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A COMPARATIVE STUDY OF SEA LEVEL CHANGE IN MALDIVES AND SRI LANKA DURING THE HOLOCENE PERIOD

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ABSTRACT

All the morphological features that comprise the continental shelf of the Maldives Islands and Sri Lanka share a geological history attributed the Quaternary period and reveal Pleistocene and Holocene sea level changes in both countries. The island chains of Maldives and on/near shore areas of the continental shelf of Sri Lanka are composed primarily of reef-derived carbonate sediments deposited during post-glacial and interglacial periods, in relation to sea level changes. However, research work carried out in Sri Lanka on sea level change is scanty compared to Maldives for an in-depth comparative study.

This paper attempts to examine the similarity of the Holocene sea level changes in the Maldives and Sri Lanka based on the review of relevant published research papers, Radiocarbon isotopic radiometric dates and changes to past sea level curves.

Key words: *Holocene high sea levels, Islands and island chains, Maldives, Sri Lanka*

INTRODUCTION

Sea level change is a naturally occurring process. Since the last glacial maximum at 18,000 yr BP, de-glaciation has taken place due to global warming and led to sea-level rise of >120m (Bird, 2010; Lambeck at el, 2002; Lange and Carter, 2014; Katupotha 1995). The post-glacial sea level rise caused the submergence of the continental shelf and sea level reached at least 2.0m or above present. As a consequence of these events, unconsolidated sandy beaches and dune deposits, beach rock, lagoon and estuarine clays with shell deposits, alluvium, buried and emerged coral reefs developed during the Holocene epoch (Younger Group of Cooray 1984; Cooray and Katupotha, 1991; Katupotha 1994, 2013a). By the Holocene (c. 10300 yr BP to Present), Sri Lanka remained with many of above physical features in contrast to the islands of Maldives which were low-lying and began to form only between 3000 and 5,500 yr BP (Kench et al, 2005).

The volcanic formations of the Laccadives and Maldives ridges, the Chagos Bank and much of the Mascarene Plateau were associated with about 2.2 km thickness of sedimentary rocks (Duncan, 1990; Duncan and Hargraves, 1990). These basement volcanics are capped with limestones extending up to 3,000m. These geological changes since Holocene epoch is very significant for the study of Holocene sea level fluctuations in the selected areas of the Maldives and Sri Lanka, which are considered to be in a tectonically stable region of the Indo-Australian Plate.

This paper attempts a comparative study on the of the Holocene sea level changes in the Maldives and Sri Lanka based on published research (Katupotha, 1988a, 1988b) and new ^{14}C isotopic radiometric dates (Table 1) as well as curves depicting changes to of Palaeogeography, Palaeoclimatology and Palaeoecology supported by evidence from other scientific studies dealing with Holocene sea level changes elsewhere.

ANALYTICAL FRAMEWORK

The chain of islands of the Maldivian archipelago is aligned north to south between 7° 06' N - 00° 45' S latitude and 72° 13'E - 73° 45'E longitude occupying the central portion of the 3,000 km-long Chagos-Laccadive submarine ridge, a major feature of the Indian Ocean basaltic seafloor. Further, the Maldives-Lakshadweep-Chagos Archipelago also comprises the most extensive coral reef and atoll community in the Indian Ocean and the largest atoll system in the world.

Sri Lanka is composed of sedimentary rocks of Miocene age along the northwestern and northern coastal stretch of the country. The rest of the Island is composed of rocks of Precambrian age and these geological and morphological features have given to the paleo-stragraphic stability of the present location between 5° 52'N - 9° 54'N latitude and 79° 40'E - 81° 54'E longitude in the Indian Ocean located to the southwest of the Bay of Bengal and southeast of the Arabian Sea. The above features indicate that the paleo configuration of Sri Lanka from bathymetry supported by terrestrial and marine sediments around the country were laid down on a submerged plananated surface (SPS) designated as a submerged peneplain by Somerville (1907) and Deraniyagala (1958)

During the Quaternary Period (from Lower Pleistocene to Late Holocene) show that the global change of sea level was uniform and reflected a change in the quantity and quality of water in the ocean, due to a change in the shape and capacity of the ocean basins, attributed to the differentially formed basements, like in Maldives and Sri Lanka which are identified as a suitable geographical area for study of sea level changes.

LITERATURE REVIEW

Numerous studies have been carried out in Sri Lanka on living coral morphology, physiographic sequences and management status, but sea level changes are not mentioned (De Silva, 1984, 1985; Rajasuriya et al, 1995, Ekaratne 1997; Öhman et al 1993; Rajasuriya 1991, 1994,Rajasuriya and White 1994,1995).

The Quaternary coastal deposits in Sri Lanka, both Pleistocene and the Holocene have been least consolidated. Following the final phase of movement , Sri Lanka's landmass gave rise to sea level fluctuations, resulting in development of submergence canyons; deposited Red Beds (only relicts of these exist now in patchy form) and sand dunes by aeolian processes; gravel deposits by fluvial processes; formation of laterite and, nodular ironstone during the Pleistocene (Coates 1935; Cooray 1963, 1984; Deraniyagala 1958; Katupotha 2013; Sommerville 1907; Swan 1983) and these formations are identified as the Older Group. Similarly, many scientists have undertaken studies on sea level changes emphasizing emerged shell beds, buried and emerged coral reefs and their constituents (Cooray 1984; Katupotha 1988a, 1988b, 1988c 1994, 1995; Rajapaksha et al, 2014; Weerakkody, 1988). Such formations are classified as the Younger Group.

