

## Geological evolution of coastal Kenya as inferred from sedimentary sequences and marines terraces

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**Abstract** - Based on extensive field and literature surveys together with radiometric dating evidence, the coastal geology of Kenya consists of the Karoo (Upper Carboniferous-Lower Jurassic) to Recent sedimentary sequences with minor local intrusions of igneous rocks of post-Jurassic age. The oldest sedimentary rocks found in coastal Kenya belong to the Karoo sequence and are exposed in the Mombasa coastal basin.

In East Africa, the Karoo grabens were initiated by passive extensional regimes with normal-fault displacements being the extensional mechanism. In coastal Kenya, the Karoo graben was initiated in the Early Permian with the possible existence of pre-rift tillitic Dwyka equivalent sediments of Late Carboniferous sediments. The extensional regime of coastal Karoo basin terminated in the Jurassic when the basin was tectonically sealed off by the Late Jurassic faults which heralded the drifting away of Madagascar from the African continent.

The Karoo basin is elongated in a broadly north-south direction and has a basin-fill of approximately 6,500 - 7,000 m comprising alluvial, fluvial and lacustrine sequences. The Karoo sediments in coastal Kenya constitute the Duruma Group which is equivalent to the Karoo Super-group seen elsewhere in East Africa and they crop out onshore west of Mombasa town parallel to the coastline.

The western boundary of the coastal Karoo basin is relatively more complex than the eastern margin, with both faulted and unconformable contact with the basement, which is of the Precambrian Mozambique Belt. The eastern margin of the basin is broadly defined by the post-Karoo Middle Jurassic marine limestones of the Kambe Formation. The limestone has both faulted and unconformable relationships with the underlying Duruma Group. The rest of the post-Karoo sediments are mainly prograding marginal to deep marine and shoreline sequences deposited in cycles separated by well-defined tectonic phases.

The uplift of the eastern shoulders of the Tertiary East African Rift during the Pliocene led to downwarping of the Kenya coastal region resulting in the deposition of fluviatile sediments of the Marafa Formation. The coastal area emerged later in the Late Pliocene to Early Pleistocene, at which time dune sands of the Magarini Formation and other lagoonal sands were deposited. In the Quaternary period, coastal Kenya was the deposition of dune and lagoonal sands, and the growth of coral limestone, intercalated with continentally derived fluvial channel sands.

### INTRODUCTION

The literature on the geological evolution of coastal Kenya is rather limited. A number of studies from small areas of coastal Kenya have been published (see Cannon *et al.*, 1981 and Sewe, 1983 for a review), but, until recently, no general geological studies encompassing a substantial part of coastal Kenya had been attempted. Recognising this fact,

the author attempted the compilation of all geological data on coastal Kenya (Caswell, 1953; Caswell, 1956; Thompson, 1956; Battistini, 1977; Rossi, 1981; Toya *et al.*, 1973; Ase, 1978; Oosterom, 1988; Karanja, 1981; Harris and Carrol, 1977, Sewe, 1993 and Sewe *et al.*, 1992). To fill the many gaps in the coverage of the area, the author carried out photo-geological studies and field surveys to collect additional data specifically for this work.

GEOLOGICAL EVOLUTION OF COASTAL KENYA AS INFERRED FROM  
SEDIMENTARY SEQUENCES AND MARINE TERRACES

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ABSTRACT

Based on extensive field and literature surveys together with radiometric dating evidence, the coastal geology of Kenya consists of the Karoo (Upper Carboniferous-Lower Jurassic) to Recent sedimentary sequences with minor local intrusions of igneous rocks of Post-Jurassic age. The oldest sedimentary rocks found in coastal Kenya belong to the Karoo sequence and are exposed in the Mombasa coastal basin.

In East Africa, the Karoo grabens were initiated by passive extensional regimes with normal-fault displacements being the extensional mechanism. In coastal Kenya, the Karoo graben was initiated in the Early Permian with the possible existence of pre-rift tillitic Dwyka equivalent sediments of Late Carboniferous sediments. The extensional regime of coastal Karoo basin terminated in the Jurassic when the basin was tectonically sealed off by the Late Jurassic faults which heralded the drifting away of Madagascar from the African continent.

The Karoo basin is elongated in a broadly north-south direction and has a basin-fill of approximately 6,500 - 7,000m comprising alluvial, fluvial and lacustrine sequences. The Karoo sediments in coastal Kenya constitute the Duruma Group which is equivalent to the Karoo Super-group seen elsewhere in East Africa and they crop out onshore west of Mombasa town parallel to the coastline.

The western boundary of the coastal Karoo basin is relatively more complex than the eastern margin, with both

faulted and unconformable contact with the basement, which is of the Precambrian Mozambique Belt. The eastern margin of the basin is broadly defined by the Post-Karoo Middle Jurassic marine limestones of the Kambe Formation. The limestone has both faulted and unconformable relationships with the underlying Duruma Group. The rest of the Post-Karoo sediments are mainly prograding marginal to deep marine and shoreline sequences deposited in cycles separated by well-defined tectonic phases.

