WILDLANKA Vol.4, No.4, pp. 190 - 208, 2016.

FUTURE PROSPECTS OF QUATERNARY CLIMATIC STUDIES OF SRI LANKA; A REVIEW

JINADASA KATUPOTHA

Department of Geography, University of Sri Jayewardenepura
Nugegoda, Sri Lanka

Email: katupotha@sjp.ac.lk/katupotha@gmail.com

ABSTRACT - **The Quaternary Research Working Group (QRWG) of Sri Lanka was set up at the 11th AGM of Geological Society of Sri Lanka (GSSL) in 1995 to encourage the researchers who are keen on Quaternary Studies of Sri Lanka. For this purpose, the QRWS successfully completed two field visits in the southern and northwestern coastal zones to observe the Quaternary and Holocene formations of Sri Lanka, although, we failed to organize an International Conference or proposed a one-day awareness Workshop/Seminar due to lack of funding. Hence, the Quaternary Research in Sri Lanka comes into view as a neglected field. However, the Group compiled a bibliography including twenty-six (26) subject categories relating to the Sri Lankan Quaternary. However, it is very difficult to fulfill the research gaps in relation to Quaternary Geography, Quaternary Climatology and Quaternary Ecology in detail.**

The Quaternary studies of Sri Lanka emerged since 1908, and pioneer scientists were British, Canadians, Germans, Indians and Sri Lankans. They described the Palaeolithic stone tools, cannibalistic Balangoda Man, the fossils of extinct animals and past climatic phases of Sri Lanka. Stratigraphic sequences, constituent material, locations and some age determinations on Quaternary formations have been completed by a few scientists. These scientists are undertaking Quaternary studies emphasizing different disciplines with limited facilities and funding. Also, the lack of age determination facilities in Sri Lanka is the main obstacle for the Quaternary studies of Sri Lanka.

KEY WORDS : Quaternary studies, Quaternary climate, Older and Younger formations, Age determination, future prospects

INTRODUCTION

The Age of man or the great Ice Age is designated as "Quaternary". It began ca. 2 million years ago and continues up to the present (Fairbridge, 1968). It comprises two epochs namely; "Pleistocene - Glacial Epoch" and "Holocene - Recent or Post Glacial". There is a controversy over the time onset of the Quaternary. Some scientists have retained the short time-scale (600,000 years) while others accept the long-time scale (1.8 to over past 3.0 million years). Subdivisions of the Pleistocene epoch and its correlation to Glacial and Interglacial stages and climatic changes have been identified from pelagic foraminifera of the Atlantic, Caribbean and Pacific deep-sea cores by Emilliani (1955 and 1978).

The oscillations between glacial and interglacial climate conditions over the past three million years have been characterized by a transfer of immense amounts of water between two of its largest reservoirs on Earth namely the ice sheets and the oceans (Lambeck, 2002). The commencement of Pleistocene glaciations occurred about three million years ago with formation of permanent ice sheets at high northern latitudes. As the ice sheets waxed and waned, the concomitant fall and rise of sea level left direct evidence for the intensity and timing of glacial cycles. The major sea-level cycles occur at intervals of ~100,000 years (100 kyr) over the past ~800 kyr, with maximum amplitudes of 120–140m, involving changes in ice volume of 50–60 million km^3. Superimposed on these are lesser cycles of a few tens of thousands of years and shorter duration (Lembeck, 2001 and 2002). The advance and retreat of the ice sheets through multiple glacial cycles, most recently the Last Glacial Maximum (LGM) around 23,000–18,000 years before present, had a major impact on the present day distribution of species (Provan and Bennett, 2008). World-wide researches, research groups, Universities and various institutions/organizations have been undertaken and continuing their activities on Quaternary Perspectives on Climate change, natural hazards and civilizations. The results of these discussions were held annually or periodically and shared the knowledge based on international or national level conferences/seminar, CDs, videos, journals and books. This key paper aims to review researches, which were undertaken on palaeo deposits, fossils, extinct animals and different aspects during the past one hundred year period in Sri Lankan context. Similarly, the author tries to explain current directions of the Quaternary climate studies, gaps and vision of Sri Lanka in relation to Quaternary period.

Analytial procedure

Geographical Settiing of Sri Lanka

The island of Sri Lanka is about 65,610 square kilometres in area, lying between latitudes 5° 52'N - 9° 54'N and longitudes 79o 30'E - 81° 55'E. Its greatest length is 432 kilometres, in a north-south direction, and its greatest width, from west to east, is 224 kilometres. The land area is compact except for the Jaffna Peninsula in the north and the nearby islands in the north-west. The only semblance of a physical link is with the southeastern coast of India across Rawana's (Adams) Bridge, which is a narrow line of islands and shallows that together form the head of the Gulf of Mannar. Along with India, our nearest neighbours are the Maldives Islands (640 kilometres to southwest) and the Andaman and Nicobar Archipelagoes (about 1120 kilometres to the east), while directly south of Sri Lanka the ocean extends unbroken by land as far as Antarctica.

Geologically, 90 percent of Sri Lanka is made up of Precambrian crystalline rocks belonging to an ancient, stable part of the earth's crust known as the Indian Shield. The Indian shield is made up of a Precambrian metamorphic terrains that exhibit low to high-grade crystalline rocks in the age range of 3.6 – 2.6 billion years (Ga). These terrains, constituting the continental crust, attained tectonic stability for prolonged periods, since Precambrian time (Sharma, 2009). U-Pb age determinations of zircons in detritus grains from Highland/ South-western Complex (H/SWC) rocks have reported ages between 3.2 - 2.4 Ga (Archean to early Proterozoic) by Kröner *et al*., 1987. It is also revealed that similar rocks have a relationship with Precambrian events, and therefore believed to be the foundation or basement rocks of Sri Lanka (Hölzl et al., 1991; Kröner et al., 1987; 1991). Recent studies on Sri Lanka during its period within the Gondwanaland ensemble (Cooray, 1984), indicate its position to be somewhere between the western crustal blocks that include South India, Madagascar and eastern Africa, and eastern blocks that include Eastern Dronning Maud Land and Lützow-Holm Bay of East Antarctica (Yoshida *et al*, 2003). Since Precambrian times to Pliocene Epoch, the Island of Sri Lanka was subjected to geological, geomorphological and sedimentological jolting and reached the present position and configuration. During the Pliocene Epoch (5.332 - 3.600 ma), well-compacted precipitated marine colloidal siliceous stratum in northwestern Sri Lanka was occurred (Katupotha, 2013). By the end of Pliocene, intensification of present Icehouse conditions, present (Quaternary) ice age begins roughly 2.58 Ma; cool and dry climate. Australopithecines, many of the existing genera of mammals, and recent mollusks appear. By Lower Quaternary (2.588 - 1.806 ma), location of Sri Lanka is assuming the present position between 5º 52´N-9º 55´N and 79º 30´E-81º 55´E.

Due to the Pliocene-Quaternary climate changes, the earlier glacial sedimentary deposits in Sri Lanka have disappeared from the greater part of Sri Lanka. It should be extremely warm and cold phases and mild climate events during the Pliocene-Quaternary times. However, there are no Pleistocene glacial deposits in Sri Lanka, but scattered erratic boulders and patches of ice-rafted deposits can be identified as glacial deposits older than Pleistocene Glaciation. Likewise, outwash plain type landforms can be identified from the “Second and Third Planated Surfaces”, while valley terrains can be identified from the upper part of the “Third Planated Surface” and the “Fourth Rugged Central Highland” of Sri Lanka emerged due to thawing of massive glaciers (Katupotha 2013). These changes have led to the deposition of the Quaternary formation and to changes in the shape of the coastal regions of the Island. The continental shelf surrounding Sri Lanka extends from the present coastline to 150m bathymetry line (Figure. 1), and it is corresponding with palaeo dropped sea level during the LGM. This submerged surface can be identified as "First Planated Surface" (Katupotha, 2012), which was designated as "submerged plateau" by Sommervile (1908) and "submerged peneplane" by Deraniyagala (1956).