Reef-island evolution, morphology and sea level changes in Maldives have been studied by scientists mostly from Europe, New Zealand and Australia (Anderson 1998; Duncan, 1990; Duncan and Hargraves, 1990; Mitchell, et al 1990; Kenth et al 2005, 2009; Mörner et al 2004, Mörner et al, 2007; Woodroffe, 2005, 2008).

The basaltic basement of Maldives is filled with sedimentary rocks about 2.2 km thick. (Duncan, 1990; Duncan and Hargraves, 1990). The total length of the island chain is 648 km north to south and 130 km east to west forming a double chain in the center, and comprises of 26 natural atolls and some 1190 islands (Naseer, 1997). Reef area statistics of the Maldives and total surface area apart from the major reef structures include atoll lagoons calculated by Naseer and Hatcher (2004). Accordingly, 16 Complex Atolls, 5 Oceanic Faros, 4 Oceanic platform reefs constitute a total of 227.45 km^2 reef island (land) areas. These physiographic units have several distinct morphological trends, increasing in lagoon depth and continuity of the atoll rim to the south, and also increasing in patch reef and faro occurrence to the north. Reef islands, occurring in a predominantly storm-free environment, are composed almost entirely of sand, rarely rising more than 3m above mean sea level (Woodroffe, 2008). The islands are composed primarily of reef-derived carbonate sediment that has deposited in the post-glacial and inter glacial periods by waves and currents. Extensive and largely intact reefs in pristine conditions in Maldives are perhaps the most complex reef systems in the world (Figure 1).

Several atolls have unusual ring-shaped reefs locally known as faros in the atoll lagoons each with own sandy lagoons and rim corals lining the rims. The atoll lagoons also have numerous knolls and patch reefs (Naseer, 1997). All of these features comprise the continental shelf of the Republic of Maldives and morphologically share the geological history related to breakup of Gondwanaland.

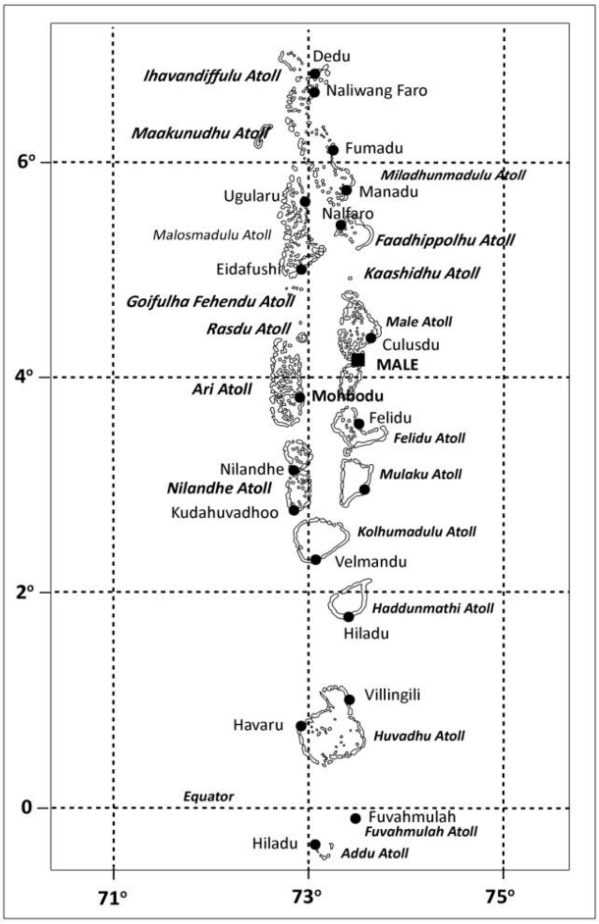

Fig. 1 Geographic distribution of the Natural Atolls of the Maldives (Source: Mörner, at el 2004: Kench at el, 2009; Woodroffe, 2008. Modified by Katupotha 2015)

The continental shelf in Sri Lanka represents a drowned extension of the coastal land area where land surface was exposed to sub aerial processes during the last glacial maximum and then modified by marine processes as sea level rise in response to deglaciation (Katupotha 1995; Swan, 1983).

The corals in the continental shelf of Sri Lanka have been categorized into four types according to the habitat. They are the true coral habitats consisting of (a) live corals, (b) calcareous substances, (c) sandstone and rocky habitats (De Silva, 1984, 1985; Rajasuriya and White, 1994, 1995; Rajasuriya et al, 1995) and about 2% of near shore fringing reefs. The distribution of corals in coastal waters of Sri Lanka is shown in Figure 2.

The growth of coral reefs around Sri Lanka was influenced mainly by the monsoons, which has a major impact on the level of turbidity and freshwater input into the coastal waters. As a result, extensive coral reef habitats are limited to areas with lower levels of sedimentation with semi-dry climates found in the northwestern and eastern coastal areas. Fringing coral reefs also occur around some of the islands around the Jaffna Peninsula and relate to the former sea level changes (Silva et al, 2013). Sandstone and rocky habitats are extensive and widespread (Swan, 1983). They can be found from near-shore areas to offshore areas, with depths are more than 50m.

