PART - IV

BET SHANKHODHAR ISLAND

Plate : 30 PANORAMIC VIEW OF CLIFF SECTION - SW OF BET SHANKHODHAR ISLAND. POCKET BEACH DEVELOPED AT THE BOTTOM.

BET SHANKHODHAR (BET DWARKA) ISLAND

Bet Shankhodhar alternately known as Bet Dwarka is a small narrow Island zone located about 2 km east of the Okha port in the Gulf of Kutch (Fig.1). The Island has a maximum length of around 13 km and width of about 3 km. It shows a northeast - southwest orientation in general and makes a characteristic topographic feature at the mouth of the Gulf of Kutch. Recently, the Island has assumed much importance because of the marine archaeological finds and as the drowned city of Lord Krishna.

The Island as a whole, is characterized by high cliffs (18 to 20 meter in height, especially on its western and southwestern side), with late Pleistocene hetrolithic strata, and presence of unimodal and bimodal cross-strata, their associated reactivation surfaces, clay drapes, score and truncation surfaces, interference and flat topped ripple laminations, desciccation and mud crack surfaces, variability of sediments and associated biogenic structures. All these features characteristically indicate low-tidal, mid-tidal and high-tidal mud flat environments prevailing during the evolution of the Island. In fact an idealized palaeotidal range fining upward sedimentary sequence comparable to the model of Klein (1971,1972) can be observed in the lithological sequence of Bet Shankhodhar. The Island lithology therefore offers a unique opportunity to study the tidal depositional sequence of the past and the present.

BACK GROUND INFORMATION

21.1 BET SHANKHODHAR-HISTORICAL IMPORTANCE

The Island is famous for its temples and shrines dedicated to Lord Krishna, chief of which is in fort Kalakot. It's name as Bet Shankhodhar is for its general shape which resembles a conch shell. Such shells are found extensively in the nearshore zones around the Island. The name is also probably after the victory of Lord Vishnu over the Demon Shankhasur in the Matsyavatar. Raman-Dwip is its another name. Early Europeans called it 'Sanjana' from a notorious pirate of the same name. Bet Shankhodhar is a well-known place for the Hindu pilgrimage, especially for those visiting the nearby Dwarka temple in Saurashtra. The old temple of Shankhnarayan was, according to a legend, built in the Satya-Yug, in celebration of the defeat of Shankhasur. The new temple of Shankhnarayan was built about 180 years ago by the Rao of Kutch. Its architecture is claimed to be similar to that of the old, which in turn resembles the temple of Dwarka though it is much smaller in size. The other six temples around the main temple were built in side the fort wall shortly after the Muslim invasion in 1460, but were destroyed during the assault by the British forces under Col.Donovan in 1858-59. Khanderao Gaekwad renovated all these temples in the same year. A fair held on Janmashtami day every year is attended by more than one lac people from surrounding villages and other parts of the country. It is estimated that an average about five lac pilgrims visit this place every year.

Recently Marine Archaeological Division of the National Institute of oceanography, Goa have covered a number of archaeological finds from the seabed of this Island. Their finds include Harappan artifacts, stone anchores, pottery etc. On the basis of these evidences and the fortification wall they have confirmed to be existing beneath the sea, the scientists of the N.I.O. propose and support the drawing of the Bet Dwarka (Shankhodhar) during the Mahabharat time.

21.2 **LOCATION :**

The Bet Shankhodhar (Bet Dwarka) is situated at the mouth of the Gulf of Kutch nearly 2 km east off Okha port and lies between 22° 25 to 22° 30 north latitudes and 69° 5' to 69° 10' east longitudes forming the part of the Survey of India Toposheet No. 41 F/3 (Fig.1).

21.3 ACCESSIBILITY :

Bet Shankhodhar is a minor port situated off the Okha harbour. It can be approached by sea by fairy boats only. Okha is the taluka headquarter in Jamnagar District and is approached by an all weather metalled road from Ahmedabad. It lies on the Western Railway meter gauge line. No National Highway passes through the area, but State Highways connecting major towns in Gujarat have a bus connection with Okha for its fishery products. Okha is also a main port on the west coast handling large volume of trade and coastal passenger services.

At Bet Shankhodhar there is a R.C.C. Jetty called passenger jetty for embarkation and disembarkation of passengers. Here sufficient water is available at high and low tides. The Bet Dwarka port has no trade worth mentioning but has the importance of being a scared place for Hindus. A number of pilgrims visits the place every year and a number of vessels ply between Bet Island and Okha port in sheltered waters for the transport of such pilgrims.

21.4 PHYSIOGRAPHY :

The Island of Bet Shankhodhar is an irregular landmass with two prominent physiographic divisions closely related to and controlled by the lithology and structure of the geological formations. The north and northeast part of the Island is characterized by the development of present sand ridges, and flat top rocky intertidal platforms (near Hanuman Point) (Fig.28). The part of the Island northeast to southwest measuring 8 km is a narrow and crooked piece of land mostly made up of Pliocene to Pleistocene deposits. Its southwest half is a rocky table land 5 to 7 meter high and covered with reserved forest. The southern coastline of the Island is irregular with deeply cut bays and rocky cliffs. The irregularity of the shoreline is probably due to the differences in competency of the rocks.

21.5 **CLIMATE :**

The climate of the Island is equable throughout the year. The month of January is usually the coldest month of the year with the mean daily maximum temperature around 26°C (78.8°F) and mean minimum temperature at 11.6°C (52.8°F). Temperature rises steadily from about begining of March till May which is usually the hottest month with the mean daily maximum temperature around 36.3°C (97.4°F). With the onset of Monsoon by about the middle of June, temperatures decrease and the entire Monsoon season becomes pleasant. The average annual rainfall during the Monsoon season is 412.2 ml, July being the month with the highest rainfall. After the withdrawal of Monsoon by about the middle of September, temperature rises a little and a secondary maximum is reached in October. Both day and night temperatures begin to drop by November.

21.6 FLORA AND FAUNA :

The potentiality of water in the Island as a whole is very low and chronic water shortages very often take place. Farming is therefore limited to some cereals like jower (Sorghum vulgaree), wheat (Triticus oostivum), bajra etc. at only a few small patches over the Island.

In the coastal zones species of the mangrove occur all along the coast. Among the species, Cher (Avicennia officinalis) are the predominant. The Inland areas on the north and south are occupied by the reserved forest of Acacia arabica (Desi Baval), Acacia senegal (Gorad), Butea frondosa (Khakhra), and thorny scrubs.

The area being arid and having limitation of water supply in free state, the existance of wild animals is also very limited. Some animals like fox, wild cats, etc. are rarely observed in the southeastern forest regions.

21.7 STUDY AND WORK PLAN :

The lithology of Bet Shankhodhar which exhibits an ideal palaeotidal range shallowing upward sedimentary depositional sequence has not been fully investigated earlier. It thus provides an opportunity to study in detail the tidally influenced sedimentary structures typically developed in the rocks exposed around the Island zone and work out their palaeotidal ranges.

Such studies may further provide a measure to compare the tidal ranges of the past with those of the present. The tidally influenced physical sedimentary structures are further associated with some important biosedimentary structures. Detail studies based on the same is likely to provide first hand information on the relative rates of sedimentation, animal- substrate relationship, hydrodynamics of the environment of deposition and occurrence of some rare events like storms during the past. It will further be interesting to study the lateral and vertical facies changes in the sedimentary sequences of these Island zones. It is, therefore proposed to study in detail the following :

(a) Older rock sequences exposed around the cliffs.

(b) Establish their relative chronology in general.

(c) Trace their vertical and lateral facies.

(d) Study in detail the sedimentary and biogenic structures developed in the various facies.

(e) Studies pertaining to petrography of sediments, heavy minerals, textural analysis and microfossils.

(f) Confirm the palaeotidal ranges.

(g) Present a sedimentation model based on all the above information.

The field methodology will involve complete mapping of the Island; preparing stratigraphic sections; field photography of important sedimentary and biogenic structures, and collections of relevant specimens for laboratory studies.

