Preliminary investigation on the Pleistocene/Holocene Sea-Level Changes along the Coastline of Tanzania, with reference to Unguja and Pemba Islands

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ABSTRACT

Along the coast of Tanzania, coral reefs, marine terraces and beach ridges are among the most important geomorphological features indicative of the Pleistocene/Holocene sea level changes. Three major terrace units can easily be identified on the mainland coast, namely, Mtoni (youngest), Tanga and Sakura (oldest). Three terrace units have also been identified on the Islands of Unguja and Pemba. On the basis of the difference in the terrace elevations between the two terrace systems it is postulated that the marine terraces on the islands probably represent minor fluctuations of sea level, rather than major phases of sea level fluctuation. A sand beach on the seaward side and several sand ridges on the landward side represent the Recent phase. The oldest Palaeoshoreline is approximately 5 m above the present sea level, and extends landward to more than 1 km. Specific localities around the two islands where Pleistocene/Holocene sea level changes has been preserved in the form of marine terraces and/or beach ridges include Chwaka, Uroa, Jambiani, Paje and Nungwi (Unguja island) and Vumawimbi and Kiuyu (Pemba island).

RESUMO

Ao longo da costa da Tanzania, os recifes de corais, terraces marinhos e cristas de praia estão entre as feições mais importantes indicadoras de mudanças do nível do mar no Pleistoceno/Holoceno. Três unidades maiores de terraços podem ser facilmente identificados na costa da Tanzania continental nomeadamente Mtoni (mais jovem), Tanga e Sakura (mais antigos). Três unidades de terraços também foram identificados nas ilhas de Unguja e Pemba. Baseando-se nas diferenças em elevação entre os dois sistemas de terraços, foi postulado que os terrços marinhos nas ilhas provavelmente representam pequenas flutuações do nível do mar e detrimento de flutuações maiores do nível do mar. Uma praia arenosa do lado do mar e cristas arenosas do lado de terra firme representam a fase recente. A paleo linha de costa mais antiga está à 5 metros acima do presente nível do mar e estende-se para mais do que 1 km pelo continente adentro. Localidades específicas a volta das duas ilhas onde as mudanças do nível mar no Pleistoceno/Holoceno são preservadas em forma de terraços marinhos e/ou cristas de praia inluem Chwaka, Uroa, Jambiani, Paje and Nungwi (ilha de Unguja), e Vumawimbi and Kiuyu (ilha de Pemba).

1 Introduction

Over geological history, sea level has fluctuated in response either to climatic changes or local factors. During the Pleistocene and Holocene periods, the world has seen major fluctuations in climatic condition. The most notable changes are those of oxygen isotope stage 5 (last interglacial) and stage 2 (last glacial maximum). During the last interglacial period (approximately 72000 -130000 years ago), the world experienced warming that is considered to have been higher than present (Burroughs, 2001). This warm period was associated with melting of both marine and land-based glaciers. As a result there was a global rise in sea level. It has been suggested that the rise in sea level was about 5 m above the present level (Ramsay and Cooper, 2002).

Owing to the sea-level rise, the last interglacial period was associated with a landward migration of coral reefs in the tropics and vast low-lying coastal areas were invaded by the reef forming organisms. As a result remnants of the high sea level stand can be identified in many tropical areas where coralline cliffs are well developed. During the last glacial maximum (oxygen isotope 2) between 25 and 10 ka the world experienced cooling with the formation of glaciers in high latitude areas. The peak of this cooling was around 18 ka (CLIMAP 1976). This cooling had a profound impact on the sea level. It is estimated that global fall in sea level was more than 100 m below the present level. Again the change was likely associated with the colonization of new shelf by coral reefs. Probably the remnant of this change is preserved in the form of underwater cliffs.

As the earth changed from Late Pleistocene glacial to the Holocene interglacial conditions, there was melting of ice sheets, which led to the global rise in sea level (Fairbank, 1989). This is documented in the form of ice rafted deposits that have been found to be widespread in the north Atlantic (Heinrich et al 1988; Hillaire-Marcel et al., 1994).