The Maldives consists entirely of coral reefs, which are the most diverse of all marine ecosystems. Coral reefs are known to host many levels of biodiversity ranging from planktonic organisms to sharks. The dominant species on reefs are corals and fishes. Both these account for a large share of the diversity of coral reefs (Naseer, 1997). Naseer while emphasizing that corals are the major organisms that form the basic reef structure, there is also a bewildering array of other organisms associated with reefs. These are perhaps the most diverse species-rich areas that exist in the marine environment today. Members of practically all phyla and classes can be found on coral reefs. Over 1000 species of fish have so far been catalogued from the Maldives and nearly 300 of these were identified for the first time. Seven species were described as new to science and several more await identification. Further over 400 species have been identified and catalogued, and many are now held in the reference collection. Scleractinian corals of the Maldives have been relatively well studied and the total number of coral species recorded from the Maldives to date is about 200, representing over 60 genera (Naseer, 1997).

SEA LEVEL CHANGES IN MALDIVES AND SRI LANKA

The oscillations between glacial and interglacial climatic conditions over the past three million years were characterized by a transfer of immense amounts of water between two of its largest reservoirs on Earth: the ice sheets and the oceans (Lambeck et al, 2002). The last Glaciation of the Earth known as the Pleistocene Glaciation started around 2.58 Ma, when permanent ice sheets were established in the Northern Hemisphere (ICS, 2009). Fluctuating ice sheets were formed, covering thousands of square kilometers including areas of Antarctica, Greenland, most of Canada, a large portion of

Fig. 2 Distribution of coral reefs in Sri Lanka (Source: Rajasuriya, 1994; Rajasuriya and White 1994; Redrawn by Katupotha 2015).

the northern United States, Scandinavia and Eurasia between c.95000 and c.20000 yr BP. Thus, the Pleistocene ice coverage extended as far south as approximately 38 degrees latitude in the midcontinent and involved several major episodes of global climate changes. Since the latest of these oscillations, the Last Glacial Maximum (between about 30,000 and 19,000 yr BP), about 50 million cubic kilometers of ice has melted from the land-based ice sheets, raising global sea level by 130 meters (Lambeck et al, 2002). Such rapid glacioeustatic changes in sea level are part of a complex pattern of interactions between the atmosphere, oceans, ice sheets and solid earth, all of which have different time scales for response to melting of ice sheets.

Based on nano fossil datum levels, the sedimentation rates from Maldives basement were 56 m/m.y for the late Miocene and early Pliocene; 22-23 m/m.y for the late Pliocene; and 38/m.y for the Pleistocene. These rates were confirmed by Mitchell, et al (1990) using the Site 716 of the Deep Ocean Drilling Programme (ODP). The ODP reveals that the volcanic basement site has a continuous sequence (upper Miocene to Holocene) of peri platform oozes and chalks from the Maldives Ridge, Indian Ocean. Mitchell, et. al (1990) conclude that no chalks were found at Site 716 throughout the Pleistocene. Chalks only occur in Pliocene and older sediments, which were formed during burial diagenesis. Mineralogical and geochemical studies of these carbonate sediments indicate that submarine burial diagenesis has played an important role in the indurations of sediments at this site. The sequence and the concentration of sediments with $CaCO_3$, Mg, Sr and Na were detected analyzing 550 samples from the Site 716, collected from MBSF (meter below seafloor) and were very significant in the study of coral atolls. The present configuration and Holocene sea level changes in the Maldives where the present islands and island chains are composed of reef –derived carbonate sediments have been deposited during post-glacial and inter-glacial times mostly by waves and currents.

The sea level at several places indicates that much of the Maldives, Sri Lanka and other Indian Oceanic islands have existed at low stand during the Last Glacial Maximum (LGM). Mörner et al (2004), show that the atolls are not dominated by catch-up reef growth as previously believed in Maldives, but are largely of pre-Holocene age. They detected large karst areas, submarine caves and shore notches from islands existing prior to the LGM Quaternary time. The Maldives lie right in the centre of the Earth's deepest geodic depression of about -100 m. At the LGM, the geodic relief appears to have been even greater. Mörner et al (2004) have constructed new sea level curves for the last 5000 years for Maldives Islands (Figure 3).These curves represent the low-amplitude oscillations and include stages when sea level was well above the present level: ±1.0~1.2m at 3900 yr BP, ±0.1~0.2m at 2700 yr BP, ±0.4~0.5m at 1000–800 yr BP and ±0.3 m at about AD 1900–1970.

Mörner et al (2004) mentioned that the islands were inhabited by 1500–1300 yr BP. Also, the people survived with a higher sea level (some 40–50 cm) around 1000–800 yr BP. Radiocarbon dates of coral fragments from a core to the leeward of Malt and of surficial coral from the reef flat of several islands indicate that the reef had reached a level very close to present sea level around 3000 yr BP, and that the islands have accumulated in the last 3000 years (Woodroffe, 1993).

