallel to the shoreline.
2. Structures to slow down the rate of littoral transport such as groynes trapping the sediment). These structures are built perpendicular to the shoreline.

Seawall (Plate 40) and revetments (Plates 29 and 41) are present in almost every highly developed coastal area within the Mombasa-Diani coast such as Kikambala, Shanzu, Bamburi and Diani just to mention a few. Groynes have been used only at Shanzu to protect the coast and the main aim, in this case is to enable accumulation of sand on the shore (Plate 42). The groynes have been formed by piling 3 rows of rocks to 1 m height, length about 15 m separated by a distance of 30 and 40 m respectively. At Kikambala, used tyres and coconut poles have been used for shoreline protection. Each used tyre costs Kenya shillings 50 (Plate 43). Mr. Moses Mutepe (in picture) also uses casuarina poles which are very resistant to decay within a marine environment and can last for at least 20 yrs. This method of coastal protection is cheap and rather successful. There is

Plate 40 shows a seawall (s) at Kikambala. Wall is held in position by mangrove poles (p). This wall has however now fallen (September, 1990; Photo by P. Abuodha).

Plate 41 shows coastal protection using limestone boulders (b) along Bamburi (June, 1991; Photo by S. Langat).

Plate 42 shows coastal protection using groynes (g) along Shanzu (September, 1990; Photo by P. Abuodha).

Plate 43 shows coastal protection using coconut poles (p) and used tyres (t) at Kikambala (September, 1990; Photo by P. Abuodha).

Plate 44 shows poles (p), limestone boulders (b) and wiremesh (w) at Kikambala being used for coastal protection (June, 1991; Photo by S. Langat).

Plate 45 shows gravels (g) along Shanzu as an attempt to nourish the beach (September, 1990; Photo by J. Abuodha).

no scour infront of the tyres as the wave-front can easily penetrate between the tyres to the backshore area.

Still further south, along the same beach, limestone boulders placed against coconut poles are held in place by a wire mesh and are being used for coastal protection (Plate 44). The coconut poles have been cemented onto the beach which is already undergoing scour beneath. Erosion on the adjacent areas has resulted into shore moving landward by approximately 10 m. At Kanamai, boulders measuring 30-100 cm in diameter has been piled up along the shoreline and also infront of buildings (Plate 29) as a means of coastal protection. At Mtwapa, gabions have been put on the fence to stop the creek from eroding residential areas during flood tide, while along Bamburi, limestone boulders (Plate 41) measuring 1-2 m in diameter have been placed against an old seawall. In some areas along this beach, boulders have been cemented infront of seawall in an attempt to protect the coast. The tilt, and surface of wall makes, it slightly more stable and therefore effective. Further south along this beach, protection using sandstone boulders, wiremesh and coconut poles has failed displacing certain stairs used for access to the beach. Along Likoni, boulders have been placed at the base of cliff to mitigate further cliff erosion.

6.4.2. Present practice in other countries

In the United States, the Netherlands, Germany and Australia beaches lost through erosion have been replenished artificially by dumping similar sand taken from coastal dunes or inland quarries onto the foreshore to restore the earlier cyclic equilibrium. At Voordelta in Netherlands, where erosion was occurring at the heads of the islands due to strong tidal currents in connecting channels, beach nourishment are used to combat beach erosion (The Dutch Coast, 1991)

6.5. Recommended restoration measures

6.5.1. Beach nourishment

To restore an eroding coastal area, artificial supply of sand (beach nourishment) and stabilization of the dunes and backshore areas by planting vegetation is practiced in some parts of the study area such as Shanzu and Nyali. Along Shanzu, beach nourishment (Plate 45) is used in combination with groynes. At Shanzu, a certain volume of sand is introduced to the beach system to serve as sediment source for littoral drift (and consequently benefit the downdrift beaches).

An important parameter for the success of a beach nourishment plan is the understanding of the hydrodynamics of the beach and the similarity of particle size distribution of the applied sand and that of the original (natural) sand. Generally, the material used for beach nourishment must have the same or a coarser particle size distribution than the material that is naturally present. The problem at Shanzu is that the material on the beach has been excavated from the backshore area resulting in an artificial cliff of 3 m in height. Along Nyali, beach replenishment (Plate 46) is done using boulders and cobbles. The boulders are supposed to be reworked by waves and therefore form more material on the beach. Beach nourishment is costly as it is often repeated regularly.

6.5.2. Planting of sea grass

Artificial planting of grass is practiced on the dunes and backshore areas on the southern part of Kikambala beach, Bamburi and Nyali. The vegetation acts as a binding factor to the sands and minimizes their erosion. At Bamburi, there is a vegetated (transplanted grass) berm with a setback line of 30 m. In some areas along Bamburi beach, erosion has proceeded 10 m inland in 20 yrs giving erosion at a rate of 2 m/yr. Undercutting of vegetated berm has

Plate 46 shows gravels (g) placed along Nyali as a beach nourishment scheme (September, 1990; Photo by P. Abuodha).

Plate 47 shows a thick vertical seawall (s) at Shanzu. A new seawall is inland of the failed seawall(s)(June, 1991; Photo by S. Langat).

formed a beach scarp of about 30 cm at Nyali (Plate 32).

6.6 Problems due to coastal protection

6.6.1. Inappropriate measures of coastal protection

At Kikambala, failure of seawall against wave erosion is already evident (Plate 40). The wall is currently slanted and held in position by mangrove poles but part of it has already crumbled. Trees infront of the seawall have been uprooted and others have their roots exposed. In 1971, a now completely eroded seawall was 4 m seaward of the present seawall as indicated by the abandoned poles on the beach. The base of the seawall was scoured by waves to a depth of 50 cm and the coconut tree roots exposed by 2 m. Seawalls are put up annually along Kikambala beach and wall repairs are done as often as need be, such as during every monsoon season. As for now, 1992, this seawall is no longer in existence and has been washed away by waves and another seawall put up instead.

At Kanamai, the failure of a seawall which occurred finally in 1982 resulted in extensive erosion in the backshore area (Plate 5) forming a 1.5 m beach scarp. The distance from the failed seawall to the beach scarp is 10 m giving an annual retreat rate of about 1.3 m. A coconut tree was observed slanted dangerously as a result of this erosion. Since the failure of this seawall, no other wall has been put up and other methods of coastal protection are being practised (Plate 29). At Shanzu a new seawall has been built behind a failed one (Plate 47). The strength of the ocean waves can be understood from the thickness of the failed wall. In other places along this beach signs of pillars for former seawalls still remain.

Along Bamburi beach, seawalls are undergoing scour at the base which has resulted in failure of some of the walls (Plate 48). The particular beach hotel (Severin, Appendix I) spends a lot of money annually (Ksh 1 million) in an attempt to protect their property. When the author visited the beach 9 months latter, it was surprising to note that even the new seawall had fallen and presently the beach owners have resorted to another method of coastal protection (Plate 41). A seawall along Nyali beach (Plate 49) is threatened by wave action which has undercut, and subsequently cracks have developed on, the wall. More intense cliff erosion has occurred adjacent to this seawall. The crack is a precursor to the seawall failure. At Likoni, remnants of former seawall have been left 22 m seaward of the

Plate 48 shows a thick seawall (s) at Bamburi. Note another seawall (sl) behind the failed wall (s) (September, 1990; Photo by P. Abuodha).

Plate 49 shows seawall along Nyali beach. Note crack (c) on the wall and the result of sediment scour (ss) beneath the wall (September, 1990; Photo by P. Abuodha).

present seawall (Plate 50). A seawall is currently being constructed at Likoni (Plate 51).

Erosion is further accelerated at Diani by the many seawalls currently in use (Plate 52). In this plate, a tree which fell in 1987 is left 55 m from the present shoreline indicating a retreat rate of 11 m/yr within this span of time. At the beginning of Diani beach, cliffs have been eroded by about 30 m inland. Apart from failure of seawalls, which are the most common in the investigated area, other forms of protection also show deterioration. For example, at Kikambala, an embarkment filled with sand and concrete cemented on top already shows signs of deterioration (Plate 53). The embarkment was constructed in 1987 in the way shown in plate 31. The groynes placed at Shanzu have also started showing signs of failure as the piles of rocks are falling.

Plate 50 shows remnants of a former seawall left 22 m seawards of the present wall at Likoni (June, 1991; Photo by S. Langat).

Plate 51 shows a recent seawall and a wall-in-the-making at Likoni. Note increased erosion at the end of the wall (June, 1991; Photo by S. Langat).

Plate 52 shows a low seawall (s) at Diani and a fallen tree (t) left seawards of this wall (June, 1991; Photo by S. Langat).

Plate 53 shows an embarkment (e) at Kikambala. Note level (l) of splash water mark on the left of the plate on a gate frame (September, 1990; Photo by P. Abuodha).

CHAPTER 7 SUMMARY AND RECOMMENDATIONS

7.1. Sedimentology

On the basis of this study, the clastic material are derived from the drainage basin of the rivers which run into the Mtwapa, Tudor and Port Reitz Creeks, the Mwachema estuary and Gazi bay. The carbonate content of beach sediments suggests that the main sources of this material are eroded from the adjacent coastal cliffs, rocky shores, shore platforms and the coral reef. A small part is also derived from the adjacent continental shelf and carried onto the beach by waves. The net littoral drift of the sediments is northwards.

Beaches undergoing serious erosion are Kikambala, Kanamai, Shanzu, Iwetine, Bamburi, Black Cliff Point, Galu and Kinondo. Stable beaches are found at Nyali and Likoni, while depositional beaches occur at Leven, Mackenzie Point, Mwachema and Gazi. Mtwapa, Kenyatta beach, Likoni and Diani could be stable beaches given no induced erosion. Shoreline areas undergoing erosion may be developed but with proper care taken by creating a buffer zone. Stable areas need careful development plans so as not to initiate erosion. Depositional areas are best for development if consideration is taken not to create disequilibrium on the beaches which would induce erosion.

7.2. Geomorphology

On the basis of field observations, the area consists of different geomorphic features on three topographical regions which are the low lying areas, transitional areas and raised areas (section 6.3). Beaches occur within transitional areas and any constructions placed adjacent to them should be with appropriate set back line (about 1 km from the shoreline). Constructions are however encouraged on raised areas such as the coastal cliffs, stable coastal dunes and beach ridges. Structures constructed near the shoreline should be considered by law to be temporary thus beach hotels, cottages, bungalows, villas should not be protected in any artificial way and should be left to fall when their time comes. This would make the beaches nourished and healthy in all the ecosystems. Care should be taken not to over develop these areas.

