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GEOLOGICAL EVOLUTION OF THE COASTAL ZONE OF SRI LANKA

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ABSTRACT

Geologically, 90 percent of Sri Lanka is made up of Precambrian (more than 570 mill. years old) crystalline rocks belonging to an ancient, stable part of the earth's crust known as the Indian Shield. This means that since Miocene times (26 mill. years ago) when the northwestern and northern parts of the island were subjected to a major marine transgression, the relative levels of land and sea have remained practically the same. However, minor oscillations of sea level have occurred during post-Miocene times, and it is these changes that have led to the deposition of the Quaternary formation and to changes in the shape of the coastal regions of the Island.

Changes of the relative levels of the land and sea are evidenced by such features as raised beaches, old strandlines, beachrock, inland buried corals and coral reef patches and inland deposits of marine shells. Palaeoclimates have also affected the coastal growth.

Geological formations of the post-Miocene times and the landforms produced by them have also controlled coastal evolution. Coastal growth stages, as shown by the evolution of sand bars, sand spits, lagoons, lakes and marshes along the western coast between Puttalam and Colombo are traced. The northwestern, northern and eastern coasts are prograding ones; coastal erosion and regression are characteristic of the southwestern and northeastern coasts. Hypothetical growth stages in the future are also postulated.

EVIDENCE FOR COASTAL EVOLUTION

The coast of Sri Lanka is about 1600 km long, and most of the northwestern, northern and eastern coastal zones are made up of post-Miocene to Recent formations. These are predominately grovels, sands and clays resting on Miocene limestone along the northwestern and northern regions, which have been laid down in the last two million years. The deposition of these sediments was controlled partly by changing levels of land and sea, and this has resulted in the outward growth of the coast in those regions. Elsewhere, coastal erosion has been more effective than deposition. Consequently, the southwestern, southern and south-eastern coastlines have been regressive rather than progressive in character, and Quaternary to Recent sediments are largely absent there.

Evidence for changes of relative land and sea levels are found in many places around the coast (Fig. 1 and Table 1). They include: raised beaches, old strandlines, beachrock, inland buried coral and coral reef patches, and marine shells below present land levels, sunken forests and submerged river channels on the continental shelf (Fig. 2). From these various lines of evidence and from 14C ages, it is possible to construct a graph showing variations in sea levels during mid and Late Holocene times (i.e. during the last 7,000 years (Fig. 3.

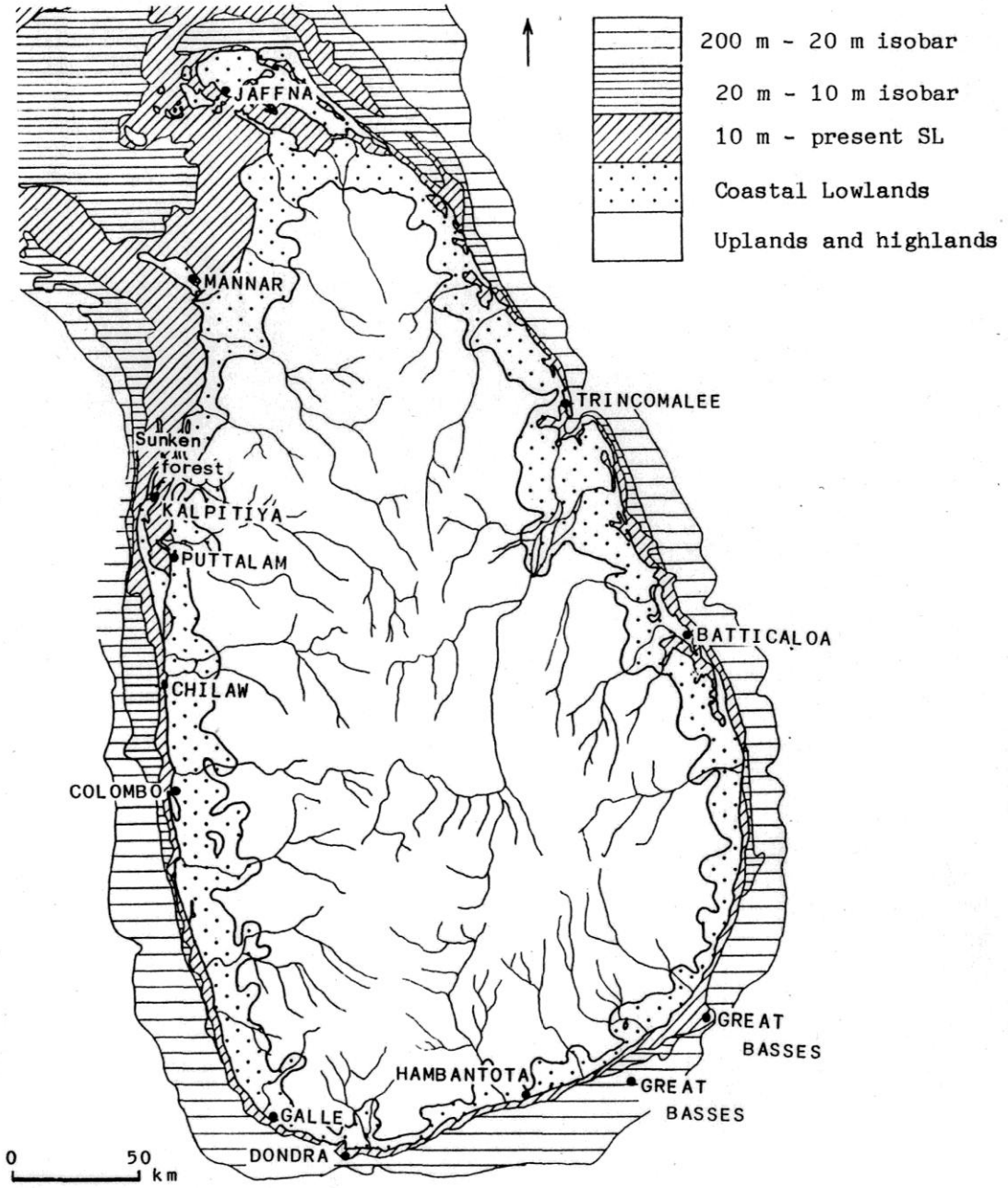

Fig. 1. Oscillation of sea level around Sri Lanka. (1) Evidence of sunken forests, submerged channels of some larger rives and well marked beachrock and coral reefs can be seen between 200m isobar and the present sea level. (2) The coastal lowlands consist of extensive buried coral deposits, emerged coral reef patches, shell deposits and Red Earth (Katupotha, 1988d).

Evidence of Former Sea Level in Sri Lanka

Metres + msl	Types of evidence			Reliability
Positive levels	Marine deposits	Geomorphological		
+ 1.6 - 4.5 + 6.0 - 10.0 + 14.0 - 18.0 + 27.0 - 36.0	shells shell beds beachrock beach deposits	coastal terraces, cut flatforms distributories		high
+ 36.0 - 43.0	---	as above		inconclusive
Negative levels	Stratigraphic	Bathymetric		
+ 0.8 - 24.0	buried valley deposits, bedrock over burdern boundary	crest of beachrock reefs	continental shelf profiles	high
- 24.0 - 27.0 - 33.0 - 46.0 - 55.0 - 64.0 - 73.0 - 91.0		shelf profiles		Moderate

(Source: Swan, 1964; Cooray and Katupotha - p. 5)

Table 2. Formations and Events in the Cenozoic Era in Sri Lanka (after Swan, 1983)

ERA	SYSTEM	EPOCH	EVENT/FORMATION
P H A N E R O Z O I C	Quaternary	Holocene 0.01 m.y. to Present	Post-glacial sea level rise, drowning of continental shelf. **Younger Group** - beach and dune deposits, beachrock, lagoon and estuarine clays, alluvium; raised beaches, lagoons formed.
		Pleistocene 2 m.y.	Marked sea level fluctuations, canyons cut or developed. **Older Group** - Red Beds, gravels, raised beach and dune deposits laterite, nodular ironstone
	TERTIARY	Pliocene 5 - 2 m.y.	Uplift and erosion
		Miocene 22.5 - 5 m.y	Limestone facies on northwest and north; arenaceous facies on northeast. Tectonic control of sedimentation, with step faulting common. Submergence, separation from India.

