Western Indian Ocean J. Mar. Sci. Vol. 4, No. 2, pp. 185–197, 2005

Sediment sources and their Distribution in Chwaka Bay, Zanzibar Island

Alfred N. N. Muzuka[1], Yohanna W. Shaghude[1], Kjell O. Wannäs[2] and Ntahondi Nyandwi[1]
[1]*University of Dar es Salaam, Institute of Marine Sciences, P. O. Box 668, Zanzibar, Tanzania;* [2]*Stockholm University, Department of Geology and Geochemistry, S-106 91, Stockholm, Sweden*

Key words: *Halimeda,* stable isotope, sediment distribution, sediment thickness

Abstract—This work establishes sediment sources, character and their distribution in Chwaka Bay using (i) stable isotopes compositions of organic carbon (OC) and nitrogen, (ii) contents of OC, nitrogen and $CaCO_3$, (iii) C/N ratios, (iv) distribution of sediment mean grain size and sorting, and (v) thickness of unconsolidated sediments. The Chwaka Bay is located on the eastern coast of Zanzibar Island and is about 50 km^2. It is a shallow partly sheltered lagoon with large intertidal area and fringing mangrove forest. The stable isotope values of nitrogen and OC, which averages 1.5±0.9‰ and -17.5±2.3‰ respectively, increases offshore indicating decrease in the influence of terrestrial material. Furthermore, nitrogen isotope values ranging from 0.3 to 3.9% suggest that the values result from nitrogen fixing plants. Because the bay has high abundance of calcareous green algae *Halimeda* plants, most likely low $\delta^{15}N$ values reflect the influence of this photosynthetic plant to the total sediment budget. This inference is supported by low C/N ratio values that averages 7.9 ± 1.4 and with highest values being confined close to the mangrove forest. The contents of OC and nitrogen, which averages 0.75±0.60% and 0.11±0.08% respectively, are highest close to the mangrove forest. The sediment thickness in the Bay is higher in the northern part than in the southern part. The character of sediments in terms of grain size differs between eastern and western parts of the Bay. The eastern part is characterized by medium to fine white carbonate sand with mean grain size higher than 2ϕ, whereas coarse sediments with mean values less than 2ϕ characterize the western part. The content of calcium carbonate is very high with values being higher than 90% for the whole Bay owing to high concentration of carbonate sand-forming *Halimeda*.

INTRODUCTION

Chwaka Bay, which is approximately 50 km^2, is one of the largest bays in Zanzibar and a major economic centre relative to other bays found on the island. The Bay is rich in fisheries resources, mangrove trees in the southern part (Figs. 1 and 2), and good site for seaweed farming. The bay is a shallow, partly sheltered lagoon and located 22 km east of Zanzibar town (Fig. 1). The Chwaka Bay can be classified as fringing reef towards open ocean with landward side being defined by rock cliffs, pocket beaches and inlets/creeks such as Mapopwe and Kinani (Arthurton *et al.*, 1999; Kairu and Nyandwi, 2000; UNEP 2001; Arthurton, 2003; Fig. 1). The Bay is protected from the open ocean by a fringing reef that is located at the bay entrance. The bay experiences a semi-diurnal tide, with a mean spring tidal range of 3.2 m (Cederlöf *et al.*, 1995). At lowest spring tide a large part of the Bay (more than 60%) is exposed, and because of this fluctuation, the tides regulate the activities of communities around the bay on short cycle bases (Tobisson *et al.*, 1998).

Previous studies have indicated that the bay is rich in sea-grasses and algae assemblages