Literature Review on Quaternary Research in Sri Lanka

The modern continents, sub-continents and islands in the Indian Ocean were essentially at their present positions during the Quaternary Period, especially by the Pleistocene Epoch, and by the Holocene Epoch. The cycles of advancing and retreating continental glaciers were corresponding to the terms glacials, interglacials, stadials and interstadials reflecting periodic changes in climate and sea levels. The warmer, cooler and drier climate conditions followed the above cycles enhanced the evolution of hominids, deposition of terrestrial deposits around the submerged planated surface. Deposition of Ratnapura beds and the similar deposits by marine and aeolian processes in many locations; basal ferruginous gravel and terrace gravel; laterite and older alluvium identified as Plio-Pleistocene deposits (Somarville, 1908; Wayland, 1919; Coates, 1935; Wadia, 1941; Deraniyagala, 1958; Deraniyagala, 1986).

These deposits designated as Older Group by Cooray. The younger alluvium; unconsolidated coastal sands; littoral sandstone; Lagoonal and estuarine deposits; dead and emerged corals as Holocene or recent deposits have designated a Younger Group of Sri Lanka Cooray, 1963, 1967, 1968, 1984; Katupotha, 1988a, 1988b and 1995).

Prehistoric research, related to Quaternary Period, on stone implements and cave man showed that the quartz and chert artifacts used by early man, and embedded deposits can be used in the examination of Quaternary events (Pole, 1907; Parsons, 1908; Hartley, 1913; Wayland, 1919, Deraniyagala, 1958, Deraniyagala, 1986). 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. 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 threefold classification of the coastal deposits and on the basis of fossils found that they had developed since Tertiary or Pleistocene periods.

Most of the northwestern, northern and eastern coastal zones are made up of 'post-Miocene' to 'Recent' formations. These are predominately gravels, sands and clays resting on Miocene limestone along the northwestern and northern regions, others resting on Precambrian basement, which have been laid down since 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

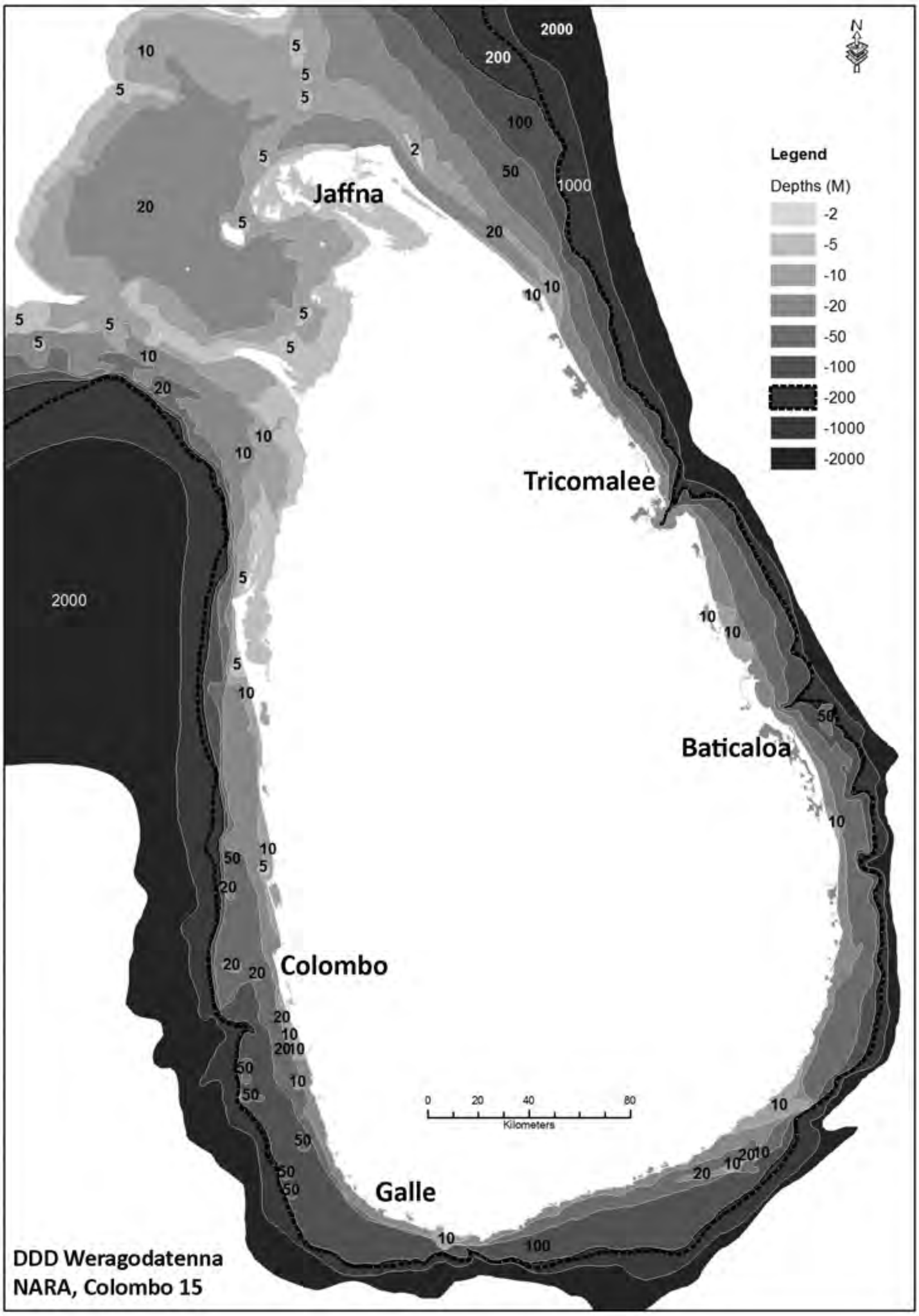

FIGURE 1: The continental shelf surrounding Sri Lanka extends from the present coastline to 150m bathymetry line. It is corresponding with palaeo dropped sea level during the Last Glacial Maximum. This submerged surface can be identified as "First Planated Surface" (Katupotha, 2013). Sommervile (1908) and Deraniyagala (1956) designated the same area as "Submerged Plateau" and "Submerged Peneplane" respectively. Sunken forest, rock outcops, rock shelters and canyons (in front of river mouths were placed due to the palaeo climate change since Pliocene-Quaternary time.

been more effective than deposition. Consequently, the southwestern, southern and southwestern coastlines have been regressive rather than progressive in character, and Quaternary to Recent sediments are largely absent there.