7.3. Coastal zone management problems

7.3.1. Erosion

Coastal erosion was identified as one of the major problems within the study area. There are 3 basic options in response to this erosion problem;

1. no action,
2. relocation of endangered structures and
3. positive corrective measures.

No action should be taken particularly if no houses are threatened and only undeveloped land or inexpensive structures are in danger. No action should be taken at Kanamai (plate 5) where the seawall has fallen and the structure built beyond the high tide mark (Plate 29) should be left to fall when its time comes. The same applies to Kenyatta beach (Plate 9) where a seawall put to protect a property has been undercut by waves. On a cliff at Nyali (Plate 24) a structure built on top of a collapsing cliff should be left to fall as its time has come. The house at Leven with already a crack at its corner (Plate 33) should also be left to fall as its time has come.

Seawalls now coming up at Likoni (Plate 51) will enhance erosion on the beach rather than stop erosion. No action should be taken at Black Cliff Point (Plate 10) to curb the erosion as there is no erosion problem here and the erosion taking place is normal for natural beach equilibrium. At Tiwi (Plate 36), very few constructions have been put up along the beach and a house like this in plate 36 should be left to fall as it was built with no regard to changes in sea level. Diani area is advantaged in that it has wide beaches (Plate 37) and a raised shore platform (Plate 23) acting as a natural breakwater. Therefore the seawalls in some parts of this beach (Plate 52) should be pulled down in order not to induce erosion. Gazi which is a sheltered bay from the direct influence of the open sea would not have erosion problems if the mangrove swamps were left uncleared. It is important to know that erosion can occur along undeveloped coasts such as noted around Black Cliff Point but there is no erosion problem until people layout property lines and build. In other words erosion becomes a problem when economic losses are emminent. Relocation of endangered structures should be done at Kikambala (Plate 40). It may be less expensive to relocate the beach hotel (Sun n' Sand, Appendix I) than to invest in shore protection which costs approximately 1 million yearly. The required set back must be carefully evaluated, in order to avoid further relocation of the same structure in the near future.

Positive corrective measures should only be taken for a highly developed beach such as Bamburi. Instead of seawalls which directly armour the shore, breakwaters which intercept and dissipate wave energy should be used in this area. The breakwater should be constructed on a regional basis all the way from the southern tip of Mtwapa Creek entrance to northern tip of Tudor Creek (Fig. 28). This corrective measure would thus include Shanzu, Bamburi, Kenyatta and Nyali beaches. Any engineering scheme for beach protection should only be accepted as a last resort and then, only for highly developed areas as Kilindini harbour. This is because once beach protection is started it cannot be stopped (Plates 47, 48, 50 and 51) and the cost-benefit ratio of saving beach property through shoreline engineering is usually greater than the value of the property to be saved. Moreover, shoreline engineering protects the interests of very few people, as such, decisions affecting coastal development should be based on the welfare of the public rather than the minority or shorefront property owners.

Whichever option(s) is chosen between the three, the present and future sea level rises should be taken into account. The most significant consequences that will result from such a transgressive evolution of the coast include increased erosion and modification of the coastal morphology with retreat of the shoreline, flooding of coastal zone, undermining the effectiveness of coastal defence structures, with higher property damage risks, and rise in the level of groundwater tables and saline intrusion, especially in estuaries. Thus it is necessary to take into account, this future sea level rise factor in any study of the protection, development and planning of coastal zones. For the immediate future, all but the people living in low lying areas seem to have little to fear from sea level rise. As for the future, no more new settlements should be established too close to the shoreline. All permanent structures should be laid beyond the 50 m contour or at least 1 km from the shoreline within Mombasa-Diani area.

7.3.2. Over development

Over development was also identified as a problem within the study area. This is more so in Bamburi, Shanzu, Nyali and Diani. Bamburi is the most affected beach because it is the most over developed. Its beach hotels have been constructed very close to the sea to an extent that the backshore floods during flood tides.

7.3.3. Stabilizing structures

Stabilizing structures built along some parts of the beaches were also identified as one of the coastal zone management problems, more so because some beach hotels have seawalls and then neighbouring private homes do not have or have different types of protection (Plates 41, 42, 43, 44, 45, 46 and 53).

This non uniformity enhances erosion in some parts of the beaches.

To protect an eroding coastal region within the Mombasa-Diani area, the following corrective measures, subdivided according to their operating principles, have been used;

1. Structures to prevent waves from reaching erodible materials such as seawalls and revetments which are constructed parallel to the shoreline. For example at Kikambala, Kanamai, Shanzu, Bamburi and Diani just to mention a few.
2. Structures to slow down the rate of littoral transport such as groynes (trapping the sediment). These structures are built perpendicular to the shoreline as at Shanzu.

Building such structures causes very drastic changes on the beach, harming the environment in the following ways (Kaufman et al, 1979);

1. They deflect wave energy, ultimately moving the beach and steepening the offshore profile.
2. They increase the intensity of longshore currents, hastening removal of the beach (Plate 9).
3. They prevent the exchange of sand between dunes and beach (Plates 40 and 48) and
4. they concentrate wave and current energy at the

ends of the wall, increasing erosion at these points (Plates 5 and 51).

In conclusion, coastal protection plans in the study area more often than not disturb the beach drift system and thus affects the sedimentary balance of the coast as is the case at Kenyatta beach (Plate 9) and Kanamai (Plate 5).

Artificial beach nourishment schemes are generally executed with the aim of protecting the coastline against the beach erosion (Plate 46) and/or to enlarge the beach for recreational purposes (Plate 45) as is shown at Shanzu and Nyali. Beach nourishment needs comparatively lower capital than stabilizing structures and maintenance costs, at the same time preserving the aesthetic and recreational values of beaches. If a beach must be repaired then this is probably the most desirable approach as it has the highest order of environmental safety in that it adds material to the beach and does not enhance erosion in the immediate neighbourhood. It also allows free exchange of sand between dunes and beach as such beach equilibrium is easily attained. The method however, must be repeated periodically and is costly.

7.3.4. Lack of coastal management system

Coastal Zone Management (CZM) is necessary for sustainable development and utilization of the coastal resources. Lack of coastal management system was found to be the major coastal problem within the study area. Public awareness can easily eradicate problems such as sweeping of the beaches, games on the beaches and mining of materials from the shore platform which are common practices in the study area. This awareness must be based on the best worldwide scientific and technical information and integrated into locally gathered and constructed models of natural and socio-economic processes. There is an urgent need to have legislative capability to safeguard the optimal use of coastal zone resources. There is also need to have a long term program on the environmental impact assessment of the coastal zone. This would protect the marine environment and its resources.

It is the responsibility of the scientific community to warn the society, if it believes that actions in the society may result in major changes in the beach equilibrium. To be effective, action must be taken locally, but keeping in mind how such an action would eventually affect the region. However, the best action may very well be not to select a static best policy, but to think in terms of strategies and sets of options leading to a continuous policy process where it is possible to reasses the political responses considering new information and new findings. In such a scheme, research and information gathering become an integral part of the policy development.

While the scientific community should be willing to accept its responsibilities, it is the politicians and the law-makers who should take action, and they should take the responsibility for introducing the necessary modifications in the behaviour of society to counteract the undesirable effects. The plans and actions must be based on local conditions and should include considerations such as local way of life, social structure, cultural heritage, financial resources, and political institutions. Advisers should have all these things in mind as they proceed to advise the coastal community, who do not necessarily understand the technical details regarding coastal protection.

In conclusion, professionals, the public, policy-makers and beachfront owners must synchronize their effort for these decisions to be realized. The only unfortunate thing is that the policy-makers are usually the beach-front owners and thus they might resist change for along time to come.

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Appendix I: Sediment sampling stations, beach profiling and field observations points.

Station Code	Shore area	Position	Unit
KIK/1	Kikambala	Sun n'Sand	beach
KIK/2	Kikambala	Continental	beach
KIK/3	Kikambala	Whispering Palms	beach
KAN/4	Kanamai	Kanamai Centre	beach
KAN/5	Kanamai	Kanamai Centre	beach
MTW/6	Mtwapa	Mtwapa	active cliffs
MTW/7	Mtwapa	James point	active cliffs
SHA/8	Shanzu	Cannon Point	active cliffs
SHA/9-1	Shanzu	Flamingo	isolated beach
SHA/9-2	Shanzu	Flamingo	isolated beach
SHA-10	Shanzu	Serena	active cliffs
BAM/11	Bamburi	Sea Haven	beach
BAM/12	Bamburi	Bamburi Chatlier	beach
BAM/13	Bamburi	Severin	beach
BAM/14	Bamburi	Whitesands	beach
BAM/15	Bamburi	Ocean view	beach
KEN/16	Kenyatta	Kenyatta beach	beach
IWE/17	Iwetine	Iwetine	active cliffs
IWE/18	Iwetine	Iwetine	active cliffs
NYA/19-1	Nyali	Reef Hotel	dune
NYA/19-2	Nyali	Reef Hotel	berm
NYA/19-3	Nyali	Reef Hotel	beach
NYA/20	Nyali	Mombasa Beach	beach
NYA/21	Nyali	Silver Beach	beach
NYA/22	Nyali	Leave camp	beach
NYA/23	Nyali	Nyali Hotel	beach
NYA/24	Nyali	Mkuungombe	active cliffs
LEV/25	Leven	Leven Beach	isolated beach
MAC/26	Mackenzie Pt.	Mackenzie Pt.	isolated beach
LIK/27	Likoni	Mombasa Island	fossil cliffs
LIK/28	Likoni	Kisingo	active cliffs
LIK/29	Likoni	Shelly	isolated beach
LIK/30	Likoni	Shelly Hotel	isolated beach
LIK/31	Likoni	Similani	isolated beach
LIK/32	Likoni	Similani	isolated beach
BLA/33	Black Cliff Pt.	Pungu Fuel	active cliffs
BLA/34	Black Cliff Pt.	Magombani	active cliffs
BLA/35	Black Cliff Pt.	Magaoni	active cliffs
BLA/36	Black Cliff Pt.	Denyenye	active cliffs
BLA/37	Black Cliff Pt.	Mfakuja	active cliffs

BLA/38	Black Cliff Pt.	Black Cliff Pt.	active cliffs
TIW/39	Tiwi	Tiwi Mosque	beach
TIW/40	Tiwi	Moonlight Bay	beach
TIW/41	Tiwi	Maweni Cottages	beach
TIW/42	Tiwi	Capricho	beach
TIW/43	Tiwi	Kibwaga	beach
MWA/44	Mwachema	Mwachema	river bank
MWA/45	Mwachema	Mwachema	river mouth
MWA/46	Mwachema	Mwachema	river bank
DIA/47	Diani	Mwakamba	beach
DIA/48	Diani	Golden Beach	beach
DIA/49	Diani	Leisure Lodge	beach
DIA/50	Diani	Ali barbour	beach
DIA/51	Diani	Diani Lodge	beach
DIA/52	Diani	Trade Winds	beach
DIA/53	Diani	Sea Lodge	beach
DIA/54	Diani	Two Fishes	beach
DIA/55	Diani	Safari Beach	beach
GAL/56	Galu	Baobab	beach
GAL/57	Galu	Diani Beachlets	beach
GAL/58	Galu	Neptune Cottages	beach
GAL/59	Galu	Chale Sea Villa	beach
KIN/60	Kinondo	Kinondo	beach
GAZ/61	Gazi	Gazi Village	sand flat
GAZ/62	Gazi	Southern Gazi	sand flat
GAZ/63	Gazi	Northern Gazi	sand flat

Appendix II shows output of a grain size analysis computer package written by Dr. Mario Fay, University of Dar-es-Salaam, version of 10.07.89.

