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COASTAL SAND DUNES OF SOUTHEAST SRI LANKA

An Aerospace Survey Supported by Laboratory Analysis of Materials

UPALI WEERAKKODY
Department of Geography, University of Ruhuna, Matara, Sri Lanka.

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Abstract: Sand dunes are the most common landforms of the Sri Lankan coasts even though little attention has been paid to them in the field of geomorphological studies in the island. In the first part of this study, the large-scale factors governing the sand dune formation are analysed, as an introduction to the aeolian environment of the SE coast. In the second part, using an aerospace survey supported by field work, the lateral and vertical distribution of dunes along the coast are described. The other relevant deposits known as red earth formation has been analysed in the third part of the study, in order to assess whether they were sand dunes in the past. Comparison of the granulametric properties unravels that the red earth formation once stood as dunes along the SE coast.

1.. Introduction

Surveying, mapping and studying sand dunes are important in nature conservancy and resource managment planning because they often possess distinguished biological habitats, attractive morphological scenery and ideal mineralogical sources. So far only a few geomorphological studies about coastal sand dunes have been made even though they are the most common landforms along many coastal tracts of Sri Lanka. An interesting study made by Swan[7] explains general facts on sand dune building in the coast of Sri Lanka relevant to humid tropical conditions.[8]

Preliminary observations carried out by the author reveal that sand dunes along the SE coast of Sri Lanka are formed due to favourable climatic and geomorphological factors which help to create an ideal aeolian environment through out millennium of years.[11,12] As a result of this long-term development some of their materials are characterized by different colours. Some dunes have buried others. In addition, deposits similar to wind blown sands remain in some parts without dune morphology. Such types of deposits known as the Red Earth Formation of the NW coast have been reported as aeolian or/and marine deposits by Wayland[9] Cooray[1] Dahanayake[2] and no concrete evidence has been put forward to prove whether or not they were post sand dunes. This shows that vital scientific questions pertaining to the field of aeolian environment of Sri Lanka still exist. Considering such scientific complexity in the field of aeolian environment in the SE coast of Sri Lanka, a research was undertaken on sand dunes to examine several geomorphological aspects;

a) Large-scale factors governing the sand dune formation along the SE coast,

b) The lateral and vertical distribution and their sequential distribution, and

c) Analysis of the relevant deposits which possess aeolian sedimentary characteristics in order to unravel whether they were sand dunes or other morphological components.

2. Methodology

Generalizing the factors of sand dune formations was carried out in order to understand the aeolian process along the west and east coasts. The data for the synthesis of factors were collected from weather reports, previous studies, etc,. Summary of wind data was derived from Zeper[13] while the information on sediment movement was adopted from Weerakkody.[10]

The interpretation of black-&-white panchromatic aerial photographs at a scale of 1:20,000 aided by field work forms the basis of dune survey of the study area. Some data on morphometry were obtained from the interpretation of Landsat false colour composites and band 4 images. The ITC* system of geomorphological survey and mapping using aerial photographs and other remote sensing techniques was used to demarcate dunes and surrounding geomorphological features of the coastal zone. The ITC* system is an applied geomorphological discipline which provides a concise and systematic picture of landforms and related phenomena of an area. According to this method, aerial photographs i.e. B & W panchromatic, infrared, false colour and satellite imagery i.e. Landsat 3, SPOT or radar imagery as required, are interpreted using a mirror stereoscope and other instruments, taking into consideration the tone, mottling pattern, contrast, texture, etc, of the photographs or imagery. The interpreted features are normally elaborated by field work and/or laboratory analysis of materials. A geomorphological map so compiled shows types of landforms, morphometric, morphogenetic and morphochronological properties of landforms as well as a classification of landforms by origin into structural, denudational, marine, fluvial, aeolian, etc, under a well arranged key. Therefore, the ITC system serves to understand morphology, morphometry, genesis as well as the chronology of the landforms of an area using geomorphological maps.[4,10,11] The survey resulted in generalized maps of sand dunes in the area.

Granulametric analysis of the samples collected from the dunes and associated deposits was used to decide whether the deposits without dune morphology were once sand dunes. Comparison of grain size distribution pertaining to different formations is normally used for such type of study.[5]

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* *International Institute for Aerospace Survey and Earth Sciences.*

The cumulative curves and histograms of the grain size distribution are the most graphical representation for such comparison. Analysis of the collected samples was carried out in the NUFFIC laboratory of the Department of Geography, University of Colombo. The analytical method used for fraction of grain separation is shown in Figure 1.

