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The Indian Ocean Coast of Somalia

FEDERICO CARBONE* and GIOVANNI ACCORDI
Dipartimento di Scienze della Terra, Centro di Studio per il Quaternario e l'Evoluzione Ambientale, CNR, Università degli Studi 'La Sapienza' P. Aldo Moro, 5, 00185 Roma, Italy

Somalia has the longest national coastline (3025 km) in Africa with an estimated shelf area (depth 0–200 m) of 32 500 km^2. The country is divided into the northern coastal plain of Guban, which has a semi-arid terrain; the northern highlands with rugged mountain ranges containing the country's highest peak (2407 m); and the Ogaden region which descends to the south from the highlands and which consists of shallow plateau valleys, wadis and broken mountains. The latter region continues to the Mudug plain in central Somalia.

From Ras Caseyr to the Kenya border, the coast runs north-east to south-west, coinciding with the displacement caused by the Mesozoic marginal subsidence. This general structure is complicated by sedimentary troughs crossing the Horn of Africa, and by large sedimentary basins, cutting the coastline and extending inland into Southern Somalia and Northern Kenya (Juba–Lamu embayment, Mogadishu basin). Offshore, the western Somali Basin extends from Socotra to the Comores. The open shelf environments developed along the Somali coast are a consequence of an extensive marine transgression, connected to coastal subsidence or inland uplift.

The rocks along the southern coastal belt are Pliocene–Pleistocene, and are characterized by a sequence of both marine and continental deposits of skeletal sands, coral build-ups, eolian sands and paleosols. As well as eolian and biogenic sedimentary processes, sea-level fluctuations, Holocene climatic changes and neotectonic movements have combined to produce the modern coastline. A notable feature is an ancient dune ridge complex, known as the Merka red dune, which rims the coast extending beyond the Kenyan border and which separates the narrow coastal belt from the Uebi Shebeli alluvial plain. Two features of note are the Bajuni Archipelago, which consists of islands, islets and skerries, forming a barrier island separated from the coast by a narrow marine sound, and a braided, channelized coastal area, which originated from the drowning of a paleofluvial net.

The southern Somali coast, with that of Kenya and Tanzania, forms part of the Somali Current Large Marine Ecosystem, encompassing 700 000 km^2, and extending 800 km between Dar es Salaam and Ras Hafun. Abundant biomass develops here due to upwelling. The shelf area has a wide variety of coral reefs, mangroves, seagrass meadows, beaches and estuaries. In shallow water areas the abraded flats are colonized by scattered coral communities with variable cover. A true fringing reef is achieved in places only in the Bajuni archipelago. All along the southern Somali coastal shelf there are spreading meadows of *Thalassodendron* seagrass, and benthic communities typical of mobile sandy substrates are limited to beach ridges and shoals developed along the coastline. Around the Bajuni barrier island and the channelized area there is more diversity. Mangroves grow on the tidal belts of the channels, and there are expanses of salt flats.

Large-scale alteration produced by man on the Somali coast is relatively recent, but has accelerated in the last few decades, especially around major cities. This alteration affects especially backshore areas where the Pleistocene coral reefs are quarried. At present, the continental shelf is not adequately monitored or protected, so coastal habitats are being degraded, living marine resources are overexploited, and pollution levels are increasing, all of which affect natural resources and biodiversity.

Somalia is one of the world's poorest and least developed countries, with few resources and devastated by civil war, but since 1993 it has been part of the Common Market for Eastern and Southern Africa (COMESA). This will affect fisheries and aquaculture in terms of the investment, production, trade and fish consumption of the member states. There are currently no marine protected areas and no legislation concerning their establishment and management, although the World Conservation Monitoring Centre (WCMC) Protected Areas Database lists Busc Busc Game Reserve as an MPA. In 1992, The WCMC also listed the following coastal sites as proposed protected areas: Zeila (important sea bird colonies on offshore islets), Jowhar–Warshek, Awdhegle–Gandershe. The area from Kisimayo to Ras Chiambone is probably of highest priority, as it is important for coral reefs, marine turtles, and mangrove resources, although it is still poorly known.

Introduction

Somalia is located on the Horn of Africa, with Djibouti to the north-west, Ethiopia to the west, Kenya to the south-west, the Indian Ocean to the east and the Gulf of Aden to the north (Fig. 1). It extends over 637 600 km^2

*Corresponding author. Tel.: +39-064453766; fax: +39-06448632.
E-mail address: carbone@gea.geo.uniromal.it (F. Carbone).

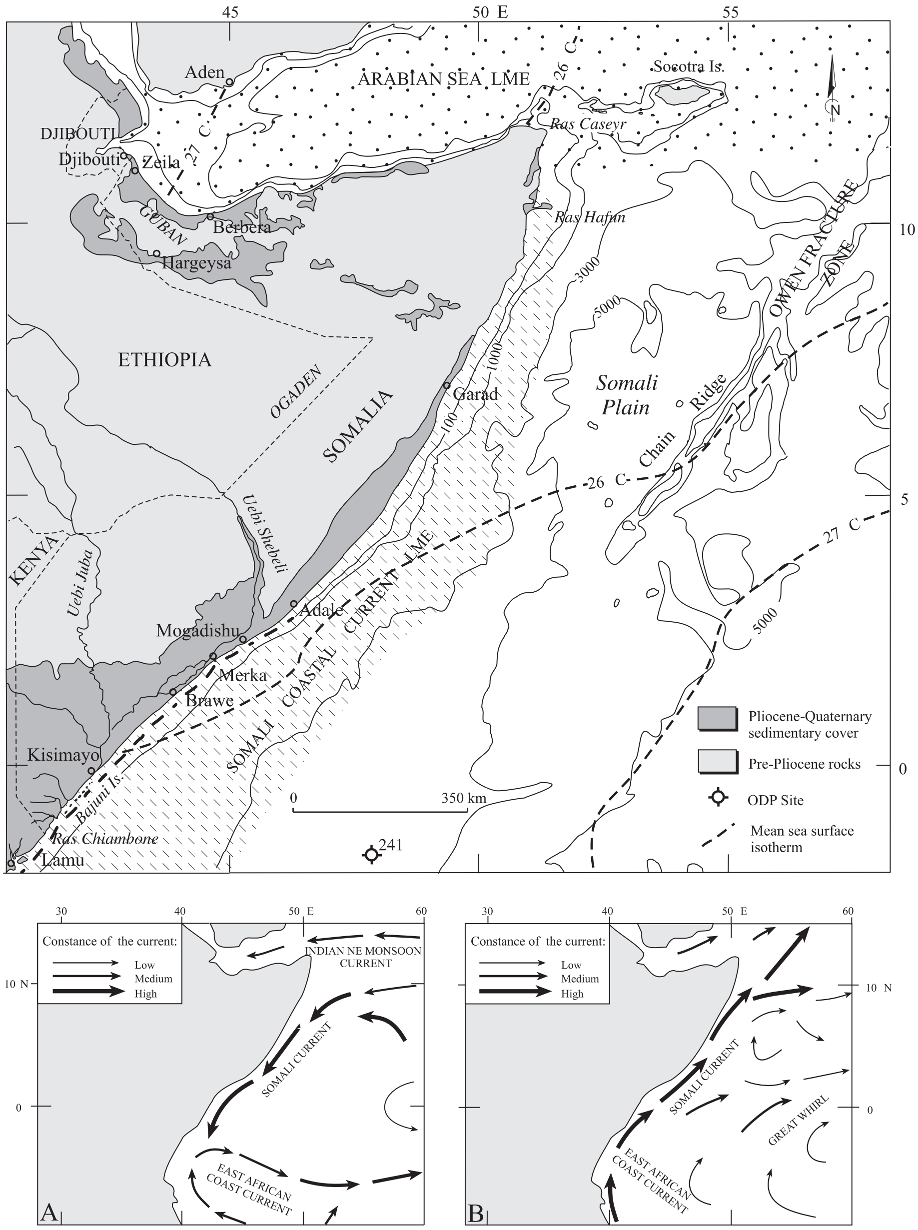

Fig. 1 Coast of Somalia and its main physiographic features. The map shows Pliocene–Quaternary sedimentary cover, the extension of two Large Marine Ecosystems of the Somali coast (cross-hatches) and Arabian Sea (dotted shading), and the annual mean surface isotherms. The dashed part along the 100 m isobath encloses the area colonized by coral reefs. Sketches A and B show the January and July Somali current.

and has the longest coastline (3025 km) in Africa with an estimated shelf area (depth 0–200 m) of 32 500 km^2. The country is divided into four geographical regions: the northern coastal plain of Guban, which has a semi-arid terrain; the northern highlands which are rugged mountain ranges that rise from the Guban region and contain the country's highest peak (2407 m); the Ogaden region which descends to the south from the highlands and consists of shallow plateau valleys, wadis and broken mountains; this region continues to the Mudug plain in central Somalia.

Little is known of the recent geological history of this extensive coast. Some general geological and morphological information is available (Stefanini, 1930, 1933; Dainelli, 1943), as well as data on mineral composition (De Angelis, 1938). Clark (1954) provides numerous observations on the Quaternary raised coral reefs and associated sediments, and data on facies distribution are given by Carbone *et al.* (1984) and Carbone (1987).

Only few and fragmentary data exist on the northern part of the Somali Indian Ocean belt (Stefanini, 1930, 1933; Clark, 1954). The whole Somali coast of the

Indian Ocean is part of the wider, shallow water ecosystem which encompasses the continental shelf of Somalia, Kenya and Tanzania, to form part of the Somali Current Large Marine Ecosystem (Alexander, 1998; Okemwa, 1998). The flat continental shelf supports a wide variety of coral reefs, mangroves, seagrass meadows, beaches and estuaries over an area of 700 000 km^2 between Dar es Salaam and just north of Ras Hafun. This continental shelf is mostly narrow and poorly surveyed, and in some places there appears to be no shelf along straight stretches of the coast, suggesting a fault origin. Indentations of the coast are generally accompanied by a widening of the shelf and the presence of strings of islands.

The existence of coral reefs developed along the coastline was formerly reported by Darwin (1842), who received from Capt. Owen and Lieut. Boteler information of 'a coral-reef extending four or five miles along the shore' near Mogadishu, and of the 'coast and islands formed of madrepore' from the Juba river to Lamu. North of Mogadishu, there are either no coral reefs whatsoever or, if there are some, they are poorly developed (Crossland, 1902, 1904). This is due to the presence of an ocean current, which brings deep cold water to the surface. Fringing reefs stretch from between 500 and 1500 m offshore from Adale to the Kenyan border; the only major break in this reef is off Mogadishu, where corals are limited to patch reefs scattered within seagrass beds. More recent data on the distribution of coral reefs and other marine coastal habitats are summarized by Sheppard and Wells (1988), while Carbone *et al.* (1994) summarize the coast south of Mogadishu, where the Bajuni barrier island lies, flourishing with coral reefs, and where there is a drowned fluvial net made up of three wide braided channels, bordered by tidal flats and mangrove thickets (Fig. 9).

