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SEDIMENT DISTRIBUTION AND COMPOSITION ON THE SHALLOW WATER CARBONATE BASIN OF THE ZANZIBAR CHANNEL

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ABSTRACT

The sediments of the shallow water carbonate basin of the Zanzibar channel were investigated to describe their general characteristics in terms of composition and grain size distribution. The surface sediment composition was dominated by carbonate sands (with $CaCO_3$ > 30%), except in the area adjacent to the mainland coastline and a thin lobe which projects from Ruvu River to the middle of the channel. The mean grain size distribution closely resembled that of the carbonate content, where the Tidally Dominated Reef Platform Sediments (TDRPS) located east of the Zanzibar channel were characterised by medium to coarse sands and the siliciclastic sediments adjacent to the mainland are characterised by fine sand. The TDRPS were the most poorly sorted sediments with sorting values between 1.2 and 1.6 phi. The present study highlights the major differences between the eastern and western side of the channel. The sediments on the eastern side of the channel, which were predominantly biogenic, are characterized by grain size frequency curves without any prominent mode. The sediments on the western side of the channel were composed of both biogenic and terrigenous material. The grain size frequency curves of these sediments have a fine mode and usually a coarse tail.

INTRODUCTION

In many parts of the world, shallow water marine environments are areas of extensive carbonate production and accumulation. Shallow carbonate deposits, widely reported in warm shallow water shelves (e.g. Harris *et al*. 1990, 1996, Li *et al*. 1998) were viewed as tropical or sub-tropical phenomena. However, from the late 1960's there has been a dramatic increase in information regarding shallow carbonate deposits outside the tropical realm. Modern shallow carbonate deposits are now widely reported in the temperate shelves (Nelson, 1978, *Nelson et al*.1982, Nelson and Bornhold, 1983, Carey *et al.* 1999, Barnhardt and Kelley, 1995) as well as high latitudes (Alexandersson, 1979, Boreen *et al*. 1993, Taviani *et al*. 1993).

In many shallow water carbonate basins, the input of terrigenous sediments to the basin is one of the most important limiting factors, affecting both the carbonate production and accumulation. Studies in many parts of the world show that, as long as the input of terrigenous material is minimal, the potential exists for carbonate production and accumulation (Nelson & Bornhold 1983). Shallow marine carbonate producers use seawater to build their skeletons. The shallow marine carbonate producers include both the autotrophic primary producers (e.g. coralline algae) and other non-autotrophic benthic sessile organisms (e.g. molluscs, foraminifera, echinoderms and sponges) as well as sedentary organisms such as corals or bryozoans. The turbidity associated with fluvial discharge of terrigenous sediment can reduce light penetration thereby reducing primary productivity. This would therefore prohibit shallow marine carbonate production by the autotrophic carbonate producers. Further, as most shallow water benthic carbonate producers are suspension feeders, the fine terrigenous materials may clog the body feeding system of these organisms (Carey *et al*. 1995) and thus inhibit their growth. Finally, high input of terrigenous material may bury the benthic carbonate producing organisms and effectively reduce the size of the carbonate basin.

The present study investigated some of the important characteristics of the sediments on the shallow water carbonate basin of the Zanzibar channel (Fig. 1-a), both in terms of sediment composition and grain size distribution. Further investigations were made on how the terrigenous sediments are redistributed in the basin. The study is expected to shed some light on the extent to which the terrigenous sediments effectively reduce the size of the investigated carbonate basin. The study covered the section of the Zanzibar channel between the two major rivers (the Ruvu and Wami), which is approximately one third of the channel (Fig. 1-a).

METHODS

Sediment samples were collected using a light (approx. 10 kg) Van Veen grab sampler, with a carrying capacity of 2 to 3 kg. The samples were collected in two phases (Fig. 1-b); the first phase, characterised by dense sampling sites (100 samples) close to Zanzibar Town, and the second phase, characterised by less dense sampling sites (40 samples) extended across the channel.

