

# EPISODIC BEACH ROCK COMPLEX AT BUNDALA COAST SOUTHERN SRI LANKA – A PRELIMINARY STUDY

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## ABSTRACT

Beach rocks are cemented sandy beaches that represent paleo coast line and occur mainly in tropical climate, but also recorded in subtropical, arid and semiarid climates. A double bedded beach rock complex was reported at the Bundala historic site, Southern Sri Lanka. The unusual arrangement was investigated with the objective of implicating the origin of beach rock complex at the mouth of Bundala lagoon. Field sampling and petrographical as well as sedimentological analysis at the laboratory were performed. Results reveal that origin of the beach rock complex is episodic and triggered by Holocene sea level changes. The lower bed which is the oldest had been formed in a meteoric or marine vadose zone in an arid climatic condition while the upper bed had been formed in a marine phreatic zone. The boundary between the two beds is deduced as an unconformity resulted by surface erosion of lower bed during a lower sea level episode occurred after the formation of lower bed.

*Keywords: Episodic beach rock, Quartz sand, Acicular aragonite fringes, Sea level changes*

## INTRODUCTION

Beach rocks are cemented beach sands representing paleo beaches (Erginal et al., 2010; Irion et al., 2012). Formation of beach rocks is expressly correlated with paleo environmental changes (Benerjee, 2000; Morner et al., 2004; Lessa and Souza, 2006). Change in global and local climate undoubtedly affects coastal morphology, sediment supply and depositional pattern of coast (Harvey et al., 1999; Stive, 2004; Dickson et al., 2007). Hence upward and downward shifting of dynamic coast line is associated with fluctuations of sea levels depending on short or/and long term climatic cycles (Clark et al., 1978; Pluet and Pirazzoli, 1991; Hansom, 2001). Interestingly beach rocks can hence be considered as the time markers of climatic changes. They have been recorded in wide range of coastal localities; beach rocks are common features in tropical beach environments and also reported in subtropical beaches (Erginal et al., 2008; Forsyth et al., 2010;

Sahayam et al., 2010). Semiarid and arid climate in those beach area form identical environments for beach sand cementation and surprisingly humid climates have also supported the lithification process (Cawthra and Uken, 2012).

Beach rocks consist of any material in beach sediment at the moment of cementation. However, they are chiefly composed of beach sand mainly quartz with many other accessory minerals such as garnet, ilmenite etc and it also consists of rock fragments, pebbles, gravels as well as coral fragments, shells/shell fragments etc (Jinsen et al., 1978; Wagle, 1990). Matrix grains are commonly lithified with carbonates such as aragonite, calcite and dolomite (Erginal et al., 2010; Cawthra and Uken, 2012).

Sri Lanka as a tropical country indisputably has favored origin of beach rocks and they form discontinuous reefs along the coast (Cooray, 2009). These are dominant in northwestern, western, southwestern and southern coasts while scattered out crops occur in some places of

eastern coast of the island. They exist with the strand line while some are few meters away in offshore indicating several episodes of cementation. Many fragmented blocks are widened two-three meters depicting an abandoned road along the coast (Shinn, 2009). The thicknesses of beds vary and range from 0.25 to 10 m.

The beach rocks formations at different levels along Sri Lankan coast indicate the traces of paleo sea level changes. According to the Katupotha (1989) the formation history is driven back to late Holocene and some corals embedded in Sri Lankan beach rocks have been dated as old as 6000 yrs BP (Katupotha, 1988). Southern coast of the country has been submerged due to mid-Holocene transgression occurred around 7300 BP and stabilized sea level around 4900 BP subsequently was reached the present level at around 3000 BP (Ranasinghe et al., 2013a). Very similar dates of sea level changes were obtained for southern coast of India but another short sea level rise has been recorded between 5200 and 4200 BP (Benerjee, 2000). Paleo climate of southern coast of the country during the Holocene has been marked by three distinct aridity periods: from 7300 to 6750 BP, from 4000 to 3000 BP and from 1100 to 500 BP (Ranasinghe et al., 2013b). However the process and the paleo climate at which beach rocks of Sri Lanka were formed are yet to be investigated.

