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EVOLUTION AND THE GEOLOGICAL SIGNIFICANCE OF LATE PLEISTOCENE FOSSIL SHELL BEDS OF THE SOUTHERN COASTAL ZONE OF SRI LANKA

JINADASA KATUPOTHA

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CONTENT

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FOREWORD

One of the functions of the Natural Resources, Energy & Science Authority of Sri Lanka (NARESA) is to award grants annually for scientific research in different disciplines with the aim of enhancing research capabilities and disseminating knowledge among scientists. In this connection every effort is made to provide researchers with the facilities and funds they need to carry out the work planned. The progress of projects are monitored by the respective Steering Committees and once the projects are completed NARESA makes an attempt to publish work that makes significant contributions to the fields of study undertaken.

NARESA is grateful to Dr. Jinadasa Katupotha for carrying out this useful study with abundant new and valuable information.

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PREFACE

This report analyzes the evolution and geological significance of the Late Pleistocene fossil shell beds on the southern coastal zone of Sri Lanka including their extent, usage, protection and management which have not been studied in detail before. The findings of this study have a bearing on (a) coastal management and (b) understanding the impact of rising sea-levels consequent to global warming.

In this report the author provides a most useful compilation of the data on geology, climate, landforms and natural vegetation in the shell-bearing areas. According to this survey the post-Glacial transgression appears to have started around 18,000 - 17,000 yr B.P. at about 120 m below the present level and lasted until about 10,800 to 10,300 yr B.P. The sea-level remained above or close to the present level during the mid-Holocene, ca. 5,000 - 6,000 yr B.P. Based on C-14 dates of geologic samples and published evidence, the author establishes five stages in the Late Pleistocene and Holocene Epochs.

Furthermore, this report presents an introduction to sea-level indicators such as coastal barrier sands, beachrock, emerged and buried corals, coralline algae, marine notches, submerged forests, fossil marine molluscs etc. and their relevance to the study of palaeo-sea levels, would be useful to geologists, geomorphologists, palaeobotanists and palaeontologists engaged in coastal studies. The point is made that the use of marine molluscs as a sea-level indicator is appropriate to Sri Lanka with due emphasis placed on the identification of shells, evolution of the shell beds and examination of their environmental values.

The shells of the study area belong mainly to three families: Veneridae (Venus clams), Arcidae (Ark shells) and Potamididae (Horn shells). The geological significance of the shell beds is described in detail at different locations emphasizing the levels, stratigraphy and their constituents all of which provide new information. Grain sizes as well as organic and inorganic contents of the shell pits also provide useful information.

On the basis of previous studies and from the present observations the author concludes that the mid-Holocene sea-level was at least 1.5 m above that of the present level with three episodes as follows:

(a) 6240 - 5130 B.P. (First episode of high sea level)
(b) 4390 - 3930 B.P. (Second episode of high sea level)
(c) 3280 - 2270 B.P. (Third episode of high sea level)

Depositional sequence and processes of the fossil shell beds indicate that the shell valves of lagoon, lake and channel beds (floors of marine and brackish pools) have mostly accumulated *in situ* consequent to the lowering of sea level around 4700 and 3600 yr B.P. when the sea level was at its present level or slightly below it. Furthermore, the southern coast itself and the shells distributed along it were buried in mud and debris which were washed down into the embayments by terrestrial waters. Using these data, the author attempts to explain the evolution of shell beds and their relationship to sea-level changes in Sri Lanka. All this information contribute to the further study of geoarchaeology, palaeogeography, palaeoclimatology and the impact of global warming on the South Asian region. Observations on debris of human bones, other animal bones, pottery and stone artifacts would undoubtedly be of significance to historians and archaeologists.

The report also takes note of the human impact on molluscan shell beds which others consider as timely. The shell miners have caused wide spread damage to private and government lands due to dumping of shell mining wastes. The author has identified the negative environmental impacts and threat to human life consequent to the above. The stagnant water pools of shell mined pits in many localities provide breeding grounds for mosquitoes, cause health hazards to the human population and threatens the existence of wild-life.

ACKNOWLEDGEMENTS

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My special thanks to Mr. William Sonnadara, Superintendent of Surveys, Hambantota Division for the kind support and arrangement of all facilities to collect levelling data from the field and Mr. G. Samarasinghe, Government Surveyor (Hambantota) and his team for helping to measure the sample heights at mean sea-level.

Thanks are extended to Research Assistant Mr. Premaratna Ekanayake who helped me in the drafting of the basic maps, collecting data and carrying out field work for the project.

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INTRODUCTION

1.1 Purpose and Significance

Deposits of coastal embayments contain high percentages of shell fragments and are therefore highly calcareous rather than silicaceous. Assemblages of bivalve and univalve molluscs occur due to the eustatic changes as well as by coastal hazards and they are a "useful" geoscientific tool in the study of former sea-level strands. This study attempts to analyze the geological significance of the Late Pleistocene shell beds on the southern coast of Sri Lanka. The study site lies within the "Dry Zone" between Tangalle and Bundala (Fig. 1.1.1). The geological significance, extension and evolution as well as utilization of the shell beds have not been the concern of any previous study. Revelation of these aspects would be of great significance to promote the mining of shells as a "cottage industry" which is presently continuing as a indiscriminate usage. Furthermore, it is necessary to preserve few selected localities as a natural heritage for geological, archaeological and palaeoenvironmental research.

1.2 Methodology

Extension of the shell beds was mapped based on detailed field investigations. The field investigations were carried out between March and December 1993. For this study shell and soil samples from twenty locations were collected for geologic analysis. All locations and sample heights were levelled to mean sea-level (msl) using TC 1600 EDM (Electronic Distance Measurement) theodolite (Set 3 B Sokkia) by Government Licensed Surveyor. Washing operation of the shells was conducted at the Department of Geography, University of Sri Jayewardenepura. Shells were identified by the author with the help of a published catalogue of shells (Seashells of Southeast Asia, R.T. Abbott, 1991; Simon & Schuster's Guide to Shells, B. Sabelli, ed. by Harold S Feinburg, 1980; and Shells of Japan, Tadashige Habe, Trans. by Thomas I. Elliott, 1978).

Colour of the soil samples and shell embedded soils was determined by the Revised Standard Colour Soil Charts (M. Oyama and H. Takehara, 1967). Separation of the grain sizes of the soil samples was undertaken using BS 410, Laboratory Test Sieve (Endecotts Ltd, London, England). Before separation of grain sizes, a weighted amount of dried soil was treated with 20% HCl to remove carbonate material. During the washing operation, plant roots and remains, silt and several organic matter were removed. The remaining was dried in an oven at about 100 C^0 for at least eight hours. The profiles of shell layers were drawn using Harvard Graphics. Formal and informal discussions were held with surrounding inhabitants to collect information on uses of shell beds and its impact on environment and health.

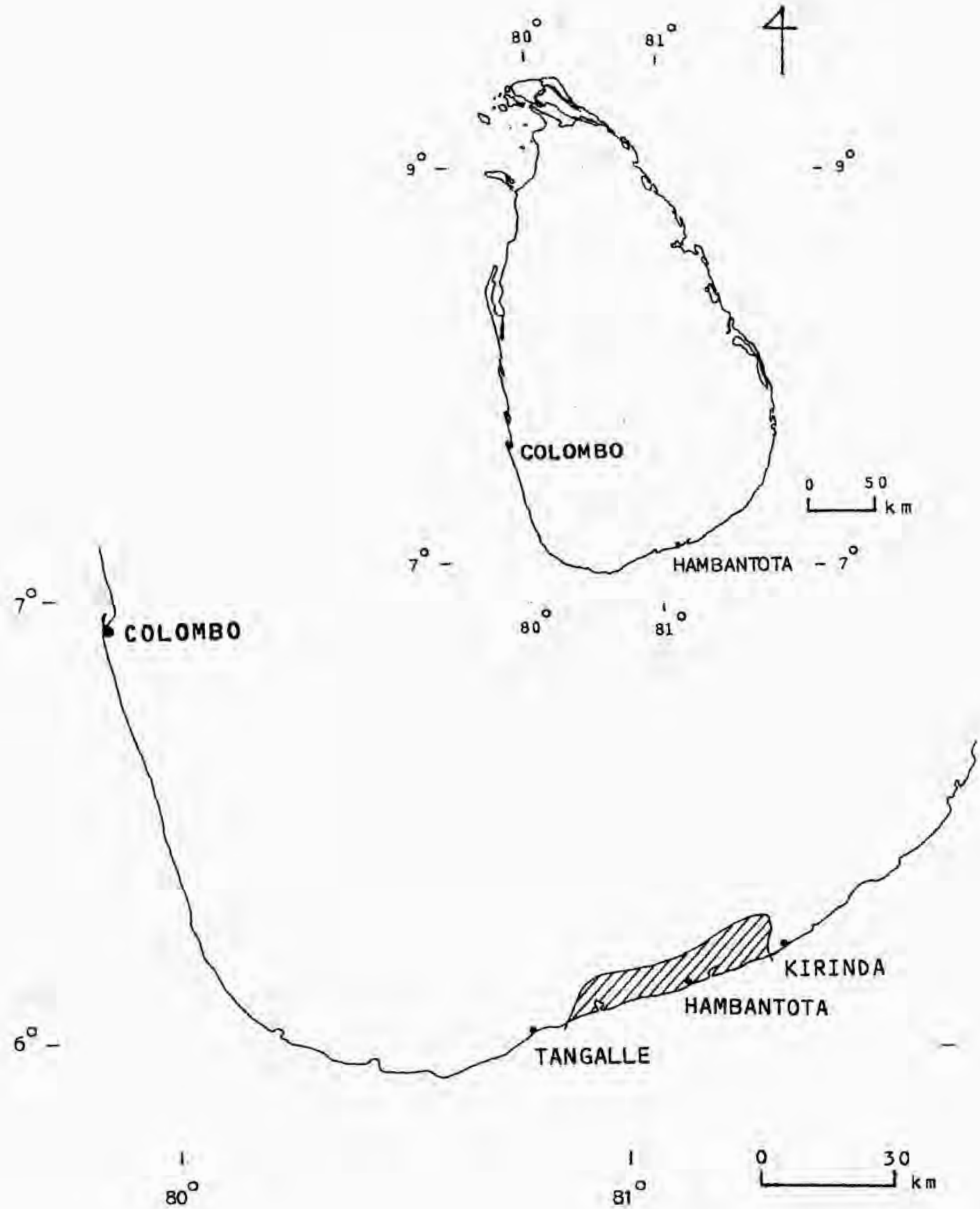


Figure 1.1.1. Location map of shell bed areas along the southern coastal zone of Sri Lanka

1.3 Limitations

Marine molluscan beds of Sri Lanka are found in several localities along the coast, sometimes about three to four kilometres inland from the present shoreline. The shells giant clam with fossil coral beds and small shells embedded in beachrock shoals occur between Ambalangoda and Matara. Besides, marine shell beds *Tridacna squamosa* and the window-pane oyster *Placenta placenta* occur at the base of the cliff-like banks of the Salape stream about 6 km inland from Kutchchaveli, north of Trincomalee; at the salterns near Elephant Pass and at Wanatavillu area (Deraniyagala, 1958; Cooray, 1984). It is necessary to undertake detailed investigations emphasizing different disciplines to examine the geological significance and the evolution of shell beds in the country.

Although, about twenty samples were collected from the southern coastal zone for C-14 dating, it should be mentioned that no such dating facilities are available in the country. However, the author used eight C-14 dates obtained previously for the interpretation of evolution of shell beds, and newly collected twenty samples will be preserved for dating purposes in the future. Due to the limited funds for field investigations and facilities for levelling, limited samples were levelled at mean sea-level.

2 PHYSICAL SETTING AND LAND USE

Extensive shell beds have been located in the Wanatavillu, north of Puttalam area on the western coast and the area between Kalametiya Kalapuwa and Bundala Lewaya (Hungama - Pallemalla) area on the southern coast. The study area, described here is situated in the southern part of Sri Lanka within longitude 80^0 48' - 81^0 16' and latitude 6^0 03' - 6^0 09' (Fig. 1.1.1). Accordingly the area stretches from Ambalangoda to Hambantota topographic sheets (1:63,360). Physical features and their characteristics including geological structure, landforms, climate, natural vegetation and soil were used to examine the evolution of shell beds. Land use in the area shows the extension of the shell beds and other economic activities.

2.1 Geology

Geologically the southern region is underlain predominately by the Vijayan Complex rocks (amphibolite facies rocks) in Precambrian age. The right bank of Walawe Ganga lies on the Highland Complex rocks (predominately granulite facies rocks) whilst the left bank comprise of biotite gneiss, hornblende-biotite gneiss, migmatitic and granitic in parts of the Vijayan Complex (Hapuarachchi, 1967 & 1968; Balendran, 1968; Geological Map of Sri Lanka, 1983; Cooray 1984). According to A Canada - Ceylon Colombo Plan Project (Resource of the Walawe Ganga Basin, 1980), study sites consist of two types of rocks;

(a) Hornblende and biotite gneisses with associated pegmatite and migmatite (Vijayan Series rocks).
(b) Quartz-feldspathic gneiss and granulite (Khondalite Series rocks).

The zone of Quaternary deposits here are somewhat narrow due to the extension of low hills and ridges close to the sea and lie on the Highland Complex and Vijayan Complex.

2.2 Geomorphology

Broadly, the study area, that is the southern coastal zone of Sri Lanka can be divided into three regions (Katupotha, 1992a), namely;

(a) Flat terrain (Lowland I, <30 m)
(b) Flat to slightly undulating terrain (Lowland II, <30 m)
(c) Undulating terrain (Lowland III, 30-150 m).

Based on elevation and the composition of the deposits, the lowlands can be grouped into three units;

(a) **Flat Terrain** (Lowland I, <30 m). The coastal belt which has been altered by aeolien and marine influences between Tangalla and Bundala is formed of narrow and long beaches, beach ridges with medium and somewhat high dunes. In some places the dunes reach heights of 15 to 20 m developed on bedrock. Salterns, salt marshes and mangrove swamps and mound topography (a hummock relief) lie behind them. These features also reflect the configuration of the underlying bedrock surface. The bedrock outcrops which are too small and too low appear as erosional remnants. Sand spits are common features at the estuaries of the Walawe Ganga and lagoons. Well-drained and imperfectly drained mixed aeolian, residual and alluvial soils occupy these areas. Lowland I is completely `flat terrain and slope is $1/2^0$ or 1^0 (1:100 or 1:60 in gradient).

(b) **Flat to Slightly Undulating Terrain** (Lowland II, <30 m) has 1^0 to 3^0 slope or 1:60 to 1:20 gradient and can be designated as 'flood plain'. The natural levee deposits of the lower Walawe Ganga basin comprise of well-drained soils. The flood plain has slightly undulating topography which exhibits many different landforms, e.g., channel scars, slip-off slopes, natural levees and slackwater areas, but rock-outcrops appear sometimes above 30m from the mean sea level on the low planation surfaces. Gravel surfaces in the area have well-drained to imperfect drained soils. The drainage in the flood plain varies from imperfectly to poorly drained. The lower course of the Kachigal Ara appears to consist largely of slackwater deposits with poorly drained soils. However, the clays of the old lagoon beds and just below the gravel beds are very plastic when wet. The gravels are known for their gem-bearing potential.

(c) **Undulating Terrain** (Lowland III, 30-150 m). Slightly undulating, undulating and rolling features appear particularly in the area between Udawalawe and Ridiyagama, and the area around Timbolketiya and towards the east of Timbolketiya the relief forms slightly undulating to moderately undulating terrain with well-drained soils. Dissected features and inselburgs in the areas around the Kiri Oya, Mau Ara, Guruwala Ara, Diyawini Oya and the Hambegamuwa Oya have been formed on intermediate planation surfaces. The gentle slopes or moderate slopes of undulating terrain vary between 3^0 and 6^0 (1:20 to 1:10 in gradient). The rocky knobs of the area rise from the surrounding plain, usually gently and sometimes abruptly, with steeper dome-like outcrops protruding 5 to 10m above the general surface.

The shell beds are mainly concentrated in the flat terrain beyond the right and left banks of the Walawe Ganga (Fig. 5.1.1). Behind the undulating terrain (Lowland hilly III), the Upland I (150-460 m) is mainly rolling and hilly terrain (6^0 to 11^0 or 1:10 to 1:5

Upland I (150-460 m) is mainly rolling and hilly terrain (6^0 to 11^0 or 1:10 to 1:5 gradient); Upland II (460 - 915 m) consists of rolling to terrain; rolling to hilly and steep terrain; steeply dissected hilly and rolling terrain; Upland III (915-1830 m) mountain ranges; steep rocklands with lithosols; steeply dissected rolling and hills; and mountainous terrain (1830m or more) extend towards the Central Highlands (Katupotha, 1992a).

2.3 Climate

According to Köppen classification, the southern coastal zone, from Matara to Bundala is classified as 'Afw"i, Amw"i', 'Asi' and 'Bsh' climates (Thambyapillai, 1960).

The selected rainfall stations of the southern coastal zone show two maximum seasons ((Fig. 2.3.1) during the Southwest monsoon (May to September) and convectional-cyclonic-depression (October to November).

2.4 Soils

Main soil types of the study area have a close relationship with the geologic characteristics, micro relief and climatic conditions.

Based on the Soil Map of Sri Lanka, four main Soil Groups of the study area are identified as follows;

(a) Reddish Brown Earths with high amount of gravel in subsoil & Low Humic Gley Soils
(b) Reddish Brown Earths & Solodized Solonetz (both (a) and (b) types lie on the undulating terrain
(c) Alluvial Soils of variable drainage and texture (covers flat valley bottoms, water logged areas etc.)
(d) Regosols on recent beach and dune sand (form barrier beaches, beach ridges, sand spits and dunes along the coast).

Rocknob plains and erosional remnants in the coastal plain are formed by granitic gneiss, quartzite, hornblende gneiss and hornblende - biotite gneissic rocks.

2.5 Natural Vegetation

According to Fernando (1968) and A Canada - Ceylon Colombo Plan Project (Resources of the Walawe Ganga Basin 1980) the southern coastal lowlands are covered by riverine forest, swamp vegetation, mangrove and littoral vegetation (see 2.6 for more information).

