PART - III

DIU ISLAND

Plate : 18 PHOTOGRAPH OF DIU : TOWN SETTLEMENT ON THE STABLIZED DUNES. VIEW LOOKING SOUTHWEST.

DIU ISLAND

GENERAL REVIEW :

The Island of Diu (38.5 sq.km in area) is situated at the southwestern tip of the Saurashtra region and lies between 20° 41' to 21° 45' north latitudes, and 71° 00' to 71° 52' east longitudes, forming part of the Survey of India Toposheet No. 41 L/14 (Fig.1). Coastal sediments across the Island consists primarily of shelf derived carbonate sands. Such sands commonly make up greater than 90% of the older and present day beach and dune sediments. The sands are known to have been delivered to the coast during and since the post-glacial marine transgression (Pleistocene to Recent). Consequently, most of the coastal sediments in Diu consist of reworked deposits of many cycles of sand depositions. Marine and marginal marine sedimentary deposits of Diu are therefore diverse and are quite significant. The depositional environments in addition to the coastal shelf zone, include, well developed beaches and beach related tidal flats, channels of tidal stream origin, salt marshes, and stabilized, and recent sand dunes.

The author has taken a complete inventory of all these environmental aspects in the discussion to be followed in the text.

BACK GROUND INFORMATION

11.1 DIU ISLAND AND ITS OCCUPANTS

The word "Diu" is derived from the Sanskrit word "Dweep". This Island or "Dweep" during the period from the forteenth to sixteenth centuary, was known as one of the best sea-ports and a naval base in India. Merchants of various countries were seen in Diu trading with India. From 1495 A.D. there were successive attempts by the Portuguese to discover sea route to India. In the later half of the fifteenth centuary the Portuguese succeeded in their attempts and Vasco-da-Gamma, Almeda and other staked their reputations and fortunes to establish Portuguese rule in India. After capturing Goa and Daman, they set their heart on Diu.

Tradition tells us that Diu was ruled in ancient time by the Great King Jalandhar. Ruins of Jalandhar temple are seen even today. It was successively under the sway of Chawda, Vaghela and Rajputs, who were dislodged by the Mohamedan ruler in 1380 A.D. In 1531 A.D. Diu formed a part of the domain of Sultan

Bahadurshah of Gujarat, but his success was short lived. Bahadurshah's nephew, who made peace with the Portuguese Governor Naronha, in 1539 A.D. allowed the Portuguese to stay and live in Diu. A Portuguese Governor was then appointed as an administer of Diu. In 1947, India attained independence and the people of Goa, Daman and Diu became impatient to rejoin the mainland. The Island became free and joined the Indian territory in December 1961.

11.2 ACCESSIBILITY

The Island is connected by road with all important towns in India via Una (30 km via Tad Bridge and 14 km via Ghoghla). There are regular G.S.R.T.C. bus services from Una and Delwada. Diu is also connected by direct bus service from Veraval, Kodinar and Rajkot. Delwada is the nearest rail station (9km) from Diu. It is connected with Ahmedabad by a Meter Gauge Railway line via Veraval.

11.3 CLIMATE

The climate of Diu is equable throghout the year. Summer and winters are both moderate. The average annual rainfall is about 625 milimeter. The maximum summer temperature is 38°C and the minimum is 11°C. During the winter temperatures range between 20°C to 25°C.

11.4 FLORA AND FAUNA

The total cultivable land is only 800 hectors and crops like bajri and jowar are cultivated. Besides, this area is covered by branching palm and xerophytic flora (Plate 19,) which indicate prolonged arid conditions.

Diu like the other coastal areas of Saurashtra is well known for marine fisheries of commercial value. Among the major fisheries of the zone are Bombay duck, Blabk pomfret, Silver pomfret, Chinese pomfret, Jumbo prawns, Jinga and Lobster.

The wildlife of the Island consists mainly of fox, wild cat, etc. Reptiles of different species are common. Several varities of birds include peacocks, wild ducks, storkes, crows, cranes and pelicans.

11.5 STUDY AND WORK PLAN

The author has been considerably handicapped in his investigation since there is practically no literature or any geological account available on the previous investigations in Diu. There are ofcourse a few earlier publications, but these are all in Portuguese language and their English version is not available. Therefore, considering the overall requirements the following methodology was planed.

1. Appraisal of the outcrops and geological field mapping.
2. Systematic collection of samples from the stabilized dunes and recent coastal dunes, beaches, tidal flats and salt marshes and inlet channels.

PLATE : 19

Branching palm and xerophytic flora on coastal dune.

3. Field photographs of important sedimentary and bio sedimentary structures (Lebensspuren)
4. Data processing and interpretation, and
5. Formulation of a sedimentation model.

PREVIOUS WORK

Geological information on the Island of Diu is rather scanty. Fedden (1884) was the first to make a passing remark on Diu. According to him miliolitic rock is nowhere encountered in the deep quarries and cliffs of Diu. Further geological investigation on Diu are known from the publications of Portuguese workers. Most of their work, however, is in Portuguese langage. Amongst these Ubaldo (1961), gave an account of the petrography of the calcarenites rocks in Diu. According to her all the rock in Diu were of uniform composition being slightly clayey detrital limestones. They were composed of oolites of aragonite as the dominant constituents. The recognition of oolites made her to conclude, recent age for most of the Diu calcarenites. Further studies were taken up by Rocha and Ubaldo (1964) on the foraminiferal fauna from the recent sediments of Diu, and the neighbouring mainland coast near Simar and Ghoghla. These were again very preliminary investigations on Diu. No further work has been resolved since then.

COASTAL SETTING, NEARSHORE FACIES AND ISLAND STRATIGRAPHY

13.1 COASTAL SETTING

The Island of Diu, on the southwestern Saurashtra open sea coast has comparatively a very simple coastal setting. Approximately a little more than three quarter of its area is occupied by the older and modern coastal sand dunes, salt marshes and carbonate sands. The remaining one third accommodates the narrow inlet water channels. An understanding of the Diu stratigraphy in general, therefore requires consideration of the sedimentary processes along its entire coastal zone.

As depicted in the geomorphological diagram (fig.16) the Island of Diu can be referred in different ways depending on the focus of the specific studies. It can be cited as an example of a broad shallow coastal zone lying almost at the landward edge of a broad shallow gently sloping continental shelf; or as a barrier Island developed at the margin of a low relief coastal plain. It can also be cited as an example of a region of salt marshes, or an extensive tidal flat. In fact most of these environments exists here and are interrelated in some way. The Island,

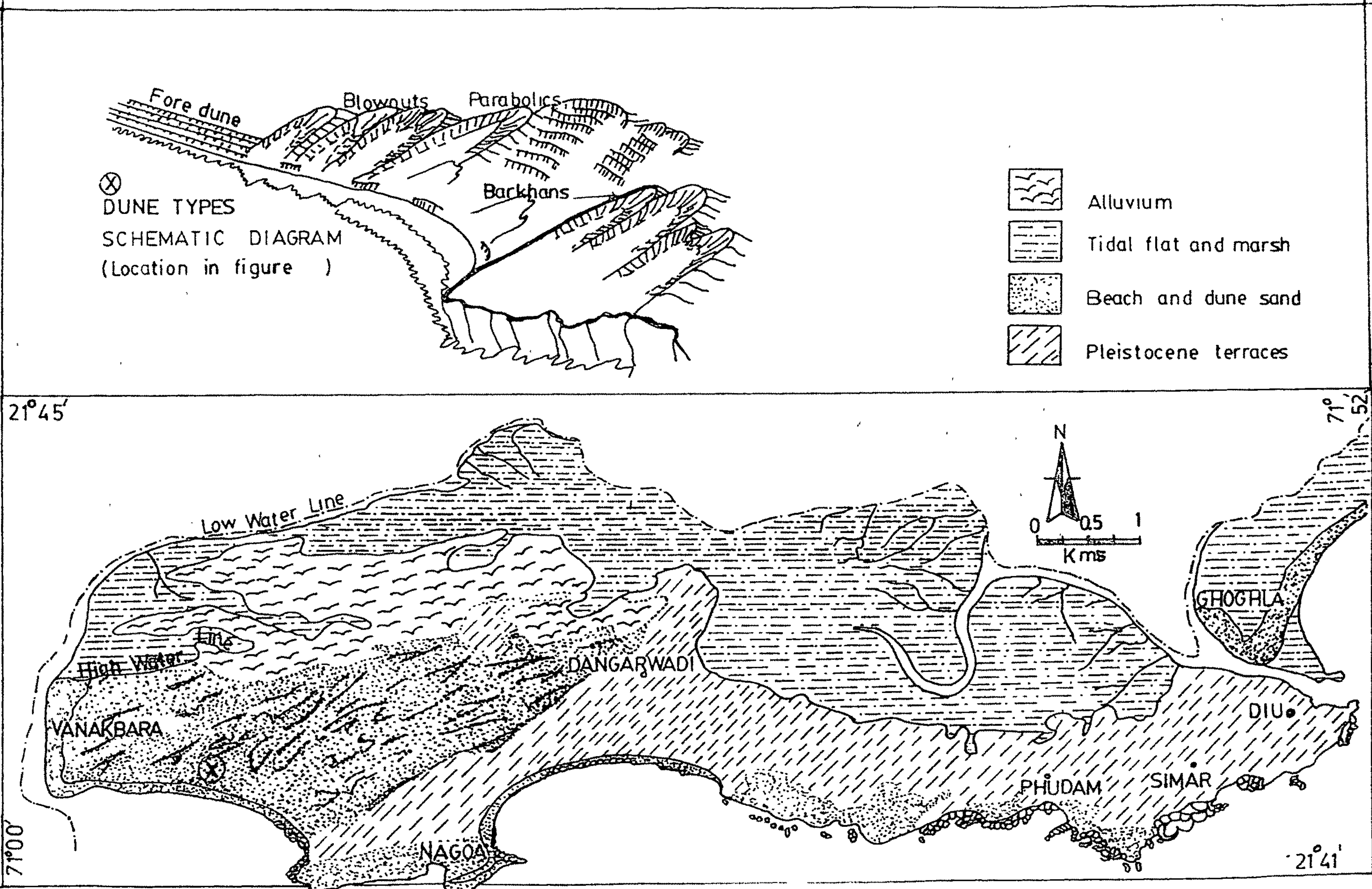


FIGURE 16 GEOLOGICAL AND GEOMORPHOLOGICAL MAP OF DIU ISLAND.

although, forms part of the open sea coast, its broad shallow gently sloping continental shelf helps to dampen the oncoming waves and wave energy resulting into wave heights to be averaged only about a meter or so. Wind velocities in general also being low (Gazetter, Gujarat State) the coastal region of Diu is categorised as a mesotidal, medium to low energy coastal zone.

The coastal setting around the Island of Diu, therefore provides an excellent opportunity to study the older (Pleistocene) shoreline deposits exposed as sea-cliffs, wave cut platforms and stabilized carbonate sand dunes and, the modern deposits of beaches, sand dunes and salt marshes. As observed in the field the same processes that have shaped the modern sedimentary facies on the coast, perhaps have also influenced the formation of the older deposits in the past without any marked significant difference.

13.1.1 THE PLEISTOCENE TERRACES AND THE DUNE FACIES

The entire town of Diu is colonised on the terraces formed on account of the stabilized dunes (Plate 18). The dune features can be observed in many of the wave cut platforms, cliff sections and the abandoned quarry facies in the Island region (Plate 20).

Most of the Pleistocene dunes along the Diu coast consist of the following basic types : (1) Parabolic, and (2) Transverse, in dunes. Most of these are laterally overlapping to form complex varities. Larger parabolic and straight-crested dunes occur

Plate : 20 PANORAMIC VIEW OF THE PLEISTOCENE LONGITUDINAL DUNE
(LOCATION : SW OF DIU TOWN)

almost normal to the present southern coast line of Diu. Some such varieties are depicted in (Plate 20). Similar fringing dunes whose presence is largely restricted to areas of "receptive shorelines" according to Cooper (1958) represent areas which are generally tectonically stable or subsiding that have been the sites of sedimentation through much of the Quaternary time.

Invariably, most of these dunes in Diu are thinly to thickly laminated, the strata being horizontally as well as cross-bedded. Large-scale cross-bedding is very common (Plate 21a), and oversteepened dips upto 40 are observed. These bedding characters are best seen in the quarry section south of the village Simar and Phudam (Plate 20). The uniform thickness of the cross-bedding units and their very long length of laminae appears similar in case of the aeolinites. The dips of the foresets vary form gentle to very high. On the whole, the direction of inclination of the cross-bedded strata are fairly regular in one direction i.e. southeast.

In some outcrops small scale contorted bedding is also noticed (Plate 21b). This appears to have developed at the base of the slip face of the large dune by the swirling action of wind. In addition the wedge planar cross stratification is very frequently developed in the dunes.

The interpretation of dune subtypes from its stratigraphic record, however is not straightforward since very often these

PLATE:21

(a) Large-scale dune cross - bedding underneath Diu fort.

(b) Small scale contorted bedding quarry section south of Simar village.

dunes are covered with vegetation and the town buildings. Furthermore, for recognisition of dune types various authors have proposed different approaches and schemes. Mckee (1966) for example, suggested that set geometry alone records the type of dune responsible for a deposit. Glennie (1970), suggests that foreset dip angles and dip-direction dispersion patterns can be used to infer dune types. Rubin and Hunter (1985), discussed ways to infer dune forms and wind regime from compound or complex cross-stratification. Brookfield (1977) and Kocusek (1981) focused the geometric relations of internal diastems related to migration of eolian bedforms and the importance of interdune deposits. It is thus obvious, that in all these considerations, stratification types and distribution set and diastem geometries, and foreset orientation and dispersion patterns need to be considered if such information is available.

Diu, as a matter of fact can provide an excellent opportunity to utilize all the above approaches to infer dune types. Diastem geometries can be delineated by tracing exhumed surfaces along the extensive cliff facies, some of which are found in closely spaced abandoned quarry facies which again need to be freshly excavated and cleaned. Cliffs are generally accesible and so sometimes can be measured for various units. However, the three-dimensional views of foreset geometries and stratification type variation in most of the cases in Diu becomes difficult on account of the vegetation cover and civil buildings on the dune field.

In spite of some such difficulties the following interstratified lithofacies were studied by the author.

(i) Grainfall Strata :

These are internally massive or have laterally continuous centimeter thick laminae with ill defined contacts. Such ill defined contact according to Schenk (1983) are produced by wind gusting.

(ii) Avalanche Strata :

Such features have been observed at the foreset toe where the coarser grained fraction tends to concentrate. Avalanche strata generally have sharp basal contacts and well-define lateral margins.

(iii) Tabular-Planar Cross-Stratification :

Very large scale tabular planar cross-stratifications dominate the dunes exposed along the southern flank of the Diu Island. Maximum preserved set thickness average 4 meters and ranges upto 6 to 7 meters.

In direction parallel to foreset strike and dip, sets can be traced or correlated for limited distance of 50 to 100 meters only when the exposures available.

Measured foreset dip angles average 15 ± 5 and range from 10 to 20. Angular discordance occurs between the top of one set and the base of the overlying set.

(iv) Trough-Cross-Stratification

Trough-cross-stratification occurs in two types : Very large scale solitary sets and medium scale grouped or solitary sets. Very large scale solitary sets have an average maximum preserved set thickness of 1 meter, ranging into 1.5 to 2 meters. Medium scale sets have maximum preserved set thickness < 0.5 meter, and have limited lateral extent.

Most of these interstratified lithofacies, when compared with the criteria established by Hunter (1977,1981) signify the sand dunes to be aeolian in nature.

13.2 MORPHOLOGIC INTERPRETATION OF STABILIZED DUNES IN DIU

The character of bounding surfaces and style of cross-stratification provide the principal evidence for morphologic interpretation of dune types in Diu. As, is well established planar climbing surfaces are generally produced by straight crested bedforms, and undulatory surfaces by crescentic bed forms. In the southern exposures in Diu, large scale tabular planar cross-stratification with broadly undulatory to flat bounding surfaces are observed to be dominating. These large scale cross-stratification can be regarded as produced from slightly crescentic simple dune with 10 to 15 meter wavelengths and saddle distance of 5 to 10 meter. The compound trough cross-stratification with 0.2 to 0.5 meter wavelength and saddle spacing of 0.3 meter is regarded following Hunter (1985) as having been deposited by compound crescentic dunes. The nature of trough cross-stratification sets within tabular planar cross-stratified sets in Diu provide some information about secondary morphologic features. These are thought to be the products of migrating scours or spurs driven by lee-slope winds.

Thus, along the southern flank of the Diu Islands the record left by the eolian bedforms is that of a grouped medium scale, and solitary large scale trough-cross-stratification bounded between undulatory surfaces. Such records forming large, compound, crescentic dunes with superimposed smaller crescentic dunes are recognised by Brookfield (1977,1984) as drass or group dunes.

13.3 PETROGRAPHY OF DUNE SANDS

The most common rock type of the dune are pelletoid calcarenite consisting essentially of sand size pellets. The oolites and superficial oolites also enter into its composition but in a very small quantity. In hand specimen the rock is dirty white to light cream coloured and is made up of bioclastic sand size grains most of which are elliptical to spherical in shape. The grain surfaces are usually smooth and polished. Some of the grains are however, dull and pitted.