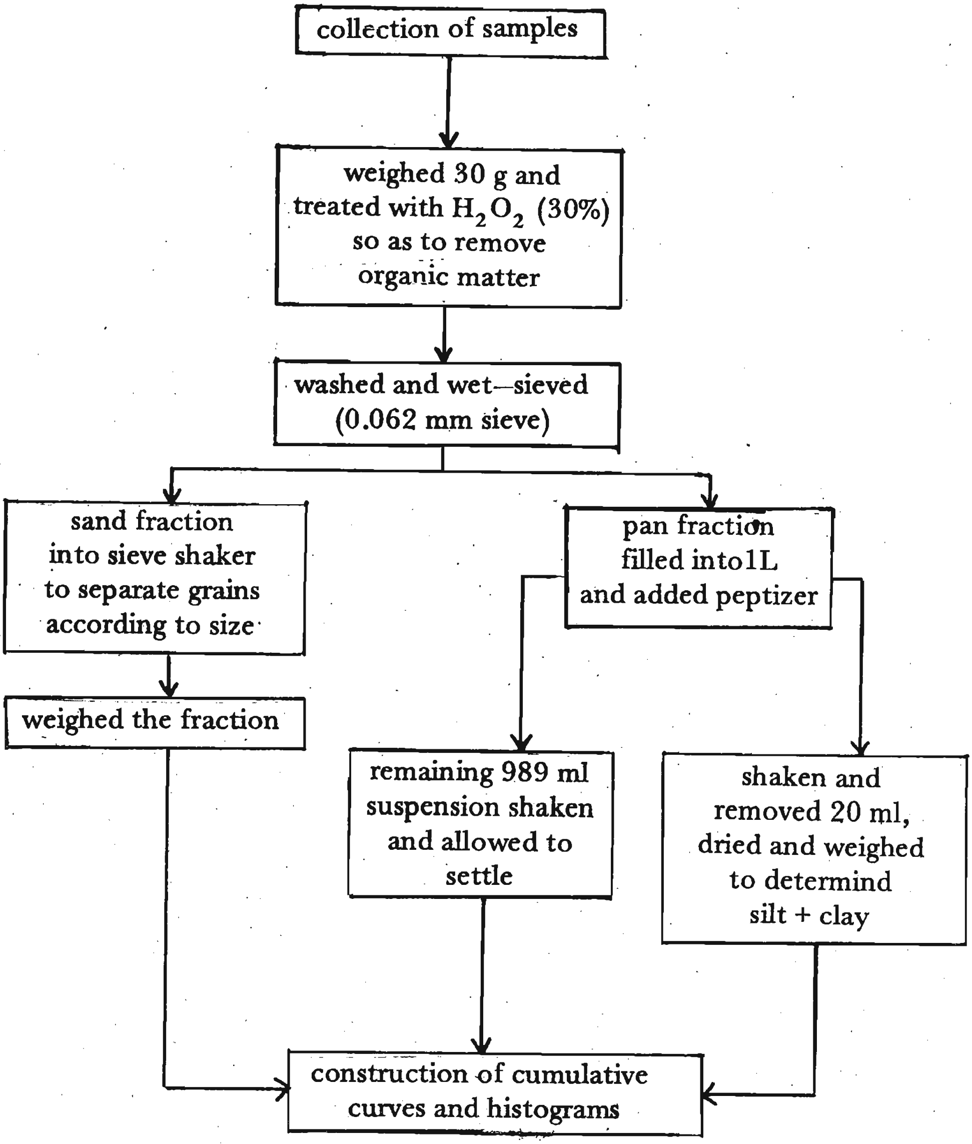


Figure 1 : The analytical method used for fraction of grain separation

Having analysed the samples, the laboratory data were treated statistically using the computer program PLOTGRAINS,[3] which result in a histogram, a cumulative curve and a calculation of percentile values. Similarity and dissimilarity between dunes and associated deposits were unravelled by a comparison of the cumulative curves, histograms and percentile values.

3. Results

3.1 The Factors Influencing the Formation of Sand Dunes along the Coast

Dunes are low hills of drifted sands. Their formation is strongly influenced by wind direction and velocity, amount of sand supply, the presence of obstructions, surface moisture content and grain characteristics. Therefore, the occurrence of coastal sand dunes in SE Sri Lanka, as elsewhere, is mainly governed by climatic factors. The amount of sand supply depends on the factors such as the direction of longshore currents, the amount of material brought by the longshore currents and the amount of material piled by wave action onto the beaches. Examination of sediment dynamics along the SE coast, unravels the amount of sand supply to the area. Therefore, climatic factors and sediment dynamics along the coast were treated here in detail as factors influencing the formation of sand dunes.

According to Sirinanda's definition[6] the study area is situated in the Dry Zone of Sri Lanka. Compared to the other wetter regions, neither the SW monsoon (mid–May to September) nor the NE monsoon (November to March) results in heavy rains in the study area. The average annual rainfall of the study area varies from 1000 to 1250 mm, most of it occuring during October, November and December. From January to October, the potential evapotranspiration exceeds the rainfall resulting in a continuous cumulative water deficiency of about 635 mm.[6] This applies to the entire study area and its surroundings, as is demonstrated by the data at Tissamaharama, situated further to the east. The average monthly water balance in which the potential evapotranspiration exceeds the rainfall clearly exhibits that the limited surface moisture content helps in drying sands making it liable to be easily transported by wind action.

Comparisons between the SE coast, East and West coast show that the study area is strongly affected by the SW monsoonal winds during eight months of the year. This dominant direction is further seen through the crest direction of dunes lying in a SW orientation along the SE coast. Data on mean wind speed and mean daily wind speed show that the most favourable conditions for sand dune formation occur along the SE coast rather than along the East and West coast of Sri Lanka (see Figure 2a & b).

Table 1 : Prevailing wind direction of southeast coast compared to east and west coasts. Similarly, the rose diagrams of Figure 2a & b illustrate that the study area has the highest wind speeds through out the year as compared to east and west coasts of Sri Lanka.

Month	Hambantota (study area)	Baticaloa (east coast)	Colombo (west coast)
January	NE	NE	N
February	ENE	NE	SW
March	E	NE	W
April	SW	E	SW
May	SW	E	SW
June	SW	SE	SW
July	SW	ESE	SW
August	SW	SE	SW
September	SW	SE	SW
October	SW	SE	SW
November	SW	NE	NW
December	NE	NE	N

The sea weaves created by the monsoonal winds reverse their direction twice a year. When SW sea waves dominate, east and northward movement of sediment occures, while the NE sea waves cause a south and westward movement. The arcuate shape of the southwestern tip of the island obstructs sediment movement during the stronger SW monsoon (Figure 3). The NE sea waves are generally not strong enough to transport sediments in bulk towards the west. The stronger SW monsoonal sea waves, however, transport the sediments from the SW beaches towards southeastern and northwestern coasts by means of longshore currents.