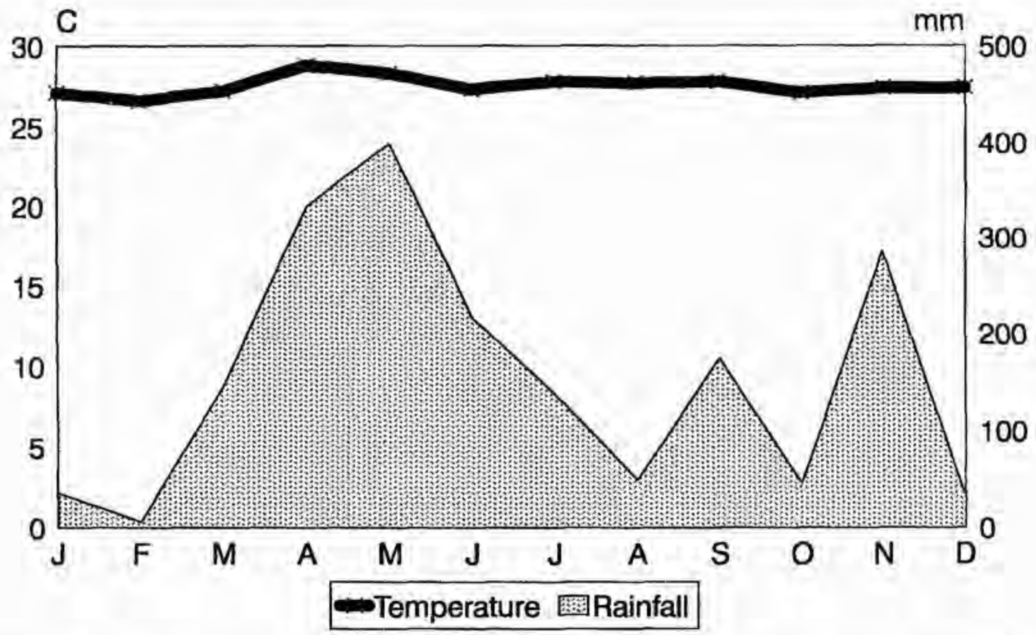


Figure 2.3.1 Monthly variations of temperature and rainfall of the Hambantota area - 1994

2.6 Land Use

The distribution and extent of the land use of the southern coast have a close relationship with geological structure, local relief, climate, soil and drainage, and climate. It is fairly different to that of the western and southwestern coasts. The coastal lowlands are covered by barren lands mainly of sand dunes. Medium sized dunes in the area are 15 - 20 m in height and they are active and migratory. Such areas were not studied in detail as they are not relevant to the study. Most of the dunes are covered by creeping vegetation as well as stunted trees such as *Spinifix littorerus* and *Ipomoea pescaprae* and scrublands (*Cassia auriculata* - Ranawara, *Ferŏnia limonia* - Divul, *Dichrostachys cinerea* - Andara, *Carissa spinarum* - Karamba etc.). Among the trees scattered within the scrublands are *Manilkara hexandra* - Palu and *Nerium odorum* - Veera. The wet lands behind the sand dunes are occupied by mangroves along the estuary of the Walawe Ganga and around lakes and lagoons.

Salt-pans, salt and brackish water lakes of the area are subjected to daily tidal fluctuations. *Sonneratia alba* (Kirilla) is the dominant mangrove species of the area. Among other important mangroves are *Nypa fructicans* Ginpol (which extended along edges of lagoons and tidal creeks), and the *Rhizophora, Bruguira* and *Ceriops* spp. Lowlands which are slightly above the mean high water springs level appear as freshwater marshes. Brackishwater and freshwater marshes are widely occupied by *Typha angustifolia* (Hanmbupan) along the lower part of the Walawe basin (Katupotha 1992a).

The undulating and low ridge and valley topography (30 - 150m), behind the coastal lowlands are covered by sparsely used croplands, homesteads and chena cultivation as well as dry zone thorny forests. The paddy lands have been concentrated in the fairly wide valley bottoms such as the area to the south of the Ridiyagama Tank and the area north of Angunakolapalessa.

3 LATE PLEISTOCENE AND HOLOCENE EPOCHS

3.1 An Introduction to the Late Pleistocene and Holocene Epochs and their Events

The Age of man or the great Ice Age is designated as "Quaternary". It began ca. 2 million years ago and continue 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 2.0 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). By means of the uranium-series method of coral reefs from the Bahamas and Florida Keys, Nilson (1983) suggests that the phases of marine limestone formations were ca.85,000, 130,000 and 190,000 yr B.P. Similar investigations of Barbados in the West Indies show that the marine high-water strands had existed ca. 82,000 (Barbados I), 105,000 (II), 125,000 (III) and 200,00 (IV) years ago and Barbados III is calculated to have reached some 20-25 higher than the others. Radiocarbon and uranium-series datings of stalagmite material extracted from submarine caves in the Bahamas have given consistent information on a low eustatic sea-level 22,000 years ago, a date which collaborates with the Last Glacial Maximum (LGM). Based on absolute dating between the Glacials and Interglacials, the tentative correlation of the Quaternary stages of north America, the Alps, northern Europe and Poland-USSR are shown by Fairbridge (1968). Similar results on different stages of the Quaternary are presented by Evans (1972), Mörner (1972a and 1972b), Kind (1972), Stearns (1976), Chappel (1974) and Pickett et al. (1985).

During the LGM, ca. 18,000 yr B.P., the sea surface circulation pattern of the Indian Ocean was significantly different from the modern pattern and the southwest monsoon wind which prevailed was weaker than today (Prell et al. 1980). Williams (1985) described that towards 18,000 yr B.P. the salinity gradient in the Bay of Bengal was very much higher than today, reflecting a drastic reduction in freshwater input from rivers. At that time, the climate was drier and windier over much of tropical Africa, Australia and South Asia with less rain in summer and stronger monsoon winds in winter. Furthermore, Kolla and Biscave (1977) prove that the amount of quartz transported in terms of atmospheric dust from the Arabian and Australian deserts into the adjoining oceans was greater than at present during the LGM. Giresse (1987) indicated that the Australio-Anthropian populations reached the Angolan coast of west Africa between the Lower and Middle Pleistocene, notably near Lunda, a poorly developed Oldowayen industry indicated in the 100 m of south Lobito and the 35 m terrace of Ponta do Giraul - Mossamedes. These facts indicated in the 100m of south Lobito and the 35 m terrace of Ponta do Giraul - Mossamedes. These facts indicate that the different palaeo-cultures had extended towards the seaside from the present coastline over the submerged continental shelves during the LGM. The end of the last glacial stage around 12,000 yr B.P. brought about a massive and rapid rise of sea-level. Fairbridge (1961), Gill (1961) and Mörner (1971 and 1982) mentioned quantitatively that the sea-level rose to its present level some 5,000 - 6,000 years ago and has since fluctuated within 3 metres of its present level, including one or more conspicuous stands at 2 - 3 m above present level some 2,000 - 3,000 yr B.P. The general form of the sea-level/time curve is asymptotic, showing a rise of approximately 1 m/100 years at first then rising to 2 or 3 cm per 100 years at 7,000 - 5,000 yr B.P. (Pethick, 1984). Giresse (1987) describes from the Ivory Coast Shelf, three negative oscillations towards the end of the Holocene. Therefore, Maud (1968) mentions that from the Durban area of the Eastern Coast of Africa there were four postglacial levels at the following heights and ages: (a) 4.5 m at 5,500 yr B.P.; (b) 2.4 m at 3,800 yr B.P.; (c) 1.5 m at 2,200 yr B.P.; and (d) 1.0 m at 1,220 yr B.P. Åse (1987) correlated Maud's findings with the mention of another four levels from the Mombasa coast.

3.2 Late Pleistocene and Holocene Events of 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. Accordingly 'Ratnapura Stages I and II appeared in the middle Pleistocene and 'Ratnapura III' 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.

Deraniyagala (1986) proved that Late Pleistocene alti-thermal 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-lumnescence) and the Pathirajawela deposits are dated at 28,440 and 64,380 - 74,200 yr B.P. The basal gravel at Pathirajawela have been overlain by wind blown sand of 64,300 - 74,200 yr B.P. and may tentatively be correlated with early Würm. This could be another episode of 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 - 60 m msl and could in fact be correlated with a ca. 30 m high sea-level with the middle Pleistocene (Hosteinian interglacial) at about 300,000 - 265,000 yr B.P., on the same basis, the 25 m gravel found in the Bundala - Levengoda area can be correlated with the 'Eem interglacial' at

In the 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). 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 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 nearshore 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.

The sea-level was about 120 m below from the present level during the Last-Glacial Maximum. The Post-Glacial transgression (PGT) appears to have started around 18,000 - 17,000 yr B.P. and lasted from about 10,800 to about 10,300 yr B.P. At many locations of the tropical subtropical coasts the sea-level remained within 3 - 5 m from the present level during the mid- Holocene (Fairbridge, 1961; Walcott, 1972; Pirazzoli, 1987). On the basis of weathering conditions, the colour and constituents of the sand and height of the beach ridges can be used as indicators to the study of the evolution of coastal lowlands of Sri Lanka (Katupotha, 1988a). Based on C-14 dates of geologic samples (Katupotha, 1988b, 1988c and 1988e, and published evidence, Katupotha (1991) recognises Late Pleistocene and Holocene events as follows:

(a) Stage I: From Late Pleistocene to Early Holocene. According to Wayland (1919), Deraniyagala (1958) and Späth (1985) desert like conditions occurred during the LGM in much of the low country. 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 Kolla and Biscave (1977), and Williams (1985). According to the dry climatic condition that prevailed, low hills and ridges were coated mainly by wind blown sand during this period. The red colouration of such sand is the basic requirement of an iron source, availability of a minimum amount of moisture, oxidizing interstitial conditions, and sediment stability is sufficient to allow the build up of iron oxides (Gardner and Pye, 1981).

Following the PGT, marine features such as low-lying ridges, well-marked troughs and terraces have been formed on the inner and outer shelves. Recent oceanographic investigations reveal that the coralline algae, limestone and calcareous sandstone had been developed gradually on these 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 since 17,000 yr B.P. This transgression has caused the rivers to fill their valleys and discharge their loads over the submerged peneplain.

17,000 yr B.P. This transgression has caused the rivers to fill their valleys and discharge their loads over the submerged peneplain.

(b) Stage II: Between Mid- and Late Holocene (6,600 - 2,270 yr B.P.). In the interpretation of C-14 dates of geologic samples from the western and southern coasts, Katupotha (1992b) recently indicates that the mid-Holocene sea-level was at least 1.5 m above that of the present level with three episodes. Following these high sea-level episodes, the former drainage basins were submerged and headland bay-beaches were created. As a result, the presently buried corals between Akurala and Matara thrived in former lagoons where factors were suitable for the growth of coral. C-14 dates reveal that in a low stand of sea-level during the Late Holocene the coral colonies were buried in muddy waters which were washed down into the embayments by terrestrial waters. Such deposits had been intermittently covered by vast quantities of coral, sand and various types of debris moved by severe monsoon waves (Katupotha, 1988d; Wijayananda and Katupotha, 1990).

(c) Stage III: Late Holocene (around 3,700 yr B.P.): It is suggested that the beachrock, slightly above mean high-water spring and inter-tidal level zone, on the west coast had been formed during this stage. As evidenced from C-14 dates of shells embedded in emerged reef patches (Hubbs et al. 1962; Katupotha, 1988b) and corals (Katupotha, 1988b and 1988c) the climatic changes have occurred after the mid-Holocene high sea-level. The origin of this beachrock can be correlated with that of the beachrock in Brazil and Venezuela (Katupotha, 1989). Further, 14C dates of shell deposits along the southern coast in the Hambantota district also prove that such changes have occurred during the Late Holocene (Katupotha and Wijayananda, 1989).

(d) Stage IV: Recent beaches and sand spits etc. Bryant (1987) explains that there has been a close relationship between CO_2 - warming, rising sea-level and retreat of coasts in both hemispheres since 100 yr B.P. Fairbridge (1961) reports on the extent of the rise of sea-level and glacial retreat since 100 yr B.P. As a result of these global changes, secular and seasonal changes of landforms have also occurred along the present coastline of Sri Lanka.

The gravel deposits, Red Beds and stone tools were already described by Wayland (1919), Wadia (1941), Deraniyagala (1958), Cooray (1967 and 1984), Cooray and Katupotha (1992) and Deraniyagala (1986) and can be correlated with the long fluvial phase which was followed by interglacial stages 2nd and 4th (between middle Pleistocene - Eemian and Late Pleistocene -middle Würm).

4 SEA-LEVEL INDICATORS

4.1 An Introduction to Sea-level Indicators and Their Significance to the Study of Palaeosea-levels

Sea-level indicators differ widely in indicative value (accuracy). They are important for the consideration of sea-level changes within the context of the geological development of an area (Plassche, 1986). Accordingly many materials such as raised marine deposits, coastal barrier sands, beachrock, ooids, corals and reefs, coralline algae, marine notches, submerged forests, marine molluscs etc. have been used from different locations in the study of worldwide sea-level changes.

Andrews (1986) describes the sediments of glacio-marine and marine origin from msl to ca. 300 m above sea-level within the areas that were formerly covered by the Pleistocene ice sheets. In addition to raised marine sediments, these areas of glacio-isostatic recovery also record traces of former shorelines, such as marine-cut terraces, and the lower limit of till and/or perched boulders. The study of raised marine features in the areas of former ice sheets has provided significant information on the viscoelastic structure of the earth and in turn provides vital data on the geometry and chronology of the ice sheets on global changes of raised marine sediments and landforms which can be applied to determine the palaeosea-level.

Former sea-level positions from barrier deposits have been discussed by Roep (1986). Based on coastal geomorphology, recent coastal sediments and fossil barrier deposits, depth distribution of sedimentary structures and shells along the present coast are widely applied to account for sea-level of the western Netherlands. Weathering conditions, colour, constituent of the sand and height of the beach ridges have been used as sea-level indicators to the study of the evolution of the western coast of Sri Lanka (Katupotha, 1988a).

Emerged beachrock reefs also provide a useful indicator of a palaeo-tide level. Although it is generally agreed that beachrock forms within the intertidal zone, the exact upper limit to the cementation processes is uncertain, particularly in areas of high tidal range (Hopley, 1986a). Problems occur with dating materials from outcrop: a maximum age may be obtained from constituent organic materials, a minimum age from the cementing matrix, but difficulties may be encountered in the interpretation of such dates. Further, Hopley (1986a) mentioned that beachrock should be used as an indicator of former sea-levels in conjunction with other types of evidence. Cooray and Katupotha (1992) and Katupotha(1989) discuss the possible correlation of submerged beachrock to reveal the post-glacial sea-level rise in Sri Lanka. According to Kump and Hine (1986) ooids are subspherical carbonate sand grains, composed of concentric laminae.

They provide a wealth of information about the environments of origin, distribution and diagenesis of a particular sedimentary deposit. These beds are also useful to evaluate the palaeosea-levels, but they make unreliable indicators when used alone.

Coral reefs are built by and contain a large range of plants and animals, many of which have a specific relationship to sea-level (Hopley, 1986b). Coral ecology and calcification, zonation and colonial morphology, in situ position, upper limit of open-water and moating during the inter-tidal level etc. are responsible for reef building to sea-level. Therefore Hopley (1986b) states that, "a gross relationship between sea-level and reef growth is quite clear, the use of coral reefs to establish palaeosea-levels has a number of reservations and difficulties".

Accordingly, other reef organisms (boring clams - *Tridacna crocea*), the encrusting rock oyster (*Crassostrea amasa*), *Lithophaga* spp. which are limited to the inter-tidal environment etc.; geochemical indicators, detrital deposits and other internal indicators can be used in the study of palaeosea-levels on coral reefs. Emerged and buried coral reef patches (most of them are in position of growth) have been used in the study of sea-level changes in Sri Lanka (Katupotha, 1988b, 1988c; Katupotha and Fujiwara, 1988; Wijayananda and Katupotha, 1989).

In tropical and temperate waters, and particularly in supersaturated seas, coralline bioherms (algal ridges and trottoir) develop in close association with sea-level and can be precision indicators of sea-level (Adey, 1986). Besides, Family Vermetidea may under certain circumstances, build conspicuous benches or corniches on the littoral zone of rocky coasts that are subject to moderate or heavy surf action in tropical and subtropical waters. Vermetid shells are wholly aragonitic, and are therefore little prone to contamination and are easily dated by C-14 techniques, which makes them all the more desirable as sea-level indicators (Laborel, 1986).

Coudray and Montaggioni (1986) describe the diagenetic products of marine carbonates as a sea-level indicator, and the reliability of textural, structural, mineralogical and geochemical diagenetic criteria in identification of sea-level changes from Pleistocene to Holocene. According to them studies of diagenesis require the use of various sophisticated analytical techniques. Absolute diagenetic products may be performed, using the classical radiocarbon, U-Th and amino-acid racemization methods. The diagenetic products of ancient marine carbonates are believed to be useful to roughly determine the location of palaeosea-level, just below or above a nearshore environment. The descriptive terms infralittoral, midlittoral (tidal and surf zone) and supralittoral are used to classify sea corrosion notches, according to their elevation relative to sea-level at the time of formation. On limestone coasts, tidal notches most useful sea-level indicators (Pirazzoli, 1986). By these means, the local erosion rates can be estimated. A fossil notch may indicate both the position and approximate duration of a sea-level stand as well as the speed of the sea-level change.

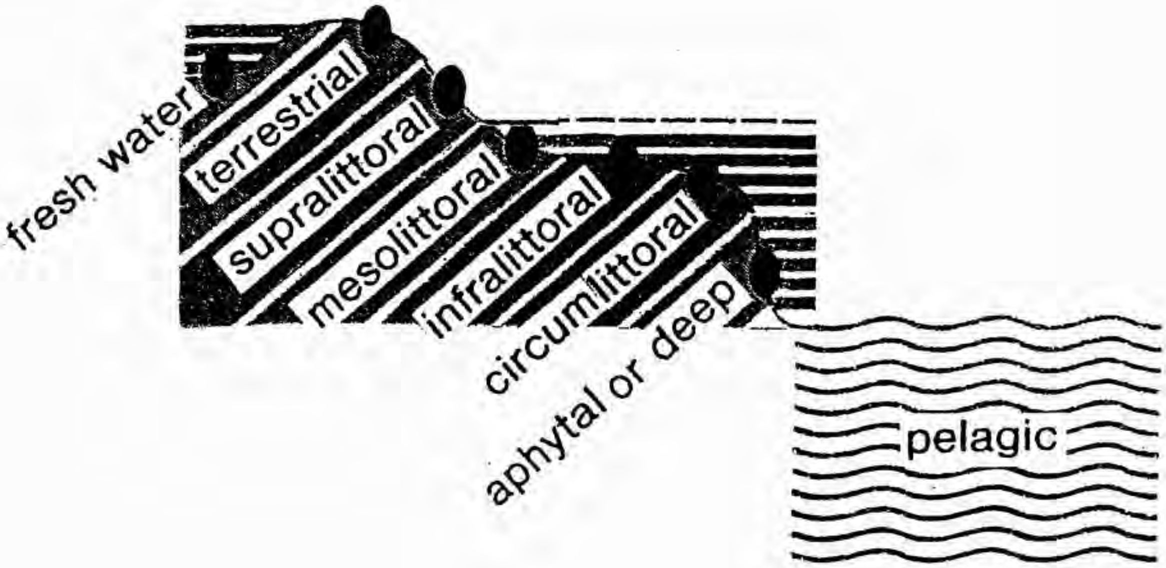
Submerged forests also form most useful indicators in the study of former sea-levels. They are defined as assemblages of tree remains, clearly in their growth position, and regularly covered by the tide. They are usually found as peat beds, containing the stumps and trunks of trees, which outcrops on the foreshore (Whittow, 1984). According to Heyworth (1986), the lowest level of the tree growth are closely related to a point between the local mean high water spring tide and highest astronomical tide and the preservation of trees in submerged forests is an accurate reflection of past sea-levels.

There are over 1000 foraminiferal species presently living in marine environments, but relatively few of these can be used as direct indicators of sea-levels (Scott and Medioli, 1986). Furthermore, Palmer and Abbott (1986) indicate that diatom analysis is a powerful tool and a valid complement to other techniques in the study of sea-level changes. Therefore, Harten (1986) discusses the possibilities of the application of ostracods to problems of sea-levels. Martin, Suguio and Flexor (1986) use the shell middens as a source for additional information in Holocene shoreline and reconstruction of sea-level.