Corresponding Author: ANNM
E-mail: muzuka@ims.udsm.ac.tz

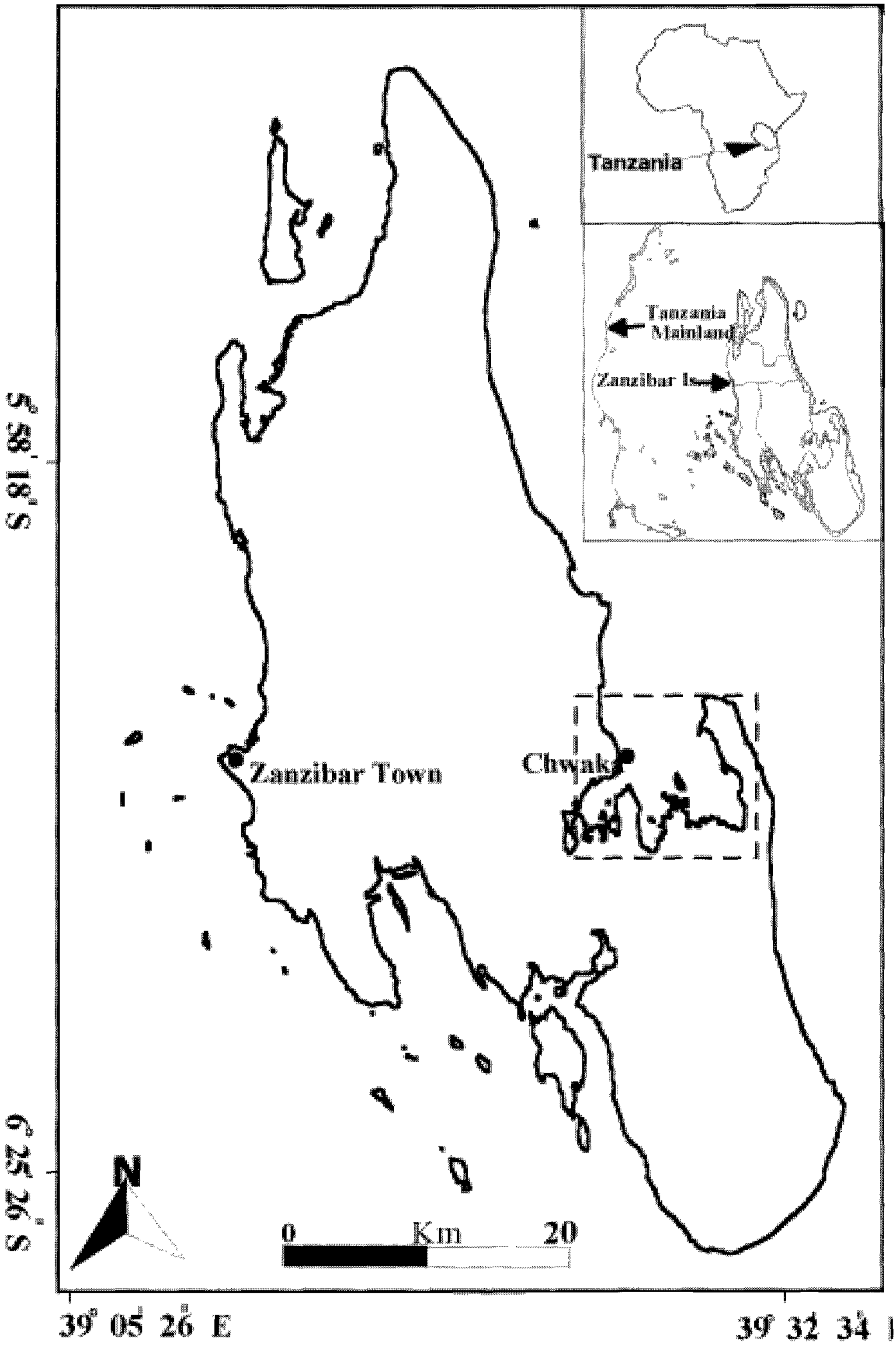

Fig. 1. Map showing location of the study area of Chwaka Bay (rectangle)

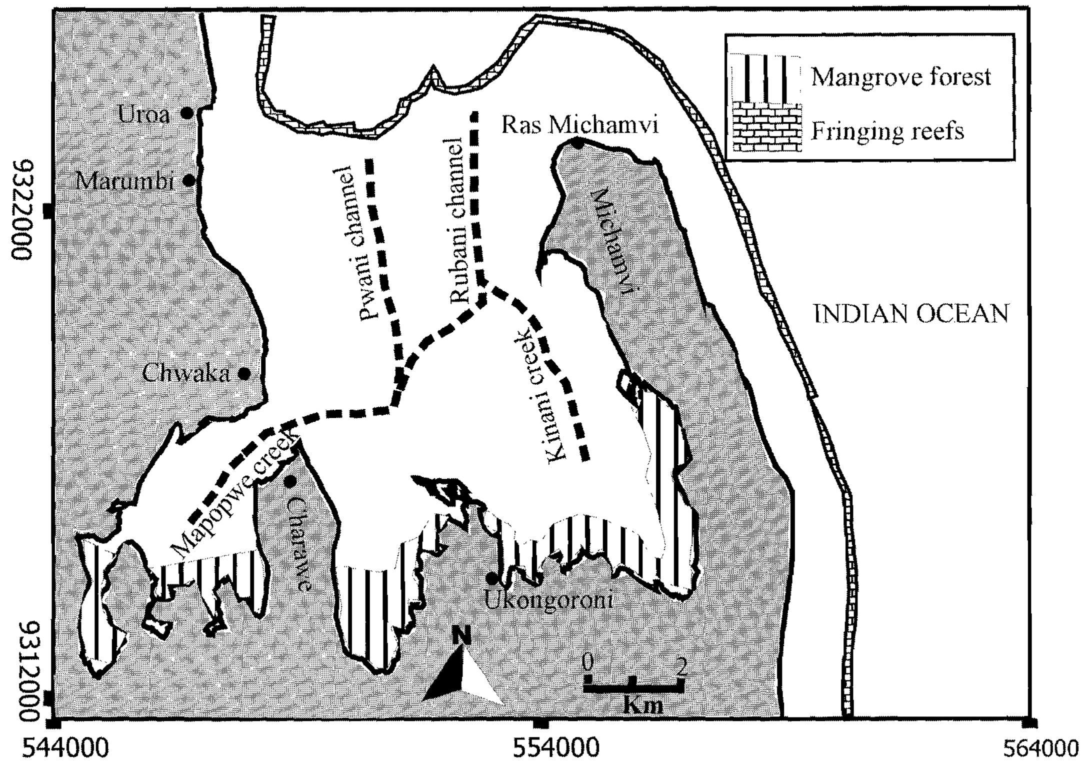

Fig. 2. Map showing the approximate location of the tidal channels (block dotted lines) and coverage of mangroves and location of fringing reefs in the Chwaka Bay

(Wolanski, 1989; Mohammed and Johnstone, 1995, Mohammed, 1998), though their distribution pattern and species compositions are poorly known (Muzuka *et al.*, 2001). One of the algae species thriving well in the Bay is the $CaCO_3$ producing *Halimeda* (Muzuka *et al.* 2001). The $CaCO_3$ rich *Halimeda* flakes are fragile and easily converted into sand, but the role of *Halimeda* in contributing to the total sand budget on the beach and within the Bay, is not known as yet.

Although *Halimeda* is likely to be one of the major suppliers of sediments to the Chwaka Bay, other sources are poorly known. In delineating various sources of organic matter in aquatic environment C/N ratios and stable isotopes of OC and nitrogen are potentially useful parameters, and have been used extensively in the globe (e.g. Sweeney *et al.*, 1980; Peters *et al.*, 1978; Macko, 1983; Anderson *et al.*, 1992; Muzuka, 1999a, 2001). These parameters have been used separately or in combination under the assumption that each source has distinct signature. For example, the stable isotope composition of organic carbon for terrestrial plants following C_3 photosynthetic pathway averages -27‰ while that of marine phytoplankton in tropical and temperate waters averages -20‰ (Sackett *et al.*, 1965; Fontugne and Duplessy, 1981; Rau *et al.*, 1989; Muzuka, 1999b). Similarly, land plants have C/N ratio values greater than 12 while phytoplanktonic material have C/N ratio values that average 6 (Meyers, 1994). In Tanzania few studies have been conducted to evaluate relative proportion of organic material derived from various environments (Muzuka, 1999a, 2001). In the Chwaka Bay such information is lacking.

It has been demonstrated that grain size distribution changes predictably along the direction of transport with mean grain size decreasing and sorting improving/getting better along the transport direction (McLaren and Bowles, 1985; Dyer, 1986; Nyandwi, 1995, 1998). Furthermore, fine-grained sediments are generally deposited in low energy environment whereas coarse-grained sediments are deposited in high-energy environment. Although information on grain size distribution helps in understanding and characterizing the depositional environment, such information is lacking in the Chwaka Bay.

From the above review of available information in the Chwaka Bay there is a lack of knowledge on sources of organic matter and sediment distribution pattern. Therefore, the present study utilizes geochemical (stable isotopes of organic carbon and nitrogen, and contents of organic carbon, nitrogen and calcium carbonate) and sedimentological (mean grain size, sorting and sediment thickness) parameters to identify sources of organic matter and to establish sediment distribution pattern in a tide-dominated Bay of Chwaka.