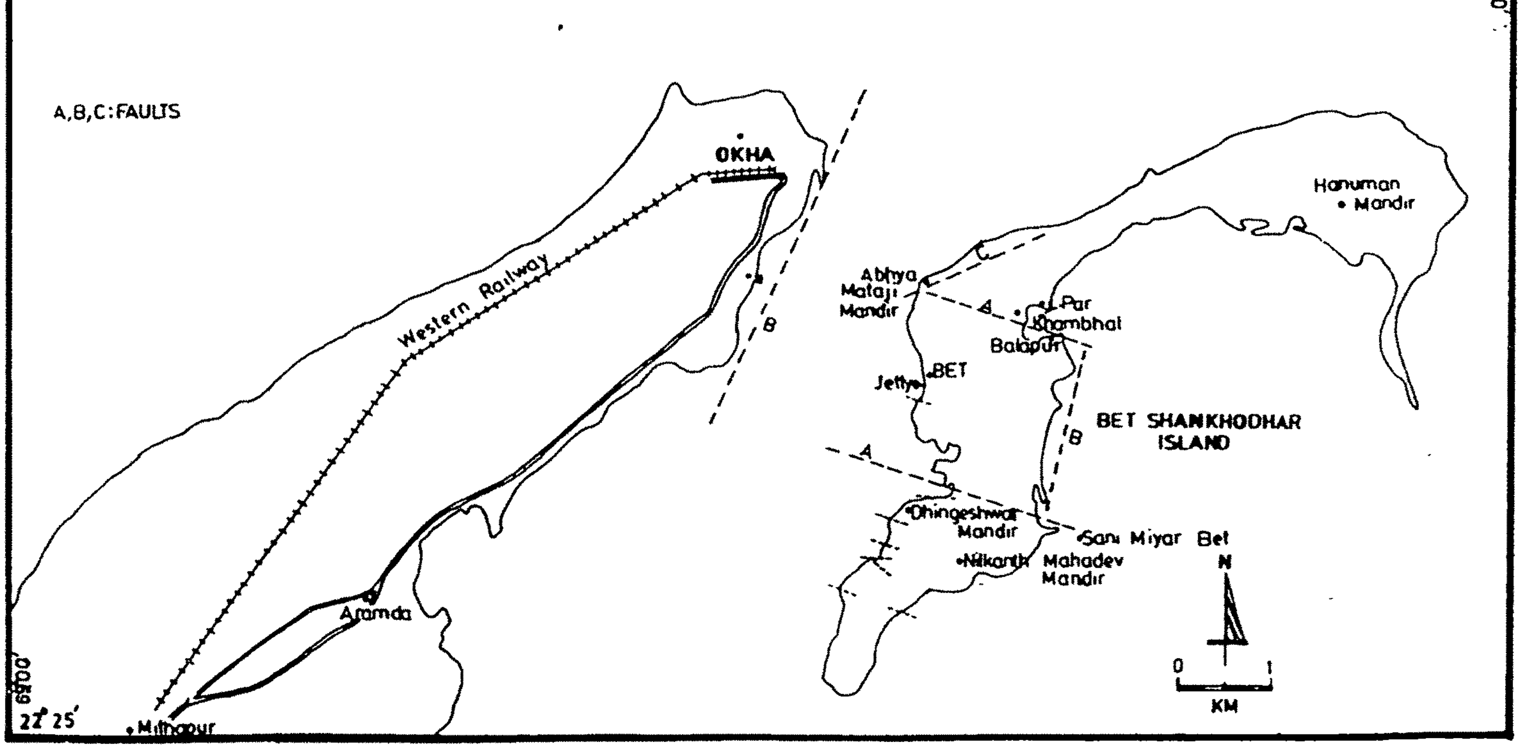
PREVIOUS WORK

The author is once again handicapped for the reason that no previous work of real insight has been known to have carried out for the Island of Bet Shankhodhar. There is, therefore a compelete lack or absence of previous work and literature pertaining to the geology and stratigraphy of the Island. Some remarks on the possible stratigraphy of the Island are however being made by a few workers viz. Krishnan (1968), Srivastawa and John (1977), and Lyall and V. Reddy (1982). According to most of these workers the Bet Stratigraphy is characterized by the Dwarka Formation of the Pliocene-Pleistocene age in general, in which case as suggested by most of the above workers, the Dwarka beds then disconformably overlie the Gaj beds of Miocene age. Lyall and V.Reddy (1982) who have studied in detail the Quaternary sediments in the Gulf of Kutch and have based their studies on the observations on the sea bed topography, have suggested, two prominant fault zone extending over the Island (Fig. 25). These are named as the Padmatirth (WNW-ESE) fault, and the Sani Miyar (ENE-WSW) fault respectively.

STRATIGRAPHY AND SEDIMENTARY FACIES (OLDER UNITS)

The Bet Shankhodhar stratigraphical sequence consist of tidally affected shoreline deposits with individual lithological units ranging from 0.75 to 2.5 meter in thickness. Most of these units are characterized by the presence of centimeter to millimeter scale laminations. The total thickness of the deposits as a whole seldom exceeds 18 to 20 meter in vertical extent. The sedimentary sequence is further marked by alternations of medium to fine grained sandstones, shales and varigated claystone layers, resting on a flat pebble conglomerate bed at the base and overlain at their top by a fossiliferous gritty sandstone bed. The beds are almost horizontal or show gentle dips upto 2 in the south, but assume slightly greater dips 2 to 5 in northeasterly part of the Island. These stratigraphic units are further affected by two major and several minor faults of various magnitudes (Fig. 25), which often impart difficulties in determining the succession of the strata in the field.

FIGURE. 25 FAULT PATTERNS IN BET SHANKHODHAR AND BET OKHA FOR COMPARISION



Important lithostratigraphic sections, however can be investigated along the cliff sections which are very well observed west of Dhingeshwar Mandir, southwest of Nilkanth Mahadev Mandir, near Sani Miyar Bet, north of village Par and Khambhal and south of Abhya Mataji Mandir (Fig.26).

Individually, most of the sedimentary units vary in their facies types, and sedimentary and biogenic sedimentary structures. Based on the lithology, sediment textures, biogenic and physical sedimentary structures eleven sedimentary facies have been defined by the author. The lateral and vertical facies variations are very common in most of these facies. At some places such changes have been marked by abrupt lithological transitions and intertonging or gradational relationships of different overlying and underlying facies. All these lithofacies contain elements that reflect by their character and organization, related events and sedimentation processes of the past.

The principal characteristics, stratigraphic positions and the inferred processes of deposition of all these facies are tabulated in the following Table no. 17.

The sedimentary characteristics and inferred processes of deposition are further discussed in detail in the text to follow. Emphasis is placed by the author on the identification, description and interpretation of the various facies types, in