4.2 Marine Molluscs as a Sea-level Indicator

Mollusca is a group of invertebrate animals which may be terrestrial, freshwater or marine in habitat. The diversity and complexity of these habitats are due to winds, waves, tides, bottom features, daytime illumination, geologic origin of shoreline and ecologic conditions of the oceans (Whitton and Brooks, 1983). They create special zones (Fig. 4.2.1) which are suitable for certain species (Abbott, 1991; Sabelli, 1979). Commonly mollusca has a shell secreted by the mantle. The shell may be either external univalve, external bivalve, internal or missing (Whitten and Brooks, 1983). However, shells of animals like barnacles and crabs are not known as Molluscs.

Shells exhibit a wide variety of pattern and colouring that often match those of the animals that built them. The many types of Molluscs have hard, calcium skeletons, and they are found in diverse forms of natural beauty and have economic and social values. Prehistoric man used them for personal adornment and as charms; even at the present time, many tribes specially in African countries wear strings of sea-shells for like purposes. Before money was invented, primitive people used certain kind of sea-shells in barter. Presently many species are used extensively as human food in Southeast Asian and also in the Western countries. The basic nature of the present day molluscan fauna, that is, the families and genera now represented, was determined millions of years ago as the great land continents were drifting into their present position.



Molluscs live in either fresh or salt water or on land. Marine molluscs may be benthic or pelagic. Benthic organisms live on or near the bottom of the sea, while pelagic plants and animals live free in the water. The benthic dominion can be divided into two zones; the littoral and the deep. The littoral zone, once again can be divided into planes, regions within which the environmental conditions are constant or change gradually. The heights plane is supralittoral, which covers the strip of beach above the high tide level. This area is submerged occasionally. The next plane is the mesolittoral, and extends from the high-tide mark to the normal tide mark. The infralittoral plane extends from the lower limit of the mesolittoral to the lowest depth at which a certain family of plants, called the *Zesteraceae* can survive. Circumlittoral plane extends down to the lowest level where green algae can survive. All these environments provide homes for a tremendous variety of molluscs.

Figure 4.2.1. Extension of marine molluscan between supralittoral and circumlittoral zones.

As the climate, both atmospheric and oceanic changed and vacillated, all, species came under new challenges to their survival. The least adaptable are found today only as fossil remnants locked in Tertiary beds; other populations were divided, isolated and evolved into new species, while many more resistant ones flourished and spread from freshwater to pelagic areas (Abbort, 1991).

The Phylum (a phylum is a large group of living things with anatomies that are similar as a result of their common evolution) Mollusca includes a seemingly infinitive variety of forms in their evolution. It is comprised of six Classes viz; Monoplacophora; Amphineura, Gastropoda, Scaphopoda, Bivalvia and Cephalopoda - with some 70,000 species in all (Peterson, 1986). Habe (1978) adds the Class Aplacophora to above six, with 112,000 species. Aplacophora dates from the Lower Cambrian; the Class has 10 species. The worm-shaped creatures have no shells. The Monoplacophora (Neolipina Class) well-known from the Palaeozoic deposits of epicontinental seas, are today only represented by those recently found from the deep sea, having a lipet-like (cap-shaped) shell. Scaphopoda (Tusk shells) practically never found in the tidal zones, but known from the shallow waters to the deep sea (was dredged from a depth of 6,900 - 7,000 m). Tube shaped shells which widen towards the aperture, are known from the Devonian period. About 500 species are known in this Class.

The Bivalvia (Pelecypoda) comprising of about 10,000 species (25,000 species by Habe), are mainly found in the areas close to the coast as fauna elements. The clams are covered with two shells on right and left. They are known from the lower Devonian. The Gastropoda (univalve) are by far the largest of the six Classes and comprise 50,000 to 60,000 species (85,000 species by Habe). It is the most varied group within the Mollusca, dating from the Upper Cambrian. Squid and Octopus in Class Cephalopoda are all predatory, swimming carnivores occurring in the major marine habitats. The shells may be found on the beaches - drifted ashore, often far from the place where the animal actually lived. They are known from the Cambrian. The Class consists of 600 species.

The Amphineura (Poliplacophora - Chiton Class) are found from the temperate to tropic areas and they usually live on rocky surfaces close to the shore. These oval-shaped bodies covered with eight shell plates arranged longitudinally date from the Upper Cambrian. This Class has 1,000 species (Habe, 1978). Considering all these shells on the basis of the quantitative investigations, it is possible to differentiate only between littoral, shallow and deep water environments as useful in the identification of former sea-levels. Shell-secreting molluscs inhabit all the different regions of the sea, from cold polar regions to the warm equatorial belt, from surface water and intertidal beaches down to abyssal depths. The warm shallow seas where reefs and rocks are abound are thickly populated by these molluscs.

The continental shelf around Sri Lanka comprises of submerged rocks, sand banks, sandstone and coral reefs. Most of these features are situated on the mesolittoral zone, known also as the intertidal zone (it extends from the high-tide mark to the normal low-tide mark) where green algae can survive. The infralittoral plane extends from the lower limit of the mesolittoral to the lowest depth at which a certain family of plants, called the *Zesteraceae* can survive. Such well developed conditions of the seas around Sri Lanka provide an ideal environment for a rich variety of molluscan shells. Kirthisinghe (1978) has pointed out that research on sea shells of Sri Lanka are found sporadically here and there in zoological journals and in the records of oceanographic surveys. Of those, Tennant (1861) listed about 400 sea shell species and the Report of the Ceylon Pearl Oyster Fisheries (1906) recorded 520 species. Therefore Kirthisinghe (1978) described about 530 species collected in the seas around Sri Lanka. Most of these species are found throughout the Arabian sea southwards to the east of Australia, and a long way from the coast of Australia.

Three types of marine molluscs are found in Sri Lanka (for further details see P. Kirthisinghe, 1978).

(1) shells of Pelecypoda or bivalve molluscs (bivalvia by Peterson,1986)
(2) shells of Gastropoda or snail-like molluscs
(3) shells of Cephalopoda

Pethiyagoda, 1978 discussed briefly the geology and economic significance of shell beds along the Hungama - Hambantota coastal area. As well Weerakoon et al (1985) reported also briefly the distribution, stratigraphy and the mining of shells in the same area. The present investigation of raised shell beds on the southern coast indicate that they have been piled up in former lagoonal embayments, alluvial mounds (hummocks) and headlands from Kalametiya to Pallemalala (Bundala).

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5 FOSSIL SHELL BEDS OF SRI LANKA

5.1 Micro-relief around the Shell Beds

All shell beds along the southern coastal zone is laid on the Lowland I Unit (Flat Terrain, < 30 m). It has slope of $1/2^0$ or 1^0 (1:100 or 1:60 in gradient). Both monsoon winds (southwest and northeast) blow parallel to the coast, rather than across it, and the waves are largely constructive southerly swell (Swan, 1982).

The coastal belt from Tangalle to Bundala is formed of narrow and long barrier beaches and beach ridges. Dune bearing barrier spits are common features at the outfalls of the Walawe Ganga and the circular shaped lagoons. Garnet and ilmenite sands are found in most shore deposits along the beach. Well-drained and imperfectly drained soils occupy these areas.

The wetlands are covered by lagoons and lakes, salt marshes and mangrove swamps behind them. Most of them appear as low outcrops along the coast. The lagoon and lakes are known locally as 'Lewayas' and these are not fed by large streams. Most of them are very saline due to the persistent winds and dry climatic conditions. These conditions have been created by rapid evaporation. Slight undulations of the area extend as lobes sloping towards the coast.

Detailed investigations indicate that the shells are highly concentrated as pockets around the Kalametiya Kalapuwa, Hungama and Lunama Kalapuwa; Mahasittrakala Lewaya; the area between Karagan Lewaya and Pallemalala and the area between Embilikala Kalapuwa and Bundala Lewaya. The extension of the shell beds is shown in Fig 5.1.1. The levels, thickness and the relief of the shell beds are summarized in Table 5.1.1. Most of these are mined from paddy fields, small mounds (hummocks), former embayments and the bottoms of lagoons, lakes and creeks. The shell beds in Hatagala extend up to Miniethiliya about 4 kilometres inland from the present coast. The shell beds at Hungama - Ovitigodayaya (paddy field) are composed of Meretrix spp (Plate 5.1.1 A). They are somewhat large (about 55 mm in size). Highly weathered pieces of elk bones and pottery fragments can be found from some mining pits.

The shells at Miniethiliya are mined from small mounds near the paddy fields (Plate 5.1.2.) and small mounds slightly elevated from the paddy fields (Location 1 & 2) of about 0.5 ha. in size. The beds at Hungama - Pallegama (Ihalagama Yaya) are also mixed with univalve shells, Anadara spp. and Meretrix spp., pottery fragments and different parts of animal bones (Plate 5.1.1 B). Similar features are found at Hatagala - Bogahagodella (Location 3) and Debaragodella areas (Location 4). Most of these shell mounds are covered by thorn bushes and stunted trees. A coconut land at Hatagala (Temple Land, about 0.25 ha. in size), has a considerable amount of shells (Location s 5 & 6; Plate 5.1.3).

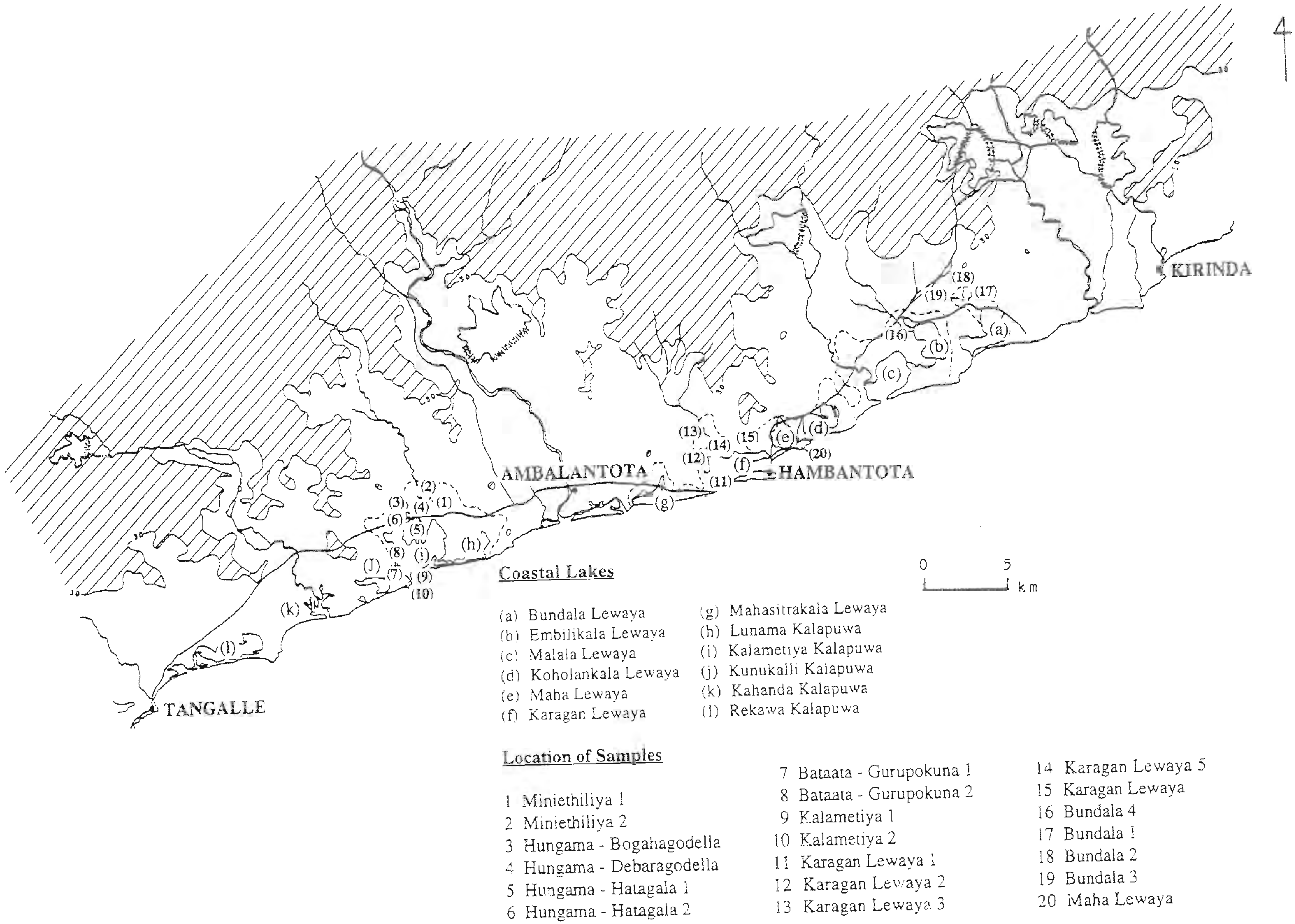
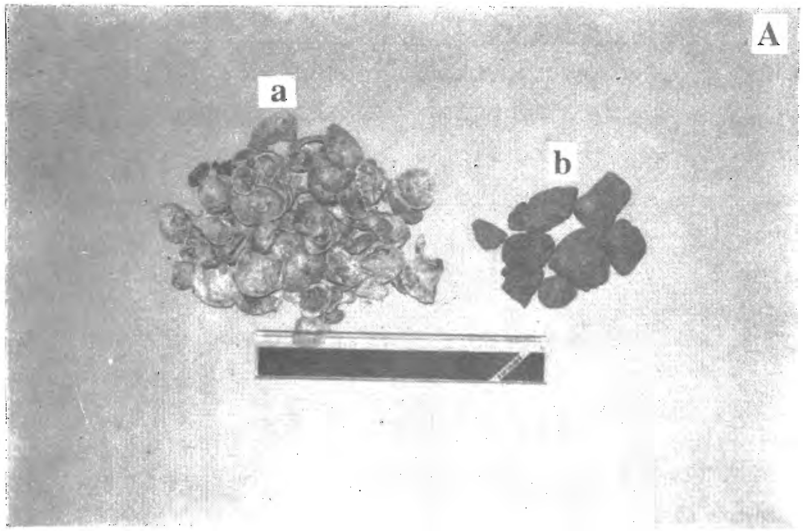


Figure 5.1.1. Extension of marine shell beds along the southern coastal zone

TABLE. 5.1.1. Details of the Fossil Shell Beds on the Southern Coast

No.	Location	Lower level of the shell beds (from msl)	Thickness of the shell layers (in metres)	Relief
1	Miniethiliya - 1	0.80	0.80	mound
2	Miniethiliya - 2	0.87	1.03	mound
3	Hungama - Bogahagodella	0.80	0.60	mound
4	Hungama - Debaragodella	-0.44	0.65	mound
5	Hungama - Hatagala (Temple Land - 1)	-0.06	1.21	mound
6	Hungama - Hatagala (Temple Land - 2)	-0.10	1.18	mound
7	Bataata - Gurupokuna	-0.90	3.00	rocky mound
8	Bataata - Gurupokuna	-0.50	1.90	rocky mound
9	Kalametiya - 1	13.25	0.45	headland
10	Kalametiya - 2	2.40	0.60	headland
11	Karagan Lewaya - 1	1.00	0.25	lag. coast
12	Karagan Lewaya - 2	4.38	0.12	mound
13	Karagan Lewaya - 3	1.30	0.40	lag. coast
14	Karagan Lewaya - 4	1.54	0.56	lag. coast
15	Karagan Lewaya - 5	1.00	0.20	lag. coast
16	Bundala - Embilikal	3.20	0.30	mound
17	Bundala Road 1	8.60	0.70	mound
18	Bundala Road	8.60	0.18	mound
19	Bundala Road 3	9.17	0.16	mound
20	Maha Lewaya	3.08	0.17	lag. coast

Source: Field Survey.



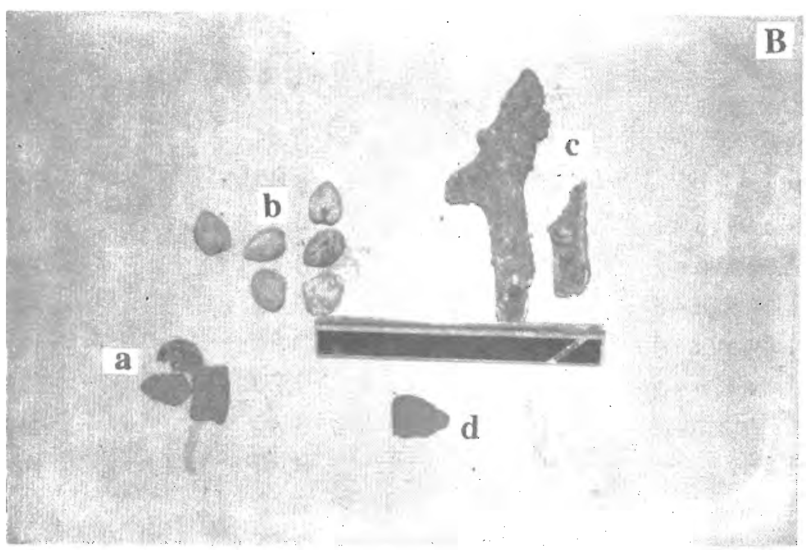


Plate 5.1.1. **(A)** ***Meretrix*** **Shells (a) and fired quartzite pebbles (b); (B) fired quartzite pebbles, (a) Meretrix shells in living position, (b) elk bones (c), and a piece of pottery (d) from Hungama - Ovitigodayaya.**

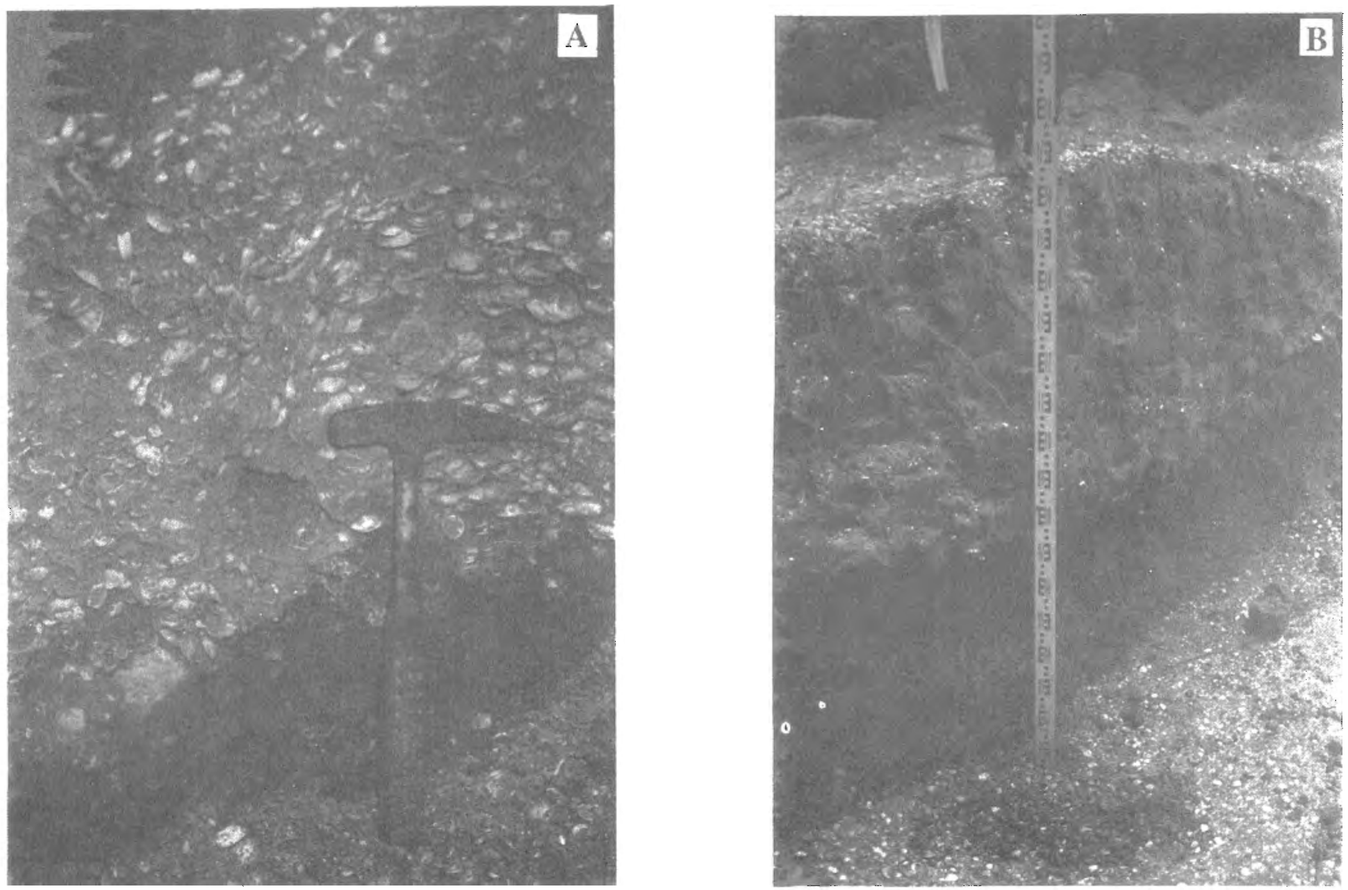


Plate 5.1.2. (A) Pieces of pottery, animal bones and quartz pebbles are mixed with shell beds; (B) about 90 cm thick soil cover underlying the shell bed at Miniethiliya (Location 1).