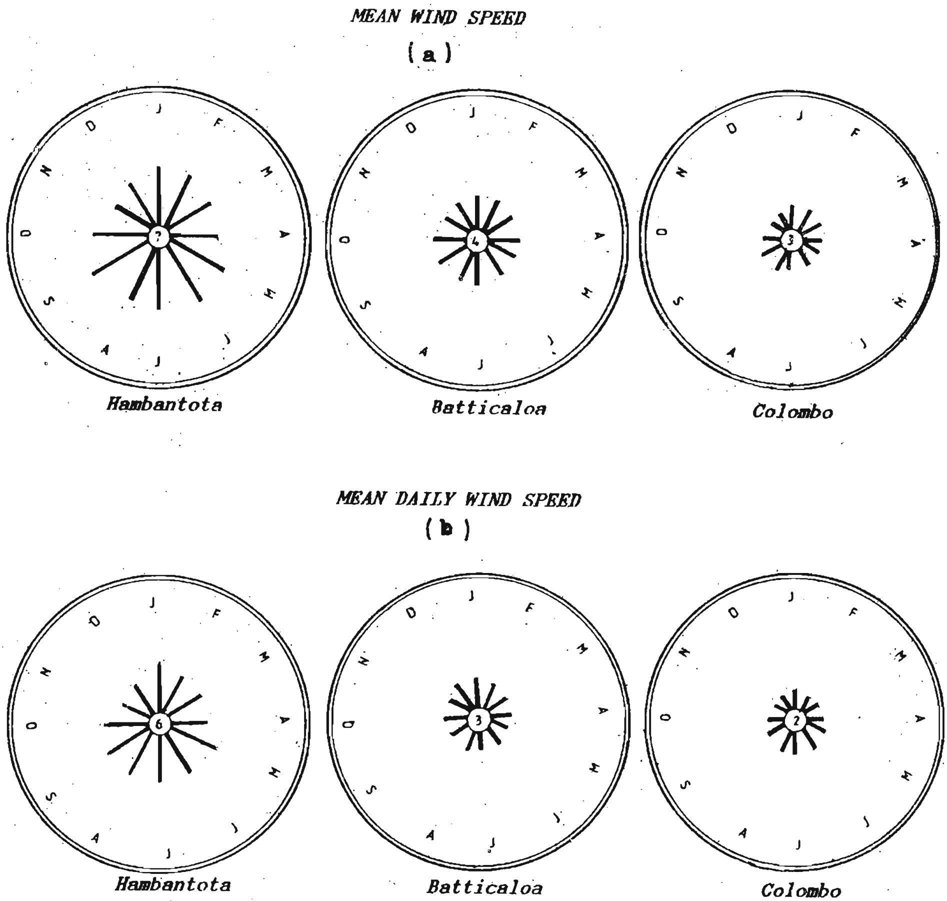


Figure 2a & b : The wind characteristics of the SE coast compared to east and west coasts (a & b). The bar length of the wind rose pertaining to Hambantota (study area), Baticaloa (east coast) and Colombo (west coast) is directly proportional to the wind speed.

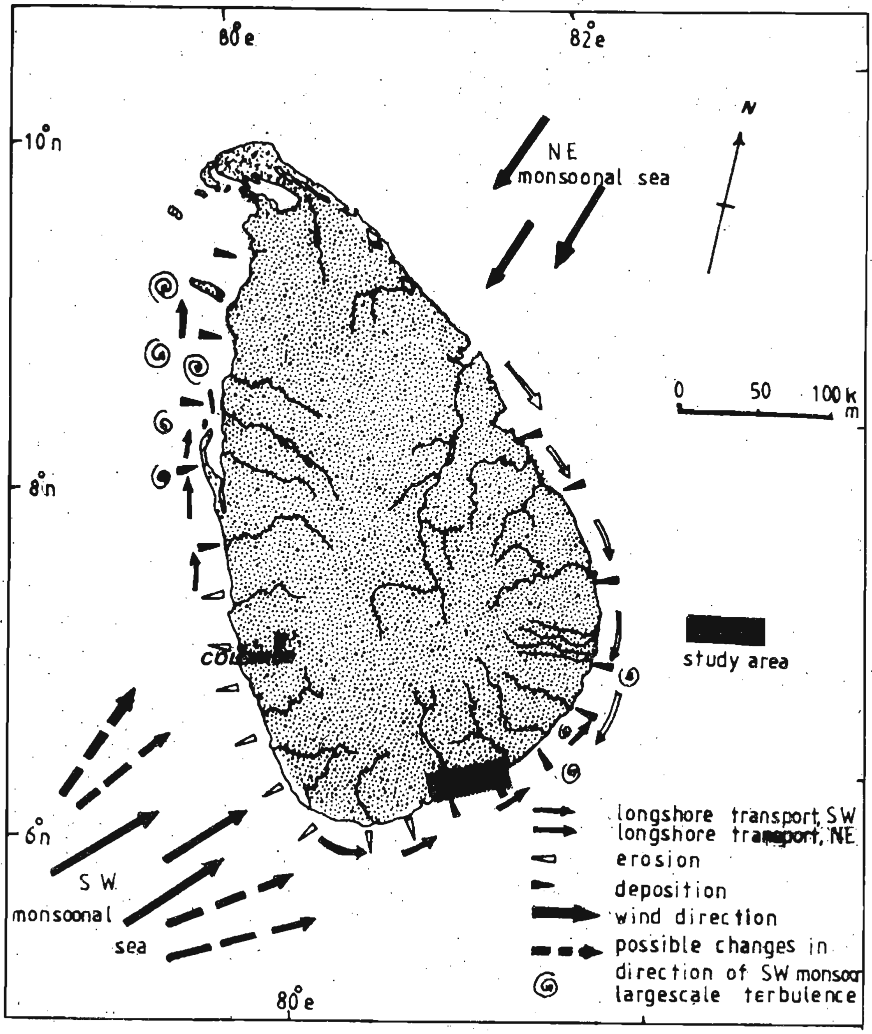


Figure 3 : Expected sediment movement under the influence of the SW and NE monsoons (based on Landsat 3, band 4 satellite images).

Longshore drift originated by longshore currents supplies ample amount of sand which is trapped by a number of concave beaches separated by rocky headlands. The waves generated by the SW monsoon are directed eastward. Thus eastward longshore currents are generated in this season. Several promontories and headlands trap sediment that is transported towards the east (Figure 4). This situation gives rise to the formation of extensive depositional beaches, especially between Hambantota and Bundala. Important traps for the eastward sediment motion are the Henagahapugala, Ussangoda, Godawaya, Mirijjawila, Hambantota, Koholankala, Bundala-modera and Bundalawella–addaragoda.