The uplift of the eastern shoulders of the Tertiary East African Rift during the Pliocene led to downwarping of the Kenya coastal region resulting in the deposition of fluviatile sediments of the Marafa Formation. The coastal area emerged later in the Late Pliocene to Early Pleistocene, at which time dune sands of the Magarini Formation and other lagoonal sands were deposited. In the Quaternary period, coastal Kenya was dominated by marine transgressions and regressions, which caused the deposition of dune and lagoonal sands, and the growth of coral limestone, intercalated with continentally derived fluvial channel sands.

#### INTRODUCTION

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#### GEOLOGY

In coastal Kenya, the Karoo (Lower Carboniferous - Lower Jurassic) basin-fill consists of a thick (6,500 - 7,000m) continental sedimentary sequence, locally described as the Duruma Group (Fig. 1). The Duruma Group is overlain by Middle Jurassic marine limestones of the Kambe Formation. These Post-Karoo marine sediments have both faulted and unconformable relationships with the underlying Duruma Group (Fig. 2). The

Duruma sequence shows a consistent eastward-younging age with no large-scale, fault-induced stratigraphic repetition (Karanja, 1981).

The Basement to the coastal Karoo basin is the Precambrian gneissic metamorphic complex of the Mozambique Belt. The western boundary of the basin is complex, with both faulted and unconformable contacts with the Basement. The eastern margin is broadly defined by the outcrop of the Middle Jurassic Kambe Limestone. The Duruma Group sediments comprise arkoses, sandstones, shales, siltstones with minor conglomerates and limestones deposited under continental alluvial, fluvial and lacustrine environments. The palaeo-position of Madagascar (Rabinowitz, 1982) during Karoo time was next to the Kenya-Somalia coast.

Therefore sediments equivalent to the Duruma Group are also found in Madagascar and in Somalia (Fig. 3). In coastal Kenya, the Duruma Group is subdivided into four principal formations namely, the Taru, Maji ya Chumvi, Mariakani and Mazeras Formations (Fig. 2). The Taru and Maji ya Chumvi Formations are correlated with the Ecca and Beaufort Groups of the South African Karoo sequence respectively.

#### METHODOLOGY

The methods of collecting data for the purpose of this work included desk-studies of available literature, aerial-photo interpretations and field observations in the study area. A comprehensive review of the published literature and unpublished reports in files on the geology of coastal Kenya was conducted by the author. Aerial photo interpretations of the geology of the study area was also undertaken. This was followed by field observations in coastal Kenya to fill the many gaps in the geological coverage of the area. In addition, the author conducted extensive interviews and discussions with many geologists who have worked in coastal Kenya, including Messrs. Karanja, Siambi and Sewe, who recently prepared an excursion guide to the geology and marine terraces of the Kenya coast for an International Workshop on Past Global Changes (PAGES) organized in Mombasa, Kenya in 1993. For radiometric dating,  $^{14}\text{C}$  ages derived from coral and bedrock samples collected from the study area by Hori (1970), Toya et al. (1973), Battistini (1977), Ase (1978, 1981) and Oosterom (1988) were used in this

work. The results of these studies and observations are described in the following sections.

### KAROO SEDIMENTS

The Karoo-age sediments in coastal Kenya consists of the Duruma Group, which comprises arkoses, sandstones, shales, and siltstones with minor conglomerates and limestones deposited in continental alluvial, fluvial and lacustrine environments. The Duruma Group is overlain by Mazeras Formation (Triassic-Lower Jurassic) which marks the termination of the Karoo-age sedimentation in the coastal Kenya basin with the deposition of fluvial, deltaic and aeolian deposits (Fig. 2).

### THE DURUMA GROUP

#### Taru Formation

In coastal Kenya, the Duruma Group is subdivided into four principal formations namely, the Taru, Maji Ya Chumvi, Mariakani and Mazeras Formations (Fig. 2). The Taru Formation (Upper Carboniferous - Permian) is subdivided into Lower, Middle and Upper Members. The estimated total thickness of the Taru Formation sediments is 3000 m (Fig. 2). The Lower Member comprises tillites which are pre-rift sediments of limited distribution in coastal area and crop out only in the Lali hills in the Mid-Galana area (Fig. 1). It is postulated that these pre-rift glacial deposits of eastern Kenya have been extensive but have now largely been eroded away (Karanja 1981). As suggested earlier, these deposits are correlated with the Ecca Group in South Africa of Karoo-age (Cannon et al. , 1981).

The Middle Taru Member is of widespread occurrence and comprises a sequence of coarse-grained, massive, arkosic sandstones. Primary sedimentary structures, other than rare water-escape and slump structures, are lacking within these sandstones, although a faint normal grading can be recorded within individual bedded units. Deposition is thought to have occurred in alluvial fans and from very rapidly decelerating, sediment-laden currents, within which individual sediment particles were unable to move freely with respect to each other.

Localised lacustrine shales and silty mudstone are also found. The Middle Taru Member appears to vary in thickness between 1,300 and 1,500 m (Fig. 2).

The succeeding Upper Taru Member comprises an 800 - 1,500 m thick sequence of low-sinuosity fluvial deposits, and, locally appreciable developments of lacustrine shales with minor limestones. Shale/siltstone horizons are prominent towards the top. These shales are locally black, carbonaceous and usually interbedded with limestone bands. This association of black laminated shales and limestones with the development of graded bedding in the Upper Taru Member suggests the deposition in the local deep-trough lakes (Karanja, 1981). Thin coral bands found in the Taru Formation indicate the existence of some animal life (Fig. 2). The Taru Formation is correlated with the Karoo age, Sakoa and Ecca Groups of Madagascar and South Africa respectively. Plant remains found in the Upper Taru Member are *Voltzia* and *Ullmania* species of Upper Permian age (Cannon et al., 1981).