MATERIALS AND METHODS

To obtain good spatial coverage of sediment characteristics in the Chwaka Bay, two hundred and ninety two locations were visited between April and September 1999 (Fig. 3). Sampling locations, which included beach areas, were spaced approximately 100 m apart and fixed using Global Positioning System (GPS). The upper 10 cm of sediment column in the Chwaka Bay was sampled during high tide period using a van Veen grab sampler. Sediment samples from beach slope, which were collected as part of the bay in order to have continuity and compare its parameters with those of submerged areas of the bay, were scooped from the upper 5 cm using a spoon sized shovel. Samples for determination of calcium carbonate ($CaCO_3$) content were dried at a temperature of 60°C, and ground to fine powder. Determination of $CaCO_3$ content was achieved by acid leaching method where approximately 2 g of sample was used. Acid insoluble residues were washed to remove salts four to five times, and then dried in oven at a temperature of 60°C. The $CaCO_3$ contents were expressed in percentages and the

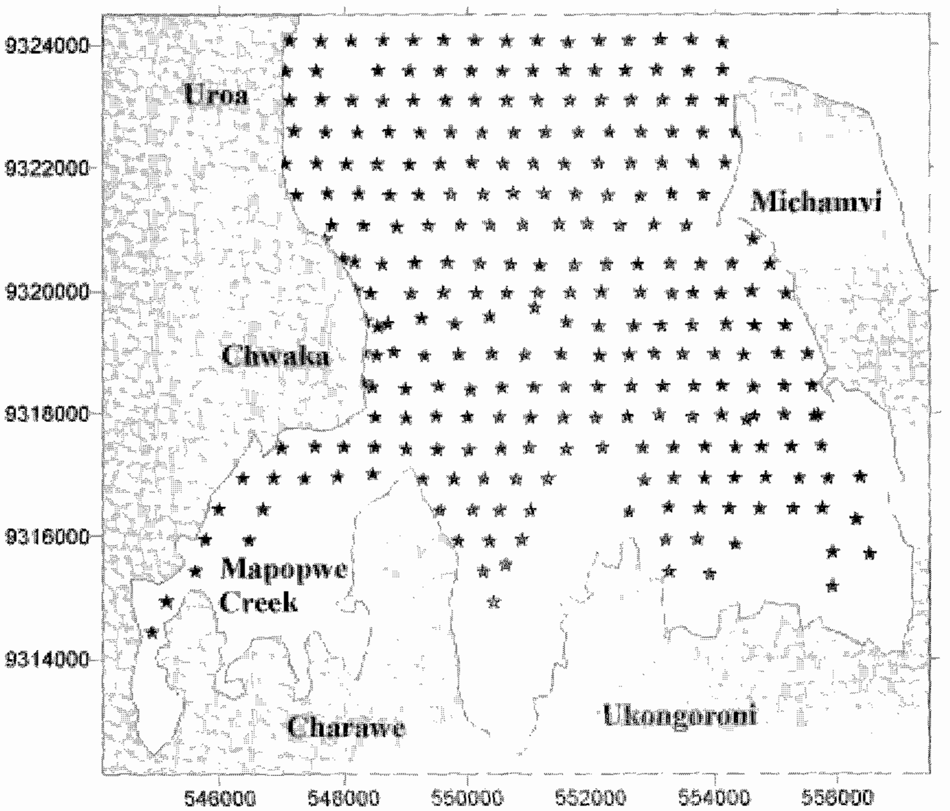

Fig. 3. Map showing sediment-sampling sites in the Chwaka Bay

reproducibility was within ±5% (n = 5%). Sediment thickness was measured from an anchored boat using a 5 m long iron bar pushed into the sediment until its refusal of further penetration presumably after reaching the basement. Only one trial was done under the assumption that sediment thickness obtained was representative of the sediment thickness of the area

All sediment samples for grain size analysis were de-salted using distilled water and then oven dried at 60°C. About 100 g of dried sample was sieved through a single stack of 11 sieves spaced at 0.5ϕ for 15 minutes. Shaking (sieving) was stopped halfway to break any aggregates present in each sieve. The results obtained from sieving were converted into weight percentage and used to calculate statistical parameters of mean and sorting using graphic (after Folk and Ward, 1957) method. Mean values are reported in phi values but can be expressed in millimeter using the equation:

$$\phi = -\log_2 d = -\left(\frac{\log_{10} d}{\log_{10} 2}\right)$$

where ϕ = particle size in phi units, and d = grains diameter in mm

Subsamples for isotope analysis were dried at a temperature of 60°C, ground to fine powder in an agate mortal, and then decalcified by dilute (1M) HCl. The resulting residue after the acid leaching was dried at a temperature of 60°C and analysed for the OC and nitrogen contents as well as their isotopic composition with an automated CHN analyser connected to a continuous flow mass spectrometer (Finnigan Mat Delta+) at the Department of Geology and Geochemistry, Stockholm University. The isotopic composition of OC and nitrogen are reported in the usual δ notation and expressed in parts per thousand using the equation:

$\delta^n X = (R_{sample}/R_{standard} - 1) \times 1000$, where $^n X$ is either ^{13}C or ^{15}N and R is isotope ratio. The isotope values of organic carbon and nitrogen are reported relative to Chicago Pee Dee Belemnite (PDB) and atmospheric nitrogen, respectively. The overall accuracy is better than ± 0.2 ‰.

RESULTS

The mean grain size in phi values for the Chwaka Bay sediments averages 1.4 ± 1.1ϕ with the western central part of the Bay being characterized by coarser sediments relative to the eastern central part (Fig. 4). Also, fine-grained sediments characterized the beach and nearshore areas (Fig. 4). Most of the Chwaka Bay sediments can be classified as coarse to fine grained sediments (Table 1A). Sorting values range from 0.38 to 3.89 and averages 1.34±0.49, with much of the bay sediments being moderately sorted (Table 1B). The stable isotope values of OC, which range from -23.8 to -13.3‰ and average -17.4±2.3‰, show a general increase with increasing distance offshore with influence of the channels being well defined (Fig. 5). Similarly, the nitrogen isotope values, which average 1.5±0.9‰, tend to increase with increasing distance offshore (Fig. 6). Furthermore, flanks of the channel are enriched in ^{15}N relative to the channels (Figs. 2 and 6). The content of OC averages 0.66±0.36%. The OC content increases across the channels from East to West and shallow areas close to the mangrove stands have relatively high contents of OC (Fig. 7). Similarly, the content of nitrogen for the Chwaka Bay, which averages 0.10±0.05% shows an East to West increase (Fig. 8). Areas close to the mangrove stands as well as western central part of the bay have relatively high contents of nitrogen (Fig. 8).