Mörner et al (2007) describes the sea level changes in Maldives based on a number of field visits. He explored the existence of multiple submarine shorelines (terraces, notches, under-cutting, etc.). Besides, he examined the nautical charts for prominent terrace/scarp levels. Based on these investigations, Mörner et al (2007) reported that there was a -150 m lowermost terrace (interpreted as the regression maximum of the LGM), a large cave at -80 m, an extensive terrace at -70 m with an undercutting at -64 m (interpreted as a possible Younger Dryas level) were noted. Identified caves and shore notches were at -27 to -38m with shore features in the order of -20m, and at a number of higher levels. Mörner et al (2007) explains, that "though we took numerous samples, our dating has not yet given any firm dating control of these submarine levels. A -2m (below sea level) *in situ* coral was dated at 5310 ±90 before present (BP; before 1950), and marks the beginning of our sea level curve here presented".

According to findings of Mörner et al (2004 and Mörner et al (2007), the existence of shore marks and caves implies that the main part of the islands is, in fact, of pre-LGM age. This was confirmed by a > 40000 radiocarbon date of a coral from the roof of a submarine cave. Anderson (1998) pointed out the existence of a LGM submarine shoreline. The caves we investigated were both of the shore-cave and karstic type. Even hollows and depressions on land seem to represent old karst weathering. This means that the Maldives during the LGM low level at about 20000 yr BP were restricted to a few large islands due to the lowering of sea levels.

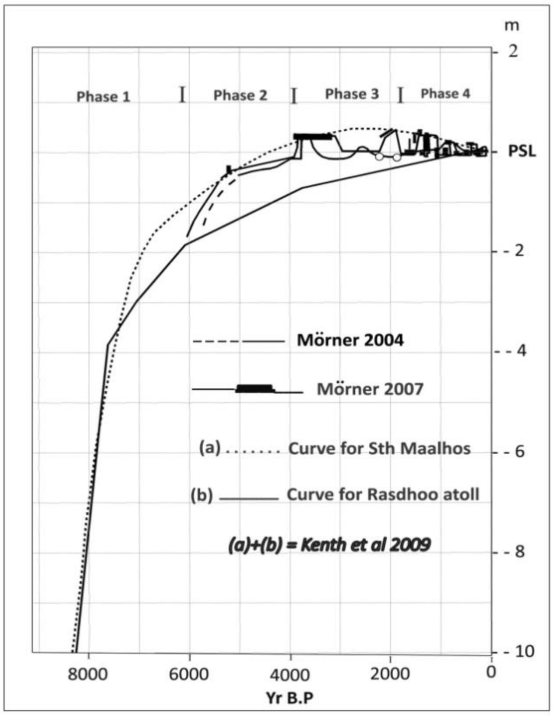

Fig. 3 Sea level curves for the last 6000 years (Morner et al, 2004; Mörner, 2007; Kench, et al 2009, Modified and redrawn by Katupotha 2015)

Those islands had flat inland surfaces and a coastal edge of high coral pinnacles. The inland floors were crossed by rivers and, most likely, overgrown by a dense tropical rain forest. Indeed, this is a remarkable biotope, promoting high biodiversity. From 5300 yr BP, there was better control of the sea level changes ascertained by morphological, stratigraphical and biological analyses augmented with extensive RADIOCARBON dating. Mörner et al (2007) recorded flat (pancake-like) *Porites* indicating that sea level had remained stable for some time, forcing the *Porites* specimens to grow laterally instead of vertically. The center and edge of an 180 cm circular disk at 0.8m below sea level were dated at 4110 and 4080 yr BP, respectively. Another disk at 0.25m (below sea level) was dated at 4025 yr BP. Subsequently, sea level reached well above the present, indicated by corals in a +1.2m flat, cemented beach (maybe a rock-cut platform) dated at 3970 yr BP and 3235 yr BP. A cemented coral rubble at 0.6m above the corresponding present deposits dated at 3820 yr BP was also observed due to high sea level with a warm and wet climate within 3200-2200 yr BP.

A higher sea level, above +0.5m and probably in the order of +1.0m, was recorded and dated as 2195 yr BP and 1965 yr BP. This event was followed by a low sea level. Archaeological finds of an ancient Buddhist civilization (the Redin) with the erection of remarkable temples and "hawittas" on several islands in the Maldives were noted during this episode of low sea level. Mörner et al also recorded construction pathways extending into the sea, and charcoal between the "stones" of the pathways were dated at 1610±40 yr BP. Pottery was also found on several islands. At the Institute of Archaeology in Uppsala, Sweden, a collection of artifacts was analyzed and found to have a likely age in the order of 1450 BP; coinciding with the period of the Buddhist settlement. Further Mörner et al stated that these dates fit well with subsequent archaeological investigations. Following the Buddhist period, the sea level rose again (Mörner et al, 2007). On the islands of Isdhoo and Gan in the Laamoo Atoll, the pathway "stones" are, at both sites, covered by coral beach gravels.