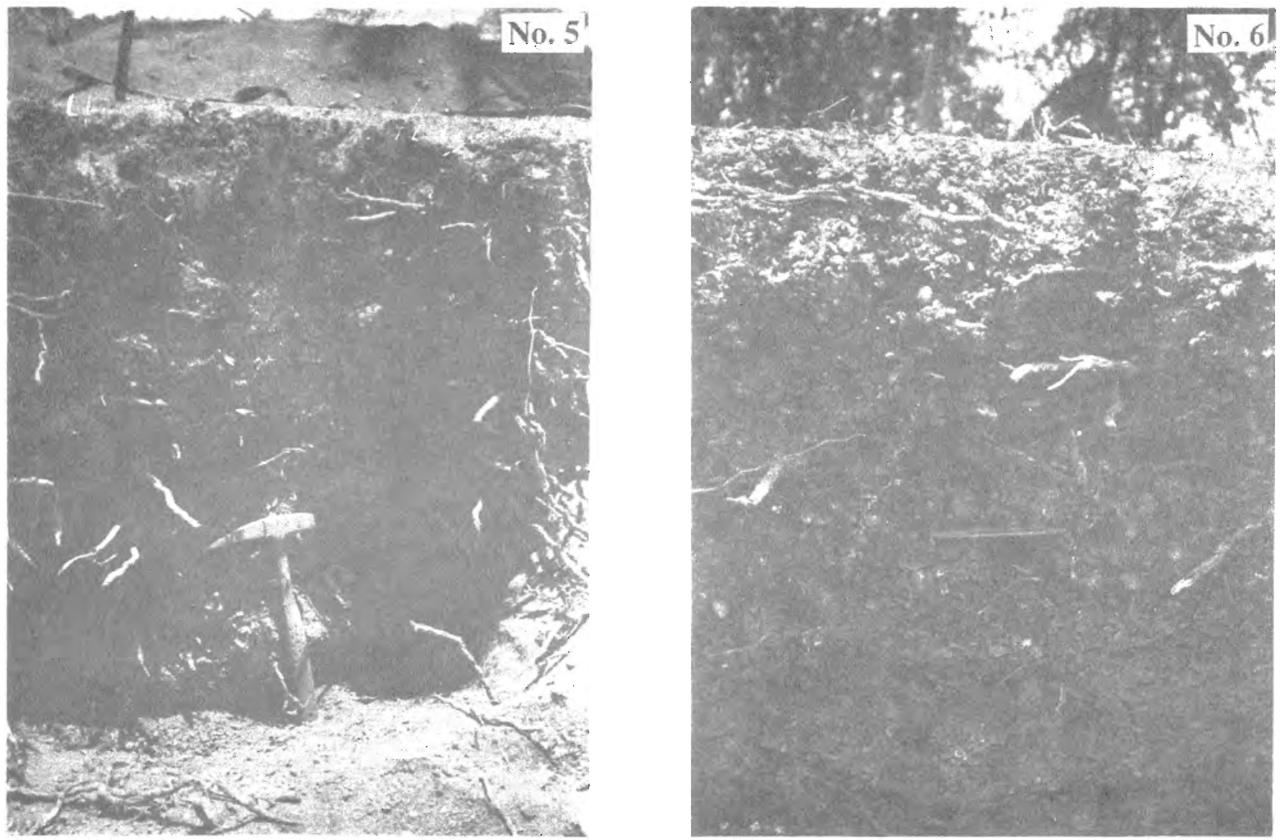


Plate 5.1.3. Debris of human bones, animal bones, pieces of pottery and stone artifacts found in shell beds at Hungama Temple Land (Location. No. 5 & 6).

Well polished oval-shaped stone artifacts, stone balls, human bones, a skull of a serpent and other animal bones as well as pottery fragments are mixed with these shell beds (Plates 5.1.4; 5.1.5 and 5.1.6a). Two morphologically distinctive beds have been deposited at Bataata (Gurupokuna) and Kalametiya areas. The beds at Gurupokuna (Loc. 7 & 8) appear as about 3 m thick deposits on mounds and a former lagoonal beach (Plate 5.1.7), while Kalametiya - Henagahapugala - beds (Loc. 9 & 10 have been deposited on a rocky headland (with a thin soil cover) which is about 14 m high from the msl. Many pieces of pottery are mixed with the shell bed in this area (Plate 5.1.5b). The shell beds at Kalametiya are fairly different from the locations 9 & 10. Eleven micro-layers can be identified in this area (Fig. 5.1.2 & Plate 5.1.8). This shell bearing bed is laid on a former lagoon and contain *Meretrix* and *Cerithedae* spp.

The shells from Godawaya to Mirijjawela are deposited as small pockets in depressions (lagoon and lake bottoms) between sandy beach and undulations which gradually increase in elevation inland. The beds at Kiula Kalapuwa consists of tiny and small to large Meretrix spp. They are below 50 mm in size. The top soil of the area is covered by Dull Yellowish Brown medium to fine sand (10 YR 4/3). The soil layer which is below the shell layer contains medium to fine Brown Soil (10YR 4/4). Somewhat large shell beds are found at Hunukotumulla on former lagoon beaches as well as lagoonal bottoms of the western bank of the Karagan Lewaya (Loc. 11) these can presently be seen as mounds. They are also covered by thorny bushes, stunted trees and grass. Some beds in the same area have been deposited by wave action (Loc. 12). The shell pockets in the northwestern area of the Karagan Lewaya (Loc. 13) and Nelumpathvila (Loc. 14 & 15) are also deposited in many places with thick and fertile alluvial soils along the lagoonal coast, stream and canal beds as well as in mounds (Plate 5.1.9). Furthermore, many shell patches are found in the area between Maha Lewaya and the Nabadewa (Plate 5.1.10), Pallemalala area, on the eastern bank of the Malala Oya. These shell beds are composed of stone artifacts and quartzite pebbles. Based on the colour of the quartzite pebbles, it is possible to infer that these may have been fired. Some beds are more than 4 km inland from the present coast. Besides, a considerable amount of shell beds are found in the area between Maha Lewaya and Embilikala Kalapuwa (Loc. 16). These beds also appear on mounds and ditches of the area covered by scrublands and stunted trees. Extensive shell beds are found in many mounds along the northern beach of Embilikala Kalapuwa and on the side left of the Bundala road. The shell beds around Bundala Lewaya occur somewhat higher when compared to those at Maha Lewaya and Embilikala Kalapuwa (Loc. 17, 18 & 19). They are also deposited on former lagoon beaches. The top soil (alluvial) cover of the area is somewhat thick. Somewhat extensive shell beds at Sippikulama, around the Maha Lewaya and Koholankala Lewaya are found on slight undulations (lobes), but the thickness of the beds are less compared to the beds at Gurupokuna, Hungama and the Karagan Lewaya. The beds at Koholankala are not so thick (Loc. 20). Furthermore, many shell patches are found in the area between Maha Lewaya and the Nabadewa, Pallemulla area, on the eastern bank of the Malala Oya.

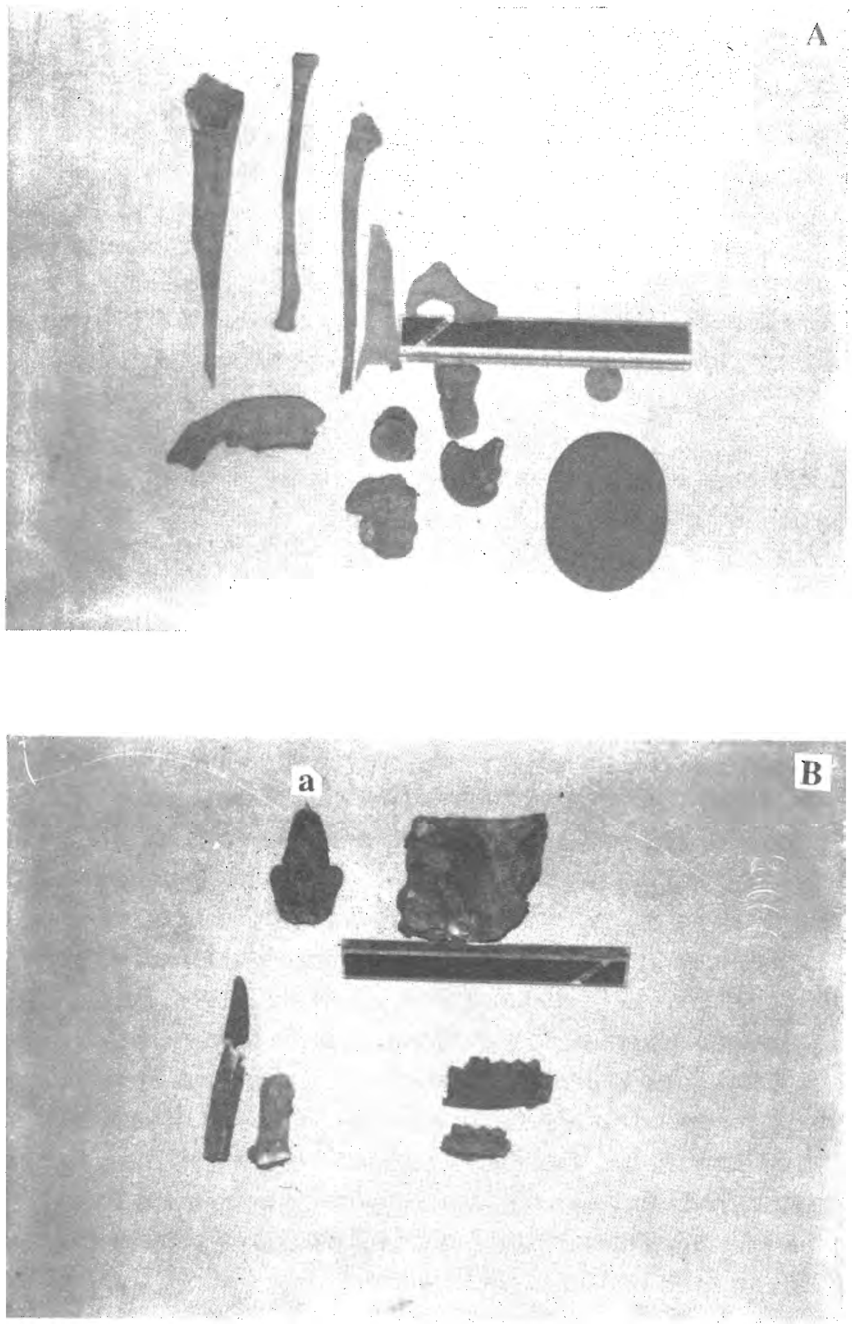
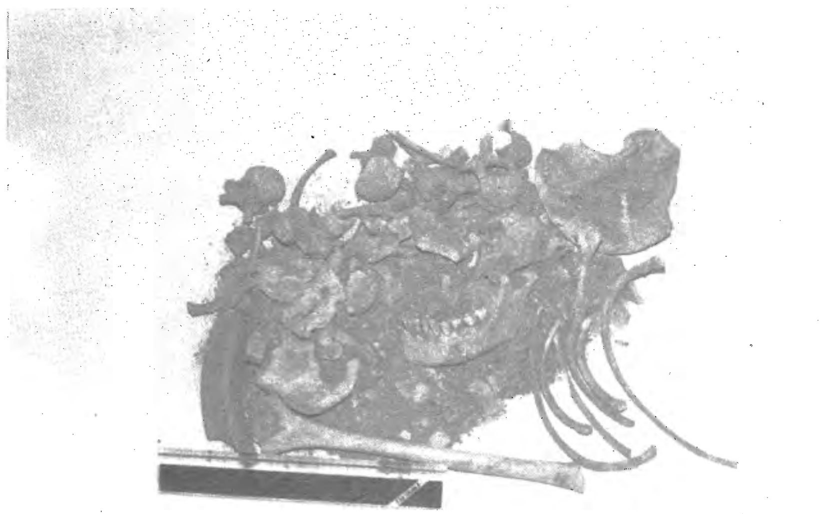


Plate 5.1.4. (A) Debris of human bones, stone artifacts and pieces of pottery; (B) Pieces of elk bones (a), serpent head (b), and other animal bones (c & d) from shell beds at Hungama Temple Land Location Nos. 5 & 6.



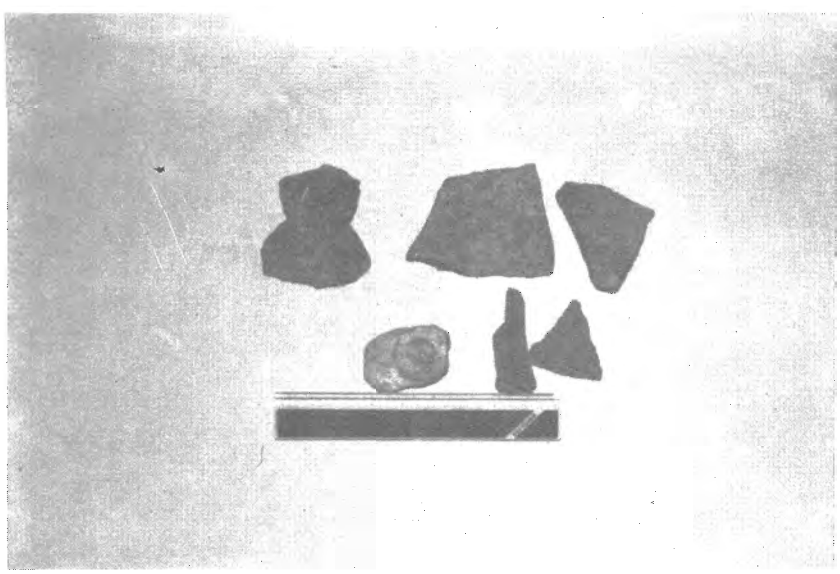


Plate 5.1.5. (A) Debris of human bones from shell beds at Hungama Temple Land (Location Nos. 5 & 6), and (B) pieces of pottery from shell beds at Kalametiya (Location Nos. 9 & 10).

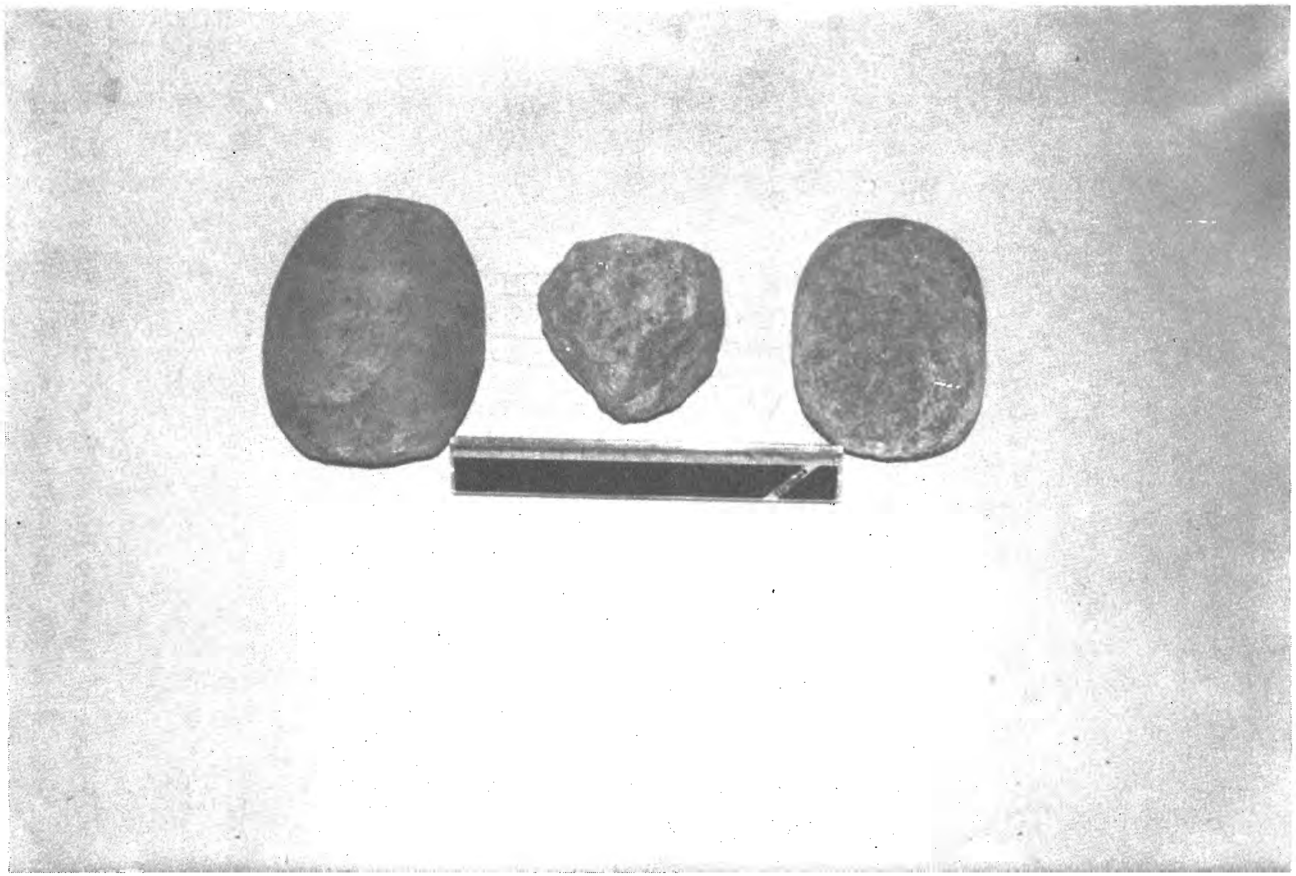


Plate 5.1.6. Stone artifacts collected from shell beds at Hungama Temple Land (a), Nabadewa (b), and Bundala (c).