The C/N ratio values range from 5.5 to 11.6 and average 7.9±1.4. Owing to a narrow range, land-offshore trend is not clear, however, slightly high values are confined close to the mangrove forest (Fig. 9). The $CaCO_3$ content ranges from 72.9 to 100% and averages 97.9±3.0% with low values being confined towards the mangrove forest (Fig. 10). Sediment thickness is greatest towards the open ocean on the western part of the Bay, with tidal channels having thinner sediment cover (Fig. 11). Most of the southern part of the Bay including the creeks has a rocky substrate (Fig. 11).

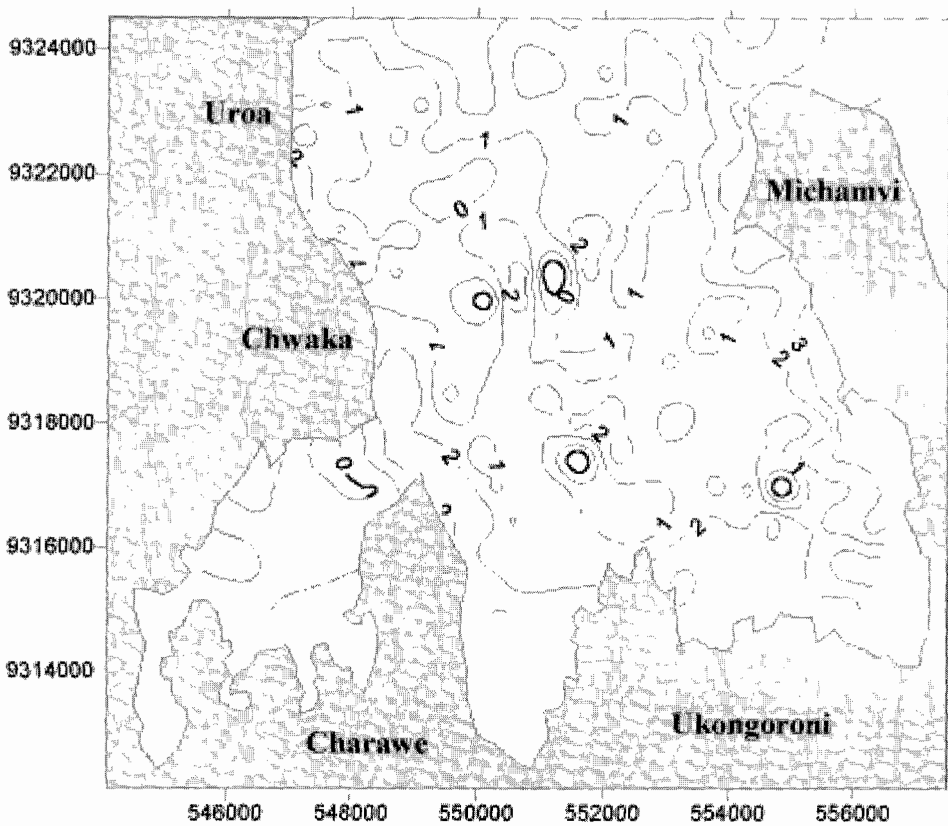

Fig. 4. Mean grain size distribution (phi units) in the Chwaka Bay with contour interval of 1 phi

Table 1. Frequency distribution of mean (A) grain size according to Wentworth (1922) and Sorting (B) according to Folk and Ward (1957) classifications for the Chwaka Bay sediments.

A: Condensed Wentworth (1922) size classification scheme for sand

phi	mm	Frequency	Percent Frequency	Wentworth Classification
-1.0-0.0	2.00-1.00	20	7.0	Very Coarse Sand
0.0-1.0	1.00-0.50	77	27.1	Coarse Sand
1.0-2.0	0.50-0.25	97	34.2	Medium Sand
2.0-3.0	0.25-0.13	71	25.0	Fine Sand
3.0-4.0	0.13-0.06	19	6.7	Very Fine Sand

B: Classification of sediment sorting as established by Folk and Ward (1957)

Sorting Values	Frequency	Percent Frequency	Degree of Sorting
<0.35	0	0.0	Very Well Sorted
0.35-0.5	15	5.4	Well Sorted
0.5-0.7	46	16.6	Moderately Well Sorted
0.7-1.0	201	72.6	Moderately Sorted
1.0-2.0	15	5.4	Poorly Sorted
2.0-4.0	0	0.0	Very Poorly Sorted
>4.0	0	0.0	Extremely Poorly Sorted

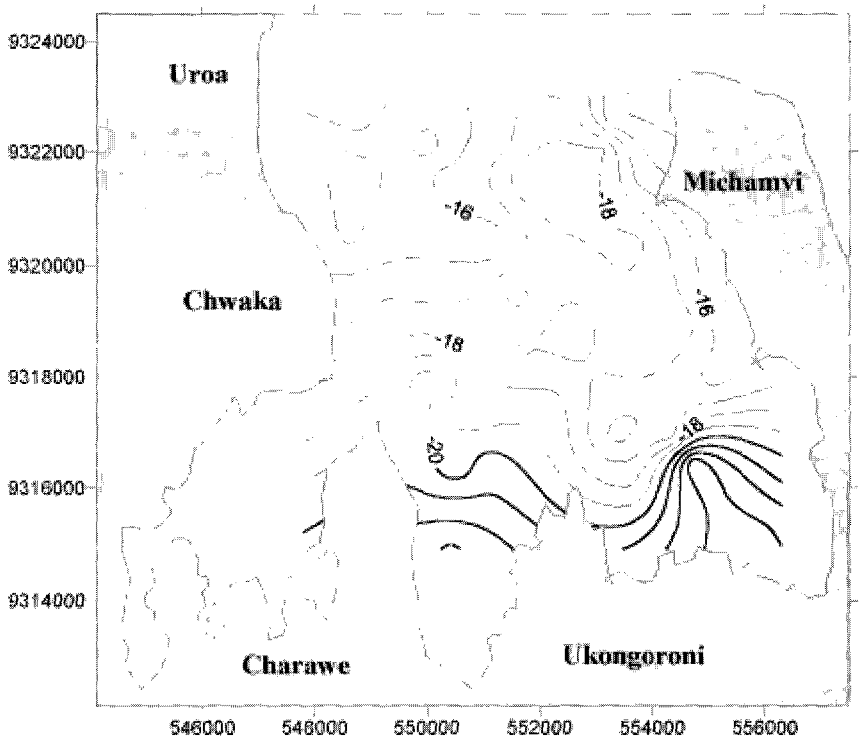

Fig. 5. Distribution of the stable isotope values of organic carbon (‰) in the Chwaka Bay with contour interval of 1‰