As a paleontologist, zoologist, and also an artist from Sri Lanka, P. E. P. Deraniyagala (1900 - 1976) specialized in fauna and human fossils of the Indian subcontinent. From 1939 to 1963 he was the Director of the National Museum of Ceylon, and from 1961 to 1964 he was also the Dean of the Faculty of Arts at the Vidyodaya University (presently University of Sri Jayewardenepura). Among the fossils and species he described are: Some fossil animals from Ceylon (1938, 1947; the cannibalistic Balangoda Man, *Homo sapiens balangodensis*; the extinct Sri Lanka lion (*Leo leosinhaleyus* 1939); the extinct Sri Lankan gaur (*Bibossinhaleyus* 1962); the extinct Sri Lankan hippopotamus (*Hexaprotodonsinhaleyus*1937); the extinct Sri Lankan rhinoceros (*Rhinoceros sinhaleyus* 1936 and *Rhinoceros kagavena* 1956). Deraniyagala described an alleged African subspecies of tiger *Panthera tigrissudanensis* in 1951. Mentioning many fields, Deraniyagala compiled 200 or more articles, abstracts, books, etc. to palaeobiodiversity, archeology and anthropology. Similarly, extinction of quaternary mammalian habitats of megafauna in Sabaragamu Basin, Sri Lanka has studied by Sumanarathna, Katupotha *et al*. Above all investigations and results of Deraniyagala are very valuable key points to undertake detailed studies on Quaternary Climate and Quaternary formations in Sri Lanka.

Deraniyagala (1958) regards the heavy tectonic actions such as faulting, tilting, dislocation and block hosting which occurred during the Pleistocene as having caused the mixing of fossils of different ages to occur in gem bearing deposits of Ratnapura. The eustatic and the climatic sequence of the Pleistocene are also identified on the basis of faunal elements from middle Pleistocene to Holocene. Based on Deraniyagala's findings, 'Ratnapura Stages I and II appeared in the middle Pleistocene and 'Ratnapura lll and 'Bellanbendi Stage' appeared in the Late Pleistocene (Katupotha, 1994). Further, 'Balangoda Stage' has been correlated with the Late Würm and 'Colombo Stage with the present climate (Table 1). In this paper, the present author's attempt to emphasize that brackish water have been entered to the Sabaragamu Basin (Ratnapura Basin) through Kalu Ganga (river) valley during the high relative sea levels occurred during the Quaternary period. Such relative sea levels have been described by Miller (2009), Martin (2002) Martı´nez-Bot (2015) and many others.

Deraniyagala (1986) proved that Late Pleistocene altithermal episodes have occurred in Sri Lanka. Aragonite of land snails of coastal dunes at Bundala was dated at 21,000±400 and 25,450±750 yr B.P (two more dates at the same area dated at 22,800 and 28,400 yr B.P by thermo-luminescence) and the Pathirajawela deposits are dated at 28,440 and 64,380 - 74,200 yr B.P. The basal gravel at Pathirajawela has been overlain by windblown sand of 64,300 - 74,200 yr B.P and may tentatively be correlated with early Würm.

This could be another episode of a low strand of sea-level in the Early Würm. Further, Deraniyagala explains that the data on the rate of tectonic uplift for the southern Indian and Sri Lankan region can be used to speculate the highest coastal gravel of the southwestern part of Sri Lanka at about 80 - 60m MSL and could in fact be correlated with a ca. 30m high sea-level with the middle Pleistocene (Holsteinian interglacial) at about 300,000 - 265,000 yr B.P., on the same basis, the 25m gravel found in the Bundala - Levengoda area can be correlated with the 'Eem interglacial' at ca. 125,000 - 75,000 yr B.P [(Katupotha, 1995a, 1997), Fig 2]. In the submerged 1st planated surface (submerged peneplain) which is bounded externally by the 100 fathom (ca. 180 m) in the continental shelf of Sri Lanka, remains of channels of some larger rivers and sunken forests can be identified (Deraniyagala, 1958). Somerville (1908) and Wickramaratne et al (1988) reported that the western continental shelf consists predominately of sand sized particles, 2 mm to 0.067 mm in diameter, composed of lithogenic quartz and biogenic

TABLE 1: Approximate dating and Events of the Quaternary Period

Blytt-sernander Classification	**European/ alps**	**Yr B.P.**	**Mid-latitude Temp./ Departures (c^o)**	**Eustatic Phases and elevation (in meter)**	**Geological Formation and archaeological event in Sri Lanka**
Late-subatlantic - 600 yr B.P	Historic	<1000	1°	E(-2)	Estuarine deposits; Aryan Settlement
Present climate - 1000 yr B.P	Viking		+0.5°		Estuarine deposits
Early-subatlanyic - 1600 yr B.P		1000-2300	+1°	S(60cm)	Estuarine deposits
-2000 yr B.P	Roman		-0.5°	S(-2)	Estaurine deposits
-2300 yr B,P	Iron age		+1°	S(1.5-2)	Estaurine deposits (inland fossil corals, coastal swamp deposts, emerged reef patches)
Late-subboreal	Bronze age	2300-3700	+1°	E(-3)	
-3000 yr B.P					Estaurine deposits (inland fossil shells), emerged beachrock
Early subboreal -4000 yr B.P	Neolithie	3700-5300	+2°	S(+3)	Estaurine deposits (inland fossil shells, coastal swamp deposts), emerged beachrock,
-4300 yr B.P			+0.5°	E(-4)	Estaurine deposits (inland fossil shells), emerged beachrock
Main Atlantic - 5500 yr B.P	Mesolithic	5300-6600	+2.5°	S(3.5)	Estuarine/ Marine deposits (inland fossil shells, coastal swamp deposits, emerged reef patches) +1.5 m or more higher sea-level than at present flourishing of laterritization
-6500 yr B.P			+1°	E(-10)	Rising of sea-level, submergence of near-shore forests*
Early Atlantic - 7000 yr B.P	Meglemose	6600-7500	+2°	S	Rising of sea-level
Late Boreal - 7500 yr B.P	Meglemose	7500-8700	+0.5°	S	Rising of sea-level
-7800 yr B.P			+1°	S	Rising of sea-level
Early Boreal- 8800 yr B.P	Klosterlund	8700-9800	+0.5	E	
		9800-10300	+1°	E(-) 15-24	Forming in laterite in the Hill Country, Rising sea-level
Younger Dryas	WÜRM Scandinavian moraine (W llc)	PLANDRIAN 10300-10500	-3°	E(-25)	Arid Phase, Balangoda culture (Neolithic 10000 yr B.P.

TABLE 1: Approximate dating and Events of the Quaternary Period (Continued...)

Allerod mild	Scanian to brandenburg Moraine (W llb)	10900-11800 11800-17500	-2º -7º	E (-) 32-40 E (-) 45-60	Iranamady late formation, Balangoda culture (Late Palaolithc), Palangature Arid Phase, Red bed formation, Balangoda culture, Mesolithic*
		17500		E(-100)	Late Glacial Maximum, Palangaturei Arid Phase, Red bed formation, Balangoda Culture, Mesolithic*
	W ll a/b	28000		S(-)100-10	Palangaturei Arid Phase, Red bed formation, Bundala dunes, Bellanbedi deposits, Late Mesolithic
	W ll a	30000-60000		S-135	Rathnapura Climatic Phase III (Early Palacolithic-52000 yr B.P)
	W l/ll a	60000-95000		S + 3 or 4	Rathnapura Climatic Phase II, Pathirajawela deposits, forming laterite
				(Epimonastirium)	
	Warthe (W 1)	95000-125000		E -100	Bundala-levangoda gravel (75000-125000 yr B.P)
	EEMAIN (R/W)	125000-235000		(or lower) E +7 or 8	Rathnapura Climatic Phase I, Iranamadu early formation ? (140000 - 180000)
				Late Monastirium E +18	Neo tectonics ?
	RISS SAALE (R)	235000-360000		Main Monastirium	
	GREATINTER			E +200	Tectonic uplift ? (265000-300000)
	GLACIAL G/M	360000-670000		(or lower)	
				Late Tyrrhenian E +45	Forming of laterite?
				Early Tyrrhenian	?
	MINDEL-ELATER(M)	670000-780000		?	
	INTER GLACIAL	780000-900000		E +60 Milazzaian	
	GUNZ	900000-1150000		E +80	?
	INTER GLACIAL	1150000-1370000		Sicilian	
	DONAU (D)	1370000-1800000		E+150 Late Calabrian	?
		18000000 to 2300000 or 2500000		S+180 Early Calabrian	?