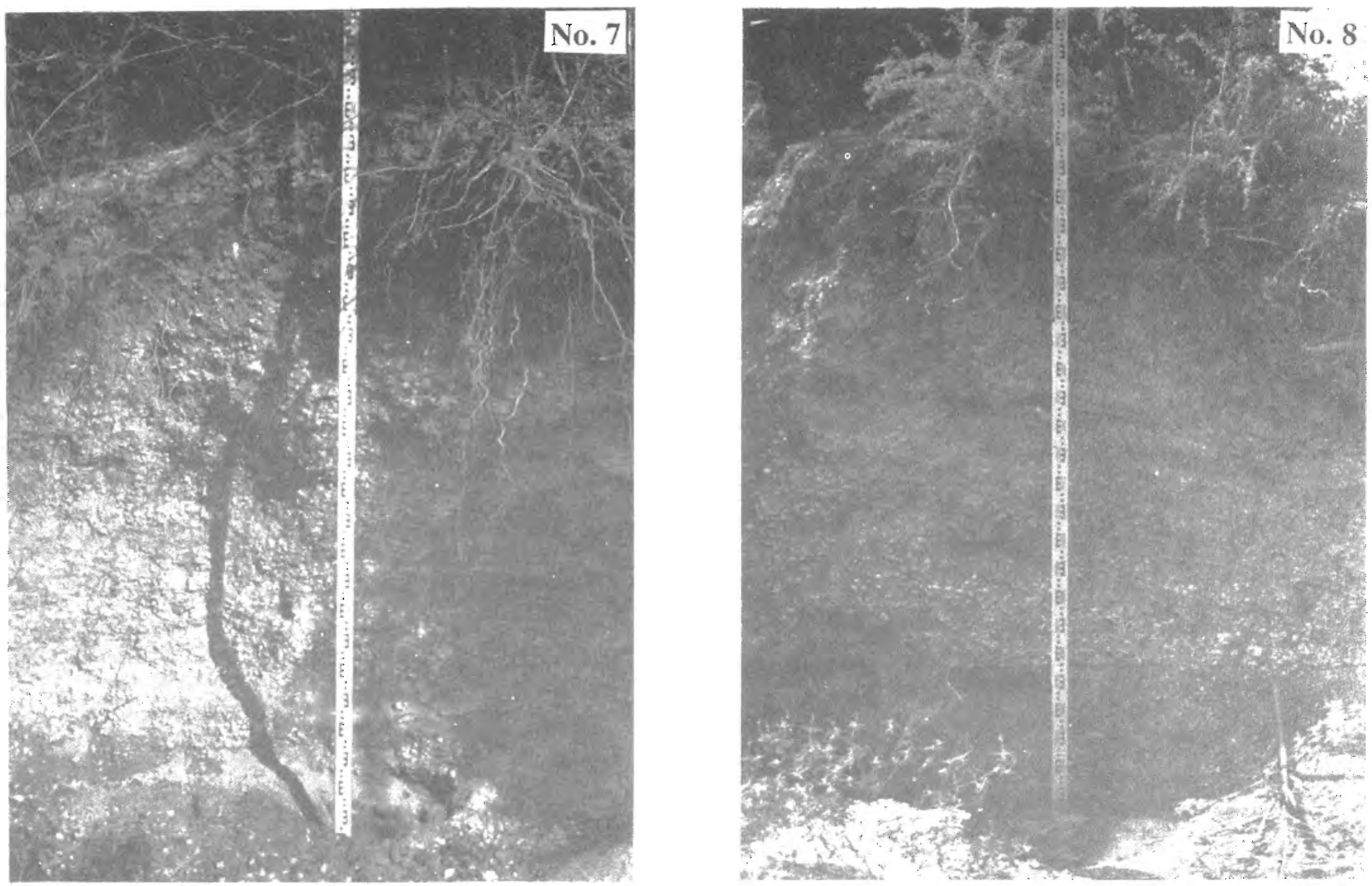
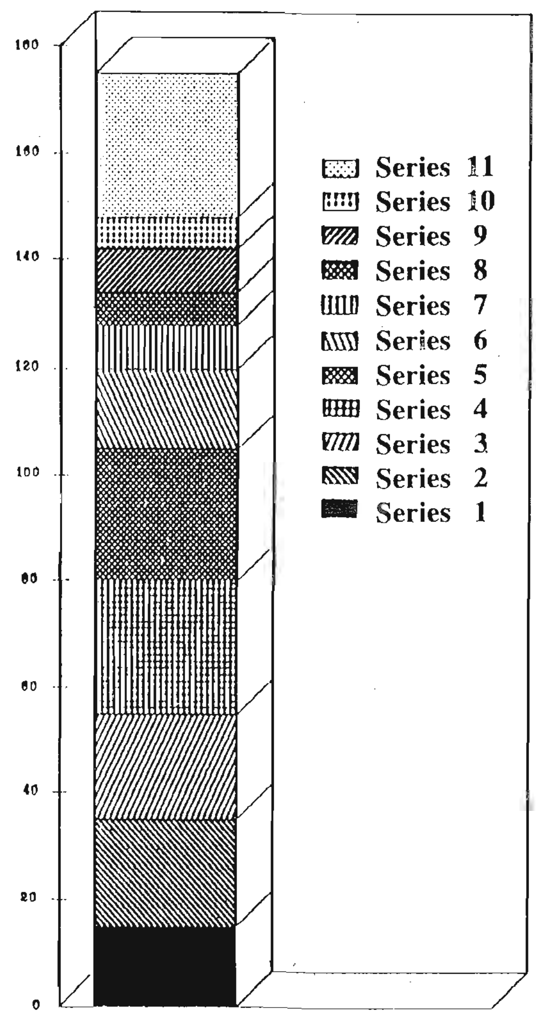
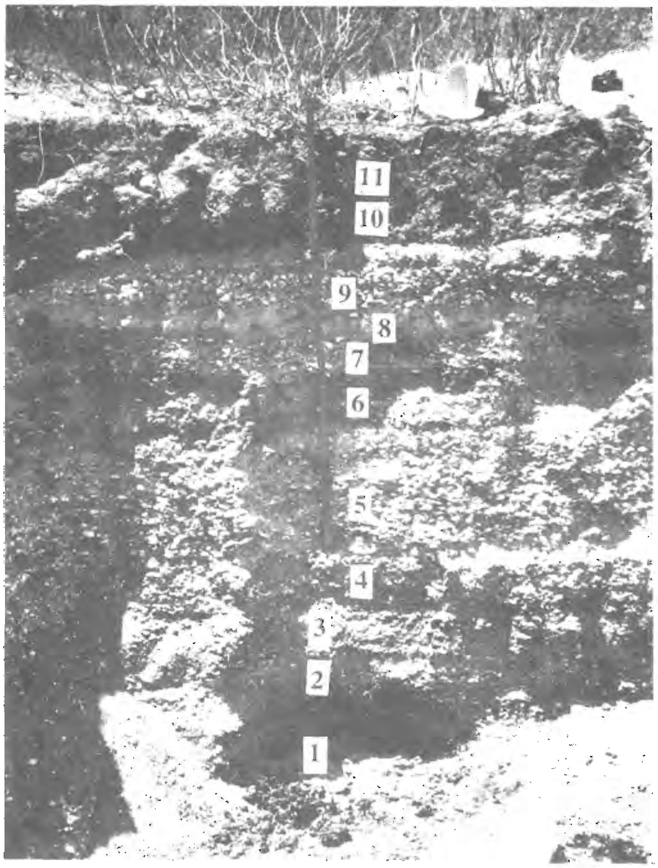


Plate 5.1.7. Horizontal deposition patterns of shell beds at Bataata-Gurupokuna indicate that shell valves have piled up by storm wave action (Location No. 7 & 8).



1 = Bluish clay; 2 = Shell and shell fragments mixed with few organic matter and calcareous clay; 3 = Shell and shell fragments mixed with more organic matter and calcareous clay; 4 = Shell composed of different kinds of shell fragments; 5 = Shell mixed with sand; 6 = Yellowish weathered shell fragments; 7 = Shell with plenty of shell fragments; 8 = Grayish sand; 9 = Shell layer; 10 = Shell and shell fragments; and 11 = Brown and gray soil.

Figure 5.1.2. Stratigraphic sequence of shell bed at Kalametiya



1 = Bluish clay
2 = Shell and shell fragments mixed with few organic matter and calcareous clay

3 = Shell and shell fragments mixed with more organic matter and calcareous clay

4 = Shell composed of different kinds of shell fragments

5 = Shell mixed with sand

6 = Yellowish weathered shell fragments

7 = Shell with plenty of shell fragments

8 = Grayish sand

9 = Shell layer

10 = Shell and shell fragments

11 = Brown and gray soil

Plate 5.1.8. Stratigraphic sequence of shell bed at Kalametiya. Eleven micro layers (series) are identified based on the type and size of shells and constituents of other material.

Plate 5.1.9. (A) Thick and fertile alluvial soil cover found in the shell bed areas at Nelumpathvila - Arabokka, and (B) Bundala.

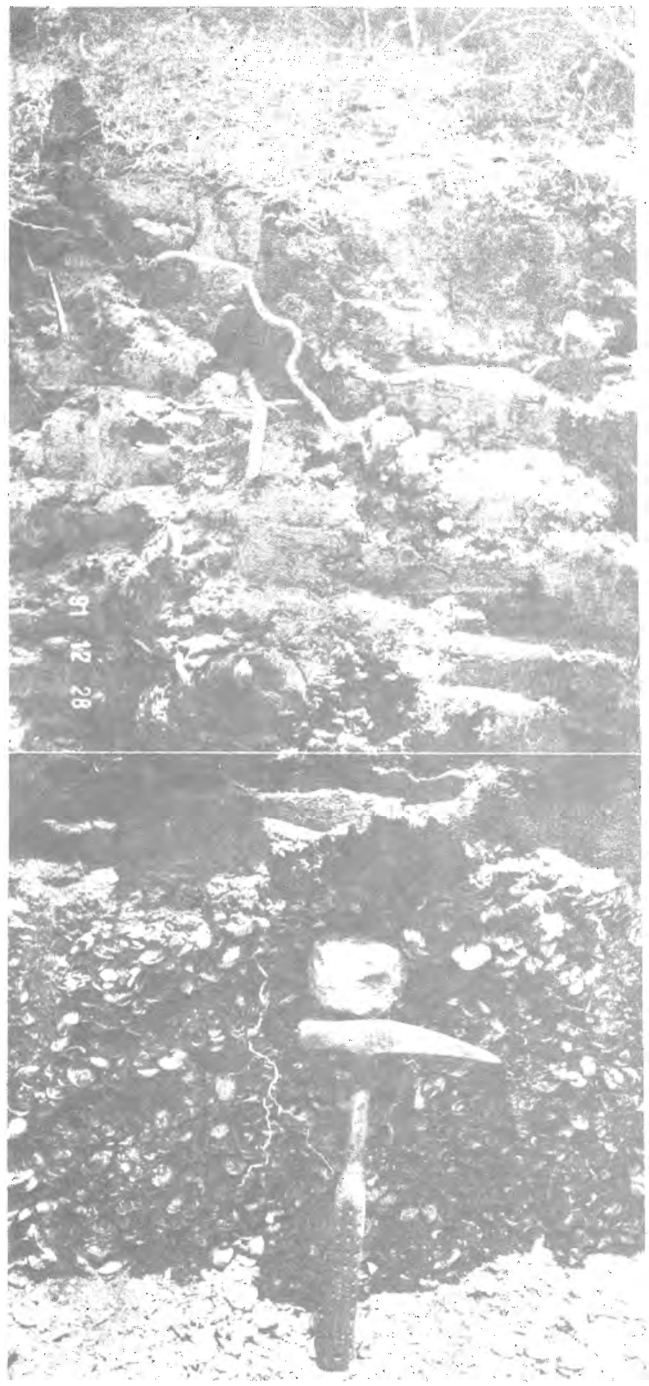


Plate 5.1.10. Glossy and well preserved shells and stone artifacts (quartzite) found at Nabadewa on left bank of the Malala Ara, about 4 km inland from the present coastline. Thick fertile alluvial soils overlain on the shell beds.

They are composed of stone artifacts and quartzite pebbles. Based on the colour of the quartzite pebbles, it is possible to infer that these may have been fired. Some beds are more than 4 km inland from the present coast.

Accordingly, all these shell beds indicate that they have been deposited on mounds and ditches, lobes of undulations along lagoons or lake beaches. Most of the beds are presently covered by superficial deposits (alluvium and wind blown sand).

5.2 Geological Significance of the Shell Beds along the Southern Coast

The shells of the study area belong to mainly three Families: *Veneridae* (Venus Clams), *Arcidae* (Ark shells) and *Potamitidae* (Horn Shells). The *Veneridae* is a large and well-known Family of hard-shelled clams (strong and glossy). Their cardinal teeth are well-developed and the lateral teeth are often strong. The shell valves in the beds from Kalametiya Kalapuwa to Bundala Kalapuwa belong to a few species; of which the dominant species is *Meretrix meretrix* (Plate 5.2.1).

The family *Arcidae* are heavy, squarish, porcelanious clams having a taxodant hinge - a straight hinge with numerous small teeth, of the same size. Most common ark shell species live in warm waters in sandy or muddy areas, while a few are found near coral reefs. The shells of this family of the study area belong to *Anadara granosa* or *Anadara uropymelana* (Plate 5.2.1).

The *Potamitidae* shells including *Cerithidea cingulata* or *Cerithidea ornata* is a large brackish water group with elongate, solid shells usually dirty brown in colour (Plate 5.2.1). Columella stops abruptly with a short, twisted siphonal canal. *Operculum corneous*, is usually many-whirled. Most Columella live in mangrove and estuarine areas. Accordingly, the levels of the shell layers, types of the constituents, colour of the soil etc. are described in detail, and shown in Figures 5.2.1 to 5.2.13. The types of shells, live position of the valves, rocky artifacts, animal bones, human bones which were found from these shell beds are shown in these plates. Many layers of different thickness, constituents and deposition patterns indicate that the shell and shell fragments have been deposited by storm waves especially at Bataata - Gurupokuna (Plate 5.1.7).

The shell beds at Kalametiya which appeared in many micro-layers can be identified based on the deposition pattern (Fig. 5.1.2. and Plate 5.1.8). The top shell layers contained *Meretrix* spp. and *Cerithedae* spp. (less than 40 mm in size) with calcareous sand which had been piled up by wave action. While the shells and shell fragments of lower layers are mixed with weathered organic material (10 YR 2/1) and calcareous clay. Bluish clay of the bottom layer in the area indicate that the shells have been deposited on a grass biomass.

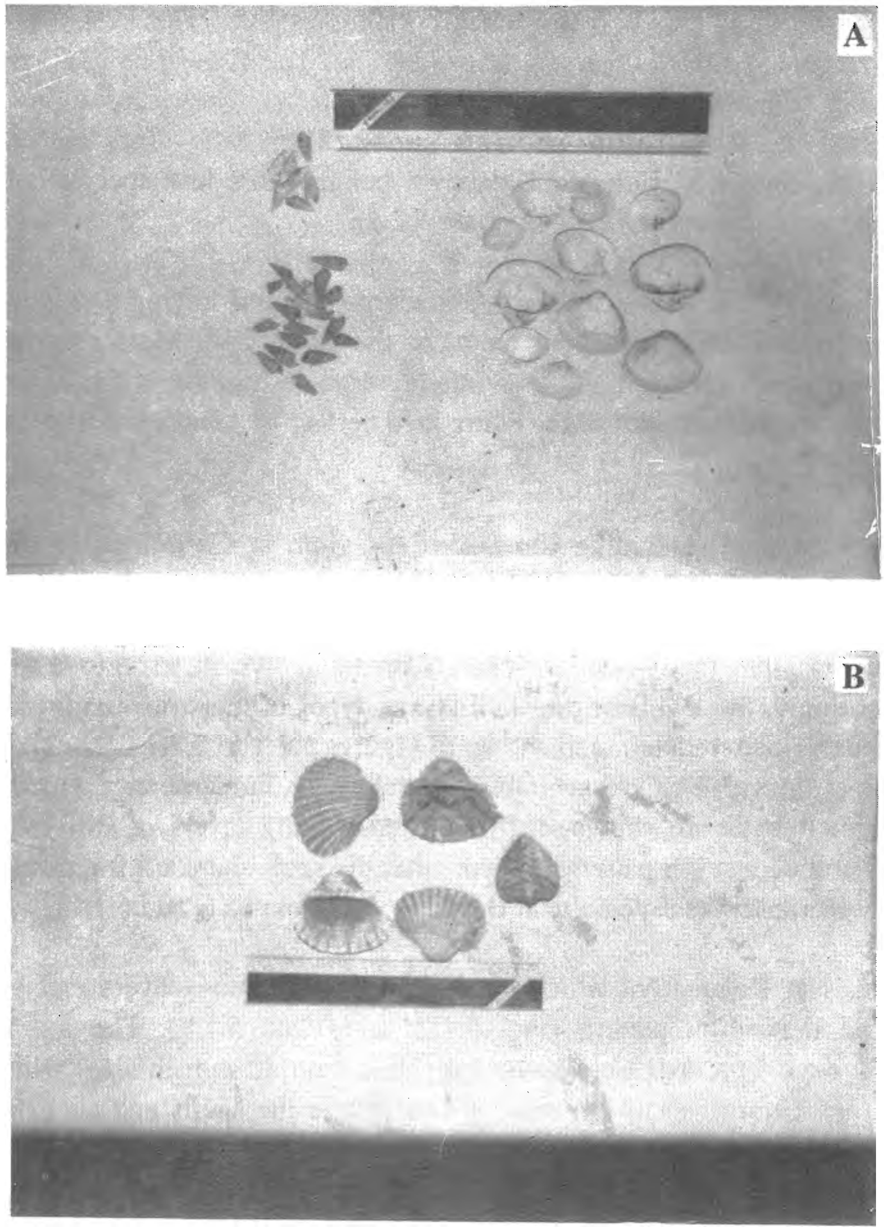
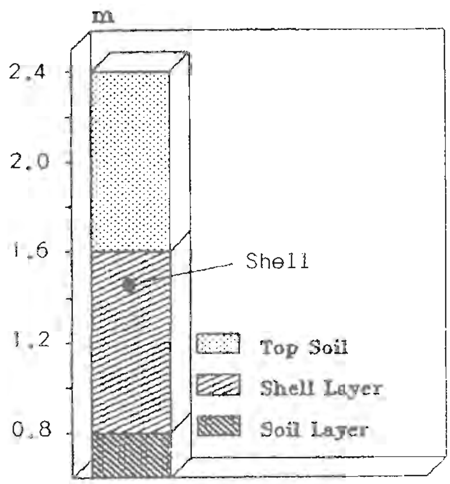
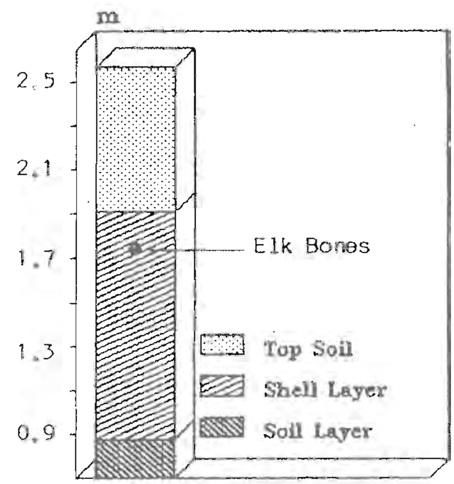


Plate 5.2.1. (A) *Meretrix* (a), *Cerithidae* (b); and (B) *Anadara* spp. (b) contained in the shell beds along the southern coastal zone.