The microscopic examination shows that the rock is fine to medium grained in composition. The ovoid to sub-ovoid grains occur in proportion which vary form 30 to 50 percent. As they do not show any internal structure they can be taken as pellets, some of which are likely to be of faecal origin. Although, in thin section studies it is difficult to recognise faecal pellets, an internal arrangement of unoriented silt and clay size grains bound together by an organic and carbonate matrix very often point out their faecal origin. In a few cases, the pellets resemble clastic or worn out calcite grains of shell fragments which have assumed the shape of the pellets. In such grains, the traces of original shell structure have been obliterated by recrystallization.

In addition to the faecal pellets described above, there are the oolites which are present only in small proportion. The other ingradients include subrounded quartz in minor quantities with occasional green volcanic glass, epidote and some other detrital grains derived from the volcanics of the Saurashtra peninsula. Foraminiferal and algal remains are also found in some thin sections. The cement is clear crystalline mosaic of sparry calcite.

Considering the general characters of calcarenites described above and following Folk (1962) the rock has been named as pelletoid calcarenite which in fact is a biocalcarenite being predominantly a product of organic activity.

Conventionally such a rock exposed throughout the coastal Saurashtra has been known as the "Miliolite" or the Porbandar limestone.

This basic type occurring in Diu can further be subdivided according to the kind of bioclastic material present in larger proportion.

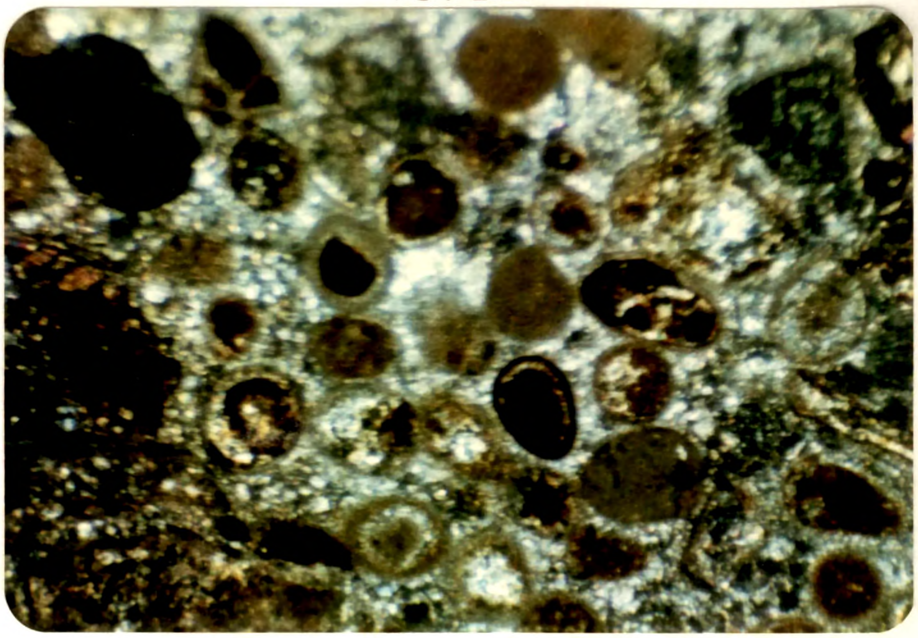
(i) Algal Biocalcarenites : (Plate 22a). Algal pellets appear to be rather abundant in many biocalcarenites. Such pellets tend to be ellipsoidal, are made of dark, organically rich cryptocrystalline calcite displaying ill-defined and interferring concentric rings. The nuclei of algal pellets are of variable nature, detrital minerals, fragments of structureless carbonate and organic debris. The algal structure appears to favour the shell fragments as nuclei, in which case they confirm to their elongated shape. In the same deposit, composite algal pellets are frequent, they are made up of numerous oolites and other debris surrounded by a thick common algal coating.

(ii) Foraminiferal Calcarenites : (Plate 22b) Foraminiferal test consisting of *Ammonia*, *Elphidium*, *Eponides*, *Amphistegina*, *Quinqueloculina*, *Spiroloculina*, *Pararotalia*, *Discorbis* and *Nonion* sp. characterize this variety of biocalcarenites. Since the formation of the dunes is favoured by the aeolian processes as discussed earlier all the foraminiferal tests have to be transported and are required to have a mixed origin. An assemblage consisting dominantly of transporated forms would indicate physical conditions of the water of the original area in which the organisms lived, rather than those of the water in which the sediment accumulated. the deposition of the shells of the larger species with the coarser sedimentary material and smaller shell with the grains of smaller size would automatically result in the production of different "pseudofaunales" in sediments of different grain size. Little is known of the effects of transportation by rolling and saltation, but, if such mechanisms are active, a subsidiary sorting action might well be introduced for spherical shells would tend to roll more easily than those with angular or compressed shapes.

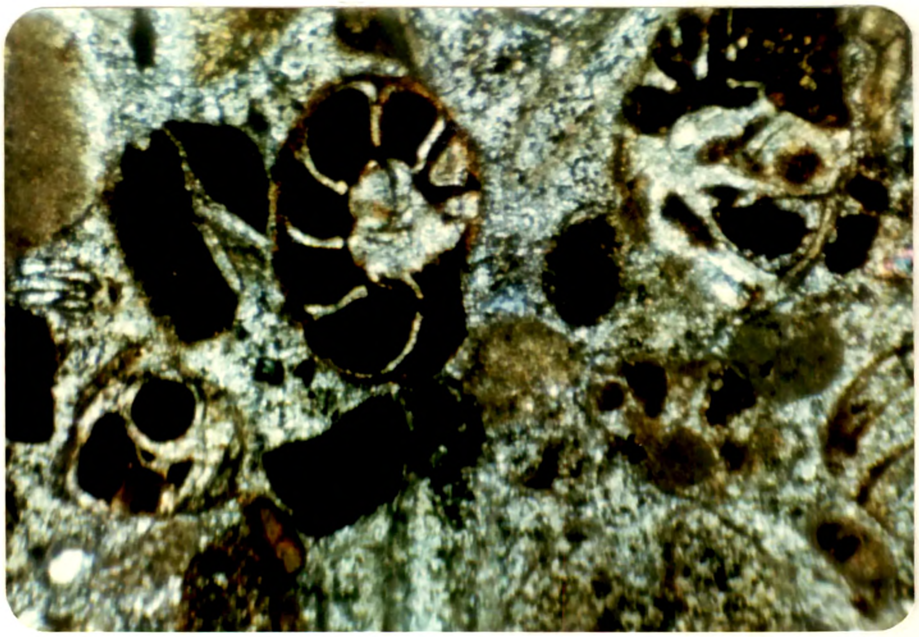
As transported individual forminifera represent an integral portion of the sediment, the same will be true for the deposited assemblages in case they at all exist. No true depositional settings of these units therefore can be confirmed.

(iii) Pelecypod Biocalcarenites : (Plate 22c) The calcarenite is made up by the accumulation of pelecypod prisms as much as 85 to 89 percent of the corresponding angular calcite fragments. The matrix is finely crystallized calcite. It also contains disseminated aggregates of pyrite and limonites. The individual particles in these calcarenites range in size from less than 1/256 to 4 mm. In addition to the calcite prisms which form the bulk of the rock, there are larger fragments and occasionally whole valves of small pelecypods. Such shells distributed at random often display mechanical wear and tear. Besides the pelecypod prisms the mechanical accumulation of ostracod tests,

PLATE:22

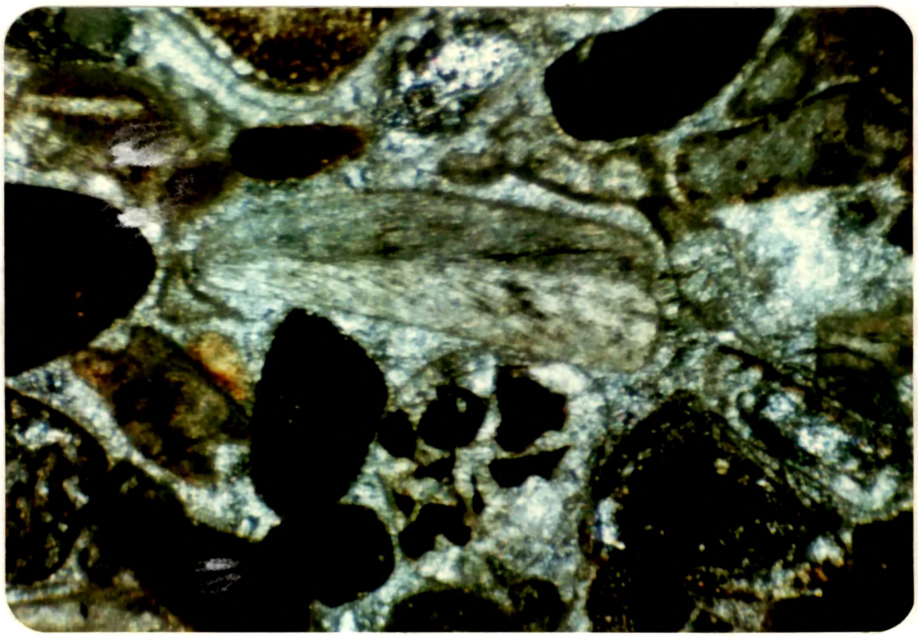


(a) Photomicrograph of algal pellet biocalcarenite x 25.



(b) Photomicrograph of foraminiferal calcarenite x 25.

PLATE : 22



(c) Photomicrograph of pelecypod biocal-carenite x 25.

is also observed in the sediments. The matrix is frequently fine grained clear calcite. The unit as a whole contains microfaunal tests displaying all stages from perfectly preserved individuals to minutely fragmented skeletal materials.

13.4 POSSIBLE TIMINGS OF DUNE FORMATION IN DIU

The exact timings of the dune emplacement at Diu is rather difficult to determine. This is because of the scarcity of datable material. Often the multiple episodes of coastal dune formation has led to recycling and intermixing of the older and younger dune materials (Viz the carbonate sands or miliolite grains). Furthermore, no human artifacts as are located in the Hiran Valley (Rajaguru and Marathe, 1978) and other parts of Saurashtra are found under the dune terraces of Diu. Neither, any datable corals or oyster shells also could be located by the author. Under the above circumstances the probable chronology of dune formation in Diu has to be linked with the information available on the chronology of the Saurashtra miliolites (dune material) studied elsewhere by different workers.

The problem of dune formation in Saurashtra is, thus, interlinked with the chronology of the carbonate sand deposits, namely miliolites. There is a general consenses of opinion that the Saurashtra miliolites are not older than Pleistocene period.

The miliolite sands covering a fairly large area on the coastal regions of Saurashtra has long attracted the attention of geologists and other earth scientists, especially for their origin and age (Carter, 1849; Sastri and Pant, 1960; Srivastava, 1968; Biswas, 1971; Lale, 1972; Govindan et.al, 1975; Sperling and Goudie, 1975; Rajaguru and Marathe, 1978; Varma and Mathur, 1977; Agrawal et.al., 1978; Allchin et.al, 1978; Hussain et al., 1980; Baskaran et.al, 1983; 1986). The Hiran Valley in particular has drawn the attention of the archaeologists for the occurrences of stone age tools in association with the miliolites (Sankalia, 1965; Rajaguru and Marathe, 1977; Allchin et.al, 1978; Marathe, 1981).

Age of miliolites has always evoked a controversy. Sastri and Pant (1960) on the basis of microfaunal analysis, assigned these rocks a Pleistocene to Sub-Recent age. Biswas (1971) preferred to place the coastal miliolites of Saurashtra as Late Pleistocene, while Lele (1972) assigned an early Quaternary age to all the miliolites of Saurashtra on the basis of relative stratigraphy. Sperling and Goudie (1975) and Agrawal et.al (1978) on the other hand have placed the inland miliolite in Late Pleistocene on the basis of archaeological evidences and ^{14}C dates, respectively. According to Agrawal et.al (1985) the first episode of dune activity in Saurashtra occurred during the Post- glacial marine transgression, particularly around 30,000 years before the present.

Other investigators (Marathe et. al, 1977; Marathe, 1981) have postulated the marine origin of miliolite occuring upto 20 km inland from the coast and 75 m above mean sea level. According to these authors, there exists two miliolite formations which belong to two transgressive phases of sea during the Quaternary. Lower and Middle Palaeolithic tools discovered in the fluvial gravels underlying the earlier miliolite (M-I) and the Late Pleistocene miliolite (M-II) respectively.

A large number of samples from Jetpur, Junagadh and Umrethi significant from the point of view of dating the Middle and Lower Palaeolithic industries in the Hiran Valley were processed by Baskaran et al. (1986) for $230_{Th}/234_{U}$ dates. The radiometric dates obtained by these authors correlating the chronology of the geomorphic events and the corresponding cultural events are tabulated in the following table reproduced after them.

Table - 13 Chronology of geomorphic events and cultural finds (after Baskaran et.al., 1986).

Geomorphic Events	Geomorphic/Cultural Finds	Age (Years BP)
Fluctuating sea level	Mesolithic and Chalcolithic	Holocene Late Pleistocene
High Sea level at 60 Kyr BP	Oyster shells Miliolite	30 kyr 57 kyr ++
Major rejuvenation	Middle Palaeolithic	57 kyr ++
High sea level at 60,84,105,120 and 135 kyr BP	Miliolite	69-196 kyr ++
Lower sea level 111 and 160 kyr Bp	Lower Palaeolithic	69-196 kyr ++

* Radiocarbon date

++ Present study using $230_{Th}/234_{U}$

+ High and low sea level dates are based on corals and
+ speleothems (Moore, 1982).

The principal miliolite formations in Saurashtra according to Baskaran et.al (1986) occurred during three periods, namely 50-70, 75-115 and 140-200 kyr before present. As mentioned by these authors the Palaeolithic tools encompass the whole range of 50-200 kyr and it was not possible for them to clearly attribute each miliolite age to a sea level stand, especially in view of recent evidences supporting tectonic instability of the Saurashtra Peninsula (Sood and Sahai, 1986) in general.

As could be followed from the above discussion most of the investigation carried out towards the age determination of the Saurashtra miliolite are either based on the miliolite samples collected from the inland locations or on the relative positions of the archaeological tools with respect to the miliolites in Hiran valley. The general belief therefore has to be that the miliolite has been forming since 200 kyr to the present and all this time it has been establishing in the form of either as the coastal sand ridges or dunes.

In conclusion, the age controvesy regarding the miliolite rocks or the carbonate sands of Saurashtra is still inconclusive and so is that of the Island of Diu. The problem is likely to be resolved by collection of continuous uncontaminated core drill samples and obtaining the radiometric and ^{14}C dates of the same. As per the existing conventions the carbonate terraces of Diu are to be of Pleistocene age in general and Late Pleistocene in particular on the basis of their relative stratigraphy and field occurrence.

13.5 GENERAL CONCLUSIONS

In spite of some of the above controversies it is possible to list the requirements and availabilities of materials for the dune formations in Diu in the past and present. These are given in order of their importance as follows :

1. Availability of an abundant inner shelf and large longshore carbonate sand supply.
2. Moderate to high breaker wave energy;
3. Strong dominant and subdominant onshore winds, and
4. Dune vegetation.

The proposed influence of these factors on formation of the dunes in Diu will be examined once agains while presenting the sedimentation model.

Interpretation

Since, the carbonate sands (Miliolites) of Diu bear measurable similarities to their counter parts in other parts of coastal Saurashtra, it will not be out of way to discuss a few generalisations available on these rocks. The "miliolite" or carbonate sands of Saurashtra in general have evoked considerable controversy regarding their origin. Chief amongst these are : whether the dune sands are aeolian or marine or are they of mixed origin ? In recent years Shrivastava (1968) and Lele

(1973,1975) have ascribed marine origin to the coastal and inland deposits. Glennie (1977), Biswas (1971), Ahmed (1972) and Sperling and Goudie (1975) have advocated aeolian origin for these, on the basis of good sorting, dune bedding and their occurrence within valleys, depressions and hill slopes. On the basis of their microscopic and SEM studies especially on the inland miliolites, Agrawal, Rajaguru, and B.Roy (1978) have preferred to call these as of aeolian origin. A brief discussion on some such views in general is outlined in the following paragraphs.

As postulated by Allen (1984, p. 364 (I)) tabular cross-bedding can occur in aeolian, fluviatile, and shallow marine deposits. Records of such aeolian sets several or many meters in thickness are given by Stokes (1968) from the De Chelly sandstone and the Navajo sandstone of America. According to Stokes (1968), the parallel planar forms of the bounding surfaces between sets represent a downward scour limit fixed by the water table. Regarding some of the structures claimed to be of aeolian origin, on the basis of these thin cross-bedding sets and their bimodality in orientation, the cosets representing the dominant dip azimuth - Allen and Kaye (1973); Carr (1973); and Nio (1976), put up an argument that the parent dunes could have been formed on sand shoals shaped by both ebb and flood tides.

Trough cross-bedding is profusely described by many proponents of aeolian theory. Sets upto many metres in thickness are recorded from aeolian sandstones, including the waterberg supergroup (Meinster and Tickell, 1975), and the Casper Formation (Knight, 1929; Steidmann, 1974). Bigarella, 1965; and Bigarell et al., 1969; 1971; Hine and Boothroyd, 1978).

