

Geomorphology of the Kenyan coast: Not as a Result of Sea-Level Change alone

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ABSTRACT

The coastal setting and the geology control the geomorphology on the Kenyan coast. The evolution of the physical environment has also been influenced by climate, wave and tidal regime, sedimentation and river discharge. The shore terraces of Kenyan coast correspond to eustatic movements of sea level. There seems to be evidence of a high water level during the late Pleistocene. For the lower terraces a Holocene age is suggested. During the Pleistocene, sea level fluctuations associated with glacial / interglacial phases left well developed raised platforms and beaches. The Kenyan coast has a strong tectonic influence and it is difficult to describe the coast in terms of emergence or submergence only. It can therefore be concluded that the geomorphology of the Kenyan coast is not only as a result of sea level changes but also due to isostatic readjustments and tectonic movements. This paper examines the previous works done on the Kenyan coast in relation to the developments that have led to its geomorphology.

RESUMO

O ambiente costeiro e a geologia controlam a geomorfologia na costa de Quênia. A evolução do ambiente físico também foi influenciado pelo clima, ondas e regimes de marés, sedimentação e descarga fluviais. A planície costeira tem uma história desde o Pleistoceno a Recente e ocorre como terraços formados durante as flutuações do nível do mar do Pleistoceno ao Recente. Parece existir evidências de um nível de água elevado durante o fim do Pleistoceno. Para o terraço inferior é sugerida uma idade Holocénica. Geomorfologicamente, a zona costeira do Quênia é uma linha de costa emergente. Esta foi, por isso, sujeita à regressão marinha desde o Jurássico. Durante o Pleistoceno, as flutuações do nível do mar associadas com fases glacial/interglaciares deixaram plataformas e praias bem desenvolvidas. A costa Queniana tem uma influencia tectónica forte e é difícil descrever somente em termos de emergência e submergência. Os vales deviam, normalmente, indicar uma linha de costa de submergência, mas a submergência podia ter ocorrido cedo do que a emergência mais recente. Este artigo examina os trabalhos anteriores feitos na costa Queniana em relação ao desenvolvimento levado a cabo na sua geomorfologia.

1 Introduction

Kenya is located on the Eastern African coast astride the equator between latitudes 5° 40' north and 4° 4' south and between longitudes 33° 50' and 41° 45' east, and border the Indian Ocean to the east. Kenya has a 574-km coastline running from Kiunga in the north to Vanga in the south (Figure 1). Kenya has two distinct monsoon seasons; northeast monsoon (December to March) and southeast monsoon (May to October). In between occurs the transition period from northeast to southeast and vice versa.

