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Quaternary Research in Sri Lanka

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ABSTRACT

Quaternary is the era which saw the appearance of mankind. There is disagreement over the duration, with some scientists retaining a short-time scale (600,000 years) while a majority accepting the long time-scale of 1.8 to 2.0 million years. It comprises two epochs - the Pleistocene and the Holocene. The Pleistocene epoch in Sri Lanka has been subdiv ided based on different types of fossils. These subdivisions are useful in the study of palaeomagnetic changes, geological f ormations and palaeolithic cultures in Sri Lanka. Radiometric dating of fossil coral and shells collected from the western and souther n coastal zone suggested mid and late Holocene three high sea-level episodes between 6,240 and 2,270 yr B.P. However, there is a need for further investigations on the whole Quaternary period by different disciplines in order to reveal the nature of the palaeogeography, palaeoclimatology and palaeoecology of Sri Lanka.

INTRODUCTION

The Quaternary period is known as the 'Age of man' or the 'great Ice Age'. It began approximately 2 million years (Myrs.) ago and continues up to the present (Fairbridge, 1968), and comprises two epochs, the 'Pleistocene' and 'Holocene'. The term Pleistocene is reserved for the 'Glacial Epoch' and 'Recent' for the 'Post Glacial'. The term 'Holocene' (wholly recent) is used most frequently for the youngest epoch.

The Quaternary Period in Sri Lanka has been subdivided on the basis of different types of sediments and fossils (Wayland, 1919; Deraniyagala, 1958; Cooray, 1967, 1968a). Radiometric dating of fossil corals and shells collected from the western, southern and eastern coastal lowlands suggests that the mid and late Holocene high sea-level episodes had occurred between 6,260 - 2,270 yr B.P. (Katupotha, 1988a,b, 1992; Katupotha and Fujiwara, 1988; Weerakkody, 1992). This evidence clearly suggests a close correlation betweem global climatic changes and palaeofluvial and marine deposits as well as landforms of Sri Lanka. However, further quantitative investigations of the Pleistocene and Holocene Epochs in Sri Lanka are necessary to unravel problems of correlation. This paper examines the recent advances in Quaternary studies in Sri Lanka and identifies the gaps and needs for further research.

SUBDIVISIONS OF THE QUATERNARY IN THE MAIN GLACIAL AREAS

There is disagreement over the duration of the Quaternary. Some scientists have retained a short time-scale (600,000 years) while others accept a long-time scale of 1.8 to 2 Myrs. Cooke (1973) critically discusses this disagreement. Subdivisions of the Pleistocene epoch and its correlation with glacial and interglacial stages have been identified on the basis of pelagic foraminifera from the Atlantic, Caribbean and Pacific deep-sea cores by Emilliani (1955, 1978). Major glaciations during the past 730,000 years have been correlated with the global climatic changes (Table 1) after studying these cores. Based on absolute dating of glacial and interglacial periods, a tentative correlation of the Quaternary Period of north America, the Alps, northern Europe and Poland-USSR is shown by Fairbridge (1968). Similar results on different phases of the Quaternary are presented by Chappell (1978), Fairbridge (1961), Evans (1972), Kind (1972), Morner (1972), Pirazzoli and Monaggioni (1986), Shepard (1961), Stearns (1976).

QUATERNARY RESEARCH IN SRI LANKA

Prehistoric research on the stone implements and cave man (Pole, 1907; Parsons, 1908; Hartley, 1913; Wayland, 1919) showed that the quartz and chert artifacts used by early man, and embedded deposits can be used in the examination of Quaternary events.

Coates (1935) correlated the submerged and emerged coastline in Sri Lanka with the Pleistocene and the Holocene Epochs. He described the coastal deposits emphasizing the extension, formative processes and their evolution. Wadia (1941) made a three-fold classification of the coastal deposits and on the basis of fossils found that they had developed since Tertiary or Pleistocene periods.

TABLE 1. Subdivisions of the Quaternary in the Main Glacial Areas.

	ABSOLUTE DATING	PROVISIONAL NUMERICAL ORDER	NORTH AMERICA	ALPS	NORTH EUROPE	SRI LANKA
	Present					
H	-					
	10,3000					
	10,300 -		LATE			
	17,000		WISCONSIN	Late Wurm		
	17,000 -		MAIN			
	30,000		WISCONSIN	Main Wurm		
LP	30,000-	Main				
	50,000	Interglacial				
	50,000 -	Last Glaciation	WISCONSIN	Early Wurm	Weichselian	Normal 6
	75,000					Humid 6
	67,000 -	Last -	Sangamanian	Uznach	Eemian	Normal5
	128,000	Interglacial				Humid 5
	128,000 -	Forth Glaciation	ILLINOIAN	RISS II	WARTHE	Humid 4
	180,000			RISS I	SAALE	
	180,000	Third -	Yarmouth	Hotting	Holstein	Normal3
MP	230,000	Interglacial				
	230,000 -	Third Glaciation	KANSAN	MINDAL	ELSTER	Humid 3
	300,000					
	300,000 -	Second -	Aftonian			Normal2
	330,000	Interglacial				
	330,000 -	Second -	NEBRASKAN	GUNZ	PRE-ELSTER	Humid 2
	470,000	Glaciation				
	470,000 -				Waalian	Normal 1
	538,000					
	538,000 -	First -	PRE -	DONAU II	WEYBOURNE	Humid 1
	548,000	Glaciation	NEBRASCAN			
EP	548,000 -				Tiglian	
	585,000					
	585,000 -			DONAU I	RED CRAG	
	600,000					
	c 600,000 -			Villa frannuchian		
	2,000,000					

NOTE: Named interglacials are underlined. Source: Fairbridge 1968; H - Holocene, LP - Late Pleistocene, MP - Middle Pleistocene, EP - Early Pleistoiene.