#### Maji Ya Chumvi Formation

The Maji Ya Chumvi Formation (Upper Permian-Triassic) comprises a basal sequence of lacustrine laminated shale, siltstone, and fine-grained sandstone overlain by lake-shoreline sandstone and minor shale/siltstone (Fig. 2). Subordinate fragmental and stromatolitic limestones are locally interbedded. The Formation is subdivided into three distinctive members and may attain an aggregate thickness of approximately 1,200 m. A borehole logged by J. Miller in 1951 in the Maji Ya Chumvi Formation penetrated 1,128 m of Maji Ya Chumvi shales and thin sandstones (Fig. 4).

The lower Member of the Maji Ya Chumvi Formation consists of deep-lacustrine, black-grey, carbonaceous shales and siltstones with subordinate sandstones and limestone horizons. Fresh water to marine fish (*Boreosomus gillioti*) remains of Lower Triassic age have been found in the nodules within the black-shale facies. A fresh water setting is supported by the presence of the phyllopod *Estheria*, which occurs most frequently in non-marine settings (Fig. 5). The upper boundary of this Member is defined by a lacustrine-shale unit containing Permo-Triassic fossil fish (*Australosomus*) remains (Fig. 5). The unit referred to as the "Fish Bed" has an 80km strike-length and represents the western edge of the Permo-Triassic lake. This lacustrine regime was sustained by renewed faulting during Late Permian times (Cannon et al., 1981).

The Middle Maji Ya Chumvi Member comprises predominantly shallow-lake grey-green shales and siltstones with interbedded subordinate fine-grained silicified sandstone horizons. The

Upper Maji Ya Chumvi Member consists of shoreline, flaggy sandstones and subordinate siltstone/shales (Fig. 6). The beds above the Permo-Triassic boundary have yielded fossils of the freshwater phyllopod *Estheria* and evidence of a shallow-water lacustrine depositional environment is indicated by sedimentary structures i.e. ripple marks, mudcracks and rain prints (Fig. 6). The existence of a fossil ecosuchian reptile named *Kenyasaurus mariakeniensis* in the Upper Maji Ya Chumvi Member points to deposition on dry land near lakes, probably on lacustrine beaches. The Maji Ya Chumvi Formation has previously been correlated with the Sakemena and Beaufort Group of Madagascar and South Africa respectively (Cannon et al. , 1981).

#### Mariakani Formation

The Mariakani Formation (Triassic) which attains an aggregate thickness of 1,800 - 2,400 m (Fig. 2) comprises a distinct sequence of pale coloured, largely cross-bedded fluvial sandstones with variably well developed shale/siltstone units. The Formation can be divided into three sandstone members separated by mappable shale/siltstone horizons (Fig. 7). The lower Mariakani Member comprises a massive, mottled, medium-grained sandstone, locally showing faintly preserved near tabular cross-stratification. The mottling is diagenetic and indicate removal of former carbonate cement by surface or near surface leaching by acidic pore waters. The Middle Mariakani Member comprises medium - to fine - grained, cross-stratified, flaggy sandstones with a basal, mappable, shale/siltstone unit (Fig. 7). The Upper Mariakani Member comprises distinctive yellow-brown (blue-grey when fresh) medium - to fine -grained sandstone unit which also has a basal mappable shale/siltstone horizon. Locally, the sandstone is silicified and cross-stratified but is also massive and thinly bedded. In general, the entire lithology of the Mariakani Formation points to reworking of the basement possibly due to renewed uplifting of the basin shoulders.

#### Mazeras Formation

The Mazeras Formation (Triassic-Lower Juassic) marks the termination of the Karoo-age sedimentation in the coastal Kenya basin with the deposition of fluvial, deltaic and aeolian deposits (Fig. 2). The Formation comprises coarse arkosic and banded sandstones with subordinate shale/silt-stone and limestone horizons. A faulted contact exists between the mazeras and Mariakani formations (Fig. 8). The Mazeras

Formation is sub-divided into three distinctive members. The Lower Mazeras Member consists of partly silicified, banded arkosic yellow sandstones. This Member displays repeated sequences which are generally coarsening upwards.

The Middle Mazeras Member also of fluvial to fluvial-deltaic deposits comprising mainly coarse arkosic sandstones, which are locally conglomeratic. The Member displays cyclic sedimentation, with well-defined coarsening upward cyclothems. Locally, graded bedding and slump structures are found. Large, silicified, tree trunks occur in a mappable shale/siltstone horizon near the base of this Member testifying further to the deltaic nature of the sedimentation. The Upper Mazeras Member comprises coarse sandstones with pebbly horizons. The pebbly facies are much coarser, much thicker and better developed in the Shimba Hills, south west of Mombasa, than any where else in Mombasa Basin (Fig.1). The total thickness of the Mazeras Formation is approximately 2000m (Fig. 2).