Natural Environmental Parameters

The climate in Somalia is tropical, arid to semi-arid, with a bi-modal rainfall pattern influenced by monsoon winds. The country has an average annual rainfall of about 250 mm with droughts being common. Mean annual rainfall in the north is less than 250 mm; it is about 400 mm in the south, and 700 mm in the south-west (FAO, 1995). Rainfall distribution is bimodal, falling in two seasons, the Gu from March to May and the Der from October to November. Occasionally the Gu season extends into June or July because of the Haggai rains, which are produced by the onset of moist onshore winds. The Gu and Der rains are caused by the passage of the Inter Tropical Convergence Zone (ITCZ), where the surface winds of the northern and southern hemispheres meet and then rise in a low pressure zone of considerable atmospheric instability. This instability causes rain to fall in isolated storm cells, the result of which is an extremely irregular rainfall pattern. The ITCZ also controls wind direction. From May to September when the ITCZ is 15°S, the wind blows from the southwest and from December to February when the ITCZ is 15°N, the wind blows predominantly from the north-east. During the transitional periods (Tangambilis), the wind drops and becomes erratic in direction.

Mean daily temperature is very constant throughout the year, the hottest months, March and April, being only a few degrees warmer than the coolest months, July and August. At Afgoye, near Mogadishu, mean daily temperature for 1953–1976 ranges from 25.2°C to 28.8°C in March with an annual mean of 27°C. However, diurnal temperature fluctuations are much greater and can range from 20°C to 35°C. The mean daily relative humidity pattern is the opposite of the temperature pattern, with high humidity corresponding to low temperatures. In Afgoye, the relative humidity measured for 1953–1976 ranges from 66.3% in March to 76.9% in July with an annual mean of 71.8%.

The Somali Current runs parallel to and close to the coast. Though frequently strong, this current is narrow, and more than 100 miles offshore it is often weak. At about 2°S, along the east African coast, variations in coastal currents throughout the year are only slight. North of 2°S, the Somali Current reverses in direction during the year, as do the monsoon winds, though not necessarily at the same time. The southward flow of the current during the north-east monsoon is restricted to south of 10°N. It first occurs in early December near the equator, expanding rapidly northwards in January (Fig. 1(A)), with velocities of 0.7–1.0 m/s. The surface flow reverses in April, when the monsoon changes to southwest. The current develops into an intense jet with velocities of 2.0 m/s for mid-May and 3.5 m/s and higher for June, observed during the International Indian Ocean Expedition in 1964 (Schott, 1983; Rao and Griffiths, 1998). During the south-west monsoon (Fig. 1(B)), near the Somali continental margin, between 5°N and 10°N, the onset of a two-gyre system is reported: the Great Whirl, with clockwise rotation, and a secondary one, the Socotra Eddy, further north (Bruce, 1973, 1979; Jensen, 1991; Tomczak and Godfrey, 1994).

The upwelling of cool subsurface water in the Arabian Sea produces an annual mean heat flux in the northern ocean; hence, there is a meridional circulation cell that carries warm surface water out of the region, and cool subsurface water into it (McCreary *et al.*, 1993). This heat flux into the Arabian Sea is associated with abrupt cooling during the south-west monsoon in summer, when, in other parts of the northern hemisphere, warming occurs (Wacongne and Pacanowski, 1996). The sea surface temperature is warmest in April and coldest in August, with a mean annual temperature of 26°C and a minimum of 21°C at Ras Hafun in August. High variations from normal values are recorded in shallow water environments, especially in the southernmost part of the Somali coast, where the presence of wide floodable areas during the rainy seasons causes the drainage of fresh water towards the sea. Thus temporary mixed salinity and mixed temperature environments develop.

Mixed, semi-diurnal, and diurnal tides occur in the Indian Ocean with a mean range of 4.0 m. These cause strong localized currents around islands and reefs which are superimposed onto the overall longshore current. On the east African coast, the tide range increases from South Africa (1.5–2 m) to Mozambique (up to 5.5 m), then decreases to 3–3.5 m in Kenya, and to 1.5 m in Somalia, at 11°N. The tidal streams are generally weak along the Somali coast, except very close inshore. Their effect on the total water flow is negligible more than a few miles offshore. South of Kisimayo, in the vicinity of the outlets of the channels, the effect of the tidal streams becomes increasingly important.

The productivity of the Somali Current LME is similar to other upwelling areas in the region. The zooplankton biomass from this system is 4 g d.w. m^{-2} and 75% of this biomass consists of copepods, 25% of euphausids (Okemwa, 1998). Off Somalia, the dominant large copepods are *Calanoides carinatus* and *Eucalanus elongatus*, and there is no significant difference in total zooplankton biomass between the two monsoon seasons.

Structural Framework

From Ras Caseyr to the Kenya border, the Somali coast coincides with the displacement caused by the Mesozoic marginal subsidence, and there are sedimentary troughs crossing the Horn of Africa as well as large Meso-Cenozoic sedimentary basins (Fig. 2), cutting the coastline and extending inland into southern Somalia and northern Kenya (Juba–Lamu embayment, Mogadishu basin). These fault-controlled basins, with thick sedimentary piles (Angelucci *et al.*, 1983; Piccoli *et al.*,

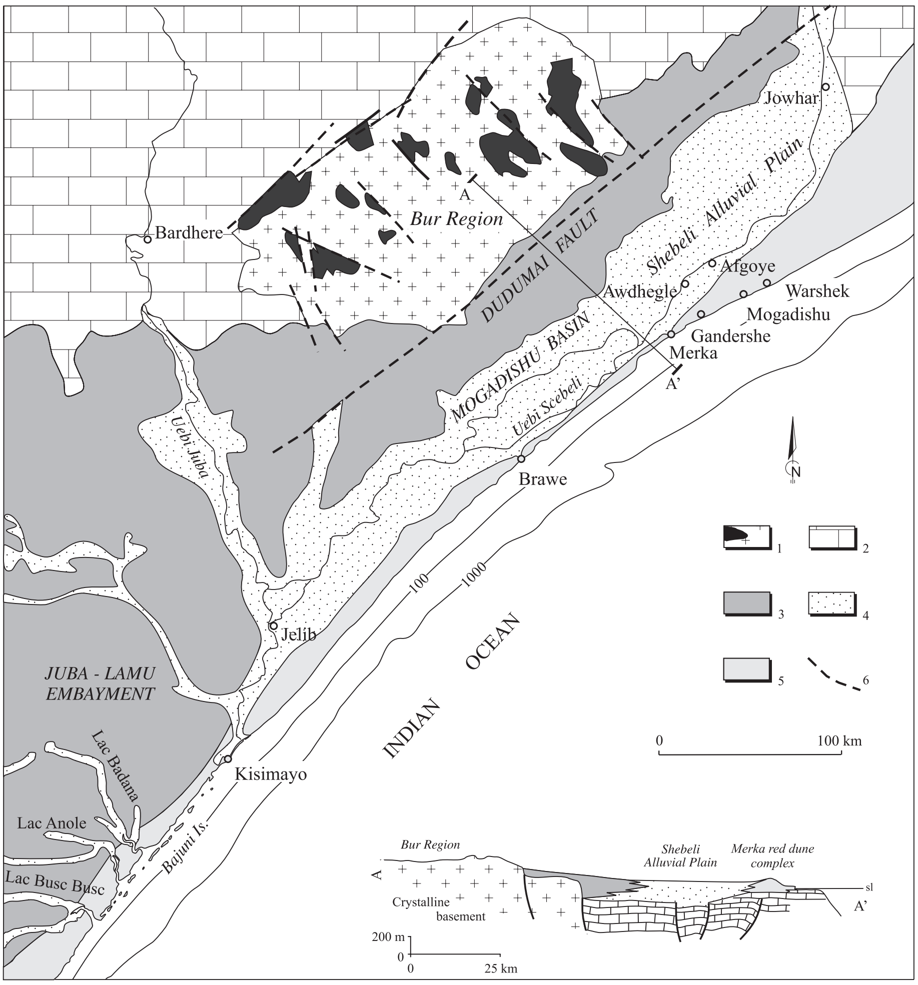

Fig. 2 Schematic geological map of the Southern Somali coastal belt: (1) pre-Cambrian crystalline basement; the black areas indicate inselbergs (burs) formed of migmatitic granite and quartzite; (2) Meso-Cenozoic sedimentary sequence; (3) Pliocene–Quaternary eolian and eluvial sediment; (4) Quaternary alluvial sediment of Shebeli River and other floodable areas (gravel, sand, loam); (5) Merka red dune complex partially covering the Pliocene reef limestone along the narrow coastal belt; (6) main faults.

1986; Bosellini, 1989), continue inland toward the south-west, to the southern part of the Rift Valley System. According to Kent (1982), both coastal faulting and inland rifting are related to the same tectonic control. Compressive phases, which originated along north-east–south-west fracture zones are linked to oceanic systems of transform faults. These developed in connection with a change in the stress regime, which occurred between the end of the Madagascar Rift about 120 Ma ago and the beginning of sea-floor spreading of the Mascarene Basin Province about 80 Ma ago. According to Boccaletti *et al.* (1988), asymmetric sedimentary basins with increasing thickness from east to west developed during the Cretaceous in connection with these tectonic movements.

Offshore, the Western Somali Basin extends from Socotra to the Comores and is bordered eastwards by the mid-ocean Owen Fracture Zone and the Chain Ridge (Fig. 1). The structural setting and the sedimentary features of the Somali Basin, described by Francis *et al.* (1966) and Bunce *et al.* (1967), have been more recently investigated by ODP oceanographic surveys. A site located 170 miles off the coast at the base of the continental rise in 4505 m water depth, recorded 470 m of Quaternary–Upper Oligocene deep water facies, overlying a 704 m section of Middle Eocene–Upper Cretaceous sediments, also of deep water environment. In Somalia and Kenya the main marine transgression took place during the Oligocene, whereas the widespread inland extension of marine water took place in the Lower and Middle Miocene. According to Kent (1974), the persistence of open shelf environments along the east African coast during the Neogene is a consequence of an extensive marine transgression which is partially world-wide, but can be connected as well to coastal subsidence or inland uplift. The Pliocene is not well documented in the Somali coastal area because of the absence of outcrops and of data deriving from hydrocarbon exploration. The development of late sedimentary basins between structural highs are documented in coastal Tanzania and Kenya (Kent *et al.*, 1971; Nyagah, 1995) by means of seismic works and boreholes.