Deraniyagala (1958) summarized different events in the Pleistocene Epoch in Sri Lanka on the basis of the behavioural patterns of cave man as well as some vertebrates and mammals and compared his findings with those of the Pleistocene events of India, Java, Burma, China, Celebes and Palestine.

Cooray (1963, 1967, 1984) categorized the Quaternary formations broadly into two major groups as (a) Holocene (recent) or Younger, and (b) Plio-Pleistocene (Older) (Table 2). Furthermore, Cooray (1968a) classified geomorphic units of the northwestern coast and correlated these with possible stages in their evolution during the Quaternary period. Cooray (1968b) described formation of the beach rocks on the west coast and related them to present or former strandlines. Cooray and Katupotha (1991) emphasized that minor oscillations of sea-level during post-Miocene times, led to the formation of Quaternary deposits and changes of shape of the coastline of the Island.

Dahanayake and Jayawardena (1979) examined the mode of occurrence and origin of 'Red Earth' and 'Brown Earth' in the northwest of Sri Lanka. Deraniyagala (1976) has described the geomorphology and the pedology of sedimentary formations of the drier lowlands which contain the mesolithic artifacts. Wickramaratne et al. (1988) reported the usefulness of inner and outer shelf sediments in unravelling the palaeoclimatic changes in Sri Lanka. Although, the above mentioned reports investigated the geological and climatological events of Sri Lanka during the Quaternary period, it is difficult to reconstruct the sequence of events even in the light of published 14C dates (Hubbs et al., 1962; Deraniyagala, 1989; Neef and Veech, 1981).

Katupotha (1988c) identified four stages in the evolution of the western coastal lowlands. Later, Katupotha (1992) disclosed the existence of three high sea-level episodes between 6,240 and 2,270 yr B.P. Based on avail-

TABLE 2. Formations and Events in the Cenozoic Era in Sri Lanka

	ERA	SYSTEM	EPOCH	EVENT/FORMATION
PHANEROZOIC	CENOZOIC		Holocene to Present 0.01 m.y	Post-glacial sea level rise, drowning of continental shelf. Younger Group - beach and dune deposits, beachrock, lagoon and estuarine clays, alluvium, buried and eme rged coral reefs, beaches, lagoons formed
			Pleistocene 2 m.y.	Marked sea level fluctuations, submergence canyons cut or developed. Older Group - Red Beds, gravels, raised beach and dune deposits, laterite, nodular ironstone
			Pliocene 2 - 5 m.y.	Uplift and erosion
		TERTIARY	Miocene 22.5 - 5 m.y	Limestone facies on northwest and north; arenaceous facies on southeast. Tectonic control of sedimentation, with step faulting common. Submergence, separation from India.

Sources: Cooray and Katupotha, 1991; Katupotha, 1988b,c; Swan, 1982.

able 14C ages from the east, west and southwest coasts, Weerakkody (1992) also identified three phases of sequential development of coastal landforms.

However, in order to understand the state of Quaternary research in Sri Lanka it is necessary to identify the Quaternary geological formations and the data available on those. Such examination will help in the identification of gaps and needs of the Quaternary research in Sri Lanka.

QUATERNARY FORMATIONS IN SRI LANKA

The Quaternary deposits occur mainly within a coastal belt that is narrow in the south and widens considerably northwards of Negombo on the west and of Batticaloa on the east (Fig. 1). These formations have been sub-divided into an older group and a younger group (Cooray, 1963, 1967)(Table 2).

Pleistocene Deposits

Basal Ferruginous Gravels

Ferruginous gravels rest on either, crystalline Precambrian rocks or Miocene limestone in many coastal areas, such as from Negombo to Mannar and 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. A large proportion of iron compounds, usually limonite, give the gravels a rusty colour (Cooray, 1967). 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 (Cooray, 1967). The gravels lie below the Red Beds and were called 'Plateau Deposits' by Wayland (1919).

Red Beds

Red Beds (Red Earth - Wayland, 1919) rest on ferruginous gravel or on Miocene limestone. They occur as

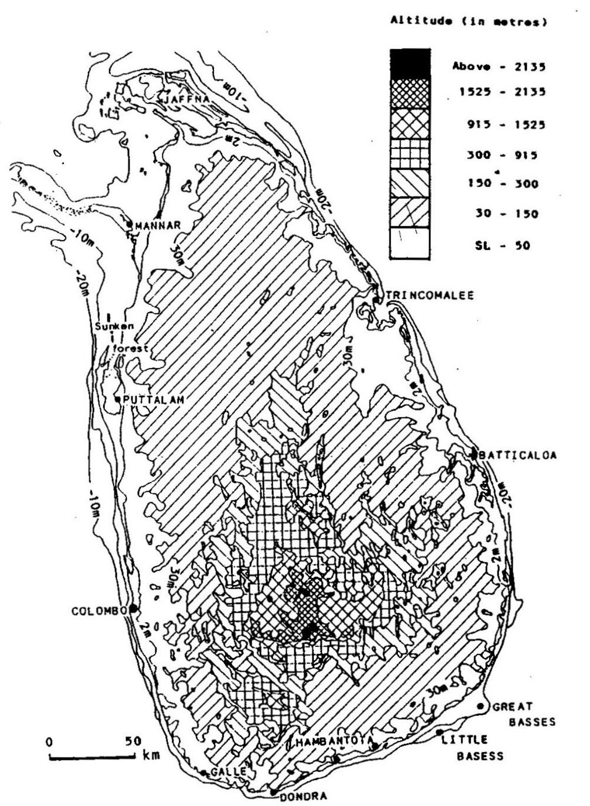

Fig. 1. Oscillations of sea-level between 20 m isobar and the present coastal lowland occurred during the Late Quaternary Period.

long ridges or 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 varies from place to place, averaging around 18 - 25 m. A maximum thickness of 40 m has been recorded at Aruakaru, about 30 km north of Puttalam. Certain deposits of white sand in the western lowlands have been derived directly from the Red Beds (Wayland, 1919).