#### POST-DURUMA GROUP SEDIMENTS

##### Kambe Formation

The Post-Duruma Mesozoic sediments of coastal Kenya consist predominantly of limestones and shales with minor sandstones (Fig. 2). The sediments are divided into the Kambe (Middle Jurassic) and the Mtomkuu (Upper Jurassic - Cretaceous) Formations. The Kambe Formation comprises dark grey, dense, oolitic, coralliferous/reefal and dark bluish limestones with interbedded shales. Kambe Formation limestones generally occur in faulted contact with the underlying Duruma Group (Fig. 2). The unconformable relationship between the Duruma Group and the Kambe Formation is observed in the Kaya Kauma (Fig. 1) and Mwachi sections (Figs 8&9). In the latter location, a basal conglomerate, approximately 10 m thick, is exposed (Fig. 9). The conglomerate comprises angular boulders of Mazeras Formation sandstones within the oolitic facies of the kambe Formation limestones. In the Kaya Kauma area, weathered Mazeras Formation arkosic sandstones are unconformably overlain by transgressive oolitic limestones of the Kambe Formation (Fig. 8).

Three distinct limestone facies within the Kambe Formation have been distinguished by Sewe et al. (1992). These include the Rare Limestone, the Pangani Limestone and the Mwachi Limestone Members, named after their type localities (Fig.1). The Rare Limestone Member is composed of micritic limestones and

mudstones, interbedded with calcareous shales (Plate 1). The unit forms a distinct pattern of alternating shale and limestone beds with thicknesses varying between a few centimetres up to approximately 0.5 metre thick (Plate 2). The beds are flat lying at the Tangil quarry near Jaribuni market on the Pipeline road and dip at approximately 8-10° southeasterly at the Rare River bridge (Fig. 1). The basal unit of the section consists of a hard and brittle mudstone devoid of sedimentary structures. The rest of the section consists of a limestone unit characterised by large scale horizontal bedding. Solution weathering produces large-cavities that are several centimeters in diameter in the limestone (Plate 3).

The Pangani Member limestones are markedly different from the Rare Member limestone with a distinguishing feature being the presence of open cavities often filled with calcite as a result of recrystallization (Plate 3). In the absence of calcite the vugs are filled with limonite. Further the limestones lack layering and structural sedimentary features (Plate 4). The absence of sedimentary structures may be related to post-depositional solution-generated diagenetic changes or bioturbation completely obliterating the primary sedimentary structures. The Pangani Limestone Member overlies the Rare Limestone Member on the south bank of the Rare River bridge (Fig. 1). The Pangani limestone is patchily oolitic and coralline. In the Pangani, Kaloleni and Lwandani river areas (Fig. 1) the limestone occurs as erosional silhouettes that stand out against the coastal peneplain to form a "Karst" topography, and contain an abundance of *in-situ* coral growths (Plate 5).

The Mwachi Limestone Member at the Kambe Quarry in the Mwachi area (Fig. 1) is a 30m-thick succession comprising, in ascending order of 15m-thick conglomerate at the base, 15 m of pisolitic limestone with belemnites and brecciated limestone blocks, wedge-shaped crossbedded oolitic limestones, and a bluish grey calcareous mudstone unit at the top (Fig. 9). Ammonites, typical of the Tethyan Mediterranean Bajocian fauna are reported from this unit (Cannon et al. 1981). The Hamanlei Formation of the Ogaden region in Ethiopia, consisting of tidal-flat and lagoonal limestones, the deposition of which preceded inner-shelf limestones, are comparable to those of the Mwachi Limestone Member. This shallow-marine environment resulted in the deposition of the oolitic/bioclastic limestones.

#### Mtomkuu Formation

The Mtomkuu Formation comprises mainly shales with subordinate sandstones, limestones, marls and siltstones (Fig.2). The Mtomkuu Formation is conveniently subdivided into three members. The Lower Member consists of shallow-marine, brown, sandy micaceous shales unfossiliferous silty sandstones and limestone bands. These appear to rest conformably on the underlying Kambe Formation (Fig 8). However, in the Mazeras area (Fig. 1), the sediments of the Lower Mtomkuu Member are in faulted contact with the Mazeras Formation sandstones (plate 5).

In the Mwachi area (Fig. 1), the Lower Mtomkuu Member has a basal conglomerate consisting of angular boulders and fragments of the Kambe Formation Limestones (Fig. 9). Slumping and discordant bedding features of the Lower Mtomkuu Member suggest a depositional wedge prograding towards a deep sea along a steep slope (Cannon et al., 1981).

The Middle Mtomkuu Member comprises deep-marine grey shales and clays. Locally and very rarely sandstone/limestone lenses are interbedded. Cherty and calcereous nodules are common. In the lower part, the shales are commonly cross-bedded (Karanja et al. 1993). The upper Mtomkuu Member (Cretaceous) is distinguished from the Middle Mtomkuu Member by development of abundant limestone/sandstone horizons. The sediments of the Upper Mtomkuu Member are locally fractured with veined baryte mineralization. In the coastal area, Upper Callovian and the Lower Oxfordian fauna are absent. This confirms a non depositional period or marine regression in the lower Upper Jurassic. The Free Town limestones form part of the limestone units of the Upper Mtomkuu Member. The Free Town limestone unit is  $^{14}\text{C}$  dated as Lower Cretaceous (Hori, 1970).