The sediment samples were washed with distilled water and then oven-dried at 45^0 C. All samples were analysed for grain size distribution by dry sieving through -1 phi (2 mm) and 4 phi (63 µm) sieves, with successive sieves spaced at ½ phi intervals. The grain size for the sieved sediments were evaluated by calculating the graphic mean, sorting, skewness and kurtosis (Folk & Ward

1957). Carbonate content in the sediments was determined by the leaching method using dilute hydrochloric acid (25%). Approximately 2 g of well-ground sub-samples were leached and the carbonate content calculated from weight loss during leaching. Leachings were done in duplicate for 10 samples and in one sample for the remaining samples. Reproducibility of the results for the duplicate sub-samples was very good (less than 2% relative difference).

RESULTS

Carbonate sediments (>30% $CaCO_3$) occupied more than 70% of the sea bottom (Fig. 2-a), with the highest carbonate content (> 80%) in the Tidally Dominated Reef Platform Sediments (TDRPS) on the eastern side of the channel, explained by Shaghude *et al* (2001). Siliciclastic sediments (< 30% $CaCO_3$) dominated the coastal strip, about 5 km adjacent to the mainland except at river Ruvu where a lobe of siliciclastic sediments projected from the river mouth to nearly the middle of the channel. The siliciclastic sediments were generally very minor components in the TDRPS, confined on the intertidal zone adjacent to Zanzibar Island. The remaining part of the sea bottom may be described as an intermediate carbonate zone (30%<$CaCO_3$<80%).

The distribution of mean grain size (Fig. 2-b) in the general perspective closely fits the distribution of the carbonate content. In particular, the TDRPS which were characterised by having the highest carbonate content, were of medium (1.0 to 2.0 phi) to coarse (1.0 to 0.0 phi) sand size, while the siliciclastic dominated zone adjacent to the mainland coast was characterised by fine (2.0 to 3.0 phi) sand sediments.

The TDRPS (Fig. 2-c) were the most poorly sorted sediments with sorting values between 1.2 and 1.6 phi. On the Folk and Ward (1957) sorting scale, these sediments may be described as being poorly sorted. The poor sorting value in these sediments is probably due to the fact that these sediments composed of various kinds of biogenic components namely the benthic foraminifera, pelecypods, gastropods, corals and ostracods (Shaghude and Wannäs 2000). The best-sorted sediments in the channel were the siliciclastic sediments close to the mainland coastline, with sorting value less than 1.2 phi. The relatively better sorting of these sediments compared to other sediments is probably due to their fine sized nature (dominated by sediments of siliciclastic origin) as fine sediments are often better sorted than coarse sediments (Folk 1964). The sediments in the central parts of the channel were also poorly sorted but their sorting range was lower than the reef platform sediments. The sorting value of most of these sediments was close to 1.2 phi..

Skewness of the sediments (Fig. 2-d) varies from positive skewness (about 0.2) to very negatively skewed (about -0.5). Investigation of the cross-shore skewness trend shows that the skewness generally changes from symmetrical or positive skewness near the shore to negatively or very negatively skewed sediments at the middle of the channel. The highest peakedness (kurtosis) in the sediments (Fig. 2-e) was found in the southern parts of the investigated area, with peakedness varying between 0.8 and 1.6. The sediments on the central and northern parts had peakedness values between 0.8 and 1.2. Although further attempt may be made to interpret these values, due to low sampling density (few samples collected in the area) in the western and southern parts of the study area, interpretation based on skewness and kurtosis, which are third and fourth statistics, respectively, is considered to be unreasonable.

DISCUSSION

To a large extent the two rivers Ruvu and Wami on the mainland control the sea bottom morphology and the sediment composition on the western side of the Zanzibar channel. The two rivers have been the major source of siliciclastic sediments on the western side of the channel. A major contribution of the sediments from the rivers Ruvu and Wami comes from the Uluguru and Nguru mountains which are tropical mountains located about 200 km from the coastline of the Tanzania mainland (Fig. 1-a). The bedrock geology of these mountains consists of metamorphic crystalline rocks of the Mozambique belt, believed to have been formed during the Pan African episode, about 550±100 m.y. b.p (Windley 1986), and probably uplifted before the Upper Carboniferous (Samson & Wright 1964). The local relief of the mountains is over 2600 m above sea level and the mountains generally receive high precipitation of over 1400 mm/per annum (Temple & Rapp 1972, Rapp *et al.* 1972).