Bundala historic site located in the southern coast of the Island is famous for 80000 years old dune formations where prehistoric evidences were also recorded (Singvi et al., 1986; Perera, 2010). Bundala lagoon which is a part of the historic site is connected via a narrow mouth with the sea and it was widened and deepened due to the impact of 2004 tsunami waves causing reappearing of a beach rock complex at the lagoon mouth. It is clearly noted that these formations are unusually arranged and it is a rare occurrence of two different beds that exist one upon the other (Figure 1).

Hence this paper is aimed in studying the origin of beach rock complex with the extraordinary arrangement by a sedimentological and petrological approach.

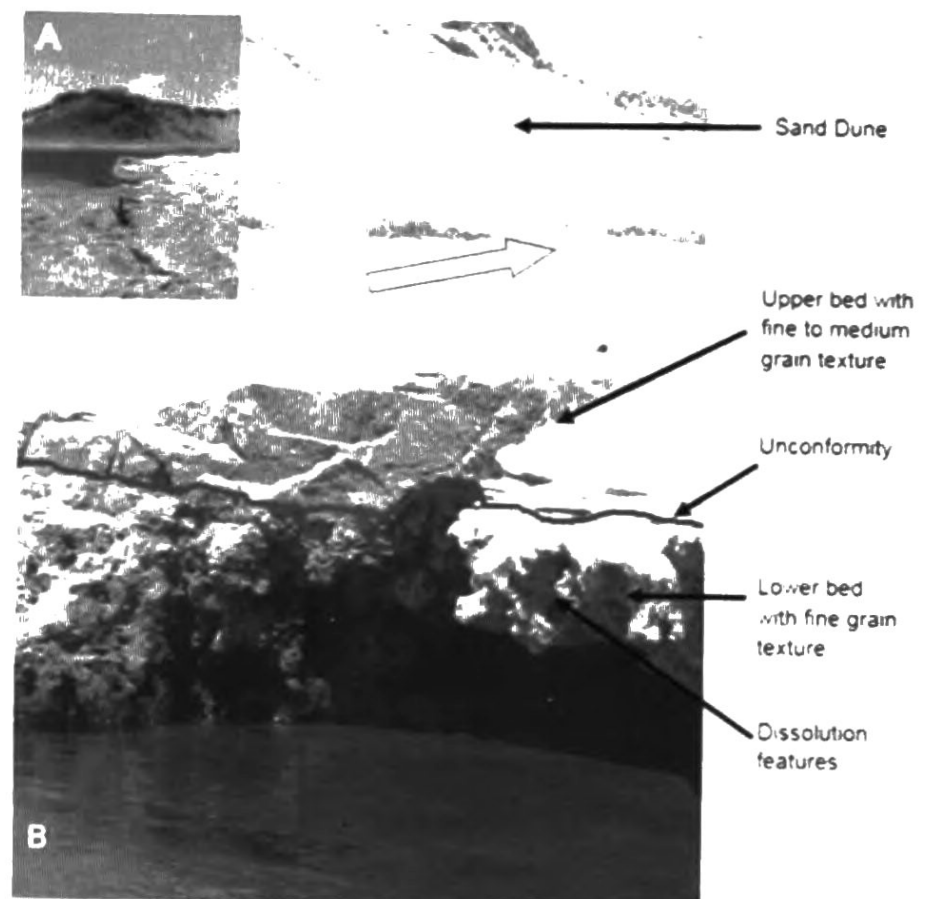


Fig. 1 Study location A) exposed beach rock complex at the Bundala lagoon mouth B) episodic double beds; Arrow head shows the sea side.