#### LATE TERTIARY SEDIMENTS

In coastal Kenya Tertiary sediments comprise limestones, marls, clays, sandstones and sands deposited in marine and continental (fluvial and aeolian) environments in Baratumu, Marafa and Magarini Formations. The Miocene Baratumu Formation consists of light-coloured yellow sandy marls, mottled clays, conglomerates, limestones and sands. The Pliocene Marafa Formation consists of continental red beds (red sands, clays, gravels and conglomerates). The Late Pliocene-Early Pleistocene Marafa Formation comprises mixed continental red beds sequences.

These sediments form the red hills landward of the Kenya coastline. The Magarini Formation overlies the Miocene, Cretaceous and Jurassic sediments in coastal area unconformably

and is Th/U-dated Upper Pliocene to Pleistocene (Battistini, 1977).

#### QUATERNARY SEDIMENTS

In coastal Kenya the Quaternary sediments consist of Pleistocene sand dunes, a coral-reef complex, Recent sand dunes and beach sands. The coral complex comprises of coral-reef limestones, coral breccias, calcarenites, sandstones and sands (Fig. 10). The extent of the coral reef offshore is variable but in some cases, is up to 2 km. The coral is limited landward in the southern and northern parts of the coast. It is best developed in the central part. The contact with the underlying rocks is unconformable and the estimated thickness is about 100 m.

Pleistocene sands comprise medium to fine-grained, well sorted sands, which cover the low ground immediately seaward of the Magarini Formation ridge. The sand ridges are old sand dunes that were deposited on the coastline and coastal margin under lagoonal, aeolian and shallow-marine environments as the sea retreated. Later extensive reworking of the sand with the rise and fall of the sea level resulted in redistribution of the sand over wider areas. The sands are lighter in colour and thinner closer to the present coastline, apparently only as a thin veneer over parts of the coral reef (Karanja et al., 1993).

The dune sands have accumulated along and near to the coastline in Recent times. As the shoreline retreated, dunes were left further inland, hence older dune sands occur further inland whereas younger dune sands are exposed beside the modern coastline. Several sand dunes are forming at the estuary of the Sabaki and Tana deltas. The dunes attain maximum heights of 30 m and are aligned parallel to direction of the south east monsoon (Karanja et al., 1993). White beach sands are accumulating on several beaches and sheltered bays at the present times. Beach sands consist of mainly quartz and carbonate. Shell fragments are common. Due to the delivery of sand into the sea by the Sabaki and Tana rivers, the beaches close to the mouths of the rivers are composed of quartzose sands. On the Malindi beaches, the quartzose sands predominate

in the area to the north of Vasco Da Gama Point with calcareous sands being dominant south of the Point (Caswell, 1956; Thomson, 1956). The calcareous sands have resulted from the reworking of the coral reef. Beach sands are unvegetated and are therefore easily eroded away by powerful storm waves.

### MARINE TERRACES

Table 1 shows the various land-surface levels that have been recognized in coastal Kenya. The Kenyan coastline is characterized by isolated raised coral reefs, lagoons and sheltered bays with low plains in the south (Fig. 11). In the central section, a sublinear fringing coral reef is broken by narrow inlets and bays and estuaries. Raised reef-flats and erosion platforms are common. In the northern part, the coast is characterized by open bays in front of deltas and estuaries.

There are also long beaches with aeolian sand dunes and lagoons. The coastline to the north of Malindi is emergent. In the central part the coastline is undergoing an erosive phase and is therefore submerged. Caswell (1953, 1956) recognized four post-Pliocene terraces at 61 , 30.5 m, 9 m and 4.5m above sea level. Toya et al., (1973) recognized six and Oosterom (1988) eight surface levels, respectively, formed since the beginning of the Pleistocene in coastal Kenya (Fig. 11). Further subdivision of some of the eight major surface levels is possible (Table 1). The land surface are considered to have developed as a result of sea-level changes. The terraces are characterized by platforms, which in some cases are covered by old beach or dune sands. Older surfaces have invariably developed soils of various types. Surface levels which are closer to the sea are limited in extent. However, further away from the sea the surfaces are better defined.

### DESCRIPTION OF THE TERRACES

#### Bofa Terrace

As can be seen in Figure 12 and Table 1, the Bofa terrace (-10 m to 2 m + MSL) is a reef platform surface exposed at low tide and fringes most of the Kenya coast. The fringing coastal reef is more evident in the central part of the coast. This surface with sheltered bays, tidal channel, tidal flats and various other features of a modern-day tropical fringing coral reef forms the first marine terrace. Landward, the platform has in some places coastal sand dunes on beaches and mangrove swamps. It has been suggested by Hori (1970), Toya et al.,

(1973) and Battistini (1977) that the sea level while falling passed its present level 18 to 20KY Before Present (B.P.), reaching a maximum low of - 120m at 14-15 KY BP and it rose to its present position about 7,000 - 6,000 years ago.