By no means therefore, all workers believe that grouped cross-bedded sets are explicable by dune migration. Further, as cited by Allen (1984) some tabular grouped sets may be formed by migrating bars and other features which are not strictly dunes but which are marked by dune like properties and mechanism.

Hemingway and Clarke (1963a, 1963b) rejected dunes as the explaination of grouped cross-bedding, because set boundaries could generally not be observed to climb. As argued by Allen (1963a) on experimental basis of dune shapes such an objection could be invalid. Experimentally, Mckee (1957) assigned trough sets to the cutting and then filling of elongated channels, an explaination which according to Allen (1963) is more appropriate to solitary than grouped sets. Sutlon and Watson (1960) also explain subcritical trough cross-bedding by channel infilling. Harms et al. (1963) and Harms and Fahnestock (1965) broadly follow Knight (1929). They suggest that each scoop shaped hollow first eroded at some later time is independently infilled by dune avalanche deposits. In every case according to these authors it seems much more likely that the cross-bedding was due to the aggrading movement of trains of dunes, with their harmoniously migrating erosional stoss-sides and depositional lee slopes.

Considering the overall evidences it may, therefore be concluded that the dune terrain of Diu although invariably is characterised by aeolian deposition may at some places incorporate marine or mixed types of sediments. Evidences on these, however are inconclusive.

DUNE ASSOCIATED GEOMORPHIC FEATURES

These include the wave-cut platforms, stacks and rock dissolution and mass transfered features like, karren, spitzkarren, solution basins, cockling and potholes.

14.1 WAVE-CUT PLATFORM

The base of the coastal dune terraces in Diu is very often marked by an eroded surface formed during the later stages of transgression that perhaps accompanied the latest rising sea level (Plate 23a). In Diu such prominant escarpments can be very well observed along its southern coastal fringe. Many a times the vertical and lateral dimensions (height and width) of these platforms vary from 10 to 20 meter. The carving is invariably irregular and indicate indented shoreline features especially in areas where the sea waves are presently active as erosional agents. The eroded platforms are mantled locally with cobbles and relict concretions. Lithologically these are made of the same carbonate material (miliolite limestone). In fact the wave-cut platform terraces are the original Pleistocene dune surfaces which have been encroached upon by the transgressive sea and under cut at their lower portions.

14.2 STACKS : (Plate 23b)

These are protruding masses of rock in the sea, isolated from the mainland. In Diu such masses can be seen south of village Simar. They constitute the same rock masses as of the Pleistocene dunes. Such isolated stacks usually vary in height from 8 to 10 m. Characteristically, the upper portion of the stacks is larger with wide convex surfaces, while the lower portion is narrow and constricted because of the constant wave action that produce a notch on its seaward direction, the landward side remaining more or less vertical. Such features are likely to be destroyed within a few years, and if studied during continuation of the time, can indicate the relative rate of the sea encroaching over the land.

14.3 SOME MASS TRANSFERED FEATURES

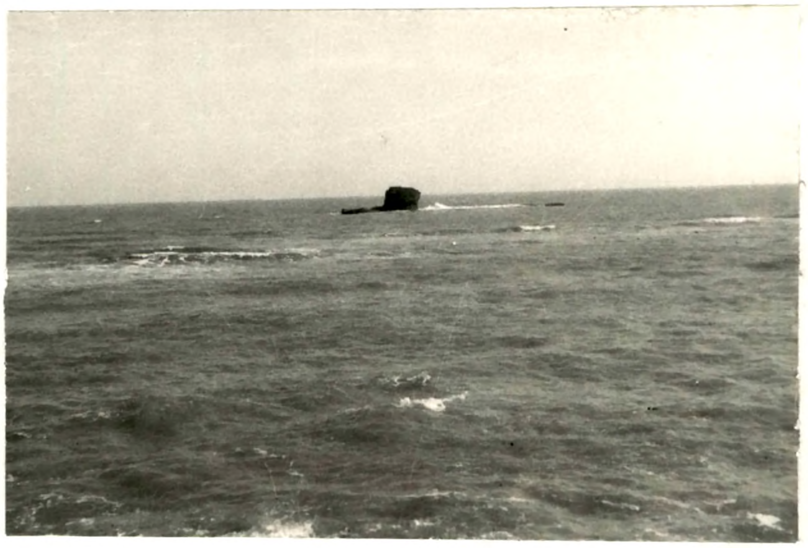
Some interesting features associated with the Pleistocene dune terraces which are formed due to dissolution or mass transfer are also observed in Diu. These include (1) Karren, (2) Spitzkarren, (3) Solution basins, (4) Cockling, and (5) Potholes. A brief description of these structures is given in the following paragraphs.

PLATE : 23

(a) Development of wave-cut platform southwest of Diu.

(b) (i) Wave-cut platform, (ii) Pocket beach, and (iii) stacks : Locality south of Nagoa village.

PLATE : 23



(c) Development of Stack south of Nagoa

(A) KARREN :

Karren are regular sculptural features developed where carbonate rocks, chiefly limestones, occur as bare rocks (without vegetation) exposed in the intertidal zone and a little above it. Karren are also the organised morphological features resulting from the dissolution of soluble rocks of which calcarenite is the most characteristics. In Diu such features can be observed south of village Simar and Phudam. In many instances, they accompany forms representing a lower order of similar forms. In most of the cases there appears in their formation the influence of the stagnant and flowing water causing dissolution in the absence of the soil or vegetation cover. It is possible that the high energy waves during the storms or rainy days could have left a large amount of their receding water bodies over the calcarenites to formulate these structures in Diu.

(i) Spitzkarren : (Plate 24a) These are assemblages of upward - pointing pyramidal to projectile - shaped bodies of rock separted by interconnected clefts or, in some instances, basin like depressions. Coastal spitzkarren in Diu are jagged, pyramidal masses of rock with locally overhanging sides roughened by cockling or irregular pits. Flat - bottomed solution basins, more commonly lie between their pinnacles. Pinnacles are seem to attain 1 meter in height but are generally shorter in vertical extent. These structures have been found on the lee sides of the coastal dunes south of village Nagwa beach near Dangarwadi. The same forces that developed the Karren are thought to be responsible in carving the spitzkarren in the calcarenite rocks of Diu (Fig.17a).

(ii) Solution Basins : These are the intertidal features formed on level to gently sloping rock surfaces and are the circumscribed hollows holding moisture/or water for a period. Solution basins are frequently observed developed in Diu on intertidal calcarenites. Such features are typically on the order of 0.25 to 0.60 m wide and 0.01 to 0.1 m deep but occasionally reach depths of 0.5 meter and width of 3 meter. In plan they are circular, oval or amoeboid, the larger ones commonly arose by the coalescenced of smaller basins (Fig. 17b).

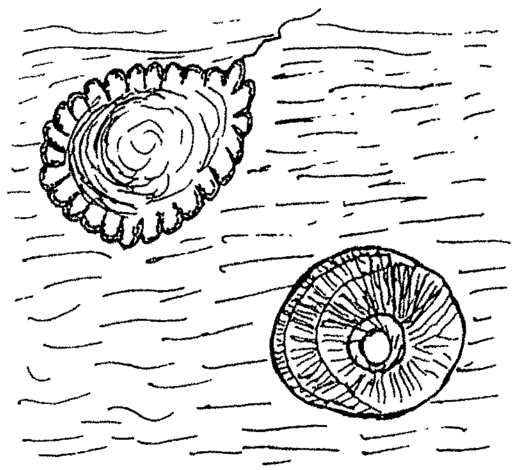
(iii) Cockling : (Fig.17c & Plate 24b) Cockling is confined to exposed surfaces of calcarenite that are seldom affected by prolonged tidal action, but which are repeatedly wetted. They can often be seen on and associated with coastal spitzkarren. The structures are equidimensional to slightly elongated cup-like pits which intersect occasionally along their flat ridges to give the rock surface a crinkled or cindery appearance. An individual pit is seldom wider than 0.03 meter and may be no more than a few milimeters across. Lichen or algae occur in some pits, but other show only bare rock.

(B) POTHOLES :

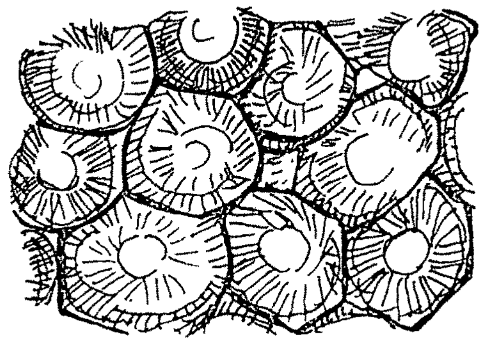
Potholes are shallow hollows to deep shafts drilled into rock surfaces by the cutting action of suspended stream borne

Figure 17 SKETCH FOR (a) spitzkarren, (b) solution basins, and (c) cockling - mass transfer features

(a) Spitzkarren



(b) Solution basins



(c) Cockling

PLATE:24

(a) Formation of spitzkarren, salt marsh in background.

(b) Cockling development in calcarenite southern coast of Diu.

debris, or by the combination of corrasion with grinding by stones too large to be suspended but small enough to roll or slide.

Potholes in Diu vary widely in form. Some are cauldron-shaped and about equally wide and deep, the smooth sides sloping inward at a moderate to steep angle toward a rounded floor. Most resemble a vertical circular to oval cylinder closed at the bottom, but with locally overhanging and occasionally deeply under cut sides. Although some cylindrical potholes have a similar depth to width, the majority are many times deeper than wide.

INTERPRETATION : The structures described above depend on mechanisms referable to the general transfer process called mass-transfer, whereby matter is removed from a solid surface into a neighbouring fluid as the result of direct chemical and /or physical dissolution, the shape and position of the interface consequently changing (Bogli, 1978). The dissolution rate depends on the properties of the solid and of the fluid, as well as on the character of the fluid stream. As with particle erosion and deposition, the material transfered experiences no change of state during the transfer. The more complex mechanisms, however, involve chemical reaction as well as at least one physical change of state (Allen, 1984). As postulated by (Allen 1984 p. 208-I). There are two modes of heat and mass transfer : free or natural convection and forced convection. In motion, though circulatory currents may result directly from the transfer, as during the evaporation of water, from a stagnant pool into stationary air. In forced convection, transfer results from the externally motivated flow of a fluid phase. Limestone dissolution into a water stream is an important example. Forced convection occurs under laminar as well as turbulent conditions, each regime being represented naturally. In Diu the mechanism undoubtly has to be the forced convection due to the rising waves from the open sea coast.

INTERTIDAL AND BACK BARRIER FACIES

Intertidal depositional environment constitute the dominant back barrier dune complexes and the nearshore sedimentary facies along the coast of Diu. As argued by Frey and Howard (1980), back barrier facies are a classifier's paradise, there are many subtle differences resulting from variations in geomorphology, sediment textures, tides and currents, and vegetation. All these can be suitably incorporated in nominating the facies. In Diu such features include back barrier beaches and dunes, tidal flats and salt marshes. Many of these facies are intergradational in nature.

15.1 BEACH FACIES :

Characteristic beach development is observed at the Nagoa and Vanakbara regions in the south and southwest part of Diu (Plate 25a,b, & 26a). The beaches represent a typical process-response system and are the most dynamic coastal environments. Most of the beaches are formed by the ingressment of the sea water through the destruction of the Pleistocene dune terraces on the southern parts of the Island. Here the uprush and backrush of the waves combine to produce textural and compositional segregation of sediments on the beaches. Most of the sand carried by the uprush is in suspension, whereas that carried by the backrush is largely in sheet flow near the bed. Transport in suspension is promoted by small particle size; in sheet flow, transport is promoted by large particle size. As a consequence, the upper part of the beach foreshore is finer than the lower part. Likewise, the combination of the uprush and backrush of waves tend to trap heavy mineral grains, which are typically smaller than the light mineral grains, on the upper beach profile. However the beach berm somewhat complicates this system. The seaward side of the berm is subjected to both uprush and backwash whereas the landward side receives only landward directed flow. Sheet flow predominates, and the textural and compositional patterns generated by this type of flow, are imposed on both sides of the berm.

Active winds very often generate various types of ripples on the foreshore and backshore faces of the beaches (Plate 26b). Stratification is commonly nearly horizontal and cover well over the surface. Bioturbation is wide spread in both these zones and it sometimes partially destroys the stratification. The ghost crab Ocypode are the most characteristic taxon in these area (Plate 26c), but other varieties of crustaceans including Callianassa major and polychaete worms are also in plenty. Detail account of the biogenic sedimentary structures observed on the beaches is given separately.

PLATE : 25

Beach formation near Nagoa

PLATE:26

(a) Beach formation south of Vanakbara.

(b) Nagoa beach : Wind and current ripples.

PLATE : 26

(c) Mosaic of crab pellets in the beach backshore facies.

15.2 COASTAL DUNES :

In Diu the recent dune field is mainly restricted in lee side of the high energy beaches between Vanakbara and Nagoa that face the prevailing onshore winds. They are most extensive on the western part of the Island and are represented by varieties of dune forms, ranging in size from 5 to 10 meters. Many of these are mobile in nature and shift their places very often, but are more prevalent in the northeast southwest direction (Fig.16).

Coastal dunes in Diu consists of three basic types (i) stable foredunes, (ii) unstable foredunes leading to blowouts, parabolics, and (iii) dune fields which contain transverse and other kinds of dunes.

(i) The foredune refers to the accumulation of aeolian sand immediately in lee of the beaches. In Diu foredune usually extend from the limits of Nagoa and the Vanakbara beaches and many a times during their migration are found to occupy the connecting country roads (e.g. Dangarwadi in Diu). The larger established foredunes around Dangarwadi have colonized shrubs and small trees

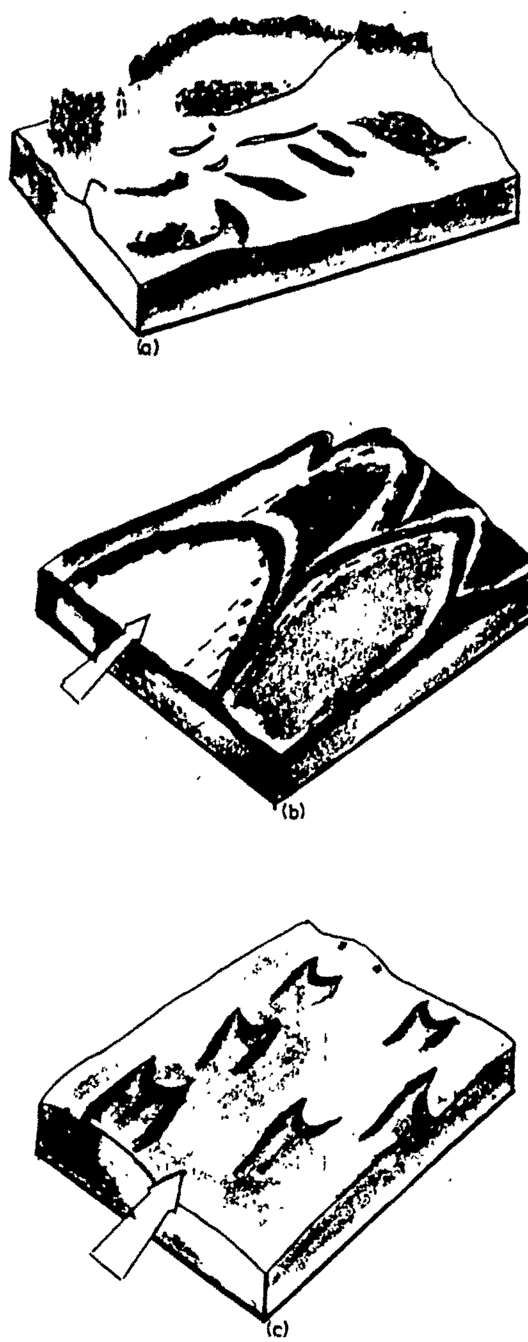
(ii) Blowouts (Fig.18) are erosional troughs or funnels which are generally initiated in the foredunes. They consists of an erosional neck and a convex, free moving usually parabolic shaped unvegetated depositional lobe extending 25 to 50 meters inland. Their axis is parallel to the onshore wind direction (i.e. south westerly).

(iii) Parabolic dunes (Fig.18/) are U-shaped dunes characterized by elongate lateral ridges and massive terminal wall, surrounding a central deflation hollow. The length ranges from a few to tens of metres. The down-wind portion of the lee side is stabilized by vegetation, which also occurs patchily in the blowout itself.

(iv) Barkhan dunes are formed as a small oval sand patch accumulating on cohesive surface in Dangarwadi area whereever loose sand is in meagre supply. Such mature dunes (Fig.18?), standing in isolation, are crescent shaped and bilaterally symmetrical. Its lateral "arms", "horns" or "wings" point down wind (southwesterly). Most barkhans have a height in the order of 2-10 meters. Very often close packing of sand causes some of these barkhans to become destorted. At places inflection in the crest line, and one of the wings is found elongated relative to the other. A common mutual arrangement of close packed barkhans north of Dangarwadi appears like a V-shaped formation of flying birds (Fig.18f).

