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Shore Morphology and Sediment Characteristics South of Pangani River, Coastal Tanzania

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Abstract—Shore morphology and nearshore sediments between the Pangani and Kipumbwi rivers in coastal Tanzania were investigated. The information was gathered using field observations, sediment sampling of the area, and interviews with Pangani residents. The distribution of sediments on the sea bottom is mainly controlled by bathymetry, with sand (medium- to coarse-grained) dominating water depths less than 10 m, and silt dominating depths greater than 15 m. Sediments in water between 10- and 15-m depth consist of a mixture of fine sand and silt. The carbonate production in the study area is limited by the high influx of siliciclastic sediments from the Pangani, Kipumbwi and Ushongo Mabaoni depo-centres.

While previous studies attribute the disappearance in the 1970s of Maziwi Island off the Pangani River mouth to sea level rise, the present study argues that anthropogenic influences may have been the major cause; if indeed the vegetation on the island was cleared as is reported, this could have hastened its disappearance. Sea level rise is also considered to be one of the potential threats to the survival of small islands like Maziwi.

INTRODUCTION

Information concerning shore morphology and nearshore sediment characteristics in coastal Tanzania is scanty. Whereas the work of Alexander (1966) provided some basic information on the major characteristics of the shore off the Tanzanian mainland north of Dar es Salaam, the work was conducted on a small scale and did not detail the shore morphology.

Guidelines for the study of shoreline change in the eastern African region have recommended a detailed study of shore morphology, and the updating of existing information (Kuria & Nyandwi, 2000). Studies that describe aspects of coastal sediment in Tanzania include those of Kaaya (1985) and Ngusaru (1995), on backshore sediments in the Dar es Salaam area, particularly on the palaeodepositional environments of these sediments; Fay et al. (1992), Muzuka (2001) and Muzuka & Shaghude (2000), conducted at Msasani Bay, north of Dar es Salaam harbour, on grain size distribution, carbonate and organic matter content; and Shaghude & Wannäs (1998, 2000), which provided a general description of sediments in the Zanzibar channel in terms of their grain size distribution, carbonate content, biogenic and mineralogical composition.

In the eastern African region, there is an increasing need to establish a coastal resource database. In the case of Tanzania, although a great deal of effort has been made to document the information on the living resources such as mangroves, coral reefs, sea grass beds, fish and other marine fauna, limited information exists on the non-living resources.

The coast of Tanzania is fed by sediments from large rivers such as Rufiji and Ruvuma in the south, and rivers of intermediate size, such as Ruvu, Wami and Pangani, in the central and

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northern parts (Fig. 1). The coast is therefore potentially rich in offshore aggregate resources, but their extent is not clearly known. Carbonate sands, eroded from various coral platforms, or produced by the organisms living within the coral ecosystems, exist offshore (Shaghude, 2001). However, apart from the Zanzibar channel, whose deposits have been investigated by Shaghude (2001), very little information exists for other parts of the coast of Tanzania.

The major objective of the present study was to collect appropriate baseline information, so as to update Tanzania's coastal resource database on non-living resources. Another objective was to investigate the shore morphology and associated recent shoreline changes along the coast of Tanzania south of the Pangani river.

MATERIALS AND METHODS

Study site

The study was conducted on the Tanzania mainland coastal section between the Pangani and Kipumbwi rivers. The section is approximately 40 km long (Fig. 1). The shore characteristics of the investigated area have been described by Alexander (1966, 1968, 1969, 1985). According to Alexander (1966) the foreshore along this section of the Tanzania mainland coast has a narrow beach with moderate to steep gradients (1/15 to 1/30) and a nearly flat outer platform (1/200) that ranges from 70 m to over 350–550 m wide, the latter width occurring off the mouths of streams. The foreshore sediments are sandy, except for occasional extensive patches of exposed beach rock along the beach.

Faults traverse the Tanzanian coastal area and play a role in shaping its present geomorphological form (Stockley 1928; Kent et al., 1971; Shaghude & Wannäs, 2000). Pleistocene and Recent faults divide the coastal plateau into three terraces. The investigated area is part of the lowest, Mtoni terrace (Alexander, 1968). Beach ridge systems are also common along many parts of coastal Tanzania, and are indicative of Pleistocene/Holocene sea level changes (Alexander, 1969; Muzuka et al., 2002). The ridges of the investigated area are elevated some decimetres to a few metres above spring tide level, suggesting that they formed either due to a fall of global sea level from a high stand of 1–3 m above its present position, or as a result of late Holocene uplifting of the Mtoni terrace (Alexander, 1969; Fay et al., 1992).