Within the Holocene period, climatic condition has fluctuated as documented by ice core records from both Antarctica and Greenland (Banola et al., 1987) and other indicators. Apart from global factors, sea level changes occur in response to the local factors. In many places of coastal Tanzania, uplifting during the Quaternary has led to the formation of many raised reef limestone geomorphologies (Stockley 1928; Kent et al., 1971). Also faulting has been common in the Tanzanian coastal area probably contributing to the present geomorphology (Stockley 1928; Kent et al., 1971; Shaghude and Wannas, 2000). All these evidence of tectonic activity might have been accompanied with changes in local sea level. Other than the work of Alexander (1968, 1969, 1985) on the distribution of beach ridges and terraces, not much have been done to document sea level changes in coastal Tanzania. Due to the lack of detailed information on the geology and chronology of the coast Arthurton et al. (1999) refer to most of the coastal rocks as of unknown age.

Since climatic variability has been documented to vary even on decadal time scale (e.g. Chambers et al., 1999), information on the sea level fluctuation over the geological time scale is important in predicting future trends in sea level rise/fall. Such data is also of paramount importance in assisting planning of coastal resources utilization particularly land.

The present work is an attempt at documenting past sea level changes over geological time scale as preserved in coastal sedimentary in Tanzania

2 Study Area Description

The present work was conducted on the east coasts of Unguja and Pemba Islands that make up Zanzibar (Fig 1). The geology of the two islands is generally similar (Stockley, 1928; Kent et al., 1971) except for the extent of exposure of some units. Whereas the oldest surface rocks (lower to middle Miocene) occur widely in Pemba they are restricted only to small localities in Unguja. Morphologically, Pemba Island is characterised by a low-lying shore with numerous marine inlets surrounded by thick mangrove stands. Unguja Island is elongate and indented only sparsely.

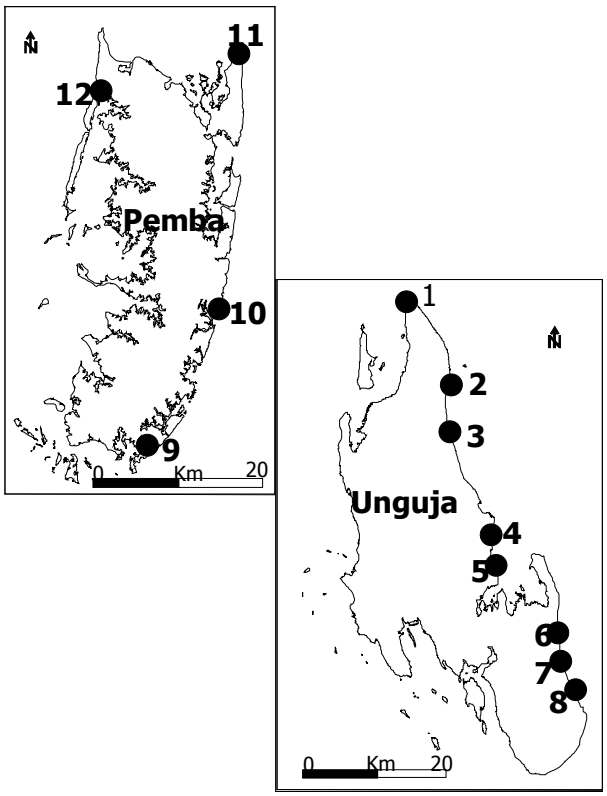


Figure 1. Location map showing the investigated sites along the eastern coast of the two islands. 1 = Nungwi, 2 = Matemwe, 3 = Kiwengwa, 4 = Uroa, 5 = Chwaka, 6 = Bwejuu, 7 = Paje, 8 = Jambiani, 9 = Ukuu Fueni, 10 = Vitongoji, 11 = Vumawimbi, 12 = Kiuyu.

3 Methodology

The fieldwork was conducted on the eastern coasts of Unguja and Pemba Islands involving the whole of the eastern coast with special attention at some sites (8 sites on Unguja and 4 on Pemba). Field excursions were undertaken to map all rock units, identify and count sand ridges, and taking attitudes. Vertical cores were retrieved from sand ridges by hammering open-ended 1m-long PVC pipes into the sediment.