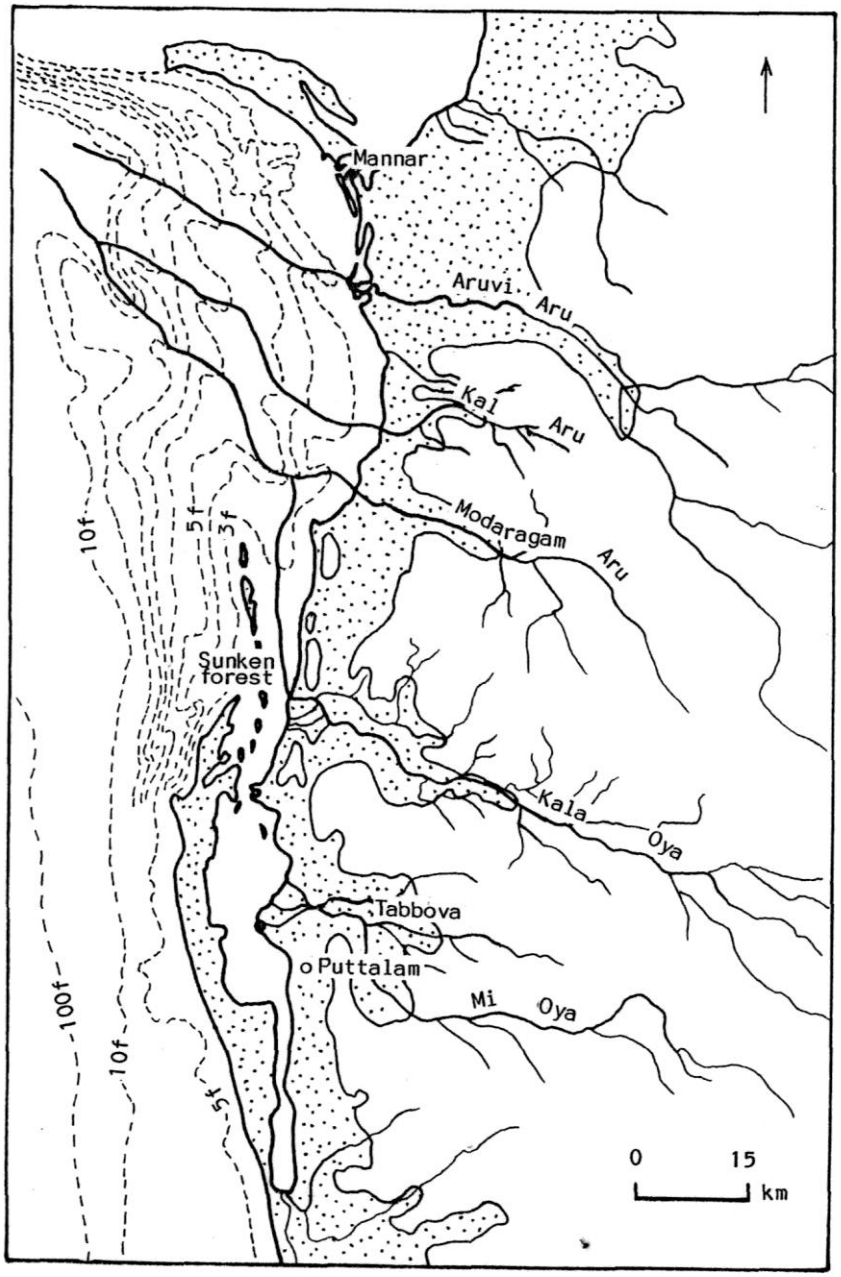

Fig. 2. Submerged river courses on the continental shelf of northwestern of Sri Lanka (After Deraniyagala, 1958).

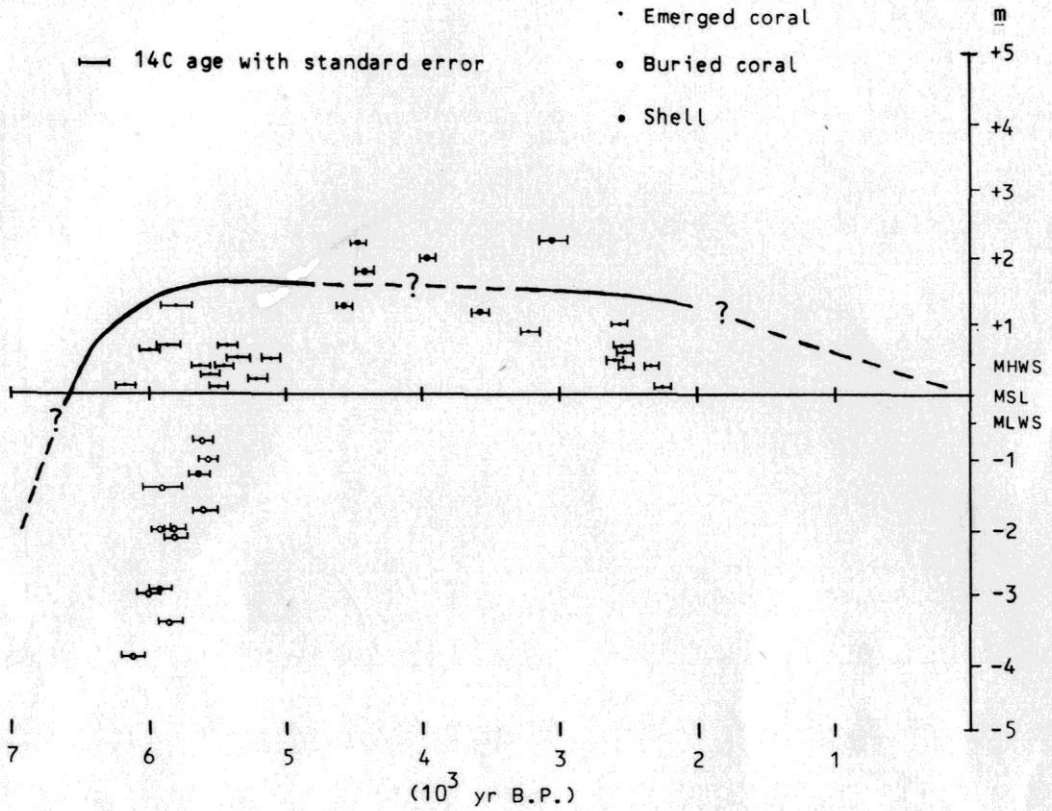

Fig. 3. Mid and Late Holocene sea level changes in Sri Lanka (After Katupotha and Fujiwara, 1989).

However, in order to understand better the evolution of the coastal zones, we need to look at the geological formations in these zones as well as at the landforms found in them. The two sets of evidence will help us to make hypothetical reconstruction of the evolution of deferent parts of the coastal zone of Sri Lanka, and also make hypothetical predictions for the future.

