Agropedology, **8**, 1-9

A hypothesis on the formation of Lakshadweep islands from pedogenetic standpoint

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Abstract

Lakshadweep Islands are coral islands in the Indian Waters of Arabian Sea. Darwin suggested the formation of coral islands highlighting the simultaneous subsidence of volcanic formation and growth of fringing reefs to develop ring reefs. An attempt is made in this paper to explain the formation and development of the islands through study of soils. Nine pedons, three in each of the islands of Minicoy, Kavaratti and Kadmat were studied in west-east transects. The colour of the soils near the Western coast was lighter with high values and it darkened progressively in the pedons of central and eastern parts of the island. Some of the other properties also followed similar trend of higher development. They are the heavier texture with increasing clay content, better aggregation of peds, the stronger $CaCO_3$ cementation in the subsoils and the higher organic carbon content. Thus the increased pedogenic activities in the soils showed that the islands are older in the eastern part than in the west. In other words, the islands are growing towards west. The soil characteristics confirm the theory that the waves gaining energy from the east and northeastward blowing winds during the southwest monsoon carried the coral debris from the western reefs and deposited them along the eastern reefs thus forming the islands. The position of the island along the eastern reefs supports this view.

Additional keywords : Minicoy, Kavaratti, Kadmat, Coral islands, Arabian Sea Islands.

Introduction

Lakshadweep Islands are coral islands in the Indian Waters of Arabian Sea. Several theories are available in the literature on the formation of these atolls. Darwin, as reported by Wood (1983), suggested that fringing reefs surrounding volcanic islands, during subsidence, grew up gradually to develop ring shaped barrier reefs and, as subsidence continued, eventually became centre island free ring reefs. The other theories are also equally interesting. According to Alcock (1902), all the Laccadive islands are remains of eroded atolls raised only a few feet above the sea level and formed entirely of coral rock and coral sand. Gardiner (1903) believed that Maldives and Laccadives were formed on a large bank which was a part of an ancient land that completely sank. Accoriding to him some of the islands are remnants of mountains that existed in the sunken land. In general confirmity with the geological history of the Indian Occen reefs, it may be stated that the reefs of Lakshadweep were built in Tertiary and Quarternary eras on volcanic structures and the present day surface features of the reefs are the results of erosional and depositional consequence of Pleistocene and Holocene sea level changes (Stoddart, 1973). All the theories explain the formation of ring reefs and subsequently the atolls but not the further development of the islands. A detailed study of the characteristics of soil profiles may help to understand the present day surface of the islands and its development. One such study was attempted in the islands of Minicoy, Kavaratti and Kadmat through investigation of the soils and the results are discussed in this paper.

Materials and methods

a. Minicoy

The island Minicoy is the southernmost in the Lakshadweep Archipelago. It lies between 8°15' to 8°20' N latitudes and 73°01' to 73°05' E longitudes with an area of 4.4 sq.

km. (Fig. 1). The island has a large lagoon on the western side measuring about 6 km across. It does not exhibit significant geomorphological differences except for micro level relief differences. The elevation above the sea level is about 1-2 m in the west and about 2-3 m in the east during high tides. The island (sand cay) has been formed along the eastern fringe of the atoll covering the complete length of 12 km from southwest to northeast.