### Uhuru Terrace

The Uhuru level (2 m to 6 m + MSL) is well developed to the north of Malindi and in the Tana delta (Fig. 12). It is a narrow surface in the coral reef at Uhuru Farm and the low ground in the Malindi Bay and fringes the Mida Creek. It is covered by unconsolidated quartz sands and shell fragments and poor soils. The surface is dominated by dune sands between Malindi and Ngomeni. Hori (1970) reported minimum age of 26.5(+ 1.3 - 1.5)Ky for a coral head from Similani, Toya et al. (1973) reported minimum age of 27.5 + 1.3 Ky and an age greater than 32.2 Ky for two coral heads from near Malindi. Battistini (1977) reported 230Th/234U age of 240 (+ 70 - 40)Ky for a coral from Kikambala beach. The samples from which these dates were derived are considered to have been from the underlying older rocks reworked into the deposits on the platform. Bedrock lithified from raised beach materials on the Uhuru level gave a <sup>14</sup>C date of 2.8 Ky (Hori, 1970), and a <sup>14</sup>C date of 1.0 to 0.8 Ky (Ase, 1981) from shell fragments in the beach sands. These dates suggest the Holocene age of the sand on the platform. The Uhuru terrace appears to have two levels, which are considered to have been formed during sea-level fluctuations dated at about 5.2 Ky and 2.8 to 2.6 Ky. The older dates may refer to the time the sea-level was at the Uhuru level height during the receding period (Karanja et al., 1993).

### Mackenzie Terrace

The Mackenzie (6 m to 10 m + MSL) surface is developed to the east of Bamburi, at Makenzie Point and Shelly Beach. Tiwi sandstones are considered to be beachrocks related to the Mackenzie surface (Ase, 1981). The surface of the platforms have well-sorted fine to medium non-calcareous quartz sand. Hori (1970) reported a <sup>14</sup>C date of 21.6 (+23-7)Ky minimum age for a coral head from Tiwi Beaches. But 20,000 years B.P. the sea

level must have been at a lower level while receding. Ase (1981) reported a  $^{14}\text{C}$  date of  $2.25 \pm 0.9$  Ky for shells buried in a dune ridge on Shelly Beach. These two conflicting dates may be related to the problem of recrystallization of calcite.

#### Mtondia Terrace

The Mtondia surface (10m to 15m + MSL) is a well-developed Pleistocene coral reef platform (Fig. 11 and 12). An outer reef flat and two ancient inner-reef flats have been recognized (Karanja et al., 1993). The *Halimeda* sandstones and other calcarenites in the Maweni quarries are an example of an outer-reef flat. Where the outer reef-flat borders the sea it forms steep rocky cliffs. The surface is overlain by a thin veneer of soils. The lower parts of the Vipingo Sisal Estates are located on the Mtondia surface. To the north of Kilifi (Fig. 11) the road to Malindi runs over the Mtondia surface over most of its length. No radiometric dates have been reported for this surface.

#### Majaoni Terrace

The Majaoni surface (25 m to 50 m + MSL) is best developed to the west of Malindi (Fig. 11). It is covered by dark soils and fine to medium white sands. To the west of the Mtondia surface, the surface has a thick sand cover. It is highly dissected by the drainage at the turn off to Takaungu and the lower parts of the Chagamwe peninsula near the coast. Alluvial-fan deposits are locally common. The Pleistocene sands cover some areas of the surface. These are probably desert phenomena. No radiometric dates have been reported for this surface.

#### Teso Terrace

The Teso surface (50m to 80m + MSL) finds topographic expression on the Chagamwe peninsula and the western parts of the southern bank of the Kilifi Creek (Fig. 12). To the west of Mtondia the surface is poorly defined. The sands on the Teso surface are fine - to - medium - grained. The soils are deeply leached. No radiometric dates have been reported for this surface.

### Cambini Terrace

The Cambini surface (70m to 130m + MSL) of flat terraces and plateau landscape is best expressed to the western part of Malindi (Fig. 12). It is the surface on which most of the Gede forest thrives. The soils are dusky red due to intense ferruginisation of the dune sands. No radiometric date have been reported here.

### Sokoke Terrace

The Sokoke surface (130m to 175m + MSL) is expressed to the southwest of Sokoke Forest (Fig. 12). The surface is almost flat and is covered by thick red soils crossed by the road from Vitengeni to Kilifi (Fig. 12). No radiometric dates have been reported for this surface.

## DISCUSSION

In addition to describing the sedimentary sequences in coastal Kenya, the data presented in this study provide information on the various land-surface levels recognized in the area. The predominantly continental Karoo sedimentation in the coastal Kenya basin came to an end after a major pre-Middle Jurassic marine-transgression phase associated with the departure of Madagascar (Rabinowitz 1982), which triggered the marine incursion into the basin, depositing shallow-marine limestones. The incursion of the sea was controlled by the Karoo-graben structural setting. Thus the eastern margin of the coastal Karoo basin is broadly defined by the outcrop of the Middle Jurassic Kambe Formation limestone. This formation unconformably overlies the Duruma Group, with which it shows both faulted and unconformable relationships as at Kaya Kauma area (Fig. 8). The Jurassic marine transgression evidently reached coastal Kenya in the Late Bajocian times. The Kambe Formation is dated Upper Bajocian to Bathonian using ammonites, corals and lamellibranchs. Typical Mediterranean Bajocian ammonite fauna has been identified in the Kambe Formation (Cannon et al., 1981). The rest of the post-Karoo sediments (the Mtomkuu Formation) are mainly prograding marginal to deep marine and shoreline sequences deposited in cycles separated by well-defined tectonic phases (Fig. 2).