Present-Day Geomorphic Features of the Coastal Zone

The rocks outcropping along the coast from Mogadishu to the Kenya border represents the top of the Pliocene–Pleistocene sequence known (Piccoli *et al.*, 1986) as the Merka formation (Fig. 2). These are deposits of skeletal sands, coral build-ups, eolian sands and paleosols, whose pattern is controlled by both eolian and biogenic sedimentary processes. These, with sea-level fluctuations, Holocene climatic changes and neotectonic movements combined to produce the modern coastline.

A notable feature of the area is an ancient dune ridge complex (Merka red dune) which rims the Somali coast from 6°N extending beyond the Kenyan border and separates the narrow coastal belt from the Uebi Shebeli alluvial plain. The wide coastal region extending from Kisimayo to the Kenyan border contains the Bajuni archipelago and three channels linked to the sea through three large outlets named, from north to south, Lac Badana, Lac Anole, and Lac Busc Busc (Fig. 9). Three villages, Istanbul, Kudai and Burgao are located on these channels. The Bajuni Archipelago consists of a series of islands, islets and skerries parallel to the coast at a distance of 2–4 km. Toward the coast, they separate a sound up to 10 m deep, where carbonate sedimentation takes place. The flat coastal belt shows a reefal substratum forming a marine terrace 4–6 m high, covered by reddish soils and dunes near the shoreline and by alluvial and marshy deposits inland.

Rivers and the alluvial plain

The country's only permanent rivers are the Juba and Shebeli, originating from the Ethiopian plateau, and draining into the Indian Ocean. There are large variations in discharge from year to year. The Shebeli river first flows to the coast, then, north of Mogadishu, changes direction, and near Mogadishu it forms a wide alluvial plain about 90 m above sea level which lowers southwards, forming a large marshy area.

According to Sommavilla *et al.* (1993) the outline of both the river and its valley have mostly resulted from recent tectonic movements, superimposed on the older faults (Fig. 2, cross-section). From wells drilled for water supply on the alluvial plain south-east of Mogadishu (Faillace, 1964) the sediments deposited by the river are up to 350 m thick. More than 250 m of this alluvial cover lies below the present sea level.

The merka red dune complex

A wide dune ridge runs parallel to the coast from 6°N to 2°S, reaching its maximum elevation of 378 m a.s.l. in the Mudug region, with a maximum width of *ca* 100 km at Adale. From Mogadishu to the Juba river mouth this runs very close to the coastline, and does not exceed 8–10 km in width, whereas it reaches an elevation of *ca* 150 m south of Merka village (Fig. 3(B)).

According to Clark (1954), the dune ridge is made up of an array of parallel dunes whose sand is similar to the recent deposits of the Juba river (Artini, 1915, 1926; De Angelis, 1938; Clark, 1954; Angelucci *et al.*, 1995). Seawards, the dune partially overlies a marine sequence (Fig. 4), rich in coral remains.

The coastal reef terrace

The Pleistocene lithologic sequence outcropping along the coast, the channel cliffs, and in various quarries in the outskirts of Mogadishu (Fig. 6) and Kisimayo shows well diversified shallow marine envi-

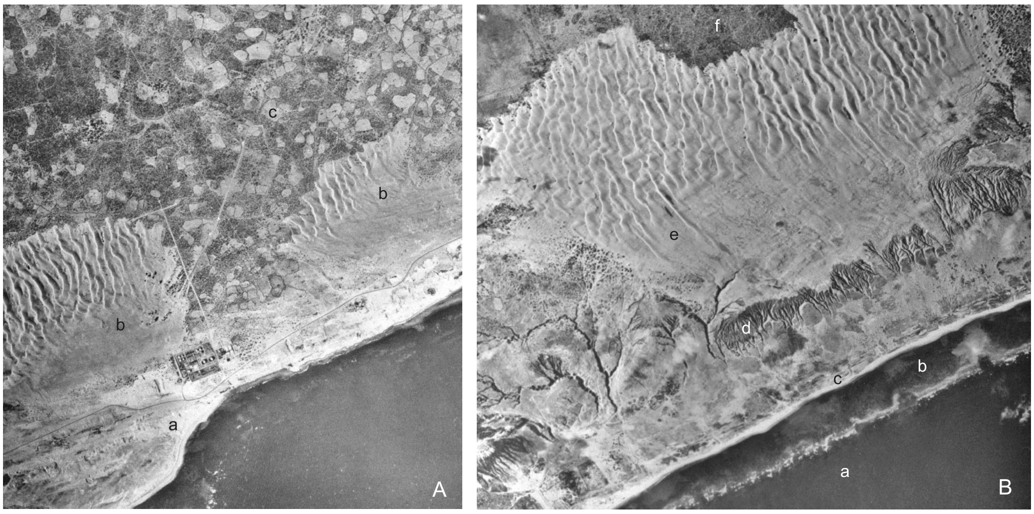

Fig. 3 Southern Somali coastal belt. (A) Effect of prolonged human use of the coastal belt just south of Mogadishu: (a) top of Pleistocene reef terrace affected by deep quarries; the oil-refinery is also clearly visible; (b) mobile dunes; (c) farmed land. (B) Coastal area near the village of Merka: (a) wave breaker line along a morphological step of the abraded shelf; (b) shallow shelf colonized by *Thalassodendron* seagrass and coral heads; (c) raised reef terrace covered by Achatina and Georgia eolianite and small mobile dunes; (d) gully erosion of the Merka red dune front; (e) wide mobile dune field; (f) Uebi Shebeli alluvial plain.

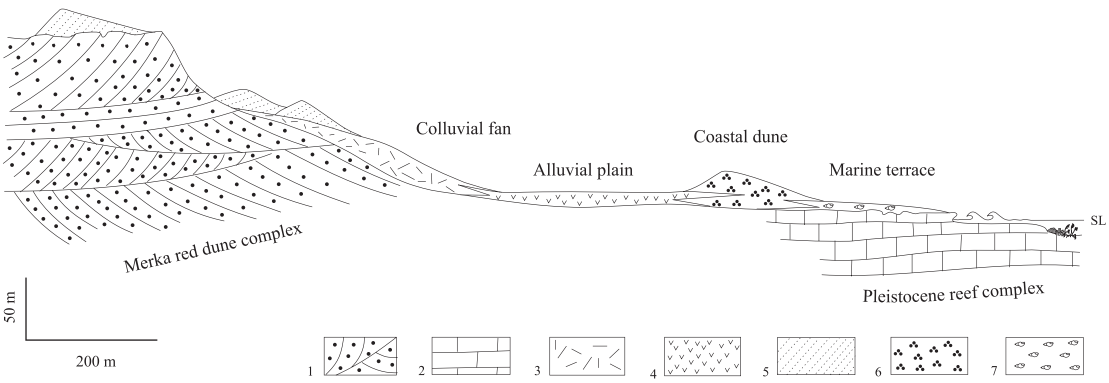

Fig. 4 Schematic cross-section from the red dune complex to the coastline near the village of Merka: (1) poorly cemented, cross-bedded quartzose sand; (2) raised Pleistocene reef limestone interbedded with quartzose–carbonate beach sand; (3) reworked sand of the red dune complex, forming small accretionary alluvial fans developed at the foot of gullies; (4) reddish residual soil deposited in floodable, protected backshore areas; (5) mobile dune fields of quartzose sand; (6) coastal dunes built by accumulation of varying percentages of quartz and carbonate skeletal grains; (7) calichified eolianite with abundant *Achatina* and *Georgia* shells.

ronments. Near Mogadishu, cliffs and quarry walls, 4–6 m thick, show a sheltered facies of a well developed fringing reef (Carbone *et al*., 1984; Carbone and Matteucci, 1990), with coral colonies in growth position (massive *Porites*, *Lobophyllia* and *Galaxea* knobs and *Acropora* thickets) overlying sandy beach deposits containing small bivalves (*Donax*, *Atactodea*, *Gafrarium*) and gastropods (*Gibbula*). This marine sequence is topped by regressive rhodolith deposits and skeletal rubbles mainly consisting of coral fragments, generally encrusted by red algae, in places showing a spur and groove morphology. It is likely that reefal limestone extend tens of meters below the present sea level, and data from a well, *ca* 50 m deep located close to the

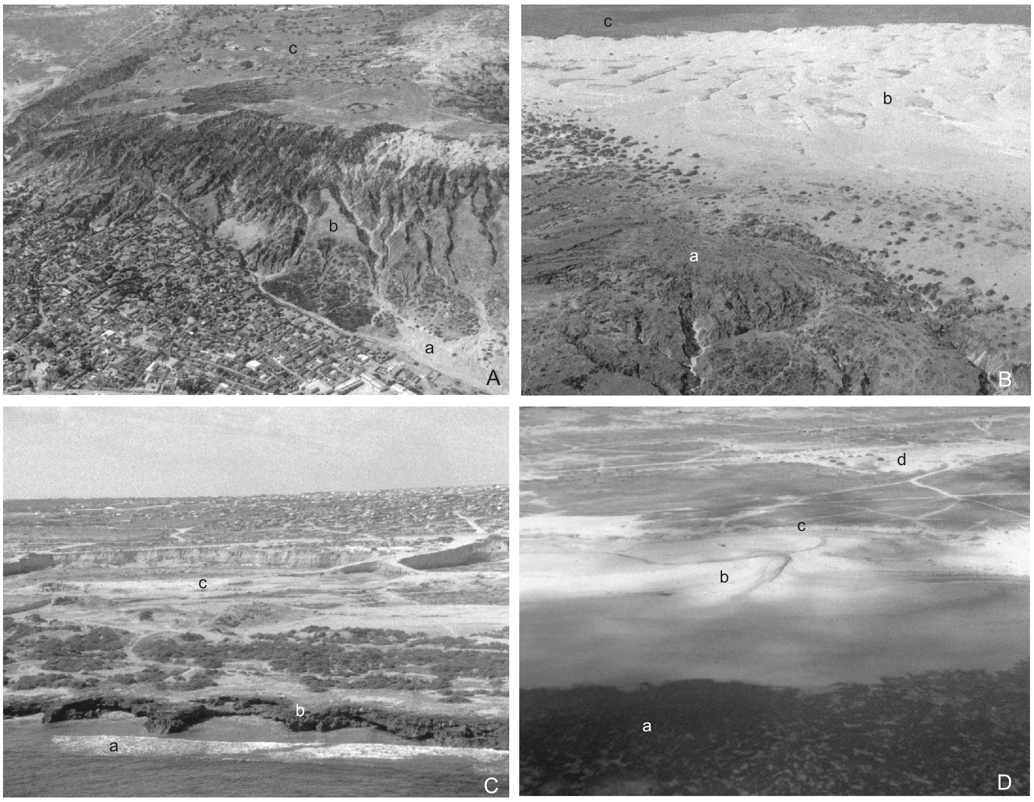

Fig. 5 Features of the coastal belt: (A) Merka red dune complex at the back of the village of Merka: (a) coalescent eluvial fans grown at base of the dune wall; (b) gully erosion of the steep dune wall; (c) top surface of the dune gently dipping towards the Uebi Shebeli alluvial plain. (B) Top surface of the Merka red dune covered by a mobile dune field: (a) poorly cemented sandstone showing a badland morphology; (b) mobile quartzose sand accumulated by monsoon winds; (c) Uebi Shebeli alluvial plain. (C) Man induced large-scale alteration of the coast near Mogadishu: (a) nearshore abraded flat; (b) wave notch in Pleistocene raised coral reef complex; (c) quarry surface often flooded during high tide. (D) Zonation of a flat coastal area south of Mogadishu: (a) *Thalassodendron* seagrass bed; (b) mobile sandy bottom; (c) coarse berm deposit; (d) flat backshore area, in places showing the effects of evaporative pumping of groundwater (white areas).