## PHYSIOGRAPHY AND GEOLOGICAL BACKGROUND OF THE STUDY AREA

The study area belongs to dry zone of the country (Figure 2). The area gets annual rainfall of less than 800 mm. The mean annual temperature is 27 °C. The area receives rainfall from southwest monsoon from June to October. Morphology of the area is characterized by coastal flat lands with small undulations which make higher grounds and vertical cliff at the coast. Some parts of the coast are characterized with dune ridges running along strand line. Geologically the area belongs to the Vijayan complex (Figure 2) which consists of high grade metamorphic rocks (Cooray, 1994).

## MATERIALS AND METHODS

Morphological characteristics of both beds were investigated and noted by close observations at the field. Six rock samples from each bed were sequentially collected for petrographic and sedimentological analysis.

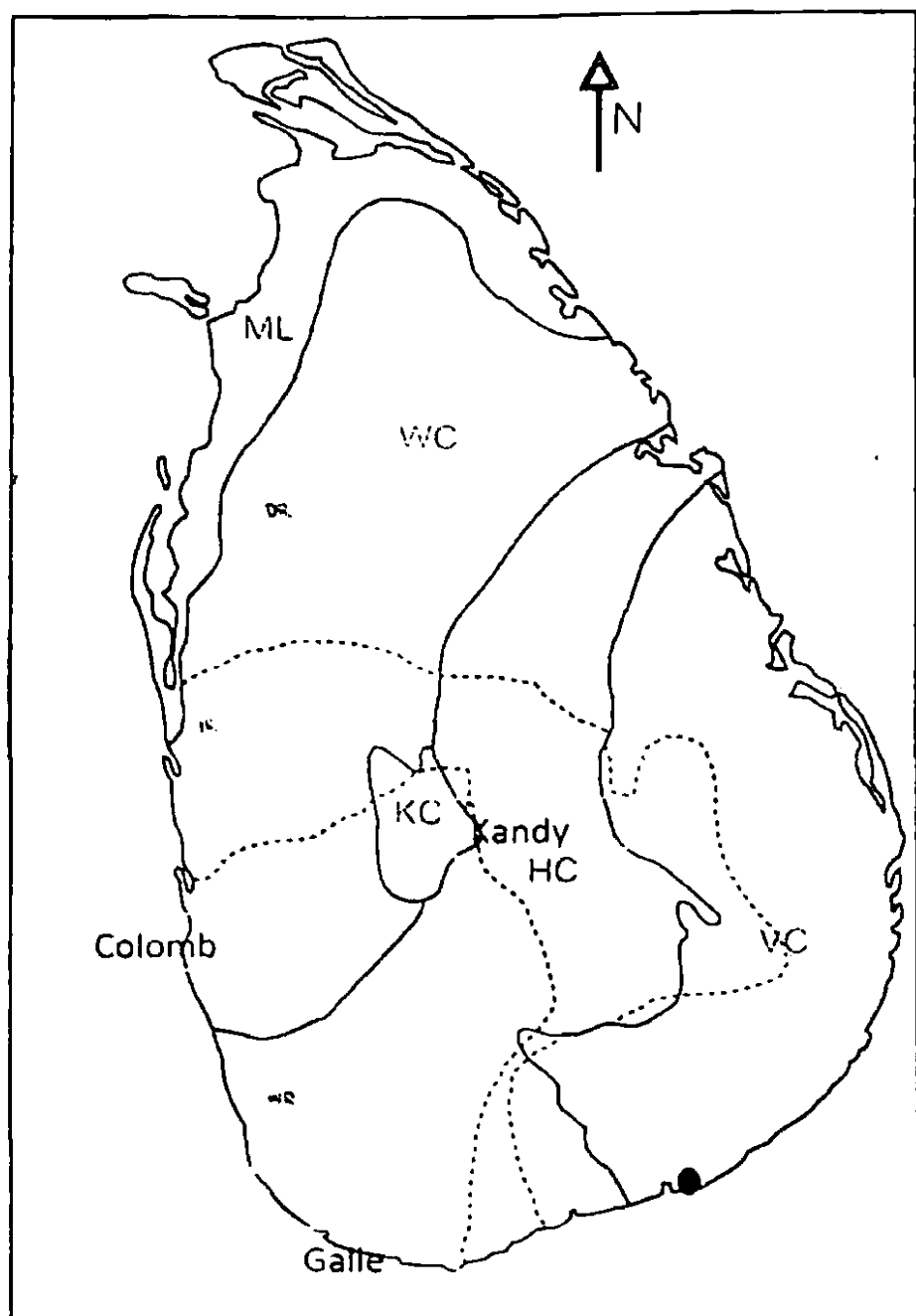


Fig. 2 Generalized map of Sri Lanka which shows 1. General Geology; HC: Highland Complex. VC: Vijayan Complex. WC: Wannai Complex. KC: Kadugannawa Complex. ML: Miocene Limestone 2. Climatic zones (dotted lines); WZ- wet zone, IZ- intermediate zone and DR- dry zone 3. Study location - Black circle.

Mineralogy and texture in beach rocks were optically observed in 10 thin sections prepared from 6 representative samples and framework mineral composition (modal analysis) was quantified using the point-counting method of Gazzi-Dickinson (Ingersoll, 1984).

Known weight of each of the collected rock sample was treated with diluted HCl to extract the matrix grains for the textural analysis and to determine the cement fraction. Separated grains after the acid treatment were thoroughly washed with acidic water to remove any remaining traces of cements. Air dried sand grains of each sample were sieved and fractions were weighed (ASTM, 2007). Effective grain sizes ( $D_{10}$ ), average grain sizes ( $D_{50}$ ), Cumulative coefficient (Cu), Mean ( $M_2$ ), Standard deviation (SD),