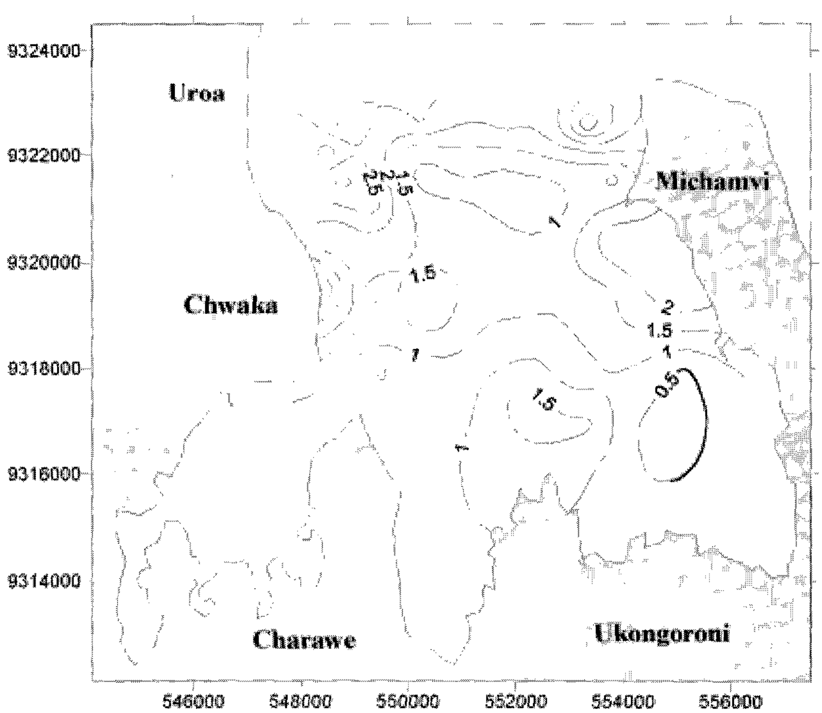

Fig. 6. Distribution of nitrogen stable isotope values (‰) in the Chwaka Bay. Note that the contour interval is 0.5‰

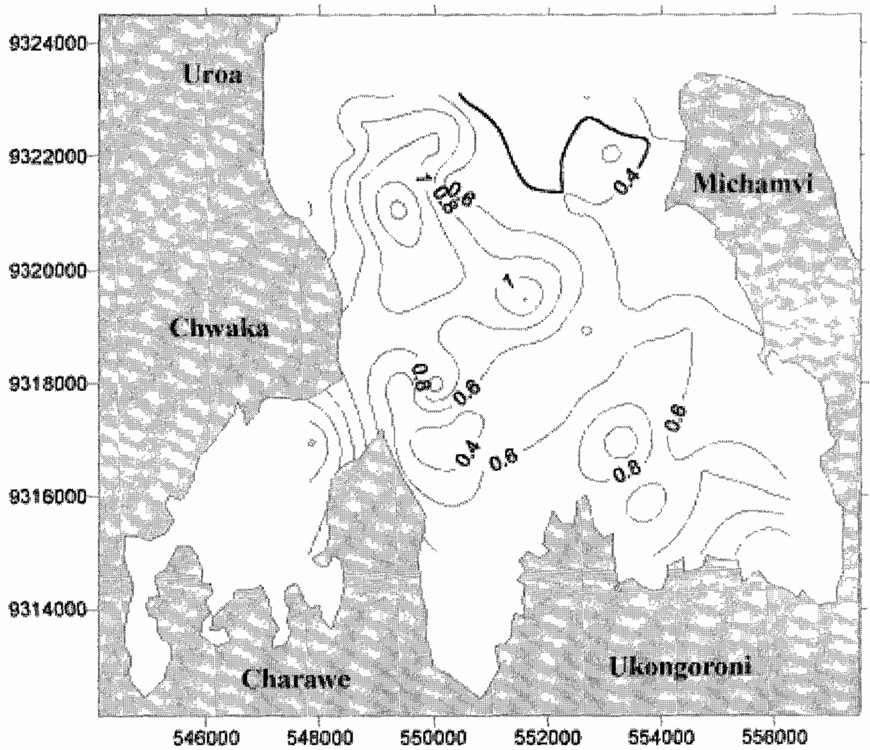

Fig. 7. Lateral variation in the percentage of organic carbon contents in the Chwaka Bay. The contours are spaced at 0.2%

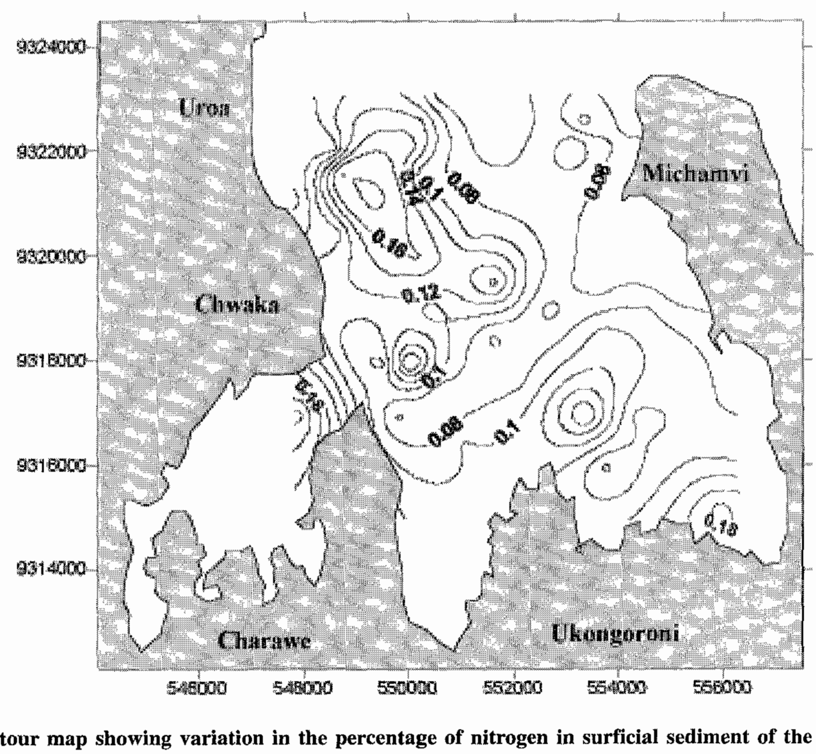

Fig. 8. A contour map showing variation in the percentage of nitrogen in surficial sediment of the Chwaka Bay Contour interval is 0.02%

