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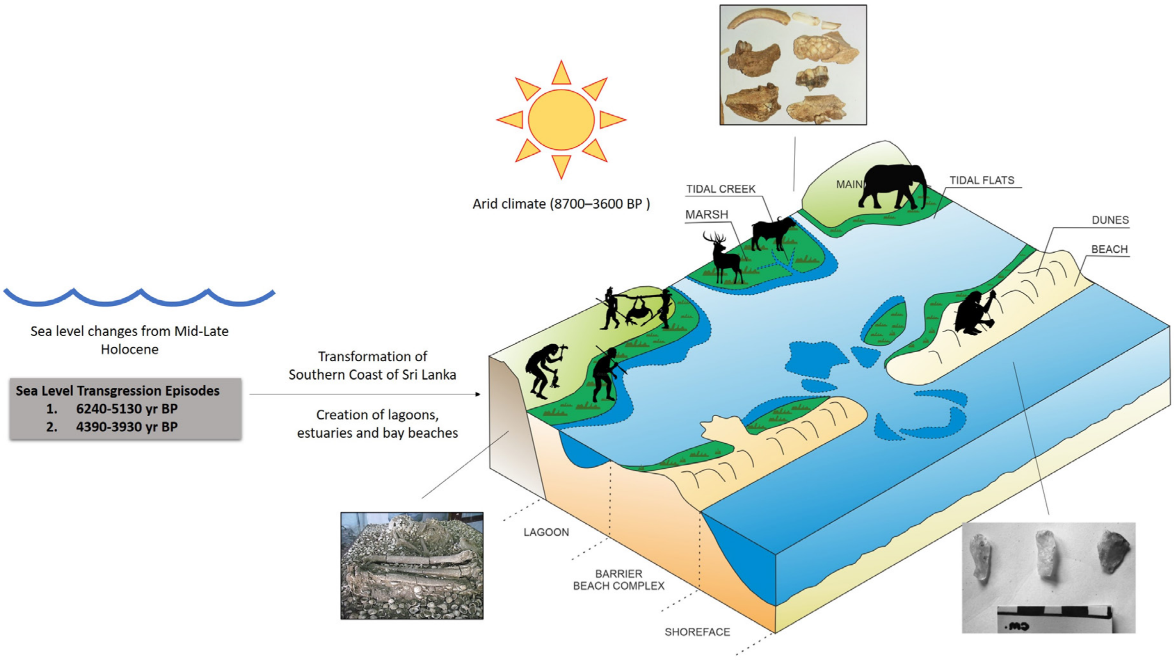

Highlights

- The human-environment interactions during the Holocene were investigated.
- The prevailed environmental conditions at coastal prehistoric sites were interpreted.
- The study area experienced lagoonal, river floodplains and storm conditions.
- Prehistoric people preferred fluvial-marine interfaces.
- They were well adapted to environmental conditions.

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Mid-to-late Holocene environmental changes along the southern coast of Sri Lanka and their impact on sediment dynamics and human behaviour

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Abstract : Understanding the past human adaptations to the environmental changes along the southern coastal area of Sri Lanka caused by sea-level fluctuations during the Holocene period has not yet been clearly understood. The present study aims to interpret the interactions between humans and the environment during the Holocene. Sequential soil samples were obtained from test pits and exposed profiles at five selected prehistoric human occupation sites located in the southern coastal area. The stratigraphy, which was determined based on field investigations and, the grain size distribution and textural parameters of soil samples were employed to establish the depositional environments of the study sites. The stratigraphy and, textural characteristics of sediments at Pallemalala, Mini-Athiliya and Kalametiya revealed that marginal lagoonal and fluvial environmental conditions have prevailed as a result of Mid-Holocene sea-level fluctuations. Conversely, the stratigraphy and sediments at Bundala indicate the influence of storm waves. In addition, Henagahapugala assumed to be occupied by prehistoric populations, seems to be a river channel and reveals comparatively less evidence of human occupation. This evidence indicates that the marginal fluvial/ marine environments were preferred by prehistoric people due to the accessibility and availability of a variety of highly nutritious dietary resources, freshwater sources and source materials for stone implements. Therefore, it is possible to conclude that the marginal environments created by Mid-Holocene sea-level fluctuations resulted in technological and cultural transformations of prehistoric people in Sri Lanka.

Keywords: Holocene; Sea-level changes; Marginal environments; Prehistory of Sri Lanka

INTRODUCTION

The coastal areas around the world changed dramatically following the end of the Pleistocene, resulting in global sea-level rise and flooding of the late Pleistocene littoral plains (Smith *et al*., 2011; Jakobsson *et al*., 2017; Brisset *et al*., 2018; Wang *et al*., 2018). The sea-level rise has been translated into the loss of human settlement areas (Nunn, 2007), reduction of hunting territories (Williams *et al.*, 2018), and modification of coastal ecosystems (Melis *et al.*, 2018) on every continent. However, disagreement has been suggested as to whether coastal plains were more desirable to the prehistoric inhabitants than the hinterland (Erlandson and Fitzpatrick, 2006; Erlandson and Braje, 2015). Further, it has been argued that coastal landscapes as an interface between land and sea, offered countless opportunities for early humans, such as settlements, reliable dietary resources, migration routes, and fertile soil for agriculture (Dupont *et al*., 2009; Walsh, 2014; Benjamin *et al.*, 2017).

The coastal morphology of the southern littoral area of Sri Lanka also changed drastically from Late Pleistocene to Late Holocene as evident from the dunes, gravel beds, inland coral and shell deposits, beach rock formations, bays, lagoons, peninsulas and so on (Cooray and Katupotha, 1991; Weerakkody, 1992; Katupotha, 1995; Ranasinghe *et al*., 2013; Ratnayake *et al*., 2017; Reuter *et al*, 2020). This shift accompanied several localized environmental changes along the south and southeast coast of the island that included: (1) rapid episodic sea-level transgression (Weerakkody, 1992; Katupotha, 1995; Weerakkody, 1997; Ranasinghe *et al.*, 2013); (2) significant droughts and drying events (Ranasinghe, 2010); and (3) the creation of headland-bay-beaches, marshlands, and lagoon systems (Weerakkody, 1992; Katupotha, 1995; Weerakkody, 1997). In addition, by the Late Holocene, ca. 3000 years BP, regional climate shifts and eustatic forcing resulted in major reconfigurations of the land and coastal morphology across large portions of the southeast coast. As a consequence of these changes, during the third and second millennia BCE, living coral colonies and shells found in lagoons, bay beaches and estuaries were converted to terrestrial shores and slowly buried by mud and alluvium (Katupotha, 1995; Ranasinghe *et al*., 2013).

It appears that the aforementioned Holocene coastal changes, as well as the associated biotic richness and diversity (Burnett *et al.*, 1998) may have rendered these coastal landforms, particularly the southern littoral area, suitable for a variety of activities such as shell gathering, fishing, and hunting (Somadeva and Ranasinghe, 2006; Kulatilake *et al.*, 2014). Archaeological evidence for human settlements and human internments has been

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found in association with Holocene shell bearing layers in several locations along the southern coast (Somadeva and Ranasinghe, 2006; Kulatilake *et al.*, 2018). The challenge is to determine how the Holocene changes in coastal ecology associated with sea-level rise influenced the behavioural patterns of past humans of Sri Lanka, particularly, in terms of exploitation, occupation, and culture. Nevertheless, the paucity of multi-disciplinary studies such as sedimentology and oceanography correlating archaeological and palaeoenvironmental records has prevented the answer to this question.

Recent studies explain that sedimentological investigations are an important component in environmental reconstruction, which may concern either ancient landscapes or human effects on a regional or local scale (Vacchi *et al*., 2016; Currás *et al*., 2017; Melis *et al*., 2018). The amount of research addressing socio-environmental connections and the cultural landscape associated with Holocene relative sea-level variations has significantly increased recently (Benjamin *et al*., 2017; Brisset *et al.*, 2018; Galili *et al.*, 2019; Peev *et al*., 2020; Rosentau, 2020).

Most of the previous studies based on sedimentological and geomorphological analyses have been explained by the main trend in the Holocene eustatic evolution of the coastal area of Sri Lanka (Weerakkody, 1992; Katupotha, 1995, 2015; Ranasinghe *et al.*, 2013, Jayasingha *et al*., 2014). However, only a few studies have been conducted focusing on the impact of coastal alterations on prehistoric settlements using geological investigations (Deraniyagala, 1992). Furthermore, the majority of integrated archaeological and palaeo-environmental research studies centred on studying human-environment interactions during the Late Pleistocene – Holocene period has been restricted to the hinterland areas (Perera *et al.*, 2011; Premathilake, 2012; Roberts *et al.*, 2017; Wedage *et al.*, 2020). Therefore, it is essential to consider how changes in climatic conditions during the Holocene period influenced the coastal settlements of prehistoric people. Thus, this study aims to determine the environmental conditions that prevailed in the prehistoric habitational sites located in the southern coastal stretch of Sri Lanka (between Tangalle to Bundala) based on a sedimentological study.

Study area

The study area described here stretches in the southern part of Sri Lanka within longitude 80° 48' -81°16' and latitude 6°03' - 6°09' from Tangalle to Bundala (Figure 1). Geologically, this area is located close to the contact zone of Highland Complex (HC) and Vijayan Complex (VC) of Precambrian basement (Cooray, 1994). Therefore, the western part of the study area is characterised by HC rocks while the eastern portion lies on the VC (Figure 2). Quaternary deposits, some of which are of aeolian and fluvial origin cover the basement.

Climatically, the study area belongs to the arid lowlands of the country's Dry Zone. The coastal area between Tangalle to Bundala experiences a mean rainfall of 760 and 1,270 mm per year with annual temperatures ranging between 27 ℃ and 32°C (Imbulana *et al.*, 2002). Heavy rains occur in October and November during convectional cyclonic depression events rather than during the southwest monsoon (Edirisinghe *et al.*, 2017). High-energy winds from May to September shape large dune systems along the shoreline. Rapid evaporation in these environments forms natural salt pans and encouraged the proliferation of thorny scrub species, creeping vegetation and stunted trees (National Wetland Directory of Sri Lanka, 2007).

This area is formed of narrow and long barrier beaches and beach ridges (Katupotha, 1995). Furthermore, dune-bearing barrier spits and lagoons occur in the estuary of the Walawe River. As one travels inland from the coast, the landscape changes abruptly into a diverse mosaic of marine, freshwater, and artificial wetland systems. The shell deposits in the littoral area between Tangalle to Bundala occur as highly concentrated pockets around the Kalametiya Kalapuwa, Hungama and Lunama Kalapuwa, the area between Karagan Lewaya and Pallemalala and, the area between Embilikala Kalapuwa and Bundala Lewaya (Katupotha, 1995, Adikari and Risberg, 2007).