Skewness ( $K_1$ ) and Kurtosis (G) were calculated from the gradational curves obtained from the sieve analysis.

Matrix cements of each bed were studied by using X-ray Diffraction (XRD) analysis with a Siemens D5000 X-ray powder diffractometer.

## RESULTS AND DISCUSSION

### MORPHOLOGICAL CHARACTERISTICS

Two distinctive beds laid on one upon the other at the lagoon mouth as observed from the land (Figure 1). Both beds are extended towards the dune formations of either side of lagoon mouth and disappeared towards sea due to intruding into beach sand. The thickness of the entire complex is less than 0.5 m. The upper bed rests on the upper surface of the lower bed and clearly visible paleo unconformity is characterized by an irregular boundary which evidence for paleo erosion of lower bed. Due to the fluctuation of lagoon water level in some parts of the lower bed which is facing the lagoon has been eroded presently.

### PETROGRAPHY

Physical observations of collected samples disclose that the textures of upper and lower bed are characterized with fine to medium grain and fine grain respectively. The upper bed is lighter in color and show laminations of dark-fine and light-medium grain bands. Those fine grained bands are composed of opaque minerals while medium grained bands are mainly composed of quartz sand. The lower bed is yellowish brown in color. No laminations were observed. Dissolution features with no orientation were also noted. The upper bed contains comparatively high amount of ilmenite and garnet. In comparison more glauconite were found in the lower bed.