QUATERNARY GEOLOGICAL FORMATIONS

The Quaternary deposits that were laid down during the last million years of the island's history occur mainly within a coastal belt that is narrow in the southern half of the island, but widens considerably northwards of Negombo on the west and of Batticaloa on the east (Fig. 4). The Quaternary formations in Sri Lanka (Table 2) have been sub-divided into two main groups (Seneviratne et al., 1963) namely, the `Older' (Basal Ferruginous Gravel, Red Beds and Terrace Gravel) and the `Younger' (alluvium, lagoonal and estuarine beds, unconsolidated sands of beaches and dunes, inland fossil corals and beachrock).

Older Quaternary

Ferruginous Gravels

The gravels contain a large proportion of iron compounds, usually limonite, and they are rusty coloured. These gravels rest on either, crystalline Precambrian rocks or on Miocene Limestone, and they are found in many coastal areas, such as Negombo to Mannar, Tangalle to Minihagalkanda. The gravels are made up of a mixture of coarse sand grains, angular fragments of chert and pellets of limestone, partly cemented with ferruginous materials. The origin of the ferruginous gravels is uncertain. They may be marine beach deposits, formed when the Pleistocene sea encroached over much of the present coastal tract, or sheet-flood deposits of an ancient river system. The gravels are generally present at the base of the Quaternary successions, below the Red Beds (Fig. 4).

Red Beds

Red Beds previously described as `Red Earth' (Wayland, 1919), rest on ferruginous gravel or on Miocene Limestone (Fig. 4), and are also widespread. The Red Beds occur as long ridges or as plateaus along the northwestern coastal zone from Chilaw to Kudremalai, in the Jaffna Peninsula and along the southern coast. The thickness of the Red Beds formation varies from place to place, but it is usually about 18 m to 25 m. Thickness of over 30 m are reached in some localities the maximum recorded being 40 m at Aruakaru, about 30 km north of Puttalam.

The composition, shape and structure of the Red Beds show that they are probably wind-blown in origin. The Quartz grains are well rounded and have smooth, polished surfaces which are seen to be finely pitted. These Red Beds were probably formed when the sea level was much lower. It is suggested that dry climatic phases occurred from time to time during the interstidials of the Quaternary period in tropical countries, and that the last occurred around 20,000 to 30,000 B.P., resulting in a wide coastal plain which provided the source of sand. Dating of Red Beds in the south by thermoluminescence has shown that microliths in them are 25,000 years or more old (Singvi et at., 1986). The Red Beds must, be considerably older.

Terrace Gravel

Terrace Gravels are found a few kilometres inland from the present coast and are local in occurrence; they are sometimes known by local names, e.g., Erunwala Gravel (Cooray, 1963) Kalladi Gravel, and Kelani Ganga Gravels (named by Coates, 1913, the Malwana

and Ranala formations). The thickness of the gravel beds are about 5 m but sometimes about 15 m above the present river levels. The gravels are made up of coarse sand and water-warned, rounded pebbles, and they are the remnants of former river terraces, formed during a highly fluvial climatic phases.

Younger Quaternary

Lagoonal and Estuarine Beds

Lagoonal and estuarine beds are of several ages. and they represent stages in the building up of the coastal region. When mapped, they reveal the changing shape and extents of the lagoons. The lagoon and estuaries along the coast are gradually being filled up by the fine silt and clay that is being deposited in them. Lagoonal flats or barrier flats near Mundel indicate that slight changes in sea level (Cooray, 1967), and subsequently being covered by water only from time to time. The oyster shells in bluish-gray mud, about 2 km from mouth of the Deduru Oya, is evidence that the river formerly flowed into a lagoon which extended further east that at present. Such an encroachment of the sea can be correlated with the mid-Holocene high sea level. Elsewhere, clay deposits with marine or brackish-water forms of the life alternate with sands and clay with freshwater forms, and these successions indicate that minor oscillations of sea level continued after mid-Holocene times.

Lagoonal and estuarine deposits around Beira Lake, on the west coast, show that this irregular expanse of water once formed part of the estuary of the Kelani Ganga; the estuary was submerged below sea level at least twice in the recent history (Wadia, 1941; Cooray, 1967). This is shown by the sequence of stratified deposits, about 10 m thick, in the bed of the Beira Lake (Fig. 5). A peat sample from the foundation pit at Galadari Hotel complex, near the Beira Lake, has been dated at 5,790+80 B.P.; this shows brackish-water marsh developed in the area following the Holocene transgression (Katupotha, 1988b). Somewhat similar successions of beds which have been developed around Wellawatte (Wayland, 1916) can also be correlated with this marine transgression.

Several examples of lagoonal and estuarine deposits along the south coast, for example at Hatagala, about 10 km west of Ambalangoda, consists of shell beds. They are found at 5 m above sea level, nearly 2 km from the coast. The marine shells, which belong to the genus Veneridea, which are from a dry lagoon bed, 1.3. m above msl, have been dated at 5,780+110 B.P. (Katupotha, 1988b). This is same marine transgression as on the west coast, and it indicates that the sea encroached over much of the southern coastal tracts as well during the mid-Holocene.

Another good example of estuarine deposits is found in the Salape Ara estuary, about 35 km north of Trincomalee. The beds of fossiliferous clay with corals occur about 4 km inland from the present coast, and at a depth of 3 m below the surface. The fossils are mainly crab shells of estuarine species, but together with them are oyster shells of the window-pane oyster and other littoral species (Deraniyagala, 1958).

Coral Reefs

Corals form in warm, shallow salt water, just below the Mean Low water Springs (SLWS) level of the sea. Buried coral reef patches are found 250 m to several kilometres inland from the present shore in the area between Akurala and Narigama on the southwest coast, and Mihiripenna, Dodanduwa, Koggala, Ahangama, Gandara, Walgama and Madihe on the south coast. The emerged coral reef patches are at or above Mean High Water Spring (MHWS) level, and are located on the small headlands at the areas of Akurala, Hikkaduwa, Dadalla,