Three previously excavated prehistoric sites, namely, Pallemalala (Somadeva and Ranasinghe, 2006), Mini-Athiliya (Kulatilake *et al*., 2014, Kulatilake *et al*., 2018) and Bundala (Deraniyagala, 1992) which have yielded archaeological evidence of past human activities, located in association with the Holocene shell deposits were selected for sample collection. Furthermore, Kalametiya and Henagahapugala, two locations that were speculated to be occupied by prehistoric people by previous researchers were also selected for sampling (Deraniyagala, 1992).

Pallemalala (6° 11' 18" N, 81° 10' 6" E) is located 1.5 km away from the coast in the vicinity of Malala Oya. During the rescue excavation conducted in 1997, two units of the prehistoric layers, a settlement and a burial floor, which were associated with the shell bearing layer were unearthed in Pallemalala (Somadeva and Ranasinghe, 2006). The burial floor was comprised of seven complete human skeletons interned in the flexed position. Apart from these complete burials, illegal diggers have unearthed a collection of fragmented bones belonging to seven individuals (Somadeva and Ranasinghe, 2006). Furthermore, a considerable amount of faunal remains assemblage comprised of terrestrial and marine species including species such as *Bubalus bubalis* (water buffalo), *Rusa unicolor* (sambar deer), *Axis axis* (spotted deer), *Sus scrofa* (wild boar), *Moschiola meminna* (spotted chevrotain), *Lissemys punctata* (flap shell turtle), *Melanochelys trijuga* (black turtle), multiple snakes and *Varanas* sp. (monitor lizard) and marine fish *Euthynnus affinis* and *Katsuwonus pelemis* have been unearthed. In addition, descriptions of the stratigraphy of the excavation walls indicate a burnt patch of shell indicative of remnants of a hearth feature. Somadeva and Ranasinghe (2006) estimated the site was in use around 4500 yrs BP based on radiometric dates obtained from nearby Hungama where similar deposits dating back to 4050±60 uncalibrated yr BP and 4650±70 uncalibrated yr BP.

In 2007 a high-density "kitchen midden" was discovered at Mini-Athiliya (6° 07' 12" N, 80° 56' 47" E) revealing discarded faunal remains, a hearth in upper shell deposit and a complete, flexed human burial in the lower layer (Figure 3a) (Kulatilake *et al.*, 2014). Similar to Pallemalala, illegal mining in the vicinity of Mini-Athiliya also has yielded several human bone fragments (Figure 3b) (Kalatilake *et al*., 2018). The settlement layer has been dated between 3990 -3830 cal yrs BP (Kulatilake *et al*, 2018). Excavations at Mini-Athiliya yielded a more diverse and assorted faunal assemblage compared to Pallemalala which was comprised of freshwater, shallow water and deep-sea marine fish, birds, ungulates and rodents. Furthermore, a considerable number of edible shellfish were present in the shell debris majority being species *Meretrix meretrix*, followed by forms such as *Anadara* sp*., Marcia* sp*., Gafrarium tumidum*, and *Turbinella pyrum.* In addition to these saltwater and brine varieties of shellfish, numerous terrestrial rainforests and freshwater molluscs were also recovered during the excavation (Kulatilake *et al*., 2018).

Bundala – Patirajawela (6° 10' 16" N, 81° 13' 30" E) is located approximately 200 m inland from the shoreline. Patirajawela was originally excavated by Deraniyagala (1992) and has been assigned a radiocarbon date of ca. 5260 cal yrs. BP. The shell bearing layer has not yielded any evidence of faunal, or human remains except for microliths and other lithic tools (Deraniyagala, 1992).

Henagahapugala (6°4'31.05" N, 80° 56' 6.91" E) was excavated in the 1980s by Deraniyagala (1992) dated to age ca. 3370 – 2880 cal yrs BP has been described as a midden containing a Mesolithic habitation underlain by a shell deposit. The latter was probed and found to be devoid of artefacts (Deraniyagala, 1992).

The Kalametiya area has not been systematically excavated yet. However, several researchers reported the presence of stone implements, animal bones and human skeletal remains embedded in the shell deposits (Katupotha, 1995). The majority of the shell species present in the deposits of Kalametiya are edible forms such as *Meretirx meretrix* and *Anadara* sp. (Siriwardana, 2014). The shell deposits in Kalametiya have been dated to 5780 BP (Deraniyagala, 1992).

In addition, recent residual soil from Hambantota, beach sediment from Malala-modara and lagoonal sediment from Rekawa were also collected as reference samples

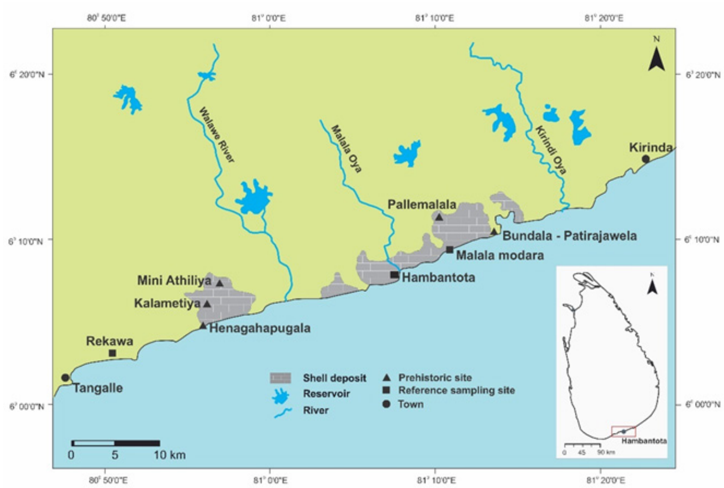

Figure 1: The map showing the sampling sites (prehistoric and reference sampling locations) of the study area. The locations of the occurrences of the shell deposits have been modified after Katupotha (1995).

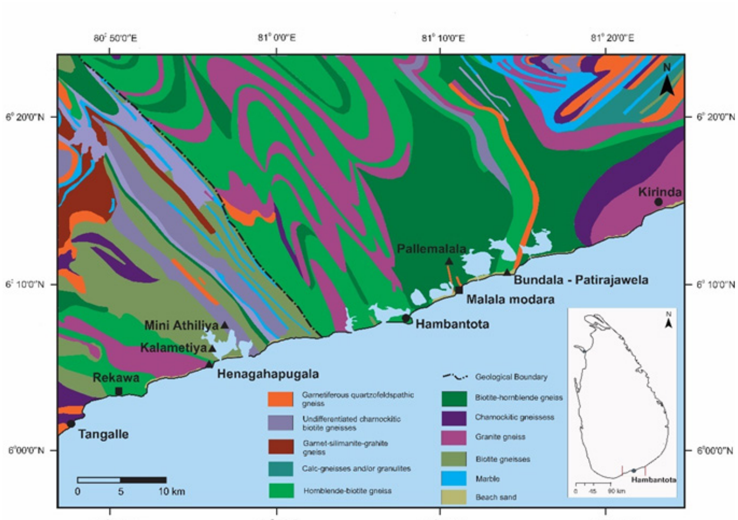

Figure 2: The map showing the simplified geological setting of the study area after the Geological Survey and Mines Bureau of Sri Lanka (2016). Sampling sites (prehistoric and reference sampling locations) are as depicted in Figure 1.

Figure 3: Human remains recovered from the shell deposit in Mini-Athiliya. (a) Complete human flexed burial and (b) isolated human skeletal fragment of maxillary dentition recovered during the collaborative excavation conducted in 2007 by one of the authors of the paper. (c) Skeletal fragment of an unknown species recovered from the Layer III of the present study.

from known environmental settings to compare with the sediments obtained from prehistoric sites.

MATERIALS AND METHODS

Sample collection

Currently, the original excavation pits have been destroyed due to mining and agricultural activities in Pallemalala and Mini-Athiliya. Therefore, sequences of samples were collected from test pits (Supplementary Figure S3a) opened approximately 100 m and 200 m away from previously archaeologically excavated sites, respectively. Samples from Bundala were collected from the previous archaeological trench (Supplementary Figures S4b and S4c). In Henagahapugala and Kalametiya, sequences of samples were obtained from the exposed profiles of a road cut and an abandoned mining pit (Supplementary Figures S3b and S3c). Samples were collected from bottom to top according to the layers as depicted in Figure 4. Surface samples were collected from the middle of the Rekawa lagoon using an Ekman-grab (Supplementary Figures S4a) while a plastic trowel was used to collect residual and beach surface samples. Approximately a sample weighing 1 kg was obtained from each layer of prehistoric sites and recent environments.

In the field, stratigraphic variations of each prehistoric site were studied. The colour of the soil samples and shell embedded layers was determined by the Munsell Soil Colour Chart (Munsell Color Company, 2000). The depositional environment of study sites was interpreted through the stratigraphy and, the textural properties and parameters of the sediments. In addition, published radiocarbon dates and interpretation of sedimentary environments in previous excavations (Somadeva and Ranasinghe, 2006; Perera, 2010; Kulatilake *et al.*, 2014) and sea-level changes studies (Fujiwara and Katupotha, 1986; Katupotha and Wijayananda, 1989; Katupotha, 1995) were incorporated into this study to correlate and interpret the sedimentary environments and depositional sequence of the lithostratigraphic layers of the selected locations in the present work.

Sample analysis

Test sieve analysis and hydrometer analysis were conducted to determine the grain size distribution of the stratigraphic layers. The oven-dried (105 °C for 24h) bulk samples were reduced by coning and quartering until a 250 g sub-sample was obtained. The obtained samples were pre-treated with 30% vol H_2O_2 and 1:10 HCl to remove organic matter, iron and carbonates (Vos *et al.*, 2014). After this pre-treatment, the samples were sifted at 1.0 ø intervals through American Standard (ASTM) test sieve (No 05 - 230 mesh sizes) sets using a Sieve-Tronic sieve shaker for around 15-30 minutes (Folk and Ward, 1957). The retained weights were weighed using a digital balance and recorded. The grain size of particles smaller than 0.063 mm that were retained in the pan was measured by hydrometer analysis. Sample preparation and the analysis were carried out according to the standard procedure suggested by Ashworth et al. (2001).