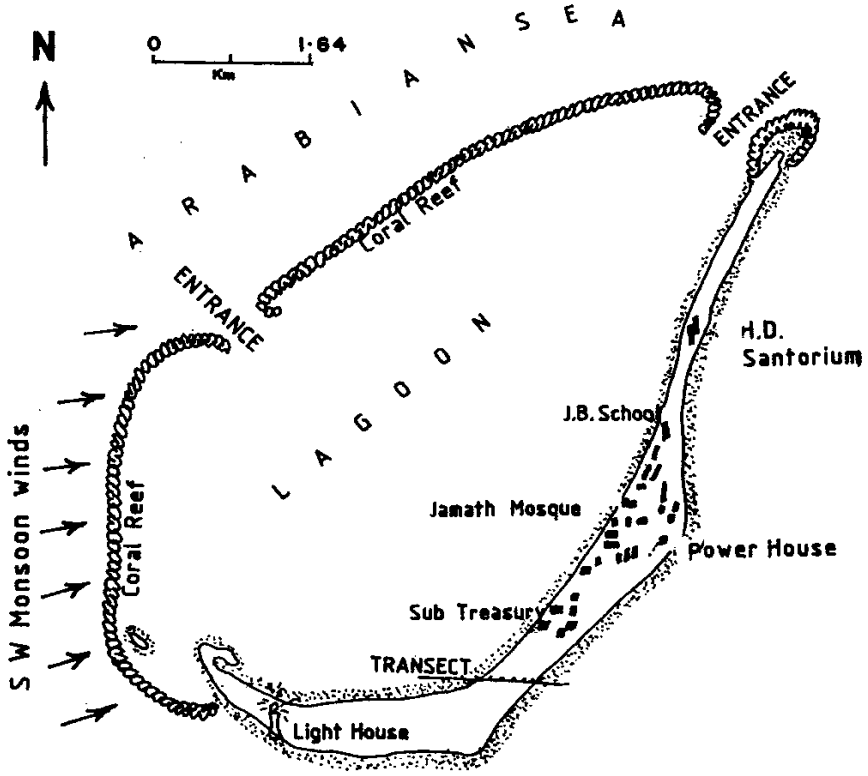

Fig. 1 Position of the land-mass inside the ring reefs and location of the transect in the island of Minicoy.

Seven pedons, in a transect, were studied for their morphological characteristics. The results of only three representative pedons are discussed in this paper.

b. Kavaratti

The island, Kavaratti lies between 10°32' to 10°35' N latitude and 72°35' to 72°37' E longitude with an area of 3.6 km^2 (Fig. 2). The island has a large lagoon in the western side which measures about 1.5 km across. The length of the lagoon is about 6 km. It is a flat island rising above the sea level to the extent of 1 to 2 metres in general during high tides. It has a narrower southern half and a broader northern half. The western shore line exhibit some undulations due to active deposition of sand. The eastern shore line has lot of beach sand stones (limestone) which act as barriers protecting the island from the cutting action of the waves.

A west-east transect passing through the farm of Agricultural department and near the secretariat building was chosen as it had minimum human disturbance on the land surface. Five soil profiles were dug along the transect (Fig.2) and the soil morphological characteristics were studied. Results of three representative pedons are reported in this paper.