Data of sample no. Nyali (NYA/20)

Class	Class-mid	Up. limit	Class freq.	Cumul. f.(%)
1	1.37500	1.50000	.50000	.50000
2	1.62500	1.75000	.60000	1.10000
3	1.87500	2.00000	1.00000	2.10000
4	2.37500	2.75000	15.50000	17.60000
5	2.87500	3.00000	20.40000	38.00000
6	3.25000	3.50000	52.10000	90.10001
7	3.75000	4.00000	9.70000	99.80000
8	4.25000		.20000	100.00000

Sum of class frequencies: 99.99999

MEASURES AFTER FOLK & WARD (1957)

Mean = 3.08 phi Sorting = .44 phi units

Skewness = -.18 Kurtosis = 1.28

SAMPLE DESCRIPTION:

Based on Folk & Ward's graphic measures this sample is described as follows:

This sediment sample is a very fine-grained sand.

Sorting: Well sorted. Skewness: Negative (indistinct coarse tail). Kurtosis: Leptokurtic.

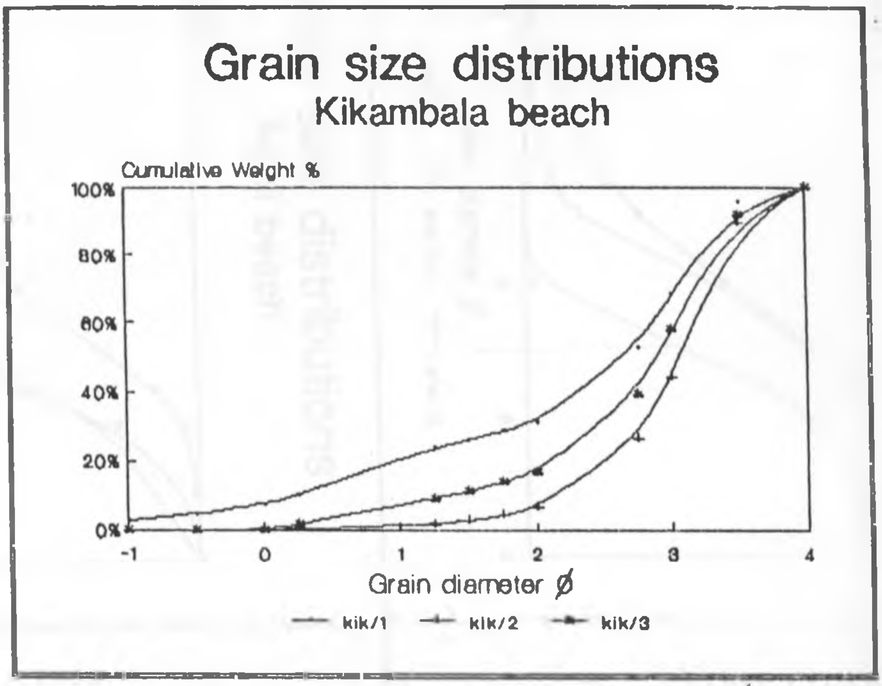
FACIES INTERPRETATION OF SAMPLE:

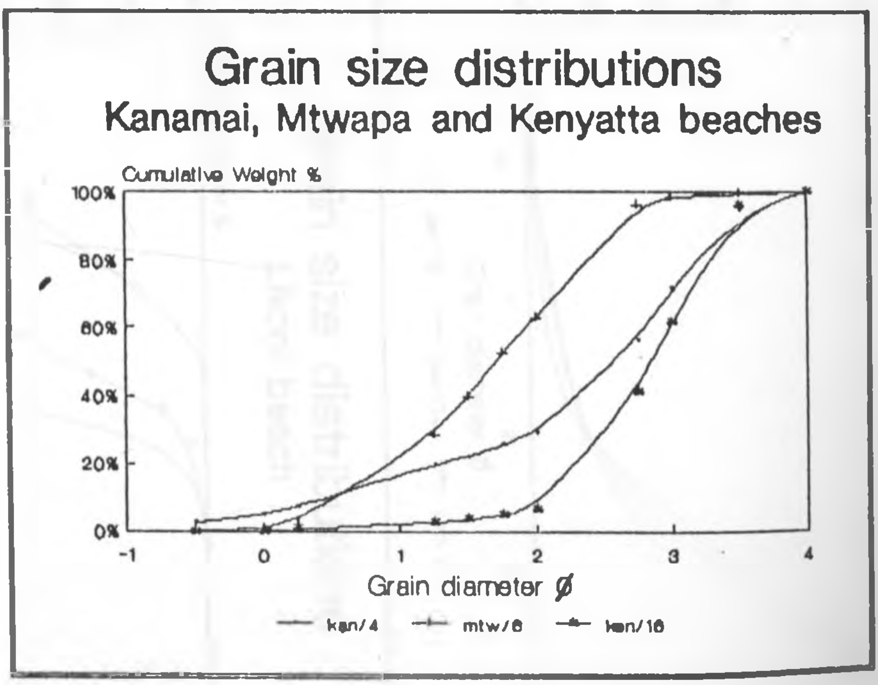
An attempt is made to interprete the depositional environment:

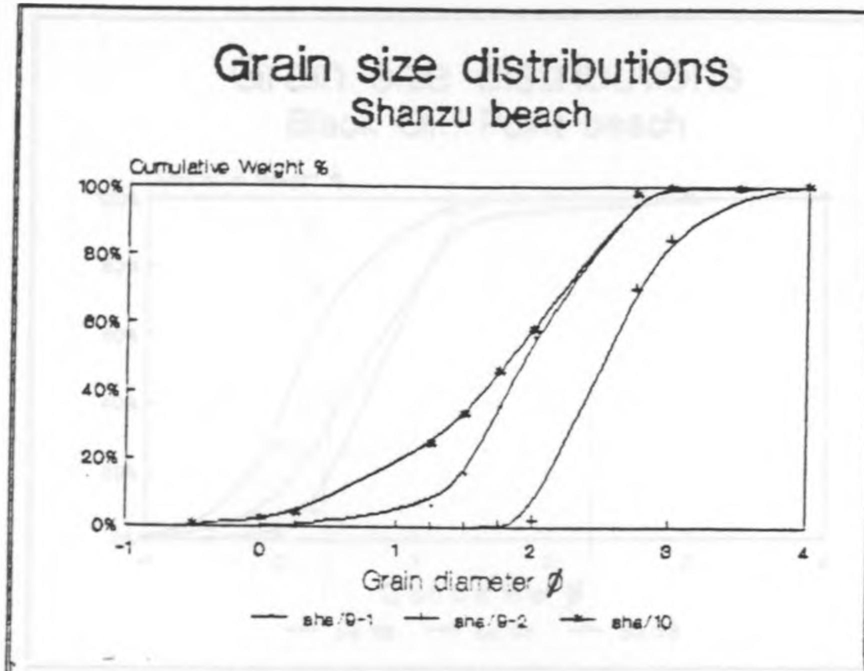
Good sorting, nearly symmetrical distribution or tail on the coarse-grained side are typical of beach sands. Check for additional characteristics: +/- parallel laminae (primarily inclined)/

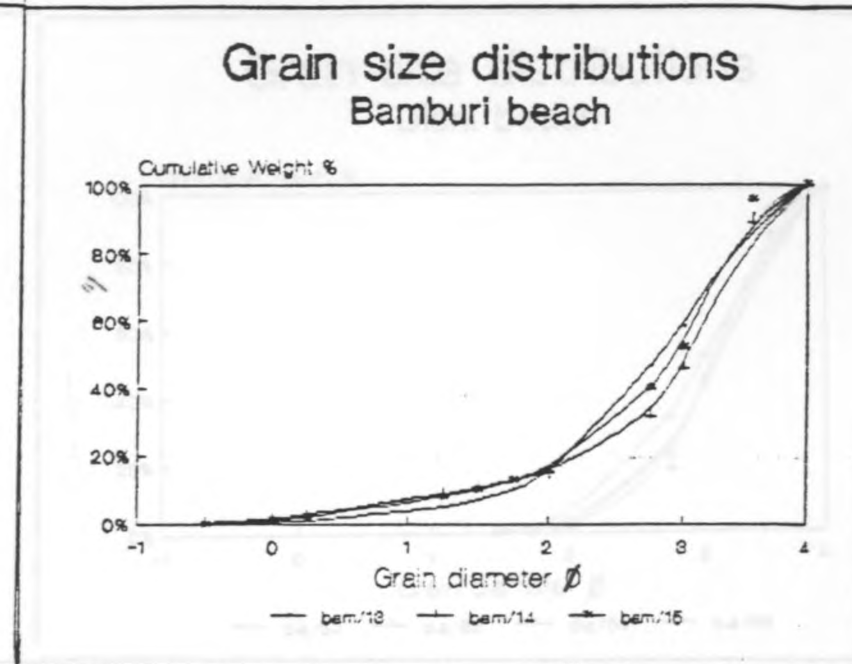
coarsening downward/ heavy mineral concentrations/ in marine beach sands often intensive bioturbation by crabs.