The weight percentage frequencies and cumulative weight percentage frequencies were computed (Folk and Ward 1957). Graphical statistical parameters developed by Folk and Ward (1957), the median (M_d), mean (M_z), sorting (σ_1), skewness (SK_1), and kurtosis (KG_1) were calculated for each layer by employing GRADISTAT v.4 software (Blott and Pye, 2001). The statistical method used to analyse sediment and interpret environmental variables shows that there is a direct relationship between the multiple processes and the depositional environment (Sahu, 1964; Folk, 1966; Solohub and Klovan, 1970; Rajganapathi *et al.*, 2013).

RESULTS

Profile description

Stratigraphic layers of the selected locations are depicted in Figure 4 and the images of the soil profiles are depicted in Supplementary Figures S3 and S4. The topmost layer of the north wall of the test pit at Pallemalala consists of blackish-grey soil, which is probably due to the high percentage of organic matter derived from leaf cover (Schulze *et al.*,1993; Boul *et al.*, 2003; Wills *et al.*, 2007). The preceding layer is comprised mainly of light grey sand. In comparison to the upper layer, the silt content is comparatively high. These sediments contained plenty of macroscopic and microscopic plant remains indicative of a long-term undisturbed profile. Layer III is distinguished from the upper layers by the presence of yellowish-brown clayey sandy soil. A significant feature of Layer III is the presence of sandy-clayey lenses which display a bluish-green colour in wet conditions. This layer is devoid of freshwater or marine molluscs except for rare occurrences of the species *Conus*. The lowermost layer is also comprised of yellowish-brown clayey sandy soil. However, sandy-clayey lenses as visible in the third layer are absent, and the layer is devoid of any plant or shell remains. Although the sediments of Layers III and IV are compositionally similar to the habitational layers of the previous excavation, they are devoid of any shell material (Somadeva and Ranasinghe, 2006).

The uppermost layer at Mini-Athiliya has a dark grey colour sandy organic-rich soil comprised of heavily fragmented shells. Even though layer II is almost similar in appearance to the upper layer, it contains mostly complete and articulated shells. Layer III is distinguished by its yellowish-brown, clayey, sandy soil with the compacted debris of shell fragments and complete shells, as well as relatively fewer contents of plant remains. This layer can be considered the habitational layer as described by the previous excavation (Kulatilake *et al*., 2014).

All three layers of Bundala- Patirajawela have a reddish-brown colour silty-sandy soil. The uppermost stratum is characterised by an abundance of plant materials and insect burrows. The preceding layer is distinguished by the high percentage of silt, having a lower amount of shell fragments and, microlithic and other forms of stone tools. In contrast to the upper layers, the bottommost layer is characterised by fully articulated, densely packed shells with a comparatively low percentage of sediments. The shell species found in this layer are dominated by *Meretrix* spp.

The soil profile of Henagahapugala is characterised by gravelly sand of reddish-brown colour which has been gradually fading from the upper layers to the bottom. Therefore, the bottommost layer is dominant in yellowish-white sand. Marine bivalves and gastropods can be observed in Layer III, Layer IV through Layer V, although the shell debris is much concentrated in Layer V. Among the species present in the layers *Meretrix* spp. are the dominant type.

The surface of Kalametiya is comprised of sandy dark grey soil with an abundance of macroscopic plant material and evidence of biological activity. The preceding layer is distinct from the upper layer by having a lower amount of plant material and grey coloured sandy soil with a yellowish-red hue. In contrast to the upper layers, Layer III is comprised of an abundance of complete and fragmented shells. Similar to Layer III of Pallemalala, sandy-clayey lenses are also present. The bottommost layer is characterised by the absence of any shell material, unlike the upper layer and a grey coloured sandy soil with a reddish hue.

Textural characteristics of the sediments

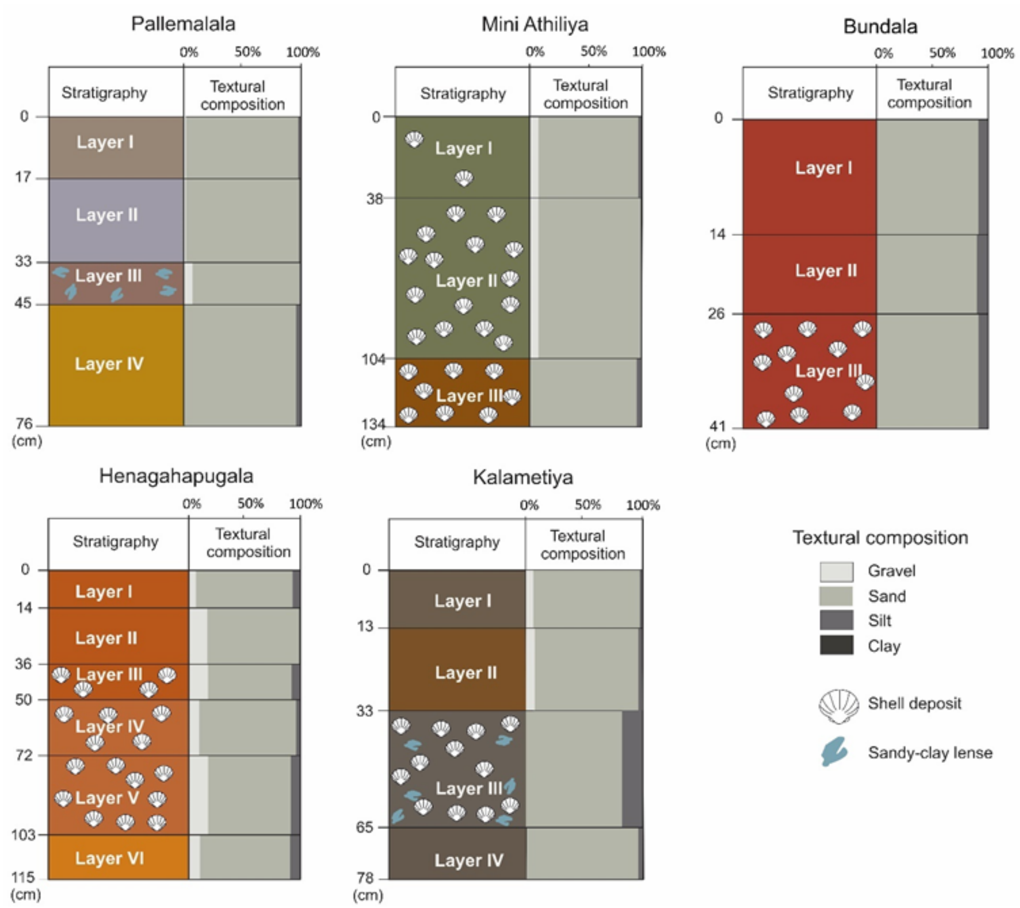

Figure 4: The stratigraphy and textural compositions of profiles of selected prehistoric locations..

The particle size distribution (PSD) of Pallemalala is dominated by poorly sorted, fine skewed, mesokurtic, unimodal sediments with medium grains, the dominant grain size (Figure 5a, Supplementary Figures S5 and S6). Except for the sediment fraction of the Layer III (excluding the clay lenses), all other layers indicate similar distributions. Layer I and III sediments at Mini-Athiliya are mostly polymodal in fines, poorly sorted with symmetrical and mesokurtic characteristics (Figure 5b, Supplementary Figures S7 and S8). However, Layer II has a unimodal distribution. The sediments at Bundala are bimodal with a fine skewed and leptokurtic nature (Figure 5c, Supplementary Figures S9 and S10). Layer II has higher fine fractions compared to the other two layers. Though the Layer III contains shells, the sedimentological distributions are more comparative with Layer I.

Henagahapugala is distinct from other localities by having a higher percentage of gravel in every layer (Figure 4, Figure 6a and Supplementary Figures S11 and 12). Layer I, IV and V are comparable with bimodal peaks in coarser fractions whereas Layer IV has a lower amount of fine content. In contrast, the PSD of Layer V is polymodal with high fine contents though it contains shell fragments like the above and below layers. The bottommost layer can be distinguished by the dominant unimodal, mesokurtic distribution of medium-grained sand.

Similar to the other localities, sediments in Kalametiya are also characterised by poorly sorted sediments. The two uppermost layers are demarcated by having a unimodal, symmetrical, mesokurtic distribution dominated by coarse-grained sand (Figure 6b, Supplementary Figure S13 and S14). Layer III is distinct from the rest by having a very poorly sorted, very fine skewed, polymodal, leptokurtic distribution dominated by fine-grained sand. In contrast, PSD of the lowermost layer is dominated by medium-grained sand and is bimodal, symmetrical and mesokurtic.

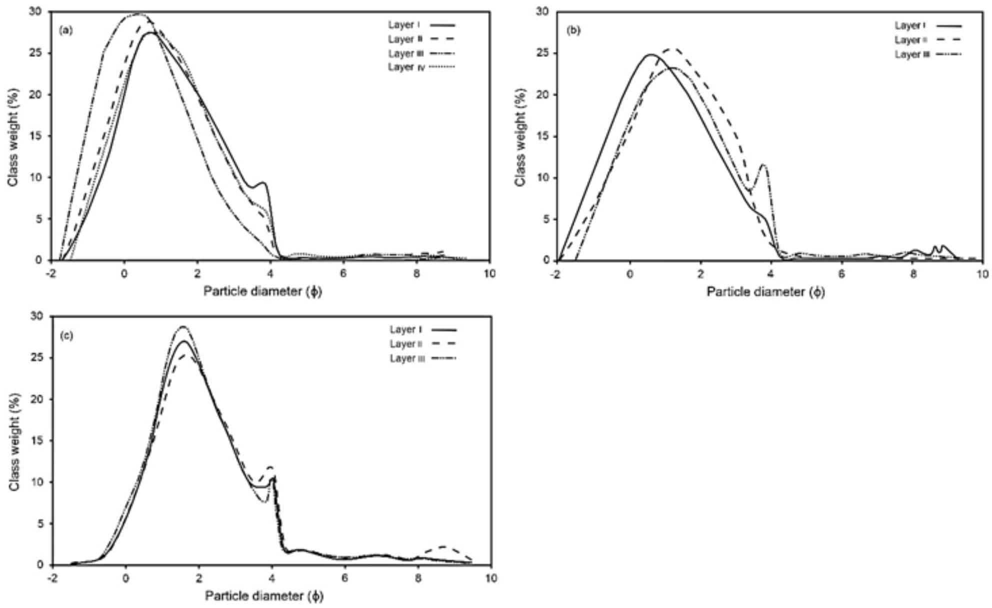

Figure 5: Particle size distribution of the sediments of the stratigraphic layers of selected prehistoric locations, (a) Pallemalala, (b) Mini-Athiliya and (c) Bundala.