The weather across the area is warm and moist, with sea-surface temperatures varying between 25 and 30 °C, and annual rainfall exceeding 1000 mm. Studies conducted further south of the investigated area show that both sedimentological and oceanographic phenomena are influenced by the monsoon winds (e.g. Lwiza, 1994; Muzuka and Shaghude, 2000; Nyandwi, 2001). During the north east monsoon the wind-generated waves approach the coast from the northerly sector and produce longshore currents with a southerly component. During the south east monsoon the wind direction is reversed and so is the wave climate. The speed of the alongshore currents is at a minimum during the northeast monsoon (November to March) and a maximum during the southeast monsoon (May to September). As a result of seasonal variability in waves and currents, climate the erosion/accretion pattern of the coastal section north of Dar es Salaam is also cyclical, but the net longshore transport is northward.

Data collection and treatment

The field work for this study was conducted in October 2002 and July 2003. It consisted of foreshore mapping, beach sediment sampling, offshore bottom sediment sampling, and gathering relevant historical information.

Beach sediment samples were collected along the middle of the beach slopes using a small shovel to scoop approximately 2 cm of surface sediment (about 1 kg of sample). The shore features were simultaneously observed and documented.

Offshore bottom sediment samples were collected using a lightweight (approximately 10 kg) Van Veen grab sampler that collected at least 1 kg of sediment. Altogether 100 sediment samples were collected. The sample locations (Fig. 1) were taken using a handheld GPS and the water depths of the offshore samples were measured using a handheld echo sounder. The water depths were then tidally corrected.

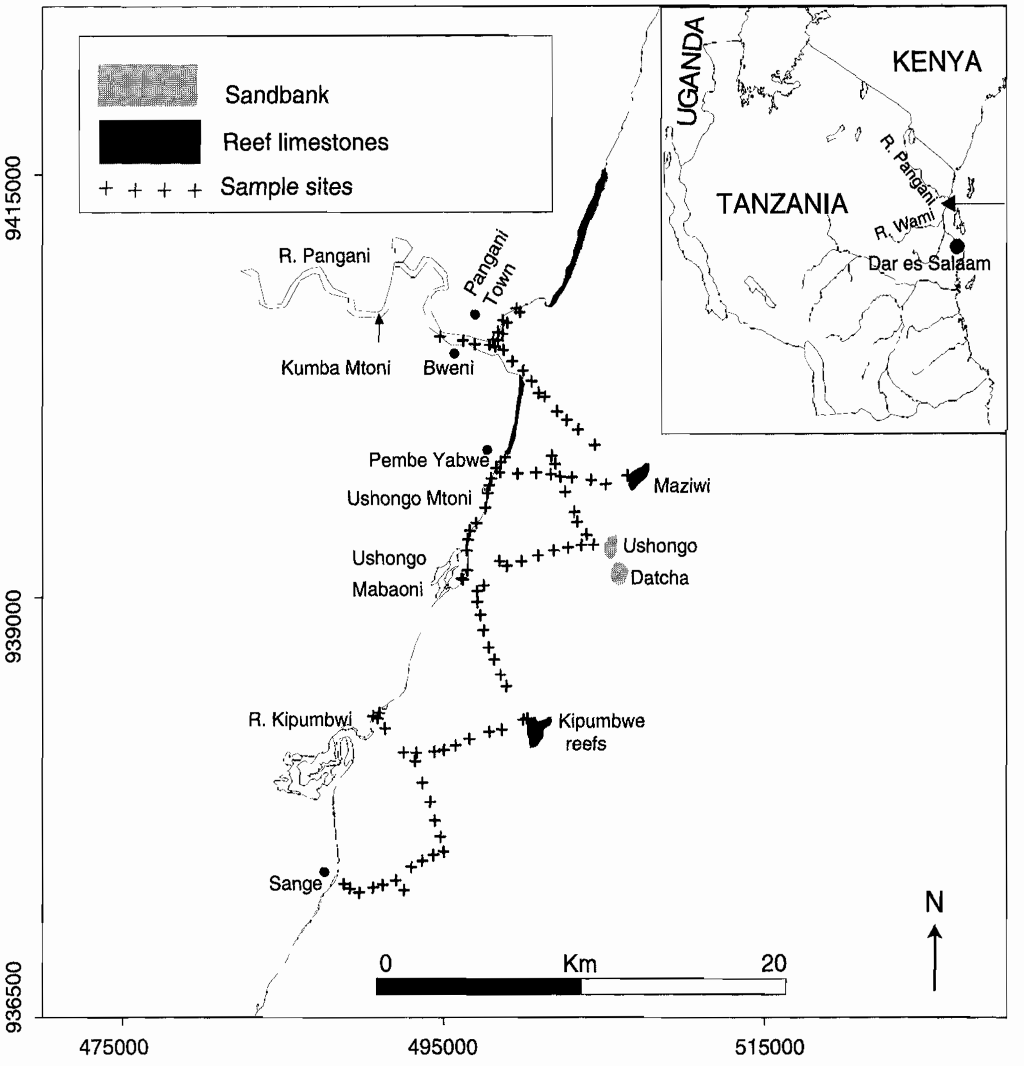

Fig. 1. The investigated shore of the Tanzania mainland, south of Pangani River (arrow). The crosses on the map represent sediment sampling locations.