The Quartz grains of the Red Beds are well rounded and have smooth, polished surfaces which are seen to be finely pitted. The wide occurrence of Red Earth in the Dry Zone of Sri Lanka has been attributed to aeolian processes and desert like conditions at the time of their deposition (Wayland, 1919). It is suggested that dry climatic phases occurred from time to time as interstidials of the Quaternary period (Wisconsin - Wurm Glacial Stage) in tropical countries, and the last occurred around 17,000 to 16,000 B.P. (Table) 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 (Singhvi et al., 1986).

Terrace Gravels

Quartz gravels occupy the edges of small river terraces and are found a few kilometres inland from the present coast-line and are local in occurrence; they are sometimes known by local names, e.g., Erunwala Gravel, Kalladi Gravel and Kelani Ganga Gravel (Cooray, 1963, 1967). The gravel beds are about 5 m thick and are sometimes about 15 m above the present river levels. Stone implements of Palaeolithic and Neolithic man have been found in the gravels composed of coarse sand and water-warned, rounded pebbles. They are the remnants of former river terraces.

Holocene Deposits

Lagoonal and Estuarine Beds

According to Katupotha (1988a,b) and Weerakkody (1992), the mid-Holocene sea-level was at least 1.5 m or more above that of the present level. Following this marine transgression, the former drainage basins were submerged and headland-bay-beaches were created. Those bays became lagoons and lakes due to the low stands of sea-level since around 4700 yr B.P.

According to Cooray (1967, 1968a) the lagoons and estuaries along the coast are gradually being filled up with fine silt and clay. Lagoonal and estuarine beds represent several stages in the evolution of the coastal region (Cooray and Katupotha, 1991). Lagoonal flats or barrier flats near Mundel and Puttalam indicate slight changes in sea level, and those subsequently have been 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 as at present (Cooray, 1967). Elsewhere, clay deposits with marine or brackish-water forms of life alternate with sands and clay with freshwater forms.

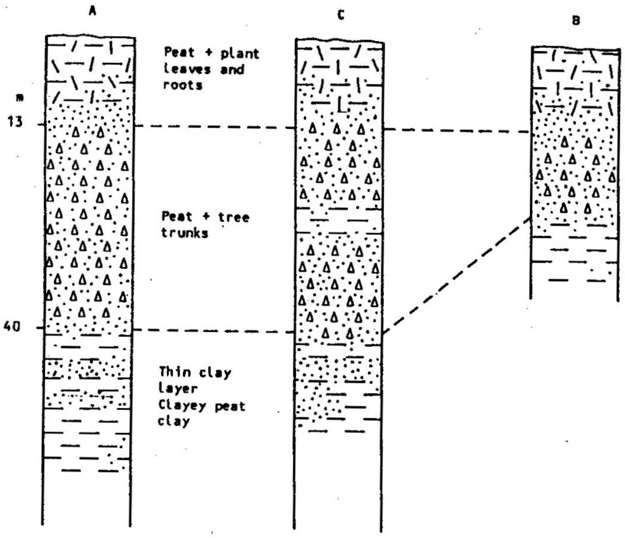

Fig. 2. Generalized stratigraphic sections of peat deposits at Muthurajawela (Dissanayake, 1984) and Beira Lake (Wadia 1941).

Lagoonal and estuarine deposits around Beira Lake, on the west coast represent a part of an estuary of the Kelani Ganga which submerged at least twice in the recent history (Wadia, 1941; Cooray, 1967). The sequence of stratified deposits in the bed of the Beira lake is about 10 m thick. A sample of peat from the foundation pit at Galadari Hotel Complex, near the Beira Lake, has been dated at 5,790 + 80 B.P.(Fig. 2). This indicates development of a brackish-water marsh in the area following the Holocene transgression (Katupotha, 1988b).

Several examples of lagoonal and estuarine deposits along the southwest (between Ambalangoda and Matara) and south coasts (between Kalametiya Kalapuwa and Bundala Lewaya) consist of buried corals and shell beds (see coral and shell beds). Another good example for an estuarine deposit is found in the Salape Ara estuary, about 35 km north of Trincomallee. The beds of fossiliferous (mainly crab and oyster shells) clay with corals occur about 4 km inland from the present coast, and at a depth of 3 m below the surface.

Buried and Emerged Coral Reefs

Buried patches of coral reef lie below the MSL (Fig. 3) 250 m to several kilometres inland from the present

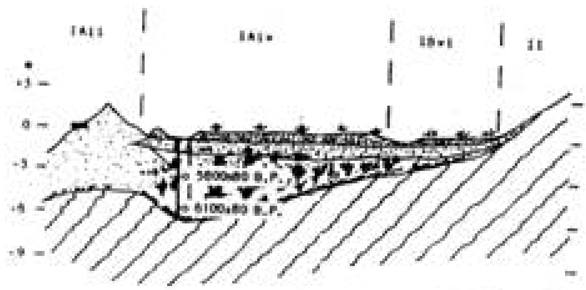

Fig. 3. Generalized sections in Wellameda - Akurala showing buried corals. (IAii) Barrier Beach, (IAiv) Barrier flats and marshes, (IBvi) Marshy flats, and (II) Peneplained basement.