(v) Dune fields Dune fields in Diu consists of extensive areas of unvegetated sands. Such areas are located around north of Nagoa beach and north of Dangarwadi. They appear to have evolved through coalescence of numerous blowout - parabolics or by direct beach foredune-dune sand transport. Mobile dune fields

FIG 18 SKETCH COASTAL DUNES (a) Blowouts, (b) Parabolic, and (c) Barkhan



near Nagoa and Dangarwadi show transverse dune forms. These are overlapping wave-like free moving dune forms normal to the dominant wind in which direction they migrate. Wind ripples, climbing or migrating are very common. Insects and other terrestrial fauna (including sea birds) are found to locally bioturbate these coastal dune deposits.

15.3 TIDAL FLATS AND SALT MARSHES

The term "tidal flat" is usually referred to indicate vast unvegetated intertidal areas typically developed in estuaries, lagoons, or sheltered areas behind spits, offshore bars, or barrier islands and around edges of protected bays (Phelger, 1969). Salt marshes on the other hand are defined as well-vegetated intertidal flats (Bason and Frey 1972). Along the coast of Diu large areas are developed landward of the Pleistocene dune terraces include such features. Here the intertidal flats are also moderately to densely vegetated, especially by the development of mangroves and some other vegetations. Hence the overall environment it indicates a transition from the tidal flats to salt marshes.

(i) Tidal Flats : True tidal flats are located in Diu at its northwestern portion, but are considerably smaller in lateral extent than are the salt marshes. These tidal flat range in size and textures from small mud flats to relatively large tracts of sandy mud and muddy sand. Larger flats studied by the author include one in Ghoghla. This qualify a tidal flat in the classical sense not only because it is unvegetated intertidal sequence having gentle seaward dipping depositional slope, but also because of diagnostic physical and biogenic sedimentary structures such as those reported by Reineck and Singh (1980). The physical sedimentary structures commonly included are :

a. Trough type megaripples having amplitude 10 to 15 cm;
b. Smaller trough type cusp ripples very often super-imposed on the megaripples, and
c. Laminated to cross-laminated and wavy laminated muds

All these structures consist, to some extent, alternating layers, lenses of sand and mud in various combinations. Faecal muds are found entrained during high-velocity flow but accumulate in cusp and megaripples troughs during the reduced flow. In general, these muddy, low energy subfacies are characterized by bioturbate textures whereas the sandy surfaces are characterized by distinct identifiable biogenic structures which are described separately.

In general the tidal flats in Diu appears to be growing presently as a result of retreating shoreline at various points due to natural and man made encroachments, no doubt related to a general gradual rise in sea-level.

(ii) Salt Marshes : Salt marshes are typically developed in Diu in sheltered areas behind the Pleistocene stabilized dunes and occupy a total area of about 18 sq.km. (Fig. 16) Diu salt marsh sediments are mostly silty clays or clayey silts, but muddy to fairly clean sands are also present locally. In Diu salt marshes, the variations in sediment composition depend primarily upon proximity of subaerial or subaqueous exposures of the Pleistocene carbonate sands, and muds. Muddy substrates are often found depleted in oxygenation and significantly smell of H_2S. At many places especially nearer to the southern dune ranges the marsh area is well drained with tidal flushings. Ecological conditions with Diu salt marshes, therefore, are rigorous and the diversity of species is low. Organisms, that are present, are the species having broad tolerance limits for such conditions. Details of these are given in the discussions on animal sediment relationship in Diu.

TEXTURAL CHARACTERISTICS OF COASTAL SEDIMENT

16.1 SEDIMENTOLOGICAL STUDIES :

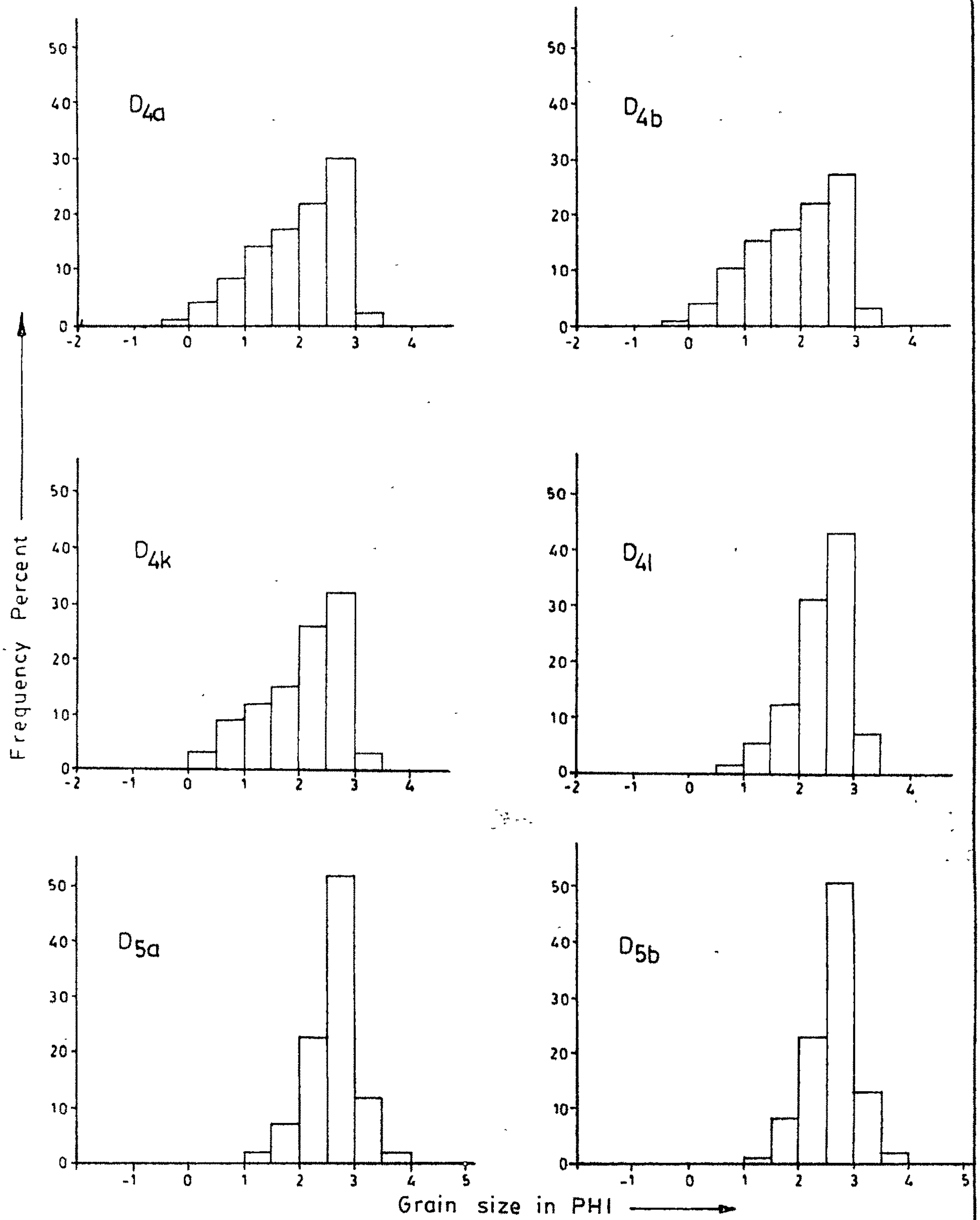
For these studies samples were mainly drawn from the localities of Nagoa and Vanakbara (beaches), Nagoa and Dangarwadi (Recent sand dunes); and Ghoghla (tidal flat and salt marsh). The textural analysis of the sediments were carried out in the same way as described (in part - II, 6.0) for Piram Island.

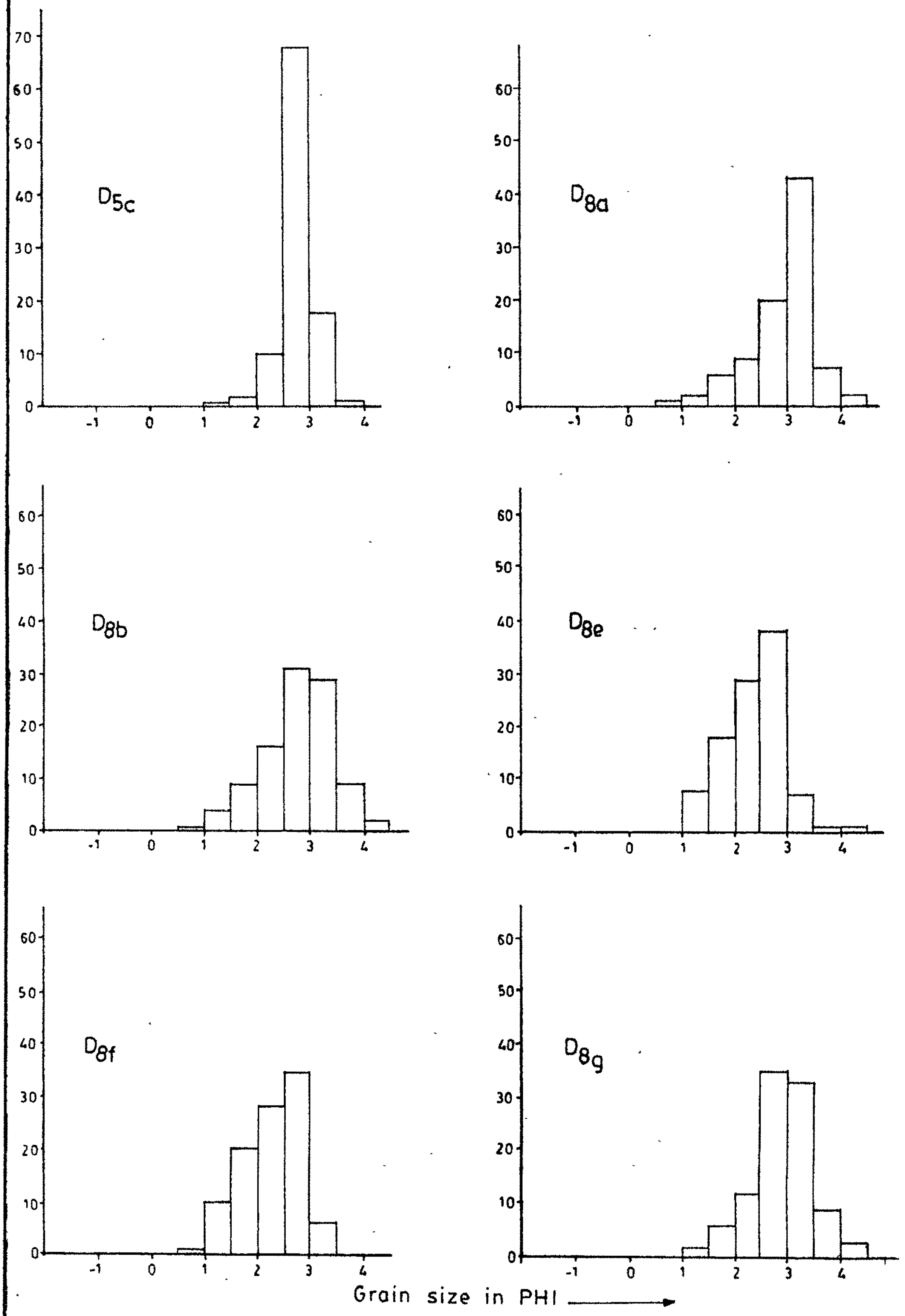
The graphic representation of the size analysis data is presented in histograms (fig. 19) and cummulative (fig.20) curves using probability ordinate graphs. The statistical parameters so obtained are tabulated in the following Table 14.

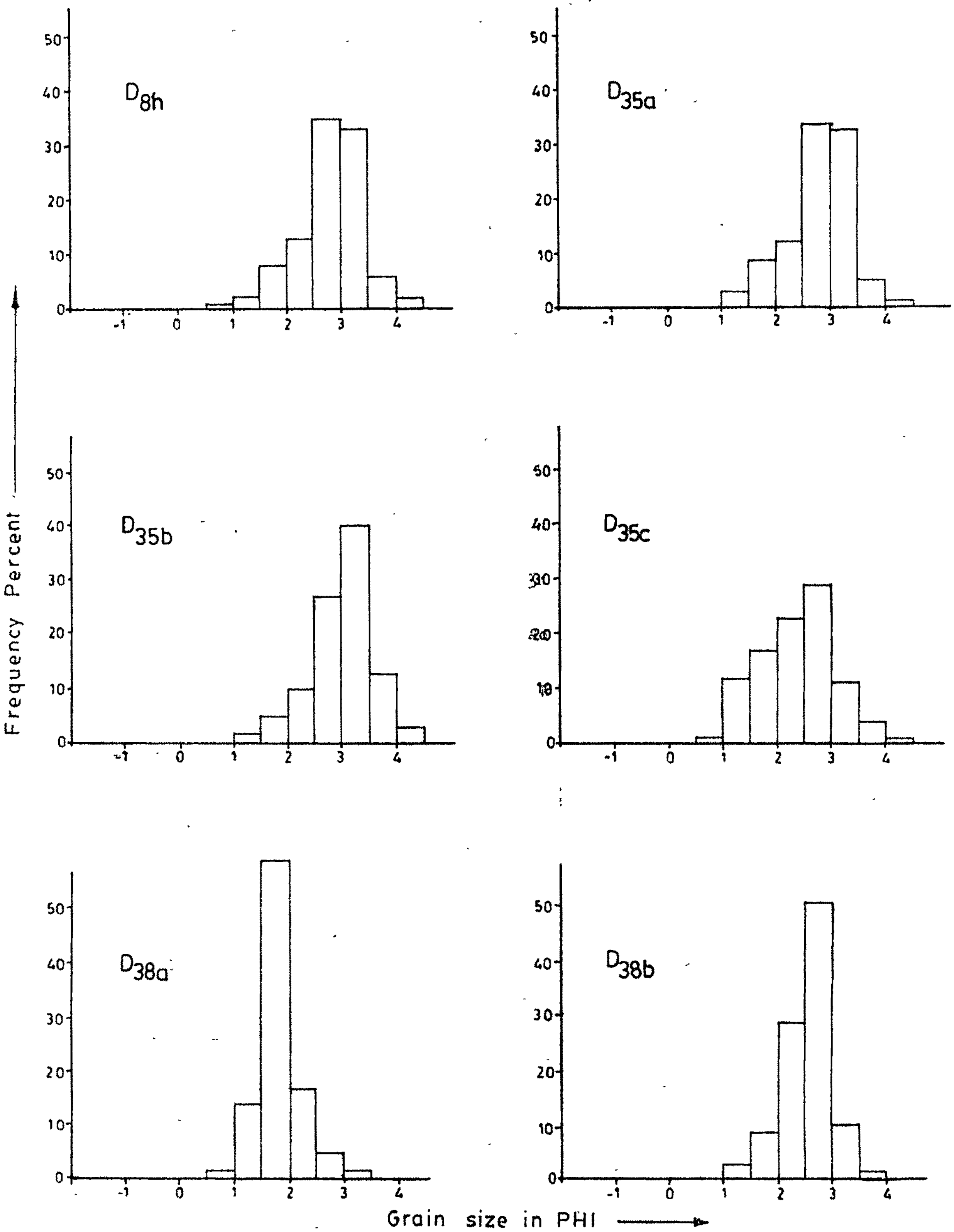
Table : 14 Sediment Characteristics of Diu Island