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

Source : *Katupotha, 1994 (Journal of the Geological Society of Sri Lanka, 1994 P.W. Vitanage Felicitation Vol 5* carbonates. Most shelf sediments had been deposited in shallow water during the last low stand of sea-level and recent sediments are found accumulated only in near shore areas and on the continental slope. During the above mentioned period, the outer shelf area was starved of sediments due to their removal through submarine valleys and canyons. This has resulted in the absence of calcareous skeletal material in the outer shelf area. Deraniyagala (1958) summarized different events in the Pleistocene Epoch in Sri Lanka on the basis of the behavioral 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.

The Quaternary deposits that were laid down during the last million years of the island's history occur mainly within a coastal belt. As mentioned by Somerville (1908), Coates (1919), Deraniyagala (1956), Cooray (1963, 1967, 1984) and Katupotha (1988c) the coastal belt of Sri Lanka 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. 1). The Quaternary formations in Sri Lanka have been sub-divided into two main groups by Cooray (1963) namely; the "Older Group" (Basal Ferruginous Gravel, Red Beds and Terrace Gravel) and the "Younger Group' (alluvium, lagoonal and estuarine beds, unconsolidated sands of beaches and dunes, inland fossil corals and beachrock). Others findings related to Quaternary Period (Pleistocene and Holocene Epochs) can be included above two Groups.

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 unraveling 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; Neel and Veech 1981). Katupotha (1988c) identified sea level fluctuation stages in the evolution of the western coastal lowlands. Later, Katupotha (1992, 1995, 2015) disclosed the existence of three high sea-level episodes between 6,240 and 2,270 yr B.P based on available 14C ages from the east, west and southwest coasts.

Quaternary Formations in Sri Lanka

The Quaternary period or sedimentary system, divided into Pleistocene and Holocene epochs. Quaternary Sedimentary System (QSS) in Sri Lanka shows the diversity of formative processes, which can be identified as sediments, deposits, beds and unconsolidated materials. As mentioned in the literature review, the QSS have been described as an Older Group and a Younger Group by Cooray (1963, 1967) and Cooray and Katupotha (1991)

Older Group or 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. The gravel lie below the Red Earth and were called `Plateau Deposits' by Wayland (1919).

Red Beds

Red Beds (Red Earth - Wayland, 1919) rest on the ferruginous gravel or on Miocene limestone. They occur as 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 - 25m. A maximum thickness of 40m has been recorded at Aruakaru, about 30 km north of Puttalam. Cross sections show that the maximum height is varied between 21 and 23m and minimum thickness of the Red Bed deposit around Mundalama is varied around 8 – 9m. The Railway Line and the Chilaw – Puttalam A - 4 Road are running parallel to the Red Sand ridge, and the main road can consider as a western boundary of the Red Bed ridge (Katupotha and Starin, 2012).

Certain deposits of white sand in the western lowlands, Seeduwa to Kandana (katupotha, 1988c), have been derived directly from the Red Beds. 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 understudies of the Quaternary period (Wisconsin Würm Glacial Stage) in tropical countries, and the last occurred around 17,000 to 16,000 B.P resulting in a wide coastal plain which provided the source of sand. Dating of Red Beds in the south by thermo luminescence has shown that microliths in they 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 kilometers inland from the present coastline and are local in occurrence; they are sometimes known by local names, e.g., Erunwala Gravel, Kalladi Gravel and Kelani Ganga (Western Province) Gravel (Cooray, 1963; 1967). The gravel beds are about 5m thick and are sometimes about 15m 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.

Between Kaduwela and Hanwella on the Kelani Ganga, for example, a high-level gravel known as the "Malwana formation" is present at 16m above the present river level (28m above MSL); a lower gravel, the Ranale formation, is found at 6.5m above the present river level (23m above MSL. The Malwana formation contains beds of well rounded, coarse quartz pebbles embedded in a matrix of laterite separated from each other by pebble-free layers of laterite. Remnants of this formation are seen capping the ridge that runs parallel with the river in Ranale and Nawagamuwa villages on the left bank of the Kelani Ganga (river), and at Mapitigama, Weelgama, Thittapattara, and Wiyalananda villages on the right bank of the same river (Cooray, 1984; Katupotha, 2013). The Ranale gravel forms a terrace about a 1-2 km wide and at a height between 10-25m above MSL. It is about 3-4m thick probably formed as ice-rafted palaeo deposits during the progressive lowering of the river valley at a later stage. Outcrops of these gravel can be seen at several scattered locations along the valley on either side of the Kelani River, some of them being away from its present course. Well rounded and polished quartz pebbles, about 2.0 cm to 8.0 cm in size, embedded in a matrix of laterite separated from each other by a pebble-free layer of laterite is shown. Likewise, the original transported materials were converted to iron-rich brown and reddish brown earth embedded with well rounded quartz gravel to pebble size are found in a hummocky area at Boraluwewa (Leekolawewa) at Bingiriya DSD in the Kurunegala District. The sizes of the well rounded and oval shaped pebbles and cobbles vary from 2.0 cm to 8.0-10 cm; can be designated as ***Boralu Formation*** by Katupotha (2013). This author believes that these sediments represent weather-worn outwash plain deposits produced in several stages during the glacial history.

Erratic Boulders

Due to the Pliocene-Quaternary climate changes, the earlier glacial sedimentary deposits in Sri Lanka have disappeared from the greater part of Sri Lanka. However, there are no

Pleistocene glacial deposits in Sri Lanka, but scattered erratic boulders and patches of ice-rafted deposits can be identified as glacial deposits older than Pleistocene Glaciation (Katupotha, 2013). Accordingly, outwash plain type landforms can be identified from the "Second and Third Planated Surfaces", while valley terrains can be identified from the upper part of the "Third and Fourth Planated Surfaces" from the "Rugged Central Highland" area.

Erratics are significant because since they are transported by glaciers, they are one of a series of indicators which mark the path of glacier movement. Their lithographic origin can be traced to the parent rock, allowing for confirmation of the ice-sheets flow route. Similarly, they can be transported by ice-rafting. Ice-rafted debris or ice-rafted deposits and stream fed deposits were deposited onto the bottom of the water body, for example, onto a river bed or an ocean floor. The boulders of the Second and Third Planated Surfaces are derived from the rocks of Highland and Wanni Complexes. The Wanni Complex is composed mainly of quartzites, calc-silicate gneisses, cordierite gneisses, garnet-sillimanite gneisses, garnet-biotite gneisses, quartzofeldspathic gneisses, meta-granites (including pink granites), granitoid gneisses, charnockites, meta-diorite, amphibolites, meta-gabbros, migmatites, monzo-diorite and pegmatites. Erratic of the Northeastern Coastal Zone are very close to the present coast. Colour and mineral composition indicate that the rocks are derived from the Highland Complex rocks. They are mainly quartzite, marbles, and garnet-sillimanite-schist and chanockitic gneisses. The erratic boulders at Valaichchenai Lagoon (coordinates 7°56'N, 81°33'E), and Uraniya (Pottuvil) Lagoon (coordinates 6°53'N, 81°50'E) are about 2.0m - 4.0m above MSL. The lithology of these boulders being composed of a heterogeneous group of gneisses, migmatites and granites with scattered sedimentary bands confirm the source to be Highland Complex rocks. The erratics exhibit rounded, oval and elongated shapes ranging in from pebbles to large boulders hundreds to thousands of metric tons in weight. These appear to have been dropped on rock outcrops or on the ground by melting glaciers moving in a northeasterly direction (Katupotha, 2013). These erratic boulders and ice-rafted deposits can be correlated with the pattern of sedimentation during the Late Paleozoic, Gondwanaland Glacial sediment from the Talchir Formation, Satpura Gondwana basin and from central India (Chakraborty and Ghosh, 2008).