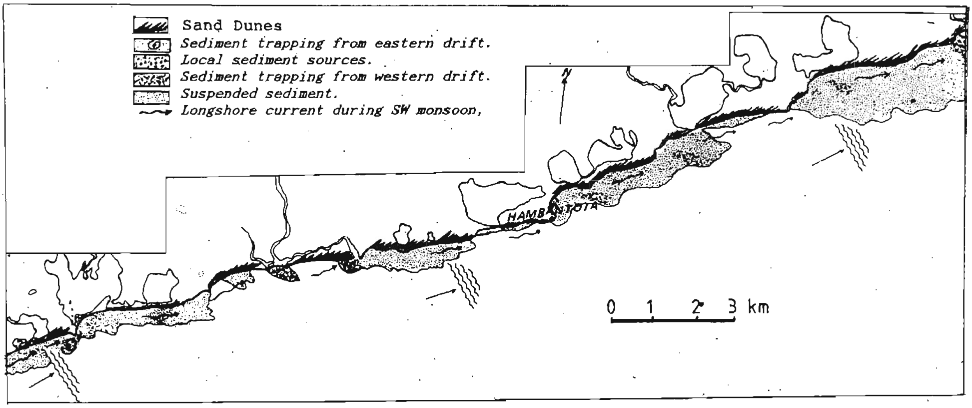


Figure 4 : Transportation of sediment by eastern and western drift. Compare with Figure 5. (based on Landsat 3, band 4 satellite images).

During the NE monsoon period, the waves coming from the east make a small angle with the beaches or are parallel to them and, the littoral drift therefore, is diverted towards the west. When the beach compartments face the east, the sediment brought by west–bound waves can easily be trapped, especially by the compartments numbered 2,6,9,13 and 14 of Figure 5. The volume however, of sediment trapped is smaller during the westward drift than it is during the eastward drift. Beach compartments facing the eastward drift receive a much larger volume of sediment transported by the eastward longshore currents. The sediments deposited along these beaches ultimately dry out and are transported by the wind action to form coastal dunes. The combination of wind characteristics and the depositional nature of the SE coast results in an ideal environment for the formation of coastal dunes.

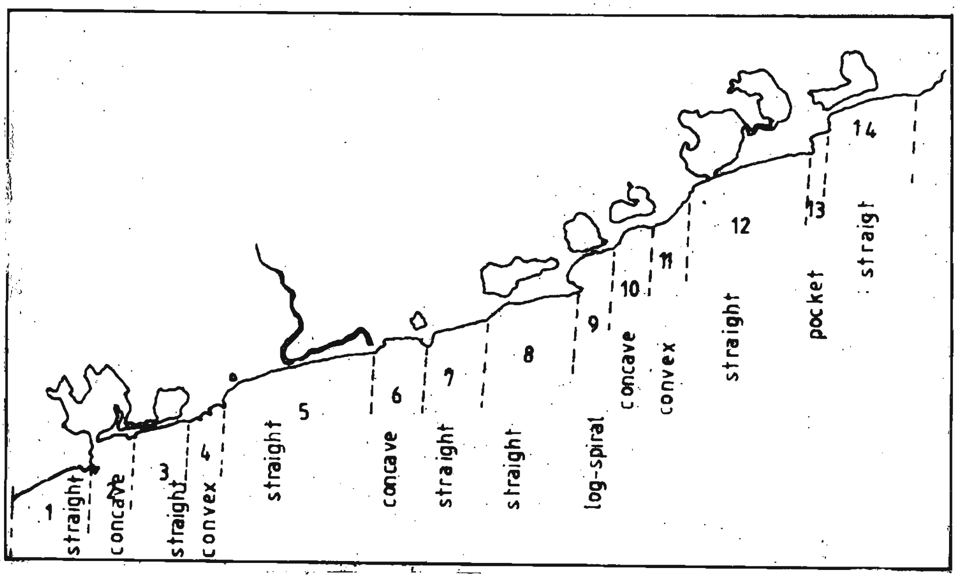


Figure 5 : Beach types along the southeast coast. (based on Landsat 3, false colour satellite images).

3.2 Spatial Distribution of Sand Dunes and Dune Generation

The dune formation along the SE coast begins from a coastal compartment east to Tangalla and occurs along the entire coast of the study area. They have developed as discontinuous or continuous belts on former barrier chains or on fluviomarine plains. Some areas are characterized by a single generation while others are occupied by two generations of dunes. Along some coastal belts, the dunes have developed into two vertical generations. A well developed dune field which obstructs the Walawe River mouth and diverts it towards the east is a good example for a coast consisting of two lateral generations of dunes (Figure 6a). The Malala–Bundalamodara coast and the Sittarakala–Mirijjawila coast are occupied by one generation of dune fields as shown by Figure 6b & c. Since the characteristics of dune distribution is different from coast to coast, the entire study area was divided into stretches concerning main features and allied phenomena of dunes. The results are shown in Table 2.

Table 2 shows that the vertical generations consist of dunes in two colours. The colour difference reflects the difference in age. The reddish colour of the older dunes may be due to oxidation of heavy minerals in

Table 2: Main characteristics of dune distribution along the SE coast of Sri Lanka.

Area	Continuity	Developed on	lateral generation	Vertical generation	red earth formation
Rekawa–Ussangoda	discontinuous belts	former barrier chains	single/ foredune	Single (yellow)	scattered deposits
Ussangoda–Walawe Ganga mouth	discontinuous belts	former barrier chains	single/ foredune	single (yellow)	absent
Walawe Ganga mouth–Godawaya	continuous	fluviomarine plains	two generations	single (yellow)	absent
Godawaya–Sittarakala	continuous	dried lagoonal floor	single/ dune fields	single (yellow)	absent
Sittarakala–Maha Lewaya	discontinuous belts	former barrier chains	single/partly two generations	single (yellow)	extensive fields
Maha Lewaya–Bundalamodara	continuous belts	former barrier chains/Insitu rocks	two generations	two generations (yellow/red)	scattered deposits
Bundalamodara–Kirindi Oya	continuous belts	former barrier chains	two generations	absent	absent

yellow = young, red = old

sands. Two types of dune formations, in vertical section, can therefore, be found on the basis of these facts; the recent (yellow) dunes and the old (reddish) dunes. In the case of lateral distribution, they also exhibit two generations of dune development as symbolized in Figure 6 by DL_1 and DL_2.