shoreline 15 km south of Mogadishu (Dal Pra' and Salad, 1986) shows a sequence of sandy layers containing variable amounts of skeletal remains which are typical of shallow water coastal environments.

The reef complex also outcrops in the Kisimayo region, where reefal bodies are found in different places. Crusty-massive and massive types prevail in the coral community (*Favia*, *Favites*, *Gonyopora*, *Porites*). The colonies are loose in coarse skeletal sediment. The top of the reef terrace is generally altered by calichification processes, showing several cavities filled with reddish sandy sediments. At many sites this marine terrace is conformably overlain by strongly calichified eolianite, bearing a rich continental gastropod assemblage (*Achatina* and *Georgia*). In places, along the coast, the Pleistocene reefal limestone is overlain by a seaward dipping beachrock.

The Bajuni barrier island

The Bajuni archipelago shows many features of a barrier island complex (Hoyt, 1967; Schwartz, 1971; Purser and Evans, 1973). The islands consist of elongate ridges parallel to the coast and separated from it by a narrow and shallow marine sound (Fig. 9). The origin of this barrier island is linked to the migration of the coastal dune field towards the continental shelf edge during the last glacial sea-level lowering. Islands, islets and skerries, separated by inlets, have allowed a widespread coral colonization of the shelf. High carbonate sediment production from coral reefs and seagrass meadows causes the build-up of sandy bodies in the shape of bars and tails, which emerge during the low tide (Fig. 7(B)). These bodies run from the islands towards the sound, forming wide protected intertidal flats, where fine sediment deposits are intensely bioturbated by infauna.

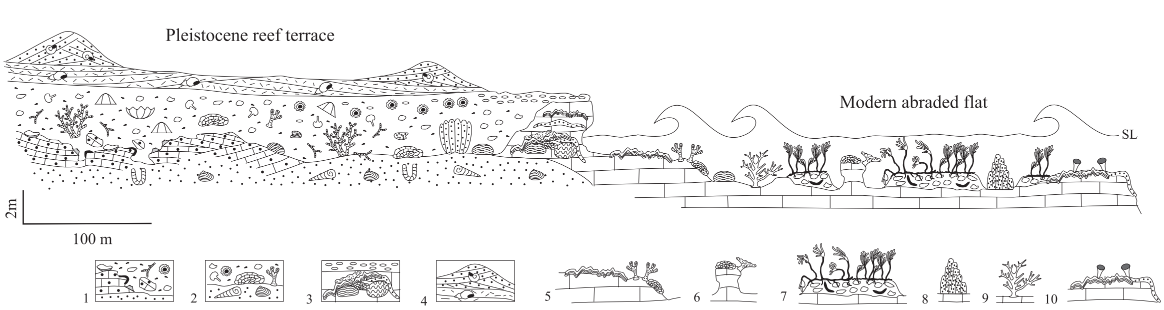

Fig. 6 Schematic cross-section of Mogadishu coast: (1) bioturbated quartzose sand with bivalves and gastropods overlain by skeletal sand; (2) well sorted quartzose sand, with gastropod and bivalve infauna, covered by coarse skeletal sand showing several coral colonies in growth position, topped by rubble, mainly of coral remains often encrusted by red algae; (3) assemblage of corals and encrusting red corallinaceans, in places with spur and groove features, topped by coral rubble; (4) eolianites and mobile dunes, rich in *Achatina* and *Georgia* shells; (5) abraded flat encrusted by corallinaceans and bordered by small fringes of branching and massive Porites; (6) erosion remnant colonized by both massive and small branching corals; (7) *Thalassodendron* seagrass bed; (8) *Porites lutea* knob; (9) *Millepora* thicket; (10) shifting substrate encrusted by corals, corallinaceans and sponges.

The islands reach an elevation of about 10 m a.s.l. Their indented seacliffs generally show a pronounced notch landward, where bioerosion is intense and wave action is weak. The boundary between eolianites and underlying skeletal limestone is barely detectable on the islands, and only in rare cases can it be found at the base of the seacliff, coinciding with the abraded flat.

The braided channelized coast

Wide tidal flats along the coast south of Kisimayo seem to be connected to three braided channels flowing perpendicular to the coast in the Bajuni sound. These channels originated during the Holocene from the drowning of a wide fluvial net extending from Kisimayo to Lamu in Northeastern Kenya. Where there is low water energy, the intertidal zone is usually occupied by mangroves (Fig. 7(B)). They trap fine sediment to build mud flats, strongly bioturbated by crabs and gastropods. In places, salt flats develop at the back of this mangal flat in sheltered coastal areas. Relict quartzose sand migrates along the channels towards their mouths, mixing with carbonate skeletal sediment produced along the channels and transported to form sand drifts at the channel outlets and beach ridges along the shore (Fig. 7(A) and (C)).

During rainy seasons, fresh water flowing into the channels is generally insufficient to modify the flourishing marine biota of the lower reaches, whereas in the upper ones, it is probably responsible for poor development of biota made up of small gastropods and thin-shell bivalves. The transition between the two environments is variable from one channel to another, depending on both their morphology and the extension of the tidal prism inside the channels.

Late Pleistocene to Present-Day Event Sequence

The modern setting of the Somali coast is the result of the interaction between tectonics of the passive east African margin and recent sea-level fluctuations. The presence of coral reef terraces, uplifted at different elevations, along the African coast of the Indian Ocean is well-documented (Ase, 1978, 1981; Crame, 1980, 1981; Braithwaite, 1984), though there is scarce and often contradictory age-dating. Braithwaite (1984) established a complete description of depositional units outcropping along the Kenyan coast. He points out the existence of a complex of terraces ranging from 4.5 to 140 m. Dates range from about 240 000 years BP ($^{230}Th/^{234}U$ dating recorded by Battistini, 1976) to about 25 000 to 27 000 years BP (radiocarbon dating by Hori, 1970; Toyah *et al.*, 1973), the last two being doubtful and coming from samples about 4–5 m a.s.l., near Mombasa and Malindi. More recent age-dating, ranging from 2640 ± 105 to 5250 ± 130 years BP, are referred to as 'beachrocks' cropping out (0.9–0.2 m high) from Lamu to Mombasa (Hori, 1970; Toyah *et al.*, 1973). In the Southern Somali coast, still some unpublished $^{230}Th/^{234}U$ dating obtained by us on massive corals and *Tridacna* shells from the Mogadishu and Lamu areas places the older reef cycle cropping out along the coast between 105 000 and 131 000 years BP. Thus, a connection can be hypothesized between a basal transgressive episode and the depositional event of the last interglacial period of the isotope stage 5. In the area south of Kisimayo several evolutive phases have been identified, corresponding to eustatic sea-level variations starting from isotope stage 5e (Fig. 8).