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. Emerged patches of coral reef occur at or above the Mean High Water Spring (MHWS) level on the small headlands around Akurala, Hikkaduwa, Dadalla, Koggala, Aranwala, Denuwala and Pallikkudawa. The upright, branching and massive corals indicate that they thrived on palaeo-bays or lagoons, and 14C dating of the corals suggest that the Holocene sea level reached ca. 1.5 m above the present sea level (Katupotha, 1988a,b, 1990b; Wijayananda and Katupotha, 1989).

Shell Deposits

The shell beds along the southern coastal zone have been laid on the Lowland 1 (Flat Terrain, below 30 m). Detailed investigations indicate that the shells are highly concentrated as pockets around the Kalametiya Kalapuwa, Hungama and Lunmama Kalapuwa; Mahasittrakala Lewaya; the area between Karagan Lewaya and Pallemalala and the area between Embilikala Kalapuwa and Bundala Lewaya. Most of these are mined from paddy fields, small mounds (hummocks), former embayments and the bottoms of lagoons, lakes and creeks (Katupotha, 1993a).

The geological sequences of these shell beds indicate that they probably accumulated throughout the area by three processes, namely:

(a) the bulk of the valves piled up by wave action on the rims of coastal embayments and mounds following the coastal progradation of 5,130 - 4390, 3930 - 3280 and after 2,270 yr B.P.

(b) the shells gathered on lagoon floors in marine or brackish pools, and deposited in situ during the same; and

(c) shells on the coastal hills and dunes were eaten by early inhabitants as well as shell eating creatures during their daily activities.

Muthurajawela Swamp

The peat swamp at Muthurajawela on the west coast covers 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. 2). Fossil marine gastropods and pelecypods in the bottom horizons, alternating layers of organic-rich terrestrial and marine sediments, tree trunks, marsh debris and concentration of sulphates indicate that these horizons were formed by sea-level oscillations during the Flandrian Transgression (Katupotha, 1988c; Senaratne and Dissanayake, 1991, Dissanayake, 1984):

Beachrock

Beachrock is a distinctive formation which forms a series of parallel reefs at many locations along the western, southern and eastern coasts, as at Chilaw, Negombo, Pamunugama, Colombo, Kaikawala, Aturuwala, Beruwala, Galle, Matara, Tangalle, Okanda, Tirukkovil, Kalmunai, Batticaloa and Mullaitivu. The composition of the beachrock varies locally. They resemble those found along the coasts of Brazil, Venezuela, Uruguay and the Hawaiian Islands (Cooray, 1968b; Katupotha, 1989). Each submerged reef on the western continental shelf represents a former strandline (Swan, 1982; Cooray and Katupotha, 1991). The beachrock at Pitipana-Negombo above MHWS level, dated at 2,470 + 70 B.P. and 3,460 + 160 B.P. (Katupotha, 1988a), suggests their age of formation on the west coast.

Coastal dunes

Wind blown accumulations of sand heaped into dunes are best developed along the northeast coast between Kirinda and Sangamankanda Point, Mullativu and Point Pedro, Elephant Pass and Chavakachcheri, across Mannar Island and the Poonerin Peninsula, Ambakandawila and Kalpitiya Peninsula (Swan, 1982). The dominating influence of the southwest and northeast monsoon winds on the coast, elongate the dunes parallel to these directions (Cooray, 1967).

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, 1968a; Katupotha, 1988c) or in the Batticaloa area.

CLIMATIC AND SEA-LEVEL CHANGES IN THE QUATERNARY

In Sri Lanka, eustacy, uplift and solar variations have influenced the Pleistocene profoundly (Deraniyagala, 1958). Such actions like faulting, tilting, dislocation and block hosting during the Pleistocene led to the mixing of fossils of different ages in gem bearing deposits of Ratnapura. On the basis of fauna, Deraniyagala identified the climatic sequence from middle Pleistocene to Holocene. According to him 'Ratnapura Stages I and II' appeared in the middle Pleistocene, and 'Ratnapura III' and 'Bellanbendi Stage' appeared in the Late Pleistocene (Table 3). Further, 'Balangoda Stage' has been correlated with the Late Wurm, and 'Colombo Stage' is proposed tentatively for present climate. Evidence for changes of relative land and sea levels are found in many places around the coast of Sri Lanka (Table 4).

Aragonite of land snails of coastal dunes at Bundala dated at 21,000+400 and 25,450+750 yr B.P. (another two dates at the same area dated at 22,800 and 28,400 yr B.P. by thermolumniescence) and the Pathirajawela deposits dated at 28,440 and 64,380 - 74,200 yr B.P. attest for Late Pleistocene atlithermal episodes in Sri Lanka. Deraniyagala (1986) considers that the basal gravels are coeval with lagoon deposits in the southeastern India at ca. 38,000 yr B.P. and it correlated with the Henglo maximum of ca, 37,000 yr B.P. (middle Wurm). The basal gravel at Pathirajawela has been overlain by wind blown sand at 64,300 - 74,200 yr B.P. and may tentatively be correlated with another episode of low stand of sea-level in the Early Wurm. Further, these data can be used to speculate on the rate of tectonic uplift for the southern Indian and Sri Lankan region.