Topography (relief) and rainfall are generally considered to be the most important factors, controlling sediment discharge to the sea for most rivers (Milliman & Syvitski 1992, Milliman 1995). Thus, the overall high precipitation on these mountains and their high relief are probably the most important factors controlling the siliciclastic sediment discharge to the sea via the two rivers, Ruvu and Wami.

The Zanzibar channel is fairly protected from the effect of long period waves coming from the open sea as it does not have a direct connection to the open ocean (Brampton 1996). However, the effects of locally generated short period waves cannot be neglected. Furthermore, as the tides are mesotidal (Boothroyd 1985), they are considered to be moderate. Both tides and waves are therefore considered to control the redistribution of the sediment laden river output from the river mouths to other parts of the coastal area on the Tanzania mainland. Exceptional development of beach ridges immediately north of the river mouths on the Tanzania mainland has been pointed out as an evidence of preferential northward transport of sediments along the shore (Alexander 1969). Thus, it appears that most of the terrigenous materials are preferentially transported northward by the longshore drift. Exception to this may be at the river mouths or tidal channels where the ebb currents may carry the fine material further offshore as demonstrated by the observed siliciclastic lobe at river Ruvu.

The study of Shaghude and Wannäs (2000), which investigated the same study area, discusses the mineralogical and biogenic composition of the sediments in the Zanzibar channel. This study proposed that the investigated area be divided into three bio-physiographic zones: 1- The coastal zone (0-10 m water depth), 2 – the reef platforms/patch reefs zone (10-20 m) and 3 – the central channel zone (>20 m). This morphological division was supported by the results of the statistical analyses on the biogenic and mineralogical data as well as the spatial distribution of the biogenic:quartz ratio. In particular, the statistical analyses show significant differences in the spatial distribution of quartz, biogenic content and the biogenic to quartz ratio (for the thin sections analysed) among the three bio-physiographic zones (Shaghude & Wannäs 2000).

While the three-fold depth divisions defining the bio-physiographic zones in the channel suggest some general conclusions about the sediment characteristics, it does not highlight the important difference between the eastern and western sides of the channel. This difference is evident from the presented results on grain size distribution parameters (namely the mean grain size and sorting), distribution of carbonate content and the sea bottom morphology. The present study provides (Fig. 3) the grain size frequency curves derived from the 49 samples used in the study of Shaghude and Wannäs (2000), to further highlight the difference between the eastern and western side of the channel. In the two-fold geographic division, the sediments east of the 30 m dashed contour (Fig. 3-e), which are essentially the TDPRS, are considered to be one division and the sediments west of this contour are considered to be another division.

The grain size frequency curves for the investigated samples (Fig. 3) indicate different dipositional environments between the eastern and western sides of the channel. The samples on the eastern side (Fig 3-a) generally do not have significantproportion of fine material and often showed a coarse tail. The fine mode in these samples is not characteristic, but generally lies between 2 and 3.5 phi (0.25 and 0.09 mm). The extremely exceptional cases in the western division are the samples shown in Fig. 3-d. The grain size curves of these samples closely resemble those of the samples from the eastern division, possibly due to their proximity to reef platforms or patch reefs.

The present study highlights the major differences between the eastern and western side of the channel. The sea bottom on the eastern side of the channel is dominated by raised reef platforms with a network of internal channels between these platforms. Only a few patch reefs are evident on the western side of the channel, which is generally characterized by a smooth topography. The bulk of the sediments on the eastern side of the channel appear to be of biogenic origin with very little contribution from the terrigenous source. The carbonate content in these sediments generally exceeded 60%. These sediments were of medium to course texture and are poorly sorted, with sorting value > 1.2 phi. The grain size frequency curves of these sediments do not have any prominent mode. The sediments on the western side of the channel were composed of both biogenic and terrigenous material and the carbonate content in these sediments is generally less than 60%. These sediments are of fine to medium texture and have a better sorting value than the TDRPS east of the channel. The sorting value in these sediments does not exceed 1.2. The grain size frequency curves of these sediments have a fine mode and usually a coarse tail.