FIG. 26 GEOLOGICAL MAP OF BET SANKHODHAR ISLAND INCLUDING STRATIGRAPHIC SECTIONS OF DIFFERENT LOCALITIES

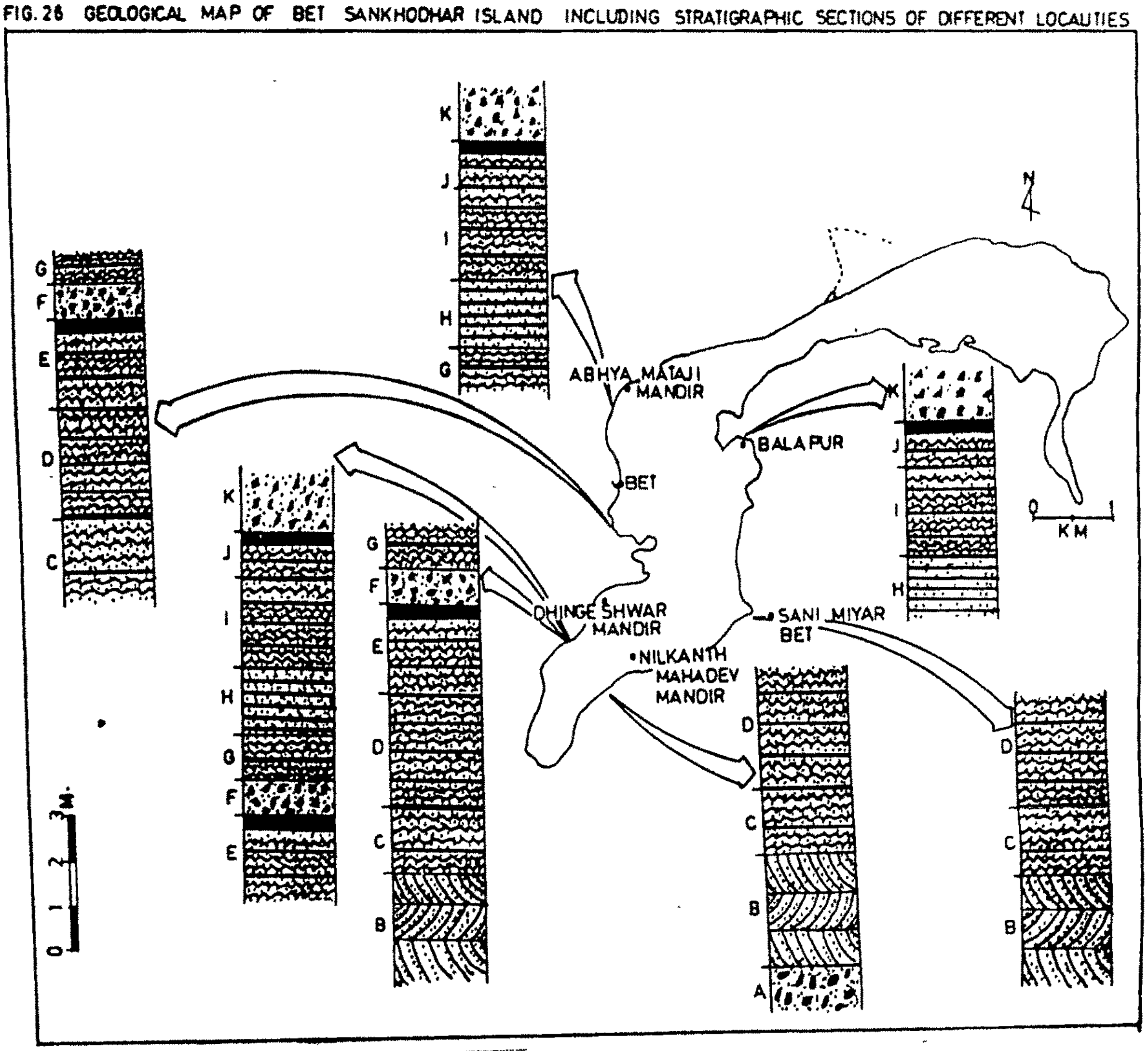


Table : 17 Distribution of lithofacies in Bet Shankhodhar with characteristics of their physical and biogenic sedimentary structures

	Lithofacies	Thickness in meter	Sedimentary structure Physical	Biogenic
K	Gritty sandstone	1-1.5	Large scale - trough - cross stratification	--
J	Laminated sandstone shale-claystone alterations	1.0	Low angle planar and through cross-laminations	--
I		2.0	Low angle planar and trough cross-laminations	--
H	Sandstone-mudstone rhythmites	1.5	Alternate thin laminations (rhythmites of sandstone and mudstone)	--
G	Laminated sandstone shale-claystone alterations	1.0	Linguid ripples	Ophiomorpha Zoophycos Scolicia
F	Round pebble conglomerate	0.75	Lenses of conglomerate with cross-bedding	Ophiomorpha
E	Laminated sandstone-shale claystone alterations	2.0	Low angle cross beddings, reactivation surfaces, flat topped ripples, rip-up-clast	Ophiomorpha Cylindricum Skolithos Palaeophycus
D		2.75	Mud cracks, ripple marks, wavy bedding, rip-up clasts clay drapes	Ophiomorpha (rafted organics)
C		1.5	Low angle thin laminations	Thalassinoides, Rosselia, Palaeophycus Planolites, Conichnus, Skolithos, Berguaeria
B	Cross-stratified calcareous sandstone	2.5	Low angle planar and trough cross-beddings herringbone cross-stratification flaser wavy, lenticular beddings	Thalassinoides, box-work, Rosselia, conichnus, Bargaueria planolites, skolithos
A	Flat pebble conglomerate	1-1.5	Bimodal cross-beddings in in the upper part of the bed, Reactivation surfaces.	Ophiomorpha box work burrows

relation to their hydrodynamic conditions and the formation of the sediementary and biogenic structures. This process sedimentologic approach is used mainly with the purpose to unravel the history of the sedimentation in the area in general and to work out a depositional model of the Bet Shankhodhar Island in terms of its palaeotidal range sequence.

23.1 FACIES : A - FLAT PEBBLE CONGLOMERATE

Stratigraphically, this is the lowest facies observed in Bet Shankhodhar Island. Good exposures of the unit can be very well located along the south and southwest cliff sections of the Island zone, especially around the Nilkanth Mahadev Mandir. Here the facies is about 1.5 meter thick and little more than 60 meter across. The conglomerate is composed of locally derived pebble of sandstone and clays (2 to 3 cm. in diameter) with clay pebbles dominating over the sandstone pebbles.

The conglomerate is matrix supported, the matrix consisting of coarse to fine grained (silt and clay sized) particles of calcareous and ferrugineous sands. Under the microscope the matrix is a fine to medium grained quartz, magnetite and mica, cemented in the calcareous and ferrugineous cement. The textural parameters of the conglomeratic material are equally significant and indicate suspension component of 9%, saltation components 47% and, surface creep components of 44%.

The clay pebble clasts are usually rounded to subrounded are disc shaped or flattened. The conglomerate, although generally horizontal at its base level becomes cross-bedded at its upper horizons (Plate 31a,b). Here, the cross-bedding structures display bimodal dispersion patterns in their development indicating alteration of currents. In many instances such cross-bedding structures are found crossed over by the burrow tubes of "Ophiomorpha" (Plate 32a). Such Ophiomorpha burrows have developed horizontally as well as vertically, pierceing through the cross-bedded laminae at various angles and even marking larg-scale box work burrow systems at their bottom (Plate 32a,b). The burrow systems appear to be keeping pace with the sedimentation phases of the cross-bedded strata, as very often the burrows that are found abruptly terminating at or near the angular cross-beds have been relocated as being reestablished themselves after the fresh reactivation phase (Plate 32a). It is further observed that the flat pebble conglomerate facies interdigitates with the overlying calcareous cross-bedded sandstone (facies - B) near the southwest cliff section (near Jetty), where as near Nilkanth Mahadev Mandir it shows an abrupt contact with the cross-bedded sandstone facies (Plate 33b). At this location, the surfaces of many of the pebbles associated with the conglomerates are seen bored by Pholad - like bivalves (Plates 34).

Interpretation : In all possibilities the flat pebble conglomerate facies in Bet Shankhodhar Island typifies the intra-formational conglomerates defined by Pettijohn (1984, p. 183).

PLATE : 31

(a) Flat pebble conglomerate showing (i) cross beddings, and (ii) vertical and horizontal Ophiomorpha burrows.

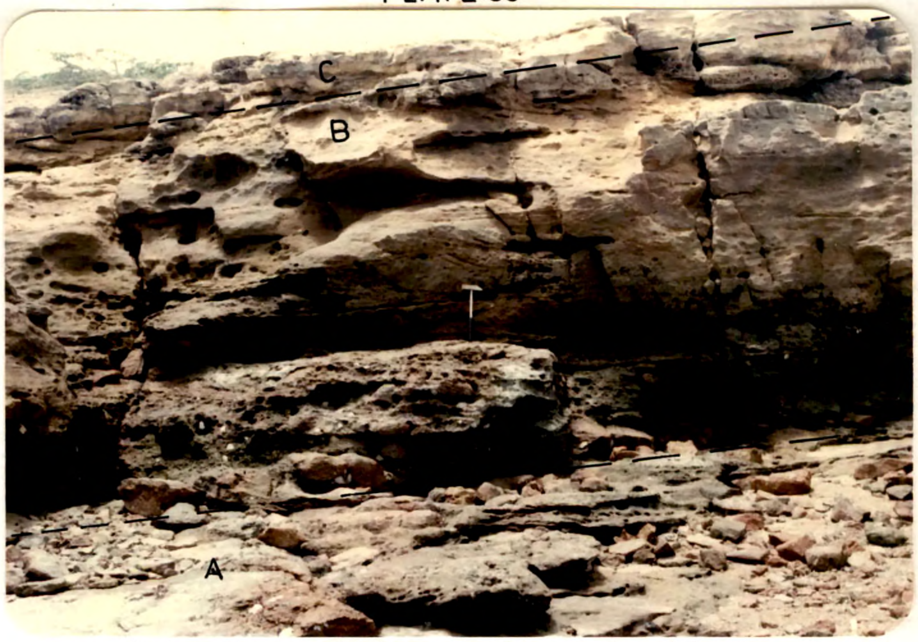
(b) Horizontally bedded flat pebble conglomerate (Loc : cliff section S of Nilkanth Mahadev Mandir).

PLATE : 32

(a) Ophiomorpha burrows piercing through cross-bedded laminae in facies A. Growth of burrows indicates fast rate of deposition.

(b) Development of large-scale box work Ophiomorpha burrows in facies A. Indicating variable rate of deposition - no erosion. (Loc : S. of Nilkanth Mahadev Mandir).

PLATE:33



(a) Flat pebble conglomerate (facies - A) showing gradual merging with cross-bedded calcareous sandstone (facies-B). Indication slow rate of deposition.