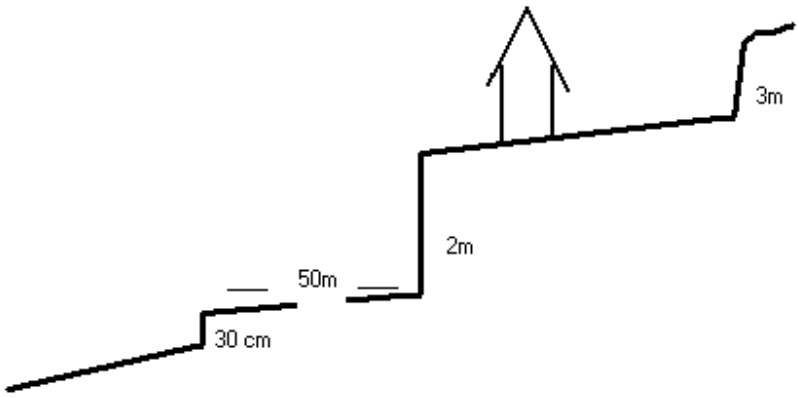


Figure 2. Typical terraces at Chwaka Bay.

Cores were sub-sampled for particle-size analysis at every 5 cm of length. Particle size distribution was determined for six cores collected from Jambiani, Kiwengwa, Matemwe, Uroa (2 cores) and Vumawimbi (Fig. 1)**.** Samples for particle-size analysis were washed of all salts, dried and sieved through a single stack of 11 sieves spaced at 0.5Φ for 15 minutes.

4 Results

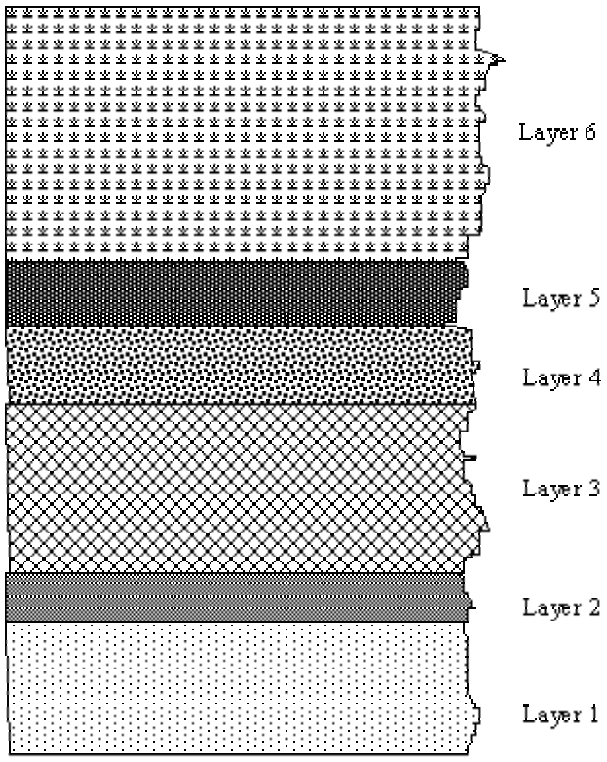
4.1 Beach terraces

On Unguja island, imprint of sea-level changes in the form of beach terraces was clearly evident at Chwaka Bay and Nungwi (Fig. 1). Beach terraces were not evident on the other parts of the eastern coast of Unguja and instead beach ridges were the most common geomorphological features indicative of Holocene sea-level fluctuations. Out of the four sites visited along the eastern coast of Pemba island, extensive beach terraces were evident at one site, namely Vitongoji (Fig. 1). At Vumawimbi on Pemba island, a small vertical cliff shows various depositional facies indicative of Holocene sea level changes.

At Chwaka Bay, three phases of paleoshoreline, which are in a series of steps are easily recognizable (Fig. 2). The lowest step, which is a sand ridge about 0.3m high starts immediately from the beach berm and extends for about 50m landward. The second step, which is made up of a coralline cliff, is 2m high and extends for another 50m landward

before encountering a third step that is about 3m high above the second step (Fig. 2). Whereas the third step that is made up of coral limestone does not show any undercut, undercuts at several places characterize the second step. The total height of the steps is 5.3m, which is agreeable with the height of the last high sea-level stand (Ramsay and Cooper, 2002).

At the northern tip of Unguja Island (Nungwi), three steps of beach terraces are evident. The vertical cliffs separating the terraces are each composed of reef limestones. Beach ridges are the most common geomorphological features superimposed on the lowest terrace but less evident on the older terraces. The second and third terraces are higher than 5 m.