All the sediment samples were washed with fresh water to remove salts, then oven-dried at 50 °C. Samples with a significant proportion of sand (54 samples) were subjected to dry sieving to determine grain size distribution. Sieving for these samples was done using a set of 12 sieves, ranging from –1 phi (2 mm) to 4 phi (63 microns) spaced at 0.5 phi intervals. Carbonate content in the samples (% $CaCO_3$) was determined by the acid leaching method, where dilute HCl (25%) was used to leach approximately 3–5 g of a sub-sample. Leaching was run in duplicates for 10 samples out of the 77 samples, which were analysed using this technique, and reproducibility was considered to be satisfactory (relative difference was less than 2%).

Historical information concerning the disappearance in the 1970s of Maziwi island and the present shoreline changes in the vicinity of Pangani river mouth was gathered by interviewing Pangani residents. Three fishermen, one news reporter and one old man (Mzee Kinyasi) were separately interviewed to collect information regarding the history of Maziwi island (Fig. 1) and its disappearance.

RESULTS

Shore characteristics and sea level changes

Close to the river mouths the beach slope was relatively steeper (> 50 °) and had coarser sediments than further away from the river mouths, where the beach slopes in most cases were gentle (< 30 °), consisted of fine- to medium-grained sand and were covered with sand ripples. Most of the ripple wavelengths were between 30 and 50 cm, with heights of about 3 cm. Bioturbation was also common on the tidal flats

Using the standardised coastal classification developed by Kuria & Nyandwi (2000) the section of the coast between Pangani Bay and the Kipumbwi river mouth may be described as a patch reef coast, with fossil reef terrace /islands (Fig. 2), with narrow or no beaches. With the exception of the shore section on the immediate south of Pangani Bay (Pangani Bay to Pembe Yabwe) which is cliffed (Fig. 2 a) with no sand beach, the remaining part of the shore may be described as a non-cliffed coast (Fig. 2 b), characterised by a Holocene shore and narrow sandy beaches. Wave-cut terraces are common along the cliffed section of the shore, indicating high wave activity. Morphologically, the non-cliffed section of the shore from Pembe Yabwe to Sange forms about three macro-bays. In comparison to the northern shore section, this part of the shore is relatively protected from wave erosion. In some parts (e.g. at Kipumbwi) significant recent shoreline accretion is evident from mangrove colonization of the foreshore, and the current shoreline lies about 100–150 m seaward from the old shoreline.

River Pangani is considered to be the largest supplier of siliciclastic sediments to the sea along this section of coast. At its entrance to the sea, Pangani Bay and estuary are the most prominent shore features. The present study has identified significant growth of the bay and evolution of the estuary during the last 50-60 years. The growth of the bay, which has taken place at the expense of shore erosion on the immediate north of the river mouth, is currently posing a considerable threat to the Pangadeco Hotel, which was originally located more than one kilometre from the shoreline.

The residents of Pangani interviewed indicated that the current erosion on the northern side of the river mouth is a recent phenomenon. Most of them associate the present erosion with the increase in the water level in the vicinity of the river mouth. Mzee Kinyasi (a 70-year-old man), revealed that during his boyhood, there were regular canoes