The uplift of the eastern shoulders of the Tertiary East African rift during the Pliocene led to downwarping of the Kenya coastal region resulting in the deposition of marine sediments

of the Marafa Formation (Karanja et al., 1993). The coastal area emerged later in the Late Pliocene to Early Pleistocene at which time dune sands of the Magarini Formation and other lagoonal sands were deposited. In the Quaternary period, coastal Kenya was dominated by marine transgressions and regressions which caused the deposition of dune and lagoonal sands, and the growth of coral limestone intercalated with continentally derived fluvial channel sands. Later marine transgressions and regressions led to the deposition of sands of various ages on the coral reef.

Therefore, the Quaternary sediments in coastal Kenya consist of Pleistocene sand dunes, a coral reef complex, Recent sand dunes and beach sands. The Pleistocene sand dunes are medium to fine-grained sands that were deposited on the coastline and coastal margin in lagoonal, aeolian and shallow-marine environments as the sea retreated. The coral-reef complex consists of coral-reef limestones, coral breccias, calcarenites, sandstones and sands (Fig. 10).

Various marine terraces have been recognized in the coastal area (Fig. 12; Table 1). The first of these terraces is the Bofa reef platform that fringes most of the Kenyan coast (Figure 12).

It has been suggested (Hori, 1970; Toya et al., 1973) that sea level, while falling, passed its present level at about 18 - 20 Ky Before Present (B.P.) reaching a maximum low of -120m at 14-15Ky BP and it rose to its present position about 7,000 - 6,000 years ago. The Bofa was probably cut during the rise. The fall and rise were not continuous processes hence sequence of marine terraces must have been cut at several levels that are now under the sea. The Uhuru surface appears to have two levels (Table 1, Karanja et al., 1993) which are considered to have been formed during sea level fluctuations dated at about 5.2 Ky and 2.8 to 2.6 Ky by Hori (1970) and Ase (1981) respectively. The older dates may refer to the time that the sea-level was at the height of the Uhuru level during the receding period (Karanja et al., 1993). The Mackenzie terrace has been radiometrically dated (Hori, 1970, Ase, 1981). But the derived dates seem to differ considerably. Hori (1970) reported a  $^{14}\text{C}$  date of 21.6 (+2.3) Ky for a coral head from Tiwi Beaches, whilst Ase (1981) reported a  $^{14}\text{C}$  date of 2.25 + 0.9 Ky for shells buried in a dune ridge on Shelly Beach. At about 20,000 years B.P. the sea level must have been at a lower level while receding. The ages of the remaining terraces, however, have not been determined.

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Plate 1: Rare River Limestone Member of the Kambe Formation - mainly micritic limestone and mudstone interbedded with calcareous shales.



Plate 2: Distinct layering of the Rare River Limestone.

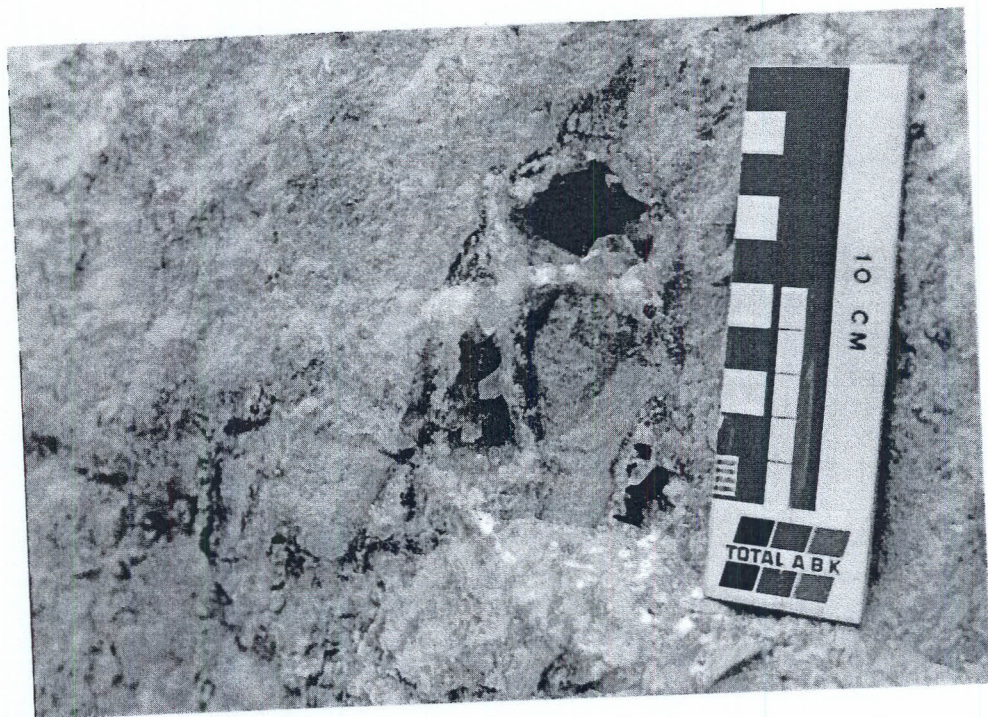


Plate 3: Large cavities filled with calcite in the Pangani Limestone Member of the Kambe-Formation.