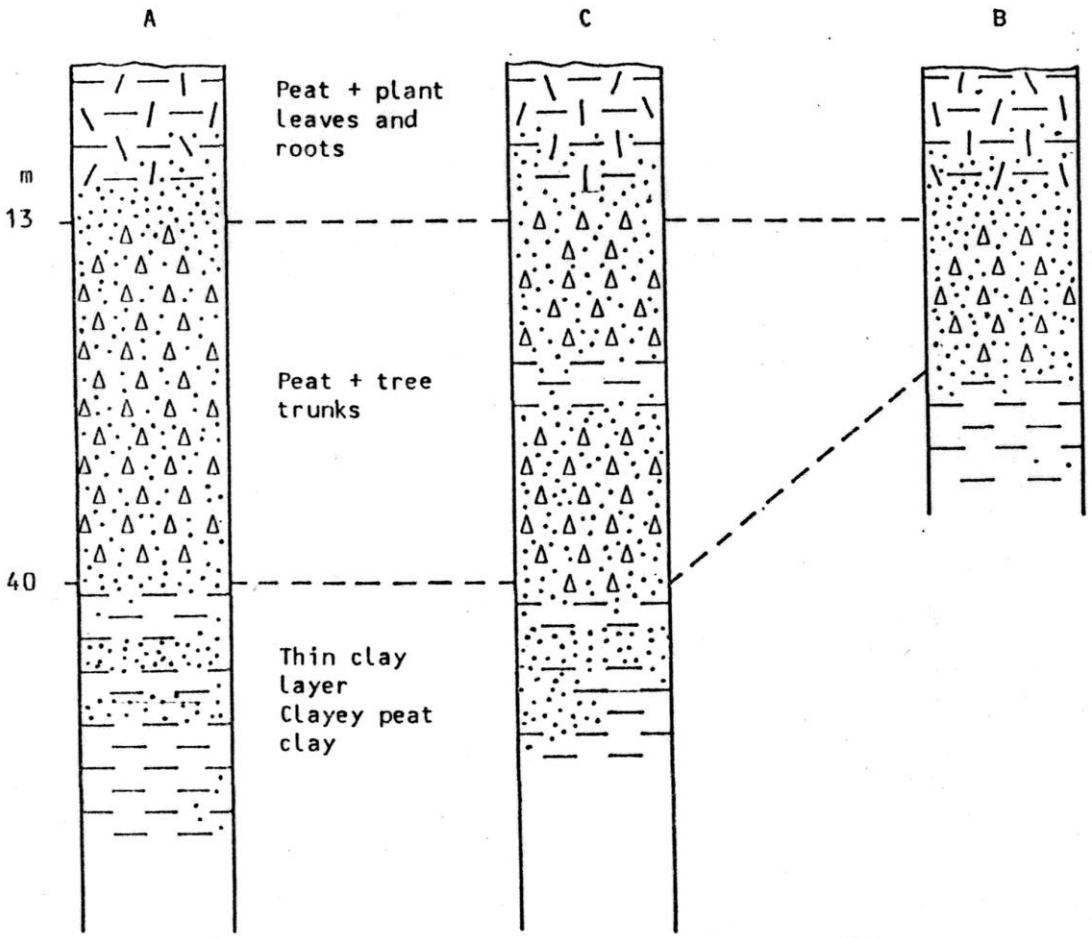

Fig. 5. Generalized stratigraphic sections of peat deposits at Muthurajawela (Dissanayake, 1984) and Beira Lake (Based on Wadia, 1941).

Koggala, Aranwala, Denuwala and Pallikkudawa. The upright branching and massive coral of these buried (Fig. 6) and emerged corals indicate that they have thrived on palaeo-bays or lagoons, when sea level was higher than that of the present level. Dating of these corals by the 14C method lead us to conclude that the Holocene sea level reaches about 1.5 m above the present sea level.

Shell Deposits

Large inland shell deposits are found at Illawankulama (northwestern coast) and in the area between Tangalle and Kirinda (southern coast); these can also be used as sea level indicators. Shell deposits particularly along the rims of emerged coastal embayments and lagoon floors have 14C ages between 4,650+60 B.P. and 3,570+60 B.P. (Katupotha, 1988b; Katupotha and Wijayananda, 1989). The depositional pattern and compositions of these deposits indicate that they probably accumulated by three processes, namely:

(a) the bulk of the valves piled up by wave action on the rimes of coastal embayments, following the coastal progradation since Late Holocene, around 4,000 B.P.
(b) the shells gathered on lagoon floors in marine or brackish pools, and they were deposited in situ during the same; and
(c) shells on the coastal hills and dunes were left by early inhabitants during their daily activities.

Muthurajawela Swamp

The peat swamp at Muthurajawela, which is a significant feature on the west coast, consists of peat deposits covering an area of 21 km^2. This deposit has an average thickness of 3.7 m and a maximum thickness of about 5 m. Two horizons have been identified, based on the stratigraphy (Fig. 5). Fossil marine grastropods and pelecypods in the bottom horizons indicate that these horizons were laid during the palaeo sea level oscillations (Dissanayake, 1984).

Beachrock

Beachrock is a distinctive formation which forms a series of parallel reef at many locations along the coast. The best exposed reefs occur along the western and southern coasts, and have, so far, been noted that Chilaw, Negombo, Pamunugama, Colombo, Kaikawala, Aturuwala, Beruwala, Galle and Matara. They are similar to those found along the coasts of Brazil, Uruguay and the Hawaiian Islands (Cooray, 1968). Each submerged reef on the western continental shelf represents a former strandlines (Fig. 7). The beachrock at Pitipana-Negombo above MHWS level has been dated at 2,470+70 B.P. and 3,460+160 B.P. (Katupotha, 1988a).

Beach and dune sands

Except for the alluvium of river flood plains, the beaches and dunes are the youngest landforms. They are present along the existing shorelines or immediately behind them as beaches, sand spits or sand bars, sand dunes, strandlines and `ridges and runnels'. Examples of old shorelines can be seen around Puttalam lagoon and in the areas of Marawila and Negombo (Cooray, 1967, 1968; Katupotha, 1988c) or in the Batticaloa area.

EVOLUTIONARY STAGES OF PARTS OF THE COASTAL ZONE

Northwestern coast

It is along the coast from Puttalam to Colombo that evolutionary stages have been most studies and can be best recognized. We look at sections of this coastal strip.

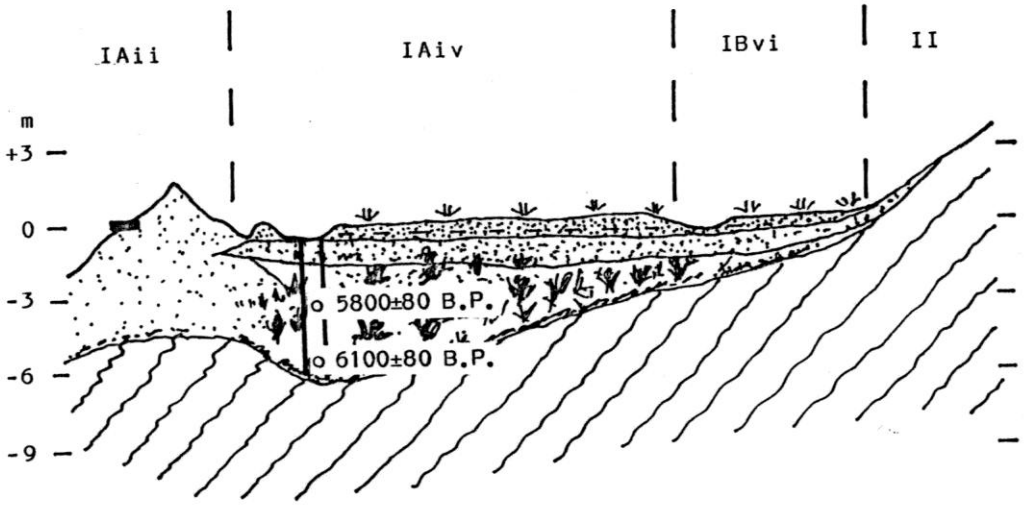

Fig. 6. Generalized sections in Wellameda-Akurala region showing buried corals. IAii = barrier beach; IAiv = mangrove fringes and marshes; IBiv = marshy flats; and II = peneplaned basement.