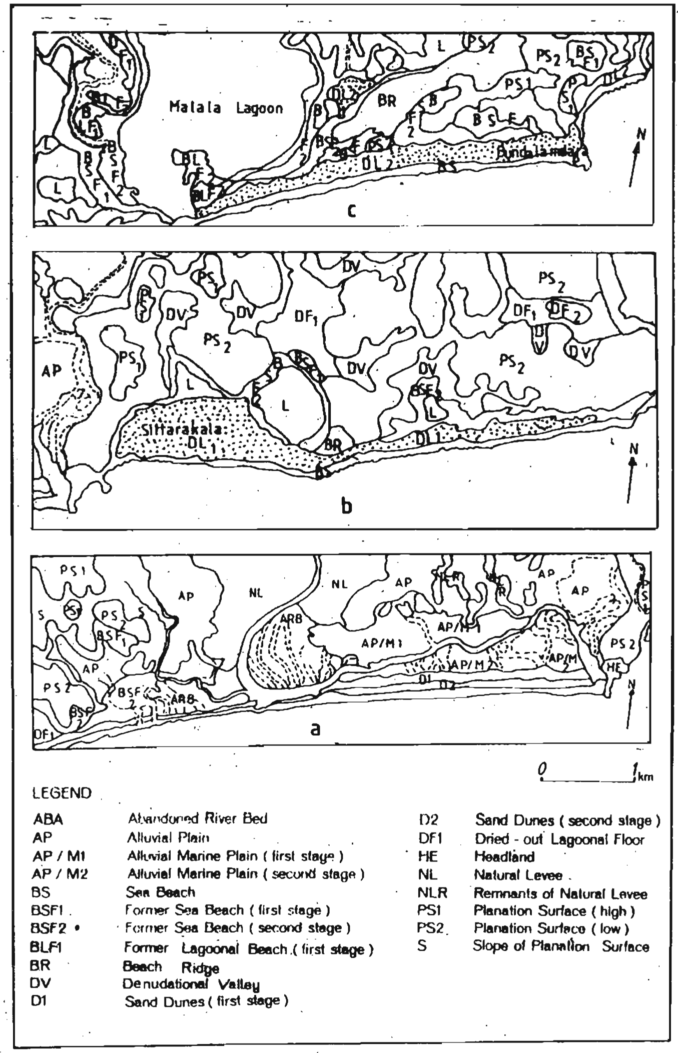


Figure 6 a,b,&c : Dune and their associated geomorphology along some parts of SE Sri Lanka. The two laterally dominated dune generations have obstructed the Walawe River mouth and diverted to the east (a). A broad dune field developed into a single generation has possibly formed on a former lagoon of which the northern part still remains as an active lagoon (b). The Malala–Bundalamodara coast is occupied by a single generation of dune field (c).

However, most of the laterally distributed dunes are secondary features, generated by wind action reworking the barrier sands. Parabolic and short longitudinal dunes are the most common types of dunes occurring along the SE coast. They have been strongly altered by later wind action and their typical physiognomy is thus largely obliterated. The problem to be solved here is whether the red earth deposits are similar to the old red dunes and to the recent (yellow) dunes along some parts of the SE coast. Analysis of granulametric characteristics of the red earth deposits help in deducing whether they are sand dunes or other marine deposits.

3.3 The Red Earth Deposits and their Granulametric Characteristics

The red earth deposits are partially consolidated materials occuring as undulating surfaces especiflly along the Hambantota and Malala areas. The surrounding area of the Hambantota town is completely covered by such deposits even on the Hambantota headland (the rest house Kachcheri premises) which is above 10 m from the present sea level. The colour of the deposits is red but different from that of the red old dunes in the Munsell soil symbols shown below,

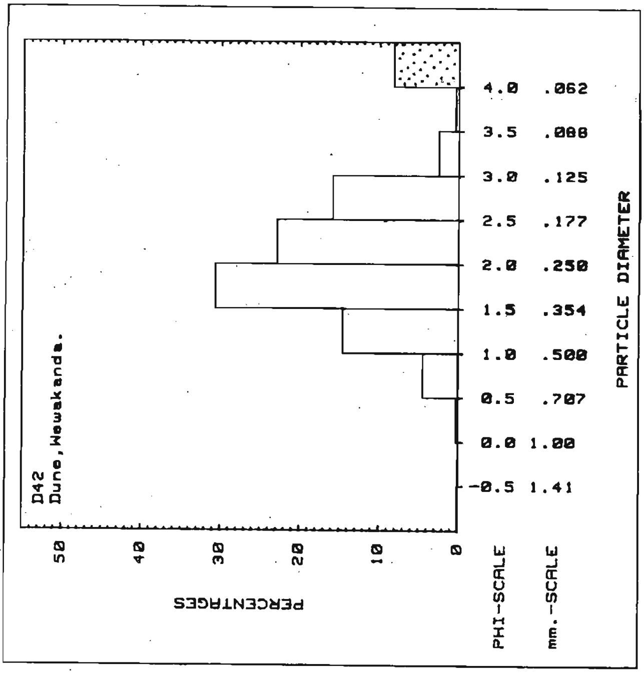
	Dry	Wet
Bundala–Koholankala red old dune	10 YR 3/6	10 YR 2.5/2
Hambantota red earth deposits	2.5 YR 4/4	2.5 YR 3/4

The granulametric analysis of the recent dune sands is graphically shown by the cumulative curves and histograms of grain size distribution in Figures 7,8 and 9. Figures 10 and 11 represent these properties for old red dune of Bundala and for the red earth deposits of Hambantota respectively. These graphs show clearly that ;

a) all samples of recent dunes (Figures 7,8 and 9) are very similar to the old red dune (Figure 10) and to the red earth deposits of Hambantota (Figure 11).

b) the old red dune (Figure 10) and red earth deposits (Figure 11) have slightly flattened S–shaped curve and high silt clay content.

The similarity of the grain population of the sands is further evident by the phi–values corresponding with the crucial percentiles in the available data given in Table 3. The more or less similar percentiles in the available data of this table support the view that the Hambantota red earth deposits represent dunes of an early period that have been reworked by latter processes including those induced by man.