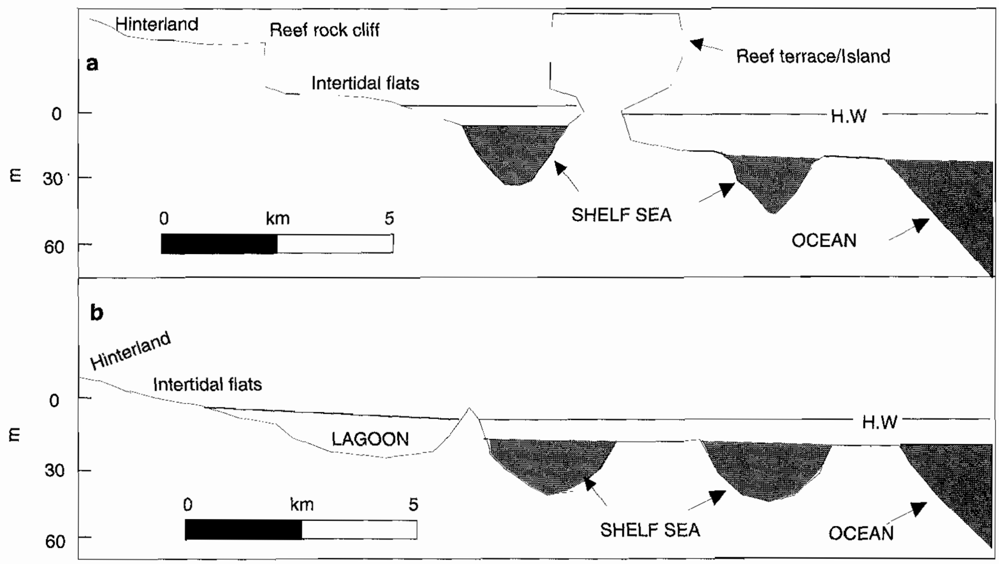

Fig. 2. Comparative shore-normal sections showing the two patch reef coastal types (a = Patch reef coast with fossil reef terrace/Islands and b = patch reef coast with sand spit shore), characterizing the coastal section between River Pangani and Kipumbwi, Tanzania. The classification scheme is adapted from Kuria & Nyandwi (2000).

ferrying students daily between Bweni village (located on the southern bank) and a primary school in Pangani Town on the northern bank. Students who could not afford the fare opted to use a footpath (which was normally dry during low tide), that was south of the canoe route (Fig. 3). Today it is impossible to cross the river by foot at this location under any tidal condition. The old man further revealed that during 1960s the present Pangadeco Hotel was about 1 km from the shoreline and the area between the present shoreline and the old shoreline was covered with mangroves and casuarinas, suggesting that the shore has been retreating at the rate of at least 20 m per year.

Another trader who migrated to Pangani 4 years ago reported that coconut tax evaders would use a passage through the beach in front of the Pangadeco Hotel to transport their coconut (using trucks) to Tanga. Efforts were made to block the illegal passage using tyre fencing which was erected at the edge of the shore. This author visited this location but did not see the tyres; they are reportedly beneath the sand as a result of the continued erosion of the shore (Plate 1). The estimated shoreline retreat during the four-year period is about 30 m, which gives an annual retreat rate of about 7.5 m

The salinity intrusion upstream is also reported to have increased significantly during the last 50–60 years. Mzee Kinyasi reported that in his youth crocodiles were common as far down stream as Kimu. Today, the crocodiles have been forced to move further upstream to Kumba Mtoni (Fig. 1) as they cannot tolerate the brackish water conditions. It appears therefore that significant saline intrusion into the Pangani river estuary has taken place during the last 50–60 years.

All the interviewees revealed that up to at least the 1960s Maziwi island was exposed above the water under all tidal conditions, and it was covered with many casuarina trees. Mzee Kinyasi reported that another island, Buyuni Mdogo (also locally known as *Msitu wa Mkwaja*), was located further south of the investigated area. Both islands were temporary homes for fishermen, who would stay there for two to three days at a time. The islands were also nesting grounds for turtles. According to Fay (1992), the original island during the late

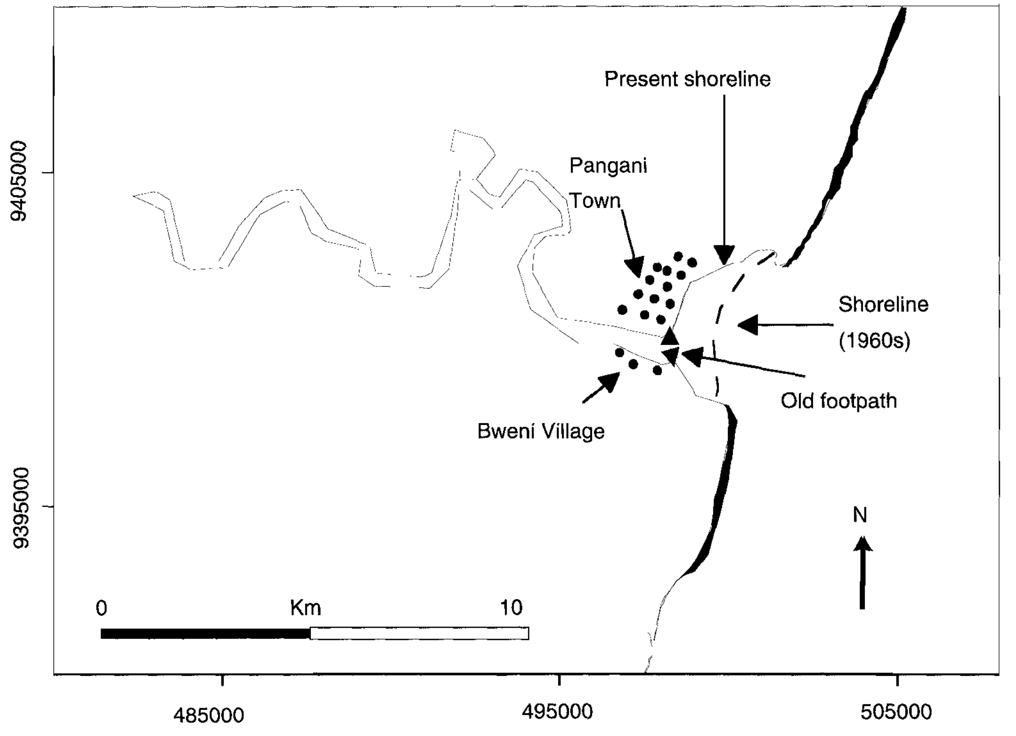

Fig. 3. The Pangani river estuary, Pangani town and the eroding coastal section north of the river mouth