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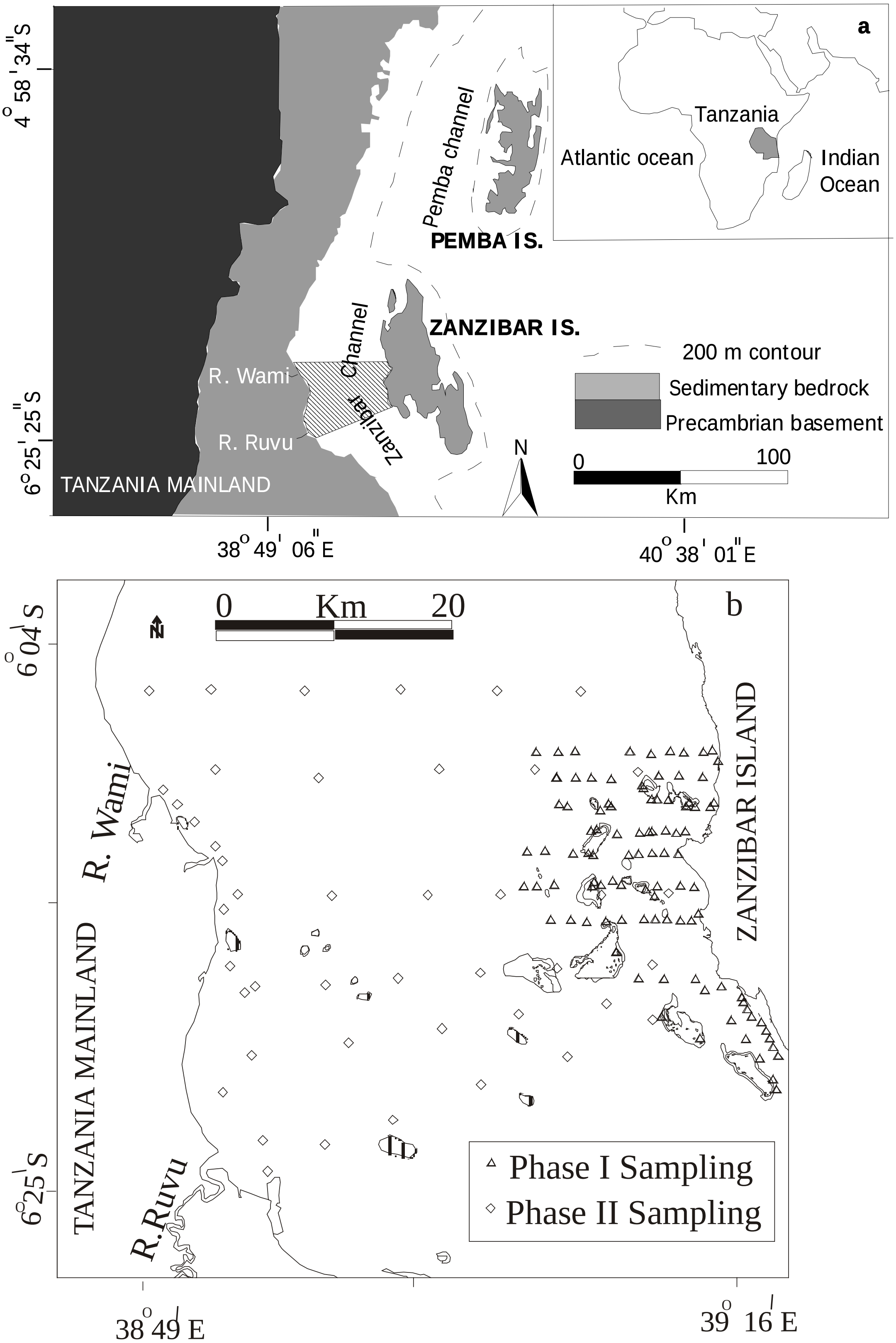

Fig.1: Map of coastal Tanzania showing (a) a[[roximate boundary of the investigated area and (b) the grab sampling. Note the high density data in the tidally dominated Reef Platform Sediments (TDPRS). The Reef platforms are shown as non-hatched polygons and the hatched polygons in the central and western sides of the Zanzibar channel are patched reefs.