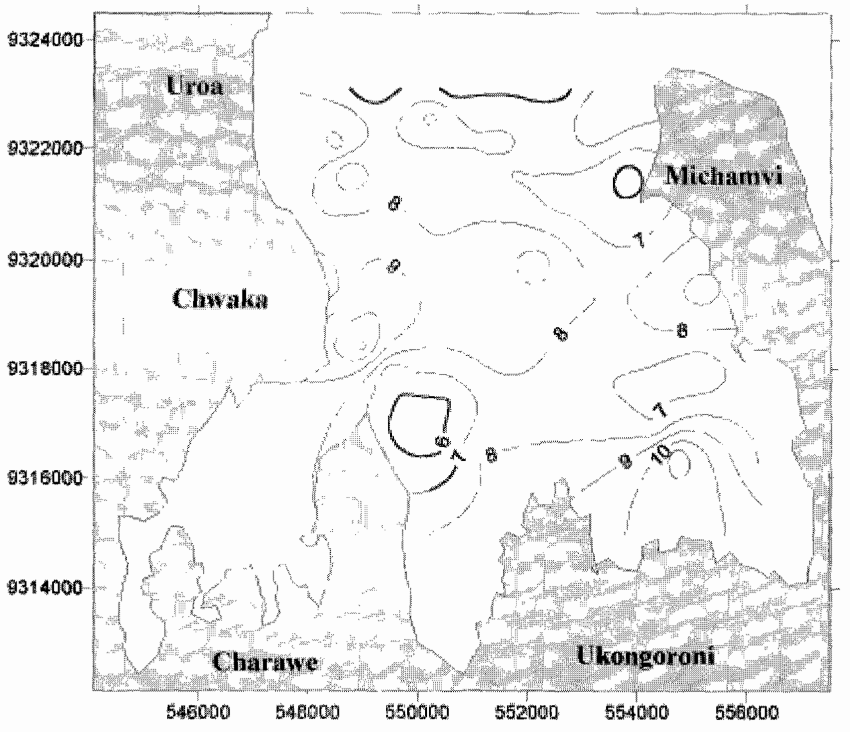

Fig. 9. Lateral variation in the C/N ratio values in the Chwaka Bay with contours interval of 1

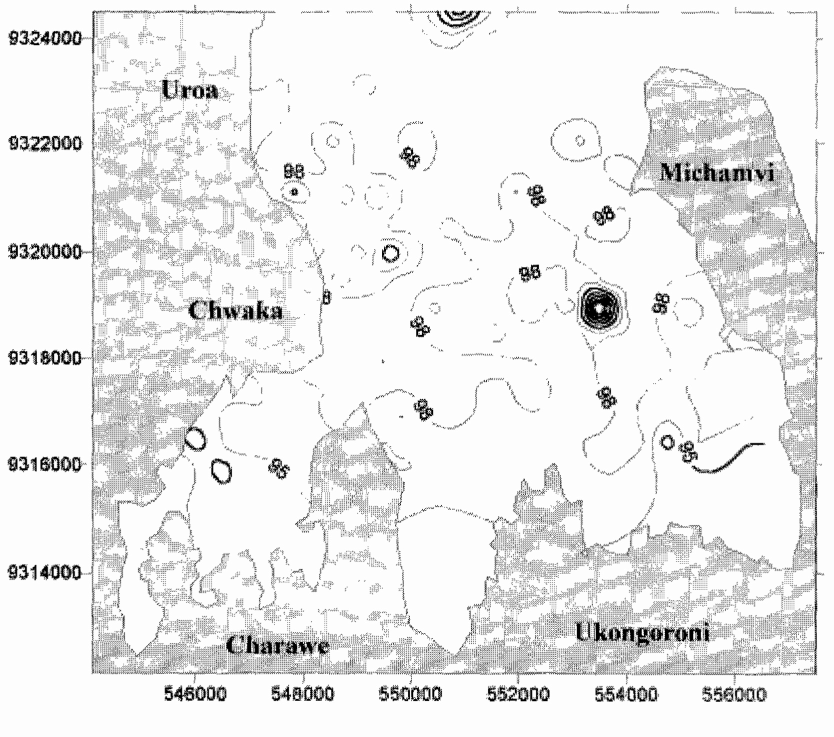

Fig. 10. Lateral variation in the percentage of $CaCO_3$ in the Chwaka Bay. Note that the contour interval is 3%

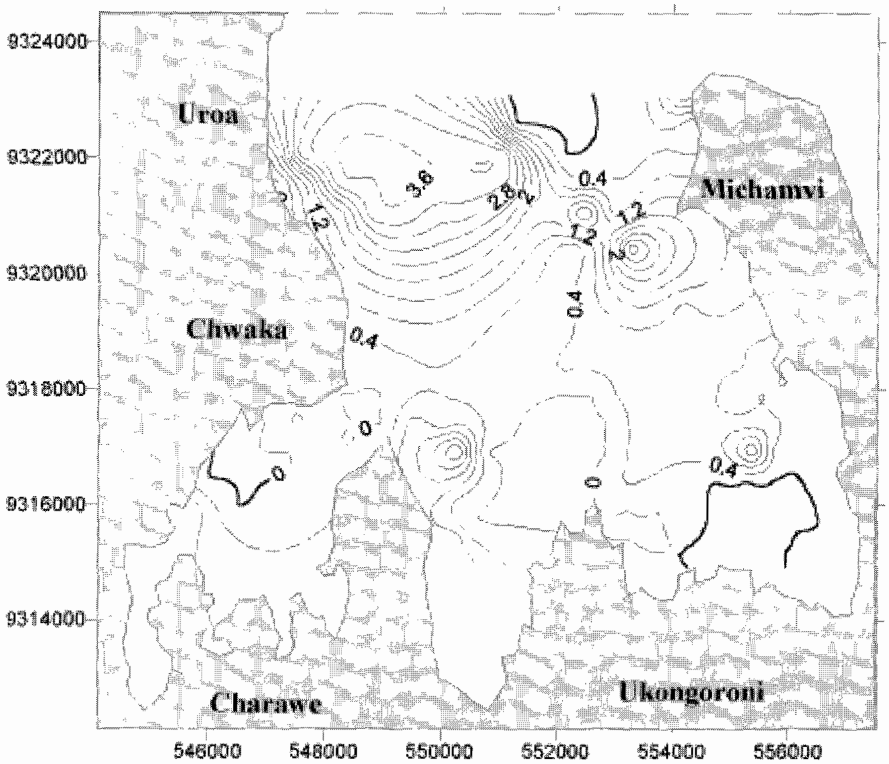

Fig. 11. Sediment thickness (meters) distribution in the Chwaka Bay. Note that the contour interval is 0.4 meters