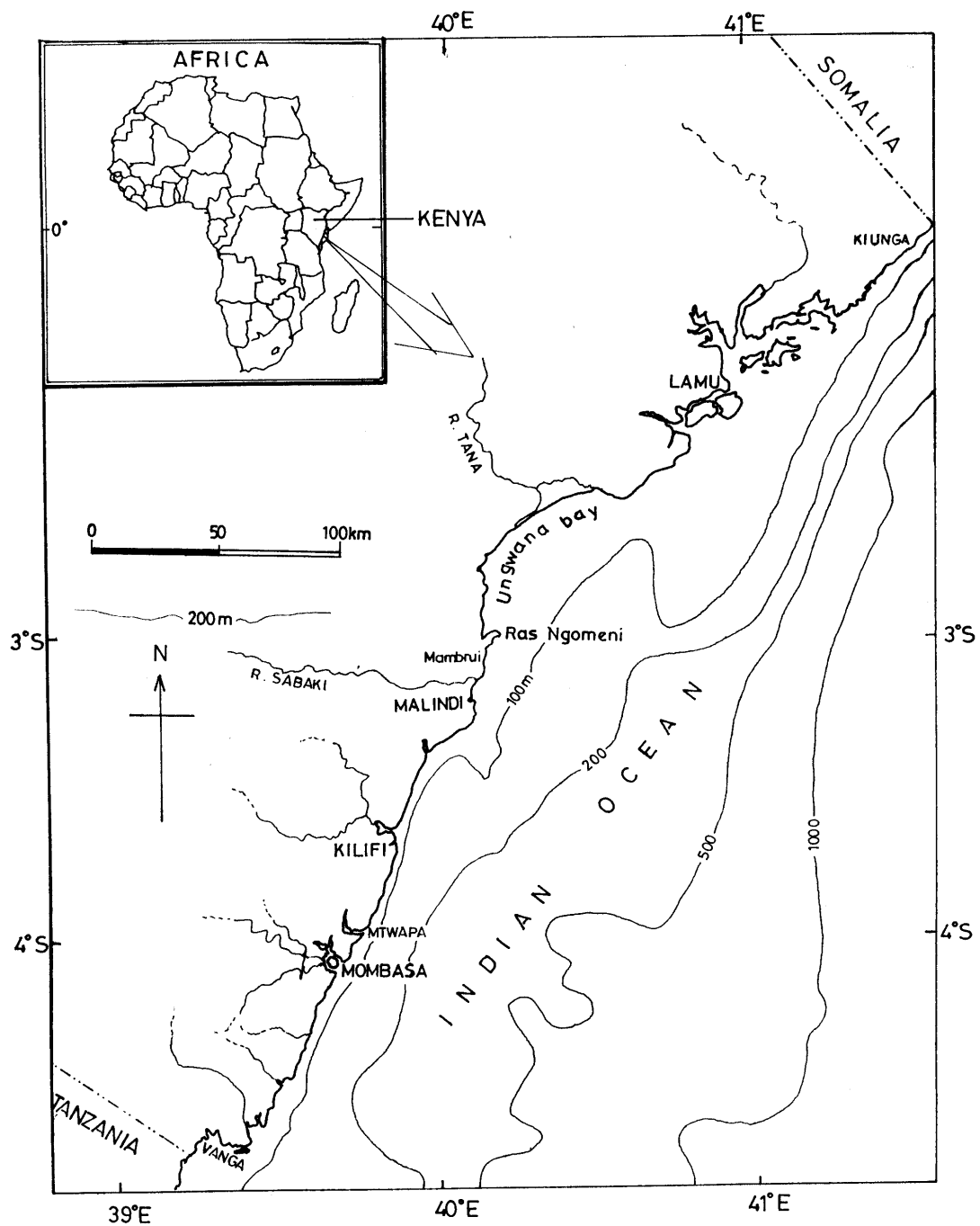


Figure 1. Map of the Kenyan coast. Inset: map of Africa showing Kenya (coast area is shaded).

Climatic patterns are important factors influencing the Kenyan coastal environments and have a bearing in the physical, chemical and biological characteristics of the ocean. The Kenyan coast experiences semi-diurnal tides. The spring tides are up to 4.0 meters and neap tides up to about 1.8 meters. Along the coast, temperatures range from 22 - 34° C during the northeast monsoon season, reducing to about 19 - 29° C in the rainy months of June- August, during southeast monsoon.

2 Methodology

Several authors have studied the shoreline and terraces along the Kenyan coast (Sikes, 1930; Caswell, 1953; Thompson, 1956; Hori, 1970; Toya et al, 1973; Ase, 1978; Read, 1981; Braithwaite, 1984 and Oosterom, 1988) using various methods. Oosterom (1988) also dated the terraces. Some authors present a generalized pattern of the number of terraces recorded either during a field based geological mapping survey or from aerial photographs where as others used field leveling for the determination of the altitude of each marine terrace, relative to either mean sea level or lowest tide level.

3 Study area

3.1 Geological setting

The coastal belt of Kenya has experienced eustatic sea-level oscillations and/or isostatic and differential tectonic movements, which have considerably influenced the coastal configuration. The continental shelf is 2 – 3 km wide with depths dropping below 200 meters within less than 4 km in most places, however, it widens significantly at the mouths of rivers Tana and Sabaki exceeding 15 km off the northern end of Ungwana Bay. A shallowing south of Lamu (Figure 1) is due to the sediments brought into the sea by River Tana, which has a considerable discharge, $4.7 \times 10^9 \text{ m}^3 \text{ a}^{-1}$ (Brakel, 1984) and the terrigenous sediment load has dominated the development of the coast. The Tana river approaches the coast in a broad floodplain and is connected with widespread deltaic environments dominated by silt/clay environments. The continental slope is generally characterized by gentle gradients of about 1:20 to the shelf edge and shows dissected appearance probably due to previous sub-aerial fluvial action.