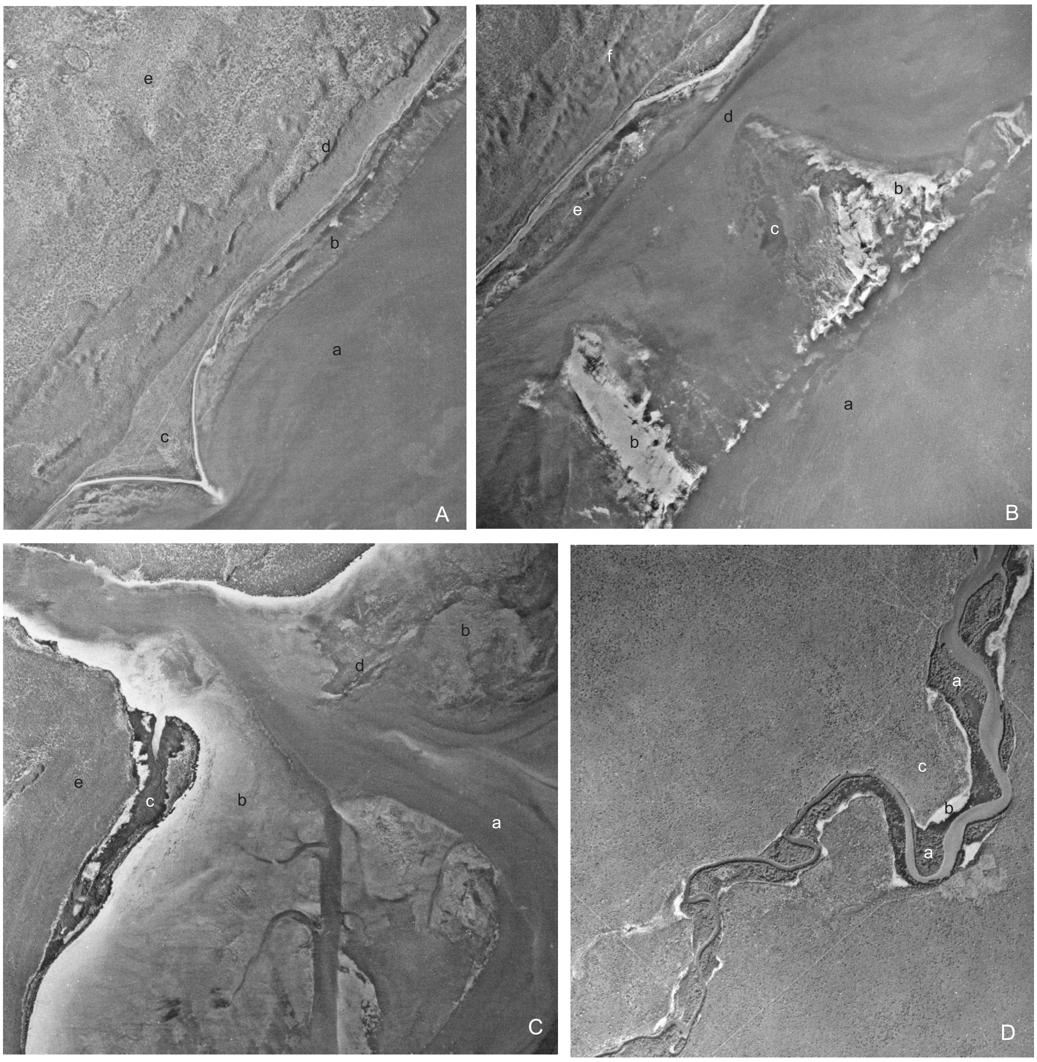

Fig. 7 Coastal belt south of Kisimayo. (A) Mainland coast protected by the Bajuni barrier island: (a) subtidal sandy bottom; (b) abraded nearshore shelf, colonized by seagrass and scattered coral heads; (c) sand spit prograding on the flat nearshore shelf; (d) old frontal dune ridge showing a fossil wave cut notch; (e) bedrock covered by eolian deposits stabilized by scrub. (B) Islets and skerries forming the Fuma island complex, showing sandy tails perpendicular to the coastline: (a) outer shelf largely colonized by *Thalassodendron* seagrass; (b) intertidal mounded and rippled sandy bottom, strongly bioturbated; (c) high subtidal bottom, mainly colonized by *Thalassodendron* seagrass; (d) subtidal mobile sandy bottom; (e) narrow shelf with seagrass and scattered coral heads; (f) old dune ridge covering the Pleistocene reef complex. (C) Lac Badana outlet: (a) low tide channel, cut in the bedrock, winnowed by tidal flows; (b) shelf where sand from the channel forms wave bars and shoals, in places stabilized by dense seagrass beds; (c) mangal bordering landward a salt flat; (d) abraded flat bordered by a small fringing reef; (e) old accretionary frontal beach and dune ridge. (D) Lac Badana channel upstream of Yamani village: (a) mangrove fringe; (b) sheltered floodable area with salt flat characteristics; (c) peneplaned area extensively covered by scrub.

Major Shallow Water Marine and Coastal Habitats

The habitat distribution along the southern Somali coast results not only from close interaction of biological, physical and chemical marine processes, but also from recent eustatic sea-level variations. In shallow water, the Pleistocene substratum is colonized by scattered coral communities, which are widely distributed but far from flourishing everywhere. The amount and

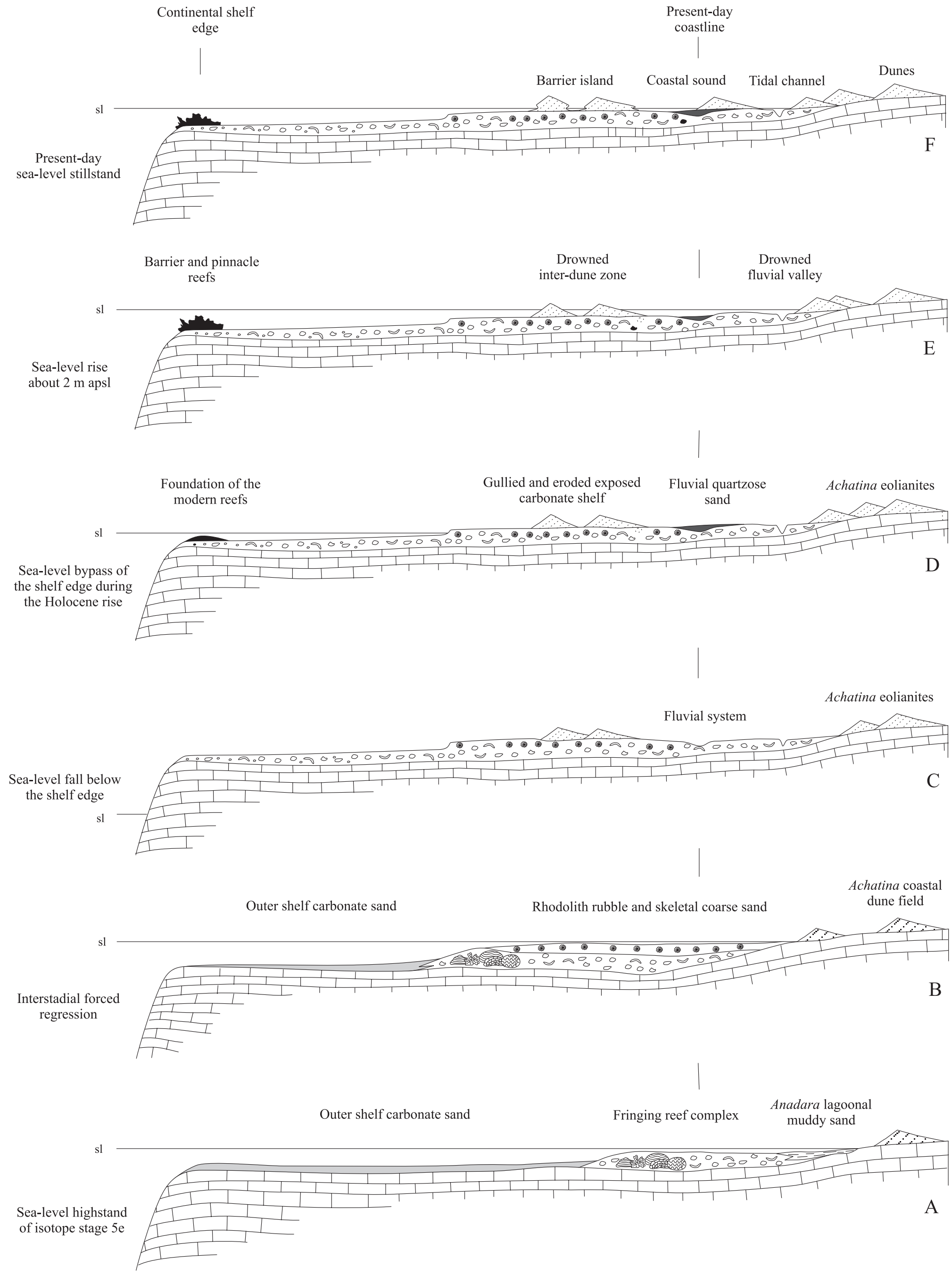

Fig. 8 Profiles showing the evolution of the shelf of the Bajuni Islands since sea-level highstand of isotope stage 5e, about 125 000 years BP. (A) Sea-level highstand of isotope stage 5e: sea-level rise with landward migration of a fringing reef complex forming the lower part of the marine carbonate sequence, overlying beach ridge facies along the coast from Kisimayo to Lamu. Protected lagoonal environments proved by muddy deposits rich in gastropod and bivalve communities. (B) Interstadial forced regression: sea-level drop with progressive seawards coastline migration. Deposition of coarse skeletal sand rich in coral remains and corallinaceans. Rhodolith rubble is present in places to form a regressive surface. (C) Sea-level fall below the shelf edge: long subaerial exposure of the continental shelf surface, with erosion and weathering. Development of a braided fluvial net, with its base level lower than the present one, and migration of a dune ridge towards the shelf edge. (D) Sea-level bypass of the shelf edge during the Holocene rise: rapid submergence of east African coast, beginning approximately 18 000 years BP (Colonna *et al*., 1996). A submerged ridge along the Bajuni shelf edge could signify the coral regrowth. The base of this ridge, located 20 m b.p.s.l., could indicate the starting point of the coral colonization 8000 years BP (Hopley, 1994). (E) Sea-level rise of about 2 m a.p.s.l.: inundation of the Pleistocene shelf with drowning of channels cut during the lowstand, and overflowing of the interdune areas. This caused formation of wide tidal flats. Deposition of beachrock takes place just above the present sea level. (F) Present-day sea-level stillstand: the present pattern, reached in very recent times, marked by beach ridges, longshore bars and wide tidal bars. Partially buried old notches, bordering the mangal flat, suggest a prograding tendency. Today, many areas inside the Bajuni sound appear to be shallowing, with increase of the mangrove colonization and decrease of the coral community in favour of *Thalassodendron* meadows.

kind of coral cover is very variable, giving rise to different coral facies. In many areas where the hard substratum is subject to stronger wave action, corals grow in the form of scattered small colonies. In more protected areas, several generations of corals succeed in forming knobs and patch reefs of varying sizes. True fringing reef topography occurs only in the Bajuni archipelago.

All along the Southern Somali coastal shelf, coral growth competes with *Thalassodendron* seagrass meadows, both inshore and offshore. Benthic communities typical of mobile sandy substrates are limited to beach ridges and shoals along the coast. A more diversified habitat is recognizable in the southernmost part of the Somali coast and in Northern Kenya, because of the presence of the Bajuni barrier island and of the braided channelized belt. Mangal flats occur on the tidal areas of the channels.

Shelf and fringing reefs

Corals along the Somali coast of the Indian Ocean are poorly investigated. After general observations by Darwin (1842), Dana (1875) and Crossland (1904), only recently have some papers (Angelucci *et al*., 1982; Carbone *et al*., 1994) contributed to the knowledge of the coral associations and their distribution pattern. Various types of reef grow on both abraded rocky substrates and stabilized sandy bottoms. Coral colonization shows the same characteristics all along the Somali shelf; only south of the Juba River mouth, the widening of the shelf and the presence of the Bajuni barrier island cause a major diversification.

Coral carpets consist of dense assemblages mainly of massive and encrusting corals, on large flat areas near the coastline where mobile sandy cover and *Thalassodendron* meadow are lacking. Coral carpets are also found offshore, on the edge of the first shelf step, about 10 m deep, coinciding with the breaker zone (Figs. 3(B) and 6); here corals are scarce in high energy areas where sparse colonies of *Pocillopra eydouxi* are found together with a greater abundance of crustose coralline algae and soft caliculate sponges. In places, crustose coralline algae predominate and *Halimeda* tufts are common as well. Corals consist only of small colonies of *Psammocora contigua*, *Pavona decussata*, *Pocillopora damicornis*, *Acropora* spp, *Favites* spp, and scattered large encrusting colonies of soft corals.