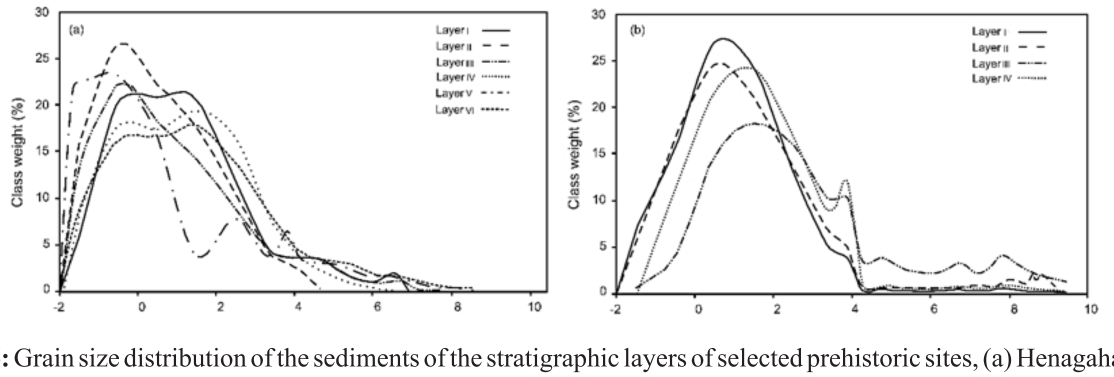

Figure 6: Grain size distribution of the sediments of the stratigraphic layers of selected prehistoric sites, (a) Henagahapugala and (b) Kalametiya.

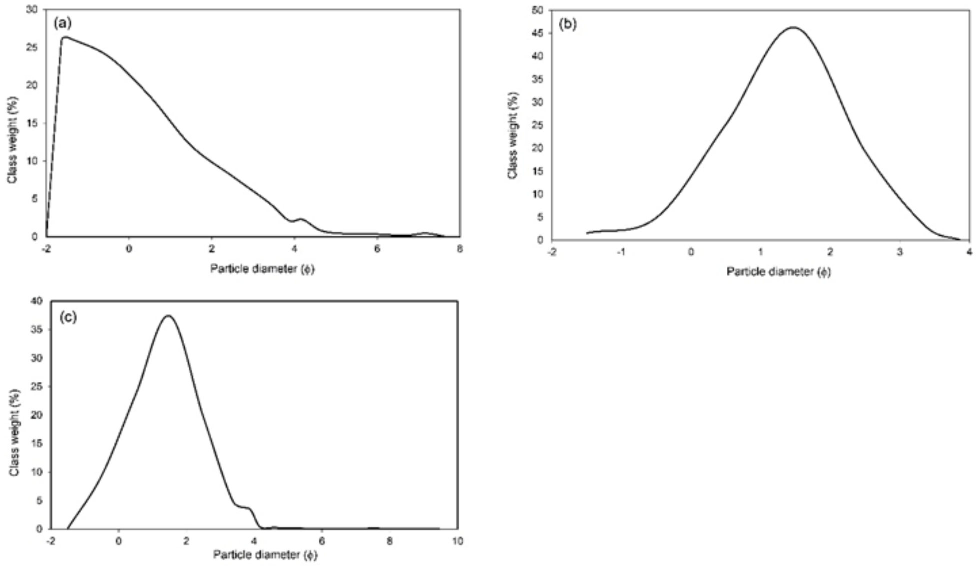

Figure 7: Grain size distribution of the sediments collected as a reference from the selected known environments, (a) residual soil from Hambantota, (b) beach sediments from Malala Modara and (c) lagoon sediments from Rekawa.

Table 1: Grain size statistical parameters of the sediments at stratigraphic layers at selected location according to Folk and Ward (1957) method. All the values are depicted in phi scale.

Location	**Layer**	**Mean**	**Sorting**	**Skewness**	**Kurtosis**
Pallemalala	I	1.36	1.34	0.13	0.94
	II	1.16	1.33	0.14	0.99
	III	0.59	1.29	0.11	0.96
	IV	1.30	1.34	0.14	0.98
Mini-Athiliya	I	0.99	1.55	0.10	1.01
	II	0.30	1.89	0.98	1.35
	III	1.49	1.40	0.08	0.93
Bundala	I	2.05	1.38	0.24	1.19
	II	2.16	1.61	0.32	1.44
	III	2.01	1.35	0.24	1.21
Henagahapugala	I	1.04	1.68	0.18	1.07
	II	0.42	1.46	0.14	0.89
	III	0.65	1.87	0.27	1.03
	IV	1.05	1.65	0.02	0.87
	V	0.43	2.07	0.44	1.08
	VI	1.20	1.93	0.12	1.00
Kalametiya	I	0.93	1.43	0.05	1.06
	II	0.99	1.55	0.10	1.01
	III	2.38	2.20	0.33	1.33
	IV	1.49	1.40	0.08	0.93
Hambantota	Surface	0.12	1.61	0.27	0.91
Rekawa	Surface	1.37	1.11	-0.04	1.02
Malala Modara	Surface	1.35	0.95	-0.06	1.08

Table 2: Summary of grain size statistical parameters. Categorizations are based on the graphical measures of Folk and Ward (1957). The grain size scale was modified after Udden (1914) and Wentworth (1922).

Location	Layer	Mean	Sorting	Skewness	Kurtosis
Pallemalala	I	Medium Sand	Poorly Sorted	Fine Skewed	Mesokurtic
	II	Medium Sand	Poorly Sorted	Fine Skewed	Mesokurtic
	III	Coarse Sand	Poorly Sorted	Fine Skewed	Mesokurtic
	IV	Medium Sand	Poorly Sorted	Fine Skewed	Mesokurtic
Mini-Athiliya	I	Coarse Sand	Poorly Sorted	Symmetrical	Mesokurtic
	II	Medium Sand	Poorly Sorted	Symmetrical	Mesokurtic
	III	Medium Sand	Poorly Sorted	Symmetrical	Mesokurtic
Bundala	I	Fine Sand	Poorly Sorted	Fine Skewed	Leptokurtic
	II	Fine Sand	Poorly Sorted	Very Fine Skewed	Leptokurtic
	III	Fine Sand	Poorly Sorted	Fine Skewed	Leptokurtic
Henagahapugala	I	Medium Sand	Poorly Sorted	Fine Skewed	Mesokurtic
	II	Coarse Sand	Poorly Sorted	Fine Skewed	Platykurtic
	III	Coarse Sand	Poorly Sorted	Fine Skewed	Mesokurtic
	IV	Medium Sand	Poorly Sorted	Symmetrical	Platykurtic
	V	Coarse Sand	Very Poorly Sorted	Very Fine Skewed	Mesokurtic
	VI	Medium Sand	Poorly Sorted	Fine Skewed	Mesokurtic
Kalametiya	I	Coarse Sand	Poorly Sorted	Symmetrical	Mesokurtic
	II	Coarse Sand	Poorly Sorted	Symmetrical	Mesokurtic
	III	Fine Sand	Very Poorly Sorted	Very Fine Skewed	Leptokurtic
	IV	Medium Sand	Poorly Sorted	Symmetrical	Mesokurtic
Hambantota	Surface	Coarse Sand	Poorly Sorted	Fine Skewed	Mesokurtic
Rekawa	Surface	Medium Sand	Poorly Sorted	Symmetrical	Mesokurtic
Malala Modara	Surface	Medium Sand	Moderately Sorted	Symmetrical	Mesokurtic

DISCUSSION

The particle size distribution of the sediments can depend on the composition of parent rocks as well as transporting medium or depositional environment (López, 2017). There are a large number of studies on present and historic sedimentary settings which have been interpreted by the correlation of size factors, transport processes and depositional mechanisms of sediments (Watson *et al.*, 2013; Ranasinghe *et al.*, 2021; Simon *et al.*, 2021).

The poorly sorted conditions and the dominance of medium to coarse-grained sand among the sediments of Pallemalala indicate the increased contribution of fluvial depositional conditions and the lack of influence of beach or aeolian depositional mechanisms (Merlotto *et al*., 2014; Nugroho and Putra, 2018). However, the high percentage of coarse sediments and the presence of bluish-clay lenses in Layer III might indicate a creek network region of a marginal environment of a lagoon or an estuary. Similar blue to green clays is recorded in many estuarine or salt marshy environments (Mortimer and Rae, 2000; Allen, 2004). The flow paths of water might be developed as the clay lenses that crossed the unsorted fluvial coarse sedimentary environment. The presence of *Conus* might be evidenced in such marginal environments. The yellowish-brown colour of Layer III and Layer IV might be due to the oxidation of iron-bearing minerals of the sediments which might indicate a dry period for the sedimentation. Probably, the paleoclimatic condition which is denoted by sediments is favourable for a prehistoric human settlement as mentioned by Somadeva and Ranasinghe (2006). On the other hand, the shell deposit encountered during the previous excavation might be anthropogenic, as some researchers have suggested (Katupotha, 1995; Kulatilake *et al*., 2014, 2018)

Based on the poorly sorted condition, the dominance of coarse to very coarse-grained sand, presence of complete and fragmented shells, higher organic content and presence of bluish-grey silty sand it can be suggested that the lagoonal conditions prevailed when the sediments of Mini-Athiliya were deposited (Chen *et al*., 1997). This is strengthened by comparing these sediments with the samples obtained from the Rekawa lagoon, which also had a poorly sorted PSD (Figure 7), dominated by medium-grained sand. Although the characteristics of shells in Layer II of Mini-Athiliya indicate a natural deposition, stone implements, highly fragmented shells and the presence of animal and human bones in Layer III, suggest that the Layer III of Mini-Athiliya is anthropogenically influenced.

The presence of interconnected shells in the bottommost layer, the lack of species diversity, and the absence of non-aquatic fauna at Bundala, lead us to assume that the development of the profile has taken place due to the natural processes and anthropogenic influence is minimal. Katupotha (1995) suggested that the shell deposits in Bundala-Patirajawela might have been deposited by storm waves. However, by considering the comparatively significant content of clay and silt, it can be suggested that the two uppermost layers of Bundala are storm flood deposits, as the area between Tangalle and Bundala experiences seasonal storm surges even today (Wijetunge and Marasinghe, 2015). Nevertheless, the occurrence of microliths in Layers II and III might indicate that these deposits were occupied by prehistoric populations despite the storm hazards. On the other hand, given the absence of other material evidence that suggests human occupation, these could be transported from elsewhere and redeposited at this location.