In the continental shelf of Sri lanka, remains of channels of some larger rivers, and sunken forests can be identified (Deraniyagala, 1958). The western continental shelf consists of predominately sand sized particles, 2 mm to 0.067 mm in diameter, composed of lithogenic quartz and biogenic carbonates (Wickramaratne et al., 1988). Most shelf sediments have been deposited in shallow water under dry climatic conditions, and recent sediments are found accumulating only in near-shore areas and on the continental slope.

Submerged features such as low-lying ridges, well-marked troughs, terraces and forests; weathering conditions, colour and constituent of the sand and height of the beach ridges; buried and emerged corals; shell beds and beachrock can be used as indicators to the study of evolution of coastal lowlands of Sri Lanka (Cooray, 1968; Dahanayake and Jayawardena, 1979; Deraniyagala, 1958; Katupotha, 1988c). Based on these and 14C dates of geologic samples, several stages in the Late Quaternary Period can be recognized :

Stage 1 : From Late Pleistocene to early Holocene. A desert like condition occurred in much of the low country and low hills and ridges were coated mainly by wind blown brick red coloured Red Beds and Brown Earth deposited on the northwestern and southern Sri Lanka (Wayland, 1919). Human artifacts of early stone-age (Palaeolithic) man were overlain by these deposits. The fossil humans horizons at Weuda of Kandy formed about 24,300 - 22,100 yr B.P. (Spath, 1985), and this period probably corresponds to a dry climatic phase and lower sea-level.

Following this features such as low-lying ridges, well-marked troughs and terraces have been formed on the drowned peneplain. Recent oceanographic investigations reveal that the coralline algae, limestone and calcareous sandstone have been developed gradually on those feature. It can be speculated that the different levels of marine terraces between the continental slope and present coastline have been formed due to the rapid rise of sea-level from ca. 17,000 yr B.P. This transgression has caused

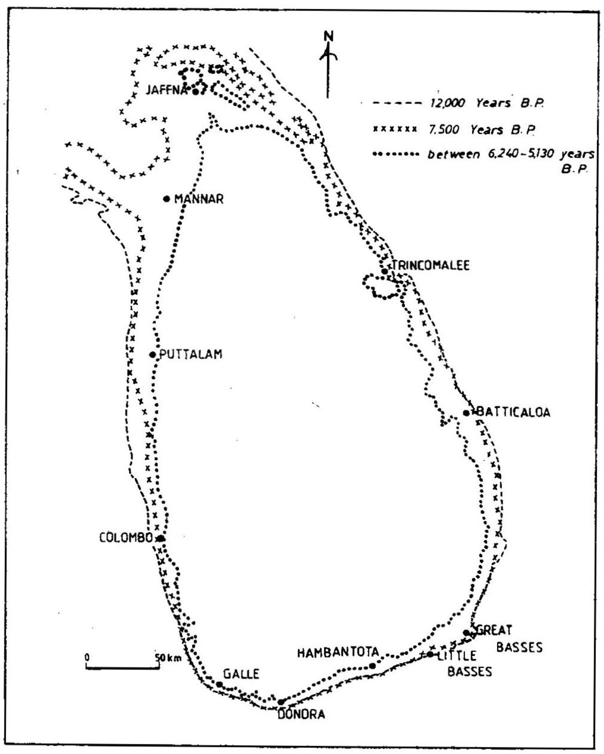

Fig. 4. Possible coastline of Sri Lanka around (i) 12,000 year B.P., (ii) 7,500 years B.P. and (iii) between 6240 and 5130 years B.P.

TABLE 3. Approximate Dating and Events of the Quaternary Period.