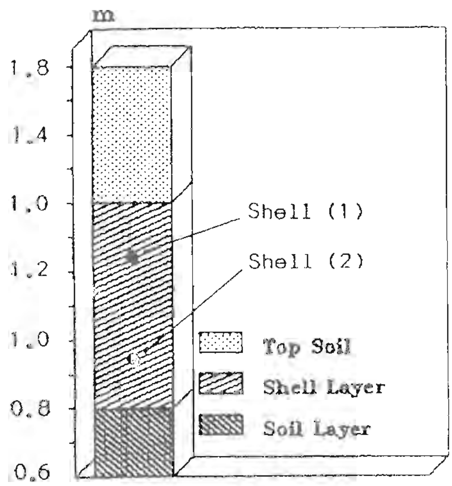
Location: No. 1



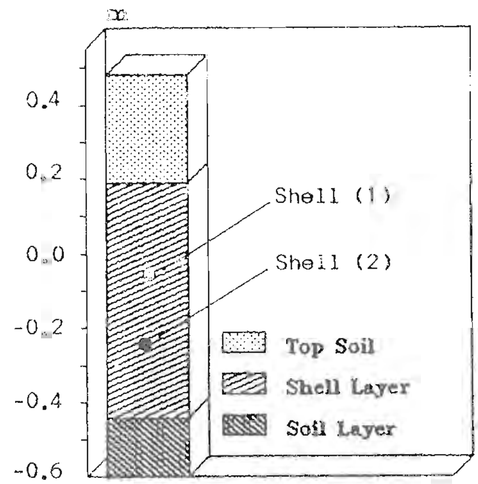
Location: No. 2

Location: No. 1 - Hungama (Miniethiliya): Ground level (from msl): 2.40 m, Upper level of the shell layer: 1.60 m, Lower level of the shell layer: 0.80 m, Thickness of the shell layer: 0.80 m, Type of sample and level: one shell sample (1.45 m). Description of samples and the stratigraphy: Calcareous clay with sandy soil (Grayish Gray Soil - 10 YR 4/2. Tiny and small to somewhat large size of shells can be found. Shells belong to *Cerithidea* spp. and *Meretrix* spp. The *Cerithidea* spp. is less than 20 mm and *Meretrix* spp. is less than 40 mm in size. **Location: No. 2 - Hungama (Miniethiliya):** Ground level (from msl): 2.56 m, Upper level of the shell layer: 1.90 m, Lower level of the shell layer: 0.87 m, Thickness of the shell layer: 1.03 m, Type of sample and level: elk bones, one sample (1.80 m). Description of samples and the stratigraphy: Elk bones (horn) together with *Meretrix* spp. were found. Shell debris, sub-rounded quartzite pebbles, coarse to fine sand with clay and other animal remains are embedded in the deposits (Plate 1). Although the shell beds of the area are about 4 kilometres inland from the present coast, the thickness of the layer is considerably high.

Figure 5.2.1. Stratigraphic sequences of shell bed at Location Nos. 1 & 2 (Hungama - Miniethiliya).



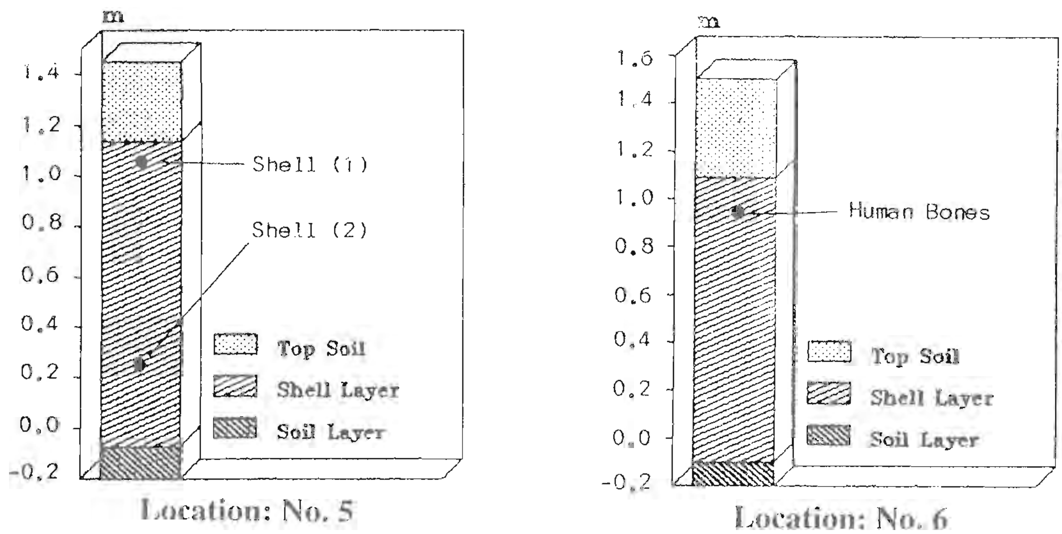
Location: No. 3



Location: No. 4

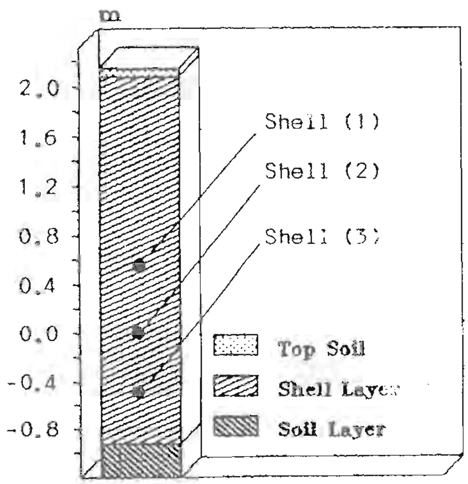
Location: No. 3 - Hungama (Bogahagodella): Ground level (from msl): 1.80 m, Upper level of the shell layer: 1.40 m, Lower level of the shell layer: 0.80 m, Thickness of the shell layer: 0.60 m, Type of samples and levels: two shell samples (1) 1.25 m, (2) 0.95 m. Description of samples and the stratigraphy: Shells, shell rubble mixed with calcareous sand and clay (Light Gray - 10 YR 7/1) in sample 1. The shells of sample 2 is mixed with Brownish Gray soil (10 YR 4/1). Quartz pebbles were also found in this sample. Shells belong to *Cerithidea* spp. and *Meretrix* spp. The *Cerithidea* spp. less than 20 mm and *Meretrix* spp. are less than 20 mm in size. **Location: No. 4 - Hungama (Debaragodella):** Ground level (from msl): 0.48 m, Upper level of the shell layer: 0.20 m, Lower level of the shell layer: - 0.44 m (below msl), Thickness of the shell layer: about 0.65 m, Type of samples and levels: two shell samples (1) -0.04 m (below msl), (2) -0.24 m (below msl). Description of samples and the stratigraphy: The shells are mixed with calcareous clay (Brownish Gray soil (7.5 YR 4/1) in sample 1. There are no pebbles or coarse sand, but quartz fragments are found. Calcareous clay with fine sand and shells (Grayish Brown soil - 7.5 YR 4/2) were in sample 2. The clay appeared compact when dry. The clams in position of life were also found in this sample.

Figure 5.2.2. Stratigraphic sequences of shell bed at Location No. 3 (Hungama - Bogahagodella) & No. 4 (Hungama - Debaragodella).

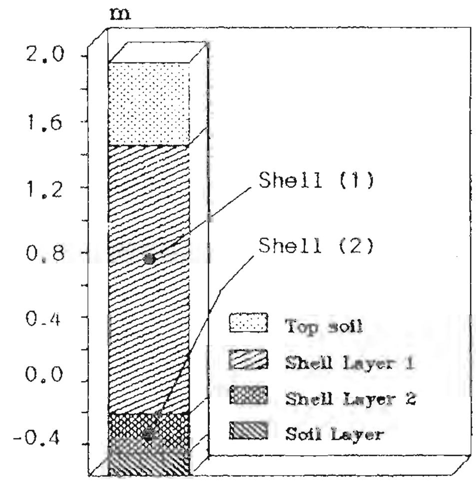


Location: No. 5 - Hatagala (Temple Land): Ground level (from msl): 1.45 m, Upper level of the shell layer: 1.15 m, Lower level of the shell layer: -0.06 m (below msl), Thickness of the shell layer: 1.09 m, Type of samples and levels: two shell samples (1) 1.05 m, (2) 0.14 m, Description of samples and the stratigraphy: Small size to large size of shells held together by Light Gray sandy soil (10YR 7/1). Many *Cerithidea* spp. are well preserved and they are less than 20 mm in size. *Meretrix* spp. of both samples are less than 55 mm in size. A thick shell layer of the mound has been mixed with stone pebbles (appear as artifacts), human bones, fragments of pottery etc. **Location: No. 6 - Hatagala (Temple Land):** Ground level (from msl): 1.50 m, Upper level of the shell layer: 1.08 m, Lower level of the shell layer: -0.10 m (below msl), Thickness of the shell layer: about 1.20 m, Type of the sample and levels: one sample (1.00 m). Description of samples and the stratigraphy: Highly weathered human skeletons are found on the shell bed (the same mound of Loc. No. 5). A part of a jaw with teeth, vertebral columns, rib cages and radius are found in this location. The last teeth of the jaw indicate that the skull belonged to a young human. Other conditions of the site are very similar to Loc. No. 5.

Figure 5.2.3. Stratigraphic sequences of shell bed at Location Nos. 5 & 6 (Hatagala - Temple Land).



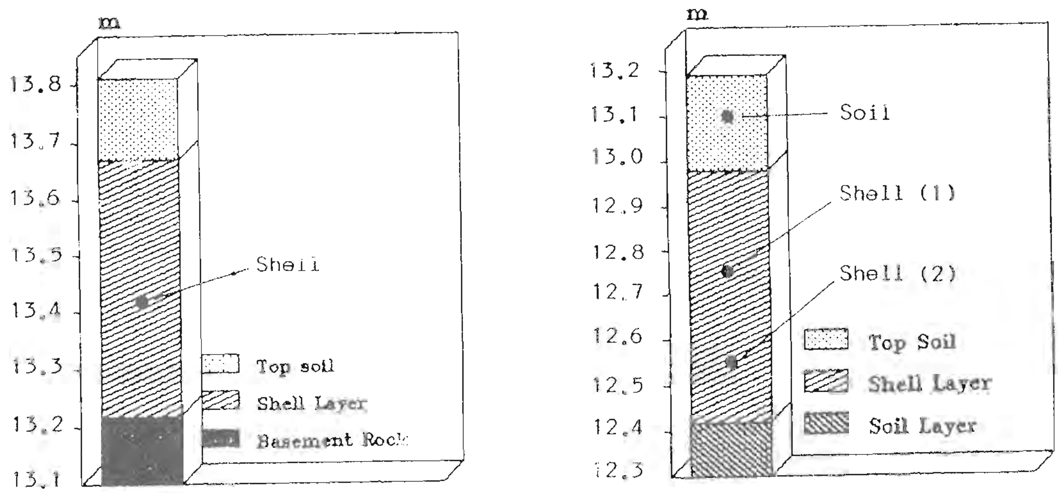
Location: No. 7



Location: No. 8

Location: No. 7 - Bataata (Gurupokuna 1): Ground level (from msl): 1.50 m, Level of the shell mound: 2.2 m, Upper level of the shell layer: 2.10 m, Lower level of the shell layer: -0.90m, Thickness of the shell layer: 3.00, Type of samples and levels: three shell samples (1) 0.60 m, (2) 0.06 m, and(3) -0.50 m. Description of samples and the stratigraphy: Sample 1 - Light Gray shelly sand (10 YR 7/1). Clear quartz fragments (rare) were found. *Meretrix* spp. of the sample 1 less than 35 mm and *Cerithidea*. spp. less than 25 mm. Sample 2 - Light Gray shelly sand (10 YR 7/1). The Meretrix spp. is small (less than 30 mm) and *Cerithidea* spp. appear as fragments. Unidentified shell fragments were also found. Sample 3 - Dull Yellowish Orange soil (10 YR 6/3). *Meretrix* spp. less than 50 mm. Somewhat weathered *Cerithidea* spp. less than 20 mm. **Location: No. 8 - Bataata (Gurupokuna 2):** Ground level (from msl): Upper level of the first shell layer: 1.95m, Lower level of the first shell layer: 1.45m, Lower level of the second shell layer: -0.50 m, Thickness of the shell layer: 2.45 m, Type of samples and levels: two shell sample (!) 0.80 m, (2) -0.45 m. Description of samples and the stratigraphy: Sample 1 is mainly composed of Light Gray Sandy Soil (10 YR 7/1). The shell *Meretrix* spp. is less than 40 in size. Sample 2 is formed by Dull Yellowish Brown Soil (10 YR 4/3), sand and shell rubble. *Cerithidea* spp. of sample 2 is less than 20 mm. The *Meretrix* spp. less than 40 mm while *Anadara* spp. less than 45 mm in size.

Figure 5.2.4. Stratigraphic sequences of shell bed at Location Nos. 7 & 8 (Bataata - Gurupokuna).



Location: No. 9

Location: No. 10 -

Location: No. 9 - Kalametiya 1: Ground level (from msl): 13.80 m, Upper level of the shell layer: 13.70 m, Lower level of the shell layer: 13.25 m, Thickness of the shell layer: 0.45 m, Type of sample and level: one shell sample (13.25 m). Description of samples and the stratigraphy: These shells *Meretrix* spp. are less than 40 in size. Broken large shells mixed together with Brown Soil (10 YR 4/3). Pottery fragments are also found. The shells are gathered even in rocky splits. The deposition pattern indicate that shells were deposited in the area due to severe storm wave action. **Location: No. 10 - Kalametiya 2:** Ground level (from msl): 3.20 m, Upper level of the shell layer: 13.00 m, Lower level of the shell layer: 12.40m, Thickness of the shell layer: 0.60 m, Type of samples and levels: Two shell samples (1) 12.75 m, (2) 12.60 m, and one soil sample 13.10 m. Description of samples and the stratigraphy: Brown fine sand with clay (10 YR 4/3) with shell and shell fragments appear in both shell samples. The shells belong to *Meretrix* spp less than 40 mm in size. Other features are same as in Loc. No. 9. Inorganic content and grain sizes of the soil sample are shown in Fig. 5.2.6.

Figure 5.2.5. Stratigraphic sequences of the shell bed at Location No. 9 (Kalametiya 1) & 10 (Kalametiya 2).

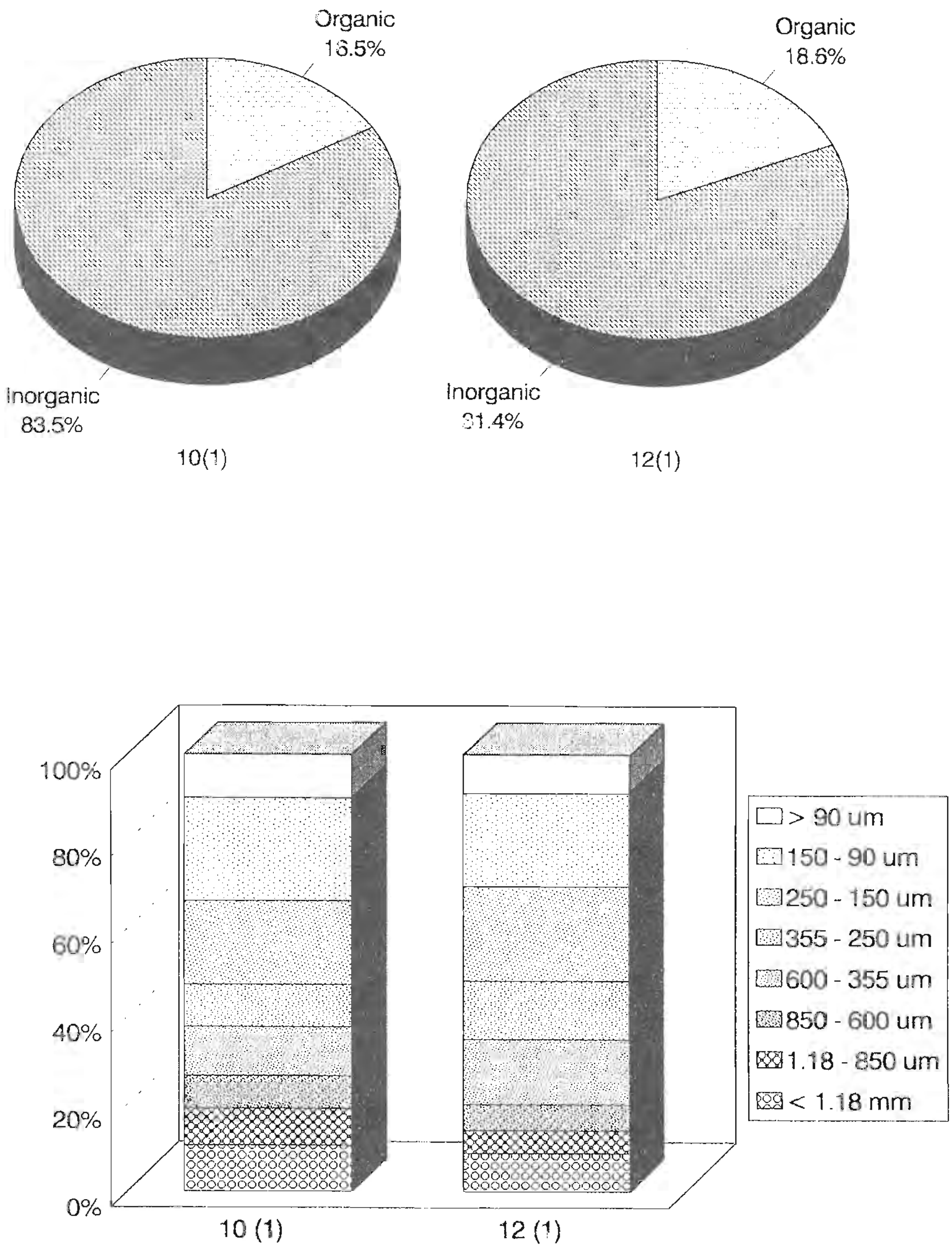
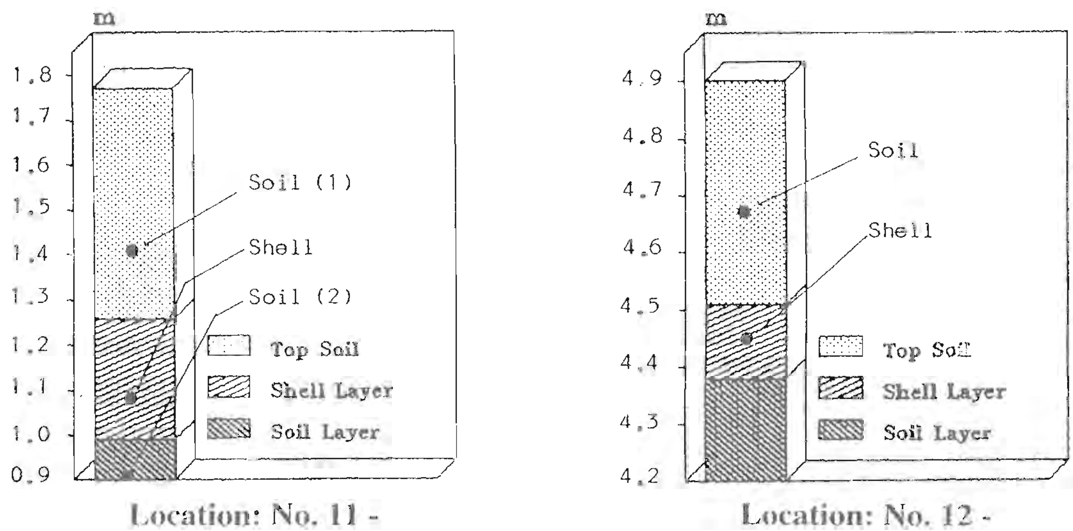