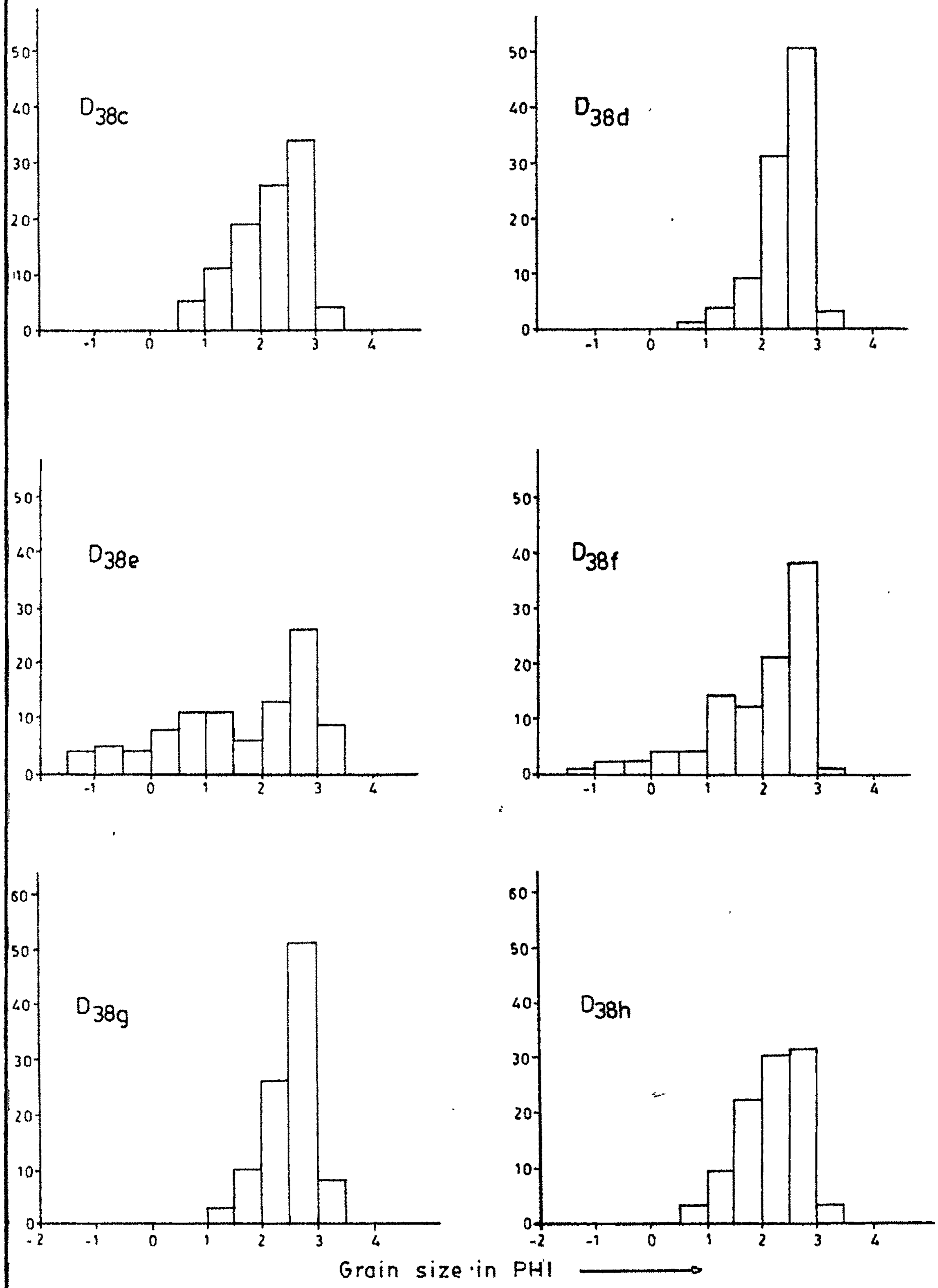
Locality	Sample No.	Mean Size (Mz)	Standard Deviation (σ_I)	Skewness (Sk_I)	Kurtosis (K_G)
	D4a	1.98	0.75	-0.27	0.80
	D4b	1.93	0.77	-0.25	0.82
Nagoa	D4k	2.23	0.67	-0.49	1.06
and	D4l	2.08	0.76	-0.41	0.96
Vanakbara	D8a	2.93	0.55	-0.23	1.26
beaches	D8b	2.75	0.63	-0.31	1.01
	D8e	2.93	0.57	-0.06	1.29
	D8f	2.82	0.58	-0.12	1.26
	D8g	2.76	0.59	-0.21	1.02
	D8h	2.98	0.59	-0.20	1.20
	D5a	2.62	0.44	-0.12	1.46
Nagoa	D5b	2.61	0.43	-0.02	1.23
and	D5c	2.76	0.30	-0.26	1.35
Dangarwadi	D35a	2.38	0.53	-0.29	0.80
dunes	D35b	2.32	0.56	-0.19	0.92
	D35c	2.33	0.99	+0.10	1.05
	D38a	2.57	0.43	-0.16	1.12
Ghogla	D38b	2.05	0.71	-0.33	0.94
Salt marshes	D38c	2.40	0.48	-0.25	1.13
and	D38d	2.52	0.43	-0.31	1.08
Tidal flat	D38e	2.18	0.55	-0.22	0.90
	D38f	2.15	0.59	-0.26	1.04
	D38g	2.28	0.43	-0.16	1.12
	D38h	1.30	0.42	-0.16	2.19

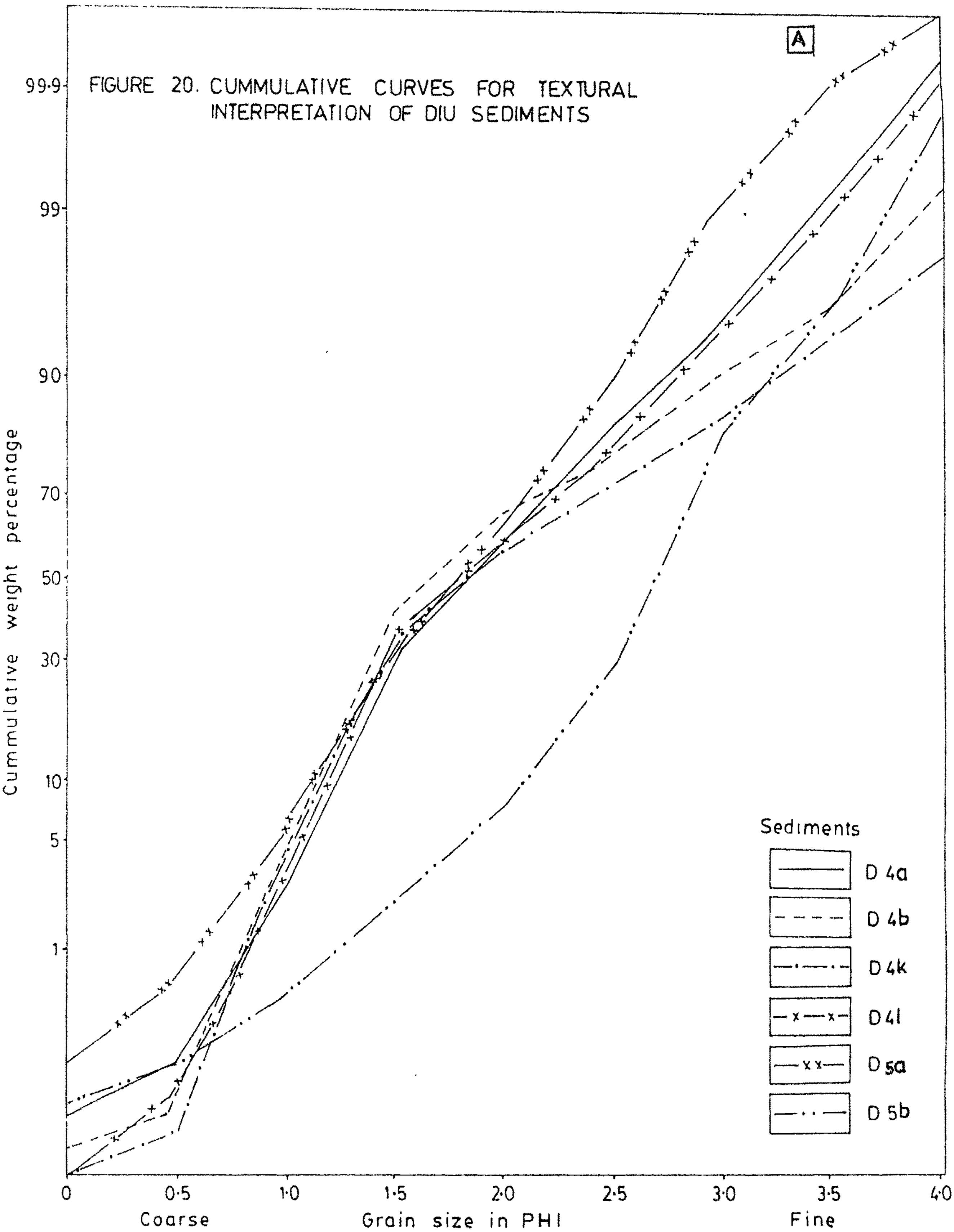
FIGURE 19 HISTOGRAMS: GRAIN SIZE DISTRIBUTION – DIU SEDIMENTS



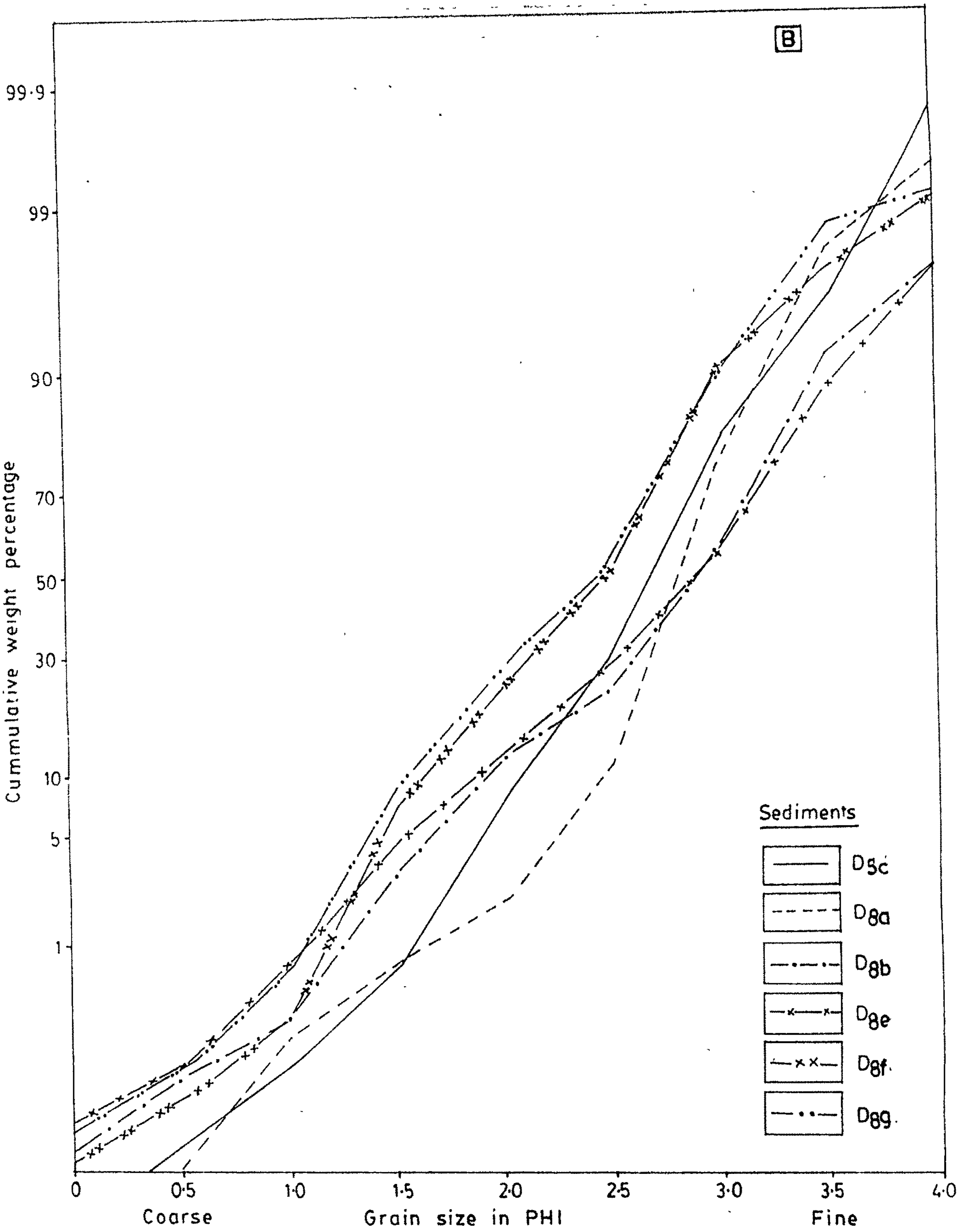

D5c
D8a
D8b
D8e
D8f
D8g
Grain size in PHI

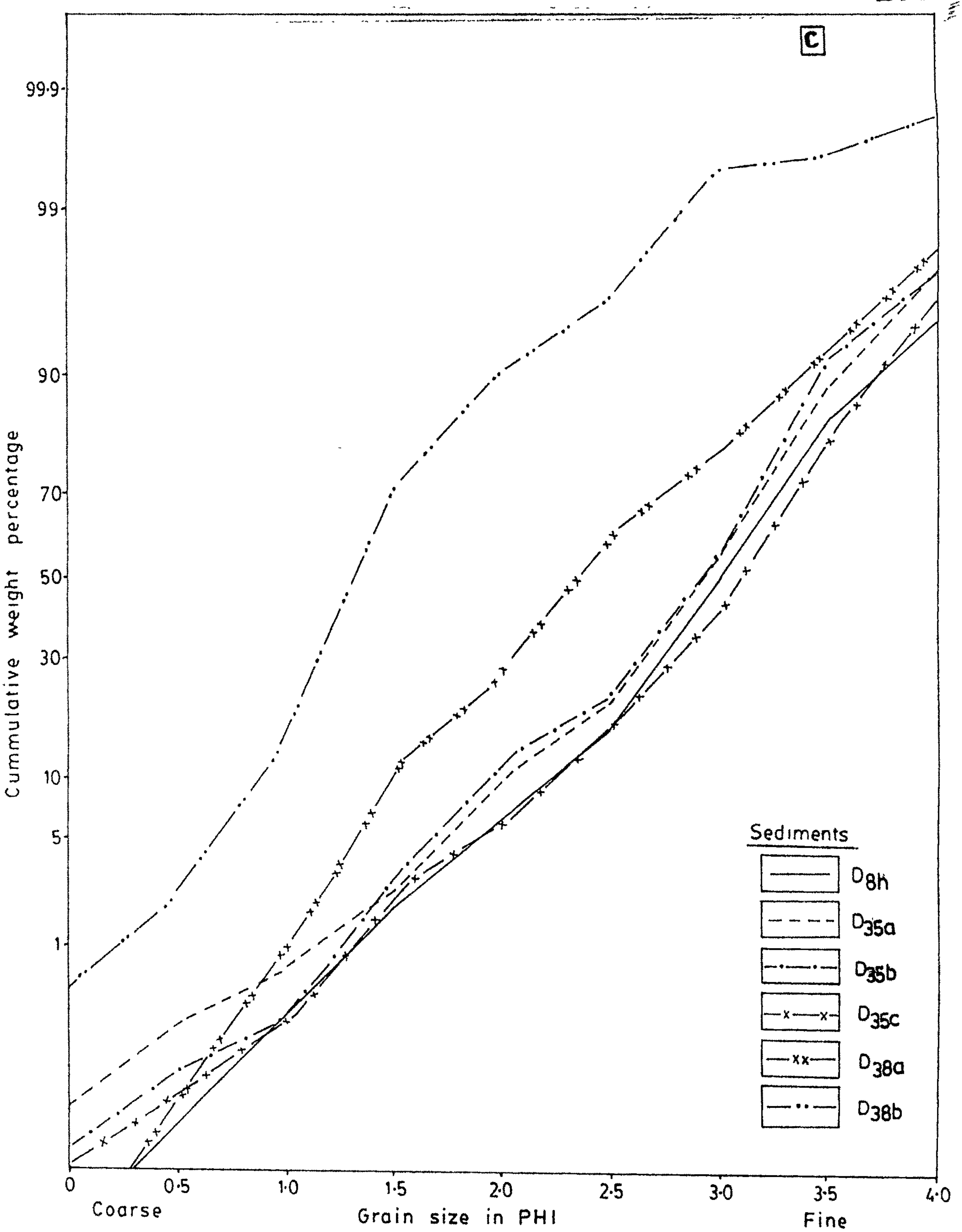

D8h
D35a
D35b
D35c
D38a
D38b
Frequency Percent
Grain size in PHI


D38c
D38d
D38e
D38f
D38g
D38h
Grain size in PHI



A
FIGURE 20. CUMMULATIVE CURVES FOR TEXTURAL INTERPRETATION OF DIU SEDIMENTS
99·9
99
90
70
50
30
10
5
1
Cummulative weight percentage
0
0·5
1·0
1·5
2·0
2·5
3·0
3·5
4·0
Coarse
Grain size in PHI
Fine
Sediments
D 4a
D 4b
D 4k
D 4l
D 5a
D 5b


B
99.9
99
90
70
50
30
10
5
1
Cummulative weight percentage
0
0·5
1·0
1·5
2·0
2·5
3·0
3·5
4·0
Coarse
Grain size in PHI
Fine
Sediments
D5c
D8a
D8b
D8e
D8f.
D8g.