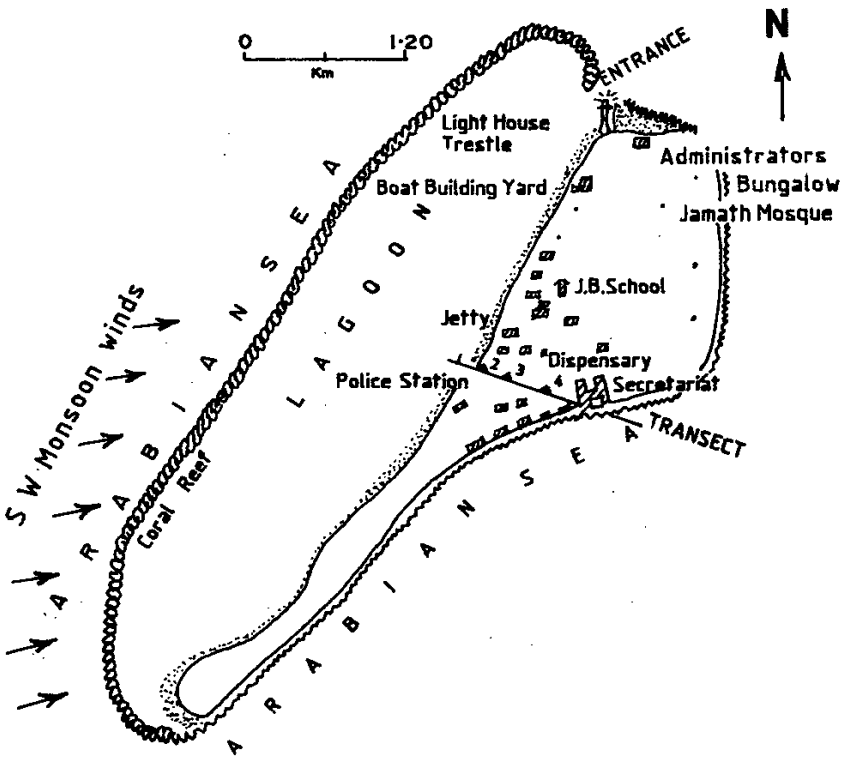

Fig. 2 Position of the land-mass inside the ring reefs and location of the transect in the island of Kavaratti

c. Kadmat

The island Kadmat lies between 11°10' to 11°15' N latitudes and 72°45' to 72°47' E longitudes with an area of 3.1 sq. km. (Fig. 3). Kadmat is a long and narrow island. It is only 570 m wide at the broadest point. The eastern reef is exposed at low tide and forms a level platform stretching from sea beach for about 100 metres. The island has a large lagoon on the western side measuring about 2 km at the broadest point. The island is, generally, flat rising 1 to 3 m in both the east and west above the sea level during high tides. A high ridge of sand runs down the western side of the island. Also there are sand deposits in the southern part giving rise to undulations whereas the northern part is flat with little fresh sand deposits. The island is aligned north-south with a slight clockwise tilt. Four pedons were studied in a west-east transect (Fig. 3) near the state farm and the data of three representative pedons are reported in this paper.

Horizonwise soil samples collected from the pedons studied in the three islands described above were dried in shade and sieved (2mm) for various estimations. Standard procedures were followed for the estimations (Hesse 1971; Soil Survey Staff 1972).

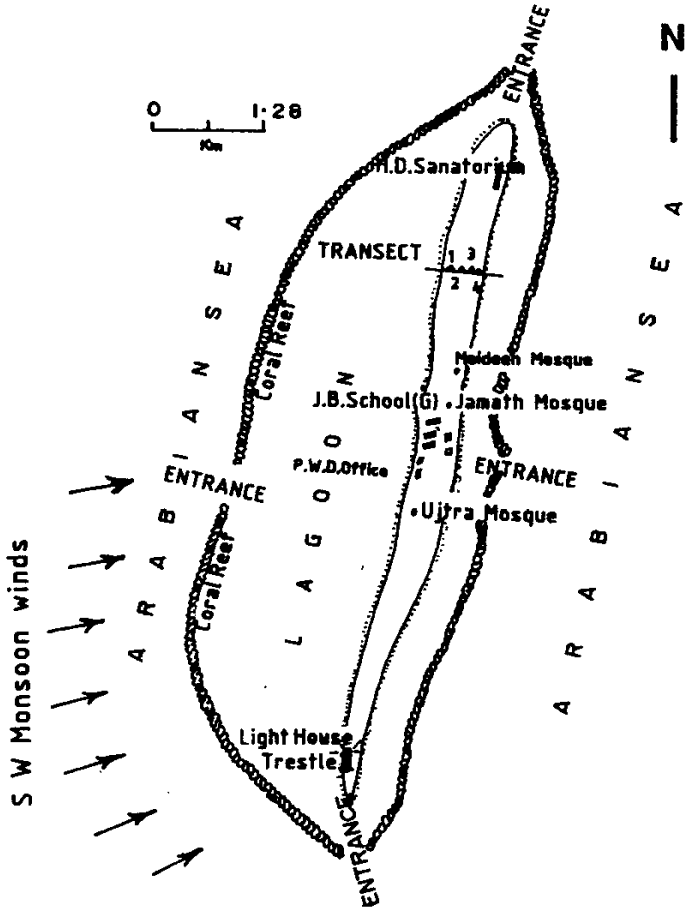

Fig. 3 Position of the land-mass inside the ring reefs and location of the transect in the island of Kadmat.