The high gravel content at Henagahapugala suggests that the sediments were deposited by fluvial actions, preferably in a river channel (Colombera and Mountney, 2019). Although Deraniyagala (1992) has identified the layers above the shell deposit in Henagahapugala as a Mesolithic (Microlithic) habitation, any evidence indicating human habitation could not be found in the present study. Furthermore, any artefacts or human or faunal remains could not be found in association with the shell deposit either. Therefore, it is possible to suggest that Henagahapugala had not been occupied by prehistoric people and the shell deposit has a natural origin. However, in contrast to the Kalametiya, the shell layer at Henagahapugala seem to have been deposited with time in a fluvial channel.

Similar to the other locations selected in the present study, all layers in Kalametiya are also represented by poorly sorted sediments. The depositional environment of the bottommost layer of Kalametiya, which is dominated by medium-grained and grey coloured sand, can be interpreted as a remnant of a lag deposit induced by a moderate energy dominated environment located on a bayside beach. It has been suggested that the area of the current Kalametiya lagoon may have been converted to an embayment during the sea-level transgressions in the mid-Holocene (Weerakkody, 1988; Katupotha, 1995).

However, these bayside beach conditions in the Kalametiya appear to be changed to lagoonal conditions when the sediments in Layer III were deposited. As evident by the high concentration of fully articulated and fragmented shells and dominance of fine-grained sand in the layer might indicate a shift in palaeo-environmental conditions, presumably from a bay-beach environment to lagoonal conditions (Adikaram *et al*., 2015). Although lagoons are typically characterised by a higher proportion of finer sediments, those that are subjected to high energy incidents such as storms tend to have high proportions of coarse grains (Kalbfleisch and Jones, 1998). Therefore, the dominance of fine-grained sand and poorly sorted condition of the sediments in Layer III can be attributed to the occurrence of storms or the influences of different depositional conditions such as the mixing of tsunami sediments with surface materials (Dahanayake and Kulasena, 2008; Jackson *et al.*, 2014).

However, the sediments in the Layer III of Kalametiya are polymodal, in contrast to the unimodal nature of the storm deposits. This could be due to the presence of trace amounts of biogenic material which were not removed by pre-treatments. Kalbfleisch and Jones (1998) have pointed out that primarily *in situ* biogenic deposits in the lagoons should be polymodal with modes corresponding to the primary breakdown of the sizes of the organisms present in the sediments. Therefore, it can be suggested that the Layer III of Kalametiya is indeed a lagoonal deposit with contributions from mixed environmental conditions.

Although human and animal skeletal remains (Deraniyagala, 1992; Katupotha, 1995; Siriwardana, 2014) have not been found at the studied site, the occurrences of shells and the textural characterises of sediments are almost similar to the sedimentary layers of the previous studies. Therefore, it can be assumed that this site is also representing a location inhabited by prehistoric people. Prehistoric hunter-gatherers occupied this area after the formation of the lagoon (Adhikari and Risberg, 2007), the human and animal skeletal remains may not be dispersed throughout the area.

Palaeo-cultural coastal landscape of the southern littoral area

In the present study, sites that have revealed reliable evidence for prehistoric human occupation, particularly, Pallemalala, Mini-Athiliya and Kalametiya appear to have been centred in marginal environments located in the marine-fluvial interfaces, such as rivers, estuaries and lagoons. Coastal marginal environments are known to be highly favoured by prehistoric populations mainly due to the availability of an abundance of resources (Brisset *et al.*, 2018). As evident by the diversity of the faunal skeletal remains assemblage unearthed from Pallemalala and Mini-Athiliya, these environments were inhabited by animals belonging to a diverse range of ecological niches were existed in these areas, ranging from terrestrial, freshwater, estuarine and marine (Somadeva and Ranasinghe, 2006; Kulatilake *et al.*, 2018). Therefore, these mosaic environments, increased the dietary resource potential of the coastal area. Furthermore, as evident by the presence of fluvial influence, it can be suggested that an abundance of streams and rivers were also present there providing freshwater and much-needed source material for microlithic implements. The availability of these resources probably has increased the carrying capacity of the southern coast. Especially, considering the unfavourable semi-arid climatic conditions that prevailed in Sri Lanka between 8700–3600 cal. yrs. BP (Premathilake and Risberg, 2003; Premathilake and Gunatilake, 2013) these fluvial-marine marginal environments may have rendered the otherwise inhabitable southern coast, hospitable.

Furthermore, the discovery of sophisticated microlithic and unique implements such as terrestrial gastropod fragments fashioned into fishhooks in Pallemalala and Mini-Athiliya (Kulatilake *et al*., 2018) indicates successful adaptation to foraging in terrestrial and aquatic environments equally. This is significant considering the absence of similar implements in the hinterland area. This evidence indicates a technological innovation. In addition, evidence of hearth found at Pallemalala and Mini-Athiliya indicate that prehistoric populations frequently occupied these environments for longer periods. Therefore, it is not incorrect to suggest that coastal Holocene hunter-gatherers preferred these fluvial-marine marginal environments and selected them intentionally. In addition, in the light of new evidence for a late Mid Holocene date for the earliest evidence of human occupation of the southern coast (Roberts *et al*, 2015), it can be suggested that these favourable conditions may have even initiated the expansion of Mesolithic (Microlithic) culture to the southern coast.

In addition, anthropogenic or natural shell deposits that occur in marginal coastal environments such as lagoons have been interpreted as preferential places for ritual and ceremonial activities by prehistoric as well as contemporary hunter-gatherers around the world (Sassaman, 2004). Burials have been considered a common feature in the large shell mounds of the Brazilian coast, which are considered cultural and ritual landmarks that are imbued with social meaning (Álvarez *et al.*, 2011). The discovery of a large number of complete flexed human internments from the lowest parts of the shell bearing layers at Pallemalala and Mini-Athiliya and the occurrence of human skeletal fragments in Kalametiya (Katupotha, 1995; Siriwardana, 2014) might indicate that the anthropogenic and natural shell deposits that occur in the southern coastal area have posed ritualistic importance for prehistoric people which urged them to select these deposits as burial grounds.

CONCLUSION

The sedimentological characteristics of Pallemalala, Mini-Athiliya and Kalametiya revealed that these prehistoric sites were situated in marginal environments located in estuaries or lagoons and fluvial channels which were subjected to Mid-Holocene sea-level fluctuations. Therefore, it can be suggested that these environments are preferred by prehistoric people due to comparatively heightened resource potential provided by an abundance of terrestrial and aquatic fauna, freshwater sources and source materials for microlithic implements. Furthermore, the discovery of several human burials in the shell deposits located in these lagoons indicates that these environments also posed a spiritual significance to prehistoric people. Furthermore, it is possible that the spread of Microlithic culture to the southeastern coast was triggered by the formation of lagoons and estuaries which resulted in by Mid-Holocene sea-level fluctuations. Therefore, it is possible to conclude that prehistoric humans in Sri Lanka developed technologically and culturally, as a result of the marginal habitats created following the Mid-Holocene sea-level changes.

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DECLARATION OF CONFLICT OF INTEREST

The authors whose names are listed in the manuscript declare that they have no conflicts of interest.

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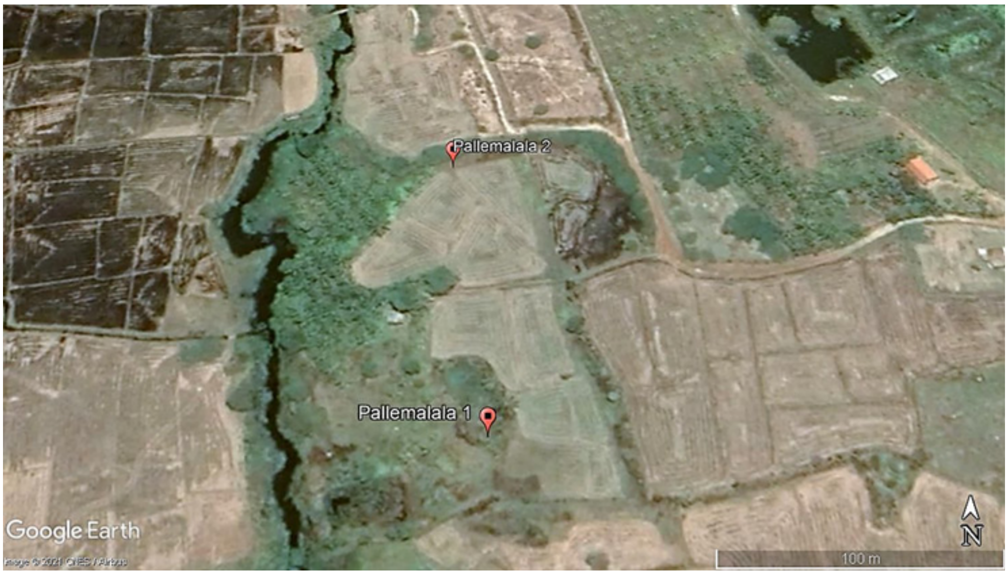
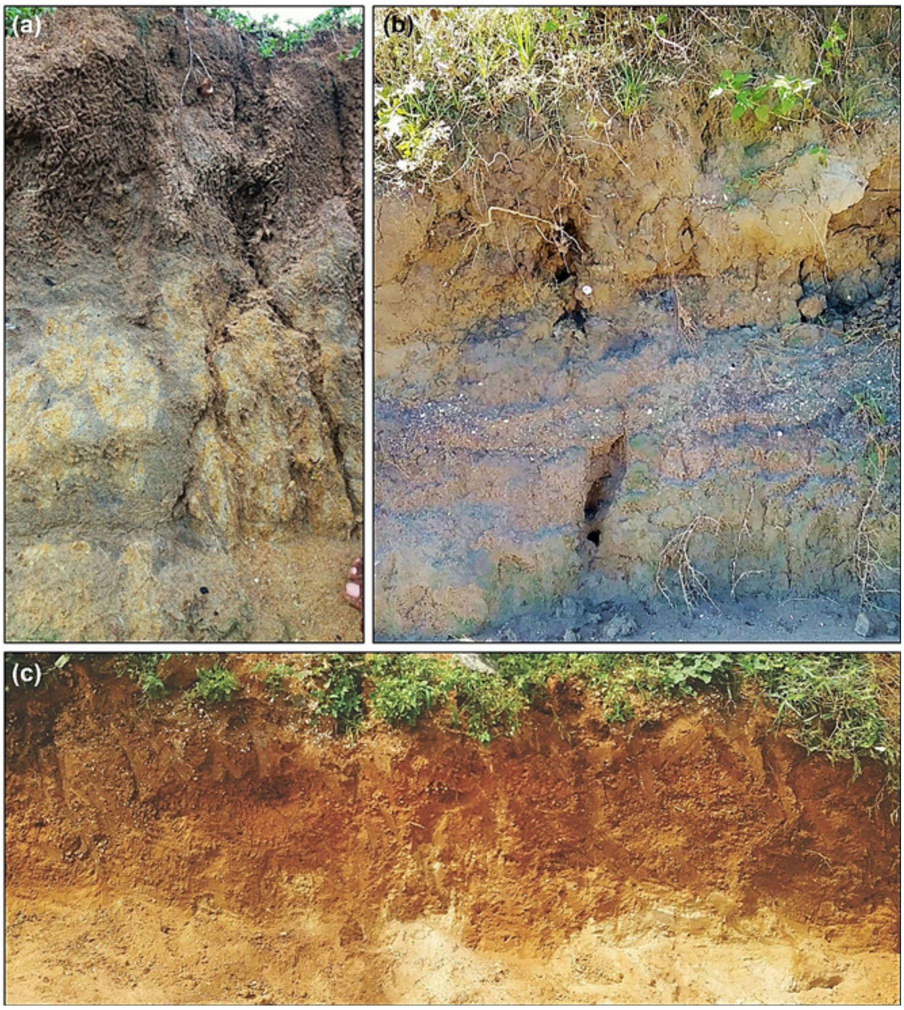
SUPPLEMENTARY INFORMATION