In the Bajuni archipelago coral carpets are also developed on the protected shelf area. Massive corals generally colonize the edges of the abraded flat surrounding the islands, the most common being *Favia stelligera*, *F. pallida*, *Favites abdita*, *F. halicora*, *Goniastrea pectinata*, *G. retiformis*, *G. aspera*, *Goniopora lobata*, *Porites somaliensis*, *Platygyra lamellina*, *P. daedalea* and some colonies of branching *Pocillopora eydouxi*. Thickly branched corals, such as *Porites nigrescens* and *Stylophora pistillata*, together with some large crustose colonies of *Echinopora gemmacea* are also found.

Real fringing reefs grow only along the shelf edge of a few islands of the Bajuni archipelago. At Ilisi (Fig. 9(A)), the northernmost island of the archipelago, a 500–600 m wide shallow shelf is bordered by a steep reefal slope 8–12 m deep, connecting to a flat sandy bottom. The fore reef is covered by skeletal sand, locally stabilized by seagrass. Here coral pinnacles are found, at times reaching the sea surface and assuming the typical micro-atoll morphology. Among the corals, *Porites*, *Goniopora*, *Millepora* and *Faviids* prevail. Branching *Acropora* thickets are also found, with wide areas of dead coral, encrusted by corallinaceans and with dense *Fungia*. The reef front is very steep and densely covered by corals mostly in the middle and upper part. In the lower part of the wall, soft corals (*Sarcophyton*) are typical, whereas the remaining spaces are occupied by crusty and plate-like corals (*Montipora*, *Hydnophora*, *Echinopora*), small branching *Galaxea fascicularis* and Acroporids, and domal massive corals (*Favia*, *Favites*, *Porites*). The upper part of the reef wall shows a gradual upward increase of branching *Porites*. The reef crest, about 30 m wide, is characterized by an extensive cover of *P. somaliensis*. Small *Acropora prolifera* thickets replace *Porites* colonies towards the reef flat. The reef flat is characterized by a landward progressive decrease of the coral cover. Where coral cover decreases, the substrate is encrusted by *Melobesia* or covered by coarse bioclastic material originating from branching corals and mollusc shells. This material is encrusted by corallinaceans and polychaetes, and is densely bored by clionids and serpulids. The rough surface of the reef flat hosts algal mats and a rich population of ophiuroids and small gastropods. The back reef area is generally characterized by a dense *Thalassodendron* meadow. The meadow is frequently interrupted by irregularly shaped depressions, covered by sand, which originates from the remains of molluscs, *Halimeda* and corallinaceans. The coral community is sparse and similar to that of the reef flat.

Smaller fringing reefs grow close to some islands where inlets allow water exchange between the sound and the open sea. At Cuvumbi island the reef front consists of a small steep wall generally showing a vertical zonation. The reef flat (Fig. 11(A)), very close to the island, is colonized by various species of branching *Acropora* and by *Tubipora musica*. Shoreward, the coral community consists of micro-atolls of *Favia stelligera* and small colonies of *A. abrotanoides*, *F. flexuosa*, *F. abdita* and *P. nigrescens*.

Along the barrier island, on sea floors particularly subject to wave and current action, corals are scarce and consist of small massive forms (*Porites somaliensis*, *Platygyra lamellina* and *Favites*), flat stout colonies of branching *Acropora* and encrusting forms of *Echinopora gemmacea* and *Hydnophora exesa*. Where maximum water energy is reached, corals are even less common, while encrusting coralline algae increase, locally forming rhodolith deposits.

In the Bajuni sound, coral knobs and patch reefs surrounded by sandy substrate rise up from the *Thalassodendron* beds. These build-ups may represent the colonization of successive generations of corals on

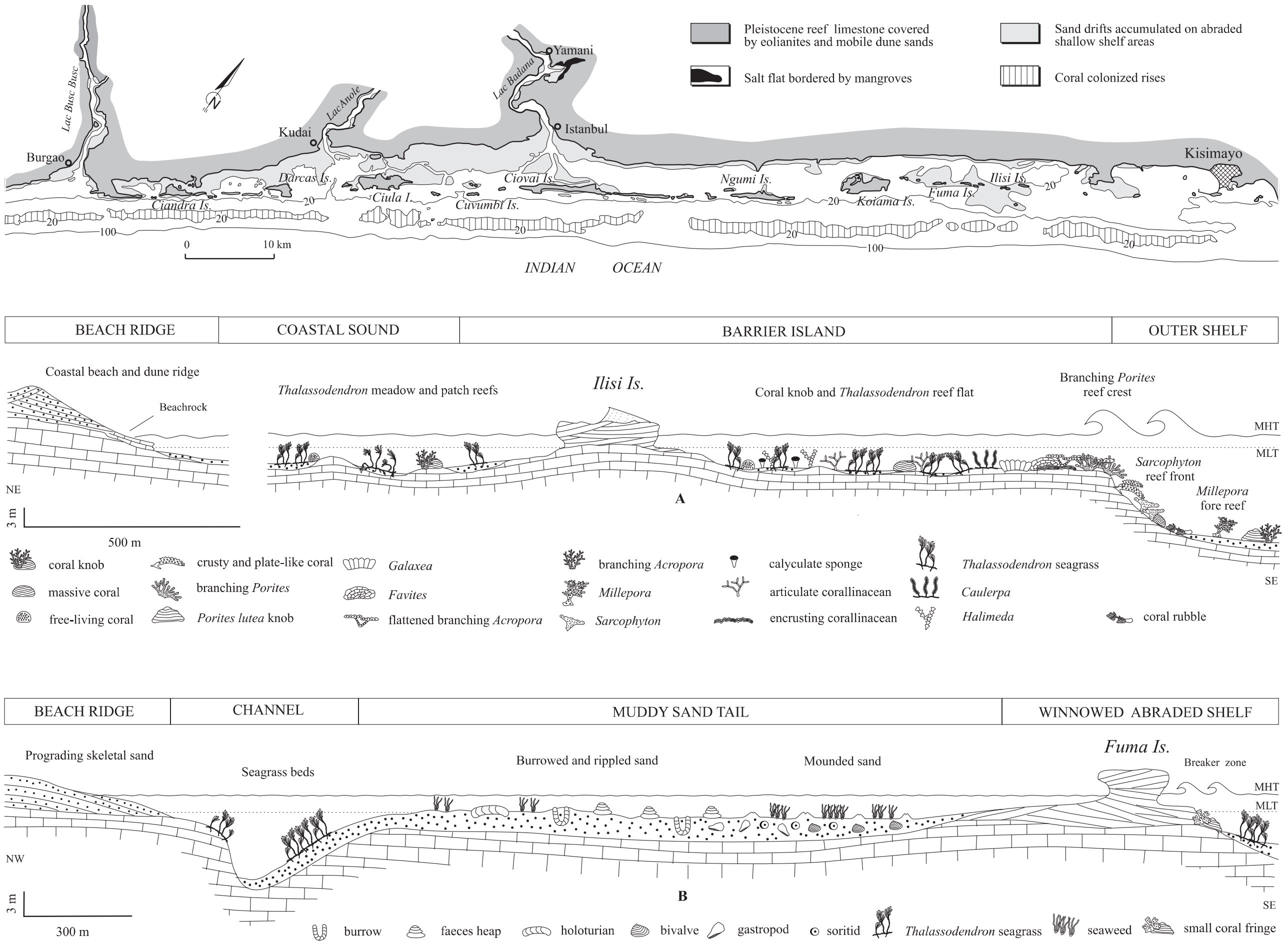

Fig. 9 The Bajuni barrier island. The benthic system is illustrated by two schematic ecological profiles through the Ilisi Island fringing reef, (A) and the Fuma Island sandy tail, (B).

erosion remnants of the hard substratum. These coral reefs show an ecological zonation: the central part of the top surface covered by encrusting and articulate corallinaceans and tufts of *Halimeda*, whereas the elevated rims, exposed at low tide, are colonized by *Acropora*, *Pocillopora* and *Millepora*; the flanks often show *Porites* and faviids in the middle part and encrusting corals like *Echinopora gemmacea* and *Hydnophora exesa* in the lower part. The surfaces without living corals show intense bioerosion by bivalves and clionid sponges. Some of them resemble table reefs (James, 1983), some of which are 200 m wide and 5 m high. The distribution of the living corals along the wall-like margins is controlled by water energy: *Acropora* communities grow mostly on the landward side; leafy and plate-like communities grow on the seaward side. Huge single colonies of *Porites lutea* grow separated from the main patches.

Seagrass meadows and sandy bottoms

Studies on seagrass beds and associated fauna have been carried out in various locations of the western Indian Ocean (Pichon, 1964; Mauge, 1967; Taylor and Lewis, 1968; Aleem, 1983), but little on the Somali coast. Few seagrass beds occur along the Northern Somali coast, but they are extensive along the southern coast from Adale to Ras Chiamboni.

Thalassodendron meadows colonize wide areas of the shallow shelf (Figs. 5(D) and 10). The sea floor is generally covered by a thick layer of rubble, encrusted by corallinaceans, bound by *Thalassodendron* roots and characterized by whole bivalve shells (*Codakia*). The stalks and blades of the seagrass support a flourishing epiphyte community of both articulate and encrusting corallinaceans, together with bryozoans. The *Thalassodendron* meadows play an important role in the production of carbonate sediment, as well as in sediment trapping, including fine muddy particles (Scoffin, 1970; Land, 1970; Patriquin, 1972). In consequence, the substratum of the meadow is more elevated than the surrounding sea floor. Unvegetated areas, usually elongated parallel to the coast, are covered by rubble or coarse skeletal sediment, or show the hard substratum. Along the edges of these depressed areas the local increase of water energy causes lateral erosion of seagrass beds. *Thalassodendron* constantly competes with coral