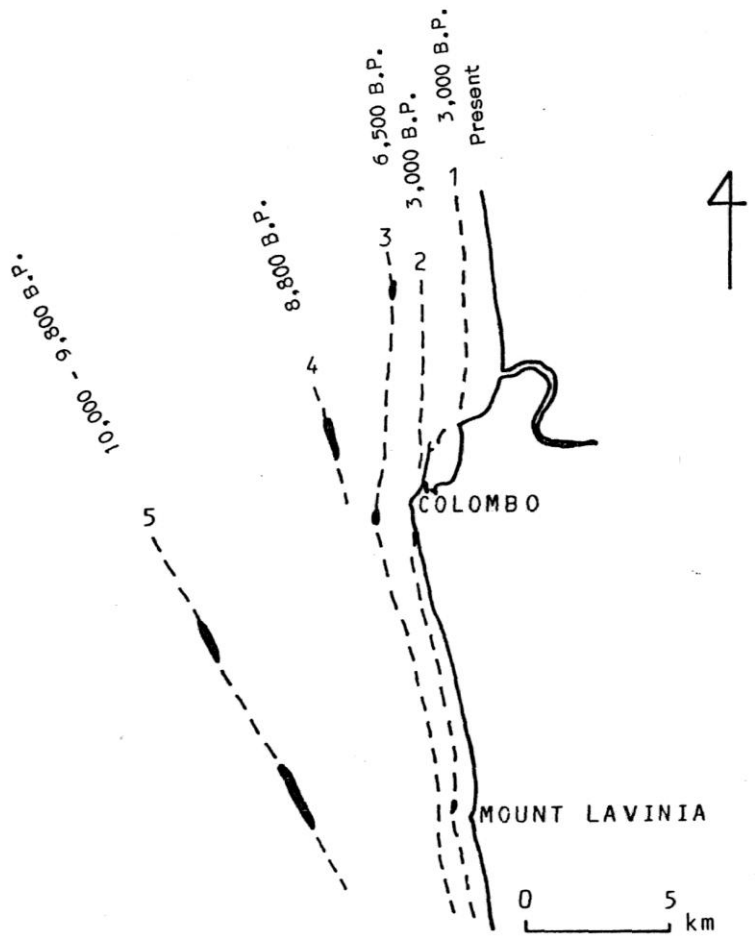

Fig. 7. Depth sequence and possible ages of beachrock on the western continental shelf in Colombo region (After Swan, 1983 and Katupotha, 1991).

The Puttalam area: Studies based on old maps, aerial photos, and landsat images have been made by Cooray (1968b) and Verstappen (1987) from which can be seen that:

(1) there have been constant changes in coastal forms in the 20th century (de Graaff, 1989);
(II) hanging strandlines are a prominent feature here (Fig. 8);
(III) sea level has been varied from near the 100-fathom line (Fig. 2) to several metres above present sea level (Cooray, 1984);
(IV) the most conspicuous changes in the coastal form have been in Puttalam lagoon and north of it (Versterppen, 1987).

The Chilaw-Puttalam area: Tentative coastal growth stages in this region has been identified by Cooray (1968b), who showed that the evolution of this coastal zone took place by (Fig. 9):

(I) the formation of offshore sand bars and spits along and early coastline;
(II) the formation of Mundel `lagoon';
(III) the conversion of Mundel Lagoon into Mundel Lake and the growth of Puttalam Lagoon;
(IV) the growth of Kalpitiya peninsula in stages;
(V) the formation of sand spits and sand bars and the islands of Kirimundel, Karaitivu, Ippantivu and Peria Arichchal.

The Chilaw area: The present coastal configuration in the chilaw area is the result of sand spit and sand bar growth, leading to the formation of a lagoon (Fig. 11). This was subsequently filled up, and the Deduru Oya presently flows through old lagoon and lake beds.

Negombo-Colombo area: The following growth stages can be postulated in the coastal stretch from Negombo to Colombo (fig. 11).

(I) growth of sand spit northwards from Mutwal and formation of Muthurajawela `lagoon';
(II) closing up of cuspate forelands and formation of Muthurajawela `lake'; northward extension of the barrier spit;
(III) filling up of the lake to form Muthurajawela swamp (later, Muthurajawela peat deposit); northward extension of spit form Negombo Lagoon.

Negombo: At Negombo itself we can recognize the following stages (Fig. 12):

(I) formation of wide beach plain with parallel ridges and runnels (as in) Puttalam;
(II) growth of barrier spit and barrier bar;
(III) formation of Negombo Lagoon;
(IV) silting up of lagoon and reduction to its present size.

Colombo: The positions of several offshore beachrock ridges here (Fig. 8) demonstrates the variations in sea level in the post-glacial period. Beira Lake was once the estuary of the Kelani Ganga. The presence of marine shells at various levels below the present surface indicate that marine transgressions over the land took place at various times during the past few thousand years

The northern region

From the geological and geomorphological evidence available, it is possible to trace the evolution of the Jaffna Peninsula in broad terms. The growth stages appear to have been (Fig. 13):

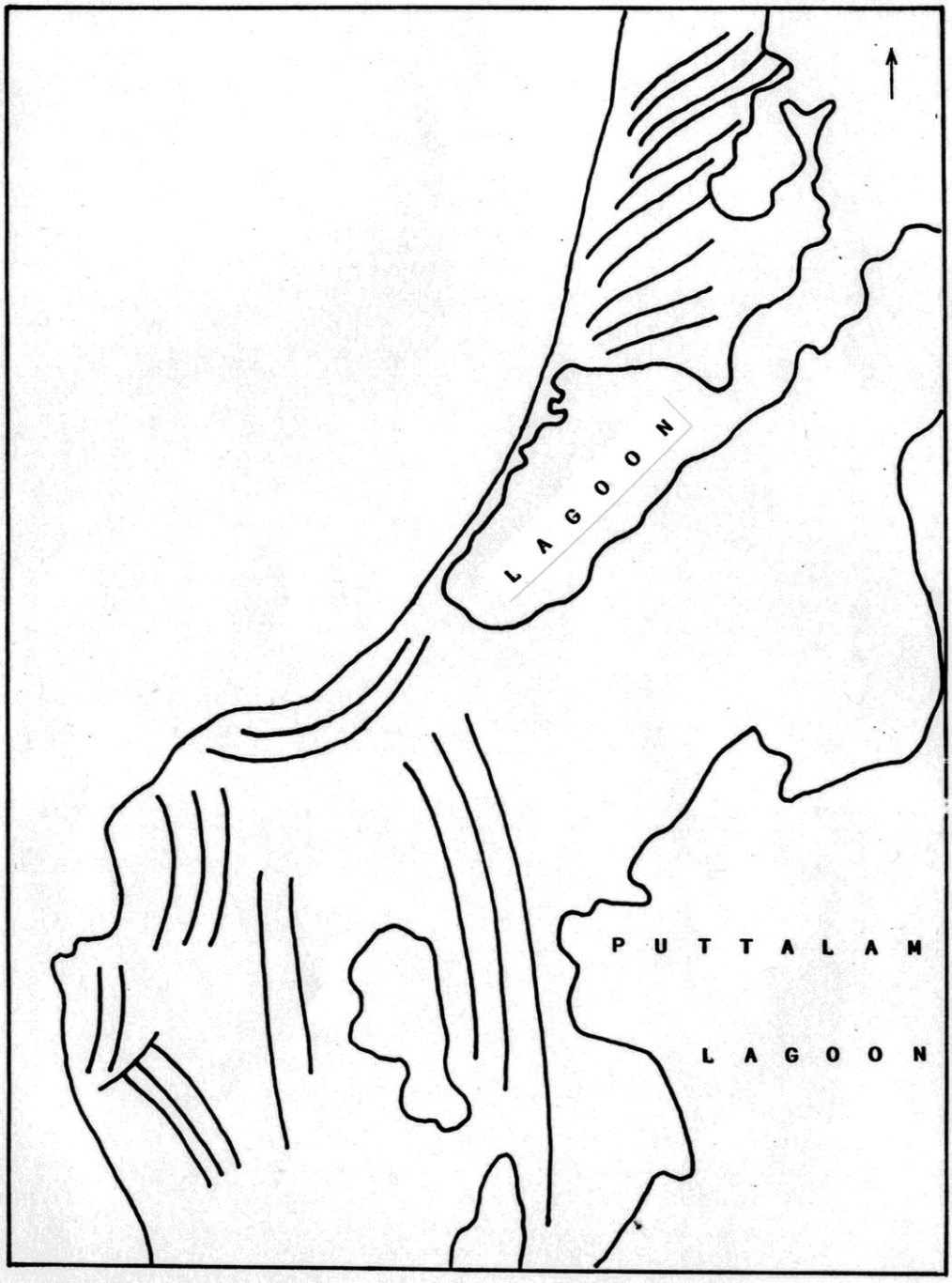

Fig. 8. Old strandlines west and south Puttalam Lagoon (Vesterppen, 1897).