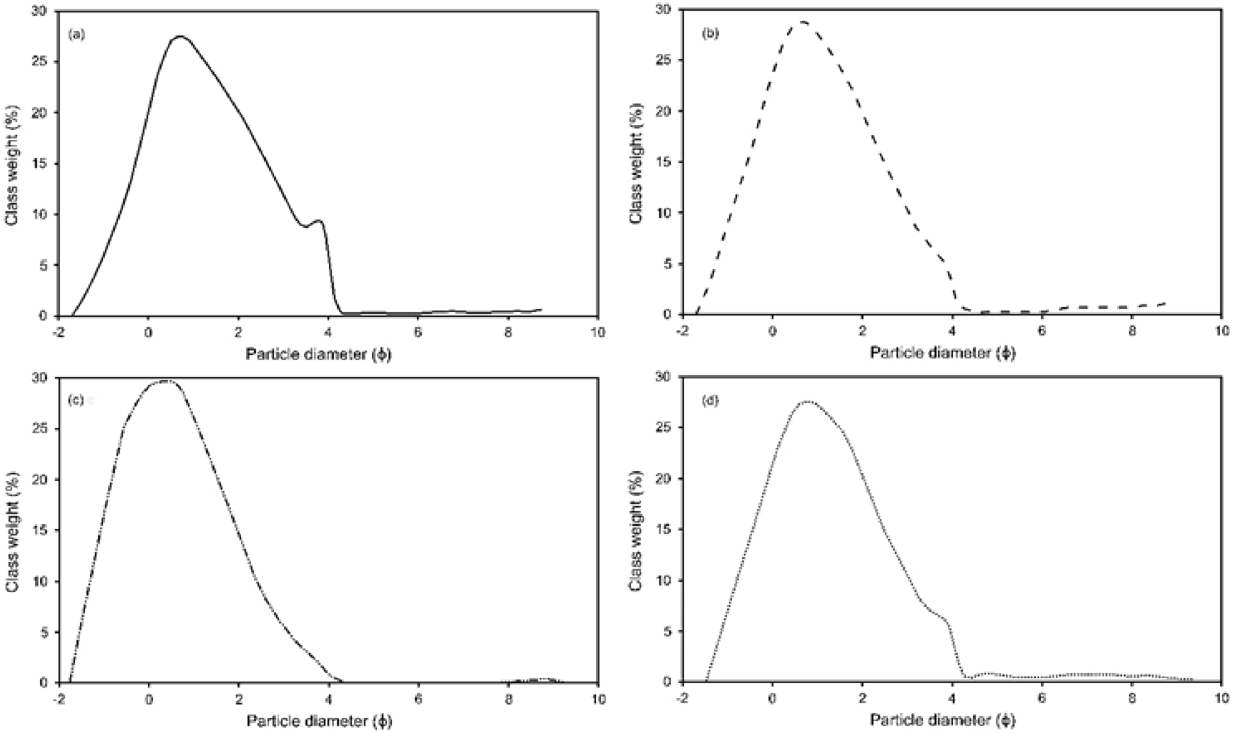
Supplementary Figure S1: Aerial map showing the sampling locations of Pallemalala. Previously excavated location is denoted as Pallemalala 1, while the location sampled in present study denoted as Pallemalala 2

Supplementary Figure S2: Aerial map showing the sampling locations of Mini-Athiliya. Previously excavated location is denoted as Mini-Athiliya 1, while the location sampled in present study denoted as Mini-Athiliya 2

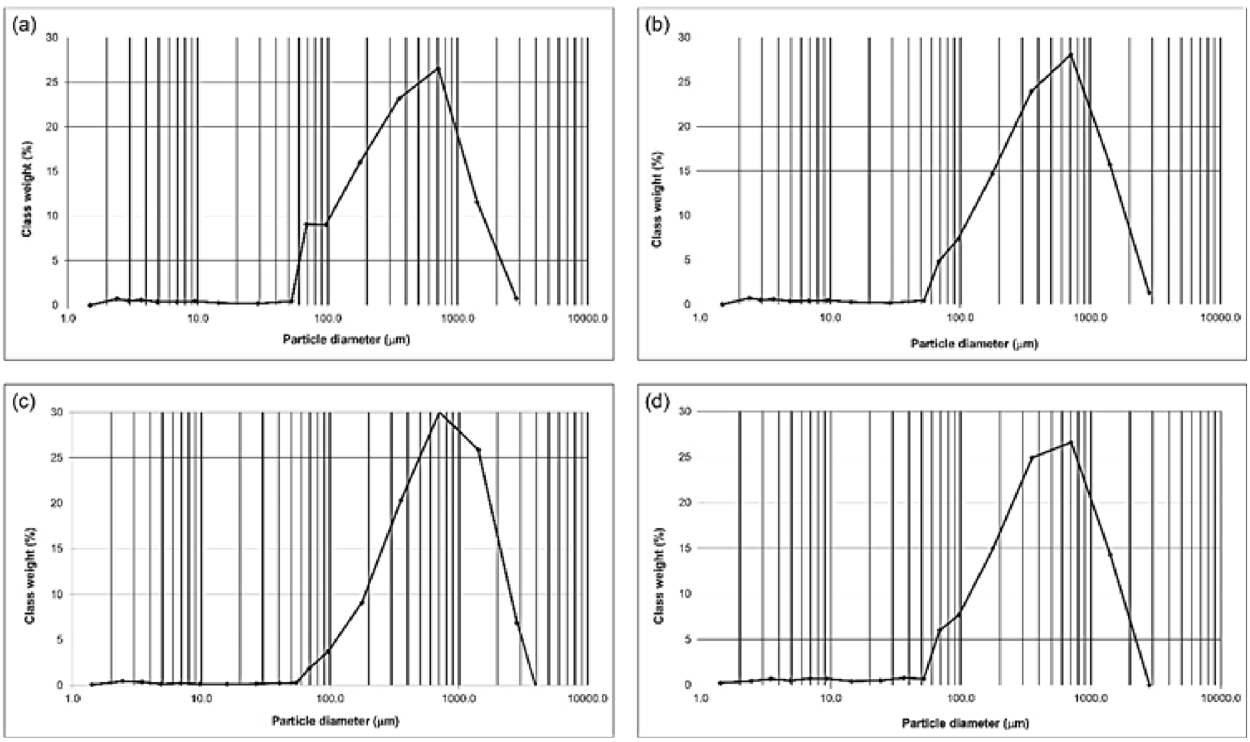


Supplementary Figure S3: Sampled excavated and exposed soil profiles of (a) Pallemalala, (b) Kalametiya and (c) Henagahapugala.

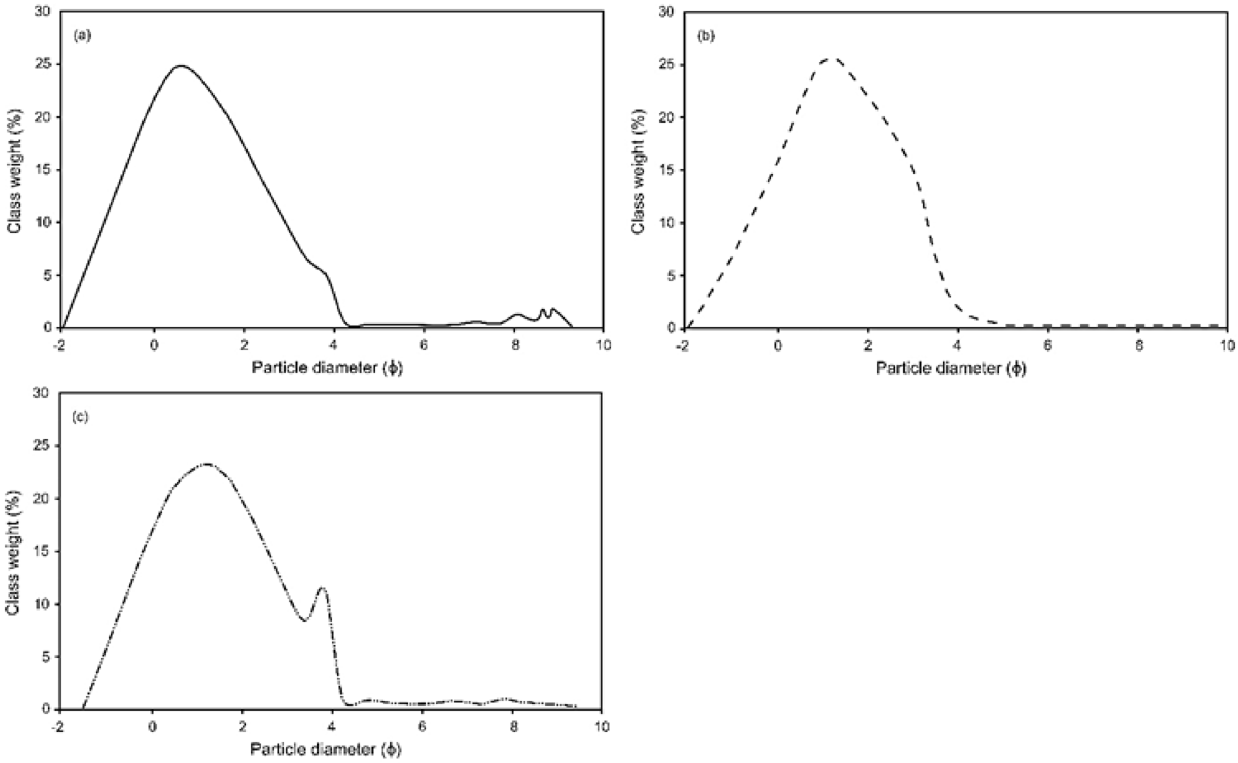
Supplementary Figure S4: Image showing KPMW collecting a surface sediment sample from Rekawa lagoon using Ekman-Grab (a) and collecting a soil sample from a previously excavated location (Deraniyagala trench) at Bundala (c). Excavated profile at Deraniyagala's trench had been collapsed (b)