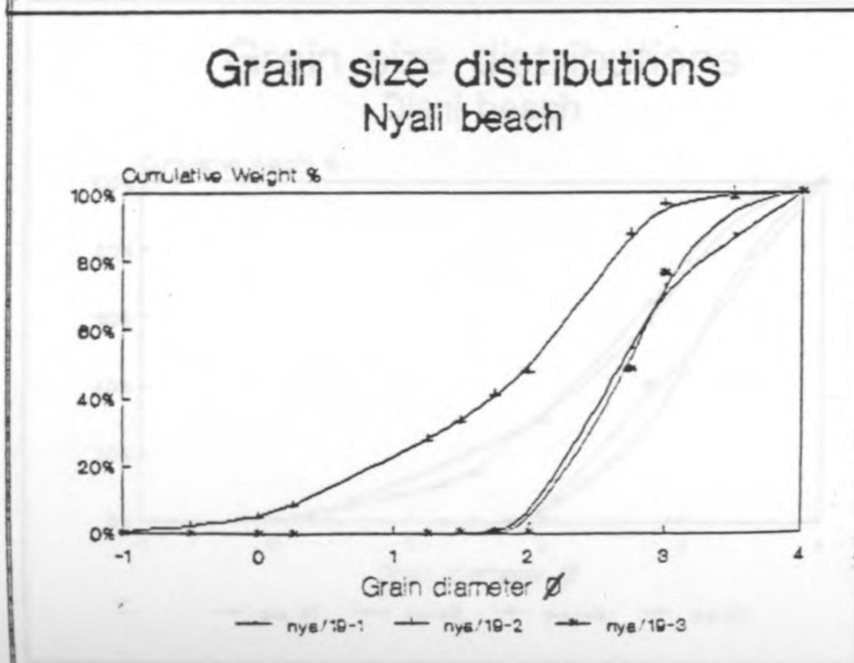
Appendix III: Superimposed cummulative grain-size curves for the Mombasa-Diani area for coarse sands, medium sands, fine sands and very fine sands.

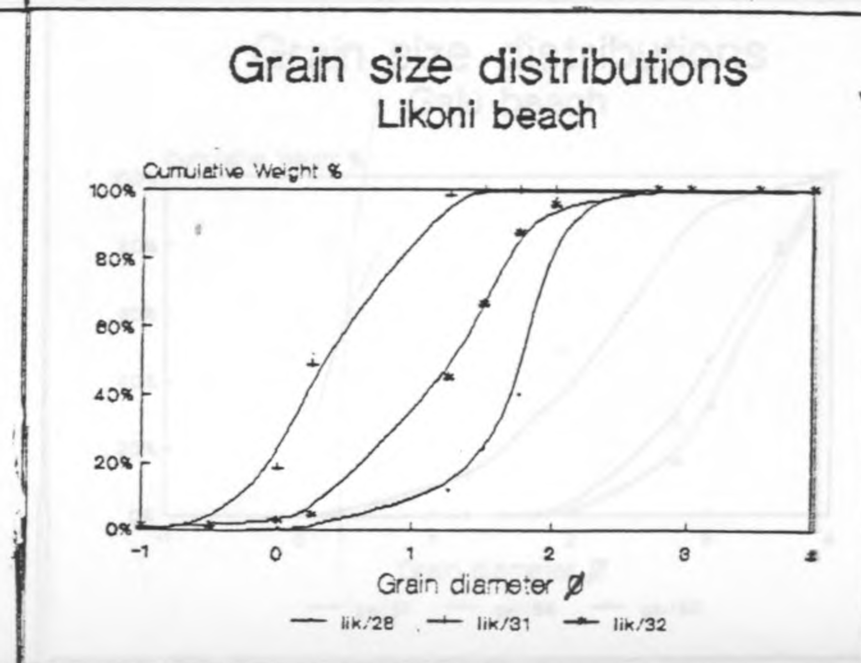


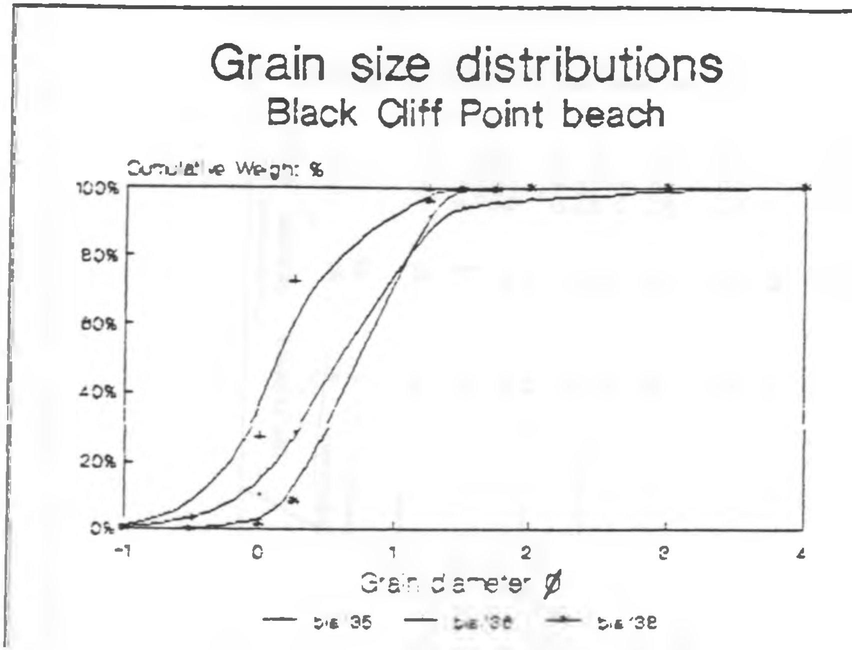


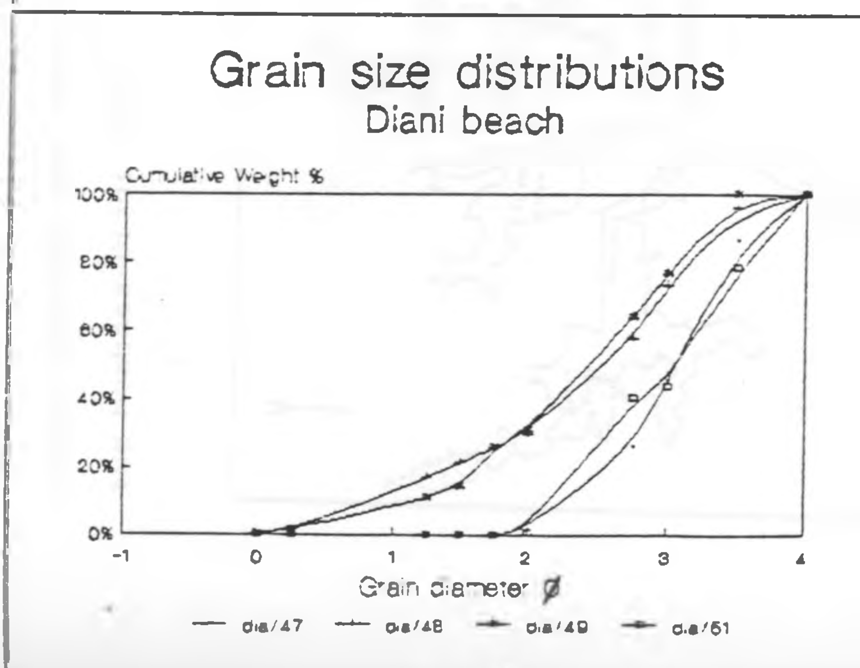

Grain size distributions
Shanzu beach
Cumulative Weight %
100%
80%
60%
40%
20%
0%
-1
0
1
2
3
4
Grain diameter Ø
sha/9-1
sha/9-2
sha/10


Grain size distributions
Bamburi beach
Cumulative Weight %
100%
80%
60%
40%
20%
0%
-1
0
1
2
3
4
Grain diameter Ø
bam/13
bam/14
bam/15

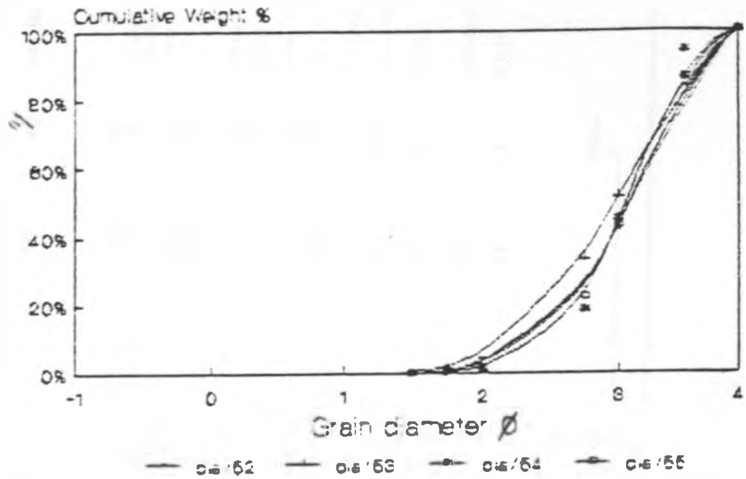

Grain size distributions
Nyali beach
Cumulative Weight %
100%
80%
60%
40%
20%
0%
-1
0
1
2
3
4
Grain diameter Ø
nya/19-1
nya/19-2
nya/19-3


Grain size distributions
Likoni beach
Cumulative Weight %
100%
80%
60%
40%
20%
0%
-1
0
1
2
3
Grain diameter Ø
lik/28
lik/31
lik/32

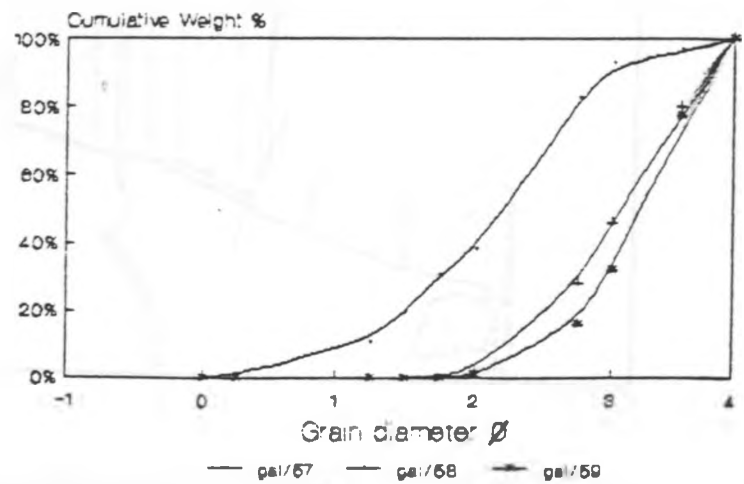

Grain size distributions
Black Cliff Point beach
Cumulative Weight %
100%
80%
60%
40%
20%
0%
-1
0
1
2
3
4
Grain diameter Ø
bla/35
bla/36
bla/38