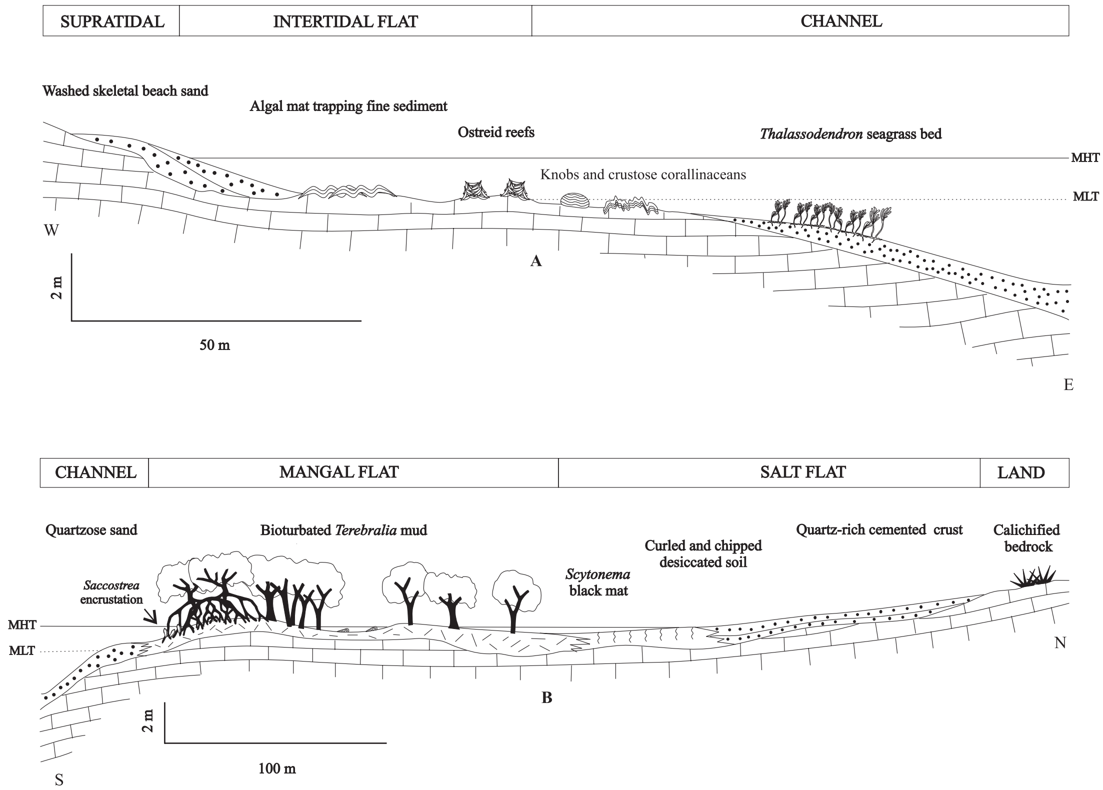

Fig. 10 Schematic ecological profiles of Lac Anole near the village of Kudai, (A) and of Lac Badana near the village of Yamani, (B).

growth expanding laterally to cover areas colonized by corals, but also being replaced by corals when increased water energy causes its erosion.

Biota of mobile substrates are typical of inner coastal areas, where beach ridges and shoals develop. The coastline north of the Juba River shows cliffs (Fig. 5(C)) alternating with beaches. Locally, erosional remnants rising from the abraded flat are connected to the coast by tombolos. Beaches are normally colonized by suspension-feeding molluscs such as *Donax* and *Atactodea*. High-water beach and berm deposits often made of shell hash, are densely burrowed mainly by crabs. During the lowest low tides, mobile sandy bottoms are widely exposed and sand is blown by monsoon winds and accumulated to form backshore eolian deposits.

A mixture of habitats occurs in the Bajuni sound. The mixing and accumulation of carbonate and quartzose sand produces different shaped tidal bars at the channel outlets (Fig. 7(C)). The coastline has a frontal beach and dune complex, at the back of which older coastlines are present (Fig. 7(A)). Accretionary sandy tails and spits accumulate mainly on the landward side of the islands (Fig. 7(A) and (B)). Locally, these tails develop perpendicular to the sound, forming wide intertidal areas, separated from the coast by a narrow channel no more than 10 m deep. At Fuma island, the intertidal area of the tail is characterized by various facies (Fig. 9(B)), mostly orientated perpendicular to the coast, with a distribution controlled mainly by the length of subaerial exposure and tidal energy.

Moving from the islands towards the centre of the sound, the high intertidal zone has beach deposits of poorly sorted skeletal sand, rimmed inshore by coarse beachrock formed by gastropod, bivalve and coral remains. They move on to a mounded zone where fine sediment is densely bioturbated by crabs and worms (Fig. 11(D)). Here, there are seagrass carpets of small *Thalassodendron* and *Syringodium*, partly buried by fine sediment. Small gastropods (strombids and cypreids) are also present, and among foraminifers, soritids are common. Moving towards the axis of the channel, the bottom is flat and covered by asymmetric ripples orientated according to the tidal currents. The strong bioturbation is marked by the presence of abundant faecal pellets and faeces heaps, disgregated during flood tide. Holothurians are common. These accretionary tails end near the channel edge, where *Thalassodendron* colonization takes place.

Mangal and braided channels

Intertidal flats have been studied in different parts of the Indian Ocean, but again, little is known of the area between Kenya and Somalia (Carbone, 1987; Hughes and Hughes, 1992; Eisma, 1998). Some are colonized by mangroves (Fig. 7(C) and (D)). The mangal forms a low-energy intertidal environment, where black fine sediment forms the habitat for the development of a

Fig. 11 The main shallow water marine and coastal habitats: (A) Cuvumbi Island reef flat, showing *Acropora* colonies during lowest low tide; (B) wide abraded flat bordering the Lac Badana outlet, emerged at low tide. The rugged surface is covered by a thin sandy sheet and scattered seagrass; (C) mangal flat at low tide near Yamani (Lac Badana). The roots are densely encrusted by ostreids (*Saccostrea cucculata*); (D) Fuma Island sandy tail at low tide showing a densely bioturbated muddy bottom; (E) ebb-oriented ripples on the beach ridge at Lac Anole outlet.

highly specialized oligotypic community. The distinctive characters of mangal and its zonations are well known (Tomlinson, 1986), even if poor information is available for East Africa (Walter and Steiner, 1936). Most mangal in Somalia is along its southwestern coast, even if isolated stands of *Avicennia marina* are found behind sand spits along the northern coast (UNEP, 1987); mangrove habitats are also reported along the Gulf of Aden (Sheppard *et al.*, 1992).

Biota in the channels is mainly controlled by migration of quartzose sand along the channels and an increase of biogenic sediment towards the sea. In the upper reaches of the channels, where quartzose sediment predominates, foraminifers are rare and consist of small *Ammonia* and *Elphidium*. The foraminiferal assemblage gradually increases seawards, including miliolids, textulariids, *Amphistegina*, *Heterostegina*, *Ammonia* and the epiphytes *Rosalina* and *Planorbulina*. Coquina facies are in places found in the deepest channel areas, where coarse washed sand accumulates, consisting of shell hash of trochids, arcids, *Solen* and bullids and abundant bryozoan remains, mainly *Fenestella*. In high subtidal zones skeletal sediment prevails, with an abundant infauna of suspension – and detritus-feeder bivalves (*Codakia*, *Anodontia*, Pinnids, *Pitar*, Tellinids, and *Modiolus*) and gastropods (Strombids, *Nassarius*, Conids, Cypreids, and *Lambis*); in places this sediment is stabilized by small seagrass beds.

The channel levees show medium- to fine-grained sediment, highly burrowed by small crabs and with asymmetric ripples orientated according to the tidal flow (Fig. 11(E)). Linear tidal bars run parallel to the channel on its flat banks, forming tidal protected areas where small washover fans and semi-permanent pools originate. Towards the outlets, in areas of scarce sand accumulation, abraded bedrock forms the channel banks (Fig. 11(B)). This hard bottom is colonized (Fig. 10(A)) by encrusting red algae, thin algal mat trapping fine sediment, and small scattered coral colonies; the cliffs bordering the abraded flat are colonized by *Saccostrea cucullata*, barnacles and boring bivalves (*Lithophaga* and *Gastrochaena*). Where the channels flow into the Bajuni sound, the sediment consists of a mix of carbonate and quartzose sand, forming wave-generated bars alternating with areas colonized by seagrass. Seawards, typical swash bars and linear tidal shoals, often associated with sets of symmetrical megaripples, give rise to small tidal deltas (Fig. 7(C)).

The intertidal abraded flats facing the channels are widely colonized by red mangroves (*Avicennia* and *Rhizophora*) and inland are bordered by old wave notches topped by a wind-scoured surface where Acacia and Baobab grow. On mangrove roots emerging at low tide grow *Saccostrea cucullata*, barnacles, sedentary polychaetes, boring organisms (clionid sponges) and *Littorina* cf. *scabra* which lives on trunks and leaves, even when completely emerged (Fig. 11(C)). *Saccostrea* flourishes in the low and middle intertidal zone facing the channels and suddenly decreases towards inner areas. In sheltered muddy bottoms of mangrove thickets, where semi-permanent pools persist during low tides, the infauna is dominated by the fiddler crab, *Uca*, while the gastropod *Nerita* occupies the peripheral part of the mangal flat. The inter-mangrove pools are highly populated by potamiid *Terebralia palustris* and *Cerithidae decollata* and by an infauna of polychaetes and arthropods (Fig. 10(B)). Scattered small build-ups, to 1 m high, of successive generations of *S. cucullata* are also found where mangrove trees thin out, on a wide intertidal flat separating the channel from the land. This flat consists of Pleistocene bedrock and is locally covered by veneers of sandy sediment. The *Saccostrea* build-ups are often arranged in strings parallel to the levee on the channel bank (Fig. 10(A)); the shells adapt themselves to the substratum without a preferential orientation and are locally associated with *Nerita*, barnacles, and polychaete worms.

Salt flats occur along the channels. In a few places, such as in Lac Badana channel, near the village of Yamani, wide salt flats spread (Fig. 10(B)). These are affected by high evaporative processes, which cause the development of a typical algal flat-sabkha plain. These gradually disappear landwards to be replaced by a sandy plain with small-scattered dunes. In the higher sabkha areas, climatic conditions and water table fluctuations induced by tides are responsible for processes of alteration of the carbonate sediment and of adhesion of eolian quartz grains to the moist sabkha surface. In the lower areas, prism cracked surfaces and curled and chipped, desiccated algal mats are found, typical of the evaporative pumping of groundwater. During the highest tides the water flows from the channel into the lower part of the salt flat, forming semi-permanent pools, where algal marshes develop. They are characterized by black *Shitonema* algal mats with typical 'pincushion' surfaces.