Blytt-sernander Classification	European/alps	Yr B.P.	Mid-latitude Temperature Departures (C^o)	Eustatic phases and elevation (in metre)	Geological Formation And archaeological event in Sri Lanka
Late-Subatlantic -600 yr B.P.	Historic	< 1,000	-1^o	E (-2)	Estuarine deposits; Aryan settlement
Present climate -1,000 yr B.P.	Viking		$+0.5^o$		Estuarine deposits
Early-Subatlantic -1,600 yr B.P.		1,000-2,300	$+1^o$	S (60 cm)	Estuarine deposits
-2,000 yr B.P.	Roman		-0.5^o	S (-2)	Estuarine deposits
-2,300 yr B.P.	Iron age		$+1^o$	S (1.5 - 2)	Estuarine deposits (inland fossil corals, coastal swamp deposits emerged reef patches)
Late-Subboreal		2,300-3,700			
-3,000 yr B.P.	Bronze age		$+1^o$	E (-3)	Estuarine deposits (inland fossil shells), emerged beachrock.
Early Subboreal		3,700-5,300			
-4,000 yr B.P.	Neolithic		$+2^o$	S (+3)	Estuarine deposits (inland fossil shells, coastal swamp deposits) emerged beachrock.
-4,300 yr B.P.			-0.5^o	E (-4)	Estuarine deposits (inland fossil shells), emerged beachrock.
Main Atlantic-5,500 yr B.P.		5,300-6,600			
	Mesolithic		$+2.5^o$	S (3 - 5)	Estuarine/Marine deposits (inland fossil corals, coastal swamp deposits, emerged reef patches) + 1.5 m or more higher sea-level than at present, flourishing of lateritization.
-6,500 yr B.P.			$+1^o$	E (-10)	Rising of sea-level, submergence of near-shore forests *
Early Atlantic		6,600-7,500			
-7,000 yr B.P.	Meglemose		$+2^o$	S	Rising of sea-level
Late Boreal		7,500-8,700			
-7,500 yr B.P.	Meglemose		$+0.5^o$	S	Rising of sea-level
-7800 yr B.P.			$+1^o$	S	Rising of sea-level
Early Boreal		8,700-9,800			
-8,800 yr B.P.	Klosterlund		-0.5^o	E	Rising of sea-level *
Preboreal		9,800-10,300	$+1^o$	S (-) 15-24	Forming of Laterite in the Hill Country, rising of sea-level *
	WURM	FLANDRIAN			
Younger Dryas	Scandinavian morain (W IIc)	10,300-10,900	-3^o	E (-25)	Arid Phase, Balangoda culture (Neo- lithic 10,000 yr B.P.) *
Allerod mild		10,900-11,800	-2^o	E (-) 32-40	Iranamadu late formation, Balangod aculture (Late Palaeolithic)
	Scanian to Brandenburg morain (W IIb)	11,800-17,500	-7^o	E (-) 45-60	Palangaturei Arid Phase, Red beds formation, Balangoda culture, Meso lithic *
		-17,500		E (-100)	Late Glacial Maximum, Palangaturei Arid Phase, Red bed formation, Balangoda culture, Mesolithic *
	W II a/b	-28,000		S (-) 100-10	Palangaturei Arid Phase, Red beds formation, Bundala dunes, Bellan-bendi deposits, Late Mesolithic *
	W II a	30,000-60,000		S -135	Ratnapura Climatic Phase III (Early Palaeolithic - 52,000 yr B.P)
	W I/II a	60,000-95,000		S +3 or 4 (Epimonastirium)	Ratnapura Climatic Phase II, Pathi-rajawela deposits, forming laterite
	Warthe (W I)	95,000-125,000		E -100	Bundala-Levangoda gravel (75,000-125,000 yr B.P.)

Blytt-sernander Classification	European/alps	Yr B.P.	Mid-latitude Temperature Departures (C^{0})	Eustatic phases and elevation (in metre)	Geological Formation And archaeological event in Sri Lanka
				(or lower)	
	EEMIAN (R/W)	125,000-235,000		E +7 or 8 Late Monastirium E +18 Main Monastirium	Ratnapura Climatic Phase I, Iranamadu early formation ? (140,000-180,000) Neo tectonics ?
	RISS SAALE (R)	235,000-360,000		E -200 (or lower)	Tectonic uplift ? (265,000-300,000)
	GREAT INTER GLACIAL G/M	360,000-670,000		E +32 Late Tyrrhenian	Forming of laterite ?
				E + 45 Early Tyrrhenian	?
	MINDEL - ELATER (M)	670,000-780,000		?	
	INTER GLACIAL	780,000-900,000		E +60 Milazzaian	?
	GUNZ	900,000-1150,000			
	INTER GLACIAL	1,150,000-1,370,000		E +80 Sicilian	?
	DONAU (D)	1,370,000-1,800,000		E +150 Late Calabrian	?
		1,800,000 to 2,300,000 or 2,500,000		S + 180 Early Calabrian	?

S = Submergence, E = Emergence, * = Marine terraces and sandstone (beachrock) formation

Sources: Deraniyagala, 1976, 1986; Fairbridge, 1968; Holms, 1966; Katupotha, 1988a,b; Katupotha and Fujiwara, 1988; Katupotha and Wijayananda, 1989; Wijesekara, 1959.

the rivers to fill their valleys and discharge their loads over the drowned peneplain. It is suggested that the desert-like conditions of the low country is very similar to the Pleistocene aridity in tropical Africa, Australia and Asia which was described by Williams (1985), and the fluvial process extended several kilometres beyond the present shore around Sri Lanka (Fig. 4). Thus, the Table 3 shows the possible climatic and sea-level changes, geological formations and cultures during the Late Pleistocene and Early Holocene Epochs.

Stage II : Mid-Holocene period (First episodes of high sea-level (6,240 - 5,130 yr B.P.). 14C dates of geologic samples (Katupotha, 1988a,b; Weerakkody, 1992) indicate that the mid-Holocene sea-level was at least 1.5 m or more above that of the present level. This reduced the size of Sri Lanka (Fig. 4). The former drainage basins were submerged and headland-bay-beaches were created. Corals (presently buried between Akurala and Matara) thrived in former embayments and gradually formed coral reefs in many places on the southwest coast. Submerged forests (Deraniyagala, 1958) in the northwestern shelf attest to this marine transgression that is observed in India and other Indian Oceanic Islands too (Katupotha, 1990).

Stage III : First phase of the late Holocene (4,390 - 3,930 yr B.P., Second episode of high sea-level). Between the stages II and III the sea-level around 4,700 yr B.P. was slightly below from the present position during the Late Holocene. The living coral colonies and shells of the lagoons and estuaries were buried by mud and other debris which were washed down into the embayments by terrestrial waters. They were intermittently covered by vast quantities of coral sand and coral debris moved by sever monsoon waves.

Stage IV : Late-Holocene (3,280 - 2,270 yr B.P., Third episode of high sea-level). Between the stages III and IV, the sea-level around 3,600 yr B.P. was also at its present level or below it. It is suggested that the beachrock, slightly above MHWS and inter-tidal level zone along the coast have been formed during this stage. 14C dates of shells embedded in emerged reef patches, buried and emerged corals, shell beds, shell deposits and beachrock prove that the climatic changes have occurred after the mid-Holocene high sea-level.