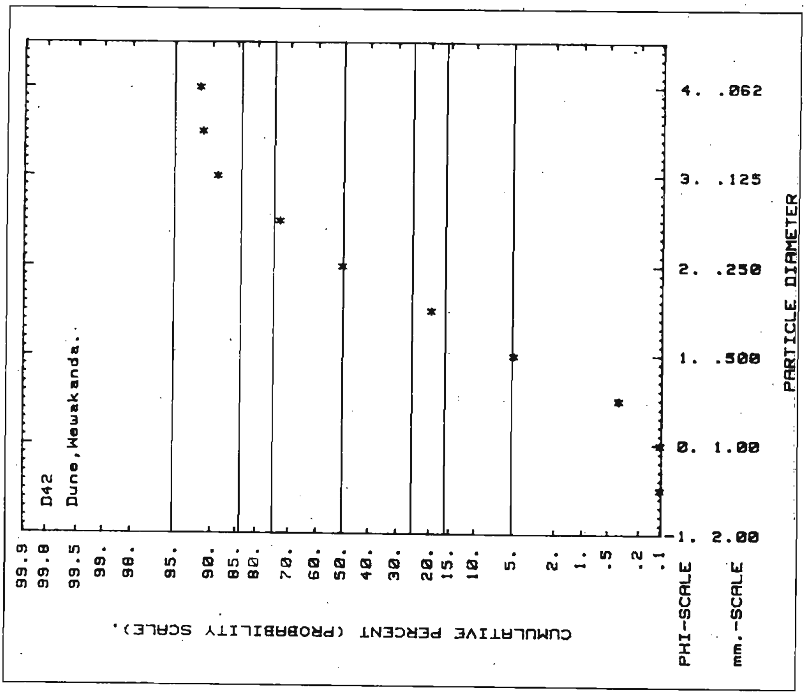
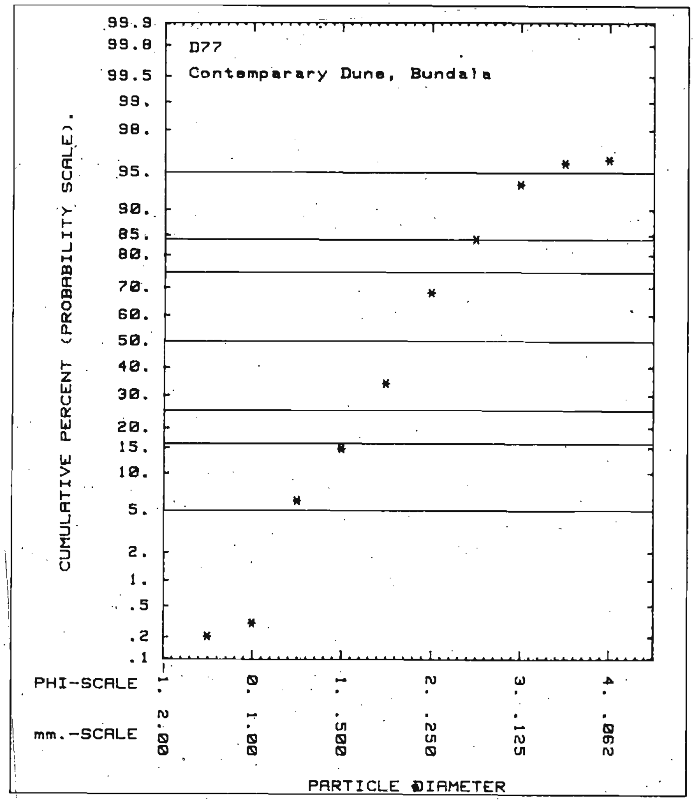


Figure 7 : Grain size distribution of recent dunes at Wewakanda. Silt/clay content is shown in the shaded column.



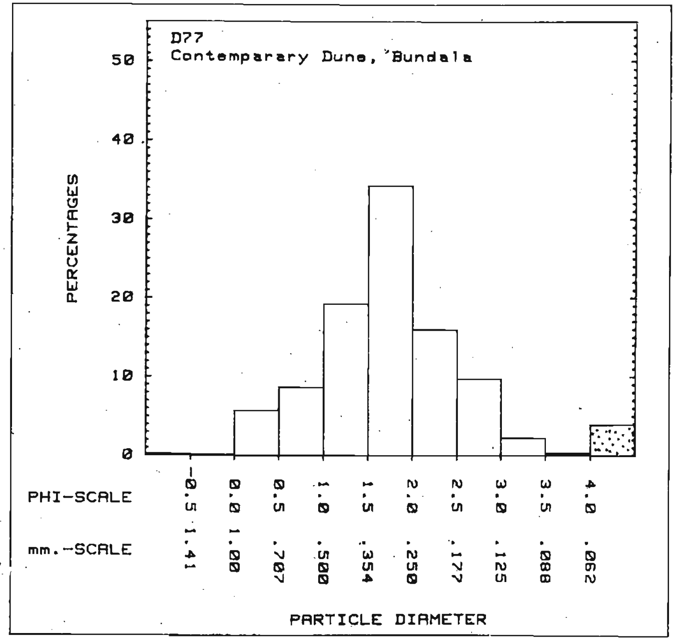


Figure 8 : Grain size distribution of recent dunes at Bundala. Silt/clay content is shown in the shaded column.