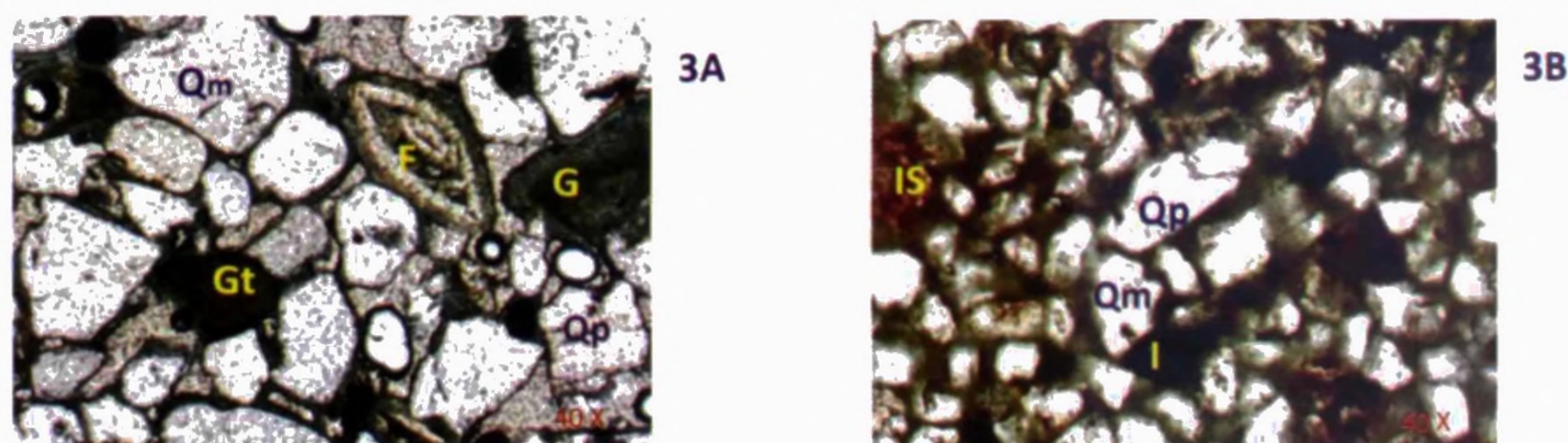
Modal analysis revealed that both beds fall in quartz arinite category (Folk, 1974). Monocrystalline (Qm) and polycrystalline (Qp) quartz occur in both beds (Figures 3A and 3B). The amount of Qm ranges from 65 to 72% and from 75 to 87% in the upper and lower beds

**Table 1 Statistical parameters (Average) of the matrix grains of both beds**

Bed	D10	D50	D60	Cu	M2	SD	SK1	KG
Upper	0.55	1.3	1.42	2.5	1.27	0.65	1.37	1.05
Lower	0.62	1.9	2.2	3.5	2.13	0.94	-1.29	1.15

respectively. The amount of Qp in the upper bed is between 15-22% and that of lower bed is between 9-18%. Both Qm and Qp in the upper bed are commonly sub rounded to sub angular. Broken sub rounded sand grains in the upper bed resulted by water agitation in high energy environments were also noted. Matrix grains of the lower bed show sub angular to angular texture which rather support for short distance transport. Qp in both beds is composed of commonly two grains while four grains (few) were also noted in the lower bed. Wavy extinction shown by some quartz grains and elongated shapes of Qm grains in both beds pinpoint a metamorphic origin. Secondary iron stains in the fractures of the quartz sand, along the grain boundaries and in the matrix of the lower bed (Figure 3B) are indicative of typical tropical weathering of iron containing minerals. Garnet grains of upper bed are mostly rounded to sub rounded while some shows very deep and dark red colors and occur scattered in both of the

Sedimentological analysis reveals that both beds contain sand size quartz grains. Upper bed consists of medium sand while the lower bed consists of fine sand as the matrix grains. Hence formation of upper bed is attributed to a high energy beach environment and in comparison with the lower bed which is possibly formed under low energy environment. According to the statistical analysis of the matrix grains (Table 1), cumulative coefficient for both beds indicate that the grains are uniformly distributed and sorted and that evidence for a constant reworking or sorting process acted on the sediments. Standard deviation of upper bed grains further characterize as moderately well sorted. But lower bed shows slightly poor sorting indicating a lack of wave action. Gradational cure of the matrix grains of upper bed is positively skewed and that of lower bed is negative. Kurtosis for both beds is noted as mesokurtic and leptokurtic. Thus, it can be inferred that both beds were formed in two