Grain size distributions
Diani beach
Cumulative Weight %
100%
80%
60%
40%
20%
0%
-1
0
1
2
3
4
Grain diameter Ø
dia/47
dia/48
dia/49
dia/51

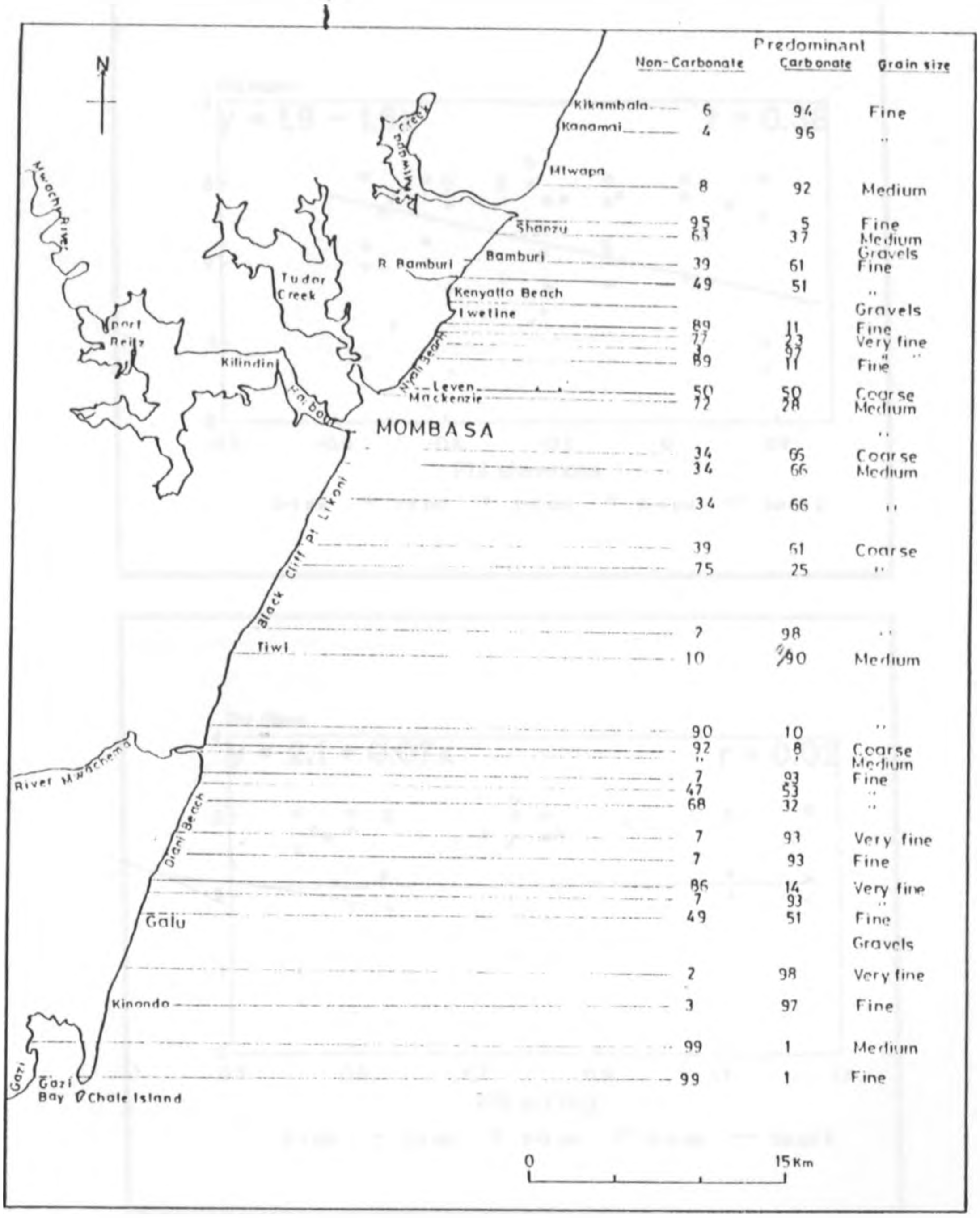
Grain size distributions
Diani beach



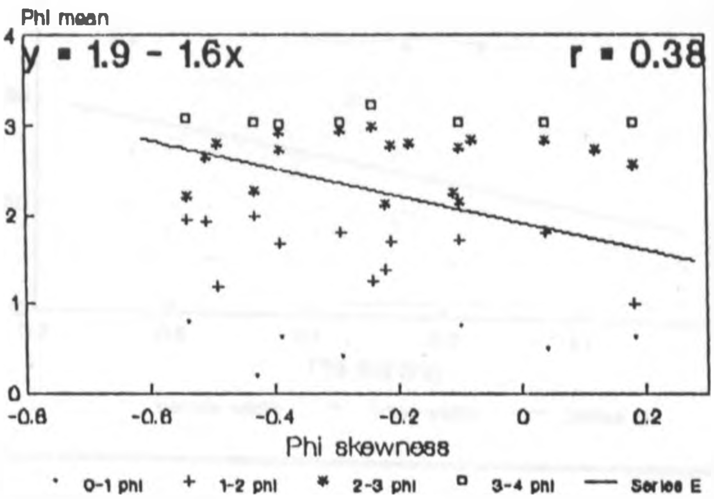
Grain size distributions
Galu beach

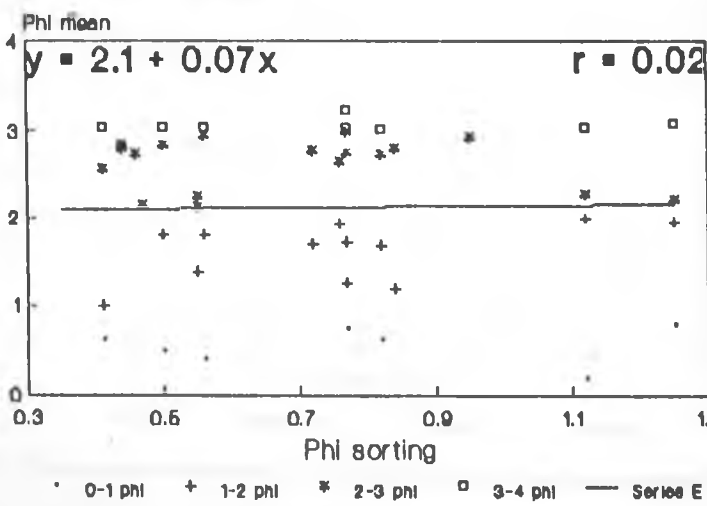


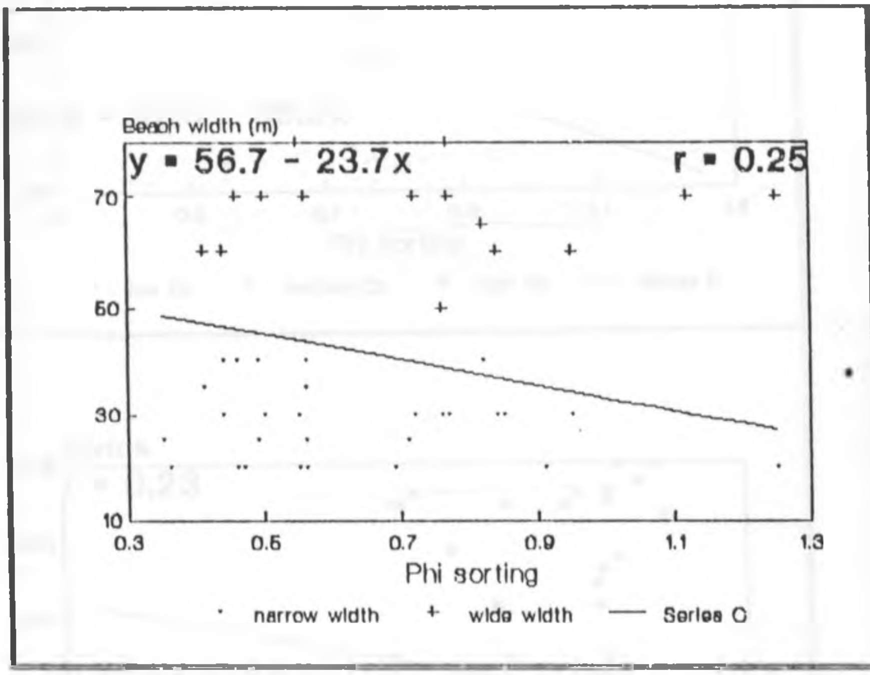
Appendix IV; Predominant nature of sediments in weight percent and grain size for beach sediments of the Mombasa-Diani area.