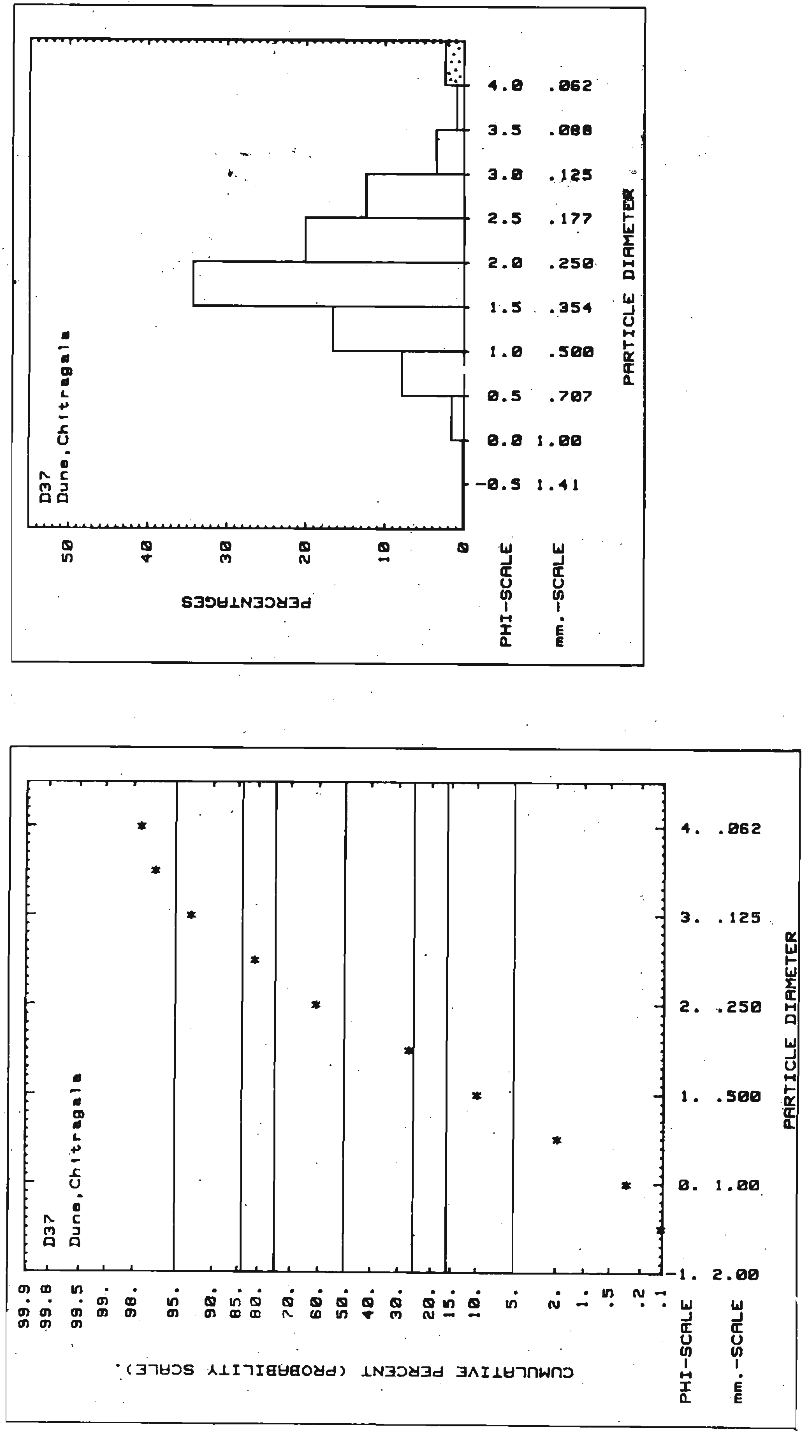
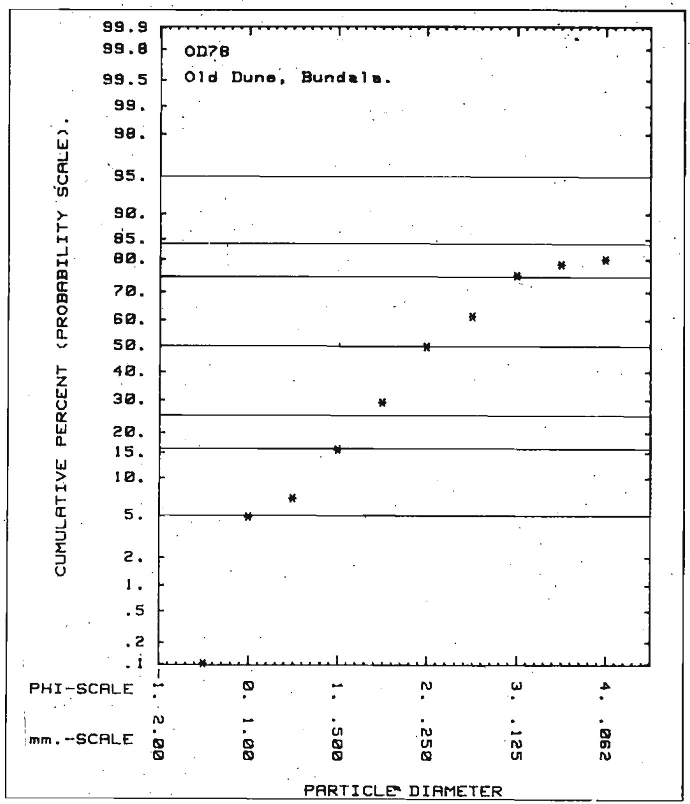


Figure 9 : Grain size distribution of recent dunes at Chitragala. Silt/clay content is shown in the shaded column.



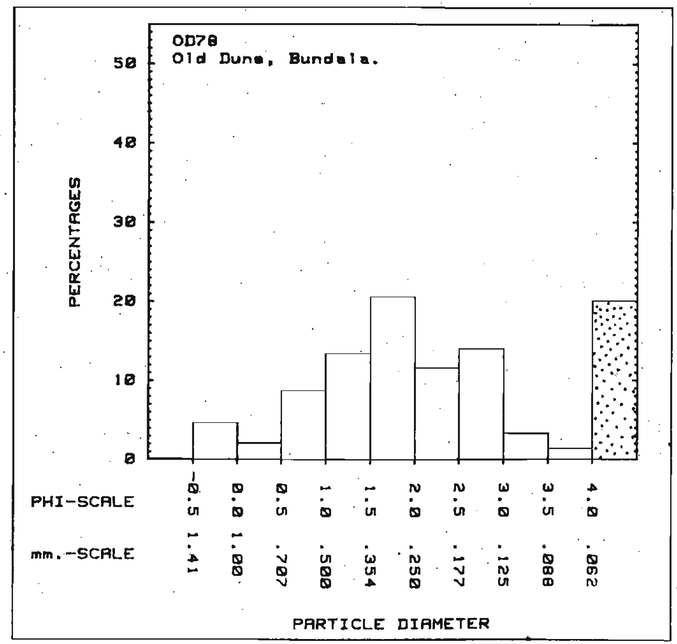
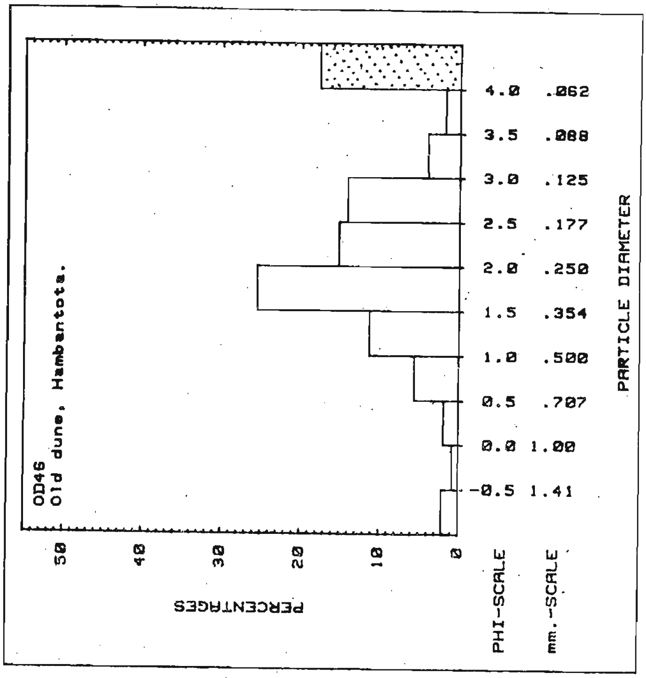