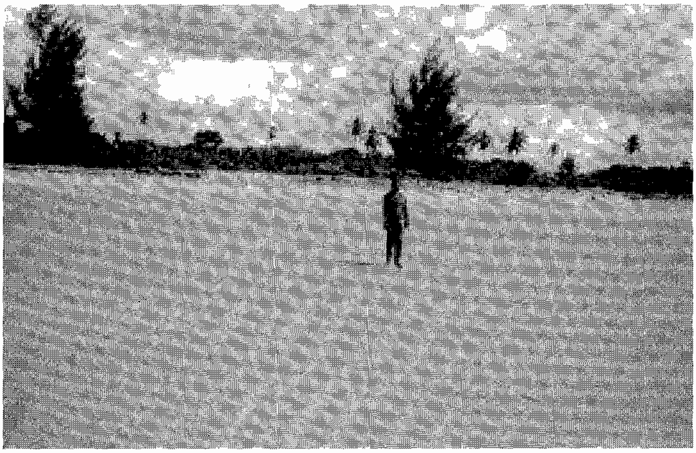

Plate 1. Beach head erosion north of Pangani river mouth. Observe that the tyre groynes (believed to be submerged) were placed in front of the person visible in the image, and the shore has retreated 30 m further inland.

19th century, was believed to be circular, with diameter of about 500–600 m. All the respondents associated the disappearance of Maziwi island with the deliberate clearance of all the trees on the island during the war between Tanzania and Uganda (1978–1980). Its trees, as well as those on Buyuni Mdogo, were felled for fear that the enemy's troops might use the island as a base and hideout.

Two other important estuarine/macro-delta systems are found at Kipumbwi and Ushongo Mabaoni. These deltas supply significant volumes of siliciclastic sediments to the sea. Of the two, Kipumbwi, which receives most of its water via the Msangasi river, is the larger. Ushongo Mabaoni receives most of its water from seasonal streams, which provide little input during the dry season. Sand spits and mangrove stands are the most prominent foreshore features at both estuaries. Another less important macro-delta is Ushongo Mtoni (Fig. 1).

Offshore fossil reef platforms, the remnants of the former Maziwi island, Ushongo and Datcha sand banks and Kipumbwe reefs are prominent features. These reef platforms are submerged during high tides and are located within 7 to 10 km of the shoreline.

Sea bottom morphology

The sea bottom morphology between the mainland and the fossil reef platforms (Fig. 4a) is characterized by a gradual increase in water depth to a maximum offshore slightly deeper than 25 m followed by a decrease in depth towards the fossil platforms. Figure 4a shows the approximate location of the 200 m contour obtained from the Admiralty Chart (Chart No 61200). In the southern parts of the investigated area the continental shelf becomes progressively wider due to the presence of Zanzibar Island located about 4 km south of the Kipumbwi river and about 40 km off the mainland coastline.

Sediment characteristics

The nearshore surface sediments are predominantly of siliciclastic origin (Fig. 4b). Using the 50% contour as the dividing line between the siliciclastic sediments and carbonate sediments, Fig. 4b shows that siliciclastic sediments occupy a coastal strip about 6–8 km wide adjacent to the mainland. The carbonate sediments occupy a relatively narrow strip (1- to 2-km-wide) adjacent to the reef platforms.

The distribution of the mean grain size of the sea bed sediments is presented in Fig. 5. The two maps (Fig. 5a &b) show that the sediment grain size is correlated with depth. Close to the shore and at shallow depths (< 10 m), the surface sediments are predominantly sand (mean grain size < 2.0 phi), but further offshore they are predominantly silty.