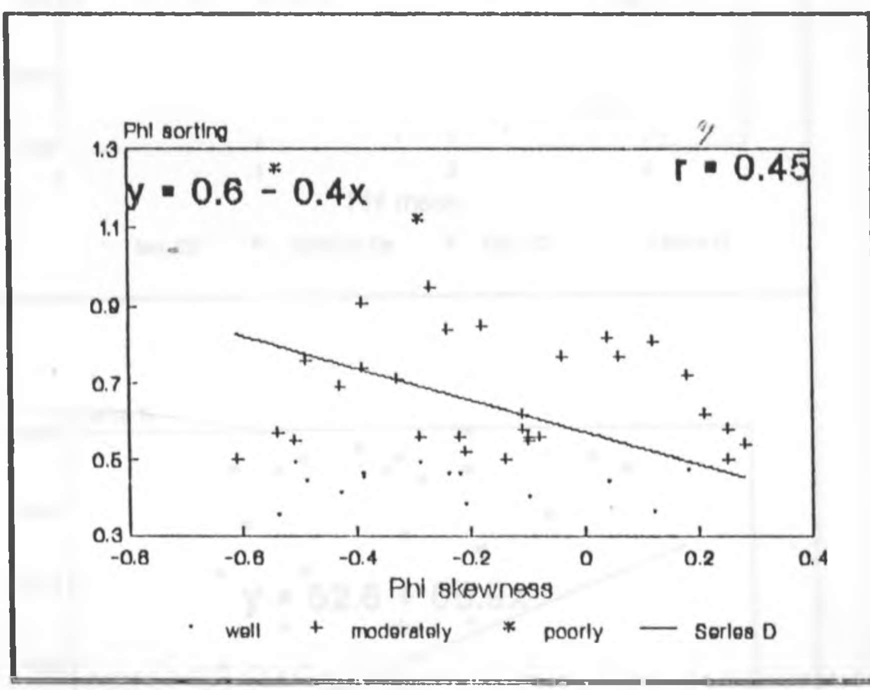


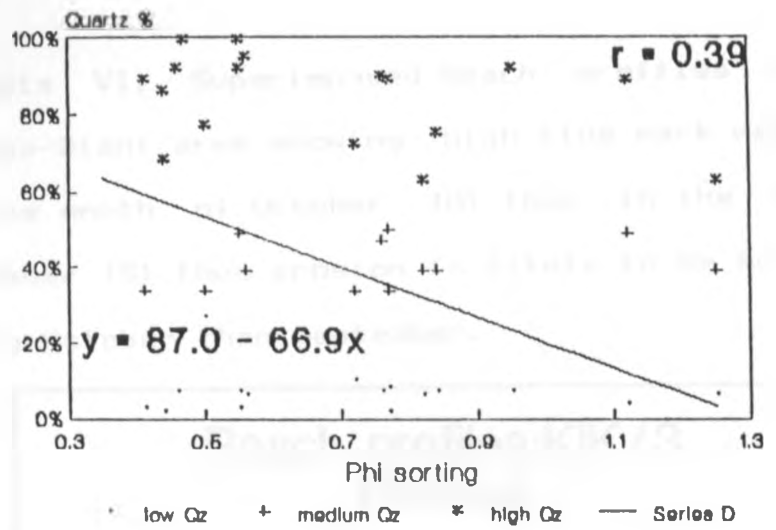
Appendix V; Correlated parameters of beach sands from Mombasa-Diani area showing mostly weak relationship of various variables (with r less than 0.5) and the equation of the best line of fit.

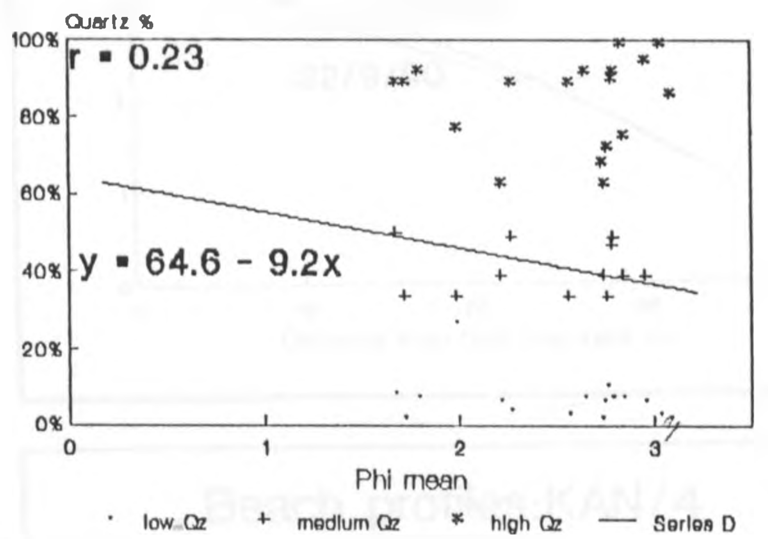


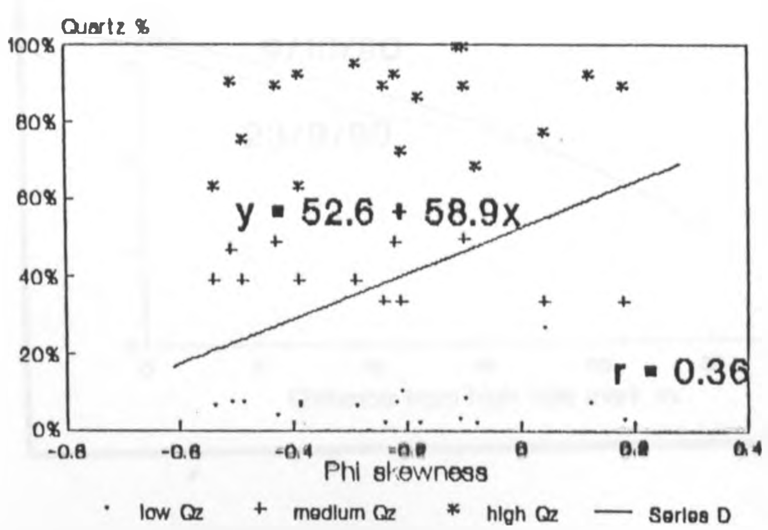



Beach width (m)
y = 56.7 - 23.7x
r = 0.25
70
50
30
10
0.3
0.5
0.7
0.9
1.1
1.3
Phi sorting
narrow width
wide width
Series C

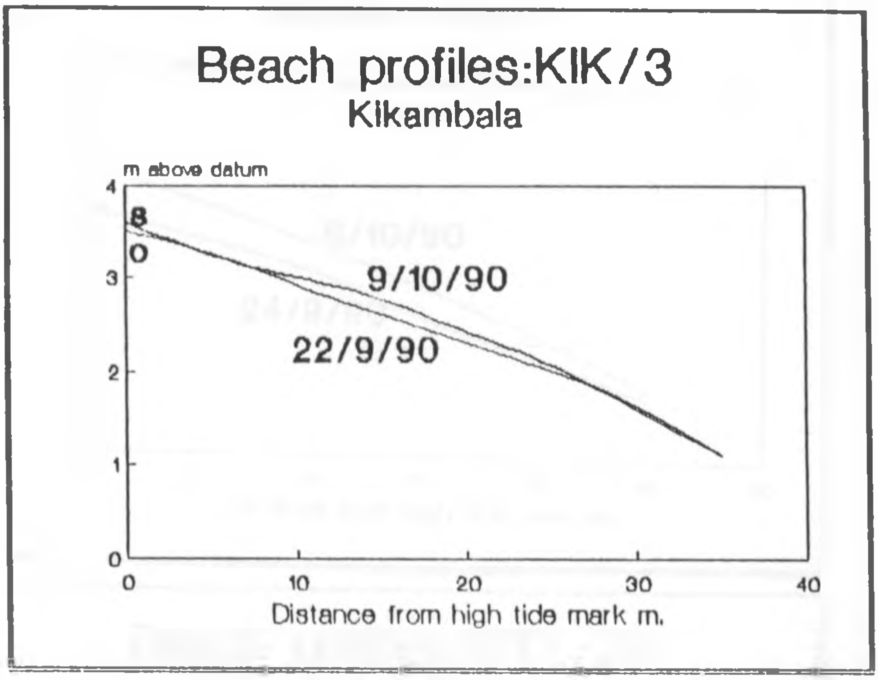

Phi sorting
1.3
y = 0.6 - 0.4x
r = 0.45
1.1
0.9
0.7
0.5
0.3
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
Phi skewness
well
moderately
poorly
Series D

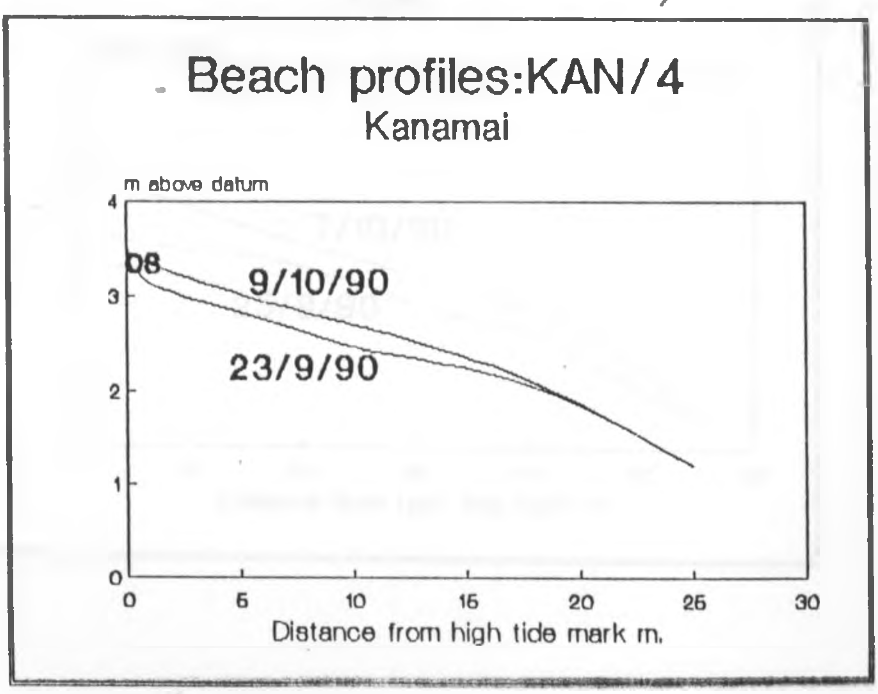

Quartz %
100%
80%
60%
40%
20%
0%
r = 0.39
y = 87.0 - 66.9x
0.3
0.5
0.7
0.9
1.1
1.3
Phi sorting
low Qz
medium Qz
high Qz
Series D