Results and discussion

Formation of the islands

The islands have formed along the eastern fringe of the atolls with a southwest to northeast orientation in the case of Minicoy and Kavaratti (Fig. 1 & 2) and a north-south orientation in the case of Kadmat (Fig. 3). The position and orientation of the islands inside the ring reefs are the result of sea surface circulation and wave action which follow seasonal monsoon (southwest monsoon) winds. The sea surface circulation in the Arabian sea is stronger and steadier during southwest monsoon compared to those in the northeast monsoon. During the southwest monsoon the surface currents in the open ocean are eastwards and clockwise in direction due to the coastal configuration. It flows northeastwards along the Arabian coast and southwards along the Indian coast as wind driven ocean current (Boievert 1966; Prasad 1951). Where reefs grow up in shallow seas, bottom currents (both geostrophic and tidal) may exert a great influence on reef form right from the beginning of the reef building by depositing sediment to the leeward side of the initial coral colonies and by transporting their coral larvae which subsequently initiate reef growth on these leeward sediments (Fairbridge, 1968). This action of sea current is accompanied by the island building action of the wind and waves. These factors begin to play a role when the reef upgrowth approaches sea level. The waves gaining energy from the east and northeastward blowing monsoon winds break the western portion of the ring reefs and carry the coral shingle and

sand towards the eastern portion of reefs. As a result, ramparts of coarse shingles are deposited at some distance in from the reef edge. The finer fragments and the coral sands are carried further on by the waves and only come to rest along the eastern part of the ring reefs as noticed in Minicoy and Kavaratii or in the lagoon when the wave energy is greatly diminished as observed in Kadmat island where the sand cay started forming at a distance of above 100 m from the eastern ring reefs. The islands or the cays are thus formed, whose position on the reef is determined by the frequency and force of waves and winds coming from southwest. This kind of deposition by the waves is a continuous process, the earliest deposit occupying the easternmost part of the atoll followed by the subsequent deposits.

The mere presence of these islands show that these islands have also been growing upwards keeping pace with sea level changes in the post glacial period. According to Wood (1983) 15000 years ago the seas were about 120 metres lower than they are now, and 7000 years ago they were about 20 metres below the present level. The sea level change should have been slow and gradual during this period. Had it been a sudden process these coral islands would not have existed because corals can grow in only shallow waters. The fact that the corals kept growing during the sea level changes support the conclusion that the changes were slow and gradual. Therefore the modern reef growth related to the present sea level must have begun only about less than 5000 years ago (Wood 1983).

Development of the islands

The discussions made above lead to the logical conclusion that age of these islands is less than 5000 years and their development progressed from east to west. The soil characteristics both morphological and chemical support this view about the development of the islands. The soils were very deep and excessively drained. The surface flow of water during the monsoonic storms was almost nil. Therefore erosion and deposition were confined to the coasts where tidal actions were significant. The texture of the soils (table 1) was sand in all the pedons near or on the western coast. It became finer and qualified for sandy loam or loamy sand in the surface layers of pedons situated in the central and eastern parts of the islands in general. Some of the subsoil layers also had sandy loam texture wherever accumulation of organic matter was observed. This kind of change in texture and presence of subangular blocky aggregates in the soils indicate definitely the maturity of the island associated with vegetation and enrichment of organic matter in the east. Several other soil features also provide support to this conclusion. The colour of the soils was generally lighter with high values (10YR 7/2 m) in the soils of western coast and it darkened (10YR 3/2 or 5/3) in the pedons of central and eastern parts. Cementation observed in the subsoil layers of pedons situated in the central and particularly eastern parts (Kavaratti-5 and Kadmat-4) also reflected the increased pedogenic activities with time. The presence of beach sandstones (limestone) in the eastern coast of all these islands provide a greater evidence to the higher development of the soils in the eastern parts.