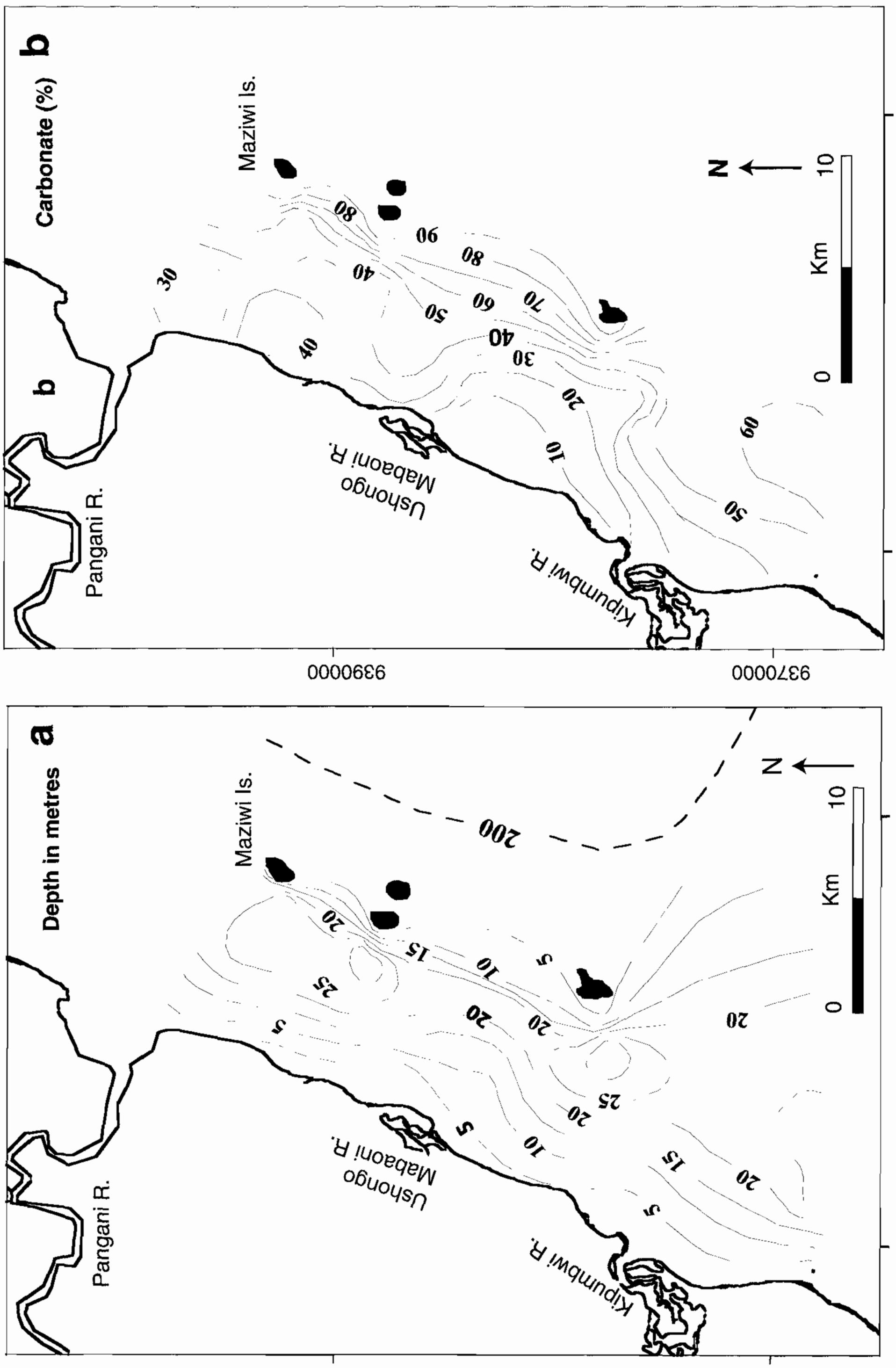

Fig. 4. The nearshore bathymetry (a) and the distribution of carbonate content in the sediments (b)