Layer 6: Sandy, devoid of shells
Layer 5: Sandy soil with few shells
Layer 4: Sand layer rich in shell fragments/whole shells
Layer 3: Pebbly (pumice) layer
Layer 2: Black sandy soil
Layer 1: Very fine beach sand over rocky base

Figure 3. Stratigraphical section at Vitongoji

At Vitongoji a series of steps is found within a distance of less than 50 m. A coral platform forming the present intertidal zone fronts a low-lying coral cliff that forms the first step. The second step is also made up of coral limestone but ends up into a short step that is composed of dunes. A vertical section through the dune shows six layers (Fig. 3). The bottom layer

Table 1: The granulometric parameters of the layers in Figure 3.

Layer	Thickness (cm)	Mean	Sorting	Skewness	Kurtosis
6	50	2.93	0.45	0.12	1.17
5	10	2.48	1.01	-0.33	1.12
4	10	-1.91	7.93	-0.84	4.32
3	30	2.07	1.78	-0.39	1.57
2	10	2.22	1.114	-0.17	0.99
1	?	3.56	0.69	-0.19	0.99

(Layer 1) is composed of very fine beach sand overlying a rocky substratum, which constitutes an old coral platform. A dark humic sandy soil constitutes the second layer (Layer 2) and is overlain by a pebbly layer that is approximately 30 cm thick (Layer 3). The pebbles are made of pumice. Layer 4 is 10 cm thick and is composed of sand, rich in shell fragments. Some complete shells of gastropods are also embedded in the layer. The overlying layer (Layer 5), which is also about 10 cm thick is sandy soil with few shells fragments. The topmost layer (Layer 6) is 50 cm thick sand that is devoid of shell fragments. The uppermost part of the layer is whitish in color whereas the rest of the layer is fine gray sand. The stratigraphic sequence reflects sedimentation during the past high sea level stand. Mean, sorting, skewness and kurtosis are presented in Table 1.

4.2 Beach ridges

The best preserved beach ridges on the eastern coast of Unguja island were found at Jambiani – Bwejuu areas as well as at Uroa, north of Chwaka. Beach ridges were also found to be the most prominent geomorphological features showing Holocene sea-level changes at Vumawimbi and Kiuyu areas on Pemba island. The ridges are essentially a series of old beach berms with very fine sand at the surface and coarse sand below (Fig. 4). Mean particle size for two cores collected from sand ridges show a peak (coarse sediment) between 20 and 30 cm (Fig. 4). Generally the lower part of the cores are characterized by coarser sediments relative to the surface sediments. The mean particle size of recent beach sediments on the east coast of Unguja island ranged between 1.5 - 1.63 phi to as fine as 2.82 phi.

At places the ridges are bounded landwards by a cliff that has several undercuts and vary in extent from place to place. At Jambiani, 7 ridges were identified within a 14 m wide tract of the shore between the berm of the present beach and the cliff while at a neighbouring site only 3 ridges were clear in a 0.5 km width of the shore. These sand ridges indicate a series of sea level stands as the sea retreated.

5 Discussion

Beach ridges and marine terraces have been identified to indicate Late Pleistocene/Holocene sea level fluctuations. Whereas the beach ridges are evident almost everywhere along the

eastern coast of Zanzibar, marine terraces are only evident at few localities on the islands. Marine terraces on the mainland have been identified by several workers (e.g. Stockley, 1928 and Halligan, 1956). Alexander (1968) identified three marine terrace units, named from the