**Fig. 3 Photomicrograph of A) Upper bed B) Lower bed, Q-quartz, F-foraminifera, Gt-garnet, G-gluconite, I-ilmenite, IS- iron stains, Qp – Polycrystalline Quartz; Qm- Monocrystalline Quartz.**

laminated layers. Ilmenite in dark color layer are oriented parallel to the lamination and they are mostly very fine with elongated shape (Figure 3B). Well compaction was noted in the upper bed, whereas matrix grains of the lower bed are loosely compacted with scattered ilmenite. Based on the mineralogy of matrix grains the original source can be inferred as alluviums generated by running water after extensive weathering of high grade metamorphic rocks.

different environmental conditions and/or climatic periods of the southern Sri Lanka.

### BIOCLASTS/FOSSILS

The fossiliferous upper bed contains mainly bioclasts of gastropods, bivalves, algal filaments and commonly benthic foraminifera. Some foraminiferal shells are stained and voids are filled with iron oxide (Figure 4A) indicating supply. Some foraminiferal shells are stained and

voids are filled with iron oxide (Figure 4A) indicating supply of iron rich cementing materials during the lithification of upper bed of iron rich cementing materials during the lithification of upper bed.

Observed foraminifera are mostly *Sporoliticulina* sps. In addition presence of low amount of carbonate pellets indicating chemical precipitation in some of the thin sections prepared for the upper bed. Surprisingly no bioclasts were recorded from the thin sections of lower bed.

### MINERALOGY OF CEMENT

Cement is mainly made up of carbonate materials and as shown by XRD analysis it is indicated that the presence of calcite, dolomite and siderite as the carbonate minerals (Figure 5).

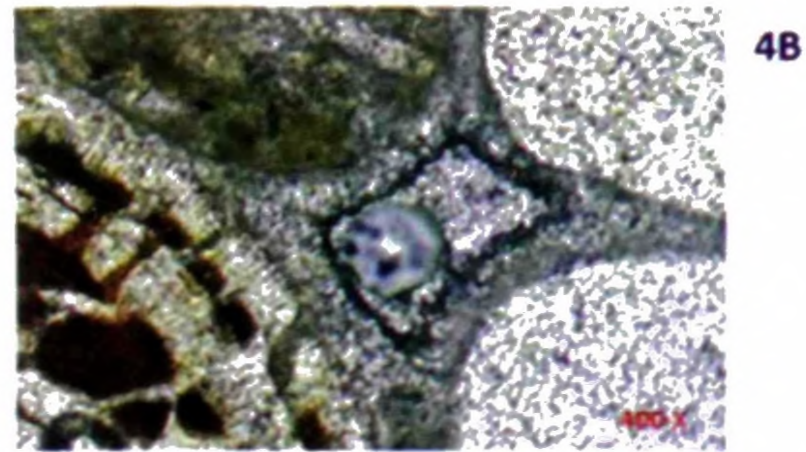
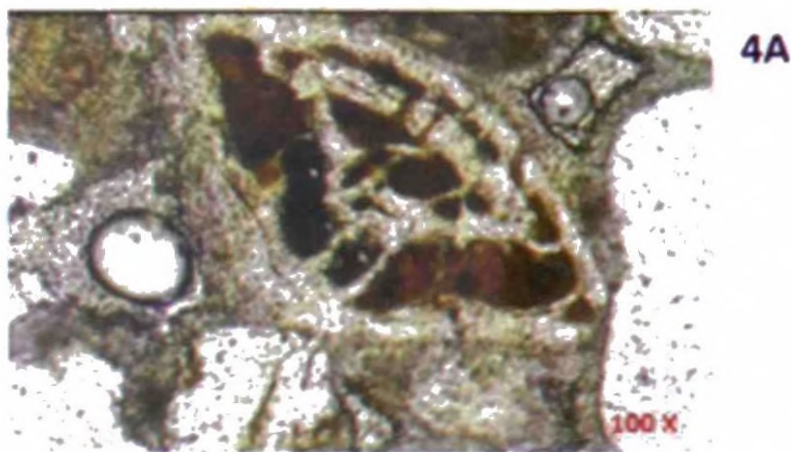


Fig. 4 Photomicrograph of A) Foraminifera shell, B) acicular aragonite fringes developed along the boundaries of quartz and fossils.