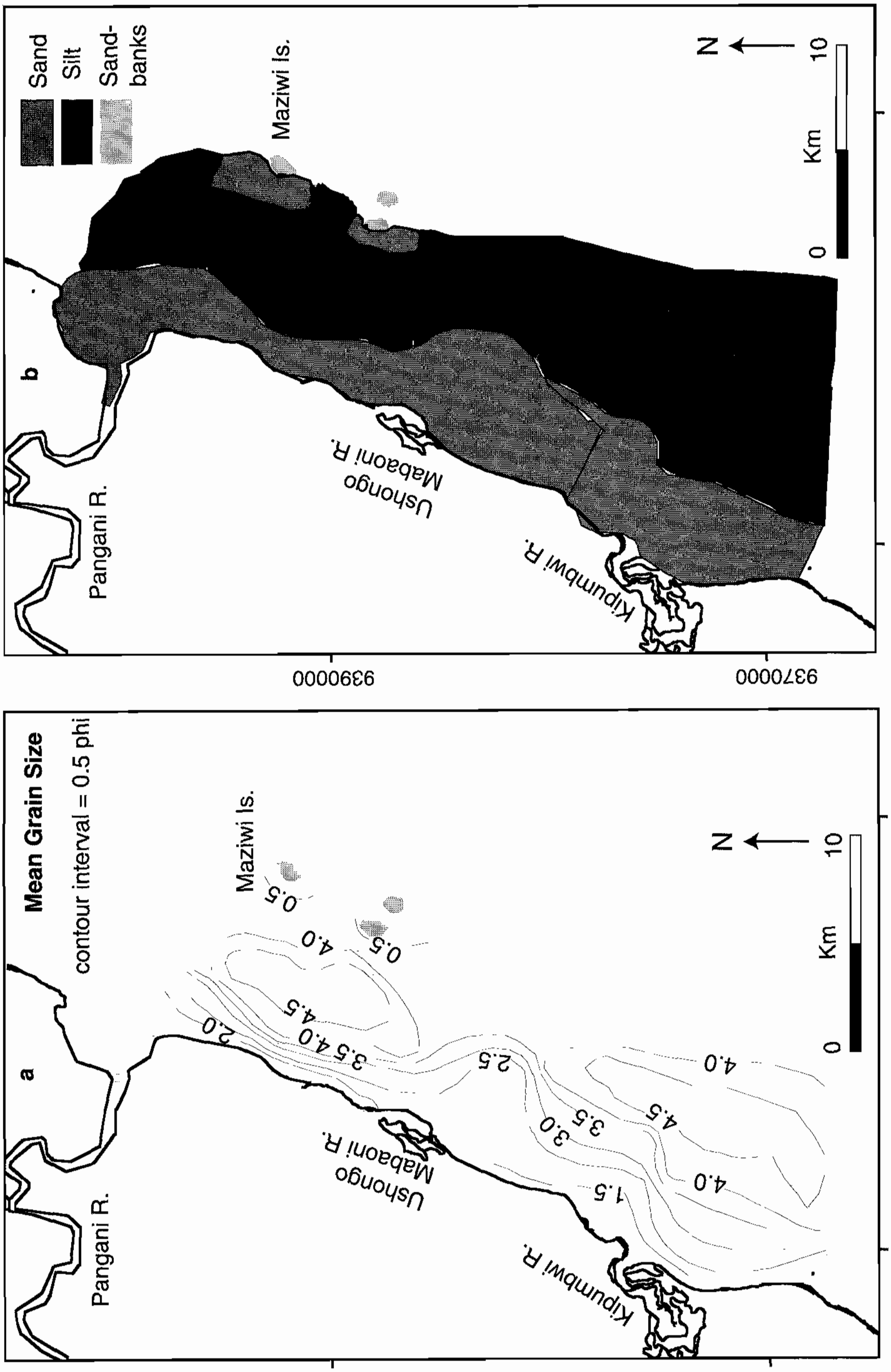

Fig. 5. (a) Distribution of sand and silt sediment classes on the sea bottom; (b) detailed mean grain size distribution

DISCUSSION AND CONCLUSION

Physical settings of the reef platform sediments

The results of this study show major differences in the energy regime between the northern and southern coastal sections of the investigated area, which is attributed to the difference in sea bottom morphology, or width of the continental shelf, between the areas. Due to the presence of Zanzibar island, the continental shelf in the south is relatively wider and the open ocean waves breaks relatively far from the shore; in the north the continental shelf is narrower, and open ocean waves break relatively closer to shore.

The hydrodynamic settings of the reef platform sediments of the area are markedly different from those of the tidal dominated reef platform sediments (TDRPS) west of the Zanzibar channel (Shaghude et al., 2002) as well as the reef platform sediments at Kunduchi area north of Dar es Salaam harbour (Shaghude et al., 2003).

The supply of siliciclastic sediments is higher in this area than in the west of the Zanzibar channel and at Kunduchi due to the presence of large rivers such as the Pangani and Msangasi, and the siliciclastic/carbonate transition is wider. The siliciclastic coastal strip in the study area is approximately 4- to 8-km wide, whereas the siliciclastic coastal strip in the other areas is less than 3-km wide (Fay et al., 1992, Shaghude & Wannäs, 1998; Shaghude, 2001). The low siliciclastic input in the TDRPS west of the Zanzibar channel was attributed to the absence of high relief features on the Zanzibar island and the limited siliciclastic source rocks (Shaghude, 2001). The low siliciclastic input in the Kunduchi sediments was attributed to the absence of major rivers (Fay et al., 1992).

Shallow water marine environments are recognized globally as potential areas for extensive carbonate production due to their primary productivity (Shaghude, 2001). Although such environments are potential sites for extensive carbonate production and accumulation, the production is greatly influenced by siliciclastic input to the depositional basin. Shallow marine environments that have low siliciclastic influx from rivers are generally considered to be potentially more important sites for carbonate production and accumulation than those with high siliciclastic influx from rivers (Nelson & Bornhold, 1983; Carey et al., 1995; Shaghude, 2001).