C
99·9
99
90
70
50
30
10
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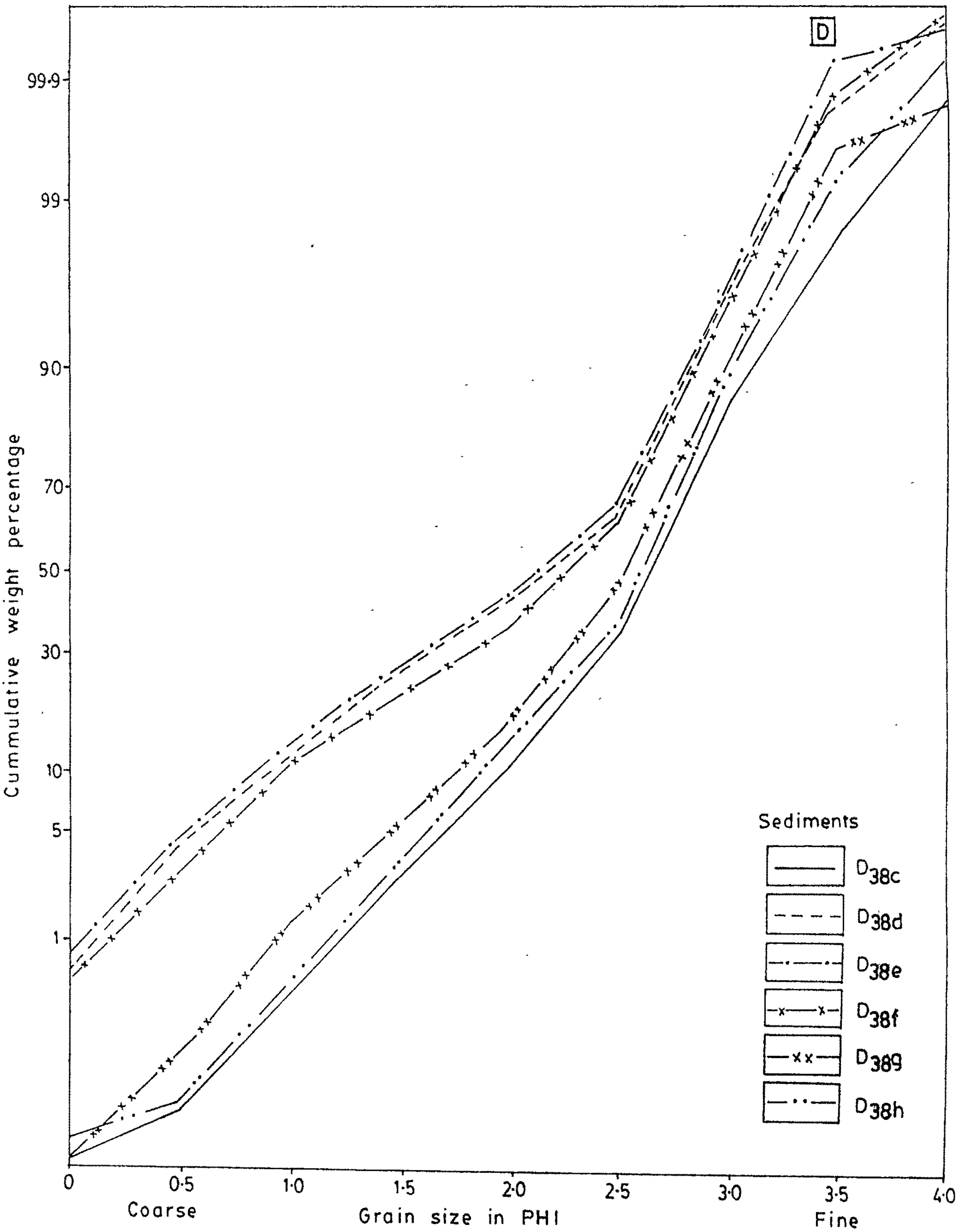
1
Cummulative weight percentage
0
0·5
1·0
1·5
2·0
2·5
3·0
3·5
4·0
Coarse
Grain size in PHI
Fine
Sediments
D8h
D35a
D35b
D35c
D38a
D38b


D
99.9
99
90
70
50
30
10
5
1
Cummulative weight percentage
0
0·5
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1·5
2·0
2·5
3·0
3·5
4·0
Coarse
Grain size in PHI
Fine
Sediments
D38c
D38d
D38e
D38f
D38g
D38h

16.2 CONCLUSIONS AND INTERPRETATION

From the tabulated data (Table 14) following conclusions are drawn :

The graphic mean size values of Nagoa and Vanakbara beach sand range from (1.93 phi) medium sand to (2.98 phi) fine sand; that of the dune sand of Nagoa and Dangarwadi (2.76 phi to 2.33 phi) are fine sand and; for the tidal flat and marshes of Ghoghla are (1.30 phi) medium sand to (2.57 phi) fine sand.

The inclusive standard deviation values suggest beach sand are moderately sorted (0.77 phi) to moderately well sorted (0.55 phi); that of the dune sand are moderately sorted (0.99 phi) to very well sorted (0.30 phi) and; the tidal flat and marsh sand are moderately sorted (0.71 phi) to well sorted (0.42 phi).

The graphic inclusive skewness values of beach, dune, tidal flat and marsh sands range from negatively skewed (-0.16 phi) to very negatively skewed (-0.49 phi). The graphic kurtosis values of the beach, dune, tidal flat and marsh sand range from leptokurtic (1.29 phi) to platykurtic (0.80 phi).

From the above interpretation, it is seen that there is very little variation in size parameters of beach, dune, tidal flat and salt marsh microenvironment for the coastal sediments of Diu.

On an average the beach, dune, tidal flat and salt marsh sediments of Diu are unimodal (Fig.19) in character and from the cummulative frequency curves (Fig. 20) it show the values by traction as 1.78 percent, saltation as 91.14 percent and by suspension 7.0 percent. The high value of saltation probably reveal the frequent cycles of deposition and erosion the coastal sediments in inland areas have undergone before their deposition.

HEAVY MINERAL STUDIES

17.1 OCCURRENCE AND DISTRIBUTION

Heavy minerals of magnetite, ilmenite, augite, tourmaline, zircon and glauconite were found associated with the sediments on beaches, sand dunes and parts of the marshy land in Diu. Magnetite has been the abundant mineral amongst these. The localities from where the samples were collected and studied include those of Jalandhar, Vanakbara, Nagoa and Ghoghla. The values of the heavy minerals were determined as per the procedure adopted and described (in part - I, 7.0) for the Piram Island. The resulting textural values and their plots are given in the following Table 15 and Fig.21. The magnetic susceptibilities of the heavies are shown in the Fig. 10b.

Table : 15 Showing Weight Percentage of Light and Heavy Crops

Location	Sample No.	Light Mineral Wt. %	Heavy Mineral Wt. %	Total Wt. %
Nagoa	D4a	96.97	3.13	100
Beach	D4i	95.66	4.34	100
	D4p	92.97	7.03	100
	D5a	88.60	11.40	100
	D5b	94.40	5.60	100
Dune	D5c	89.90	10.10	100
	D8a	98.75	1.25	100
	D8e	98.03	1.97	100
Vanakbora	D8i	98.33	1.67	100
Beach	D22a	99.43	0.57	100
	D35a	69.43	30.57	100
Dangarwadi	D35b	58.50	41.50	100
interior Dune	D35c	66.83	33.17	100
	D38f	97.47	2.53	100
Ghoghla salt	D38h	97.87	2.13	100
Marshes	D38j	97.20	2.80	100

Observations and Interpretation

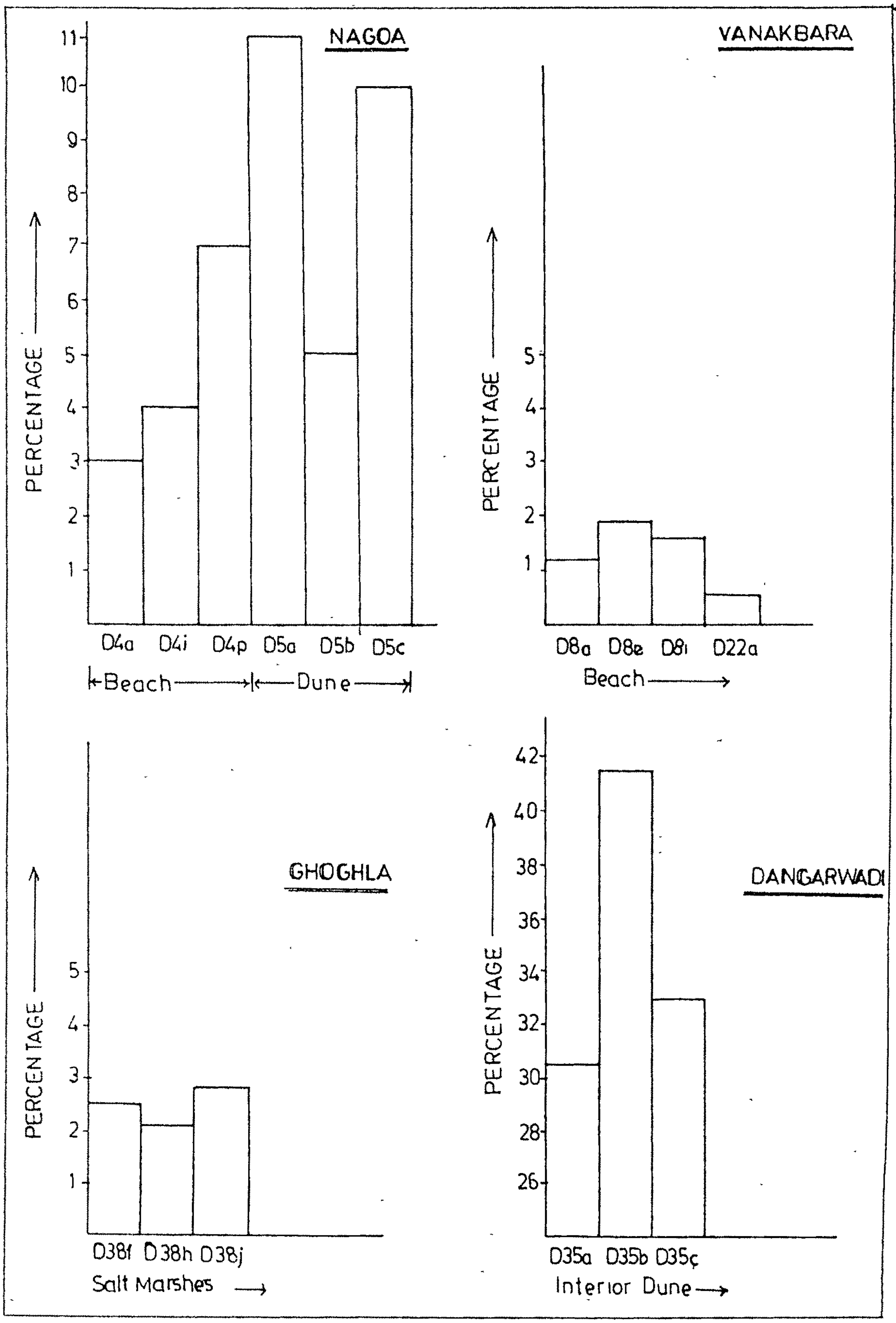
The maximum concentration of heavy minerals (Table 15) on the beach face (7 percent) is observed at the Vanakbara beach. The Nagoa beach comprises only 1 to 2 percent concentrations, while at Ghoghla a uniform distribution of 2 percent is observed.

On the coastal sand dunes at Vanakbara the concentration values obtained show variation between 6 to 11 percent of heavy sand and the maximum values so obtained are from the top of the dune face. The interior dune fields surprisingly comprise maximum concentration between 31 to 42 percent in their bulk composition.

As could be gathered from the above conclusions and the concentration variations diagram (Fig.21), the heavy minerals have invariably occupied their highest concentration on the crests of either the beaches or the dunes. The possible reasons for such selective concentrations of heavies could be the reason as explained earlier i.e. the combination of the uprush and backrush of waves along the beaches that tend to trap heavy mineral grains which are typically smaller than the light mineral grains on the upper beach profiles. These finer grains during slack water conditions get subjected to wind action and shift to the crest of the migrating dunes and also get spread over the marsh sediments. May be for these reasons, the fine grained heavies have their highest concentrations on the dune crests and over the marsh sediments.

The provenance of the heavy minerals could once again be attributed to the inland areas of the Deccan traps and, their transport to their present sites to the longshore agencies active on the coast of Saurashtra.

FIG.21 DISTRIBUTION OF HEAVY MINERALS IN COASTAL ZONES - DIU ISLAND.



SEDIMENT TYPES

As mentioned earlier, the distribution of sediments in Diu is largely a function of physical (mechanical) processes operating along the coast (eg. waves, currents, tides and wind etc.) Furthermore, the Island of Diu is directly facing the Arabian sea, especially along its southern fringe and sustains an open coastal environmental zone. With this background it could be quite interesting to study the sediment types and their microenvironments at different localities. The sediments from Nagoa, Vanakbara and Ghogla were considered for these studies.

On an average, most of the sediments comprise 70 to 75 percent carbonate grains, the remaining 30 to 25 percent consisting of quartz, felspar, and heavy mineral concentrates (magnetite, ilmenite, tourmaline and zircon) and rock fragments. Most of these samples are fine grained. Based on their textures and grain characteristics the following sediment types, in order to understand their field distribution, are suggested and illustrated in Fig.22.

The sediment types are : (a) Lamillibranch/foraminiferal sand, (b) foraminiferal sand, (c) compound grain sand, and (d) pelletoidal/foraminiferal sands. These sands are found in juxtaposition to one another as one moves from the lowest level of the beaches to the dune crests. Very often they are also found intergrading and no clear cut division can be ascertained. A brief description of these sand types is given in the following paragraphs.

18.1 DESCRIPTION AND INTERPRETATION OF SEDIMENT TYPES

(i) Lamellibranch/foraminiferal sand (Plate 27a).

Grain size : Medium grained

Sorting : Moderately sorted

Total foraminifera in measured sample : 1841

Sedimentological description : This sand type consists of angular to sub angular skeletal fragments, subrounded to rounded tests of foraminifera and coralline clasts. The shell fragment shows algal borings and varying degree of abrasion. Such sands are located in isolated patches on most of the upper beach facies.

Relation to environments : The coarser fraction which is generally concentrated in isolated patches in the upper tidal units is usually made of large size lamellibranch shell fragments. May be these were the indigenous or semiindigenous elements in the nearshore regions. The coralline debris are apparently the exotic forms since corals require hard substratum and therefore might have been derived from hard rock areas including local offshore highs. It is probable that the longshore currents may have brought this material to the coast and the surf action may have helped the material to be spread in patches on the upper beach faces in Diu.

(ii) Foraminiferal sand

Grain size : Fine grained

Sorting : Moderately sorted

Total foraminifera in measured sample : 2948

Sedimentological description : This type of sediment consist of whole tests of perforate large foraminifera together with lamellibranch shell fragments and minor amount of faecal pellets (ellipsoidal grains). The foraminifera consist of biconvex trochospiral species of Ammonia and Eponides. These species form the dominant group of foraminifera and the bulk of the sediment type. At places the foraminiferal test show algal borings and varying degree of abrasion.

Relation to environment : Most of the foraminiferal test indicate their shallow water origin. Although polished, many of the tests have not been broken during their transportation. It is, therefore, difficult to ascertain whether the test have been carried from their original sites where the animal lived or they belong to the nearshore dune fields from where they have been recycled. At the same time it can not be ignored that the longshore currents and waves could have also played their roles in bringing the tests and spreading them along the beaches. This, however, could have taken place when the wave or currents were comparatively reduced. However, the beaches at Nagoa and Vanakbara are developed much inland from the coast and the wave and current energies by the time they reach the beach sites with their load of sediments would almost be on decline of their true vigor allowing the whole tests to remain unbroken.

(iii) Compound grain sand (Plate 27b)

Grain size : Fine to very fine grained

Sorting : Well sorted

Total foraminifera in measured sample : 1410

Sedimentological description : Compound grain sand consist of fine grained, angular to subangular compound grains of terrigeneous material and rounded to elliptical faecal pellets. The foraminiferal tests are dominated over the pellets. The sediments on the whole are fine grained and well sorted.

Relation to environment : The compound grain sand are invariably located on the beach upper facies and on the dune crests. It is possible that the sediments were subjected to wind action when the beach upper surfaces were getting dry. These were then shifted to the dune fields.

(iv) Pelletoidal/foraminiferal sand

Grain size : Very fine grained

Sorting : Very well sorted

Total foraminifera in measured sample : 2874

Sedimentological description : These type of sediments are extremely variable in character. Its most constant components, however, are the perforate foraminifera and faecal pellets which occur in equal proportion, though minor proportions of the subangular to subrounded compound grains also enter in to their composition. The dominant groups of foraminifers include Ammonia, Discorbis and Cibicides.

Relation to environment : These carbonate sands characterise, but are not limited to or restricted to any particular environment. They nearly always are found in moderate

to high energy setting of coastal beach and dune fields. The
dune sands are obviously derived from the calcareous beach sands by the onshore wind transportations.