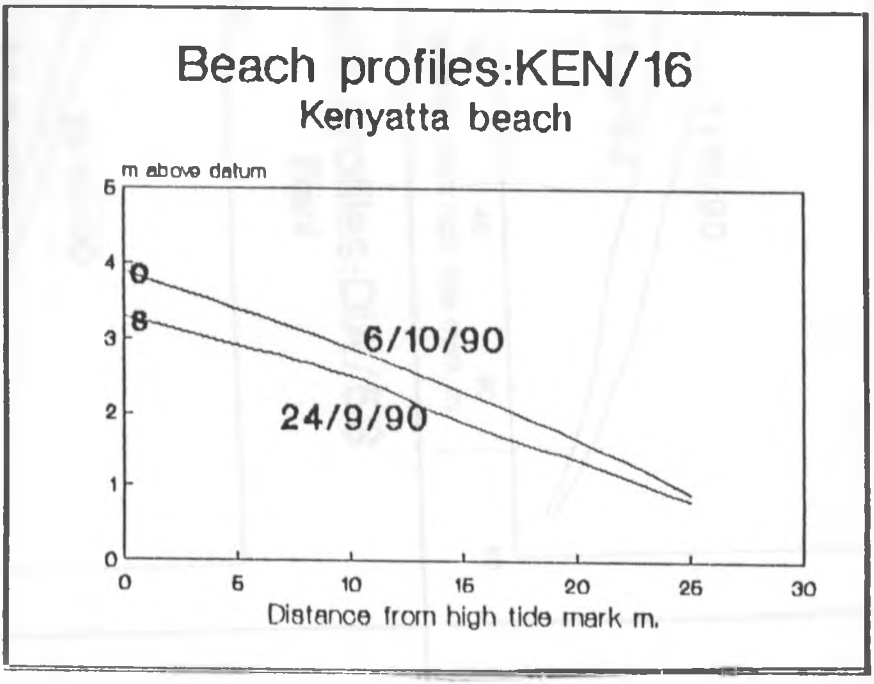

Quartz %
100%
80%
60%
40%
20%
0%
r = 0.23
y = 64.6 - 9.2x
0
1
2
3
Phi mean
low Qz
medium Qz
high Qz
Series D

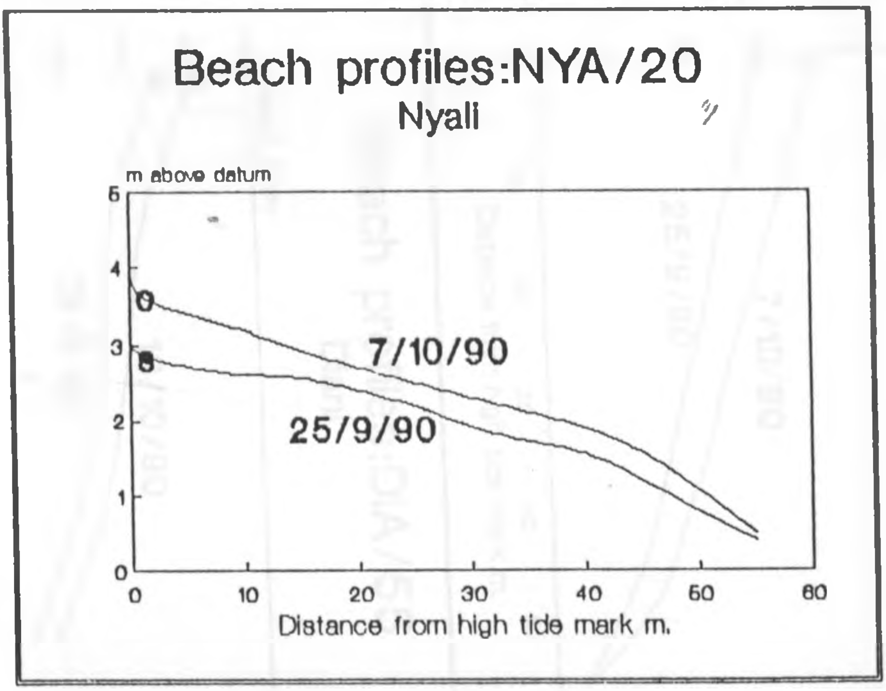

Quartz %
100%
80%
60%
40%
20%
0%
y = 52.6 + 58.9x
r = 0.36
-0.8
-0.6
-0.4
0
0.4
Phi skewness
low Qz
medium Qz
high Qz
Series D

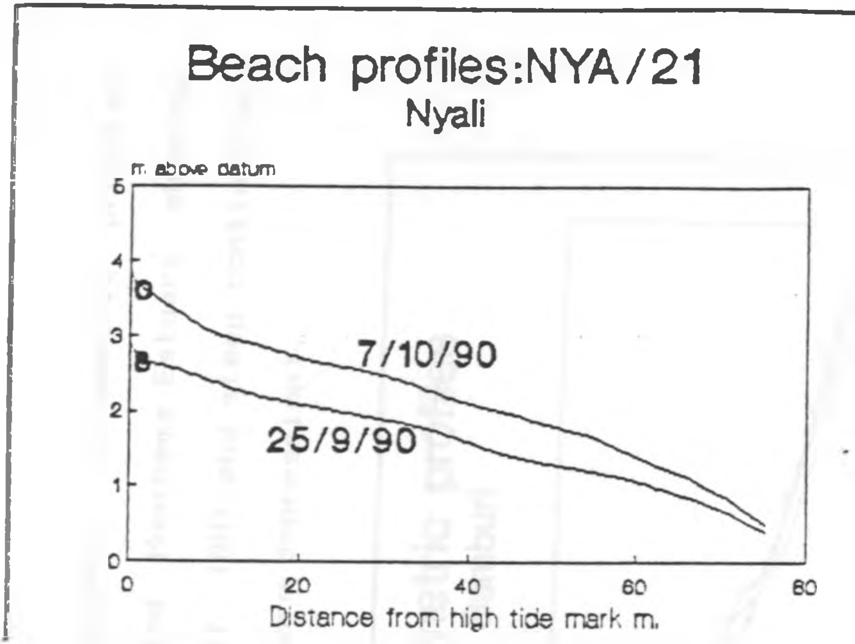
Appendix VI; Superimposed beach profiles for the Mombasa-Diani area showing high tide mark was higher in the month of October (O) than in the month of September (S) thus erosion is likely to be more during October than September.

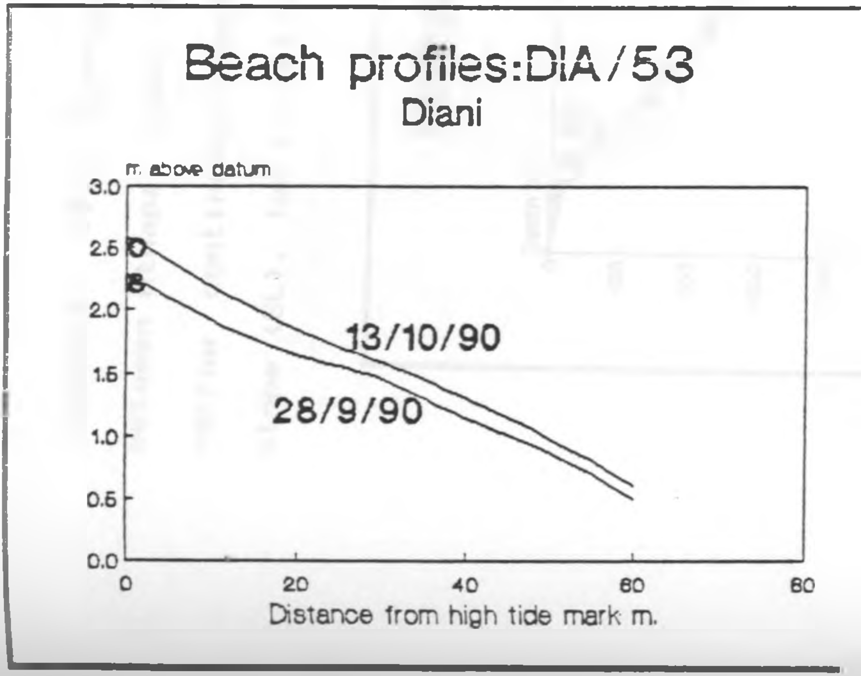


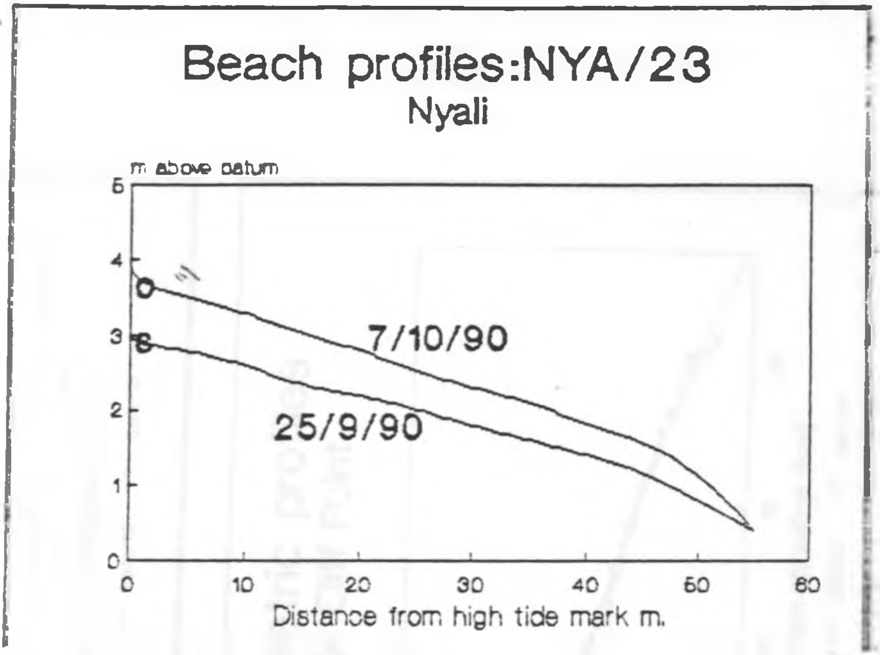


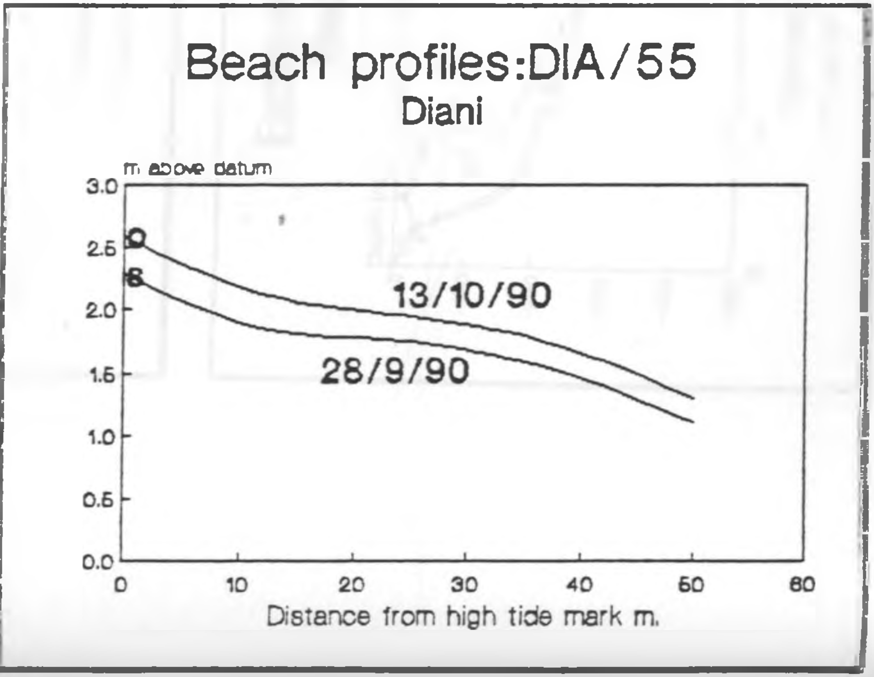

Beach profiles:KEN/16
Kenyatta beach
m above datum
6/10/90
24/9/90
0
5
10
15
20
25
30
1
2
3
4
Distance from high tide mark m.