A gastropod from the upper beach was dated at 1420 BP at Gan (Addu Atoll). At Isdhoo, however, two samples indicated 1725 yr BP and 1760 BP which are in contradiction to the charcoal date just below (redeposit ion or a larger "sea correction" may be the explanation by Mörner et al). An extreme storm or a tsunami might well have been responsible for the beach material at those sites. On the island of Viligili (just west of Male), a lower level of corals *in situ* peaks at +0.6m and is dated at 1500 yr BP. The corals identified in this bed need a minimum depth of about 0.6m, implying that sea level must have been at +1.2m. This bed is covered by an erosional colluvial material from a period of sea level lowering with the formation of an extensive beach rock at about +0 m. At the surface, there are traces of a weak soil formation. Subsequently, sea level rose again and there is a second generation of corals *in situ* reaching between +0.5 and –0.6m and of a biological habitat corresponding to a sea level of about +1.2 m. A good coral in growing position was dated at 1285 (central bottom part) and 1235 (upper edge). Therefore, Mörner (2007) reported that there had been a high sea level around 1500–1400 yr BP, a low sea level around 1400–1300 yr BP, and a new high sea level around 1300–1200 yr BP. The high level seems to have lasted, at least, up to 1100 yr BP judging from a date from the crest of a +2 m beach ridge on Hithadhoo in the Addu Atoll.

By 1050 yr BP, the sea level may have fallen to just below the present as indicated by a date of 1055 yr BP of an operculum cemented in a beach rock on Hithadhoo (Addu) and a date of 1045 of a gastropod in a deep soil on a small island in the south of the Baa Atoll.

A shore deposit (in a core) at 0.3m was dated at 890 yr BP (AD 1060). Finally, at Lhosfushi in the South Male Atoll, the excellent site of the so-called "Reef Woman" namely a female skeleton resting on a sandy shore deposit and covered by coral debris of a rising sea level with a fossil show at +0.4–0.7 m was discovered. (Mörner et al, 2007). The "Reef Woman" was dated at 875 yr BP (AD 1075). This low sea level seems to have lasted for about 200 years (~1050– 850 BP). Again, sea level seems to have risen rapidly to a level in the order of between +0.4 and +0.7 m evidenced from the a clear stratigraphic sequence at the site of the "Reef Woman." On Viligili Island, a beach ridge 0.8 cm above was dated at 835 yr BP (AD 1115) and 795 BP (AD 1155), providing a second record of a high sea level in the order of +0.7 m.

Mörner et al (2007) also reports that a new low sea level period is indicated by the onset of gyttja deposition at 660 BP (AD 1290) in Lake EigigaliKili on Hithadhoo (Addu) and a human male skull in a deep soil on Kudadhoo (Baa) dated at 640 yr BP (AD 1310). Similarly, a thick beach rock on Isdhoo dated at 450 yr BP (AD 1500).

At Gan, there is a fossil beach ridge at a level some 0.5~0.6 m above the present sea level. Shells in the sediments prior to the formation of the beach ridge were dated at 415 and 340 BP (AD 1545 and 1610). Corals in a sand layer in a submarine cave at 20m, below sea level, were also dated at 400 BP (AD 1550) and might perhaps represent a tsunami event.

Gastropods and fine corals in a sand layer from a 27m (below sea level) submarine cave in Addu were dated at 230 and 205 BP, respectively (AD 1720 and 1745). The spreading of sand at such depths below the actual sea level might always be taken as a possible trace of a paleo-tsunami. In this case, it is supported by evidence of a major destructive flooding in 1733.

A low sea level is indicated from about 200 to 160 BP (AD 1750–1790) by buried peat layers in two fens on opposite sides of the Island of Goidhoo. An intra-peat sand layer dated at 190 BP (AD 1760) is likely to represent a true tsunami event (further below). At 160 BP or AD 1790, the peat is covered by lacustrine "gyttja", which signifies a rise in ground water level linked to a rise in sea level. Both lakes seem to have dried up relatively recently, most probably due to the drop in sea level in the 1970s. There is evidence of a sub-recent sea level some 20 cm higher than the present one in most of the islands in the Maldives (Mörner et al, 2004). In the 1970s, sea level fell to its present position (Figure 3).

The above curve is characterized by a number of oscillations in the order of 0.5 to 1.5 m indicating several levels well above the present one. The new sea level curve of the Maldives expresses the sea level changes in this region (Lat. 7^{o}N–1^{o}S; Long. ~73^{o}E) as a combined effect of all forces involved (Mörner et al, 2007).

A new model of reef-island evolution, based on detailed morpho stratigraphic analysis and radiometric dating of three islands in South Maalhosmadulu Atoll, Maldives, is presented by Kench et al (2005). Islands were initially formed on a foundation of lagoon sediments between 5500 and 4500 yr BP when the reef surface was as much as 2.5 m below modern sea level. Islands accumulated rapidly during the following 1500 years, effectively reaching their current dimensions by 4000 yr BP Since then the high circum-island peripheral ridge has been subjected to seasonal and longer-term shoreline changes, while the outer reef has grown upward, reducing the energy window and confining the islands (Kench et al, 2005, 2009).

This new model has far-reaching implications for island's stability during a period of global warming and raised sea level, which will partially reactivate the energy window although it is not expected to inhibit upward reef growth or compromise stability of the Islands.