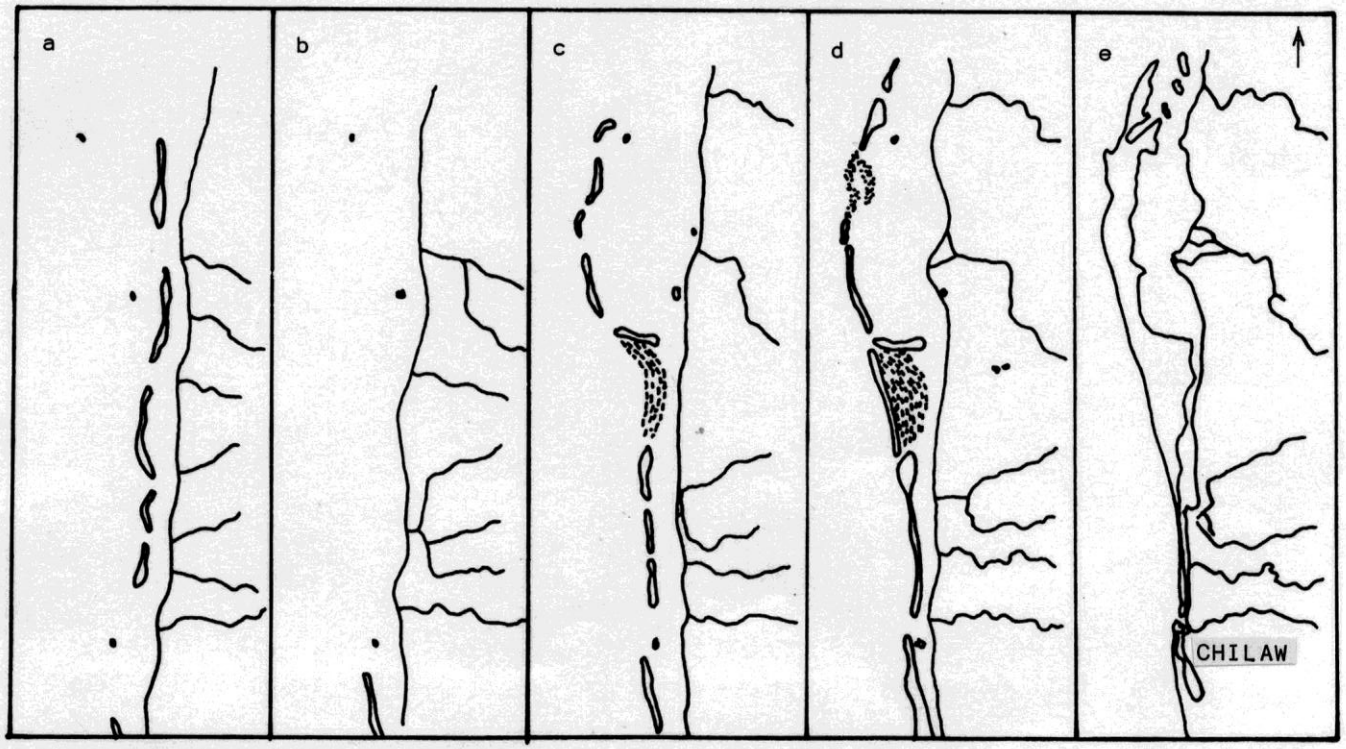

Fig. 9. Possible growth stages, nortwestern coastal plain (Cooray, 1967).

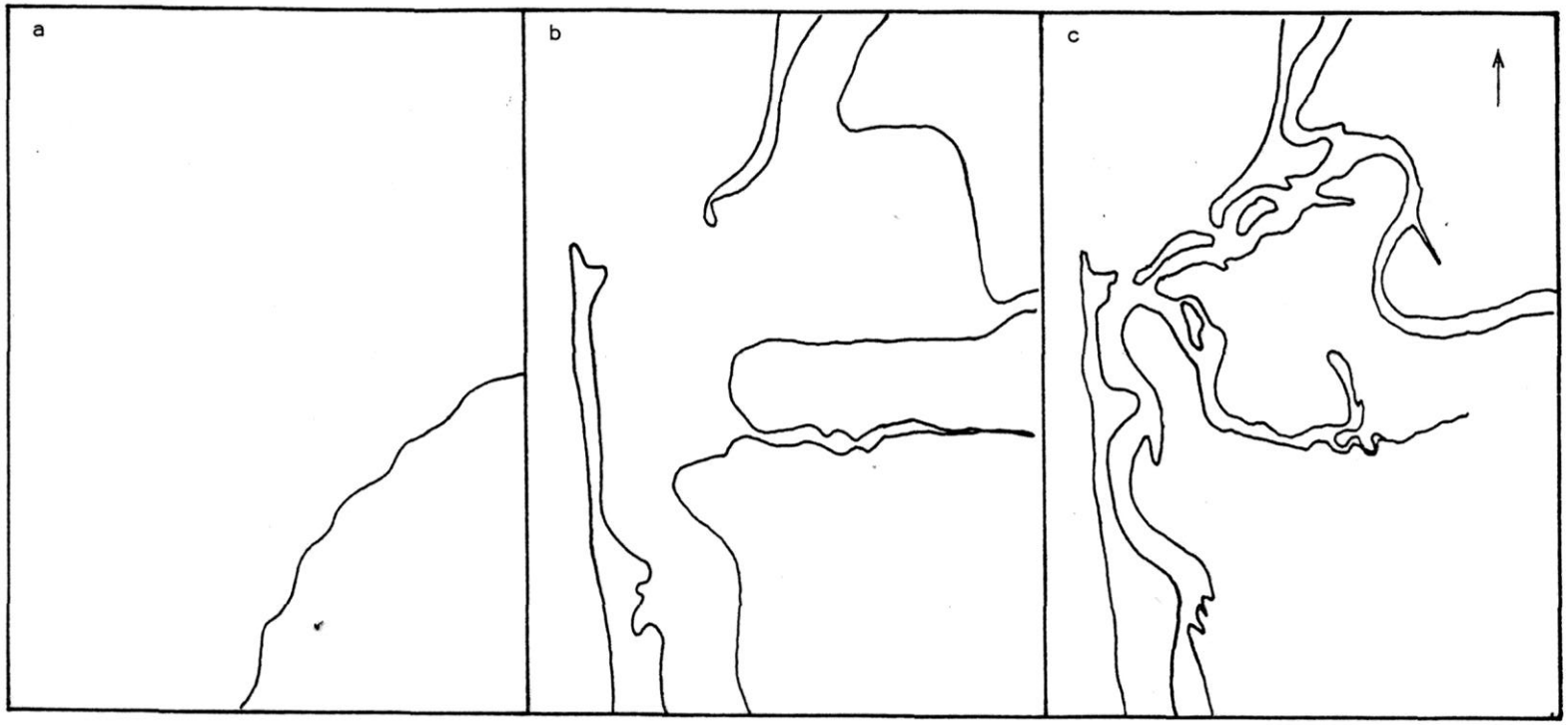

Fig. 10. Possible growth stages in Chilaw region (Cooray, 1984).