FIGURE 22 DISTRIBUTION OF SEDIMENT TYPES IN DIU ISLAND

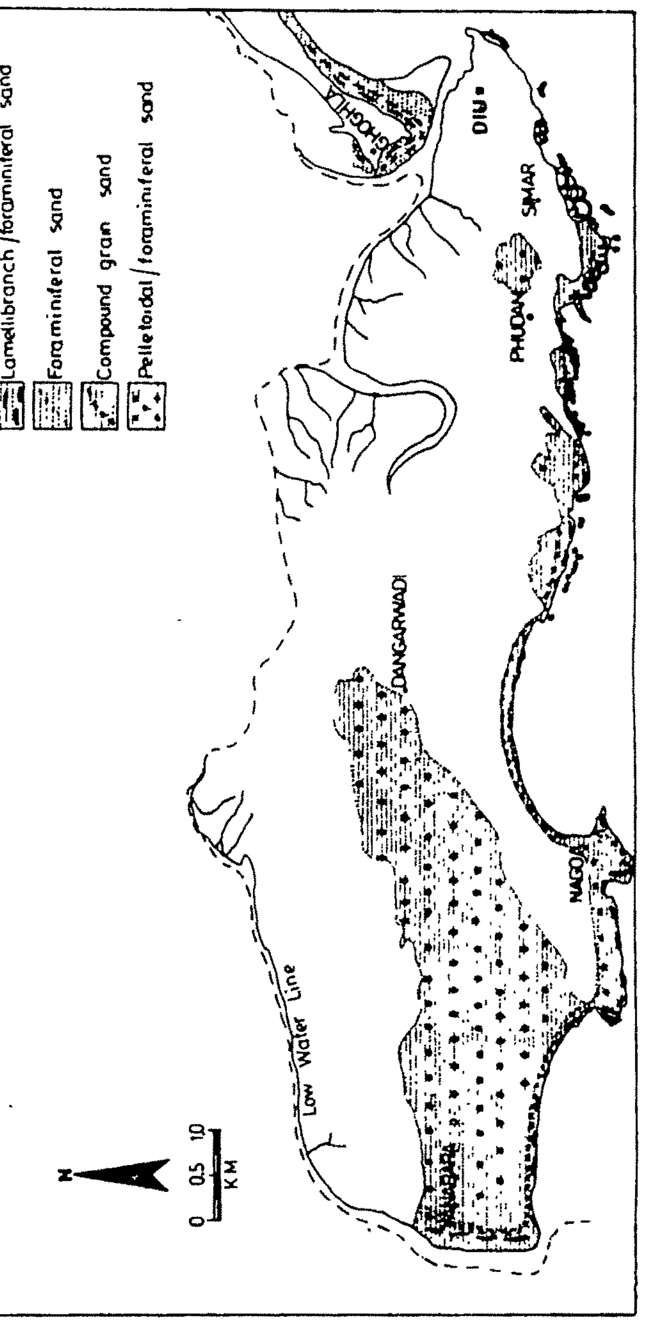
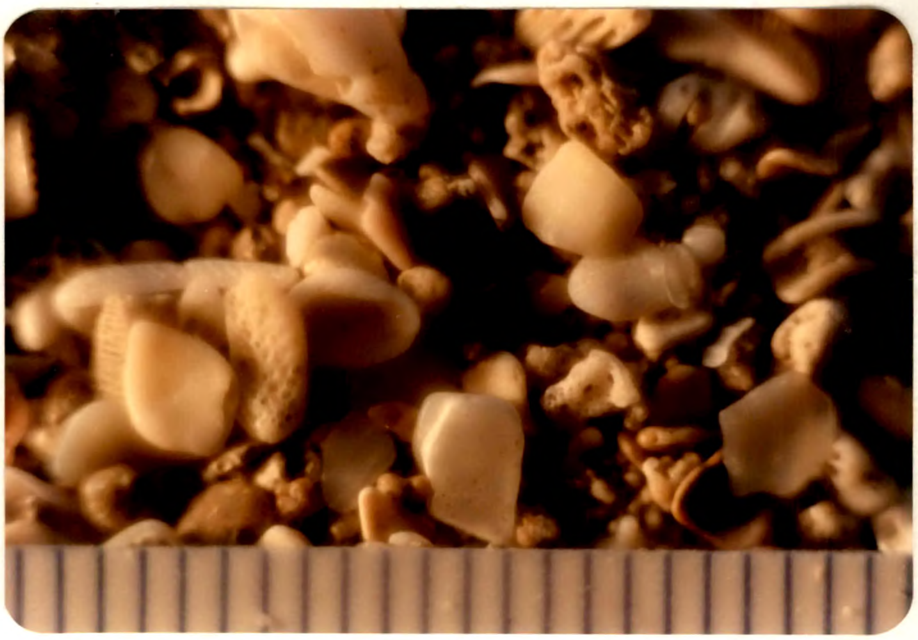
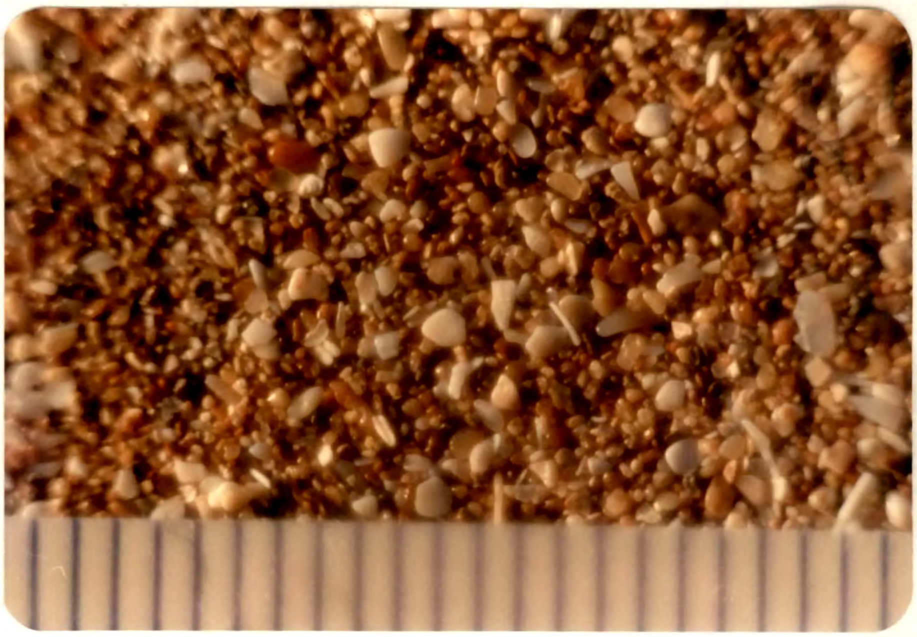


PLATE : 27



(a) Lamellibranch/foraminiferal sand x 6.



(b) Compound grain sand x 6.

ANIMAL SEDIMENT RELATIONSHIPS

For consideration of the animal sediment relationships in Diu, the author has followed the same pattern as was established for the textural studies of the sediments viz., beaches, dunes and salt marshes. The beaches and dunes are reach in foraminiferal tests (70% to 75%), while a great variety of animal activities (trails, tracks and burrows) characterize parts of the foreshore and backshore of the beaches and especially the salt marsh regions.

This study once again is subdivided into two main categories reflecting the fundamental attributes of the animals or their record present in the depositional system. It includes the morphotype patterns of the foraminiferal tests and the lebensspuren (biogenic activities) or the bioturbation caused because of the animal activities.

19.1 MORPHOTYPE PATTERNS

The foraminiferal tests isolated from the beach sands, the dune and the tidal flat samples comprise the following morphological types :

(a) Biconvex trochospiral consisting of Ammonia and Eponides 71%.

(b) Milioline consisting of Quinqeloculina and Spiroloculina 3%.

(c) Plano-convex trochospiral species of Pararotalia, Discorbis and Cibicides 18%.

(d) Rounded planispiral species of Nonion, Elphidium and Amphistegina 8% and

(e) Conical tapered, including species of Bolivina and Textularia about 1%.

Morphotype patterns of these foraminiferal test obtained at Ghoghla, Nagoa, Vanakbara in foreshore and backshore beach sands, dunes and tidal marshes are presented in the following Table No.16 and distribution diagram (Fig.23a,b)

Table : 16 Distribution of Morphotype Patterns in Diu Sediments

Location	Sample No.	Microenvironments	Morphotypes in percentage				
			BT	M	PT	RP	CT
Ghoghla	D38a	Saltmarsh	81	2	10	6	1
	D38e	Saltmarsh	79	2	11	7	1
	D38i	Saltmarsh	76	2	17	5	1
	D35c	Interior dune	37	3	41	16	3
Nagoa	D22a	Lower beach	82	2	12	3	1
	D25a	Upper beach	77	3	12	7	1
	D25e	Dune first line	70	3	23	4	1
	D25i	Interior dune	68	1	21	8	1
Vanakbara	D28a	Lower beach	73	4	13	10	0
	D28e	Upper beach	67	3	22	8	1
	D28i	Dune first line	70	4	16	8	2
	D5b	Interior dune	70	4	17	8	1

Interpretation : As could be seen from the distribution diagram (Fig.23a,b) a gradual decrease in the biconvex trochospiral (BT)

FIG 23a DISTRIBUTION AND RELATIVE ABUNDANCE OF FORAMINIFERAL TYPES - DIU SEDIMENTS

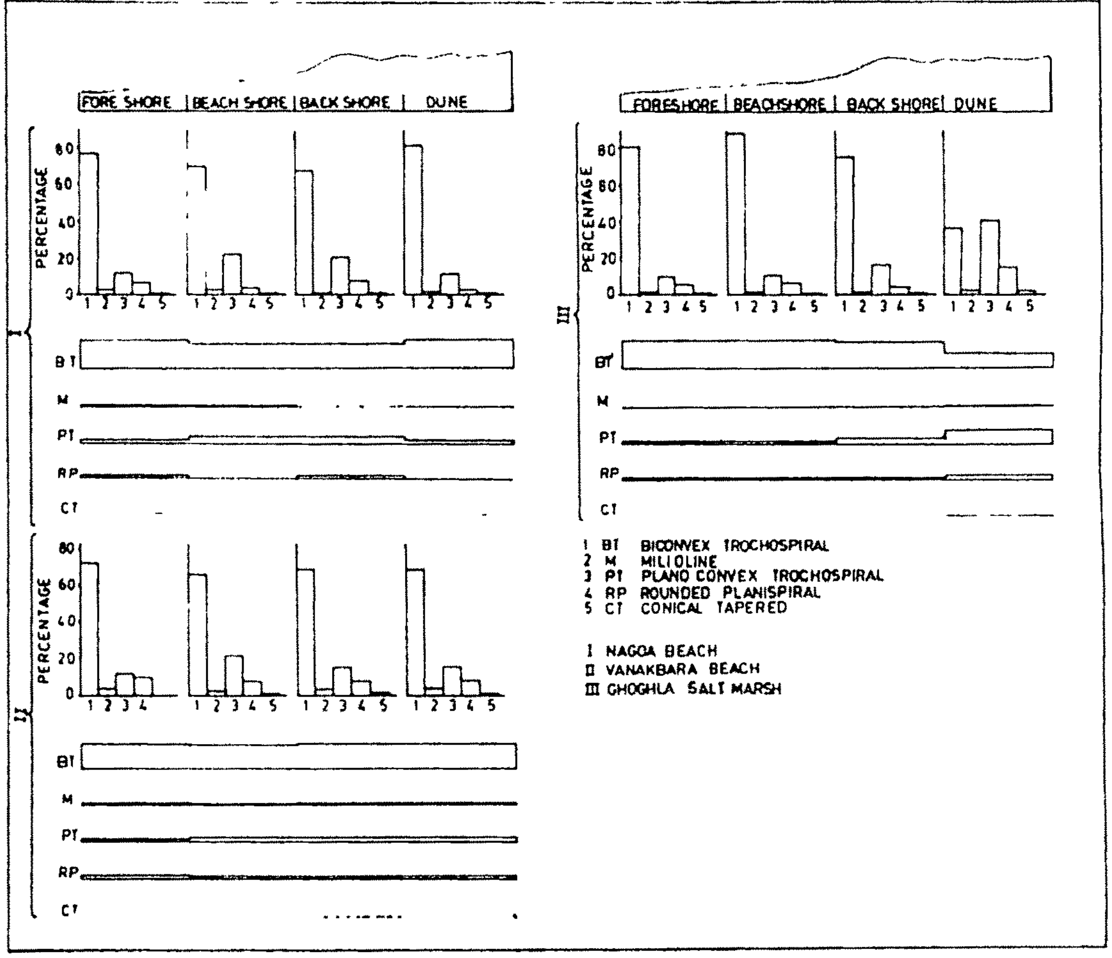
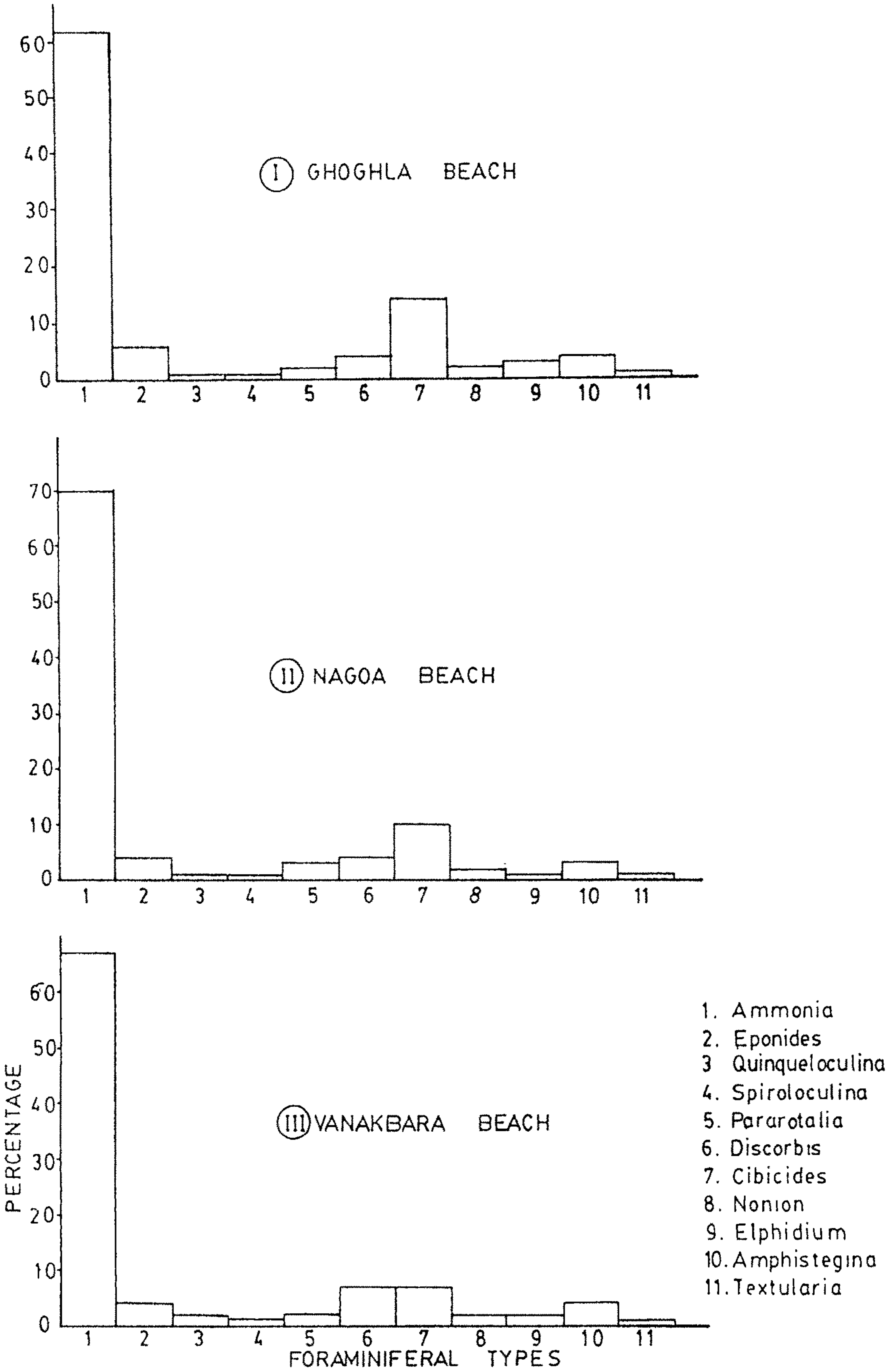


FIG. 23 b HISTOGRAM SHOWING VARIATION IN PERCENTAGE OF FORAMINIFERAL TYPES IN DIU SEDIMENTS



varieties of foraminiferal tests is observed from the beach foreshore to the dune crest and towards its leeward side, at Ghoghla, Nagoa and Vanakbara localities. The milioline (M) on the other hand show no particular trend in their distribution. Contrary to biconvex trochospiral (BT), the planoconvex trochospiral (PT) and the rounded planispiral (RP) varieties in general show their preference to the wind borne transport mechanisms as greater quantities of their accumulations are found on the dunes, dune crests and on leeward side of the dunes.

On the whole, the biconvex trochospiral varieties are dominant in the areas that are prone to frequent wet and dry conditions, while the highest percentage of planoconvex trochospiral varieties could be expected in comparatively drier parts of the beaches and dunes. Such criteria could be important and rather significant to be suitably used to confer the parts of the older sand dunes, whether, nearer to the coast (water influenced) or away from the coast (whether they have aeolian influence in deposition). This proposition, however could not be tested by the author for the stabilized pleistocene dunes in Diu, on account of the difficulties in collecting the systematic stratigraphic samples from the dune fields as quoted earlier. The author is further aware that this proposition has to be applied with utmost caution, since the foraminiferal tests in the carbonate sands of Diu have undergone frequent depositional cycles.

19.2 LEBENSSPUREN AND BIOTURBATION

Lebensspuren or biogenic sedimentary structures in Diu are mainly restricted to various patterns or trends in animal activities like the tracks, trails and burrows. Recognisation of the specific originators of these structures, at times, becomes rather difficult on account of the water cover that these structures are subjected during the tidal oscillations. Broadly, the ichnofacies or the biogenic environments that could be followed while observing such features include the little bioturbated beach and dune crest zones; the moderately burrowed upper middle sections of the beaches; the highly bioturbated lower-middle sections of the foreshore parts of the beaches, and the crypto-bioturbated foreshore, tidal flat and tidal marsh regions along the coast. It is further noted that the foreshore and tidal flat/marsh sediments although intensely reworked, the organisms at a larger have not obscured the primary physical sedimentary structures on these zones.