DISCUSSION

As pointed out in the previous section, the stable isotope values of organic carbon and nitrogen for the Chwaka Bay increase with increasing distance from the mangrove stands towards the open ocean. A similar trend of increasing isotopic values of OC and nitrogen, with increasing distance from shore, has been reported in the Tanzanian coastal waters off the city of Dar es Salaam and Zanzibar town (Muzuka, 1999a, 2001). The observed $\delta^{13}C$ and $\delta^{15}N$ trend in the Chwaka Bay can be attributed to a progressive decrease in the influence of land-derived materials, including the mangrove litter. Influence of land-derived material is high along the tidal channels of Mapopwe, Kinani and Rubani, and implying that the tidal channels act as conduit of land derived materials to offshore areas. Assuming that the stable isotope composition of the mangrove fresh leaves, which averages -27‰ (Muzuka and Shunula 2000), represents terrestrial end member and that of *Halimeda* (-13‰) represents marine end member, relative proportion of terrestrial material along the channel is about 36% close to the open ocean. Although fresh mangrove parts have C/N ratios that are higher than 20 (Muzuka and Shunula, 2000) this signature is not reflected in the underlying sediments owing to mixing of nitrogen rich material derived from marine primary producers such as phytoplankton and algae. As a result, C/N ratios do not indicate any terrestrial influence in the Bay.

As depicted in Fig. 11, thickest sediment cover is found towards the open ocean on the western side of the main tidal channel while thinnest cover is found in the southern part of the Bay. According to preliminary results of *Halimeda* distribution, which are the major producers of carbonate sand in the Bay, highest concentration of *Halimeda* is observable in the western sector of the Bay (Muzuka *et al.*, 2001). The observed sediment distribution pattern could have resulted from preferential deposition of *Halimeda* flakes owing to high primary productivity. Other possible factors include circulation pattern in the Bay and/or Holocene rise in sea level, where both processes lead to erosion or deposition. According to the work of Wolanski (1989), Cederlof *et al.* (1995), Mwaipopo (1998) and Nyandwi and Mwaipopo (2000) the eastern side has stronger tidal currents relative to the western part of the bay. Thus the western part, with weaker currents could act as a deposition center (depocenter) of sediments eroded from other parts of the Bay, and thus, thicker sediment column. Furthermore, the western part of the Bay under the weaker currents conditions favour the production of *Halimeda* as it is often associated with low energy regime (Harney *et al.*, 2000).

The grain size distribution pattern shows that the eastern part of the Chwaka bay has finer material relative to the western part. This could be attributed to differences in energy level and type of sediments deposited. Coarser material would imply high-energy condition in the western than in the eastern side. This is contradictory to the above statement where field measurements have indicated that the eastern side has stronger tidal currents relative to the western part of the bay (Wolanski, 1989; Mwaipopo, 1998). The observed trend can happen when the type of sediments are fragile (easy to disintegrate) after being subjected to stronger currents. Owing to enrichment in ^{13}C that indicate in situ source, high concentration of $CaCO_3$, and high cover of *Halimeda* (Muzuka *et al.*, 2001), which is a major producer of carbonate rich sand, it can be concluded that coarse sediments in the western sector are a result of deposition of *Halimeda* flakes. Finer particles in the eastern part could be a result of perpetual grinding of fragile *Halimeda* flakes, as a result of strong tidal currents existing in the area.

The contents of OC and nitrogen as well as the C/N ratios for the Chwaka bay are slightly elevated close to the mangrove forest relative to other parts of the bay. Elevated values of C/N ratios indicate contribution of mangroves to the organic matter preserved in the sediments. Preferential preservation of OC and nitrogen could be attributed to anoxic conditions existing in mangrove areas owing to high input of material in the mangrove stand. Materials in other parts of the bay are derived from the *Halimeda* and owing to shallower depths and exposure of large part of the bay during low tide; oxygen penetration is high, thus causing fast oxidation of organic matter.

The content of $CaCO_3$ for the beach slope sediments is relatively high and is similar to the sediments collected from the bay. This shows that dilution by silisiclastic (terrigeneous non-carbonate) material from land is minimal, and most likely the sediments are derived from the Bay. Lack of siliciclastic material can be attributed to non-existence of rocks that can lead to production of siliciclastic materials. Although the eastern part of Zanzibar Island is lithologically covered by Pleistocene raised reef limestone, carbonate at the beach is not derived from the surrounding raised reef limestone owing to the lack of rivers and streams capable of transporting measurable amount of carbonate sediments.

CONCLUSION

The stable isotopes of OC and nitrogen show that sedimentary organic matter in Chwaka Bay are largely of marine origin with influence of allochthonous materials being confined in the tidal channels and decreasing further offshore. Coarse-grained sediments are confined in the western part of the Bay where the *Halimeda* spp cover (which is the major producer of carbonate sand in the Bay) is high, an indication that hydrodynamic conditions alone do not control sediment grain size distribution. Because the *Halimeda* produces large quantity of sand, any activities that will lead to the disappearance of the *Halimeda* will accelerate beach erosion in the areas surrounding the bay. Sediment thickness in the bay is generally thin with most of the areas being less than 0.5 m.

Acknowledgement—We are grateful to the anonymous reviewer for very constructive comments that led to the improvement in the quality of this paper. We are also grateful for cooperation with Mr J. Kangwe and the field assistance by Idrissa, A., Nassor, A., and Vuai, A. We also highly acknowledge D. Salum for the laboratory assistance. The Sida-SAREC Regional program funded this project.

REFERENCES

Anderson B., Scalan, R. S., Behrens, E. Wm., & Parker, P. L. (1992) Stable carbon isotope variations in sediment from Baffin Bay, Texas, U.S.A.: Evidence for cyclic changes in organic matter source. *Chem. Geol.* **101,** 223-233.

Arthurton R.S. (2003) The fringing reef coasts of eastern Africa - present processes in their long-term context. *Western Indian Ocean J. Mar. Sci.* **2,** 1-13.

Arthurton, R.S., Brampton, A.H., Kaaya, C.Z. & Mohamed, S.K. 1999 Late Quaternary coastal stratigraphy on a platform-fringed tropical coast - a case study from Zanzibar, Tanzania. *J. Coastal Res.* **15,** 635-644.

Cederlöf, U., Rydberg, L., Mgendi, M., and Mwaipopo, O. (1995) Tidal exchange in warm tropical lagoon. Chwaka bay, Zanzibar. *Ambio* **24,** 458-464.