The Holocene reef chronostratigraphy from South Maalhosmadulu has divided into four distinct phases by Kench et al (2009, Figure 3). Accordingly, Phase 1 is characterized by a steady sea level rise, flooding during the last interglacial surface ca. 8100–6500 cal yr BP (~7 mm/yr). After ca. 6500 cal yr BP, the rate of sea-level rise slowed to <1 mm/yr (phase 2), with sea level first reaching its present level ca. 4500 car BP During phase 3, sea level continued to rise to at least 0.5 ± 0.1 m above present until ca. 2100 cal yr BP, after which it fell to its current position (phase 4), and can compare with phases of Mörner et al 2004 and 2007 curves (Figure 3).

Above results will help to clarify the pattern of Holocene sea-level change in the Maldives. Accordingly, the elevated micro atolls on South Maalhosmadulu provide evidence of a late Holocene sea-level high stand of +0.50 ± 0.1 m ~2000–4000 yr ago and confirm that emergent reef build-up are not missing from the central Indian Ocean. Experimental results from Kench et al (2009) also improve the understanding of the regional similarities and differences in sea level in the Indian Ocean during the Holocene. The Hulhudhoo curve shows broad agreement with the rapid rise in sea level and reef growth during the period 8000–6500 yr B.P in both the eastern and western Indian Ocean. However, this rise ended later in the Maldives than in the western Indian Ocean occurring at ca. 6500–5500 cal yr BP rather than 7500–7000 yr BP In both cases, the rate of sea-level rise, then slowed to ~1 mm/yr.

The micro atoll evidence of a higher sea level 2000–4000 yr BP was identified in the Maldives. It is significant that the discrepancy between our results and those from the western Indian Ocean sheds new light on the reconstruction of regional sea level changes. Kench et al (2009) emphasized that their results also have important implications for the future formation of coral reef islands. As suggested by Woodroffe et al (2005), confirmation of a sea level high stand allows critical reevaluation of the relationship between sea level, reef growth, and island formation. In the Maldives, islands were formed 5500–4500 yr ago (Kench et al., 2005) and persisted as sea level rose to 0.5 ± 0.1 m above present during the high stand ca. 2000–4000 cal yr BP. Consequently, the Maldives provides the geological analogy that demonstrates the reef islands, which are capable of accommodating rising sea level comparable to project into the next century.

SEA LEVEL FLUCTUATIONS IN SRI LANKA

Rapid sea level rise from LGM and Holocene sea level fluctuations in the Maldives have a good co-relation with sea level fluctuations in Sri Lanka. This depth of sea level (20-30m to 180m) of the slope of the present continental shelf (CS) around Sri Lanka, can be correlated with the 100-fathom line (180m approx.) margin of the submerged plateau (submerged Planated Surface by Katupotha, 2013a, 2013b) also described by Somerville (1907) and Deraniyagala (1958) and may be a result of melting of palaeo-ice sheets during climatic cycles especially from 42000 yr BP towards the Post Glacial Transgression (PTG). The continental shelf consists predominately of particles, 2 mm to 0.067 mm in diameter, composed of lithogenic quartz and biogenic carbonates. Most shelf sediments had been deposited in shallow water during the last low stand of sea level than at present, but with the rising sea level up to Early Holocene.

All dead corals (reefs and patches) and living corals (reefs and patches) in Sri Lanka have thrived on the submerged planated surface and

Table 1 New Radiocarbon dating of shell samples collected from Southern Coast, Sri Lanka

No.	Sampled area	Elev.	Age (yr BP)	USS No.
1	Miniethiliya 1 (HG)	+1.4 ~ +1.5	3750± 40	ST14228
2	Hatagala 5-1 (HG)	+1.1	4200± 35	ST14229
3	Hatagala 5-2 (HG)	+0.2	4175± 40	ST14230
4	Hunukotumulla 12	+4.45	6080± 60	ST14232
5	Arabokka 14 (KM)	+1.6	5460± 60	ST14233
6	Bundala 18	+8.7	3760± 45	ST14234
7	Bataata 8-2	-0.3	3530± 70	ST14231

HG = Hungama, KM = Kalametiya, STI = Department of Quaternary Research, University of Stockholm, Sweden.

inland due to the PTG and Holocene high sea levels (Figure 4). Such levels can be correlated with submerged reef levels of Maldives

described by Anderson (1998) and Mörner et al (2007).

The coral islands in Palk Bay, around Mannar Island and the submerged coral islands of Rawana's Bridge have also been developed on calcareous sandstone, Miocene limestone as well as unconsolidated sandy patches. Similarly, coral reefs (barrier-type reefs) and patches from Chilaw to Mullativu (anticlockwise) have developed on sandstone reefs and different types of granitic-gneissic rocks of Highland, Wanni and Vijayan Complexes. Evidently, sea level rise and submergence of first planated surface in Sri Lanka is related to Mid Holocene and Late Holocene epochs. These fluctuations have been summarized by Katupotha (1994, 1995), who recognizes five stages (phases) in the Late (Upper) Pleistocene and Holocene events based on 49 ^{14}C radiometric dating (Katupotha, 1988a

1988b). To compare sea level changes in Sri Lanka and Maldives, a new set of ^{14}C radiometric dates (Table 1) were used as seen in the Figures 4, 5 and 6.