Beach profiles:NYA/20
Nyali
m above datum
7/10/90
25/9/90
0
10
20
30
40
50
60
1
2
3
4
Distance from high tide mark m.

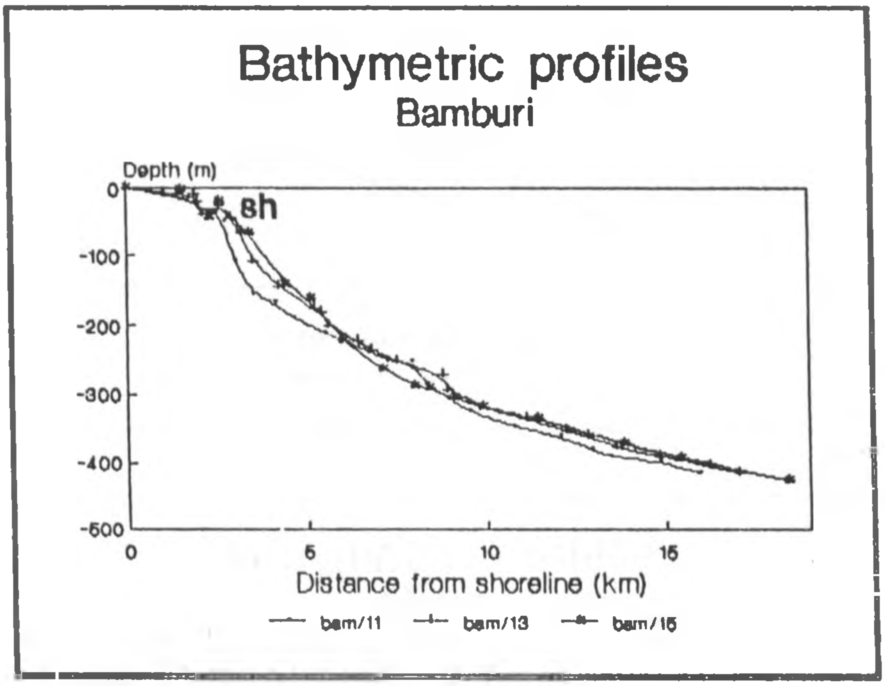

Beach profiles:NYA/21
Nyali
m. above datum
7/10/90
25/9/90
Distance from high tide mark m.

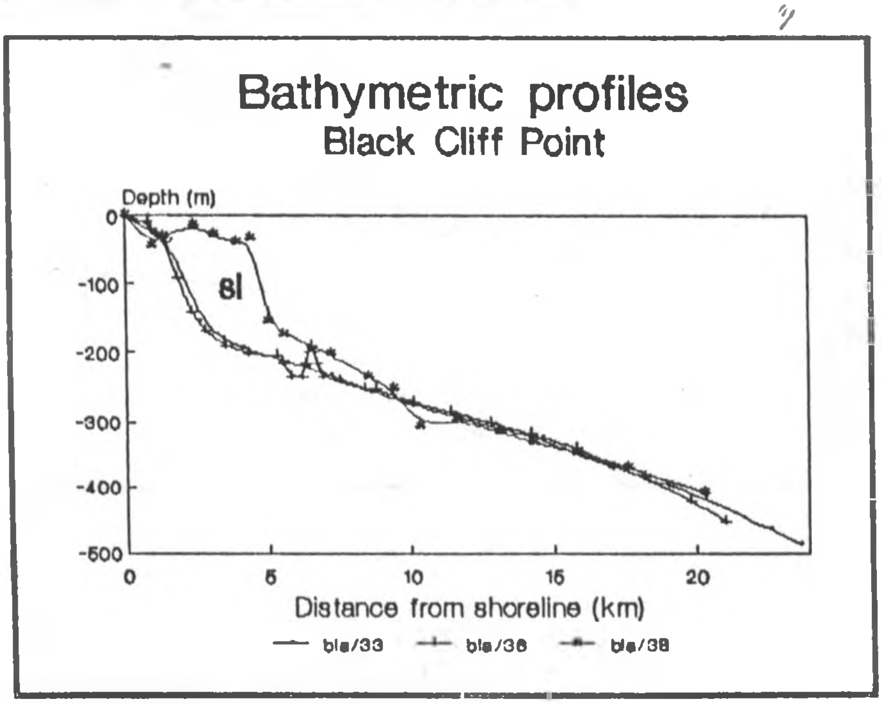

Beach profiles:DIA/53
Diani
m. above datum
13/10/90
28/9/90
Distance from high tide mark m.

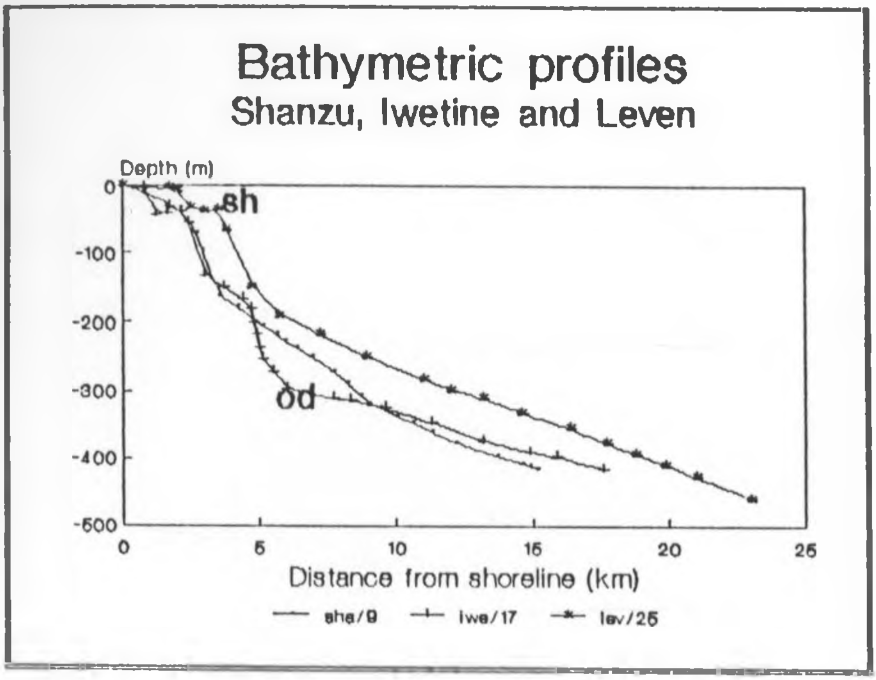

Beach profiles:NYA/23
Nyali
m above datum
5
4
3
2
1
0
7/10/90
25/9/90
0
10
20
30
40
50
60
Distance from high tide mark m.

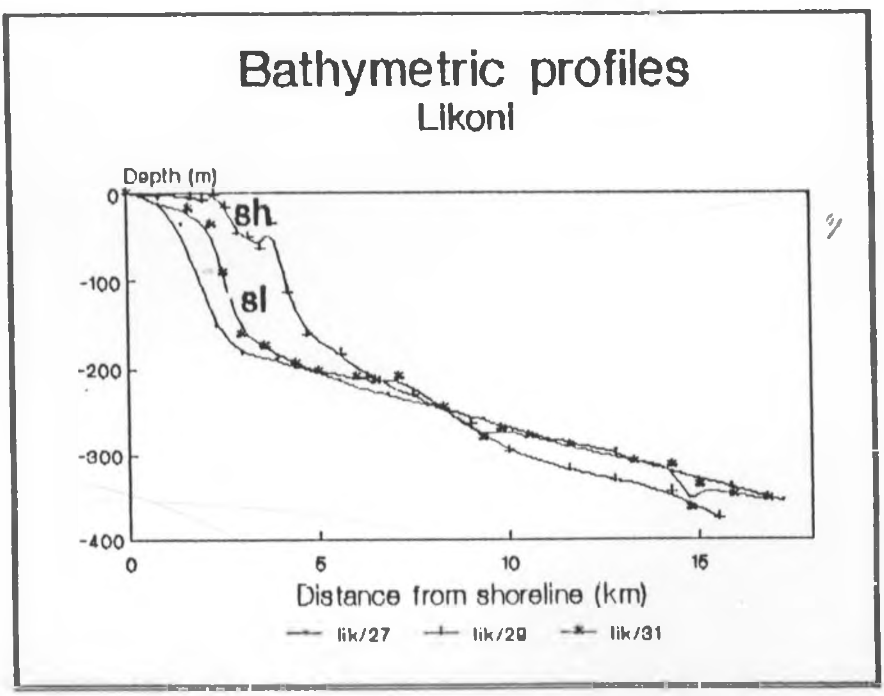

Beach profiles:DIA/55
Diani
m above datum
3.0
2.5
2.0
1.5
1.0
0.5
0.0
13/10/90
28/9/90
0
10
20
30
40
50
60
Distance from high tide mark m.

Appendix VII; Superimposed bathymetric profiles between Mtwapa Creek and Mwachema Estuary showing narrow continental shelf (SH) and steep continental slope (SL). (od is offshore depression).






Bathymetric profiles
Shanzu, Iwetine and Leven
Depth (m)
0
-100
-200
-300
-400
-500
0
5
10
15
20
25
Distance from shoreline (km)
sha/9
iwe/17
lev/25
sh
od


Bathymetric profiles
Likoni
Depth (m)
0
-100
-200
-300
-400
0
5
10
15
Distance from shoreline (km)
lik/27
lik/29
lik/31
sh
sl