Pleistocene formations identified along the coastal plain from the west to the east are; the Holocene (Recent) reef deposits, Shanzu calcarenites member, Mombasa limestone member and the Kilindini sands member (Figure 2). The reef deposits consist of an assemblage of coral limestone, calcarenites and intercalations of quartz sands, sandstone pebbles, silt and calcareous algae. This reef formation extends 3 - 5 km from the present shoreline, underlying the coastal plain, and attains elevations of up to 30 m above sea level. The Kilindini sands comprise mainly quartz sands with subordinate silts and clays.

3.2 Geomorphological setting

The coastal belt of Kenya comprises of the following main topographical features which are closely related to the geological characteristics of the area: the Coastal Plain, the Foot Plateau, the Coastal Range and the Nyika. The altitude of the Coastal Plain is generally less than 45 m above sea level. Different geologic features form the coastal belt. Geomorphologically, the Kenyan coastal zone is an emergent coastline. It has thus been subjected to marine regression since the Jurassic period. During the Pleistocene, sea-level fluctuations associated with glacial / interglacial phases left well developed raised platforms and beaches. The Malindi area, in the north, has experienced a shoreline progradation of up to 750 m over the last 40 years. The north

coast is also characterized by a predominance of sand dunes and tombolos, exemplified at Ras Ngomeni, in addition to recognized higher land uplift and arching.

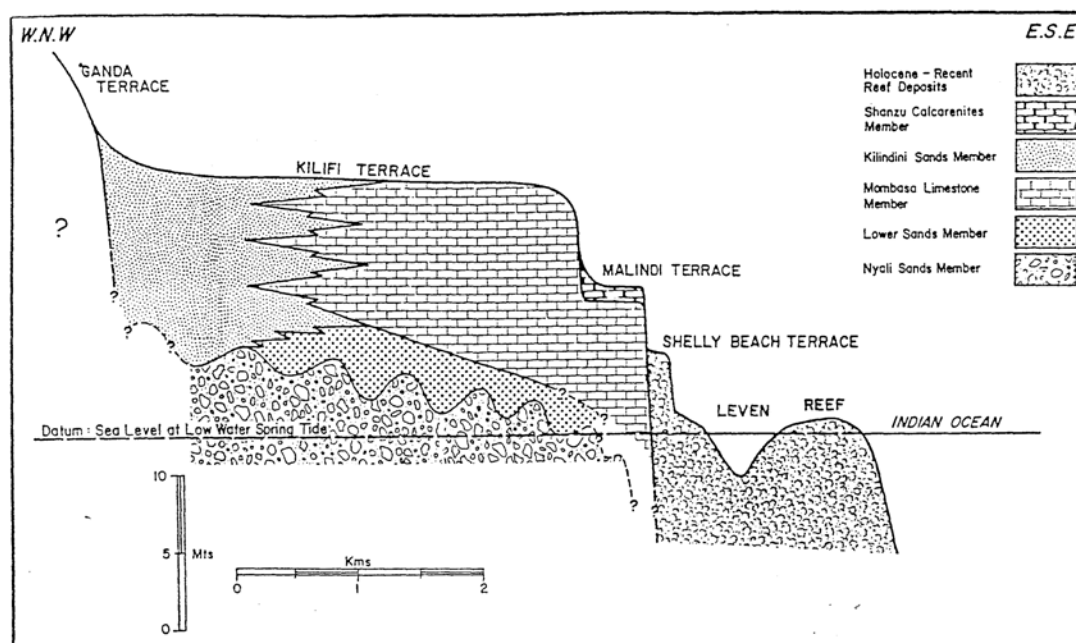


Figure 2. Coastal terraces, stratigraphy and diagrammatic cross section of the Southern Coast of Kenya (source: Read, 1981).

Three different coastal types are recognized along the Kenyan coast which include the Fringing reef shoreline of southern Kenya; the deltaic shoreline of Sabaki and the Tana River and the ancient delta area of the Lamu Archipelago (Kairu, 1997). Inland, behind the coral rocks are found low-lying clays and shales which filled what must have been lagoons in front of the barrier reefs. The geomorphology is divers consisting of sandy beaches, dunes, creeks, muddy tidal flats and rocky shores bordered by cliffs (Ase, 1978, 1981; Ojany, 1984; Oosterom, 1988; and Abuodha, 1992).