(i) Little-Bioturbated zones : The upper backshore beaches and the sand dunes are those which come under this category. There is practically no bioturbation or the biogenic activities present here are restricted to some trails left out by the creepers and to the tracks made by birds (Plate 28a).

(ii) The moderately burrowed upper middle section of the beaches and the highly burrowed and bioturbated lower middle section of the beaches and tidal flats : These zones are considered together since the bioturbation and lebensspurens found in these zones vary only in their relative densities, maximum being near the shore zone while minimum away from it. These zones are invariably characterized by the activities of the arthropods, bivalves, gastropods and polychaete worms.

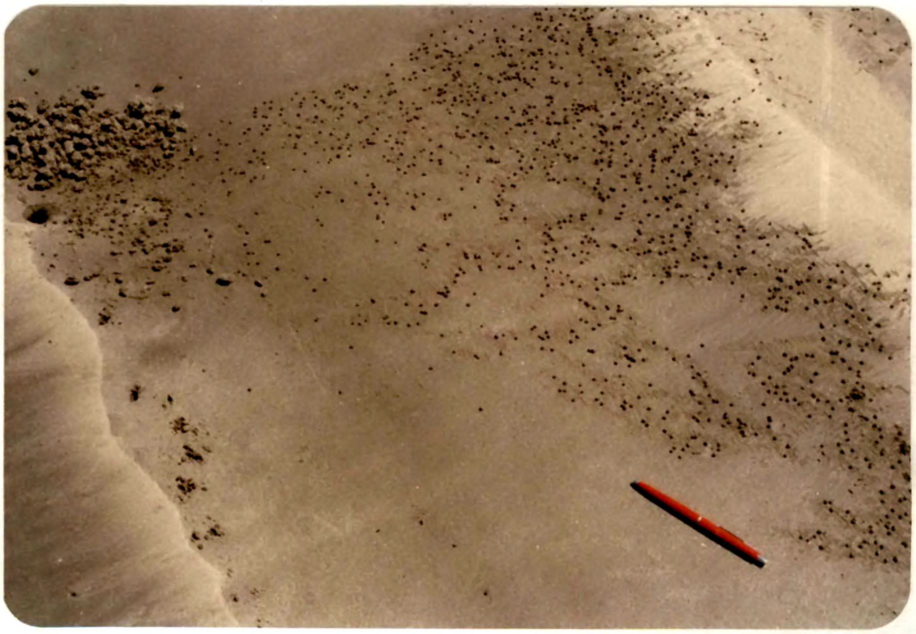
Arthropods : Arthropods represent a significant portion of the infauna and epifauna in the above zones. Distinctive lebensspuren produced by a few of their decapod varities include those by *Uca pugnax*, *Ocypoda* and *Callianassa major*.

Uca Pagnax are abundant locally, burrowing in high intertidal zones and on the upper middle sections of the beaches. Burrows consist of unlined vertical or J-shaped shafts about 10-15 cm in depth. Abundant burrowing produces almost complete bioturbation during emergence of the tides. Their feeding activities over the sediments very often tend to churn the upper sediment layers (Plate 28b).

The biogenic activities of the species of *Ocypoda* crabs is rather interesting. For their nutrition, these crabs extract the lime and mud from the calcareous sands, put it into their mouth munch in the nutrients and expel the ball like pellets. The greates number of such pellets can be located at the foreshore and the backshore regions along the beaches. These activities gather momentum especially during the receding tides. There are two different types of pellet forming activities by the decapods as observed by the author in the field. In the first place the grazing activities marked on the sediment surfaces are not restricted adjacent to their shafts but follow an irregular

PLATE : 28

(a) Tracks made by birds in search of food. Trails by creepers are visible along side tracks.



(b) Crustacean pellets in the process of being transported by the receding tidal currents, in the foreshore zone.

patterns of distribution along their moving tracks. Here, the pellets are usually large and may be attributed to the adults. In the second case, the dense pellets are restricted very near or around the shaft burrow. The size of the pellets in such cases is comparatively very small and the work involves smaller forms. As further observed that the grazing activity of the decapods accelerates during the receding tide period when the Ocypod organism comes out on to the surface from its dwelling holes and scratch or excavate the wet sediments of beach. Such excavated material is spread around and form a mosaic of structures and trackways. Most of the pellets so generated are spheroidal but occasionally they can be ellipsoidal. The pellets are friable and rarely attain diameter upto 8.0 mm.

The young Ocypod also are found engaged in excavating activities and pellet formation during the receeding tide intervals. Their dense small scale pellets very often form beautifly radially arranged structures on the sediment surface (Plate 26c). As mentioned earlier, the freqency of both types of Ocypoda pellets systematically decreases towards the backshore and the beach berm regions.

Burrows of the shrimp Calliansass major are the other varieties of arthropods that are abundant and most characteristic of foreshore environments at the Nagoa and Vanakbara beaches. They are, however found only in the clean sands, representing high-energy environments. Their burrows have a thick lining to their walls and are knobby in their exterior characters. Portion of their burrows occasionally is found rising above the sediment water interface. The openings are relatively narrow and rarely exceed 2-3 mm in diameter. Such burrows are found to extend vertically downward about 10-15 cm in the sediments and then spread laterally and became branched. In many instances such burrow stuctures form a complex interconnecting maze of side boxworks with numerous openings to the surface.

Bivalves : Many species of bivalves are found dead on the foreshore and backshore surfaces of the beaches, but relatively no live specimen were recovered. Individual lebesspuren are therefore not very distinctive. Some V-shaped, downward bending and truncations of laminae located on the foreshore beach sediments in Diu, following Frey and Howard (1969, pl 3, Fig. 6), can be attributed to the bivalve activities in general.

Gastropod Trails : Gastropod are the most abundant epifauna visible on the beachshore and the tidal flat environments. The gastropods are generally active animals, that move widely across the surfaces and are responsible for most of the different types of trail viewed on the foreshore and tidal marsh regions in Diu. The surfacial sediments of these zones are characterized by fine sand particles. Immediately after the receeding tide these sediments contain about 70% to 90% water, which behave temporarely thixotopically. Gastropods move on these surfaces and their behavioural activities are easily left in the from of impressions as trails. Such trails are common because the lower fleshy parts of the gastropod animals come in constant contact with the soft substrate below. The animals therefore produce different types of trails, reflecting different modes of their feeding and grazing activities arised by the organisms. In most cases the trails left on the beach sediments indicate natural consequences of their endless search for food. Two different modes of gastropod trails are noticed by the author (a) the crawling trails and (b) the feeding trails.

(a) Crawling Trails : (Plate 29a) The crawling trails are represented by a large number of varieties. The trail morphologies are characterized by simple, unbranched, straight to gently curved, winding, looping and meandering forms, very often consisting of two marginal ridges. Such ridge often display prominant bilobate or trilobate markings and transverse structures over them (Plate 29a). Trails with delicate U-shaped transverse ridges are very common on the foreshore and the tidal flat zones of Diu. Flat ribbon like trails are also very common (Plate 29a). Dimensions of the trails greatly vary from one plan to another and may represent different size individuals. Maximum observed length of upto 2.5 meter and width of upto 4.0 centimeter are found to occur in Diu.

In the fossil record of such surface trails in the form of irregular meanders and represented by concave epirelief are assigned to the trace fossil group called Scolicia (De Quatretages 1849).

(b) Feeding Trails : (Plate 29b) Feeding trails although less abundant as compared to crawling traces in Diu are sometime very prominant features. Such trails, when present are long, smooth, unbranched, horizontal,irregularly curving and bedding, typically

PLATE:29

(a) (i) Flat-ribbon shaped gastropod crawling trail with prominant V-shaped bilobate markings, (ii) burrowing gastropod and their mounds.

(b) (i) Crawling, and feeding trails of gastropod.

(ii) Backfilled structures are seen in middle and upper most portion.

(iii)Gastropod in the act of burrowing

alternating, winding or are attaining straight course. Most of these excursions leave backfill structures and characteristically reveal the feeding and the sediment ingestation of the animal. Dimensions of these biogenic structures vary in both length as well as width indicating different individuals. Maximum observed length of the trail was 100 centimeter and width was of 3.0 milimeter.

Polychaete Worms : Many polychaete worms are found to build dwelling small scale burrow tubes in beach foreshore and tidal marsh zones. Commonly such tubes are found developed in the high energy environments where sand proportions are more and where a quick exchange of nutrient is possible. Polychaete Nereis, Diapatra and Onuphis are thought to be the polychaetes as to be the originators of these structures. Most of the burrow forms are vertical or cylindrical tubes that extend for considerable length into the substrates.

The tubes are good analogues to the biogenic structure Skolithos (Haldemann, 1840).

(iii) Cryptobioturbated zones : Most of the above described biogenic sedimentary structures are represented in the cryptobiturbated zones of the foreshore and the tidal flat/marsh regions in Diu. They, however, are characterized by their greater or most intense densities of individual trace marking organisms on these zones.

In addition to the forms already described in detail, this zone has some significant biogenic structures formed through the activities of vertebrates. These include the larger and small feeding holes excavated by the bottom dwelling fishes Such fishes further have at places reworked a large amount of sediments and even disrupted or truncated the sedimentary beddings.

SEDIMENTATION MODEL

20.1 GENERAL CONSIDERATION

In the preceeding columns, the coastal zones in the Island of Diu are identified on the basis of their complex combinations of variables. It is in fact these variables that have created the unique morphological and environmental character of this Island as a whole. It will now be appropriate to take a stock of some such variables before attempting to draw the sedimentological model for the Island of Diu.

(1) The coastal sediments across the Island of Diu, consists primarily of shelf derived carbonate sands, which commonly make up more than 90 percent of the beach and dune material.

(2) All these sands regardless of their composition are predominantly well to very well sorted and are medium to fine grained in character.

(3) Such sands are being delivered to the coast since the post-glacial marine transgression (Pleistocene time). Consequently, most coastal sediments consists of reworked deposits of many generations.

(4) The southern coast of Diu appears semicircular in its larger context within the Saurashtra peninsula (Fig.24), but actually displays a crescentic to semicrescentic configuration when considered individually with respect to its Island zone alone.

(5) The land bound area of Diu with its coastal relief rarely exceeds 20 meter in height.

(6) Such land configurations in Diu are related more to the local geological structures, particularly a series of stabilized dunes, which are superimposed upon each other.

(7) This dune pattern appears to have developed at a time of lower sea level to produce the cuesta topography described earlier.

(8) The position of the present day shoreline is the result of the subsequent submergence that took place after the retreat of the Pleistocene glaciation, and transgression of the sea.

(9) On the southern coast which face the prevalent winds from the southwest direction, the shore zone is eroded relatively more by the wave action and the erosional products are deposited

offshore by retreating currents moving seaward, while in the shallow offshore sea floor adjacent to these coasts, fine and medium grained sands are affected by the landward bottom currents and sand is being transported into the littoral zone by the tidal and wave induced currents. This sand in turn is shifted by the winds to form the Recent sand dunes.

(10) The rocky southern coast in contrast to its inland part is usually barren of vegetation because of severe abrasion by the wind and friable nature of the miliotic rocks.

(11) This non-resistant cliffed coast have a configuration controlled by their relief and lithology. Beaches are usually absent or narrow, and composed of coarse material drained from reworked local deposits.

To summarize, the physiograhy of the Island can best be explained in terms of its geological and geomorphological history.

20.2 THE MODEL

It is now possible to integrate the various processes, and their relative magnitudes, into a process response model for the development of the Island of Diu. This model has been evolved from the interpretation of the individual physiographic divisions presented earlier. The main concepts include tidal currents, wave and wind processes that were the main agents influencing the geomorphologic set up of the Island during the past and the present. Most of these processes are thought to have operated individually or simultaneously under fair weather conditions.

This concept involves three prime modes of coastal sand accumulation occuring at different times.

(1) Accretion of successive low beach ridges parallel or subparallel to each other due to shore normal wave induced sand transport and eolian accumulation in the beach shore.

(2) Accumulation of eolian sand into a foredune ridge behind a relatively steep beach and nearshore zone.

(3) Wave and wind erosion of the beach and foredune resulting in complete or partial removal of vegetation and the inland transport of sand as transgressive sand sheets or blowouts.

These three modes of accumulation are likely to have developed under quite distinct environmental conditions. Such conditions occurring around Diu during the Pleistocene-Holocene, and recent time can now be visualised as below :

I. <u>Middle to Late Pleistocene Falling Sea-Level Stage</u> : Around 30,000 years BP (as suggested by Agrawal et al 1978).

This event coincide with the sudden and relatively rapid growth in subaerial deposition soon after the termination of the middle pleistocene marine transgression. In Diu such an event promoted the landward sediment transport to be modified as parallel or subparallel low-beach ridges normal to the shore (fig.24). Such an analogus phenomena is explained by Schofield (1975). According to him a rise in sea level promotes coastal erosion and sea level fall promotes both large scale progradation when it falls. Thus, the erosion in the past around Diu, must have reduced or provided a temporary halt or break in shoreline activities of dune formation (i.e. during the periods of sea level rise). This implies that the sand moved landward to form the "dune belts" in Diu during the lower sea-level periods. The dominant morphological tendency during such a stage would be an onshore sediment motion resulting in sediment transfer from subaqueous environments to beach and foredune zones. This further implies that abundant carbonate sands were present in the near shore zone when wave conditions favoured their onshore transport.

II. Late Pleistocene Early Holocene Rising Sea-Level Stage

On the global scale this period should correspond with the late glacial marine transgression which commenced about 17000 years before the present until 6000 year B.P. when still stand stage was reached. During this time the present Island of Diu was probably a coast of high precipitation. This should have promoted the effective stabilization of the parallel to subparallel coastal ridges or dunes. The termination of the transgression, however must have left the nearshore gradient rather flatter.

III. Middle Holocene and Late Holocene Still Stand Stage

Global still stand stages during mid-Holocene and Late-Holocene are known to have occurred during the last 6,000 year. Such stages will when compared with the stages recommended by schofield (1975) would involve modifications in the barrier dune complexes. The modifications involving eolian reworking rather than seaward growth, sediment motion resulting in sediment transfer from the subaqueous environments to beach and foredune zones. This implies that the wave climate was attempting to attain an equillibrium with respect to its shoreward gradient. This was the stage when the non-resistant cliffed coast of Diu possible reached it semicrescentic configuration. This was also the stage during which the southern dune terraces or cliffs in Diu were rapidly eroded, and, were characterized by their wave cut platforms and narrow pocket beaches as seen at present. The coast in fact acquired a variety of trends related to erosion that acted along the lithological weaknesses.

It may be finally be concluded that, although the eolian accumulation periods in Diu are poorly documented in terms of their absolute ages, the model presented by the author on the available data on morphology, stratigraphy and chronology is quite consistant to provide a working hypothesis towards the evolution and development of the Island of Diu during the past and the present. It could be the first step in general to provide the basis for the future geological studies to provide detail information on the Island of Diu.

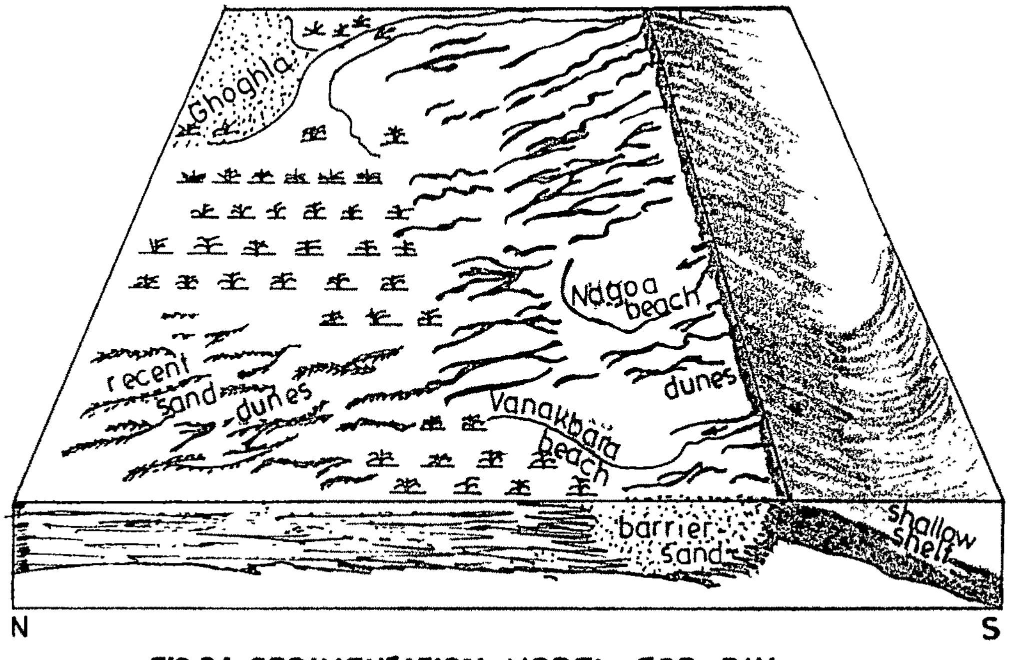


FIG 24 SEDIMENTATION MODEL FOR DIU