All these events evidently relate to the origin, formation and evolution of coral islands, reefs and coral patches as well as shell deposits in Sri Lanka. These five stages can be summarized as follows:

(a) **Stage 1: From Late Pleistocene to Early Holocene.** Sea-level and ecological changes as well as cultural phases between the Late Pleistocene and Early Holocene Epochs in Sri Lanka have been followed by the dry climatic conditions. By the end of this stage (phase), the sea level was -10m to -20m below the present level (Figure 4) and the submerged reefs, islands are related to this phase. The levels of this stage can be clearly correlated with the Anderson's (1998) and Mörner et al, (2007) observations for Maldives.

(b) Stage 2: Mid Holocene Period (first episode of high sea-level; 6,240-5,130 years BP). Radiocarbon dates (Carbon-14) of emerged coral samples from the west, south and east coasts by Katupotha (1988a, 1988b), Katupotha and Wijayananda (1989) indicate that the mid-Holocene sea level was at least 3-5m high than that of the present sea level in Sri Lanka (Figure 5). This sea level variation during this period can be correlated with Maldives, India and other islands in the Indian Ocean (Katupotha, 1990). Although, the Maldives high sea levels did not exceed the Sri Lanka's high sea level, these changes occurred during the

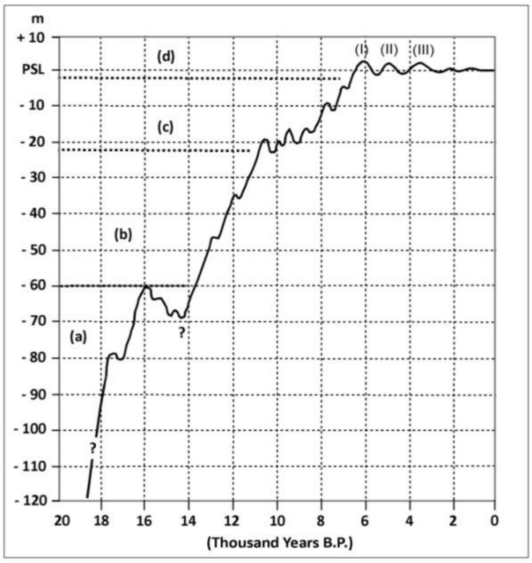

Fig. 4 Sea-level oscillations in Sri Lanka since Last Glacial Maximum (Katupotha 1995; Redrawn by Katupotha (2015) using new 7 RADIOCARBON ages (Table 1)

same period (Mörner et al, 2004, 2007; Kench et al, 2009).

(c) **Stage 3: First Phase of the Late Holocene (4,390 - 3,930 years BP, second episode of high sea-level)**. Between the Stage 2 and Stage 3, the sea-level around 4,700 years BP was slightly above the present Mean Sea Level (MSL). This episode of high sea level compares with the Holocene high sea levels of Maldives.

(d) **Stage 4: Second Phase of the Late-Holocene (3,280 - 2,270 years BP, third episode of high sea-level).** Between Stages 3 and 4, the sea-level around 3,600 years BP was also at or below the present MSL (Figure 5). It is suggested that the beach rock, slightly above supra-tidal level zone along the coast were formed during this stage. This level also largely coincides with the sea level curves of Figure 3.

(e) **Stage 5: Development of Recent Beaches and Sand Spits, etc.** Bryant (1987) explains that there has been a relationship between CO_2 warming, rising sea-level and retreat of coasts in both northern and southern hemispheres since AD 1850. Footbridge's (1961) studies also indicate the rise of sea-level and glacial retreat since 100 years BP. Many archaeological sites, monuments, Forts, monasteries and other physical features along the coast of Sri Lanka are

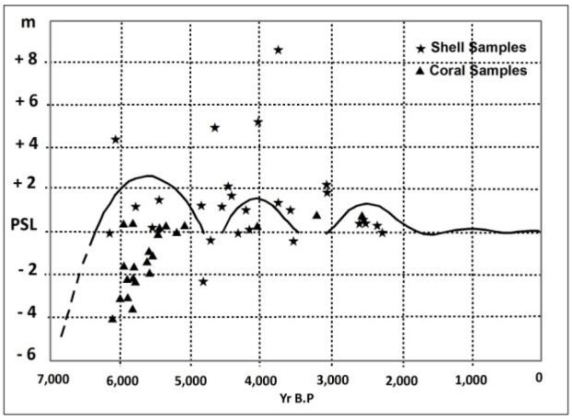

Fig. 5 Mid and Late Holocene high sea-level episodes in Sri Lanka, Katupotha 1988c, 1994 & 1995: The curve modified using new ages (Table 1)

in conformity with the Mörner's (2004, 2007) and Kenth et al (2005, 2007) research findings.

Dated coral samples from emerged reef patches at Hikkaduwa, Dadalla, Aranwala, Koggala, Denuwala, and Pallikkudawa could be positively compared with the age groups of Mid-Holocene (Atlantic) and Late Holocene (Sub boreal and Subatlantic) statigraphic time scales from other parts of the world. Dated sequences of buried corals reveal that the growth of corals was continued in inland bays or lagoons (to the east of Dondra Head) during Mid Holocene transgression of the sea (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:

(1) The bulk of valves piled up by severe palaeo wave actions on rims of coastal embayments following coastal progradation since Late Holocene (Late Sub boreal). It is possible to infer that such waves could be generated either by tsunamis as well as storm surges and cyclones etc. tsunami waves had been hit the southern coast of Sri Lanka around 2200 yr B.P, 3810-3750 yr B.P, 4215-4175 yr B.P and around 6100 yr B.P;

(2) Shells accumulated in lagoon floors of marine or brackish pools, and deposited *in Situ* since Late Sub boreal (around 5,000 to 2,500 Yr B.P). Similar fluctuation of sea levels has been reported by Mörner et al (2004, 2007).