(b) Contact between facies A and facies B. Net work of <u>Thalassinoides</u> burrows underlying (facies - B) (Loc : cliff section SW of Nilkanth Mahadev Mandir)

PLATE : 34

Pholad bivalve borings in flat pebbles (facies - A).

According to Pettijohn (1984), the intraformational conglomerates are the deposits formed by penecontemporaneous fragmentation and redeposition of the stratum in question. Such fragmentation and redeposition according to him are but a minor interlude in the deposition of the formation and such a deposition in same cases as suggested by him may be wholly subaqueous. As further claimed by Pettijohn (1984) the debris contributing to the conglomeratic material are always of very local origin, and undergone very little or practically no transportation, and are thus only slightly worn.

As discussed earlier by the author the basal conglomerates observed in the Bet Shankhodhar Island are characterized by their flat pebble forms that are matrix supported, and have restricted composition of their intraclasts. Following Pettijohn (1984) it could now be emphasized that the accumulation of the basal conglomerates in Bet Shankhodhar may be attributed to their intitial sedimentary response of transgression. The abruptness in their lateral distribution possibly is related to their being accumulated in small patches or lenses. The coarse and fine detritus associated with these was perhaps derived locally by mass wasting and erosion of the older rocks and reflect wave alternation and is consistent with the observations of Komar (1976). The textural parameters worked out by the author further support such a deposition, involving greater amount of surface creep and saltation components.

23.2 FACIES : B - CROSS-STRATIFIED CALCAREOUS SANDSTONE

These are slightly purplish to grey coloured sandstone units interdigitating or abruptly resting over the basal flat pebble conglomerates. The sandstones are often variable in their thickness with maximum observed thickness of about 2.5 meter exposed along the cliff section southwest of the Dhingeshwar Mandir and South of Nilkanth Mahadev Mandir respectively (Plate 33a).

Texturally and compositionally the facies is a medium to fine-grained, moderately sorted sand and silt with more than 20% of calcareous components. The sand fraction ranges from 0.5 TO 0.1 mm.

The facies includes some spectacular sedimentary structures. The most common being the low angle planner and trough cross-bedding structures. The most distinctive sedimentological features observed in this facies, however, are the interbeddings of cross-bedding sandstone units forming the herringbone cross-stratifications, the flaser, wavy and lenticular beddings. The facies is almost devoid of animal traces except near its contact with the overlying facies. Here the facies is dominated by large scale vertical and horizontal burrows of Thalassinoides and their box-work networks (Plate 33b). Such profused net works of Thalassinoides burrows at their overlying contacts with the sandstone shale - clay intercalated facies (Facies - C) once again show abrupt termination in the burrow growth. The other trace fossil involved at this contact zone include large varities of *Rosselia*, *Conichnus*, and *Bergaueria* burrows. In addition there are small and large-scale varities of *Planolites*, and *Skolithos* burrow tubes.

Interpretation :

The diversity of sedimentary and biogenic sedimentary structures within this facies implies non-uniform mixture of environments dominated by current and wave processes. In order to understand the interplay of such wave and current processes responsible in the formulation of the cross-bedded calcareous sandstone facies in Bet Shankhodhar, it will be imperative on the part of the author to discuss in detail the likely ways in which such processes must have acitvely worked in the past. These details are attempted in the following paragraphs.

(i) Low-anlge cross-laminations :

There are almost 8 to 10 alternations of parallel-laminated sands merging up into texturally related cosets of cross-lamination in the southwest cliff section of Dhingeshwar Mandir (Plate 33a). According to Pettijohn (1984, p. 109) such a cross-bedding and the sand wave responsible to produce it in subaqueous environment is related to the water depth. Allen's (1963, p. 198) compilation of sand wave height and water depth further shows a linear increase in height with depth. This relationship enables the author to compare his observations in Bet Shankhodhar and estimate the likely water depth from the cross-bedded scale proposed by Allen (1963). The water depth thus estimated is around 2.5-3.0 meter .

(ii) <u>Herringbone Structures</u> :

As mentioned earlier herringbone structures are a common phenomena with the cross-bedded sandstone facies in Bet Shankhodhar. Such structures are known to be excellent markers of the process response phenomena. As explained by Davis (1983, p. 337) the rise and fall of tides on diurnal or semidiurnal basis are the prime cause for the formation of these structures. The rise commonly creats a great deal of sediment movement due to flooding and ebbing currents created by the passage of successive tidal waves. These tidal currents are generally moving in opposite direction and the bed forms generated by their bed load transport and their contained cross-stratification that reflects such conditions often result in being the typical herringbone pattern (Plate 35). The implications according to Davis (1983) are that the flooding tides move up the gentle slope of the tidal flat and that during ebb conditions the opposite motion takes place. Such a phenomena is very well represented in the cross-bedded sandstone facies. Furthermore, as seen from the photograph (Plate 35) much of the flood and ebb cycles in Bet Shankhodhar appears to have carried the bed load transport dominantly of sand-size particles only and therefore mud was always kept in suspension and the sand deposition was therefore dominating in the earlier phases (mud parts being almost absent).

PLATE : 35

Herringbone structures in facies B.

This phase, however appears to be gradually or abruptly changing as illustrated in plates 36a,b, where the mud suspension have taken over the sand domination and comparatively lower-energy situation enhanced the formation of various types of biosedimentary structures.

(iii) <u>Flaser, Wavy and Lenticular Bedding Structures</u> : (Fig.27)

The middle part of the cross-bedded sandstone facies is characterized by many wave generated structures. The main cause for the formation of such analogous structures has been stated by Davis (1983, p. 78). According to him oscillatory flow produced by waves interact with the sediment substrate to produce a variety of bed forms including the flaser and the lenticular bedding structures. As further explained by him, when such cross-ripple beddings contain thin streak of mud in ripple trough the resulting bedding type is called flaser bedding (Fig.27a).

In Bet Shankhodhar such wave generated structures are commonly observed in the section exposed south of the Jetty cliff. Here it is often found grading into a sequence of mud with discontinuous cross-stratifications of sand lenses. The ripple sand at this place somewhat resembles the features known as boundings; some are connected to each other while some are not (Plate 36b). In fact, at this locality typical styles from flaser bedding through lenticular varities can be distinguished (Plate 36a,b, Figure 27). Such a spectrum of bedding types according to Reineck, (1960), depends on two primary conditions;

availability of both sand and mud and alternation of relatively high and quiescent conditions. Flaser bedding in the cross-bedded calcareous sandstone facies therefore, could have developed when the low-energy conditions filled ripple generation and suspended mud accumulated as thin veneer over the ripple and along the troughs (Plate 36a). As it could be further confirmed, (same plate) with the advent of high-energy conditions and ripple generation the mud from the ripple crests was perhaps removed resulting in thin, discontinuous mud streaks in the rippled sequence. It also becomes apparent that as the availability of the mud increased in the system there reached a point when the mud got incorporated in continuous fashion in the rippled sequence characterized by undulating thin mud layers between rippled sands forming what is known as the "wavy beddings". This undulating character further appears to have diminished with the increase in mud proportion at the top of the sequence (Plate 36b).

It may, thus be concluded that the sedimentary structures and textures in the cross-bedded calcareous sandstone facies in general imply deposition of the facies from a combination of wave and current processes. The interbedding of cross-bedded units with a wide-varitey of sedimentary structures including the wavy, (Fig.27b) lenticular (Fig.27c), flaser and herringbone type imply an alteration of traction and suspension deposition from current of variable but relatively great velocity or capacity of flow.