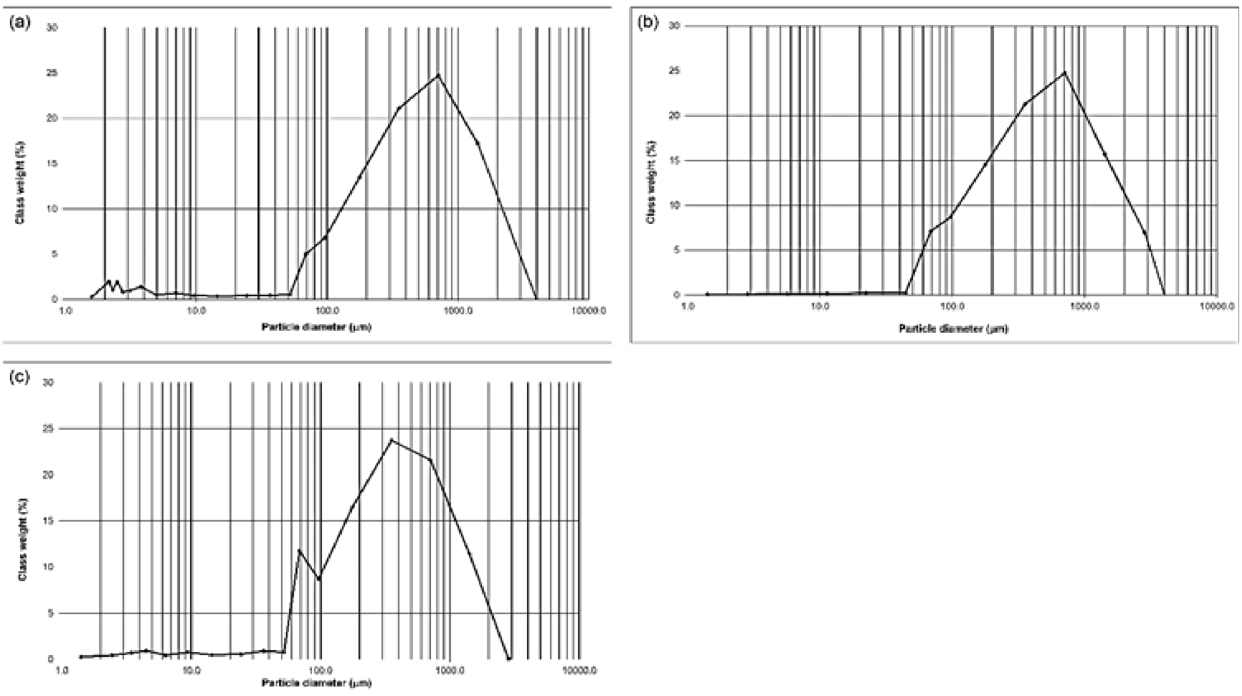
Supplementary Figure S5: Particle size distribution curves of the stratigraphic layers, Layer I (a), Layer II (b), Layer III (c) and Layer IV (d) at Pallemalala in phi units.



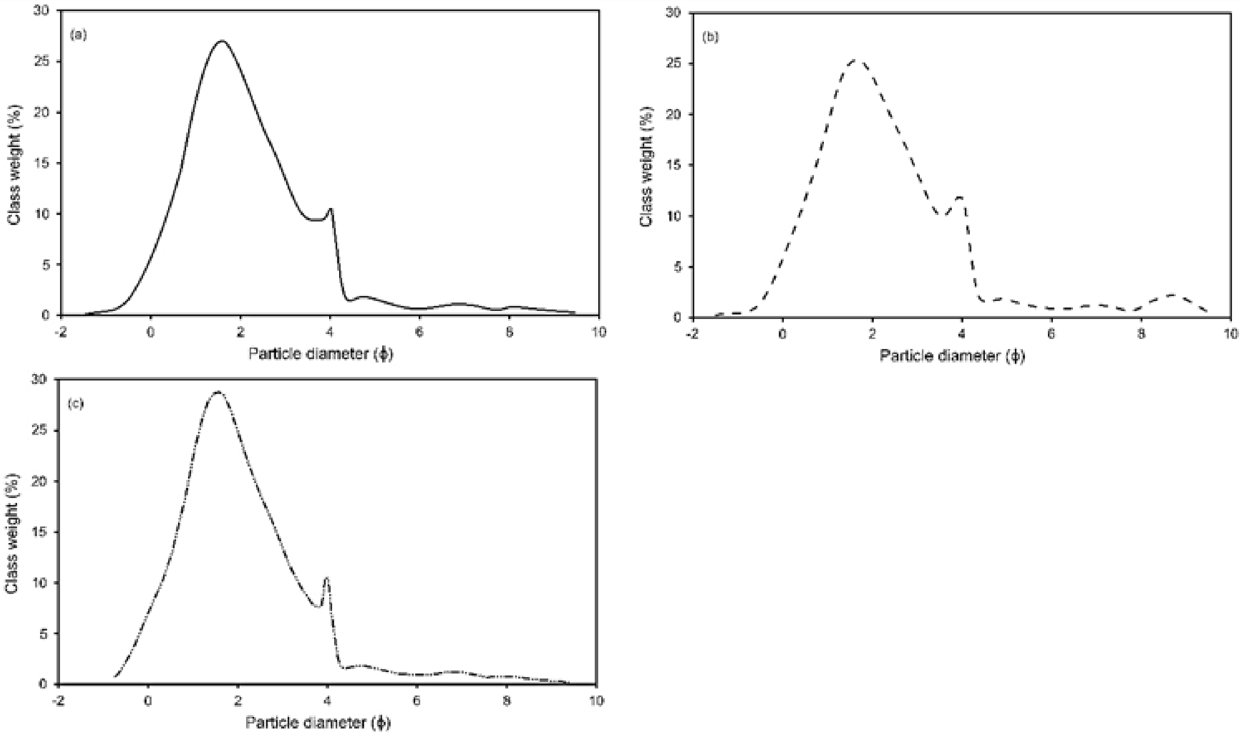
Supplementary Figure S6: Particle size distribution curves of the stratigraphic layers, Layer I (a), Layer II (b), Layer III (c) and Layer IV (d) at Pallemalala in microns.



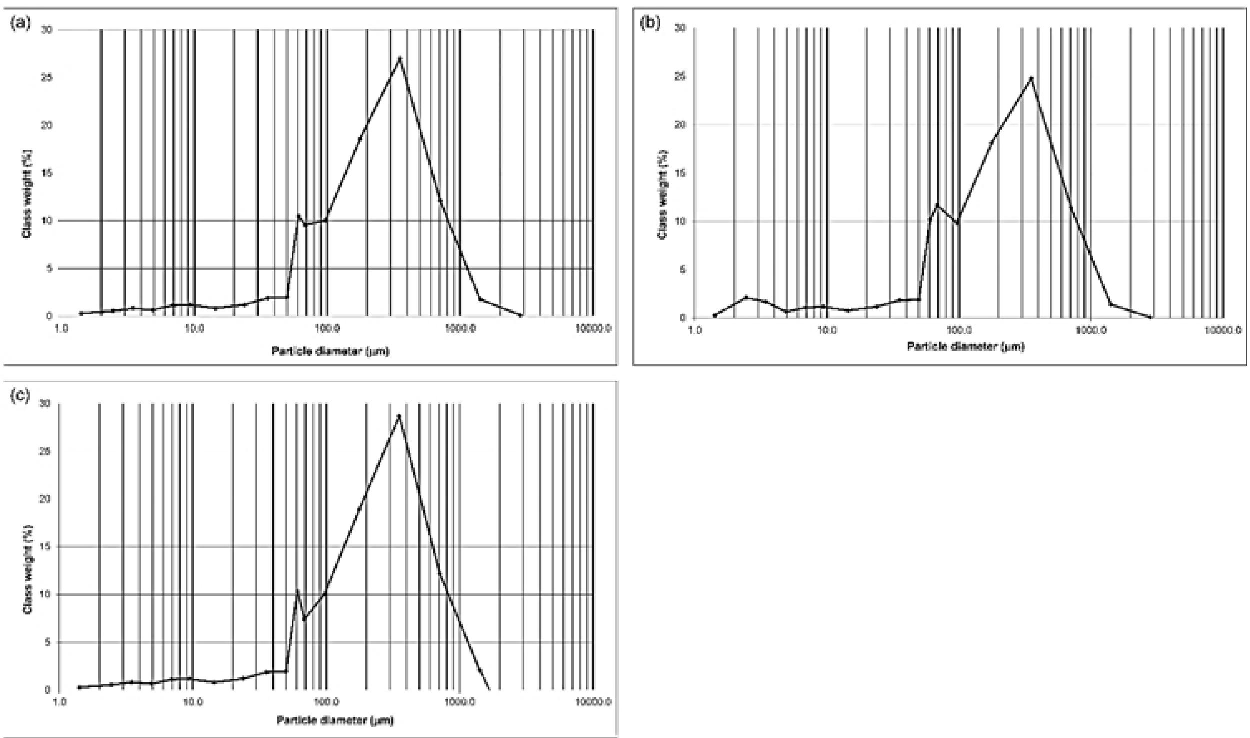
Supplementary Figure S7: Particle size distribution curves of the stratigraphic layers, Layer 1 (a), Layer 2 (b) and Layer 3 (c) at Mini-Athiliya in phi units.