Plate 4: Pangani Limestone Member of the Kambe Formation - no distinct layering and structure features found in Rare River Limestone.

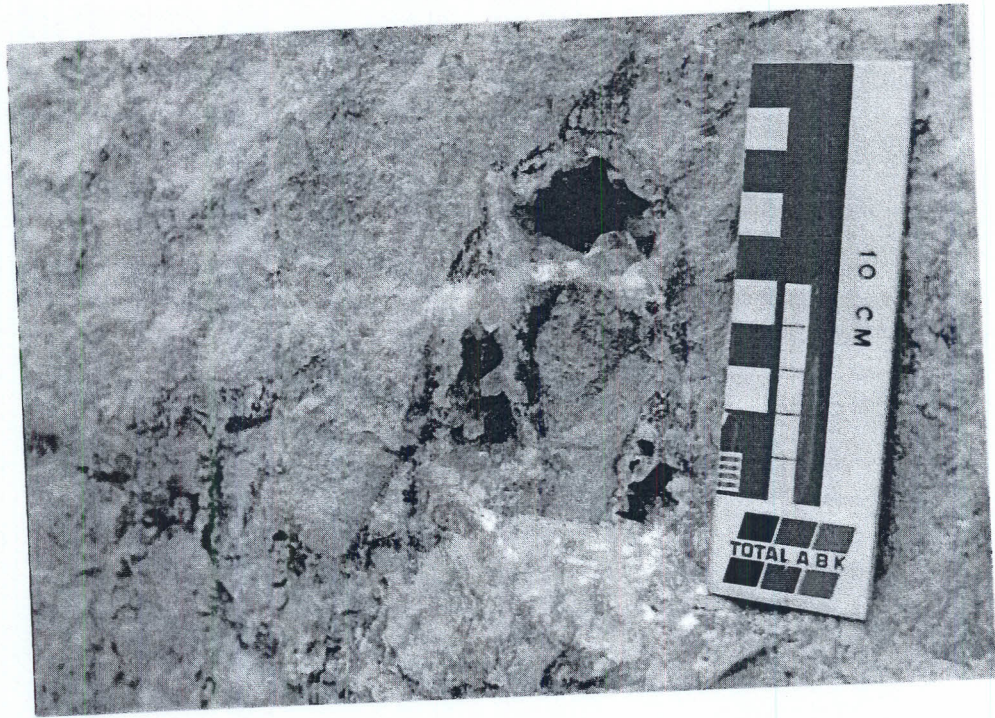


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Plate 1: Rare River Limestone Member of the Kambe Formation - mainly micritic limestone and mudstone interbedded with calcareous shales.



Plate 2: Distinct layering of the Rare River Limestone.



Plate 5: Erosional silhouettes and "Karst" topography in the Pangani Member Limestone.

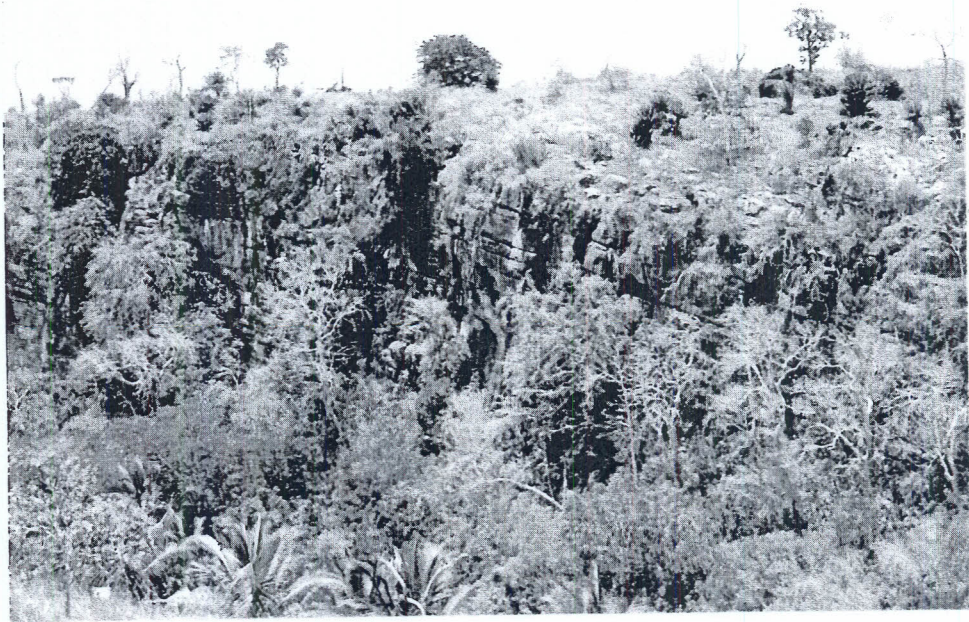


Plate 6: Faulted contact between the Mazeras Formation sandstone and the overlying Kambe Formation limestone.



Plate 5: Erosional silhouettes and "Karst" topography in the Pangani Member Limestone.



Plate 6: Faulted contact between Mazeras Formation sandstone and the overlying Kambe Formation limestone.