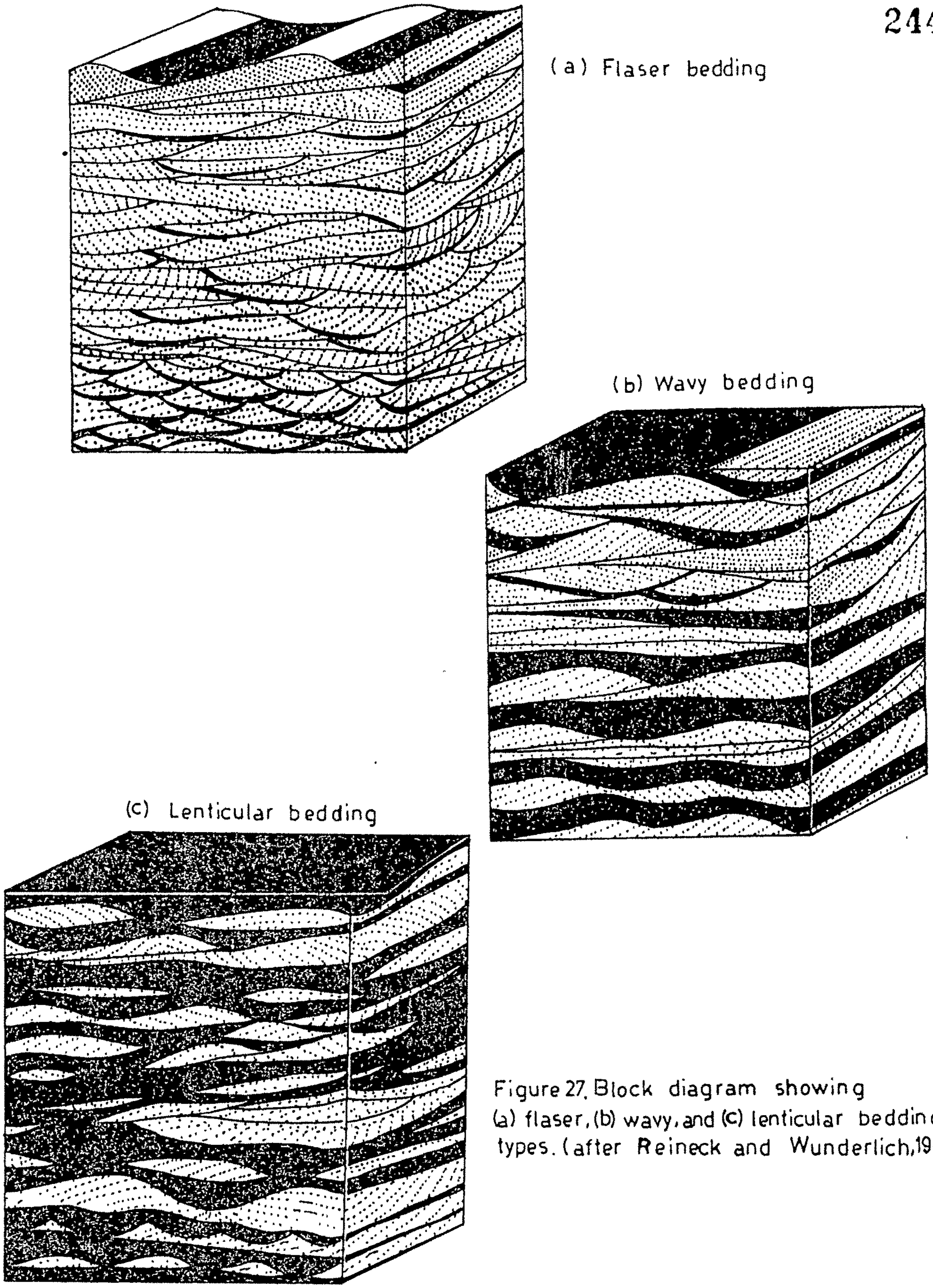


Figure 27. Block diagram showing (a) flaser, (b) wavy, and (c) lenticular bedding types. (after Reineck and Wunderlich, 1968a)

PLATE : 36

(a) Flaser, wavy and lenticular beddings in cross-bedded calcareous sandstone (facies B). Indicating fast rate of deposition (Loc : West of Dhingeshwar Mandir).

(b) Calcareous sandstone (facies B) showing flaser bedding through lenticular beddings indicating fast rate of deposition. (Loc : SW of Dhingeshwar Mandir).

The total lack of burrowing in the lower and central part of the facies supports rapid rates of sediment deposition and/or constant sediment transport.

23.3 FACIES : C,D,E, G,I,J - LAMINATED SANDSTONE-SHALE-CLAYSTONE ALTERATIONS

Except for minor differences the facies C,D,E,G,I, and J display an almost identical style of their formation. All these facies are therefore considered together.

The facies C,D,E,G,I, and J which invariably include the laminated sandstone shale-claystone alternations are by far the most widely distributed lithological units in Bet Shankhodhar. Good exposures of these facies can be observed south of Nilkanth Mahadev Mandir (C,D), southwest of Dhingeshwar Mandir (C,D,E,G,I,J), north of Balapur village (I,J), and south of Abhya Mataji Mandir (G,I,J) (Fig.26). In most of these places the laminated sandstone-shale-claystone intercalated facies has been a fine to medium grained, moderately to well sorted siliciclastic sand with fine or clay sized calcareous material. The average grain size ranges from 0.1 to 0.05 mm. The sand fraction is often 10 to 15% quartz sand with silt and clay content of over 60 to 70% with minor amount of hematite, magnetite and micaceous flakes. The grains are usually inequigranular, subangular to subrounded in shape, moderately to very well sorted. A few thin sections show presence of pellets most probably of faecal origin.

The facies as a whole displays a very prominent golden yellow to dark red and pinkish colour.

Early in stratigraphic sequence the facies - 'C' comprising the laminated facies type is found to have been developed quite abruptly over the Thalassinoides burrow net works of the underlying unit B, haulting the burrow growth (Plate 33b). Such a relationship is also noted in north of the Nilkanth Mahadev mandir cliff section where the overlying laminated clay in addition to its spread over the Thalassinoides burrow have developed a compeletely new set of trace fosils assemblege, including small scale varieties of Planolites and Skolithos (Plate 37a,b). The other trace fossils which are found alongwith such a boundary layer in the southern section include Conichnus, Bergaueria, and Rosselia burrows (Plate 38a,b). The Paleophycus (Plate 39a,b) burrow and the underlying rock supporting it at the Jetty section are found to have been bored indicating a slight hault in the further phase of sedimentation.

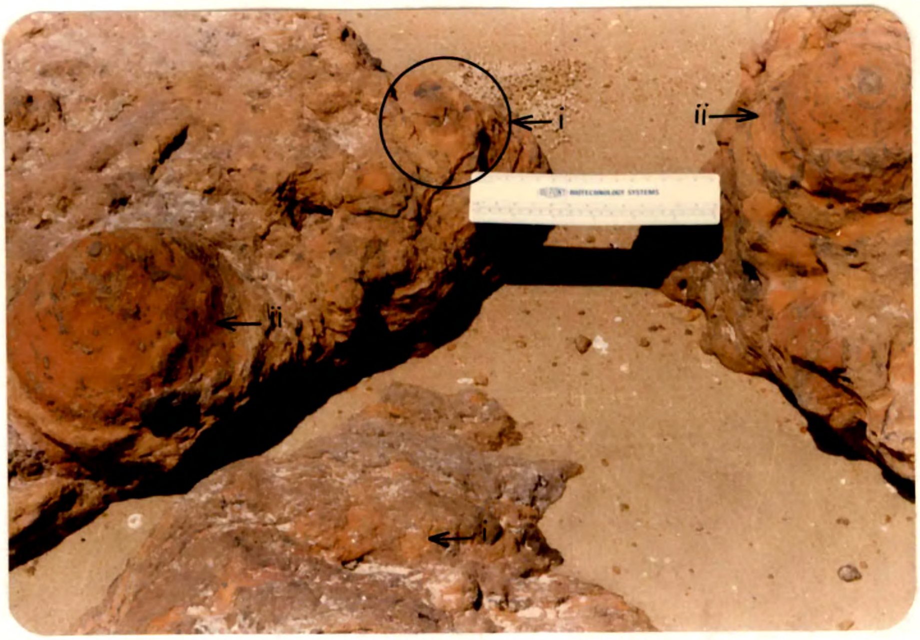
The transition between facies - 'B' and 'C' thus indicate commencement of new set of environmental conditions. The coarser to medium grained sand fractions giving way to the extensive deposition of fine clay material through suspension. Such clay drapes have almost left the Thalassinoides type organisms in the cross-bedded sandstone facies to be suffocated and perished (Plate 33b). These evidences are therefore suggestive of a phase following some high energy conditions when a large amount of clay

PLATE : 37

(a) Planolites in facies - C, with some very small unidentified vertical burrows in underlying the facies - B with Thalassinoides burrow net-work system.

(b) Ripple marks and Skolithos burrows in facies - C. (Loc : cliff section W of Bet jetty).

PLATE : 38



(a) Conichnus and Bergaueria burrows in facies - C.

(b) Rosellia burrows in facies - C.

PLATE:39

(a) Palaeophycus Tubularis burrow in facies - C.

(b) Palaeophycus tubularis and P. alternatus burrows in facies - C.

material was set into suspension was later deposited on the burrowing organisms there by truncating their growth. In nature such events are very often related to storms.

The most common sedimentary structures in facies - 'D' are slightly inclined to parallel lamination (Plate 40a,b). In some situations the laminated sand facies contains wave beddings, rafted organics (north of Sani Miyar), angular clay rip-up clasts, and 1 to 2 cm clay drapes on laminated sand bodies (Plate 40b).