Younger Group or Holocene (Recent) Deposits Lagoonal and Estuarine Beds

According to Katupotha (1988a, 1988b) 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 (Silva *et al*., 2013). Cooray (1967, 1968a) revealed that 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; Katupotha 1988). Elsewhere, clay deposits with marine or brackish-water forms of life alternate with sand and clay with freshwater forms.

Laggonal and esturine 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), Katupotha (1988c) validated this situation based on a 14Cdate (5,790±80 B.P) from a peat sample collected from the foundation pit at the Galadari Hotel close to the Beira Lake (Katupotha, 1988b). The sequence of stratified deposits in the Beira Lake is about 10m thick. This indicates the development of a brackish-water marsh in the area following the Holocene transgression. Evolution of coastal landforms during the Holocene Epoch along the west and southeast coasts of Sri Lanka formed the brackish to terrestrial systems after the mid-Holocene highstands (Katupotha and Fujiwara, 1988; Ratnayake 2016). Based on AMS 14C radiometric dating and δ13C stable isotope analyses of materials from Bolgoda Lake, the development of lagoonal and estuarine deposits can be correlated with the Late Pleistocene and Middle to late Holocene environmental changes in the depositional system of the tropical brackish Bolgoda Lake (Ratnayake *et al*, 2016).

Muthurajawela Swamp

The peat swamp at Muthurajawela on the west coast covers an area of 21 km2. 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. 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. Calcareous algae from the surface of beachrok, elevation 0.25m, approximately above high tide level, indicates that such beachrock reefs have been formed during the coastal progradation (third episode of high sea level, katupotha, 1993 and 1995) had begun after Late Holocene. 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

Windblown 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; Katupotha 2015). 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 Hood 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, 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 in 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, 1899b, 1990; Katupotha and Fujiwara 1988; Katupotha and Wijayananda 1989). The depositional environment of the Bolgoda Lake has divided into two phases according to OM abundance and composition (Ratnayake et al 2017). The first phase was from ca. 7.0 to 2.5 cal ky B.P., and the second from ca. 2.5 cal ky B.P. to the Recent. These results can correlate with Holocene high sea level episods.

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 Lumnama Kalapuwa; Maha-sittrakala Lewaya; the area between Karagan Lewaya and Pallemalafa and the area between Embilikala Kalapuwa and Bundala Lewaya. Most of these are mined from paddy fields, small mounds (hummocks), former embay-ments and the bottoms of lagoons, lakes and creeks (Katupotha, 1995).

The deposition patterns and composition of shell deposits from Hungama to Bundala, indicate deposition at rims of emerged coastal embayments or lagoon floors by three processes as given below: The geological sequences of these shell beds indicate that they probably accumulated throughout the area by three processes (Katupotha, 1988a, 1988b, 1995 and 2015).

PRESENT STUDIES

The Quaternary studies of Sri Lanka emerged since 1908, and pioneer scientists were British, Canadians, Germans, Indians and Sri Lankans. As a Sri Lankan, P.E.P Deraniyagala described the cannibalistic Balangoda Man, the extinct animals (Fauna and their relationship to India and other countries), Palaeontology, Palaeobiology, Palaeolithic stone tools and past climatic phases of Sri Lanka. Similarly, others worked on Older and Younger Groups of the Quaternary emphasizing basal Ferruginous Gravel, Red Beds and Terrace Gravel (as Older Group formations) and alluvium, lagoonal and estuarine beds, unconsolidated sands of beaches and dunes, inland buried and emerged fossil corals and beachrock (as Younger Group forma-tions). Stratigraphic sequences, constituents material, locations and some age determinations as well as comparative studies of these forma-tions have been completed by few scientists. But all research works and their results were scattered here and there.

Katupotha *et al* (2000) compiled a Bibliog-raphy of the Quaternary of Sri Lanka, and entries included from 1908 to 1995. All entries are categorized by subject, study location and availability. If we go through carefully all entries, it is clear that the outcomes were on an individual basis. Most of the authors have done their research without outside finding, least or minimum financial support or official level. Likewise, as a pioneer, I gathered few scientists including Professor P.G. Cooray, and we estab-lished initially Quaternary Research Group 1993, it was officially set up at the 11th AGM of Geological Society of Sri Lanka (GSSL) in 1995. The Group successfully completed two field (1995 & 1996) visits to Ussangoda (southern coast) and Aruakkalu gravel deposit and Miocene limestone deposits respectively. The committee members gave full support to aware the university students and other partici-pants, who are interested the Quaternary studies.

As a co-convener, I and others endeavored to hold an "International Conference on Quater-nary Processes and Resources of the Circum-Indian Ocean Region" (IOSC 99). For this purpose, we debrief financial support from many Government Departments, Academic Institutions and even Presidential Secretariat to sponsor and help for Quaternary Research of Sri Lanka. Unfortunately, we could not get any support, and this is the situation and the attitude of the Government and other Institutions. It is very difficult to undertake individual research on Quaternary climate, processes and event of Sri Lanka. However, examination in detail of the Quaternary period in Sri Lanka is very significant to reveal the Quaternary Climatol-ogy, Quaternary geography and Quaternary ecology. Such revelations will be utmost value to study present and future scenarios of climate and sea level changes.

FUTURE PROSPECTS

The Quaternary period or rock system is related to or denoting the most recent period in the Cenozoic era, following the Tertiary period and comprising the Pleistocene and Holocene epochs. The entire Quaternary Period is referred to as an ice age due to the presence of at least one permanent ice sheet covered an Antarctica; however, the Pleistocene Epoch was generally much drier and colder than the present time. This situation has clearly identified from different locations of the world by many scientists (Chappell *et al*. 1996; Chappell, 2004; Emiliani, 1955; Evens, 1972; Hansen *et al*., 2013; Holmes 1966; Lambeck, 2001; Lambeck *et al*., 2002; Loutre, 2003; Miller, 2009; Wunsch, 2004).

Milankovitch hypotheses provides periodic variations in the earth's position relative to the sun as the earth orbits, affecting the distribution of the solar radiation reaching the earth and causing climatic changes that have profound impacts on the abundance and distribution of organisms, best seen in the fossil record of the Quaternary Period (the last 1.6 million years). The hypotheses included: (1) Northern hemisphere high latitude solar insolation controls climate change form of the original hypothesis); (2) Obliquity and precessional band energy is discernible in spectra of climate proxies; (3) Obliquity and precessional band energy dominate climate variability between about 18,000 yr and 42,000 yr periods; and (4) Obliquity and/or processional band energy, irrespective of control, or ‘‘pace’’ the 100,000 yr interval characteristic of the glacial–interglacial shifts of the Pleistocene (Wunch, 2004). Accordingly, it is possible to infer that the last few million years have been punctuated by many abrupt climate transitions, many of them occurring on time scales of centuries or even decades.