Figure 5.2.6. Organic and inorganic contents and grain size analyses of soil samples 10.1 and 12. 1



Location: No. 11 - Karagan 1 (Hunukotumulla): Ground level (from msl): 1.80 m, Upper level of the shell layer: 1.25m, Lower level of the shell layer: 1.00m, Thickness of the shell layer: 0.25 m, Type of samples and levels: two soil samples (1) 1.40 m (soil), (2) 1.08 m (shell), and (3) 0.90 m (soil)). Description of samples and the stratigraphy: Sample 1 is formed of 7.5 YR 4/2 Grayish Brown medium to fine sand clay soil. Content of inorganic matter and grain sizes are shown in Fig. 5.2.10 (11.1). Sample 2 has Grayish brown soil (7.5 YR 4/2). *Meretrix* spp. are less than 40 mm in size. Three shells are found in position of life (30 mm less than in size). Somewhat compact, Sample 3 is Grayish Yellow Brown (10 YR 4/2) in colour). Calcareous clay patches and weathered ironstone pebbles are found. Grain sizes and content of inorganic matter are shown in Fig. 5.2.10 (11.3). **Location: No. 12 - Karagan 2 (Hunukotumulla):** Ground level (from msl): 4.90 m, Upper level of the shell layer: 4.50 m, Lower level of the shell layer: 4.38 m, Thickness of the shell layer: 0.12 m, Type of samples and levels: one soil sample (1) 4.70 m, and one shell sample (2) 4.45 m. Description of samples and the stratigraphy: The shells mix with Brown soil (7.5 YR 4/3) and fine sand and calcareous materials. Pebbles are very few. Plant remains are evident. *Meretrix* spp. is less than 45 and *Anadara* spp. is less than 65 mm in size. Content of inorganic matter and grain sizes are shown in Fig. 5.2.6 (12.1).

Figure 5.2.7. Stratigraphic sequence of shell bed at Location No. 11 (Karagan 1 - Hunukotumulla) & 12 (Karagan 2 - Hunukotumulla).

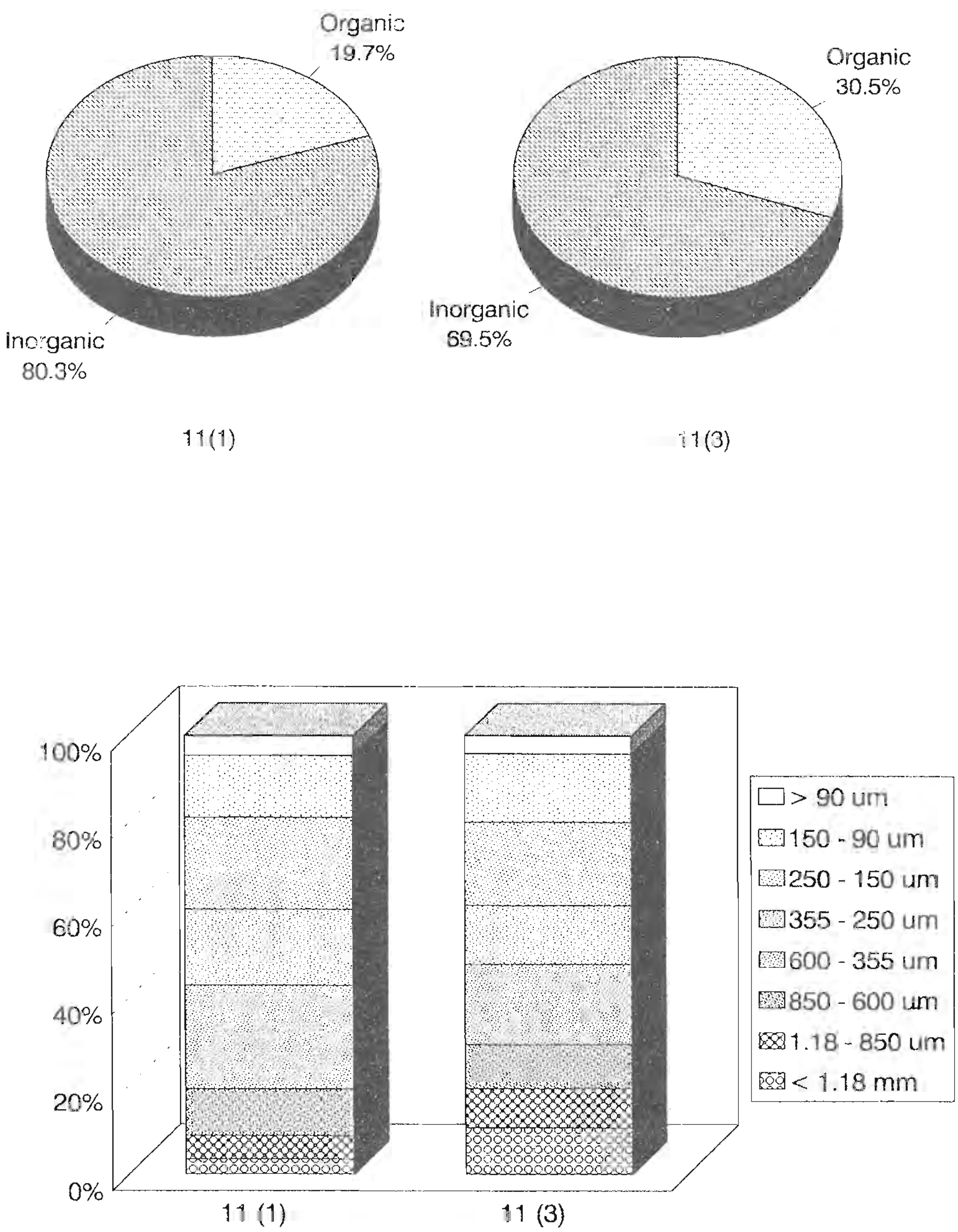
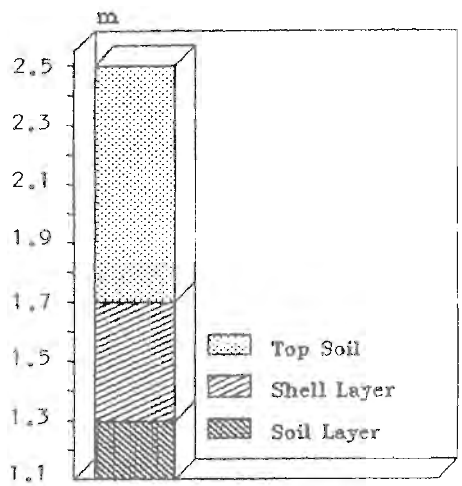
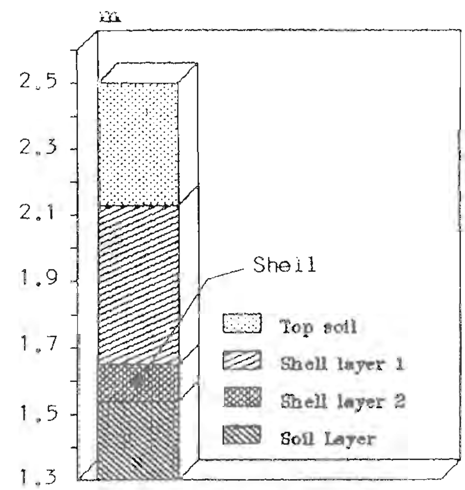


Figure 5.2.8. Organic and inorganic contents and grain size analyses of soil samples 11.1 and 11.3.



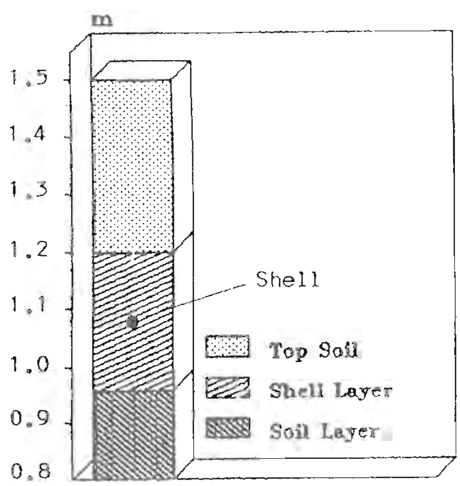
Location: No. 13



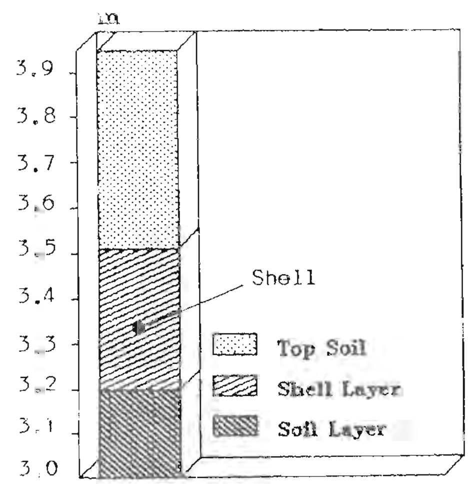
Location: No. 14

Location: No. 13 - Karagan 3 (Arabokka): Ground level (from msl): 2.50 m, Upper level of the shell layer: 0.70 m, Lower level of the shell layer: 1.30 m, Thickness of the shell layer: 0.40 m. <u>Description of samples and the stratigraphy</u>: The shell layers of the area composed of Dull Yellowish Brown Soil (10 YR 5/4) with fine sandy clay and shelly sand. *Meretrix* spp. of the sample is varied from small to somewhat large (less than 40 mm). **Location: No. 14 - Karagan 4 (Nelumpathvila):** Ground level (from msl): 2.50 m, Upper level of the first shell layer: 2.10 m, Lower level of the first shell layer: 1.65 m, Lower level of the second shell layer:, Thickness of shell layer: **Figure** about 0.55 m, Type of the sample and level: one shell sample (1.60 m). <u>Description of samples and the stratigraphy</u>: The shell layer composed of Dull Yellowish Brown Soil (10 YR 5/4) with fine sandy clay and shelly sand. *Meretrix* spp. of the sample is somewhat large (less than 40 mm).

Figure 5.2.9. Stratigraphic sequences of the shell bed at Location Nos. 13 (Karagan 2 - Arabokka) & 14 (Karagan 4 - Nelumpathvila).



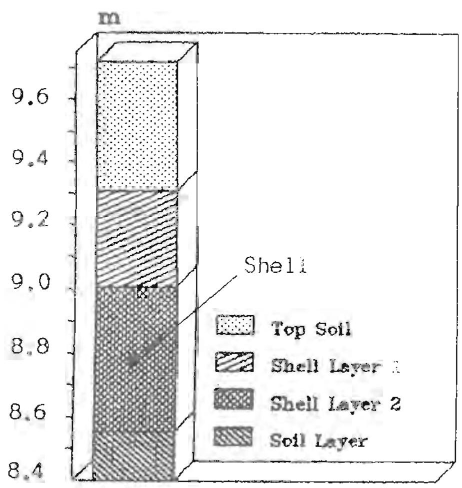
Location: No. 15



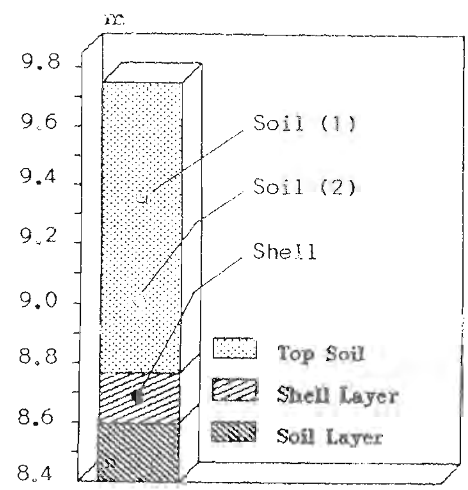
Location: No. 16

Location: No. 15 - Karagan 5 (Nelumpathvila): Ground level (from msl): 1.50 m, Upper level of the shell layer: 1.20 m, Lower level of the shell layer: 1.00 m, Thickness of the shell bed: 0.20 m, Type of sample and level: one shell sample (1.09 m). Description of samples and the stratigraphy: Sample 1 - Brownish gray soil (10 YR 6/1) with calcareous sand and clay. The shell layer composed of Dull Yellowish Brown Soil (10 YR 5/4) with fine sandy clay and shelly sand. *Meretrix* spp. of the sample is somewhat large (less than 40 mm). **Location: No. 16 - Bundala (Embilikala):** Ground level (from msl): 3.90 m, Upper level of the shell layer: 3.50 m, Lower level of the shell 3.20 m, Thickness of the shell layer: 0.30 m, Type of sample and level: one shell sample (3.35 m). Description of samples and the stratigraphy: The shells contained Grayish Brown Soil (7.5 YR 4/2) with fine sand and clay, weathered pebbles, quartz fragments, plant remains. *Meretrix* spp. is less than 45 mm and weathered *Cerithidea* spp. appeared as fragments.

Figure 5.2.10. Stratigraphic sequences of the shell bed at Location Nos. 15 (Karagan 5 - Nelumpathvila) & 16 (Bundala-Embilikala).



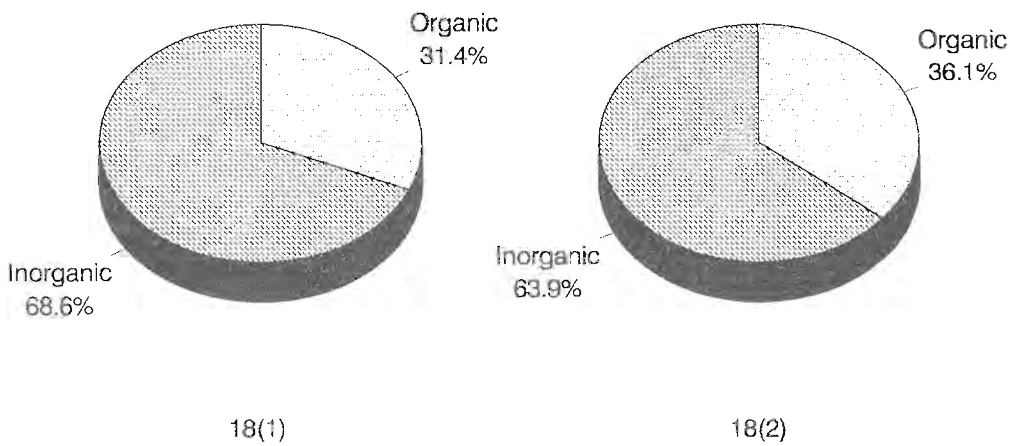
Location: No. 17



Location: No. 18

Location: No. 17 - Bundala Road 1 (near 4th km post): Ground level (from msl): 9.70 m, Upper level of the first shell layer: 9.30 m, Lower level of the first shell layer: 9.00 m, Lower level of the second shell layer: 8.60 m, Thickness of the shell layer: 0.70 m, Type of sample and level: one shell sample (8.80 m). Description of samples and the stratigraphy: Dark Brown (7.5 YR 3/3) medium sand to fine sand with clay soil is somewhat compact. Plant roots and other organic matter are found. Damaged *Meretrix* spp. is less than 30 mm in size. Weathered *Cerithidea* spp. is below 20 mm in size. **Location: No. 18 - Bundala Road 2 (near 4th km):** Ground level (from msl): 9.75 m, Upper level of the shell layer: 8.80 m, Lower level of the shell layer: 8.60 m, Thickness of the shell layer: 0.20 m, Type of samples and levels: two soil samples (1) 9.30 m, (2) 9.00 m, and one shell sample (3) 8.70 m. Description of samples and the stratigraphy: Dark Brown medium sand to fine sand with clay soil (7.5 YR 3/3) of samples 1 and 2 is somewhat compact. Plant roots with other organic matter are found. The shells (sample 3) have been deposited with Grayish Brown Soil (7.5 YR 4/2), medium to fine sand, calcareous clay and feldspar pebbles (rare). *Meretrix* spp. is below 30 mm and weathered *Cerithidea* spp. is less than 20 mm in size. Grain sizes and content of inorganic matter are shown in Fig. 5.2.13.

Figure 5.2.11. Stratigraphic sequences of the shell bed at Location Nos. 17 (Bundala Road 1) & 18 (Bundala Road 2).