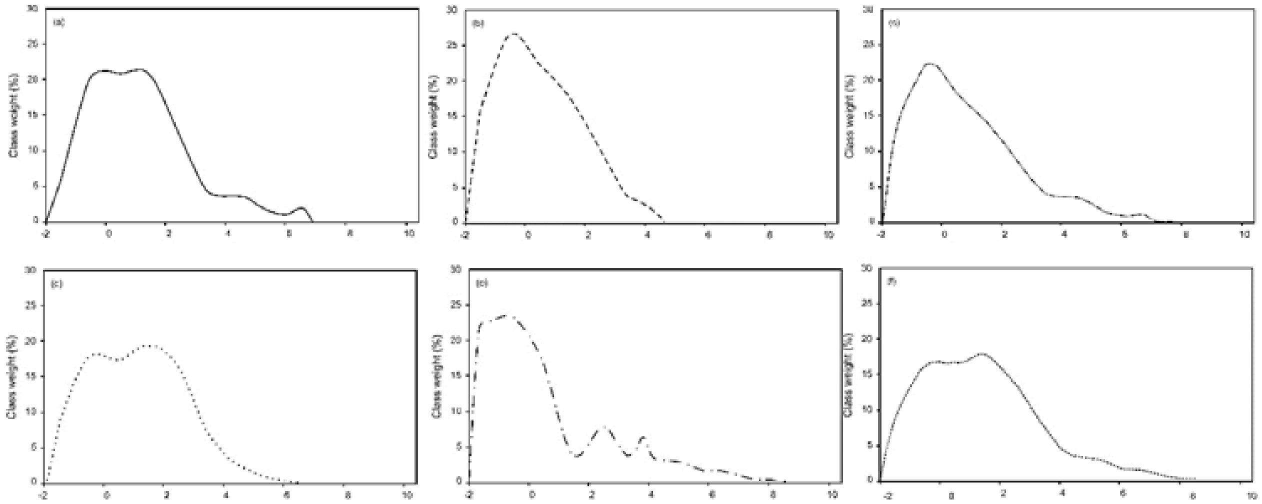
Supplementary Figure S8: Particle size distribution curves of the stratigraphic layers, Layer I (a), Layer II (b) and Layer III (c) at Mini-Athiliya in microns.



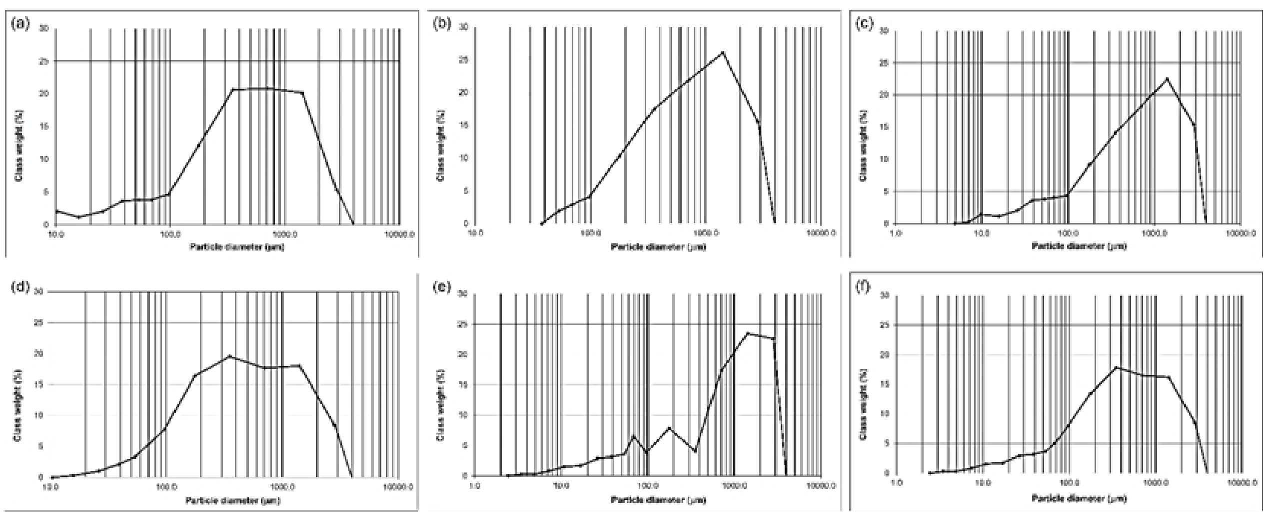
Supplementary Figure S9: Particle size distribution curves of the stratigraphic layers, Layer I (a), Layer II (b) and Layer III (c) at Bundala in phi units.



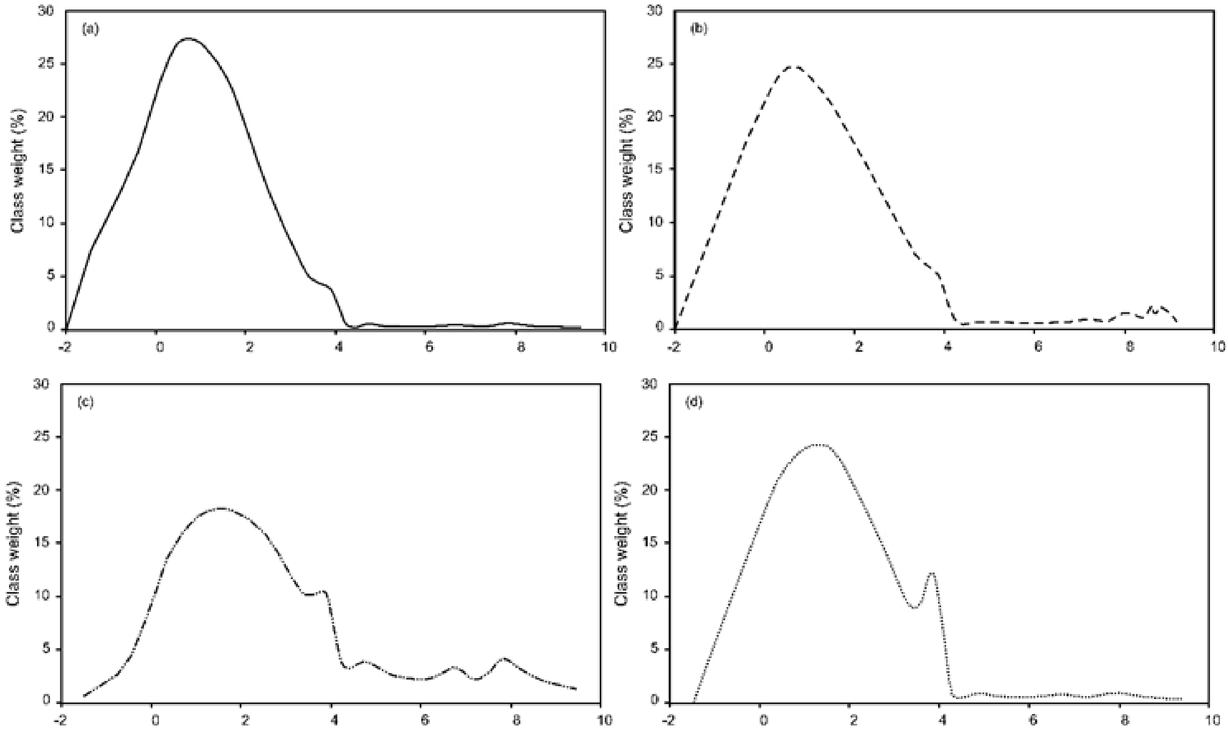
Supplementary Figure S10: Particle size distribution curves of the stratigraphic layers, Layer I (a), Layer II (b) and Layer III (c) at Bundala in microns.



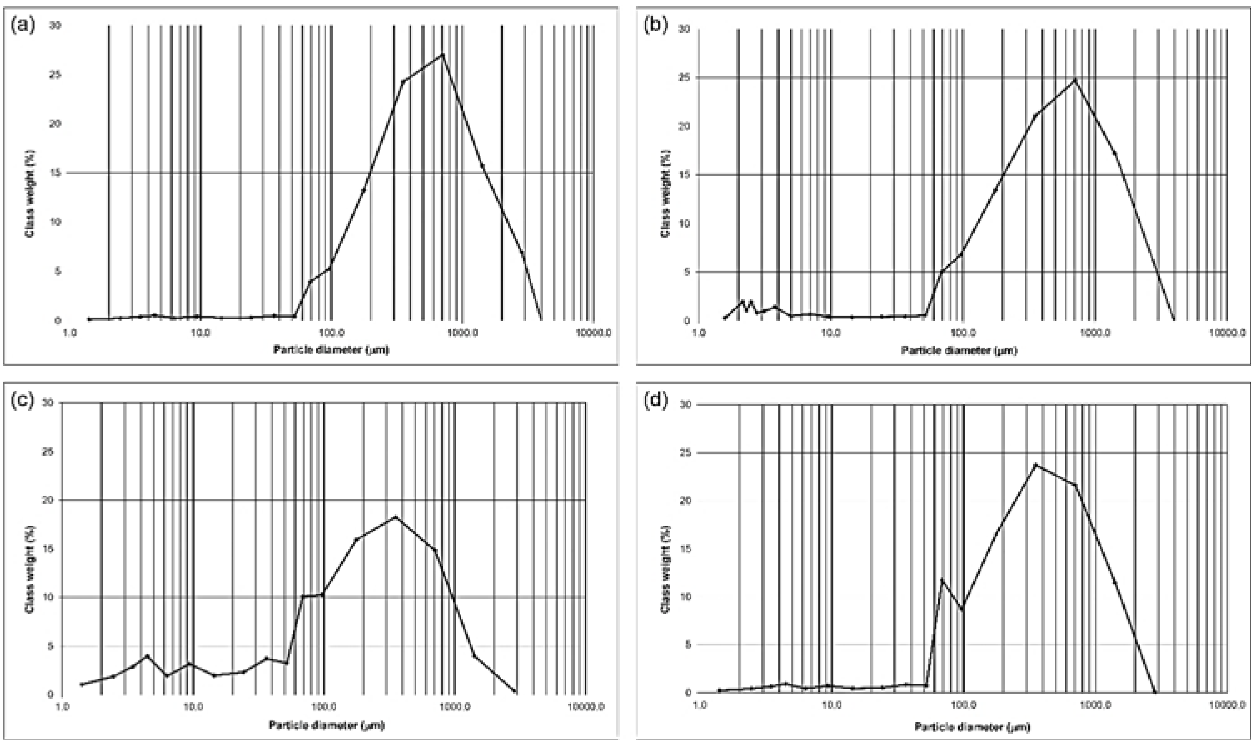
Supplementary Figure S11: Particle size distribution curves of the stratigraphic layers, Layer I (a), Layer II (b), Layer III (c), Layer IV (d), Layer V (e) and Layer VI (f) at Henagahapugala in phi units.



Supplementary Figure S12: Particle size distribution curves of the stratigraphic layers, Layer I (a), Layer II (b), Layer III (c), Layer IV (d), Layer V (e) and Layer VI (f) at Henagahapugala in microns.



Supplementary Figure S13: Particle size distribution curves of the stratigraphic layers, Layer I (a), Layer II (b), Layer III (c) and Layer IV (d) at Kalametiya in phi units.



Supplementary Figure S14: Particle size distribution curves of the stratigraphic layers, Layer I (a), Layer II (b), Layer III (c) and Layer IV (d) at Kalametiya in microns.