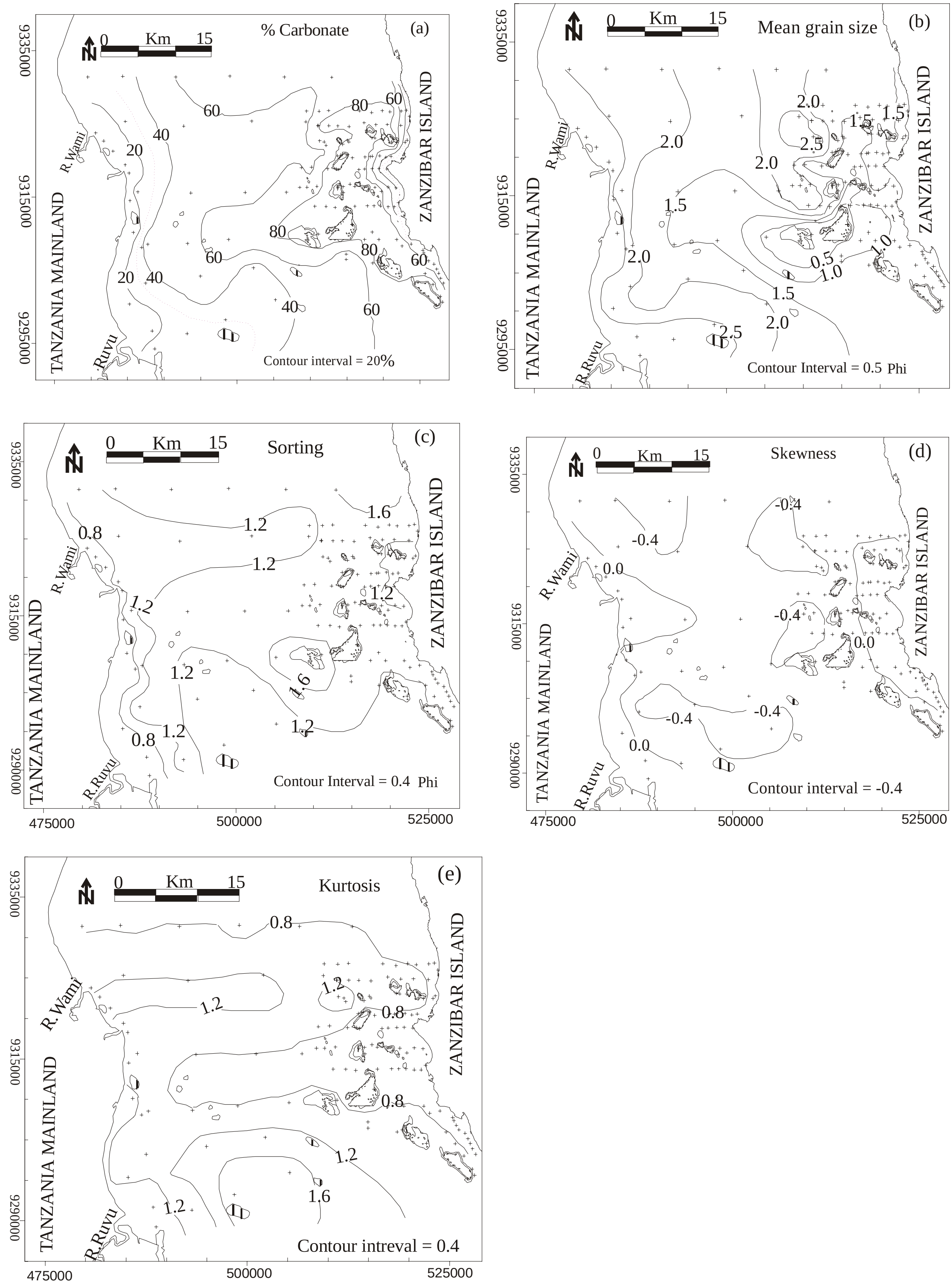

Fig. 2 Map showing (a) the distribution of carbonate content (b) the mean grain size distribution (c) sorting (d) skewness and (d) kurtosis of the investigated area in the Zanzibar channel. The small cross symbols in the figures are the sampling points. Note the siliciclastic/carbonate sediments boundary (a) shown by the dotted lines (30% $CaCO_3$).