Sea level change during the Quaternary is primarily a consequence of the cyclic growth and decay of ice sheets, resulting in a complex spatial and temporal pattern (Lambeck and Chappell, 2001). Observations of glacially induced sea level changes also provide information on the response of the mantle to surface loading on time scales of l03 to l05years. Regional analyses indicate that the earth-response function is depth dependent as well as spatially variable. Comprehensive models of sea level change enable the migration of coastlines to be predicted during glacial cycles, including the anthropologically important period from about 60,000 to 20,000years ago (Fig. 2 and Fig 3). Based on this information, it is possible to conjoin 150 - 180m bathymetry lines of the present continental shelf (First Planated Surface) with LGM sea level, 20,000 years ago.

In order to gain a better understanding of our current climate system, we need to comprehend the causes of past climate transitions and cycles. In Sri Lanka, eustacy, uplift and solar variations have influenced the Pleistocene overwhelmingly (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 (Table 1). 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 1).

Further, `Balangoda Stage' has been correlated with the Late Würm, and 'Colombo Stage' is proposed tentatively for present climate (Katupotha, 1993 and 1995). Evidence for changes of relative land and sea levels are found in many places around the coast of Sri Lanka. 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 thermo-luminescence) and the Pathirajawela deposits dated at 28,440 and 64,380 - 74,200 yr B.P attests for Late Pleistocene atlithermal episodes in Sri Lanka.

Deraniyagala (1986) considers that the Basal Gravels of Sri Lanka 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 Würm). The basal gravel at Pathirajawela has been overlain by windblown 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

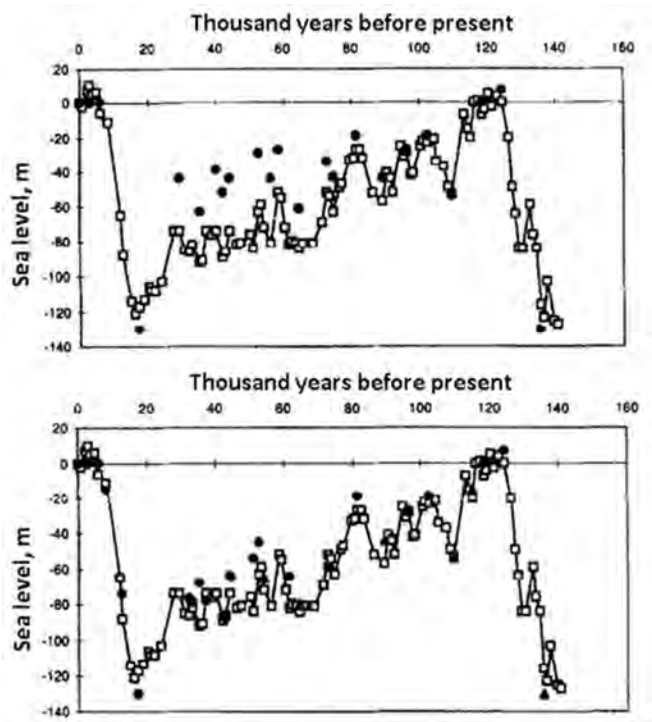

FIGURE 2: Upper: Previous estimates of sea levels for the last 140 ka. 0 = sea levels deduced from coral terraces at Huon Peninsula; 0 = estimates based on combined benthic and planktic deep sea core 6'*0 data. Lower: 0 = new results between 30 and 75 ka (Chappell *at el*., 1996).

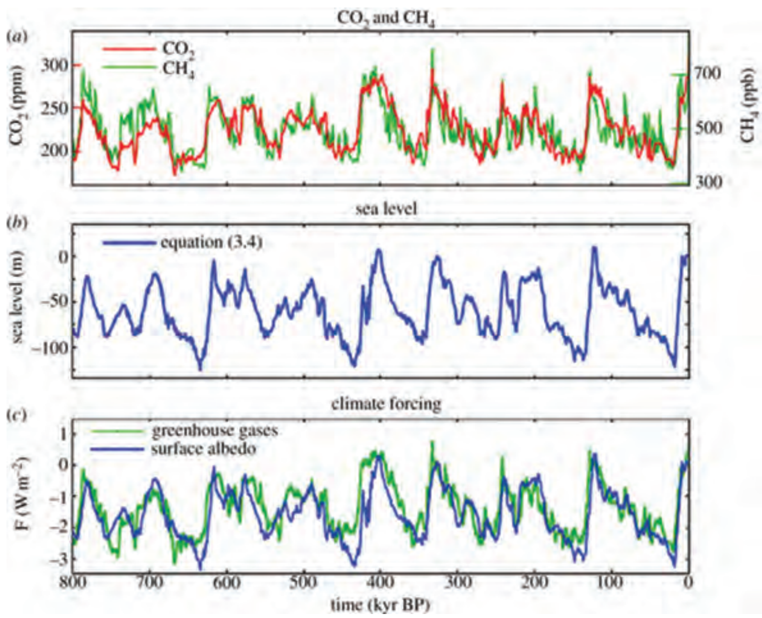

FIGURE 2: (a) CO2 and CH4 from ice cores; (b) sea level from equation and (c) resulting climate forcing (Hansen, *et al*., 2013).

Early Würm. Further, these data can be used to speculate on the rate of tectonic uplift for the southern Indian and Sri Lankan region. The continental shelf of Sri Lanka, remains of channels of some larger rivers, and sunken forests can be identified cordingly (Deraniyagala 1958). 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 the coastal lowlands of Sri Lanka Katupotha, 1994; 1995). A desert like condition occurred in much of the low country and low hills and ridges were coated mainly by windblown 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 BP (Spath, 1985), and this period probably corresponds to a dry climatic phase and lower sea-level. Following this feature such as low-lying ridges, well-marked troughs and terraces have been formed on the drowned Planated Surface (Katupotha 2013). Recent oceanographic investigations reveal that the coralline algae, limestone and calcareous sandstone have been developed gradually with those features. 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 BP. This transgression has caused 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 kilometers beyond the present shore around Sri Lanka.

However, here are no reliable age data sets in order to study the Quaternary events in Sri Lanka, except Deraniyagala (1986), Katupotha (1988a, 1988b and 2015; Ratnayake *et al*. (2017), Spath (1985) and few others. These gaps clearly obvious in 'Older Group', Ratnapura deposits as well as 'Younger Group' formations. The entire Quaternary Period in Sri Lanka, including Plio-Quaternary to the present, is necessary to study emphasizing sea levels and climatic cycles to fulfill the gap between previous work and future prospects. The scientists, who is undertaking on Quaternary studies emphasizing different disciplines, continue with limited facilities and funding. For this purpose Universities, Government Departments and related institutions (Archaeology, Geology ect.) and palaeonotologiast, sedimentologists, geographers, zoologists and botanists need to work with mutual understanding and a common goal. Also, policy makers need to offer funding support for form Quaternary Research Laboratories and age determination facilities in Sri Lanka, which are the main obstacle for fulfill on Quaternary scientists of Sri Lanka.