Stage V : Recent beaches and sand spits etc. There has been a close relationship between CO^2 - warming, rising sea-level and retreat of coasts and glaciers in both hemispheres since 100 yr B.P. (A.D. 1850)(Bryant, 1987; Fairbridge, 1961). As a result of these global changes, the secular and seasonal changes have also occurred along the present coastline of Sri Lanka.

EVOLUTION OF THE COASTAL ZONE

Different types of geological formations and landforms of the post-Miocene times have controlled the evolution of the coast. Changes of the relative levels of the land and sea, old strandlines, beachrock, inland buried and emerged corals, marine shelly deposits around the present coast and continental shelf show different stages of this evolution.

Western Coast

It is along the coast from Puttalam to Colombo that evolutionary stages have been most recognized (Deraniyagala, 1958; Cooray, 1967, 1968a; Cooray and Katupotha, 1991; Katupotha, 1988c). The following is a summary of the outcome of researches.

Identification of :

a) changes in coastal forms in the 20th century;

b) hanging strandlines;

c) sea level changes from near the 100-fathom line to above present sea-level;

Understanding the :

1) formation of offshore sand bars and spits and beachrock shoals (Figs. 5, 6) along an early coast line, and (a) the growth of Kalpitiya peninsula; (b) the formation of the islands of Kirimundel, Karaitivu, Ippantivu and Paiya Arichchal
2) formation and conversion of: (a) Mundel 'lagoon' into Mundel Lake and the growth of Puttalam Lagoon (b) Muthurajawela lagoon into a lake and a swamp and later into a peat deposit. (c) Negombo and Chilaw lagoons to their present size
3) formation of wide beach plain with parallel ridges and runnels (as in) Puttalam;

Northern Region

On the basis of geological and geomorphological evidence evolution of the Jaffna Peninsula and the islands off the northern coastline has been attempted (Cooray and Katupotha, 1991).

The southwestern and Southern Coasts

Erosion, and retreating shorelines of the southern and southwestern coasts of Sri Lanka, have been made evident by numerous offshore islets and the rocky headlands alternating with bays. Several phases of coastal evolution since mid-Holocene can be recognized (Katupotha and

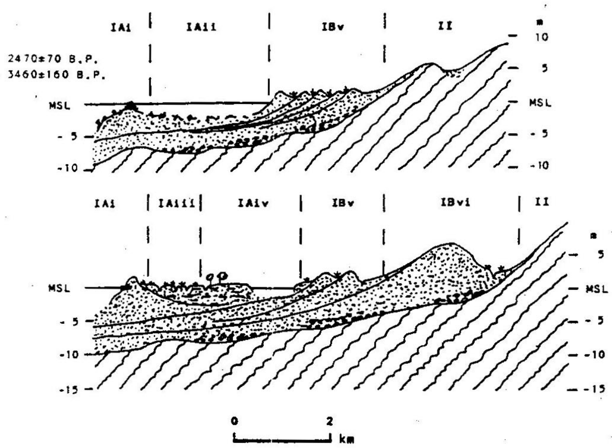

Fig. 5. Generalized sections at Pitipana - Negombo. (IAi) beachrock shoal, (IAii) Barrier Beach, (IAiv) Barrier flats and marshes, (IBv) Old sand ridges, (IBvi) Marshy flats, and (II) Peneplained basement.

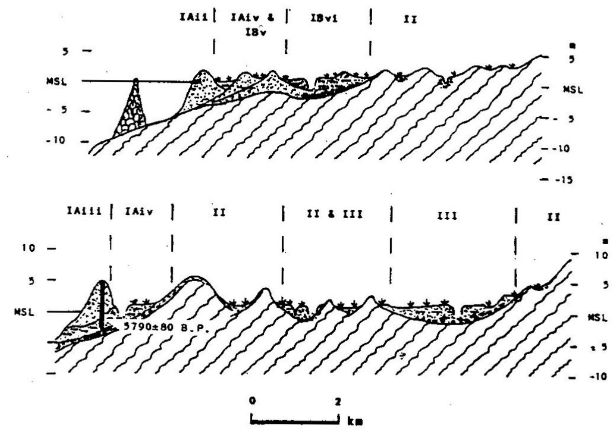

Fig. 6. Generalized sections at Mattakkuliya and Colombo Fort. (IAi) beachrock shoal, (IAii) Barrier Beach, (IAiv) Barrier flats and marshes, (IBv) Old sand ridges, (IBvi) Marshy flats, (II) Peneplaned basement, and (III) Alluvial flood plain.

Fujiwara, 1989; Katupotha and Wijayananda, 1989; Wijayananda and Katupotha, 1989; Weerakkody, 1992).

East Coast

A prograding coastal region is extremely evident on the east, north and south of Batticaloa (Cooray and Katupotha, 1991) where the study of coastal evolution would be most profitable (Fig. 7). It would be possible to trace growth stages of coastal landforms. Coastal deposits and formations record sea-level oscillations during their evolutionary phases.

The formations, from outer shelf to lowlands along the coasts of Sri Lanka have a close relationship with the climatic and sea-level changes which followed the low stands of sea-level during the early Wurm as well as the LGM and the rapid rise of sea-level during the Pleistocene transgression, (Fig. 8). The Pleistocene formations already described by Wayland (1919), Wadia (1941), Deraniyagala (1958, 1986), Cooray (1963, 1967) can be correlated with the long fluvial phase which followed the interglacial stages (Tables 3 and 4).