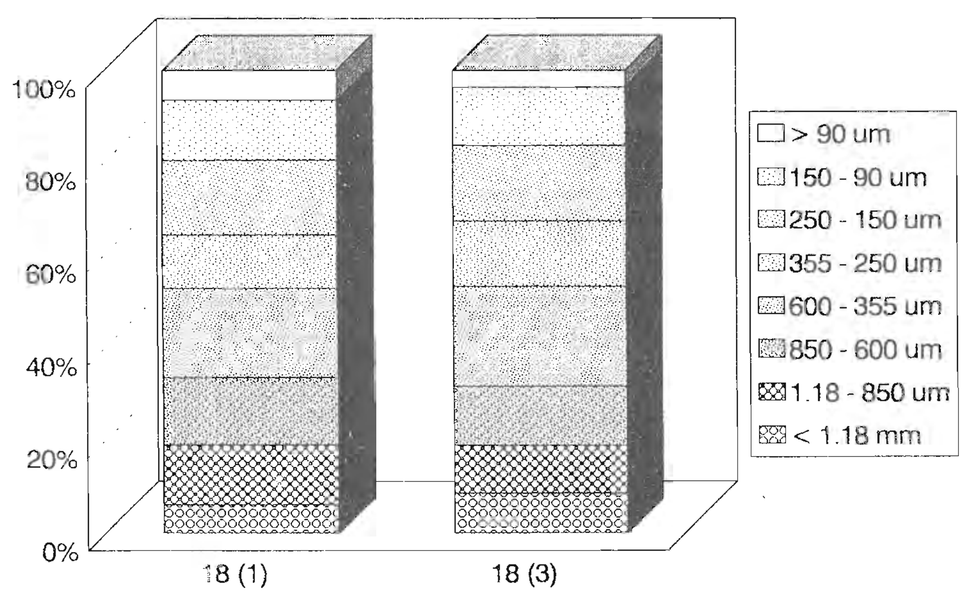
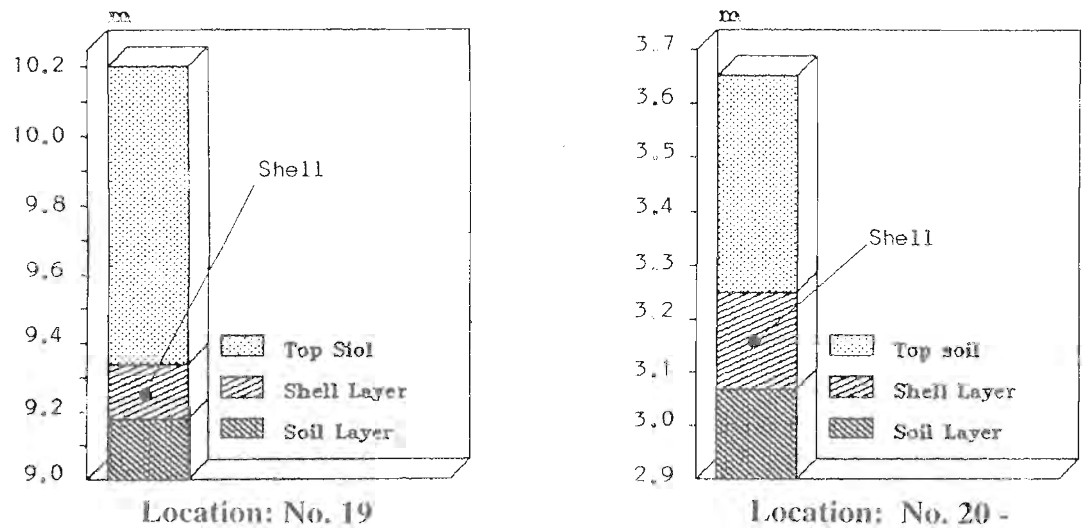


Figure 5.2.12. Organic and inorganic contents and grain size analyses of soil samples 18.1 and 18.2.



Location: No. 19 - Bundala Road 3 (near 4th km post): Ground level (from msl): 10.20 m, Upper level of the shell layer: 9.33 m, Lower level of the shell layer: 9.16 m, Thickness of the shell bed: about 0.17 m, Type of samples and levels: one shell sample (9.25 m). Description of samples and the stratigraphy: Stratigraphic conditions, types of shells and embedded soils of the location are as same as locations 17 and 18. **Location: No. 20 - Maha Lewaya (Koholankala):** Ground level (from msl): 3.65 m, Upper level of the shell layer: 3.25 m, Lower level of the shell layer: 3.08 m, Thickness of the shell layer: 0.17 m, Type of sample and level: one shell sample (3.16 m). Description of samples and the stratigraphy: Shells mixed with Dull Yellowish Brown Soil (10 YR 4/3) with calcareous clay. Well preserved *Meretrix* spp. of the sample is less than 35 mm in size.

Figure 5.2.13. Stratigraphic sequence of the shell bed at Location Nos. 19 (Bundala Road 3) & 20 (Koholankala).

5.3 Evolution of the Shell Beds and Their Relationship to Sea-Level Change

Katupotha (1992b) has recently indicated that the mid-Holocene sea-level was at least 1.5 m above that of the present level with three episodes as follows;

(a) 6240 - 5130 B.P. (first episode)
(b) 4390 - 3930 B.P. (second episode)
(c) 3280 - 2270 B.P. (third episode)

Following these high sea-level episodes, the former drainage basins were submerged forming lagoons and lakes further inland, sometimes 3 to 4 km inland from the present coast. The undulating lobes which were extended towards the coast and outcrops became headland. As a result headland-bay-beaches were created in many areas along the southern coast. Furthermore, the corals presently being buried between Akurala and Matara thrived in such embayments where factors were suitable for the growth of coral especially on the southwestern and southern coasts, while molluscs lived in Intermediate and Dry Zone coastal embayments.

Around 3,700 yr B.P. it is suggested that the beachrock formed slightly above mean high-water spring and inter-tidal level zone, on the west coast had developed during this stage. As evident from C-14 dates of shells embedded in emerged reef patches (Hubbs et al. (1962; Katupotha, 1988b) and corals (in positions of growth) from emerged reef patches (Katupotha, 1988b and 1988c) the climatic changes have occurred after the mid-Holocene high sea-level. The lowering of sea level can be recognized between 5030-4390 years B.P. and 3930-3290 years B.P. by C-14 datings of shell beds (Fig. 5.3.1 and Table 5.3.1).

The bulk of the shell valves of these shell beds have been piled up by exceptional storm wave action on mounds, in lagoons and lake bottoms and on sand dunes and headlands. Present investigations prove further that the shell valves of lagoons, lake and channel beds (floors of marine and brackish pools) mostly accumulated as in situ consequently on the lowering of sea level. Hence, the sea level around 4700 and 3600 yr B.P. was at its present level or slightly below it (Katupotha 1988b; 1988c; Katupotha and Wijayananda 1989). Further, C-14 dates of shell beds along the southern coast in the Hambantota district prove such changes have occurred during the Late Holocene. The coral colonies along the southwestern and southern coasts and shells along the southern coast were buried in mud and debris which were washed down into the embayments by terrestrial waters.

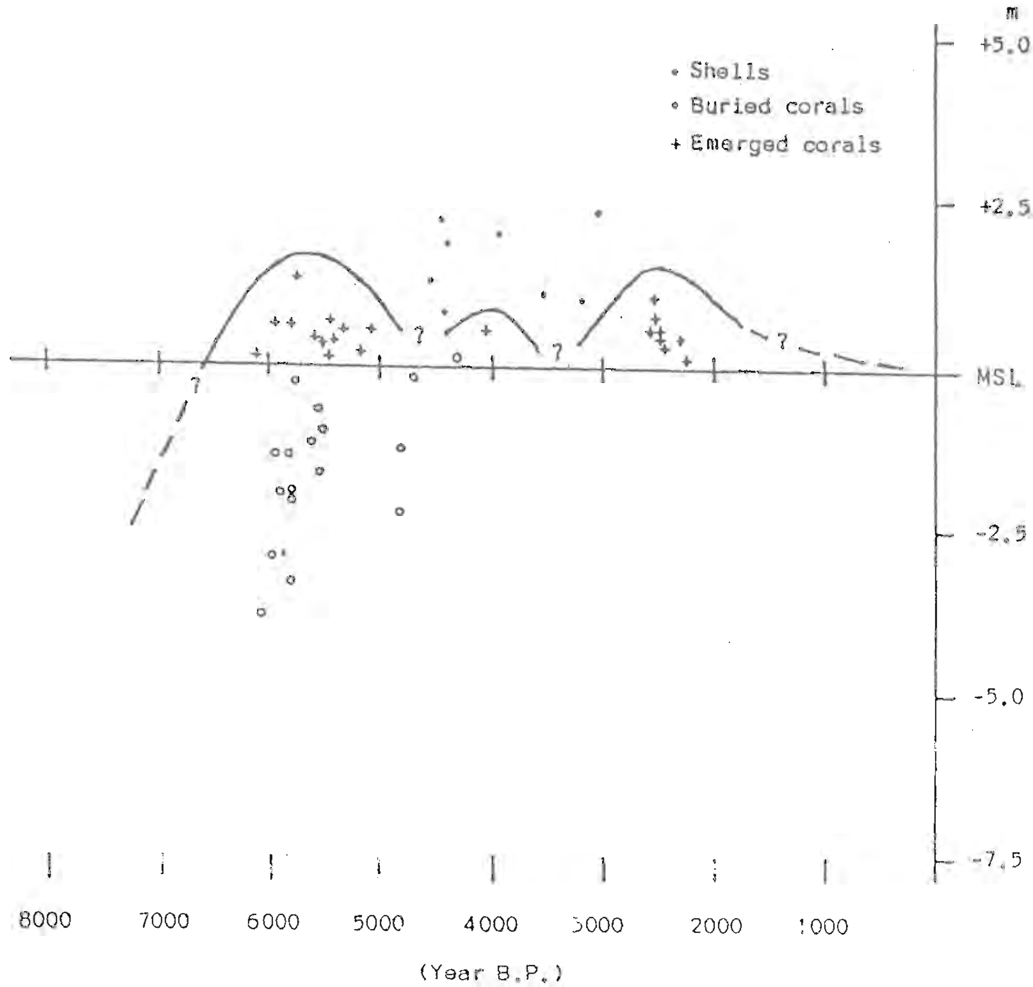


Figure 5.3.1. Three episodes of high sea-levels in Sri Lanka

TABLE 5.3.1 Datings of Shell Beds along the Southern Coastal Zone

No.	Locality	Elevation (in metres)	Age (yr B.P.) (half-life = 5568±30	Laboratory No.
1	Hungama	+ 1.3	5780±20	HR 120
2	Hungama	+ 0.8	4440±60	HR 264
3	Kalametiya	+ 1.2	3570±60	HR 265
4	Kalametiya	+ 2.2	4460±60	HR 266
5	Kalametiya	+ 2.0	3960±60	HR 267
6	Karagan	+ 2.3	3050±100	HR 123
7	Udamalala	+ 6.5	4050±60	HR 122
8	Udamalala	+ 5.0	4650±70	HR 268

Source: Katupotha 198b and 1988c.

Furthermore, the deposits had been intermittently covered by vast quantities of coral and/or shelly sand and various types of debris moved by severe monsoon waves. This is shown in Miniethiliya, Hatagala, Bataata - Gurupokuna, Kalametiya, Hunukotumulla, Nelumpathvila, Nabadewa and around Malala Lewaya areas. The colour and constituents of the layers show that they are subjected to local weathering conditions. Thickness of the top soil cover varies locally, sometimes more than 1 m thick alluvial soil underlain on the shell beds. The deposition sequences of some shell patches of the mounds at Udamalala and on dune deposits help to infer that the valves have been discarded by early inhabitants and animals.

6 HUMAN IMPACT ON MOLLUSCAN SHELL BEDS IN THE SOUTHERN COAST

6.1 Mining of Shell Beds as a Cottage Industry

The shell beds are extensively mined for production of lime, chemicals and chicken grit by local people throughout the area along the southern coastal zone. The mining of shells continue using women and children as labour on a daily paid or contract basis. Family members or neighbours continue the mining and washing operation from early morning till evening, despite the threat from wild-elephants in some areas especially between Karagan Lewaya and Bundala.

Some shell bed areas are the property of private owners but rest are state lands. Chena cultivation is undertaken in many park country areas. Bundala Sanctuary in the area has been declared as a National Park. Owners as well as middle men undertake 75 percent of the mining industry either legally or illegally.

A cleaned quantity (a pan full - tachchiya - or a shuttle -koodaya) is sold to the buyer for Rs. 3/= (the quantity may be about 6 kg). A quantity filling a normal tractor trailer is sold between Rs. 900/= and Rs. 1200/= by the miners.

The prices depend on purity and the size of shells. Four to six days are taken to collect a trailer load by two people. This also depends on the thickness of the top soil layer. If the top soil layer is thick, for e.g. about 80 cm or more and the shell layer is thin for e.g. about 10 - 15 cm, such areas are not selected for mining immediately. For mining of shells, people remove about 1 m thick surface layer of residual or alluvial soil which is suitable for paddy cultivation and other seasonal crops. This is a very strenuous job. Before the shell is sold, it is necessary to separate fragments and dust by washing or sieving. These operations are mainly conducted in mining pits. During the washing operation, the tiny fragments and calcareous clay are added to the water pools, and during sieving, fragments of shells and dust are thrown away. Such materials have never been used for any purpose.

6.2 Mining of Shell beds and Environmental Degradation

Mining is highly unsystematic and wasteful (Weerakoon et al, 1985). As a result of desultory mining of shell in private lands, government lands and protected areas the following negative environmental impacts and threat to human life have taken place.

(a) stagnant and polluted muddy water pools exist in depressions created by the mining of shells. They provide breeding grounds for malarial and other types of mosquitoes;

(b) the muddy water pools act as fatal spots for wild-animals, and sometimes even for people. Some pits endanger wild-elephants;

(c) the scrubs, stunted trees and wetlands of the park countries and the Bundala National Park provide suitable breeding grounds for different kinds of birds (peacock etc.) and many wild animals (deer, elk, elephants etc.). Continuing mining of shells of these areas is a hindrance and discourage the existence of wild-life;

(d) concentration of $CaCO_3$ in the soil by discarded fragments and dust as well as pits and mounds in the area have been responsible for degradation and destruction of the scrublands, cultivated lands (6.2.1 and 6.2.2), marshy lands and mangrove swamps as well as for the depletion of micro fauna and flora;

(e) air pollution occur due to dust and smoke as a result of the burning of shells for production of lime; and

(f) during mining and separating of shells and packing of shells lime, calcareous clay and dust enter the human body causing cutaneous, bowel and heart diseases etc.

Therefore, public awareness is needed for sustainable use of these natural resources and for the protection of the environment and health of the people in the area. Public awareness for proper use, protection and management of the shell beds can be undertaken by rural level societies, youth clubs and with the help of secondary school level students.

The shell miners damage the private and government lands, and they waste the shell resources due to desultory usage and improper management. Accordingly, environmental degradation sets in.

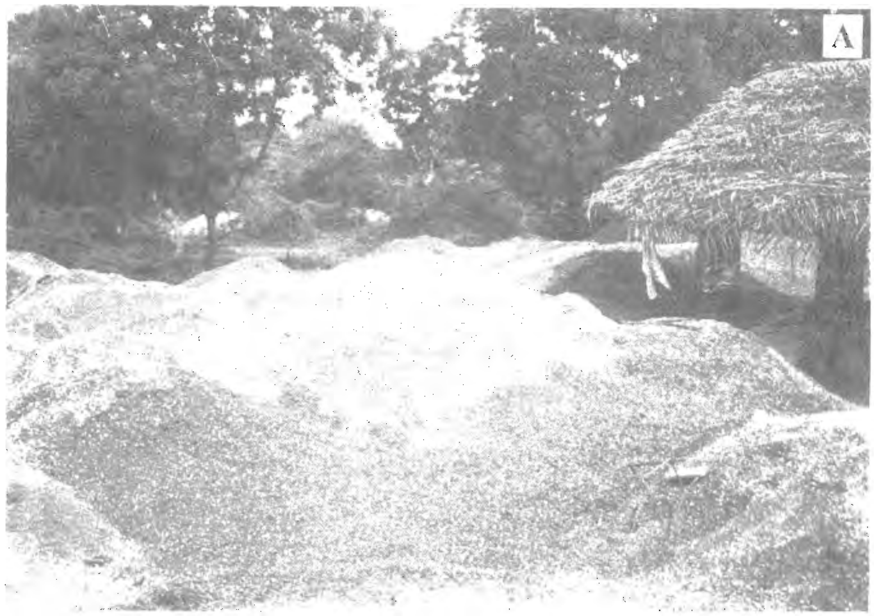


Plate 6.2.1. Wanton mining of shells, discarded shells and fragments and abundant shell pits (A & B) at (Location No 15 indicates the human impact on environmental degradation.

Plate 6.2.2. Destruction of scrubland and alluvial soil due to mining (A & B) at Bundala ((Location Nos. 17, 18 & 19).

7 SUMMARY

This chapter summarizes the results obtained. Chapter 1 recognizes the geological significance, evolution and uses of the shell beds. These shell beds are a natural resource which can be used for national development in many ways. Chapter one reveals relevant aspects of shell beds and their optimum usage, protection and management.

The second chapter is a comprehensive account of the physical characteristics and landuse of the shell-bearing areas. Accordingly, geology, geomorphology, climatic conditions, soil, natural vegetation and landuse in the area have been discussed briefly. These features have a close relationship in the formation, distribution and the usage of shell beds along the southern coastal zone.

Chapter three highlights a summary of the world-wide events of the Late Pleistocene and Holocene Epochs. The oscillation of sea-levels and formation of different kinds of marine beds are discussed here. Based on published evidence, it is possible to indicate different levels of marine terraces between the continental slope and the lowland of Sri Lanka.

The study of palaeosea-levels, sea-level indicators and their significance are mentioned in chapter four. For this purpose, geologic, faunal and floral materials have been used by palaeontologists, palaeobotanists and geomorphologists and geologists. Therefore marine molluscs, their diversity and complexity as well as behavioral characteristics are also discussed for identification of shells, evolution of shell beds and examination of their environmental values in Sri Lanka.

Chapter five focuses on the emerged shell beds of Sri Lanka. Extension of shell beds have been widely limited to mounds, former lagoonal beaches, bottoms of lagoons, lakes and streams. Stone-artifacts, pieces of bones, pieces of pottery etc. are mixed with those shell beds, and their extension differ locally. These materials have great value in the study of palaeobotany, palaeontology, and physical anthropology. The geological significance of the shell beds are described in detail in each location concerning the levels, soil and their constituents. The evolution of these shell beds have been indicated by using the author's C14 datings obtained a few years ago.

Chapter six mentions the possible human impact on shell beds. The shell miners damage the private and government lands and waste the shell resources due to desultory usage and improper management.

8 RECOMMENDATIONS

The recommendations listed here have been prioritized in terms of short term and long term measures. The short term measures can be proposed for the economical use of shell beds and long-term measures anticipate the protection and management of the resources. These guidelines will be supported to promote the cottage industry, human health and to prevent the environmental damage caused by unsystematic and wasteful mining.

Short-term measures:

(a) Shell mining of government land and private land should be prohibited and license should be issued because the greatest damage is caused by illicit, unsystematic and desultory usage

(b) The lands should be given-out only on a short-term lease (2 or 3 month basis)

(c) License holders should be requested to pay a reasonable license fee to agree to a certain standard deposit to be charged against any environmental damages and agree to the back-filling of pits

(d) A copy of every license should be sent to the Grama Niladari for evaluation of the procedure

(e) No license should be issued to protected lands. Furthermore, mining should be completely prohibited in the Bundala National Park and other Parks

(f) Throwing away of shell fragments, shelly sand and soil to water-pools should be stopped. By this, concentration of $CaCO_3$ could be minimized in the water-pools, soil and wetlands for the protection of fauna and flora

(g) Public awareness should be initiated to protect public health. This can be done through rural level officers for e.g., Grama Niladari, Rural Development Officer, Public Health Inspector etc.

(h) Environmental Education Programmes in shell mining areas should be carried-out on a systematic basis to enhance the awareness of environmental protection, public health and sanitation. This can be implemented by the Central Environmental Authority or District/Divisional level Environmental Authority.

Following long-term measures proposed will be helpful for sustainable livelihood and environmental management of the shell bearing areas.

(a) Labourers should be employed to close abandoned shell pits. For this purpose, the money already deposited as license fee by owners could be utilized.

(b) Public awareness is needed to use discarded shell fragments, shelly sand and dust. This calcareous material is very suitable for use as fertilizer for paddy fields, coconut, rubber and tea lands where the alkaline minerals, for e.g., $CaCO_3$ are washed down from the *A-horizon* of the soil. This will provide extra income for the shell miners.

(c) People individually or in groups who are willing to build their own shell plant or produce slaked-lime, chicken-grit and chemical lime as well as fertilizer from waste material should be encouraged. However, it is necessary that responsibility be taken by the Divisional Secretariat or Local Government Authority to introduce the products for market at reasonable prices and to protect such producers from middle men

(e) Existing law for the protection and management of the natural resources should be enforced without any political interference.

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