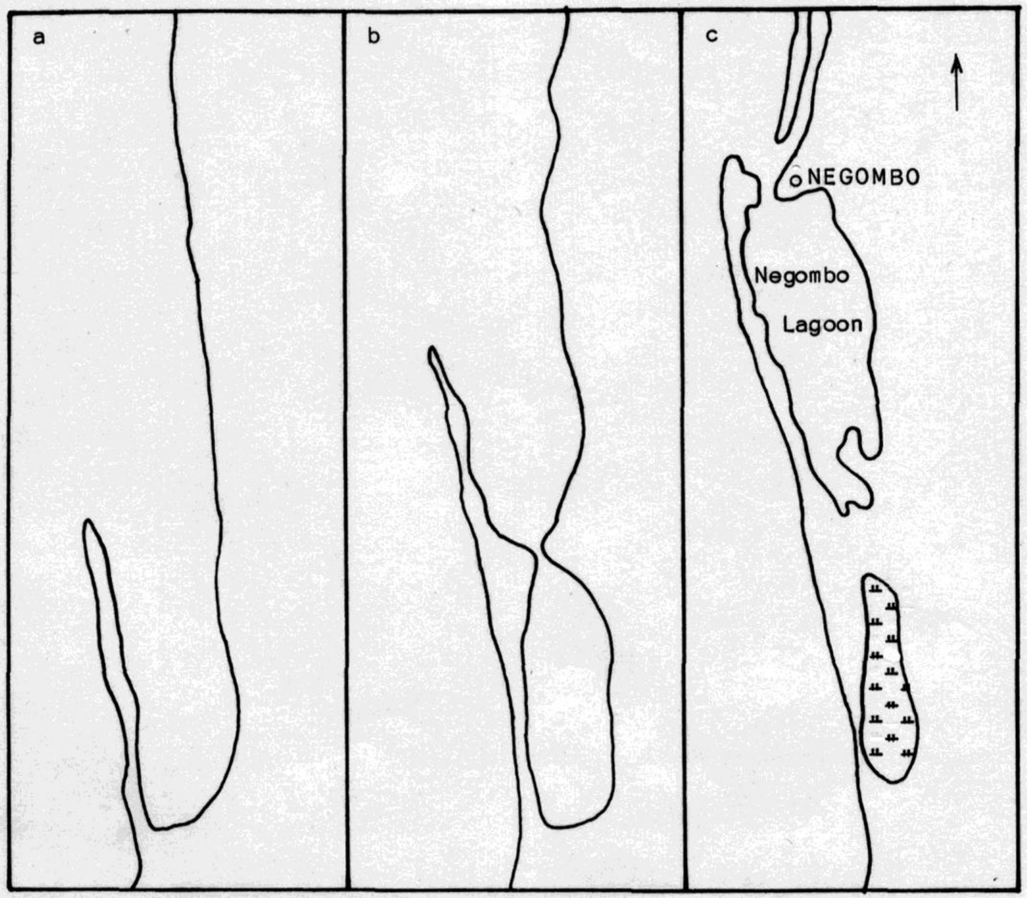

Fig. 11. Possible growth stages, north of Colombo.

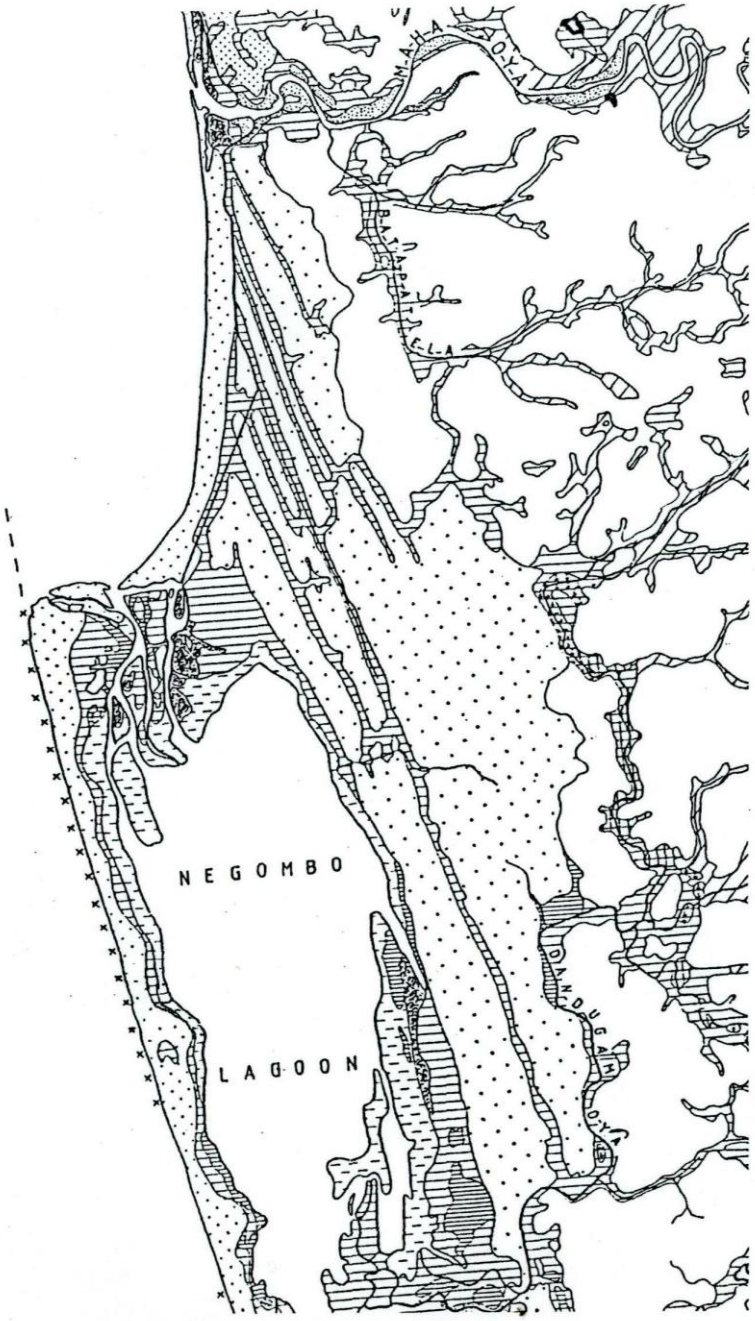

Fig. 12. Possible growth stages in Negombo region (Katupotha, 1988c).