Much of the Quaternary research in Sri Lanka still concentrates on Palaeolithic cultures, and only a few researches studied geologic and climatic events of the Quaternary. However, these studies hardly provide sufficient information on the Quaternary stratigraphy, climatic and sea-level changes. A linkage between archaeological

TABLE 4. Evidence of Former Sea Level in Sri Lanka

METRES + MSL	TYPES OF EVIDENCE		RELIABILITY
Positive levels	Marine deposits	Geomorphological	
+ 1.6 - 4.5	shells	coastal terraces	
+ 6.0 - 10.0	shell beds	cut flat forms,	high
+ 14.0 - 18.0	beachrock	distributories	
+ 27.0 - 36.0	beach deposits		
+ 36.0 - 43.0	- -	as above	inconclusive
Negative levels	Stratigraphic	Bathymetric	
	Buried valley	crest of continental	
-0.8 - 24.0	deposits, bed-rock over burden boundary	beachrock shelf profiles reefs	high
- 24.0 - 27.0			
- 33.0 - 46.0		- shelf profiles	Moderate
- 55.0 - 64.0			
- 73.0 - 91.0			

Sources: Swan, 1982; Cooray and Katupotha, 1991.

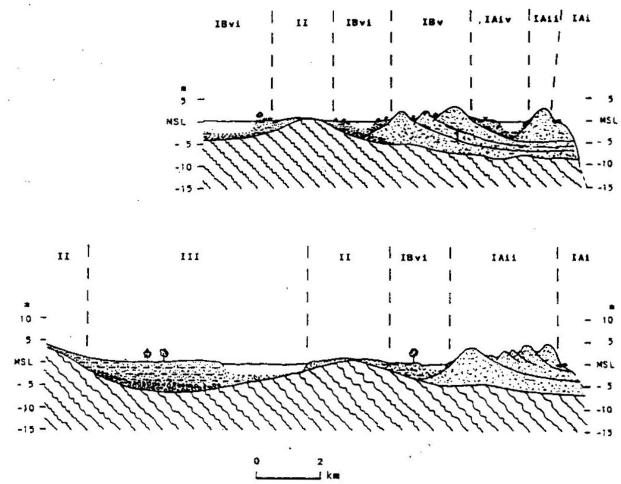

Fig. 7. Generalized sections at Kokuvil and Nochchimunai (Batticaloa). (IAii) Barrier Beach, (IAiv) Barrier flats and marshes, (IBv) Old sand ridges, (IBvi) Marshy flats, (II) Peneplaned basement, and (III) Alluvial flood plain.

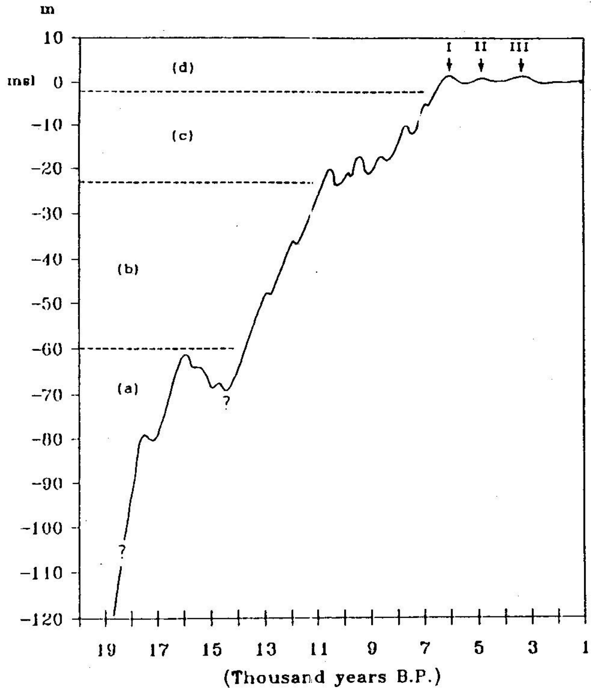

Fig. 8. Eustatic oscillations in Sri Lanka since last-Glacial Maximum. (a) Development of coralline algae, limestone and calcareous sandstone reefs on the continental shelf; (b) submergence of river valleys and development of marine terraces; (c) submergence of river-valleys and coastal forest; formation of 25 m, 18 m, 10 m, and 2 m levels of beachrock in the near-shore zone; (d) I, II and III = three episodes of high sea-level (Katupotha, 1993b) (about 1.5 m) higher than at present; development of coastal lagoons and lakes, estuarine deposits, inland buries coral deposits, emerged coral reef patches, inland shell deposits, present beachrock and coastal swamps.

and geological investigations is hampered due to lack of radiometric dating facilities. More quantitative research emphasizing on geology, sedimentation, climatic changes, neo-tectonics, faunal and floral habitats, and the development and evolution of early cultures would be needed for a better understanding of the Quaternary Period of Sri Lanka.

CONCLUSION

The Quaternary Period began approximately two million years ago (according to many estimates) and continues upto the present. Quaternary deposits found in Sri Lanka include deep-sea deposits, shallow marine deposits (continental shelf), coastal and fluvial deposits. The development of these geological formations can be correlated with the global climatic changes which followed the 'Glacial' and 'Interglacial' stages. Findings on Quaternary events in Sri Lanka, eg. geological formations, climatic and sea-level changes and neo-tectonic activities, have not been successfully compared with those of other tropical countries. Therefore, detailed investigations of continental shelf sediments, bathymetry, radiometric dating of different kinds of sea-level indicators, and quantitative research on neo-tectonics, are further needed to unravel the phases and formations of the Quaternary of Sri Lanka.

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