Increased sedimentation from rivers affects the seawater quality, with detrimental effects to the carbonate producers. In coral ecosystems, siltation blocks the feeding apparatus of the coral polyps and also reduces the light available to their algal symbionts (Wagner, 1999). Increased sedimentation also effectively limits the extent of the carbonate basin. The extent of siliciclastic influences on the marine carbonate depositional basin depends on the amount of siliciclastic sediments discharged, which in turn depends on the size of the drainage basin and its geomorphic and tectonic characteristics. (Milliman & Meade, 1983; Milliman and Syvitski, 1992; Milliman, 1995; Harris et al., 1996; Robertson et al., 1998). In the study area, the high influx of siliciclastic sediments is the major factor limiting carbonate production and accumulation.

Recent shoreline changes, coastal erosion and salinity intrusion

This study has shown that, while coastal erosion is a threat in the vicinity of the Pangani river mouth, the threat is minimal further south. Coastal erosion in Tanzania is a serious problem (BEMC, 1987; Shaghude et al., 1994; Mohammed and Betlem, 1996; Nyandwi, 2001), whose causative factors are generally site-specific, and are both natural and anthropogenic. Natural causes include wave activity, tides, longshore currents, sea level rise, and tectonic processes. Human activities include the removal of coastal vegetation such as mangroves, sand and gravel mining along streams which drain the beaches, as well as sand and gravel mining on the beaches, and the destruction of offshore barriers such as coral reefs.

The rate of coastline retreat to the north of the Pangani river mouth is between 7 and 20 m/year. Significant shoreline retreat on the immediate north of Pangani river mouth is also evident from aerial photographs (V. Makota, TCMP; pers. commun.). High wave activity in the vicinity of Pangani is a major causative factor of coastal erosion immediately north of the Pangani river mouth. The wave erosion may be exacerbated by upstream activities such as damming, which may trap significant amount of sediments and reduce the natural sediment flux to the beach. Waves higher than 2 m are common especially during high tide, and during extreme high spring tides, the waves may exceed 3 m in height. The high wave activity in this coastal section has been attributed to the narrowness of the continental shelf, which forces the large open shelf waves to break close to the shore. This coastal section also lacks a continuous reef structure, which might otherwise protect the shore during normal tide conditions.

Immediately to the north the substrate is composed of loose sandy material and erosion is proceeding rapidly. To the south the shore is composed of hard reef limestones; wave-undercut beach terraces are the dominant features here and the shoreline is retreating relatively slowly.

The Nyumba ya Mungu dam, commissioned in 1968 and located 75 km south of Mt. Kilimanjaro (one of the major water and sediment contributors to the Pangani river) has a storage capacity of 875 million m^3 (Kitova, 2001). The dam is a reservoir for the power plant at Nyumba ya Mungu (8MW) and other power plants further downstream; namely Hale (21 MW), Old Pangani (15 MW) and New Pangani (66 MW). Although historical data for the sediment flux for the river before damming activities are not available, recent studies estimate the potential soil erosion upstream of Nyumba ya Mungu at 24t/ha/yr and sediment deposition rate into the reservoir at 13t/ha/yr (Ndomba, 2002), suggesting that at least 50% of the sediments eroded upstream of the dam are trapped in it. The accelerated beach erosion at Pangani could therefore be related to reduction of sediment supply to the coast.

This study found evidence of significant increase of salinity intrusion at the Pangani river over the last 60 years. The observed increase in salinity intrusion along the estuary could possibly be associated with reduced fresh water discharge from the river. The water in the Pangani river and its smaller tributaries is increasingly being extracted for irrigation, domestic use, small-scale industry and hydropower plants (Huggins, 2000; Kitova, 2001). Although there are no statistical data to quantify the extent of water abstraction, several studies report that water scarcity in the Pangani Basin is becoming an issue of concern (e.g. World Bank, 1997; Maganga et al., 2001; Ruwa et al., 2003). Irrigated agriculture is currently considered to constitute the highest proportion of water abstraction in the Pangani catchment (Kitova, 2001). A total of 29,000 ha are under irrigation, ranging from commercial plantations with several thousand hectares, to traditional plots of a few hectares. The irrigation efficiency in most cases is reported to be as low as 30%; most of the water is lost before reaching the farms. The demand for domestic water is also high. Maganga et al. (2001) report that due to water scarcity, water levels in storage reservoirs are low, and competition for water between different sectors (e.g. farmers and hydropower generators) and between groups of the same sector (e.g. different groups of farmers) has intensified. It is therefore reasonable to associate the observed increase in salinity intrusion with the water scarcity in the Pangani basin.

The history of Maziwi Island and its recent disappearance as presented here agree with the earlier history presented by Fay (1992). Both studies report the island disappeared during the late 1970s. Fay (1992) attributes the disappearance of the island to sea level rise. However, the present study suggests that anthropogenic factors were the major cause. While sea level rise may threaten the survival of small islands like Maziwi, vegetation clearing may hasten their disappearance.

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