The clay content (table 2) increased to about 10 percent towards central (Kavaratti-3, Kadmat-2) and eastern parts (Minicoy-7, Kadmat-4) from about 2-4 percent in the west coast of these islands. The increase in clay content corresponded to the increase in the percentage of organic carbon. The organic carbon content was low in the soils of western

Table 1. Morphological characteristics of the soils

Depth (cm) 1	Horizon 2	Colour (moist) 3	Texture 4	Structure 5	Roots 6
Pedon : Minicoy-1					
0-20	C1	10YR 7/3	sand	sg	many, fine
20-40	C2	10YR 7/3	sand	sg	many, fine
40-60	C3	10YR 7/3	sand	sg	many, fine
60-80	C4	10YR 7/3	sand	sg	few, medium
80-120	C5	10YR 8/4	sand	sg	few, medium & coarse
120 +	.....Water.....				
Pedon : Minicoy-4					
0-25	A	10YR 4/3	loamy sand	sg	many, fine to coarse
25-60	C1	10YR 6/3	sand	sg	many, fine to coarse
60-75	C2	10YR 6/3	sand	sg	many, coarse
75-90	Cm	10YR 7/3	sandy loam	m	Common, coarse
90 +	.....Water.....				
Pedon : Minicoy-7					
0-20	A	10YR 4/3	sandy loam	1f sbk	many, fine to coarse
20-70	C1	10YR 7/3	sand	sg	many, fine to coarse
70-80	C2	10YR 6/2	sandy loam	sg	root accumulation
80-100	C3	10YR 7/3	loamy sand	sg	Nil
100-140	C4	10YR 7/3	sand	sg	Nil
140 +	.....Water.....				
Pedon: Kavaratti-1					
0-25	C1	10YR 7/2	sand	sg	many coarse
25-50	C2	10YR 7/2	sand	sg	many coarse
50-75	C3	10YR 7/3	sand	sg	many coasre
75-100	C4	10YR 7/3	sand	sg	many coasre
Pedon: Kavaratti-3					
0-19	A	10YR 5/3	sandy loam	1f sbk	many fine to coarse
19-66	C1	10YR 5/3	sandy loam	sg	many fine to coarse
66-98	C2	10YR 7/2	loamy sand	sg	common fine to coarse
98-132	C3	10YR 7/1	loamy sand	sg	few fine to coarse
132-150	C4	10YR 6/2	loamy sand	sg	few fine to coarse
150 +	.....Water.....				
Pedon : Kavaratti-5					
0-25	A	10YR 3/2	sand	1f sbk	many fine to coarse
25-51	C1	10YR 7/3	sand	sg	many fine to coarse
51-100	C2	10YR 8/3	sand	sg	few coarse
100 +	stony layer with slight cementation				
Pedon : Kadmat-1					
0-10	A1	10YR 6/2	sand	sg	many, fine
15-40	A2	10YR 4/3	sandy loam	1f sbk	many, fine to coarse
40-85	C1	10YR 6/3	sand	sg	many, med. to coarse
85-110	C2	10YR 7/2	sand	sg	common med. to coarse
110-116	C3	10YR 6/2	sandy loam	1m sbk	root accumulation
Pedon : Kadmat-2					
0-18	A1	10YR 3/3	sandy loam	1f sbk	many, fine to coarse
18-40	C1	10YR 6/3	loamy sand	sg	many, fine to coarse
40-80	C2	10YR 6/3	sand	sg	common coarse
80-120	C3	10YR 6/3	sand	sg	few, coarse
120-154	C4	10YR 7/3	sand	sg	few, coarse

1	2	3	4	5	6
Pedon : Kadmat-4					
0-24	A	10YR 3/3	loamy sand	1f sbk	many, fine to coarse
24-42	C1	10YR 6/3	loamy sand	sg	few, med. to coarse
42-55	C2	10YR 6/3	loamy sand	sg	Nil
55-80	C3	10YR 7/3	sand	m	Nil
80+	Cm	Cementation			

coast and increased in the pedons of central and eastern parts of the islands. The distribution of soil organic matter seems to have a stronger relationship with the distribution of clay in the soil. Similar results were reported by Gregorich et al., (1988) who examined the soil organic matter distribution between size separates and found that clay (< 2μm), silt (2 to 50 μm) and sand (50 to 2000 μm) contained 60,30 and 5% of the whole soil organic matter, respectively.