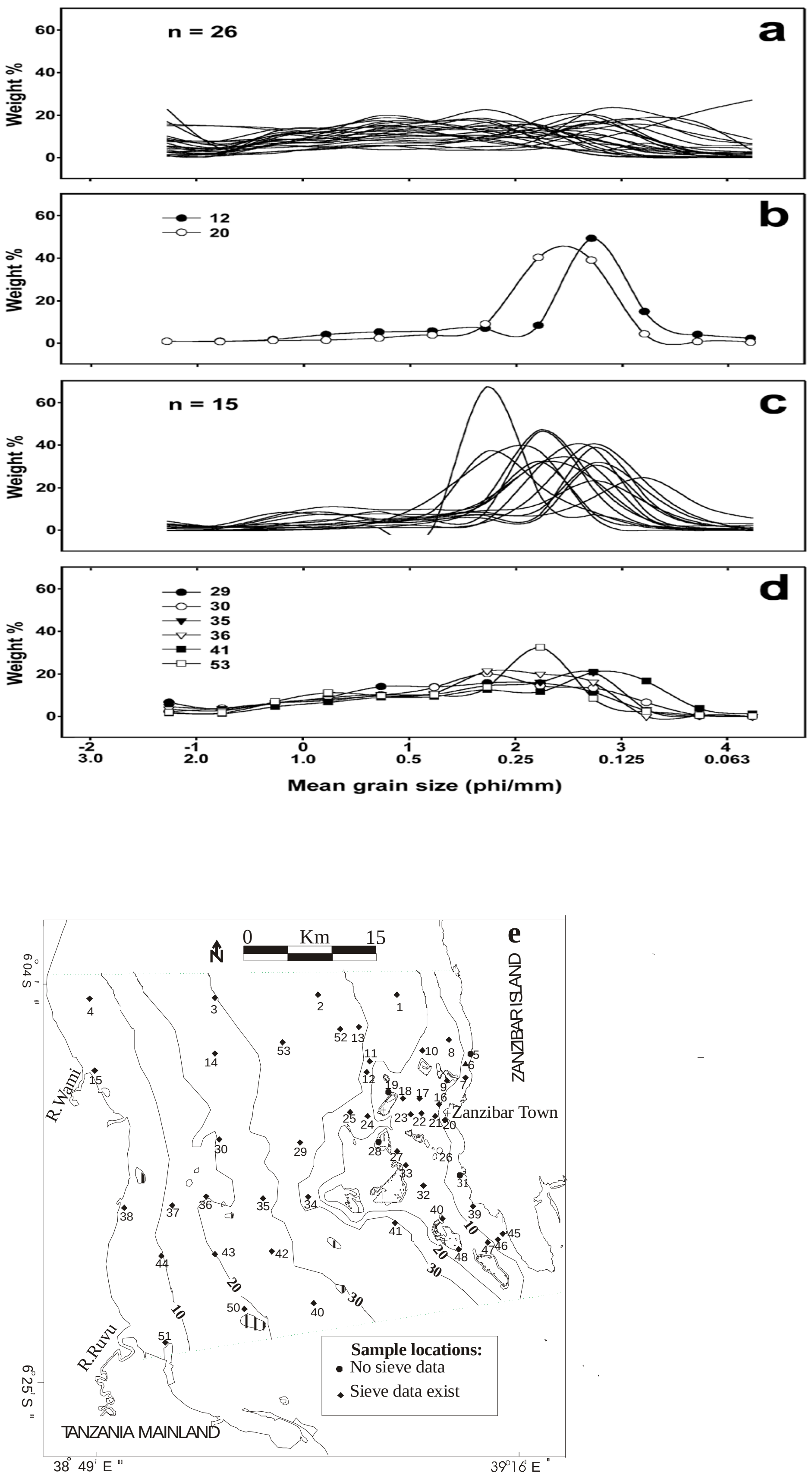

Fig. 3: Grain size distribution curves of the investigated samples, a-b = eastern side, c-d = western side; c = location of the 49 samples whose grain size distribution curves are discussed. Note that a and c represent the typical cases, while b and d represent the abnormal cases