(3) Shells located on coastal hills and dunes used by early inhabitants (Katupotha, 1988b). Comparatively, there was not such record from Maldives pointing to the lack of human habitations during the above period.

Emerged Holocene shell beds along the southern coastal zone, between Kalametiya lagoon and Bundala Lewaya have been found together with stone artifacts, pieces of pottery, human bones and other animal bones. Similar finds were reported from Maldives, but the chronology was not compatible..

Correct interpretation of sea-level indicators and their relationship to present day mean sea level and with the quality and reliability of age determinations will pose problems to researchers as a consistent methodology throughout the Indo-Pacific for the analysis of sea level data is lacking.

However, despite the Indo- Pacific region being a large geographical region, the nature of Holocene sea-level change is broadly similar in all locations examined in this paper.

Differences do exist in the timing and magnitude of the Mid-Holocene High Stand (MHHS) and the nature of late Holocene sea-level fall across the region, especially Maldives and Sri Lanka (Mörner et al 2004 2007; Kench et al, 2005, 2009, Katupotha 1988c, 1995, 2013b).

As mentioned above, there is no MHHS of sea level identified from the Maldives in contrast to its existence in Sri Lanka. Besides, Holocene sea-level fluctuations inferred from sea-level index points by Woodroffe and Benjamin (2005) from the southern Langebaan Lagoon salt marsh (South Africa) also correspond with high stand of sea levels of Sri Lanka.

The East Indian coastline, Bangladesh and Sri Lanka indicate two mid and late Holocene high stands. The first peaking at 3m above current mean sea-level at 7300 cal yrs BP, followed by a c. 2 m RSL fall, and a second pulse of minor RSL rise culminating at +3 m between 4300 and 2500 cal yrs BP (Woodroffe and Benjamin 2005). However, Late Holocene sea level fluctuations in Maldives and Sri Lanka are compatible with minor discrepancies (Figure 6). Although, Kench et al (2005, 2009), Mörner et al (2004 and 2007) describe in detail the sea level fluctuations from 4000 yr BP to present time, up to AD 1900 -1970, the lack of reliable and critical age determinations so far in Sri Lanka is a setback for such comparative studies.

To identify sea level fluctuations with time intervals are very important for future predictions of cycles of sea level fluctuations. To this end, reliable geologic material is needed

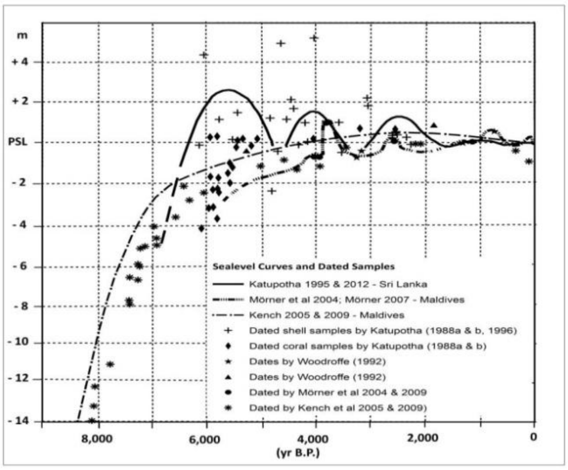

Fig.6 Holocene sea level fluctuations indicate that some similarities can be identified from the curves depicted by Katupotha (1994 & 1995), Kench (2005 &2009) and Mörner et al (2004) and Mörner 2007; Redawan by Katupotha, 2016)).

to be collected with accurate leveling measurements to mean sea level (MSL) measurements of locations for radiometric dating. Without such detailed studies, we cannot predict future sea level changes as mentioned by Mörner et al (2007), Woodroffe (2008) and others.

SUMMARY

Although, Maldives and Sri Lanka are located close to each other within the tropics close to the equator, these two countries have a different geological evolutionary history and basement rocks as well as the processes of accumulation and of recent sediments and formation of sedimentary rocks. Except for the Miocene limestone in northwestern and northern coastal zones, sediments and sedimentary rocks on the relatively narrow continental shelf in Sri Lanka are not so thick as compared to those in the shelf areas of Maldives. However, these formations were significant to understand the variation of the palaeoclimate and sea level changes of the two countries.

Since the Last Glacial Maximum , about 50 million cubic kilometers of ice melted from the land-based ice sheets, raising global sea level by 130 meters from the present level. These changes in sea level over a period from 19000 yr B.P to present, resulted in formation of palaeo reefs, coral islands, canes, platforms, and old river courses were submerged from time to time. Research studies have revealed that the mid-Holocene sea level fluctuated 3 or 4m from the present mean sea level in many Indian and Pacific Oceanic Islands and littoral states. Such changes in sea level were also recorded in Sri Lanka, but comparatively in Maldives, the rise in sea level did not exceed 1.0m from the present sea level which was not significant.

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