Table 2. Physical and chemical characteristics of the soils

Depth (cm) 1	Clay % 2	Silt % 3	Sand % 4	$CaCO_3$ % 5	O.C. % 6	pH 7
Pedon : Minicoy-1						
0-20	3.6	0.0	96.4	100.0	0.45	7.92
20-40	3.7	0.5	95.8	100.0	0.36	7.96
40-60	3.0	0.3	96.7	99.4	0.23	8.30
60-80	1.7	1.2	97.1	100.0	0.21	8.50
80-120	2.2	1.1	96.7	99.4	0.25	8.40
Pedon : Minicoy-4						
0-25	5.4	5.8	88.8	95.0	0.98	7.90
25-60	4.8	0.0	95.2	95.0	0.20	8.55
60-75	3.6	0.0	96.4	96.6	0.79	8.40
75-90	14.3	0.0	85.7	96.1	0.89	8.35
Pedon : Minicoy-7						
0-20	16.4	4.5	83.3	92.3	1.59	7.90
20-70	5.9	5.0	86.8	96.1	0.98	8.40
70-80	15.4	4.1	88.4	92.3	1.76	8.25
80-100	5.2	3.9	91.7	95.0	0.90	8.60
100-140	4.4	2.4	93.7	97.7	0.34	8.65
Pedon : Kavaratti-1						
0-25	1.5	0.0	98.5	96.1	0.71	8.20
25-50	2.8	0.0	97.2	96.1	0.75	8.75
50-75	1.8	0.0	98.2	94.0	0.41	8.88
75-100	1.4	0.7	97.9	98.8	0.34	8.78
Pedon : Kavaratti-3						
0-19	12.1	6.0	81.9	89.1	1.63	8.28
19-66	2.5	3.0	94.5	99.4	0.79	8.78
66-98	8.2	3.7	88.1	97.7	0.83	8.88
98-132	6.9	1.8	91.3	98.3	0.79	8.95
132-150	6.1	3.0	90.9	100.0	1.05	8.88

1	2	3	4	5	6	7
Pedon : Kavaratti-5						
0-25	3.6	0.0	86.4	96.1	1.93	8.10
25-51	2.2	0.0	97.8	99.4	0.53	8.37
51-100	1.8	0.0	98.2	99.4	0.38	8.74
Pedon : Kadmat-1						
0-15	4.9	0.0	96.1	96.7	1.22	7.95
15-40	11.7	0.0	88.3	88.0	1.46	8.15
40-85	3.5	2.2	94.3	94.5	1.10	8.60
85-110	4.3	0.0	96.7	98.3	0.53	8.70
110-116	13.7	2.4	83.9	91.8	2.93	8.25
Pedon : Kadmat-2						
0-18	10.2	1.6	88.2	88.6	1.84	8.20
18-40	7.9	0.0	92.1	98.3	1.14	8.40
40-80	4.2	0.0	95.8	98.3	0.77	8.63
80-120	2.9	0.0	97.1	97.7	0.60	8.55
120-154	3.1	0.0	96.9	98.3	0.64	8.68
Pedon : Kadmat-4						
0-24	9.6	3.3	87.1	85.3	1.72	8.13
24-42	6.5	6.5	92.3	94.5	0.85	8.35
42-55	7.0	7.0	93.0	99.9	0.57	8.45
55-80	4.8	4.8	95.2	99.4	1.70	8.70

The variation in properties such as colour, texture, soil aggregation, $CaCO_3$ cementation, clay content and organic carbon content among the pedons suggests that the soil development has progressed to a higher level in the eastern part compared to the recent deposits in the western part of the islands. The soil development is an index of the development and stability of the islands as the soils form the surface of the earth above the sea level the former being only a few fert above the latter. Thus the position and shape of the island inside the ring reefs and the soil characteristics explain the formation and development of these Lakshadweep islands.

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