CONCLUSION

Although, the Quaternary studies of Sri Lanka emerged since 1908, the research work and findings are concentrated into two groups: Older and Younger Groups. The geologic formation related to the above two groups is basal ferruginous gravel, red beds and terrace gravel (as Older Group formations) and alluvium, lagoonal and estuarine beds, unconsolidated sands of beaches and dunes, inland buried and emerged fossil corals and beachrock (as Younger Group formations). It is obvious that cannibalistic Balangoda Man, the extinct animals, Palaeolithic stone tools and Ratnapura Gem Gravel deposits were not included the above two groups. Stratigraphic sequences, constituent material, locations and some age determinations as well as comparative studies of these formations have been completed by individual basis. However, it is required quantities research on 'Quaternary Climate, palaeoanthropology, faunal and floral fossils, extinct animals, extinct types of vegetation, etc. to fulfill the gap between previous work, and future prospects. For this purpose, it is required to organize National/International level conferences with invitations of recognized organizations such as IGCPs, INQUA etc.

The scientists, who are undertaking on Quaternary studies emphasizing different disciplines, continue with limited facilities and funding. For this purpose Universities, Government Departments and related institutions (Archaeology, Geology, etc.) and palaeonotologist, sementologists, geographers, zoologists and botanists need to work with mutual understanding and common goal. Also, policy makers need to offer funding support to establish Quaternary Research Laboratories and age determination facilities in Sri Lanka, which are the main obstacle for the Quaternary scientists of Sri Lanka.

ACKNOWLEDGEMENTS

My grateful thanks go to Ms. D.D.D. Weragodatenna, NARA, Colombo 15 and to Ms. Navoda Gunarathna (Record Indexing Officer - J. R. Jayewardene Centre Museum, Colombo 7) for the help rendered in the completion of this paper.

REFERENCES

Chappell John (2004). Sea Level. In. *Encyclopedia of Geomorphology. International Association of Geomorphologists*, First published 2004 by Routledge 917-925.

Chappell John, Omura Akio, Esat Tezer et al. (1996). Reconciliation of late Quaternary sea levels derived from coral terraces at Huon Peninsula with deep sea oxygen isotope records. *Earth and Planetary Science Letters* 141 (1996) 227-236

Coates JS. (1935). The Geology of Ceylon. *Spolia Ceylanica* **19 (2):** 101-187.

Cooray PG. (1963). The Erunwala Gravel and the probable significance of its ferricrete cap. *The Ceylon Geographer* **17:** 39-48.

Cooray PG. (1967). An Introduction to the Geology of Sri Lanka. *Ceylon National Museum Publication*, Colombo: 184-176.

Cooray PG. (1968a). A note in the occurrence of beachrock along the west coast of Ceylon. *Journal of Sedimentary Petrology*, **38:** 650- 654.

Cooray PG. (1968b. The geomorphology of the part of the northwestern coastal plain of Ceylon. *Zeitschrift fur Geomorphologie, NF Supplement* **7:** 95-113.

Cooray PG. (1984). An Introduction to the Geology of Sri Lanka. 2nd Revised Edition. *Ceylon National Museum Publication*, Colombo : 140-142.

Cooray P.G and Katupotha, J. (1991). Geological evolution of the coastal zone of Sri Lanka. *Proc. Symposium on "Causes of Coastal Erosion in Sri Lanka*", CCD/GT7., Colombo, Sri Lanka, 9-11, Feb. 1991.

Chakraborty C and Ghosh S.K. (2008). Pattern of sedimentation during the Late Paleozoic, Gondwanaland Glaciations: An example from the Talchir Formation, Satpura Gondwana basin, central India. *Journal of Earth System Science*, August 2008, **117:** 499

Dahanayake K, Jayawardcna, S.K. (1979).

Study of red brown earth deposits of northwest of Sri Lanka. *Journal of Geological Society of India*, **20:** 433-440.

Deraniyagala P.E.P. (1938). Some fossil animals from Ceylon, Part II. *Journal of the Royal Asiatic Society* (Ceylon Branch) **34:** 231–239.

Deraniyagala P.E.P. (1947). Some fossil animals from Ceylon, Part V. *Journal of the Royal Asiatic Society (Ceylon Branch)* **37:** 221–230.

Deraniyagaia P.E.P. (1958). The Pleistocene of Ceylon. *Ceylon National Museum Publication*, Colombo.

Deraniyagala S.U. (1976). Tice geomorphology and pedology of three sedimentary formations containing a Mesolithic industry in the lowlands of the Dry Zone of Sri Lanka. South Asia Occasional Papers and Theses, South Asia Frog., Cornell University 11-27.

Deraniyagala S.U. (1986). Pleistocene coastal sediments in the Dry Zone of Sri Lanka: chronology, palaeo-environment and technology. Ancient Ceylon, *Journal of the Archaeological Survey Department of Sri Lanka* **6:** 50-62.

Dissanayake C.B. (1984). Geochemistry of the Muthurajawela peat deposit of Sri Lanka. *Fuel* **63:** 1494-1503.

Emilliani C. (1955). Pleistocene temperatures. *Journal of Geology* **63:** 538-575.

Emilliani C. (1978). The causes of the ice ages. *Earth and Planetary Sci. Let.* **37:** 349-352.

Evans P. (1972). The presence slat us of age determination in the Quaternary (with special reference to the period between 70,000 and 1,000,000 years ago), *24th IGC*, *1972*, **Section 12:** 16-21.

Fairbridge RW. (1968). Quaternary Period. In: *Encyclopedia of Geomorphology*, R.W. Fairbridge (eds.), Rein Hold Book Cor., New York; 912-931.

Hansen J.M, Sato G.R, Kharecha P. (2013). Climate sensitivity, sea level, and atmospheric carbon dioxide. *Phil. Trans. Roy. Soc. A*, **371**, 1-38.

Hartley C. (1913). The stone implements of Ceylon. *Spolia Zeylanica*, **9 (34):** 117-123.

Halms A. (1966). Principles of Physical Geology. *The ELBS Society and Thomas Neison*: 677.743.

Hölz S, Köhler H, Kröner A, Liew TC. (1991). Geochronology of the Sri Lankan basement. In: *The crystalline crust of Sri Lanka, Part 1: Summary of Research of the German-Sri Lanka consortium, Geological Survey Department of Sri Lanka, Professional Paper. Kroner*, A. (eds.), 1991: 237-257.

Hubbs LC, Bien SC. Suess E. (1962). La Jolla National Radiocarbon Measurement ll, *Radiocarbon* **4:** 204-238.

Katupotha J. (1988a). Hiroshima University radiocarbon dates 1, west and south coasts of Sri Lanka. *Radiocarbon* **30 (1):** 125-128.

Katupotha J. (1988b). Hiroshima University radiocarbon dates 2, west and south coasts of Sri Lanka. *Radiocarbon* **30 (3):** 341-346.

Katupotha J. (1988c). Evolution of the coastal landforms in the western part of Sri Lanka. *Geographical Sciences (Hiroshima Univ.)* **43 (1):** 18-37.

Katupotha J. (1989). Coastal landforms during the Holocene Epoch in Sri Lanka: are they comparable to those in Brazil and Venezuela, Ext. Abs. *International Symposium on Global changes in South America during the Quaternary,* Sao Paulo (Brazil), May 8-12, 1989, pp 188-191.

Katupotha J. (1990). Sea level variations: evidence from Sri Lanka and India. In: *Sea level variation and its impact on coastal environment*. G.V. Rajamanickam (eds.). Tamil University, Thanjavur; 53-79.

Katupotha J. (1992). New evidence of Holocene sea-level changes of Sri Lanka. *Journal of the Geological Society of Sri Lanka* **4:** 3944.