Population and Natural Resources

The total population of Somalia is 9 077 000 of which 64% is rural; the annual demographic growth rate is approximately 3.1% and the average population density is about 14 inhabitants km^{-2} (FAO, 1995). The coastal population is about 30% of the total and there is a strong tendency of migration to the major cities (Fig. 12). Somalia is mostly an agricultural and pastoral land with a cultivable area estimated at about 8 million ha in 1985, or 13% of the total area, but only about 980 000 ha cultivated with annual crops, i.e. 12% of the cultivable area. In 1993 about 18 000 ha consisted of permanent crops (FAO, 1995). Agriculture is the most important sector, while livestock accounts for about 40% of the gross domestic product and about 65% of the export earnings (CIA, 1999). About 60% of the indigenous population are nomads and semi-nomads who depend upon livestock for their livelihood. Crop production is only 10% of the gross domestic product and employs about 20% of the work force. Another export product is bananas, while sugar, sorghum and corn are produced for the domestic market.

Mineral resources are poorly exploited, even if they are potentially significant. Such deposits, mainly located in the north, include quartz and piezoquartz, uranium, gypsum anhydride and iron ore; meerschaum sepiolite is mined in the central region. In the south, several minerals are present in a narrow coastal belt, about 70 km long, at the mouth of Juba River. The occurrence of potentially valuable minerals in these places was first reported by Artini (1915). More recently, Frizzo (1987) (unpub. data) focused on the mineral characterization and economic evaluation of the placers. Even the Merka red dune complex, extending along 900 km of Somali coastline of the Indian Ocean, notable as a water reservoir in a region with generally arid climate, was recently evaluated (Angelucci *et al*., 1994, 1995) in the area

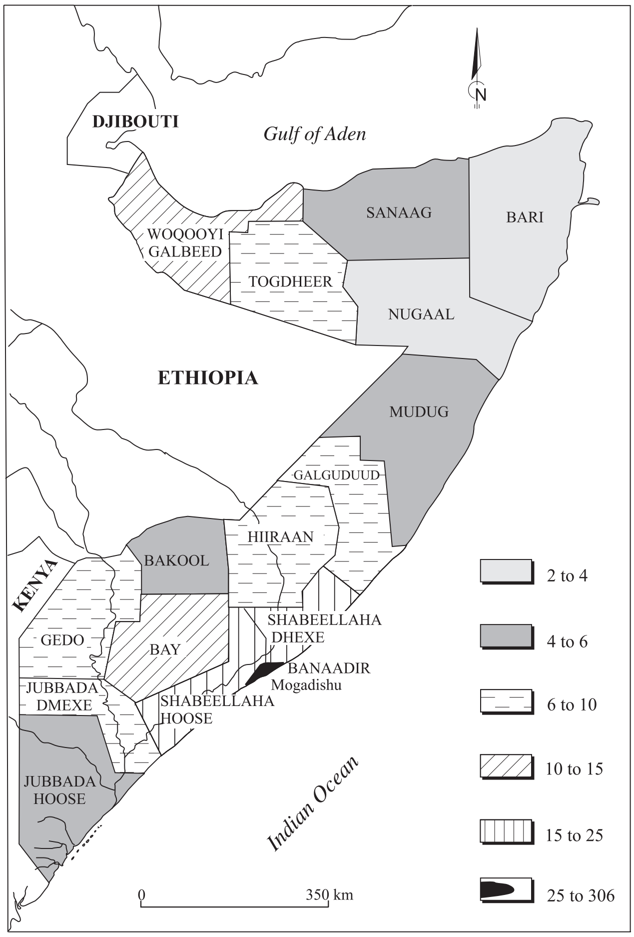

Fig. 12 Region boundaries and relative Somali population density indicated as inhabitants km^{-2}. Boundary representation is not necessarily authoritative.

between Mogadishu and Merka. The mineral composition (80 wt% of quartz combined with 15 wt% of feldspar) and the grain size (between 420 and 88 μm) make this a suitable source of raw material for a potential national glass industry. Exploration for oil and natural gas was initiated by AGIP Mineraria in the 1950s and subsequently intensified by various companies. The results are synthetized by Barnes (1976). Recently, the area of the Red Sea–Gulf of Aden was chosen by the World Bank (O'Connor, 1992) as a prototype of regional basin promotion for reasons both of geology and economic development. Bott *et al.* (1992) indicated good potential oil and gas deposits in Northern Somalia, while in the southern part of the coast, various foreign oil exploration plans were cancelled due to civil war after 1991.

Water resources in Somalia are mostly surface water. Total internally produced renewable water resources are estimated at 6 km^3 yr^{-1} and the incoming surface water resources at 9.74 km^3 yr^{-1}. In 1987, total water withdrawal was estimated at 0.81 km^3. Agricultural water withdrawal is about 0.79 km^3 or 97% of total withdrawal (FAO, 1989, 1995).

Along the Gulf of Aden, the mountainous zone is subject to torrential flows. The land slopes down towards the south and the south-flowing watercourses peter out in the desert sands. The rest of the country consists of a plateau, crossed by the two main rivers of Somalia, Uebi Shebeli and Uebi Juba. Over 90% of their discharge originates from the Ethiopian highlands and there is large variation from year to year. The discharge decreases rapidly through seepage, evaporation and overbank spillage due to low channel capacity and water abstraction. Often the rivers cease to flow in the lower reaches early in the year. Contribution to river flow inside Somalia occurs only during heavy rainfall, whereas that of other drainage basins to surface water is generally irrelevant. This normally consists of occasional runoff in seasonal watercourses. Groundwater potential is limited because of the scarce recharge potential.

Modern hydrogeological research in Somalia was first carried out by Wilson (1958), and by Hunt (1951) and Macfadyden (1952) in British Somaliland. Faillace (1964) reported on the Uebi Shebeli valley, and Popov and Kidiwai (1972) on the Mudugh and Galgaduud regions. More recent papers deal with central Somalia (Pozzi *et al.*, 1983), Uebi Shebeli valley (Sommavilla *et al.*, 1993), the groundwater near Mogadishu (Dal Pra' and Salad, 1986; Dal Pra' *et al.*, 1986). Sommavilla *et al.* (1993) describes an ancient hydrological system of buried paleochannels, still visible in satellite images, when the Shebeli paleoriver probably flowed into the Indian Ocean just north of Mogadishu.

Irrigation and drainage development is very poor. In the main irrigated areas in the Juba and Shebeli valleys, there is no organized system of water allocation and management. There are no dams on the Shebeli River within Somalia, but off-stream storage exists in Jowhar (200 million m^3). A second off-stream storage reservoir (130–200 million m^3) is proposed for Duduble, upstream of Jowhar. Another proposed dam, primarily for hydropower, is in Bardhere on the Juba River. This should also provide maximum water control and storage for irrigation projects in the Juba valley. Total irrigation potential is estimated at 240 000 ha. In 1984, the total irrigated area was about 200 000 ha, only 50 000 ha of which had reasonably controlled irrigation (FAO, 1995).

The main official body in charge of water resources is the Ministry of Mineral and Water Resources (MMWR), and its Water Centre (NWC). The Water Development Agency (WDA) is responsible for operations exploiting groundwater resources for domestic water supply. A study carried out by the World Bank (1987) outlined a proposed strategy for the development of irrigation, drainage and water management systems.

Effects from Human Activities and Protective Measures

Modifications along the coast have occurred over countless centuries. Somalia has long been involved in trade in the western coast of the Indian Ocean. Chinese merchants have stopped here since the tenth century and Greek merchant ships and medieval Arab dhows also plied the Somali coast that formed the western part of the 'bilad as Sudan' (the 'Land of the Blacks'). More specifically, medieval Arabs referred to the Somalis and neighbouring peoples as the Berbers. By the eighth century, the Somalis essentially developed their present way of life, which is based on pastoral nomadism and Islamic faith. The large-scale alteration of the coastal belt, mainly near major human settlements, like Mogadishu and Kisimayo, began in the nineteenth century, during the colonial period (1891–1960), when the need to accommodate larger vessels induced harbour development. This led both to the destruction of wide coral fringes in nearshore shallow water areas and to direct alteration of the coastal belt on a massive scale, accelerated in the last few decades. In fact several quarries (Figs. 3(A) and 5(C)) have been cut into coral reef terraces bordering the coast near the major cities to provide building materials. The short thickness (4–6 m) of this uplifted reef terrace, which is buried by eolian sand a few tens of meters from the coast, has forced the inhabitants to exploit the narrow coastal belt extensively, digging quarries as far as the sea cliffs. As a consequence, the coastal environment of these areas has been deeply transformed. Inside quarries, pools and marshes have developed and have given rise to the growth of oligotypic communities, where algal mats flourish.

An increased alteration of coastal marine ecosystems occurred in the 1980s when a refinery was built in the outskirts of Mogadishu. The building of a slaughter house, which scattered its waste into the sea, has attracted large numbers of predatory fishes, mainly sharks, to the shallow waters.

Fisheries are another issue for ecosystem protection. The Somalis are traditionally devoted to pastoral nomadism, thus only recently have fisheries been developed, particularly since the 1974–1975 drought, when nomads were resettled in fishing co-operatives. Fish are caught for the domestic market, with a surplus for export; lobster fishing is increasing rapidly due to foreign market demand. In the late 1980s, about 17 000 metric tons of fish were caught annually. Tuna, now being processed, is a potential export product. Since 1993 Somalia has been part of the Common Market for Eastern and Southern Africa (COMESA), founded in 1993 in Kampala, Uganda. The COMESA treaty specifies objectives and activities regarding fisheries. This will have an impact on fisheries and aquaculture in terms of investment, production, trade and fish consumption of member states. Somali coasts that are subject to rapid and largely uncontrolled occupation by human activities are often the most at risk from environmental change.

Paradoxically, this coast, which is not subject to great industrial activity, is undergoing rapid degradation of the natural environment because of the absence of protective measures. At present, the coast is not adequately monitored. This has led to a situation in which coastal habitats such as mangroves and coral reefs are degraded, living marine resources are overexploited, and pollution levels are increased, while inadequate data are collected to characterize impact on natural resources and biodiversity.

Somalia is one of the world's poorest and least developed countries, having few resources, with much of its economy devastated by civil war. Once this situation ends, this country will become a high priority. There is potential for the development of marine parks in the Bajuni archipelago and adjacent channelized coastal areas. The Lac Badana National Park (0°25′ + 1°30′S; 42°30′ + 43°30′E) could be extended to include part or the entire archipelago (UNEP, 1987). This area, from Kisimayo to Ras Chiambone, is important for coral reefs, marine turtles and mangrove resources although little is known about it. There are currently no Marine Protected Areas and no legislation concerning their establishment and management although the WCMC (World Conservation Monitoring Centre) Protected Areas Database lists Busc Busc Game Reserve as an MPA. The WCMC in 1992 also listed as proposed Protected Areas the coastal sites of Zeila because of their important sea bird colonies on offshore islets, Jowhar–Warshek and Awdhegle–Gandershe.

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