The mean percentage of cement (mostly carbonate) is 35% and 38% for the upper and lower beds respectively. The upper bed cement is characterized by mainly aragonite, micrite and biomicrite while that of the lower bed is mostly micrite. The sand grains and bioclasts were coated with isopachous acicular aragonite fringes which are perpendicular to the grain boundaries (Figure 4B). In addition some of the bioclasts (especially foraminifera shells) were observed with re-crystallized rims.

### FORMATION HISTORY OF THE BEACH ROCK COMPLEX

According to petrographical and sedimentological evidences, matrix grains of both beds are of alluvial origin.

They are the weathering products of high grade metamorphic rocks. However, the textural properties suggest that the grains of lower bed had been transported a short distance and deposited primarily in an alluvial environment comparatively during a period of lower sea level (Deraniyagala, 1986; Cooray and Katupotha, 1991; Ranasinghe et al., 2013a). Further, it can be inferred that the sands had been originated from a quartz rich granulite. With the change of climatic condition, the sands may have been deposited after being sorted and reworked by the prevailed wind under an arid climate of Holocene period (Singhvi et al., 1986; Deraniyagala, 1986; Alappat, 2011; Katupotha, 1988, 1989; Ranasinghe et al., 2013b). The rise of sea level which supplied the carbonate cement and continuation of windy conditions had caused the lithification of sorted sands/dune

sands in meteoric or marine vadose zone where rapid cementing is possible. It is clearly noted that several episodes of sea level fluctuations during the late Holocene have impacted on coastal formations. Many of those formations tend to be shifted up and down (Cooray and Katupotha, 1991; Benerjee, 2000; Ranasinghe et al., 2013a).

Paleo fluvial channels had cut the dune/beach deposits when the regression of sea levels and continental shelf area (Wicramaratne et al., 1988; Wijayananda, 1994). Hence it can be argued that lithified beach rocks were exposed and eroded so that the present observed paleo unconformity has been formed with the subsequent deposition. Retreated sea level which was at the same location of earlier beach rocks