Facies 'E' and 'G' are almost identical except separated by a lenticular band of Round pebble conglomerate in the center (Plate 41a). The laminated sandstone-shale-mudstone bodies are ocassionally massive whenever the clay content greatly increases greater than 90%. In case of loosing such a proportion to around 60% it displays low-angle cross-bedding structures between the prominent parallel laminated sets (Plate 38a & 41b). These low-angle cross-beddings further display reactivation surfaces and clay rip-up clasts (Plate 42) associated with them, implying current of alternating velocity and direction during their formation. Top of the facies 'E' is further marked with occurrence of mud cracks indicating their subaerial exposure. The rippled, very fine-grained mud cracks in facies 'E' appear to be developed locally (Plate 43). The mud cracks are upto 2 to 3 centimeter wide and several centimeters long. The sequence of mud deposition (Slack water), mud cracks (emergence), and

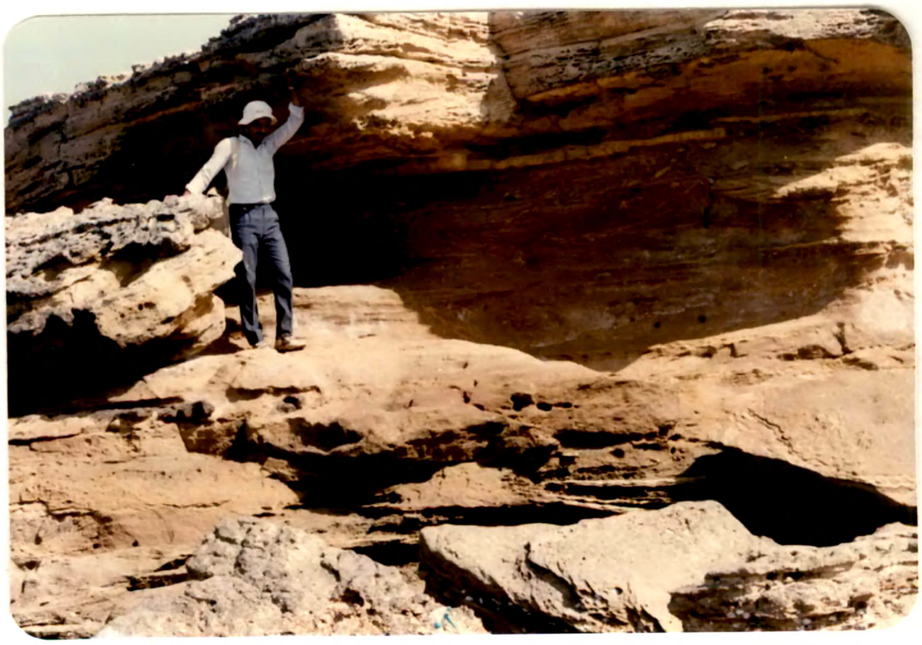
PLATE :40

(a) Contact of facies C and D. Beds almost parallel (Loc : W of Dhingeshwar Mandir).

(b) (i) Rafted organics, (ii) wavy beddings; and rip--up clasts in facies - D. (Loc : S of Belapur).

PLATE : 41

(a) Section exposed SW of Dhingeshwar showing facies, D,E,F,G, & H. Note : the lensoid of round pebble conglomerate (facies - F).



(b) Section showing contact of facies G and H (Loc: SW of Dhingeshwar Mandir)

PLATE : 42

Clay rip-up clast, cross and parallel lamination sets in facies E and G. Note the Ophiomorpha burrows keeping space with the sedimentation (Loc : W of Dhingeshwar Mandir).

PLATE : 43

Mud cracks on the top of facies - E
(Loc : NW of Dhingeshwar Mandir).

overlying rippled sand (resubmergence) is further suggestive of short-period fluctuations in water level.

In addition to the cross-bedding structures there are some other sedimentary structure associated with these facies, especially in their middle and upper most levels. These include the flat topped current ripples in facies - E (Plate 44a), and linguid ripples in facies G (Plate 44b). Moreover, both these facies have preserved excellent biosedimentary structures that include varities of Ophiomorpha burrows (facies - E and G) (Plate 44b). Cylindricum and Skolithos (facies - E), and Zoophycus (?) (facies - G) (Plate 44a,b & 37b). The turning burrows of Ophiomorpha found in facies - E (Plate 46a) are extremely conspicuous and indicate possible response of the Ophiomorpha animals to the changing velocity and directions of the water currents.

The facies 'I' and 'J', in their texture and composition are almost identical like any other facies in their group with medium to fine grained moderately sorted sand and silt in varying proportion of mud. Facies - 'I' conformably overlies the mudstone rhythmites (facies - H) and in turn overlain by the facies - J (Plate 46b). The most common sedimentary structures are the low-angle planner and trough cross-laminations. The most distinctive characteristic of facies - I, however are the interbeddings of cross-bedded sands within 5 to 10 cm. thick beds (Plate 46b). Both these facies are devoid of burrow traces.

PLATE : 44

(a) Flat - topped ripples in facies - E

(b) Linguid ripples on the top of the facies - G. A large scale horizontal burrow can be seen at the bottom of the section (Loc : NW of Dhingeshwar Mandir).

PLATE : 45

(a) Ophiomorpha irregularie and Cylindri--cum burrows in facies E.

(b) Zoophycos (?) in facies - G.

PLATE : 46

(a) Ophiomorpha borneensis in facies - E. Development of burrow indicating variable rates of deposition with little erosion till such time the burrow got truncated.

(b) Cliff section showing contacts of facies H, I, J, & K (Loc : SW of Dhingeshwar Mandir).

The depositional style, sedimentary structures and textures of both the above facies imply their deposition from a combination of wave and current processes. The interbeddings of cross-bedding and their widely varying composition and textures imply an alternation of traction and suspension deposition from currents of variable, but relatively great velocity or capacity of flow.

The total lack of burrowing suggests rapid rates of sediment deposition and/or near constant sediment transport.

23.4 **FACIES : F - ROUND PEBBLE CONGLOMERATE :**

Volumetrically, the round pebble conglomerate facies is a relatively minor component of the Bet Shankhodhar lithological sequence. However, its composition and stratigraphic position are distinctive and significant. It's exposures can be located south of the Jetty cliff section, northwest Abhya Mataji Mandir and, north of Khambhal section. The facies comprises rounded pebbles of clay and occupies shallow depressions between the overlying and the underlying laminated sandstone-shale-claystone alternations (facies E and G). Lateral extent of this facies is very limited (Plate 41) with both of its lower and upper contacts being abrupt.

In this facies a crude lateral and vertical size grading occurs amongst its clasts distribution (Plate 47). The clasts in the lensoidal band are 2 to 33 cm in size and made up of calcareos and clayey material bounded in very fine grained muddy matrix. Under the microscope the matrix appears to be equigranular, moderately sorted, subrounded to subangular quartz grains with calcareous and ferrugineous binding material. The conglomerate as a whole is clast supported. Rarely some very large scale Ophiomorpha burrows are found associated with this facies (Plate 47).

Interpretation : Like the basal conglomerate (facies - A), the round pebble conglomerate facies also appears to have accumulated in patches and lenses deriving its coarse detritus from local sources, its mass wasting and erosion. Transport and rounding of the clast could only have been possible accomplished by high-energy waves (like storm). This observation is once again consistant with those by Komar (1976), on the modern sediments processes. Furthermore, the clast supported framework and rounding of clasts in the facies suggest high agitated, shallow marine conditions.

The large-scale development of Ophimorpha burrows in this facies is autochthonous and represent rapid depositional conditions with a minor hiatus after which the original condition of deposition as in facies - E appears to have been restored.

PLATE : 47

Ophiomorpha burrow in round pebble conglomerate (facies - F) (Loc : SW of jetty cliff section).

23.5 **FACIES : H - SANDSTONE - MUDSTONE RHYTHMITES**

The facies 'H' which comprise the sandstone-mudstone rhythmites is characterized by very thin laminations of alternating mud and sand particles (Plate 46b). Such cyclically deposited units are termed "rhythmites" (Bramlette, 1946). Similar rhythmites according to Davis (1983, p. 68) are very often characterized by alternating layers of sediment textures, composition, or both, and reflect accumulation under alternating physical and chemical conditions of deposition. According to Reineck (1967), rhythmites are often produced by the tidal conditions and are therefore the results of a combination of suspended sediment accumulation (mud) and bed load transported sediment (fine sand). As further stated by him the resulting interbedded sand and mud seqences (tidal bedding) represent sediment accumulation from alternating flood and ebb tidal currents. As claimed by Harms et.al. (1975) most of such rhythmites composed of mud and sand are characterized by flat layers typically representing the upper flow regime plane bed conditions, although some may develop under flat bed condition prior to the initiation of ripples.