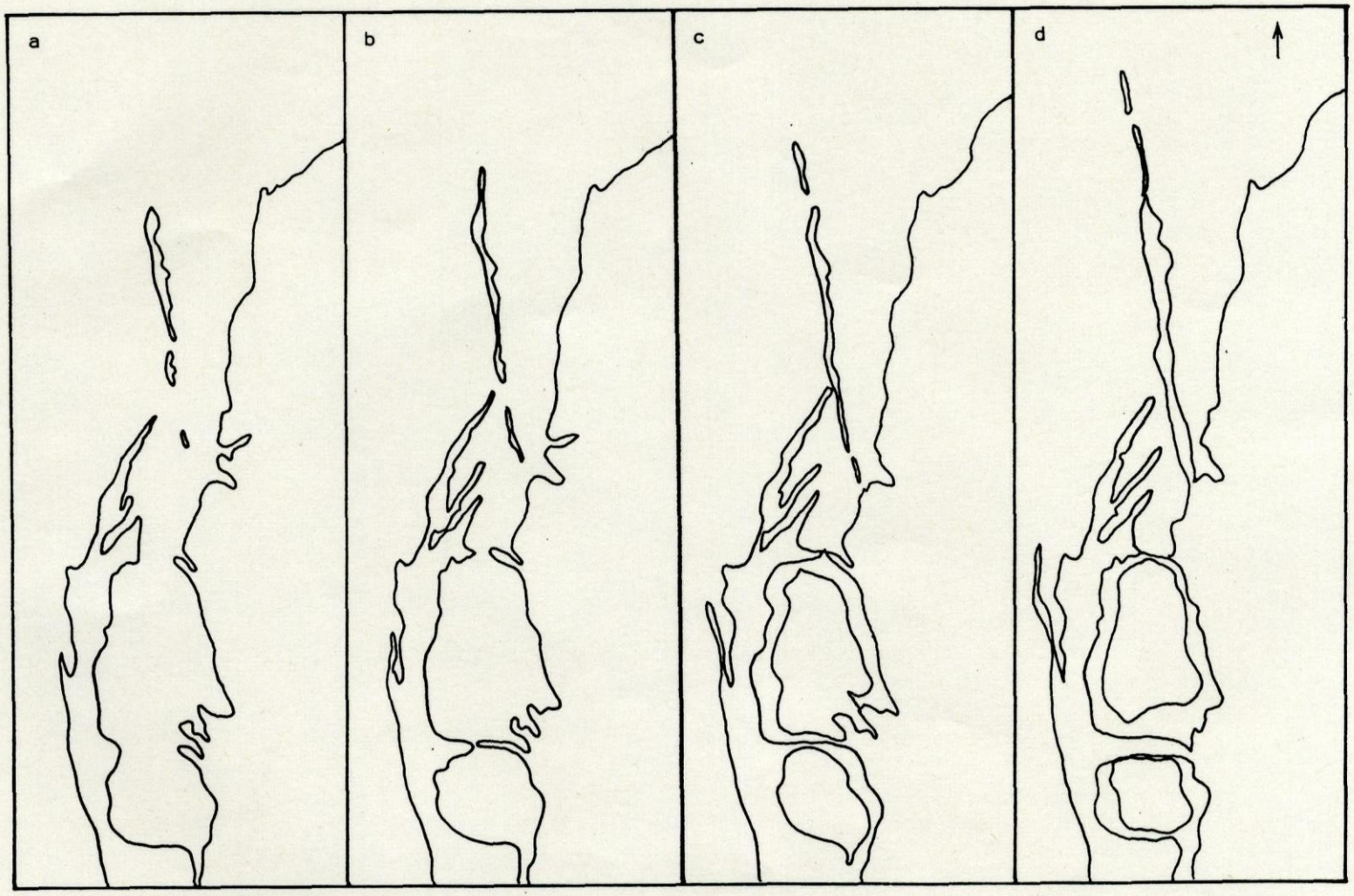

Fig. 13. Possible growth stages, Puttalam area.

(I) formation of islands off the northern coastline in Miocene times;
(II) attachment of these island to the mainland by sand bars and sand spits.

The southwestern coast

Erosion is the dominant process along the southwestern coast of Sri Lanka, and the shorelines here are essentially retreating ones. The presence of numerous offshore islands, for example, off Hikkaduwa and the rocky headlands alternating with bays, are near Alutgama, is evidence of this feature. Coastal erosion along the southwestern coast is a major environmental problem facing the country at present, and large sums many are being spent on devising ways and means of protecting this part of the coastline from the averages of the annual southwest monsoon during May to August, when erosion is intense.

However, longshore drift at other times in the year does produce sand bars and sand spits, which led to the diversion of the river mouths at several points. The mouth of the Kalu Ganga and the Bentota Ganga have been diverted in this manner.

Other coastal regions

A prograding coastal region is extremely evident on the east, north and south of Batticaloa, as shown by the present topographical maps. This is an area where the study of coastal evolution would be most profitable. As in the Puttalam region, it would be possible to trace growth stages by studying the sand bars, sand spits, and lagoonal changes from old maps, aerial photos and landsat images.

Trincomalee is the other noteworthy area, where erosion has produced a series of headlands and bays, the formation of which has been controlled largely by the geological formations present there. The precambrian crystalline rocks vary in their resistance to erosion and so the more resistant rock types give rise to headlands and the less resistant ones to bays.

THE FUTURE

Taking the as a guide to the future, it is possible to postulate some of the changes that might take place along the northwestern and northern coastal regions in the next few thousand years.

Puttalam area: The sequence here might be (Fig. 13):

(I) closing of the cuspate lowlands at Kalmunai point in the Kalpitiya Peninsula and the lowland opposite on the mainland;
(II) formation of Puttalam `lake' and Kalpitiya `lagoon' north of it;
(III) closing up of cuspate lowlands at Kalpitiya and opposite it in the mainland, and formation of Kalpitiya `Lake';
(IV) formation of barrier islands south of Karaitivu, resulting in the formation of two lagoons;
(V) extension of Kirume;
(IV) extension of Kirumundel spit to form a third `lake'; and
(VI) silting up of Puttalam Late and conversion of Mundel Lake into marshy land, and finally a peat deposit similar to that at Muthurajawela.

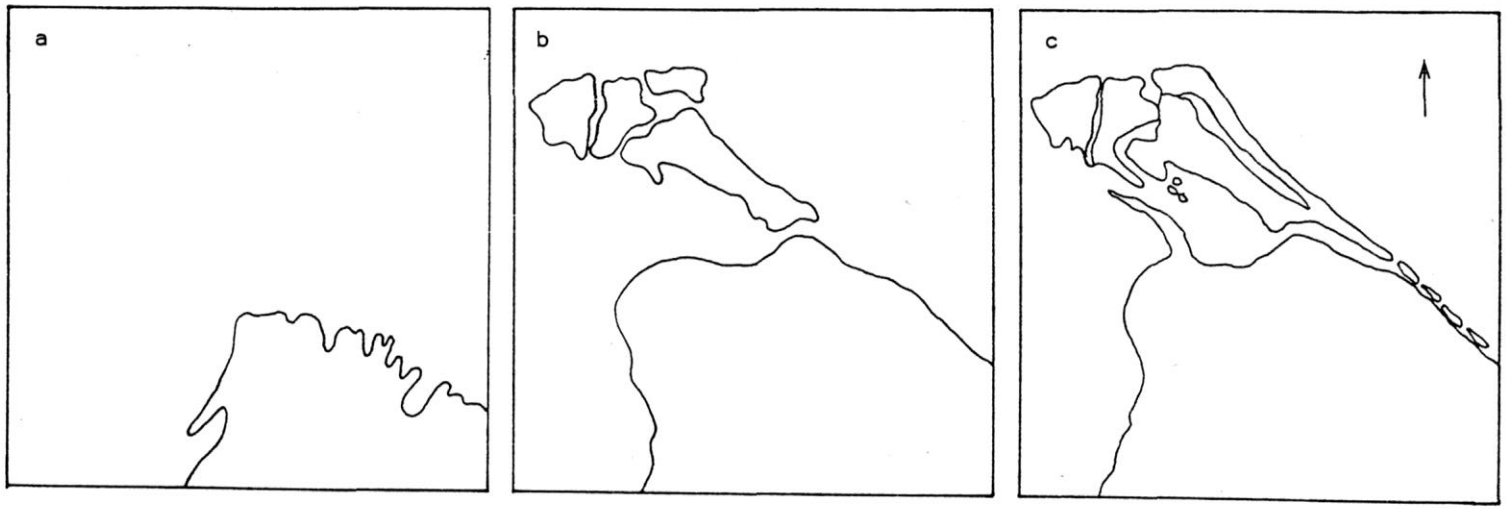

Fig. 14. Possible growth stages, northern Sri Lanka.

Jaffna Peninsula: Here we can envisage (Fig. 14):

(I) joining up of the western islands to the mainland by sand spits and sand bars;
(II) extension of Mandativu spit northwards to join the mainland;
(III) conversion of Jaffna `lake'.

These postulated changes are largely conjectural, but although the stages might differ, the general picture of extension of the land surface in northwest, north and east in the next few thousand years is a distinct probability. The processes of growth will be aided by the slow but gradual rise of sea level that is taking place in present times, and only catastrophic changes or sudden change in climate will alter the evolutionary process going on at present.

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