In the Northern section, the Coastal Plain is broad, reaching widths of more than 50 km towards the Tana delta. Dune ridges are the main characteristics of the coast. Sometimes at least two generations of dune ridges can be found, the older probably being of young Pleistocene age, the younger closer to the sea of Holocene age (Ase, 1978). The foreshore area between Malindi and Mambrui (Figure 1) generally consists of wide low-gradient extensive beaches, bordered landward by sub-horizontal berms and seaward by runnel and swash bars. These are succeeded inland by an array of complex dune ridge systems of up to 50 m in height. The beach ridges, closely associated with the dunes are of variable Holocene age.

In the Southern section, the Coastal Plain is 3 - 6 km wide and attains elevations of up to 50 m, its landward boundary is marked by the rise of the Foot Plateau, whose elevations range from 60 -140 m. Coral rocks characterize the coastline and sandy beaches are protected from the open ocean by patch and fringing reefs. Except for the interruption of the reefs at the creeks by outflow of fresh water from rivers, the reefs

run parallel to the entire shoreline at a distance of 1-2 km (Abuodha, 1992). Cliffs formed by wave erosion with raised shorelines are the most prominent feature indicating a shoreline of emergence. Mangrove swamps are very common, especially in muddy areas where fresh water enters the coast.

4 Results

4.1 Coastal terraces and the age of the shorelines

The shore terraces of Kenyan coast correspond to eustatic movements of sea level. Along the Kenyan coast up to seven raised terraces at various altitudes are found (Table 1). There seems to be evidence of a high water level during the late Pleistocene. For the lower terraces a Holocene age is suggested. These terraces are easily identified along the southern coast of Kenya. The upper most terrace has been named Matuga surface (Hori, 1970), Marafa Terrace (Toya et al, 1973) and Cambini (Oosterom, 1988). The Chagamwe terrace follows with an age of between 650 000 – 750 000 BP and elevation of 40 – 85 m above chart datum. Oosterom called this terrace Tezo. The Upper Mombasa Terrace (15 – 37) m above chart datum is also called the Ganda terrace (20 – 37) m above chart datum and Kilifi terrace (15 – 18) m above chart datum (Table 1, Figure 2). Ase (1978) and Oosterom (1988) had different names for this terrace (Table 1). The Lower Mombasa terrace is also called Malindi terrace (Figure 2) / Levels II – IV and Mackenzie with elevations of between 6 - 12 m above chart datum and an age of 130 000 BP. Shelly Beach terrace is also called Level I and Uhuru I with elevations of 4 – 6 m above chart datum and an age of 10 000 BP. The present day reef platform is also called Uhuru II with elevations of 2 – 4 m above chart datum and zero age. Also characteristic of the continental slope morphology are the marine terraces at about –5 m and –15 m (Read, 1981) and at –8 m and –35 m (Thompson, 1956), which probably correspond to levels of the shoreline during the various stages of eustatic decline.

4.2 Shorelines as indications of land and sea level movements

The Kenyan coast is a passive continental margin. Faults with NE-SW trends generate the majority of the Kenyan coastal depositional basins. Along certain straight segments of the coast, the continental shelf is markedly absent, suggesting a fault origin. This occurrence is supported by a sudden drop of the sea-floor topography off the coast which is attributed to the postulated Ruvu-Mombasa fault (Abuodha, 1992). This fault apparently maintains a NNE - SSW orientations along the coast. Thick sedimentary deposits of Permo -Triassic to recent cover the coastal zone. The coast therefore has a strong tectonic influence and it is difficult to describe the coast in terms of emergence or submergence alone. A number of creeks north of Mombasa, such as Mtwapa and Kilifi creeks would indicate a recent rise in sea level, as would the submerged terraces; while several raised beach terraces now occurring 1-2 km inland indicate a recent sea level drop. The dynamics of the sea level in this area are insufficiently studied to allow any unequivocal statements about trends in sea level fluctuations. It has been assumed that the shore terraces of Kenya correspond to eustatic movements of sea level. However, if the datings are reasonably correct, the terraces would be found well below sea level if no rise of land had occurred during