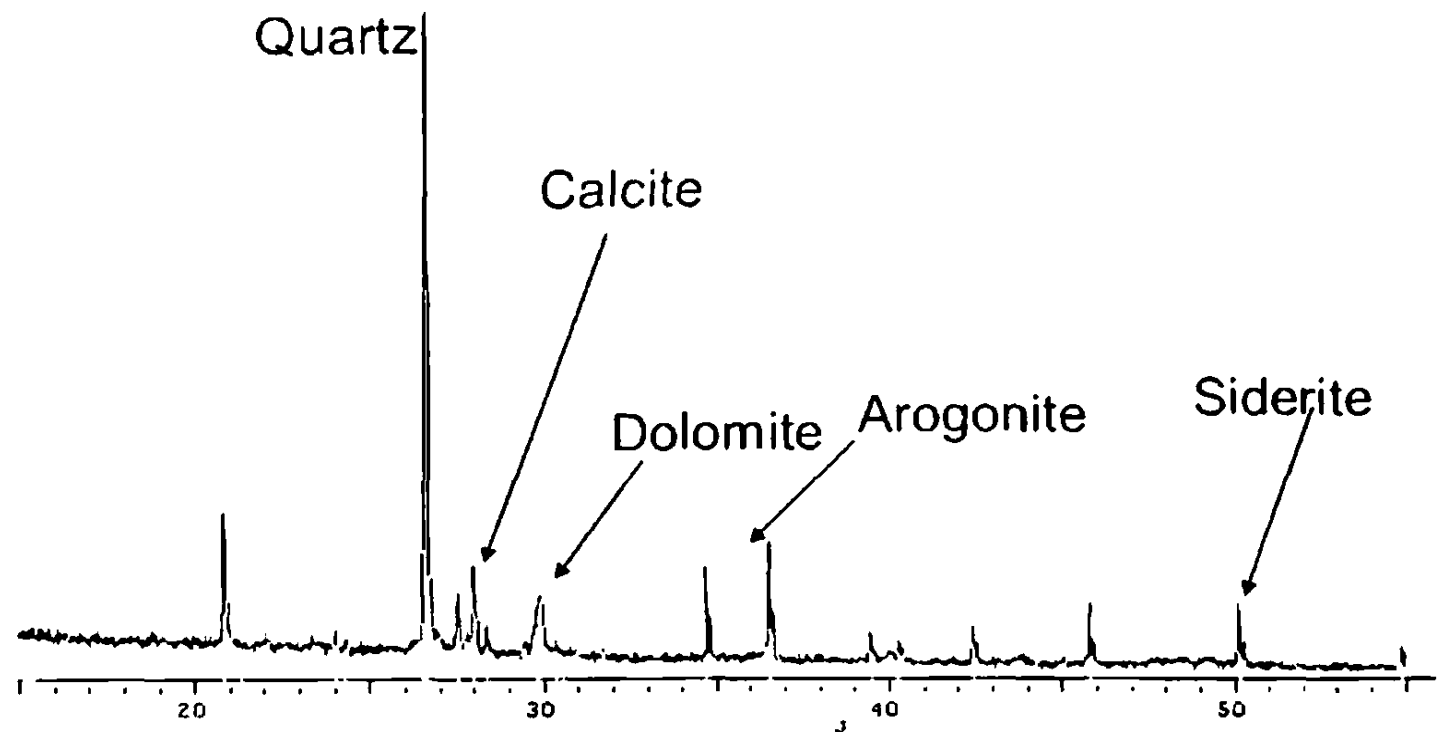


Fig. 5 XRD diagram of beach rock cement of the upper bed.

has caused to deposit the marine deposits as alluvial sands. The marine deposits were then transported may with the long shore current from the west. The sand deposited on the erosional surface has been reworked in a high energy environment. Shallow and calm environment occurred during the cementation process resulted for the formation of fossiliferous upper bed under preotic conditions on the eroded lower bed.

## CONCLUSIONS

The origin of the doubly bedded beach rock complex at the mouth of the Bundala lagoon, Southern Sri Lanka is concluded as episodic. Petrographical and sedimentological analysis reveal the presence of two lithification events for beach sand under two different beach environments in the past. According the literature, the processes have possibly been triggered by the paleo sea level changes occurred during the Holocene period. The lower bed which is the oldest has been formed in a meteoric or marine vadose zone in an arid climate while the upper bed has been formed in a marine phreotic zone. The possible unconformity between two beds could have been resulted by erosion during a lower sea level episode occurred after the formation of lower bed.

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## APPENDIX

*Appendix Table 1 Percentages of minerals identified in both beds*

Sample	Qm	Qp	Qt	Gt	Ilmnt	Gl	Wamb
Tu1	69	19	88	5	6	0.5	0.5
Tu2	72	15	87	6	6.5	0.5	0
Tu3	65	22	87	4	8.5	0.5	0
Tu4	67	21	88	4.5	7.5	0	0
Tu5	70	16	86	4.7	8	0.6	0.7
TI1	87	9	96	1	1.5	1.2	0.3
TI2	84	11	95	2	2	1	0
TI3	75	18	93	2.5	3.5	0.6	0.4
TI4	77	17	94	1	4.1	0.7	0.2
TI5	81	14	95	1.3	2.2	1.3	0.2

*Tu- Thin section-upper bed, TI- Thin section-lower bed, Qm- Monocrystalline Quartz, Qp-Polycrystalline Quartz, Qt- Total Quartz, Gt- Garnet, Ilmnt- Ilmenite, Gl- Gluconite, Wamb- Weathered Amphibole*