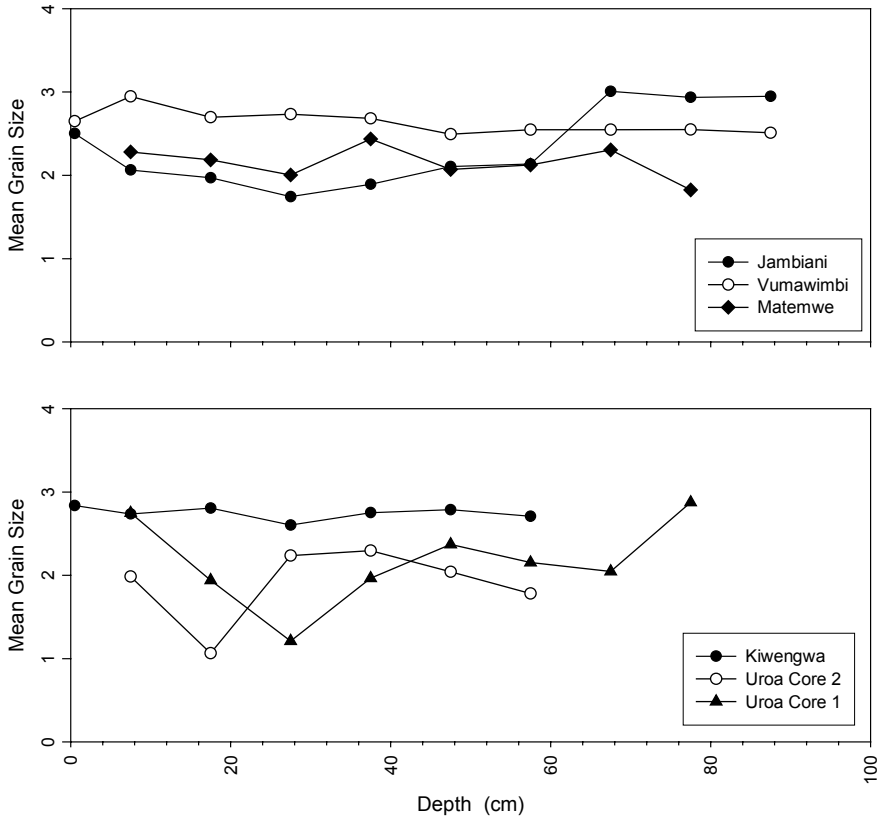


Figure 4. Mean particle size (given in phi) of core samples taken at various sand ridges at Unguja Island.

lowest (youngest) to highest (oldest) as the Mtoni, Tanga and Sakura. The Tanga terrace occurs continuously along the section of the shore between Dar es Salaam and the Kenya boarder, but the other two terraces occur in a discontinuous manner along the shore.

The seaward margin of the Tanga and Sakura terraces is characterized by the presence of tilted cliffs of coral limestone. Alexander (1985) reports four former marine levels in the vicinity of Tanga, at 2-3 m, 4.5-6 m, 24-27 m and 41 m, the latter three being the most

prominent. The lower two terraces were interpreted to represent minor Holocene sea-level fluctuations.

On the basis of the marine terraces described by Alexander (1968, 1985) two major similarities between the terraces on the mainland shore and those found on the two islands

can be noted i.e. sand ridges are common geomorphological features superimposed on these terraces especially on the lowest terrace, and that the terrace steps are composed of reef limestones. It appears that uplift, which has been reported by Alexander (1968) to be the dominant process for the terrace origin on the mainland, is also responsible for the origin of the terraces on the two islands. Despite this broad similarity terrace elevations on the mainland is several folds higher than on the islands (no terrace system on the island exceed 10 m above the present sea level). In the absence of chronological data it becomes rather difficult to correlate the terrace units on the islands with those found on the mainland, but on the basis of the elevation figures described above it seems that the terrace units on the islands represent minor sea level fluctuation during the late Holocene.

The wide spread occurrence of coral limestones on Unguja and Pemba Islands shows that the sea level was once very high to cover much of the islands. Thus, steps of cliffs and sand ridges observed both on the mainland and islands of Unguja and Pemba reflect the extent of shoreline changes.

6 Conclusions

Marine terraces and beach ridges are important geomorphological features which help to unlock the late Pleistocene/Holocene history of sea level fluctuations. The observed marine terraces on the two islands are similar to those reported by Alexander (1968) on the shore of Tanzania mainland coast in that all consist of steps of coral limestone indicative of marine and tectonic origin. However, the elevations of the marine terraces of the two islands are much lower than those found on the mainland suggesting that the marine terraces on the islands probably represent minor phases of late Holocene sea level fluctuations rather than major phases of sea level fluctuations.

The downcore distribution of the mean particle size of the beach ridges indicate changes in the energy regime during deposition of the sediment, indicative of regressive and transgressive phases. Future work on the marine terraces and beach ridges in Tanzania requires geochronological data to provide further light on the absolute time scale on the Holocene sea level fluctuations.

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