The formation of sand-mud rhythmites in the Bet Shankhodhar stratigraphic sequence are thus consistent with the observation of most of the workers mentioned above.

The facies is almost devoid of any burrow traces and support the concept of alternating physical and chemical condition during its deposition.

23.6 FACIES : K - GRITTY SANDSTONE

The massive gritty sandstone facies (1.5 to 2.0 meter in thickness) forms the youngest stratigraphic unit in Bet Shankhodhar. It outcrops in many localities in the Island zone. However, its exposures north of Sani Miyar Bet, and south of Nilkanth Mahadev Mandir cliff section are rather conspicuous. Outcrops of this facies north of the Sani Miyar Bet appear almost at the ground level (exposed between the low and high tide marks), while in the southern cliff sections it characteristically is found occupying its top most position in the stratigraphic sequence. This difference in level is attributed to the effect of north south trending fault, located by the author (Fig.25).

The facies consists of fine to coarse grained assorted particles of sand, gravel and shell fragments. The overall framework of the facies is clast supported. The coarse and gritty composition vary from 10 to 60%, while the whole or fragmented shell material comprise upto 30 to 40%, the rest being calcareious mud. Under the microscope the rock comprises coarse to fine grained sand and skeletal fractions that are poorly sorted, and are angular to subangular. It includes minerals like quartz (blue, green, yellow), magnetite, hematite, bounded in calcareous and ferrugeneous matrix.

The most distinctive characteristic feature of this facies is the normal grading of gravel, sand and shell beds which vary in thickness from 15 to 20 cm. Individual beds have sharp to erosional bases and grade into similar overlying units.

The facies as a whole displays a characteristic large-scale trough cross-stratification (Plate 48), with its general inclination towards northeast direction. It further exhibits an erosional discordance with the underlying facies - J, in the southernmost outcrops region (Plate 48), while it shows almost conformable relationship with the underlying strata along the Jetty cliff section (Plate 46b).

<u>Interpretation</u> : The predominance of normal grading and sharp basal bounding surfaces in the gritty sandstone facies implying scour, traction and resuspension is due to the generation and waning of flow associated with unidirectional currents.

PLATE : 48

Section SW of Dhingeshwar showing facies E to K. Large scale cross bedding in facies K.

AGE OF BET SHANKHODHAR SEDIMENTS

24.1 GENERAL CONSIDERATION

In the absence of reliable fossil zones and any earlier reference the prediction of age for the stratigraphic sequence exposed in Bet Shankhodhar has to be a matter of conjecture. The understanding, threrefore has to come from the neighbouring area of Okha Mandal which was first mapped by Fedden (1884). According to Fedden (1884), the rocks occupying major portion of the Okha Mandal can be separated from the Gaj rocks of Miocene age on account of the marked change in their appearance, mineral character and absence of typical Gaj fossils in them. This group of various lithological character was termed 'Dwarka beds' by Fedden (1884). As further claimed by Fedden (1884) some later portion of Dwarka beds could be marked as Pleistocene. No detail reasons have been specified by him.

Little work was done subsequently, till the Okha-Mandal area was reinvestigated by Shrivastava and Rizvi (1961) for the O.N.G.C. According to these workers the lower portion of the

Dwarka beds of Fedden (1884) comprising a thinly laminated, soft, silty, reddish - yellow and variegated clay is occasionally gypsiferous especially near its contact with the Gaj rocks. This rocky seqence, as claimed by them passes upward into yellow, silty, slightly porous, calcareous yellow marl. Such rocks as further claimed by them are easily distinguishable from the Gaj clays and marls despite their close resemblance to the latter in lithology and appearance, and by the scarcity of megafossils in them. Based on these observations Shrivastava and Rizvi (1961) suggested an uppermost Miocene to Pliocene and certain higher beds in the sequence a Pleistocene age.

Considering the above arguments it becomes obvious that the laminated silty-clayey alternation observed in Bet Shankhodhar may not be the same which were reported at the contact of the Gaj beds by Shrivastava and Rizvi (1961). In all possibilities therefore these could be tentatively referred to the upper most Dwarka or Pliocene continuing into the Pleistocene time.

NEARSHORE SEDIMENTARY FACIES

The Bet Shankhodhar Island as a whole exhibits a rather simple geomorphological pattern in the distribution of its sedimentary facies (Fig.28). Its entire coastline can be subdivided into three major units based on variations in shoreline features that are controlled by the local geology and the present-day shoreline processes. The three units include - (1) Portion of the Bet, north and northeast of the axis joining the Balapur-Abhya Mataji Mandir sector; (2) The central portion of the Bet, situated north to the axis joining the Sani Miyar Bet in the east to the Jetty section in the west; and (3) The southern most part of the Bet Sankhodhar Island comprising the entire area located south of the above axis. Various landscape features and sedimentary facies studied in this zones are described in the following text.

25.1 NORTHERN PORTION OF THE ISLAND

The part forming this Island zone occupies nearly 50% of the total land area of Bet Shankhodhar Island. It is characterized by a relatively flat and low lying region which is frequently subjected to the high-water conditions. This area covering the northern and northeastern shoreline zone, in the absence of any rock exposures beyond the Abhya Mataji Mandir region and in contrast to the central and the southern parts of the Island zones, appears to be a drowned low land region. The possible formation of this structurally controlled straight line coast probably resulted from differential erosion along the boundary between the partially submerged north-fault block of the unresistant Pliocene-Pleistocene sediments in the north and an uplifted block in the center and the south of the Island (Fig.25). Any, unresistant sandstone shale-claystone of the normal sequence were thus possibly and subsequently eroded by the sea water in the long period of time. The most important effects of such a drowning was perhaps the deposition of the north northeast extensive beach and beach sand ridge system. The other developments include small linear and pocket beaches at the eastern tip of the Island, and in areas situated north and northeast of Balapur. Some recent mud flat development especially around the Hanuman Mandir in the east could have been caused as a partial modification of this coastal zone during the recent time.

(i) Beaches and Beach Ridges : Two prominant beaches and beach-ridge systems are observed in the northern coastal region. These includes beach and beach ridge system extending from the Abhya Mataji Mandir extending over 4 to 5 km across the straight north coast and the other south of Hanuman Mandir ,covering the southern most tip of the northern Island zone.

Abhya Mataji Mandir beach and sand ridge : This beach ridge system is a predominant shoreline feature in the Bet Shankhodhar Island (Fig.28 & Plate 49). It is about 4 to 5 km in length and runs almost parallel to the coast. It attains a maximum height of about 5 meter near the light house and gradually extends towards the shore to be merged with it as a foreshore beach. The maximum observed distance between the foreshore and the backshore beach seldom exceeds 50 meter. The slopes of the ridge although appears to be smoothened because of the wind effects, the ridge system as a whole shows steep inclination with the backshore parts of the beach. The part of the ridge facing sea are always found saturated with water as it is often sub-merged with the high water (intertidal) zone. Around this region the beach surface is generally smooth but occassionally shows symmetrical ripples, rill marks, mosaic of crab pellets, especially during the receeding tide. The upper and lower portions are invariably affected by wind and develop wind ripples (Plate 49). Such ridges in the central part of the Island are covered with very poor vegetations mainly scrubs.

Hanuman Mandir Sand Ridge : This beach-sand ridge system about 2 km in length forms a characteristic neck towards the land around the Hanuman Mandir region and then attains a characteristic tail-like geomorphic feature at the extreme

PLATE : 49

Abhya Mataji Mandir sand ridge with wind ripples and coastal vegetation.

northeastern part of the Island (Figure 28). This ridge is convex at the top but steeply dipping on both the east and west directions. It is always found covered with water on all the sides except near the land. This beach-ridge system is relatively very narrow and is composed of thin layers 1 to 1.5 meter of poorly sorted sediments that rest on the eroded rocky platform.