Dyer, K.R. (1986) Coastal and Estuarine Sediment Dynamics. Wiley, London, 342p.

Folk, R. L. & Ward, W. C. (1957) Brazos river bar. A study in the significance of grain size parameters. *J. Sed. Petrol.* **27,** 3-26.

Fontugne, M. R., & Duplessy, J. C. (1981) Organic carbon isotopic fractionation by marine plankton in the temperature range -1 to 31°C. *Oceanologica Acta* **4,** 85-90.

Harney,J. N., Grossman, E. E., Richmond, B. M. and Fletcher III, C. H. 2000. Age and composition of carbonate shoreface sediments, Kailua Bay, Oahu Hawaii, Coral Reefs, **19,** 141-154

Kairu, K. & Nyandwi, N. (2000) Guidelines for the Study of Shoreline Change in the Western Indian Ocean Region. IOC Manuals and Guides No. 40. UNESCO 2000 (English), vii + 55pp.

Macko, S.A. (1983) Source of organic nitrogen in Mid-Atlantic coastal Bays and continental shelf sediments of the United States: Isotopic evidence. *Carnegie Institution Geophysical Laboratory Yearbook (1982/83), Washington.* pp. 390-394

McLaren, P. & Bowles, D. (1985) The effects of sediment transport on grain size distributions. *J. Sed. Petrol.* **55,** 457-470.

Meyers P.A. (1994) Preservation of elemental and isotopic source identification of sedimentary organic matter. *Chem. Geol.* **114,** 289-302.

Mohammed, S. M. (1998) Nutrient Dynamics and Exchanges Between a Mangrove Forest and a Coastal Embayment: Chwaka Bay, Zanzibar. PhD Thesis Stockholm University Kiasta Snabbtryck AB, Stockholm

Mohammed, S. M., & Johnstone W. J. (1995) Spatial and temporal variations in water column nutrient concentration in a tidally dominated mangrove creek. Chwaka Bay, Zanzibar. *Ambio* **24,** 482-486.

Muzuka, A. N. N. (1999a) Stable isotope compositions of sedimentary organic matter off Zanzibar Town. *Tanzania J. Sci.* **25,** 55-70.

Muzuka A. N. N. (1999b) Isotopic compositions of tropical East African flora and their potential as source indicators of organic matter in coastal marine sediments. *J African Earth Sci.* **28,** 757-766.

Muzuka, A. N. N. (2001) Sources of organic matter in the Msasani Bay and Dar es Salaam harbour. In: Richmond, M. D., and Francis, J. (eds) Marine Science Development in Tanznaia and Eastern Africa. Proceedings of the 20th Anniversary Conference on Advances in Marine Science in Tanzania. 28 June- 1 July 1999, Zanzibar, Tanzania. IMS/WIOMSA, p. 61-76.

Muzuka, A. N. N. & Shunula, J. P. (2000) Stable isotope compositions of carbon and nitrogen of mangrove stands along the Tanzanian coastal zone. Unpublished research report no. IMS/2000/03.

Muzuka, A. N. N., Kangwe, J. M., Nyandwi, N., Wannäs, K., Mtolera, M. S. P., & Björk, M. (2001) Preliminary results on the sediment sources, grain size distribution and percentage cover of sand-producing *Halimeda* species and associated flora in Chwaka Bay. In: Richmond, M. D., and Francis, J. (eds) Marine Science Development in Tanznaia and Eastern Africa. Proceedings of the 20th Anniversary Conference on Advances in Marine Science in Tanzania. 28 June- 1 July 1999, Zanzibar, Tanzania. IMS/WIOMSA, p. 51-59.

Mwaipopo, O. (1998) On tidally induced flow and the associated thermal behaviour in Chwaka Bay, Zanzibar. M.Sc. Thesis, Göteborg University, 44pp.

Nyandwi, N. (1995) The Nature of the Sediment Distribution Pattern in the Spiekeroog Backbarrier Area, the East Frisian Islands. Berichte, Fachbereich Geowissenschaften, Universitaet Bremen, Nr. 66 Bremen, 162pp.

Nyandwi, N. (1998) Sediment distribution patterns in the back barrier areas of the Wadden Sea, Spiekeroog Island, Germany. In: Alexander, C. R., Davis, R. A., and Henry, V. J. (eds.) Tidalites: Processes and Products. SEPM Special Publication No. 61, 15-22.

Nyandwi, N. & Mwaipopo O. U. (2000) Hydrodynamics of Chwaka Bay, a shallow mangrove-fringed tropical embayment, Tanzania. In: Flemming, B. W., Delafontaine, M. T., and Liebezert, G. (eds) Muddy Coast Dynamic and Resource Management. Elsevier Science B.V., Amsterdam, p. 3-12.

Peters K. E., Sweeney, R. E. & Kaplan, I. R. (1978) Correlation of carbon and nitrogen stable isotope ratios in sedimentary organic matter. *Limnology and Oceanography* **23,** 598-604.

Rau, G. H., Takahashi, T.& Des Marais, D. J. (1989). Latitudinal variations in plankton _^{13}C: Implications for CO2 and productivity in past ocean *Nature* **341,** 516-518.

Sackett, W. M., Eckelmann, W. R., Bender, M. L. & Be, A. W. H. (1965) Temperature dependence of carbon isotope composition in marine plankton and sediments. *Science* **130,** 235-237.

Sweeney, R. E., Khalil, E. K. Kaplan, I. R. (1980). Characterization of domestic and industrial sewage in southern California coastal sediments using nitrogen, carbon, sulfur and uranium tracers. *Marine and Environmental Res.* **3,** 225-243.

Taira, A., & Scholle, P.A. (1979) Discrimination of depositional environments using settling tube data. *J. Sed. Petrol.* **49,** 787-800.

Tobisson, E. J., Andersson, Z., Ngazi, L., Rydbergy, L., & Cederlöf, U. (1998) Tides, Monsoons and Seabed: Local knowledge and Practice in Chwaka bay, Zanzibar. *Ambio* **27,** 677-685.

UNEP (2001) Eastern Africa Atlas of Coastal Resources - Tanzania. UNEP, Nairobi. 111pp.

Wentworth, C. K. (1922) A scale of grade and class terms for clastic sediments. *J. Geol.* **30,** 377-392.

Wolanski, E., 1989. Measurement and Modelling of the Water Circulation in Mangrove Swamps. COMARAF: Regional Project for Research and Training on Coastal Marine Systems in Africa-RAF/87/038. UNESCO, Series No.3, 43 pp.