Figure 10 : Grain size distribution of old red dunes at Bundala. Silt/clay content is shown in the shaded column.



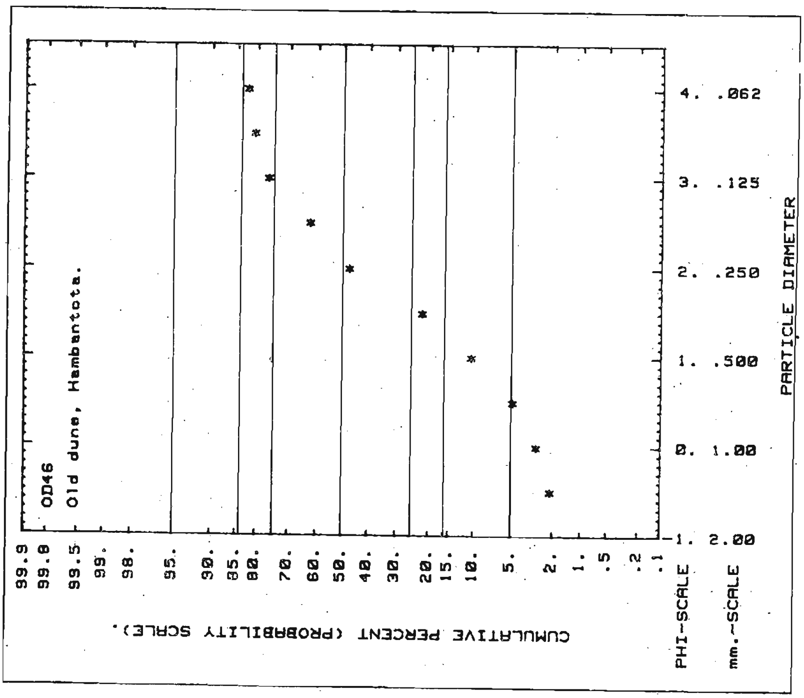


Figure 11 : Grain size distribution of red earth deposits at Hambantota. Silt/clay content is shown in the shaded column.

Table 3 : Phi–values corresponding with crucial percentiles for dunes and red earth deposits. (ND = Not determined).

Percentiles	Phi values for				
	Recent dunes			Old dunes	red earth deposits
	Chitragala	Bundala	Wewakanda	Bundala	Hambantota
5	.77	.46	1.01	.05	.52
16	1.23	1.05	1.42	1.02	1.28
25	1.70	1.30	1.61	1.37	1.58
50	1.85	1.74	2.00	2.02	2.09
75	2.34	2.20	2.55	2.99	2.94
84	2.60	2.50	2.81	ND	ND
95	3.22	3.22	ND	ND	ND

The age of the recent dunes can be guessed on the basis of some historical evidence. In the eastern part of the Bundala coast, a Buddhist stupa was built possibly by King Kavantissa. This stupa supposedly dates from 300–100 BC, which period marks the dawn of the Sinhala culture. The basement of the stupa is at least 10 m below the present surface and the ruins are partly buried by wind blown sands. Thus the formation of recent sand dunes commenced at least 2000 years BP. The beach rock slightly above sea level and underlying the old red dunes separating the Bundala lagoon from the sea dates from 2710 (±60) BP (sample Grn 13309). The recent dunes to the seaward post–date the beach rock, the red old dunes probably predate it. As shown by the author, in previous studies,[11] the era of dune formation that dominated the SE coast was followed by sea level recession from +5 to +2 m.

4. Conclusions

The coastal sand dunes of SE Sri Lanka have developed in two generations, in their lateral distribution. Similarly, two geneaations of dune development in vertical section are prominent in some areas along the coast. The laterally originated two generations may possibly be due to the laterally regressed sea level since the mid-Holocene time. The vertically dominated generations may have been formed due to the drop in sea level from +5 to +2m or/and during two successive periods of wind activity occurred since the mid-Holocene time. A fossilized dune field which remained as red earth deposits and which was reworked by latter processes, persists. The red earth deposits possibly correspond to similar deposits in the NW coastal region, which presumably date from same period. Cooray[1] states that 'Wayland, who first described the deposits (in the NW coast) thought that the Red Earth was a wind blown deposit mainly on the evidence of the small well–rounded quartz grains. He did, however, recognize that there were certain features which supported argument against such origin. It is most probable, therefore, that the red earth ridges formed the old shoreline of this northwestern portion of the island, and that formation originated partly as a beach deposit and partly as dunes'. Having studied two sites at Puttalam lagoon and Aruwakalu hills, Dahanayake[2] concludes that "the resulting products due to aeolian action could be well sorted dune sands". These previous conclusions support the view that the dune formed along the coasts of Sri Lanka during early Holocene or late–Pliestocene have been submerged by the mid–Holocene marine transgression which has been proved by the author to have occurred around 4000 BP.[11] The properties both in aeolian and marine of the Red Earth Formation of the NW coast and the high silt/clay content of the red earth deposits of the SE coast prove that formerly established dunes along these areas have been submerged by the mid–Holocene marine transgression. The lateral and vertical generations of sand dune formation demonstrate the recession of sea level followed by the marine transgression.

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