Katupotha J. (1993a). Evolution and geological significance of the Late Pleistocene shell beds on the southern coastal zone of Sri Lanka, NARESA *Final Report* (130 pages).

Katupotha J. (1993b). Local sea-level indicators for investigation of coastal evolution in Sri Lanka during the past 20,000 years. Ext. Abs. *International Symposium on "Quaternary Coastal Evolution Models, Processes and Local to Global Factors*, Oostdukerke, Bel¬gium, 15-18 September 1993: 78-82.

Katupotha J. (1995). Evolution and geological significance of Holocene emerged shell beds on the southern coastal zone of Sri Lanka. *Journal of Coastal Research* **11 (4):** 1042-1061.

Katupotha J. (2012). Palaeoenvironmental evidence in northwest Sri Lanka: Evidence from Mundal Lake and its environs. *National Conference on Palaeobiodiversity*: 98-109.

Katupotha J. (2013). Palaeoclimate change during Glacial Periods: Evidence from Sri Lanka. *Journal of Tropical Forestry and Environment* Vol. **3(01):** 42-54.

Katupotha J. (2015). A comparative study of sea level change in Maldives and Sri anka during the Holocene Period. *Journal of Geological Society of Sri Lanka* Vol. **17** (2015), 75-86, *J.W. Herath Felicitation Volume.*

Katupotha,J. Fernando M.P and Weerakoon D. (2000). Bibliography of the Quaternary of Sri Lanka. Professional Paper, No. 6 *Journal of the Geological Society of Sri Lanka*.

Katupotha J. and Fujiwara K. (1988). Holocene sea level change on the southwest and south coasts of Sri Lanka. Palaeogeography, *Palaeoclima-tology, Palaeoecology*, **68:** 198-203.

Katupotha J. and Wijayananda N.P. (1989). Chronology of inland shell deposits on the southern coast of Sri Lanka. *Quaternary Research* **32:** 222-228.

Katupotha J. and Starin, F. (2012). Old Raised Beaches and Dune Ridges: Evidence from Kiriyankalli to Mundal in Northwest Sri Lanka. *Punkalasa* 2012, Department of Archaeology, **ll:**1-16.

Kenneth A.R.K, Deraniyagala S. U (1989). Fossil remains of 28,000-year old hominids from Sri Lanka. *Current Anthropology* **30(3):** 394–399.

Kröner A, Cooray P.G, Vitanage P.W. (1991). Lithotectonic subdivision of the Precambrian basement in Sri Lanka The crystalline crust of Sri Lanka, Part 1, Summary of Research of the German-Sri Lankan Consortium. *Geological Survey Department of Sri Lanka, Prof. Paper* **5:** 5-21.

Kröner A, Williams I.S, Compston W, Baur N, Vitanage P.W, Perera L.R.K. (1987). Zircon ion microprobe dating of high-grade rocks in Sri Lanka. *Journal of Geology* **95:** 775-791.

Lambeck K, Chappell J. (2001). Sea Level Change through the Last Glacial Cycle. *Science* **292:** 679-686.

Lambeck K, Esat M. Tezer, Potter Emma-Kate (2002). Links between climate and sea levels for the past three million years. *Nature* **419:** 199-205.

Laurence H. (1993). The Coming (or Present) Ice Age- A long-term perspective on the current global warming fad. 21st Century 1993-1994: 23-35

Loutre M.F. (2003). Ice Ages (Milankovitch Theory) Universite´ catholique de Louvain, Louvainla-Neuve, Belgium 995-1003.

Miller, G.K. (2009). Sea level change, last 250 million years. In. Encyclopedia of Paleoclimatology and Ancient Environments, Gornitz, V. (Ed.), 2009, XXVIII, 879-887.

Martin A.P, Lea W.D, Rosenthal Y et al. (2002). Quaternary deep sea temperature histories derived from benthic foraminiferal Mg/Ca. *Earth and Planetary Science Letters* **198:** 193-209

Martı´nez-Bot M.A, Rohling J, Sexton P.F et al. (2015). Plio-Pleistocene climate sensitivity evaluated using high-resolution CO2 records. *Nature* **518:** 49-54.

Neef G, Veeh N.H (1961). A Holocene coral reef in southwestern Sri Lanka. *Ceylon Journal of Science (Bio. Sci.,)* **22 (1):** 116-119.

Parsons J. (1908). The modes of occurrence of quartz in Ceylon. *Spolia Zcylanica* **5(20):** 171-177.

Provan J, Bennett K.D (2008). Phylogeographic insights into cryptic glacial refugia. *Trends in Ecology and Evolution* **23(10):** 564-571.

Pole J. (1907). A few remarks on prehistoric stones in Ceylon. *Journal of the Royal Asiatic Society of Ceylon* **19 (58):** 272-281.

Ratnayake, A.S. (2016). Evolution of coastal landforms during the Holocene Epoch along the west and southeast coasts of Sri Lanka', *Interdisciplinary Environmental Review*, Vol. 17, No. 1, 60–69.

Ratnayake A. S., Sampei Y., Ratnayke N. P., Roser B. P. (2016). Middle to late Holocene environmental changes in the depositional system of the tropical brackish Bolgoda Lake, coastal southwest Sri Lanka. Palaeogeography, *Palaeoclimatology, Palaeoecology 465* October 2016 DOI: 10.1016/j.palaeo. 2016.10.024

Senaratne A, Dissanayake C.B. (1991). Palaeoenvironmental significance of some major and trace elements in a tropical back-barrier peat deposit, Sri Lanka. *Journal of the Geological Society of Sri Lanka* **3:** 51-58.

Sharma R.S. (2009). Cratons and Fold Belts of India, Lecture Notes in Earth Sciences 127, 41 C Springer-Verlag Berlin Heidelberg 2009: 41-115.

Silva E.I.L, Katupotha J, Amarasinghe O et al. (2013). Lagoons of Sri Lanka: From the Origins to the Present. International Water Management Institute (IWMI), Colombo, Sri Lanka. Doi: 10.5337/2013.215: 2013.

Singhvi A.K, Deraniyagala S.U, Sengupta D. (1986). Ther¬moluminescence dating of Quaternary red-sand beds,: a case study of coastal dunes in Sri Lanka. *Earth and Planetary* Sci. Letters **80:** 139-144.

Somerville B.T., 1908. The submerged plateau surrounding Ceylon. *Spolia Zeylanica* **5(18):**

Swan B. (1982). The Coastal Geomorphology of Sri Lanka: An introduc¬tory Survey. University of New England, Armidale, New South Wales

Wadia D.N (1941). The geology of Colombo and its environs. *Spolia Zeylanica* **23:** 10-18.

Wayland E.L. (1919). Outline of the stone age of Ceylon. *Spolia Zeylanica* **11:** 85-125.

Weerakkody U. (1992). The Holocene coasts of Sri Lanka. *The Geographical Journal* **158(3):** 300-306.

Wickremaratne W.S, Ranatunga N.G. Wijayananda N.P. (1988). Continental shelf sediments of western Sri Lanka. Proc., *44th Annual Sessions*. SLASS, Part 1, Colombo, P 135.

Yoshida M, Tani Y, Rajesh H.M, Santosh M. (2003). Diversity in the position of Sri Lanka within the Gondwanaland ensemble. *Journal of the Geological Society of Sri Lanka* **11:** 5-20.

Received Date : 08 December 2016
Accepted Date : 15 December 2016