Table 1. Correlation of the coastal terraces in southern Kenya according to earlier studies

| Author | Sikes (1930) | Caswell (1953) | Thompson (1956) | Hori (1970) | Toyah et al. (1973) | Ase (1978) | Read (1981) | Braithwaite (1984) | Oosterom (1988) | Age (Oosterom) |
|---|-------------------|----------------|---------------------|-------------------------------|----------------------------|-----------------------------------|----------------------------|-----------------------------------|--|------------------------------|
| Study Area | Southern Kenya | Mombasa area | Malindi area | Southern Kenya | Southern Kenya | Mombasa area | Mombasa - Mtwapa area | Southern Kenya | Mombasa area | |
| Terrace Name and Elevation Above Datum | 75 m | Foot Plateau | Foot Plateau | Matuga Surface 80-120m | Marafa Terrace 80-120m | | | | Cambini-I 85-130m Cambini-II 70-90m | 950 000 BP 750 000 BP |
| | 50 m | Foot Plateau | Foot Plateau | Changamwe Surface 45-70 m | Changamwe Terrace 45-70 m | | | | Tezo I+II) 40-85 m | 750 000 BP 650 000 BP |
| | 12m level | 37 m Terrace | 36 m terrace | Upper Mombasa Terrace 15-37 m | Ganda Terrace 20-37 m | VII: 20 m | Ganda Terrace 20 m+? | + 20 m | Majaoni-I 35-50 m | 650 000 BP |
| | 24 m level | | | | | | | | Majaoni-II 25-35 m | 475 000 BP |
| | | | | | Kilifi Terrace 15-18 m | VII: 17 m VI: 15 m V: 13.5m | Kilifi Terrace 15-18 m | | Mtondia-I 15-25 m Mtondia-II 10-15 m | 300 000 BP 180 000 BP |
| | 9 m old sea beach | 7.6 m platform | 7.5 m beach terrace | Lower Mombasa Terrace 10 m | Malindi Terrace 7-10 m | IV: 12 m III: 9 m II: 7 m | Malindi Terrace 7-10 m | +10 to 12 m + 8m | Mackenzie-I 8-10 m Mackenzie-II 6-8 m | 130 000 BP |
| | 4.5 m beach | - | - | Shelly Beach Terrace 5 m | Shelly Beach Terrace 4.5 m | I:5 m | Shelly Beach Terrace 4.5 m | +6 m +4 m | Uhuru-I 4-6 m | 10 000 BP |
| | | | 2 m level | | | | | +2 m Present day reef platform | Uhuru-II 2-4 m | 0 |
| Submarine terraces are present at -8 m and -35 m (Thompson , 1956) and at -5 m and -15 m (Read, 1981) | | | | | | | | | | |

the time in question. Reasons for the uplift would be:

- Loading by water during the Eemian transgression when the sea level was about 3 m higher than today
- Isostatic readjustment to the loading of the more than 100 m thick littoral reef and
- Denudation

Evidence of tectonic movements can be seen in the dipping of sedimentary strata on the coast in Kenya. Stable shorelines built from lithified beach rock and reef limestone are resistant to erosive forces, while low lying and unconsolidated shoreline are vulnerable to shoreline change.

Tide-level recordings tell us of the sea-level movements over the last 200 years. Evidence of changes in sea-level can be seen in increased flooding of low coastal areas, drowning of valleys and shore features, including some ancient man-made features and density currents penetrating further upstream.

The coastal limestones of Kenya have been interpreted as the products of mid-Pliocene movements, which lifted the inland area relative to the coast. Thus the reef is of sub-aerial origin and correlate with a period of low sea-level stand.

5 Summary and conclusion

It has been assumed that the shore terraces of Kenya correspond to eustatic movements of sea level. However, if the datings were reasonably correct, the terraces would be found well below sea level if no rise of land had occurred during the time in question. Evidence of tectonic movements can be seen in the dipping of sedimentary strata on the coast in Kenya. It can therefore be concluded that the geomorphology of the Kenyan coast is not only as a result of sea level changes but also due to isostatic readjustments and tectonic movements.

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