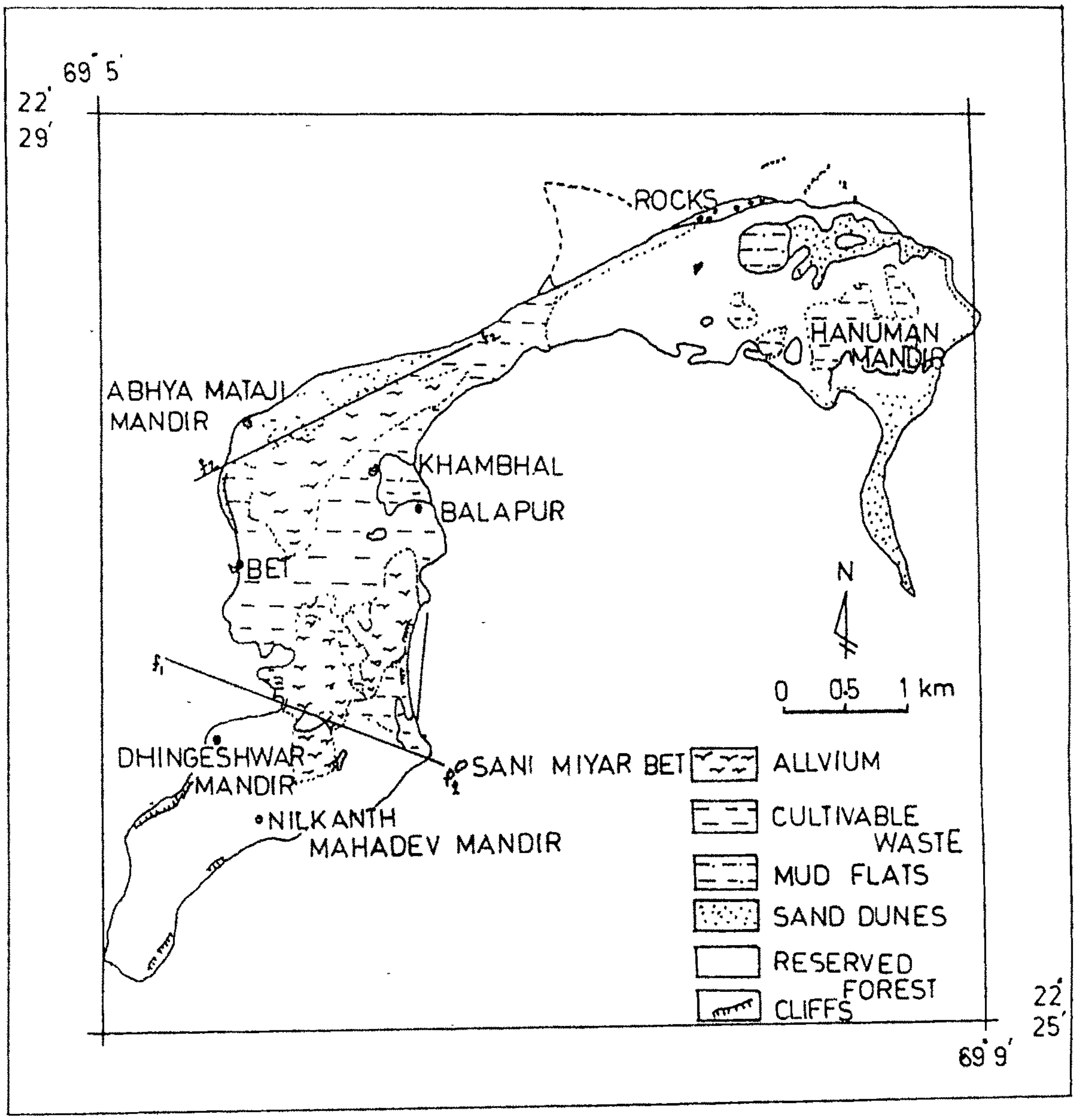
(ii) Smaller Pocket Beaches : In contrast to the northern and northeastern shore-line zone where large scale beach, beach-ridge systems are developed, the eastern parts of the Island are characterized by smaller pocket beaches. The obvious reasons are the low-energy and lack of availability of sediments. Such beaches are possibly formed whenever suitable condition were available, like the rise in sea-level, and slowly landward migrating sand (viz. during storms).

In general, the massive sands of the beaches and sand ridges are usually mature, well sorted quartz and carbonate sands with rare inclusion of gravel. Shell content commonly range from 5 to 25%, although, it may exceed 60% locally. Sediment maturity is reflected in relatively high degree of rounding and occurrence of some stable heavy minerals like magnetite, ilmenit, augite, rutile etc. The major source of these sediments appears to be from the shoreward migration of the littoral zone sediments during the tidal exchange. Furthermore, in most of this area the backshore and offshore gradients appear rather low as seen from the rocky platforms surrounding most of the northern region (Fig.28).

(iii) Intertidal Rocky Platforms : These include the partly submerged portion of the coast that could be observed at the northern extremity of the Island zone. It forms the outermost shore zone with resistant flattened rock exposures. Such exposures can only be seen during the receeding tides. In its general appearance, composition and texture the rocks shows measurable similarities with the gritty sandstone lithological unit. More details on this rock were not available because of inaccessibility to the area which is, all the time affected by waves.

(iv) Tidal Flats and Marshes : Like the pocket beaches, some small depressions in the northeastern part of the Island have developed into small tidal flats and marshes. The reasons appear to be the availability of protected regions where the wave energy has been greatly reduced and the erosion of the mud has been relatively less. Such tidal flat and marshes are found north of Hanuman Mandir, and North of Balapur (Fig.28). The sediments of the tidal flats are fine to coarse grain sand with their major part consisting of mud. The sedimentary, and biogenic structures include small scale ripples, undulatory beddings, gas escape structures and animal tracks and trails. The ripples are very often found filled with faecal pellets possibly of crabs and some other crustaceans.

FIG. 28 GEOMORPHOLOGICAL MAP OF SHANKHODHAR ISLAND



25.2 CENTRAL ISLAND PORTION :

The section exposed between the Sani Miyar Bet and Balapur in the eastern Island zone; and that between north of Dhingeshwar Mandir and south of Abhya Mataji Mandir in the western Island zone comprise the central Island portion of Bet Shankhodhar (Figure 25). The central block in relation to the northern block appears to have raised up, while in comparison with the southern block it appears to have gone down at different levels. The whole block as a matter of fact is affected by a number of faults of various magnitudes which have often rendered difficulties in establishing the chronology of the stratigraphic sequences in the field. The main faults that were found affecting this block include the Sani-Miyar, the Balapur faults trending, WNW-ESE, the Abhya Mataji fault trending NEN-SWS, and the north-south fault located north of the Sani Miyar Bet. Various effects of these faults can be listed as under :

(i) Upward movement of the central block as compared to the north block along the Balapur-Abhya Mata axis.

(ii) Downward displacement along the Sani-Miyar Bet north Dhingeshwar axis.

(iii) Tilting of the block in the northeast direction.

(iv) Downward movement along the north-south fault line along Sani Miyar Bet and Balapur bringing down the younger gritty sandstones to their present intertidal level.

(v) Formation of 10 to 15 meter cliffs on the western side of the Island between north of Dhingeshwar Mandir and the Abhya Mataji Mandir.

In contrast to the northern block, no development of prominant beaches or marshes are observed along the coastal region along the central block. Its eastern part which include some major cliff section are however, often subjected to direct wave action which inturn result in collapse of the unsupported rock portions. Such collapsed rock debris accumulated near the foot of the cliff comprise unsorted material of varying size and shape from some very large-scale boulders to fine sand. Like the northern part at a few places some pocket beaches and mudflat are also being seen to have been developed. No mangrove vegetation was anywhere observed.

A conspicuous geomorphological feature which could be observed adjacent to this block is a small tiny Island about 4 meter in height and 8 to 10 meter in circumference, called the Sani Miyar Bet. The Island is circular to oval in shape and constantly subjected to the tidal influence. In all possibilities this Island indicate a stack like feature separated from the main land on account of the encroachment of the sea.

The characteristic features of the central block are therefore related primarily to the physiographic and geologic factors, rather than to the processes acting upon the nonresistant outcrops in marking the present day shoreline features of the Island.

25.3 **THE SOUTHERN ISLAND PORTION :**

This Island zone is once again characterized by cliffs of unresistant sedimentary rocks and their large-scale collapse material. Such cliffed coast on the western side of the block is an exposed wave energy environment that experiences a marked increase in energy levels because of the constant wave attack. The eastern part of the land on the other hand is characterized by relatively low-energy environments, although it displays some well developed cliffs (Plate 30). This low energy environment on the eastern side has further allowed locally available sand material to move landward with rising water levels and there by develop small linear beaches. Many smaller or pocket beaches, therefore can be seen along the eastern side of the southern block. Since no beach progradation is found along the entire south block, the major source for the linear beaches could be predicted to have come from the shoreward migration of the littoral zone sediments during the tidal exchange.

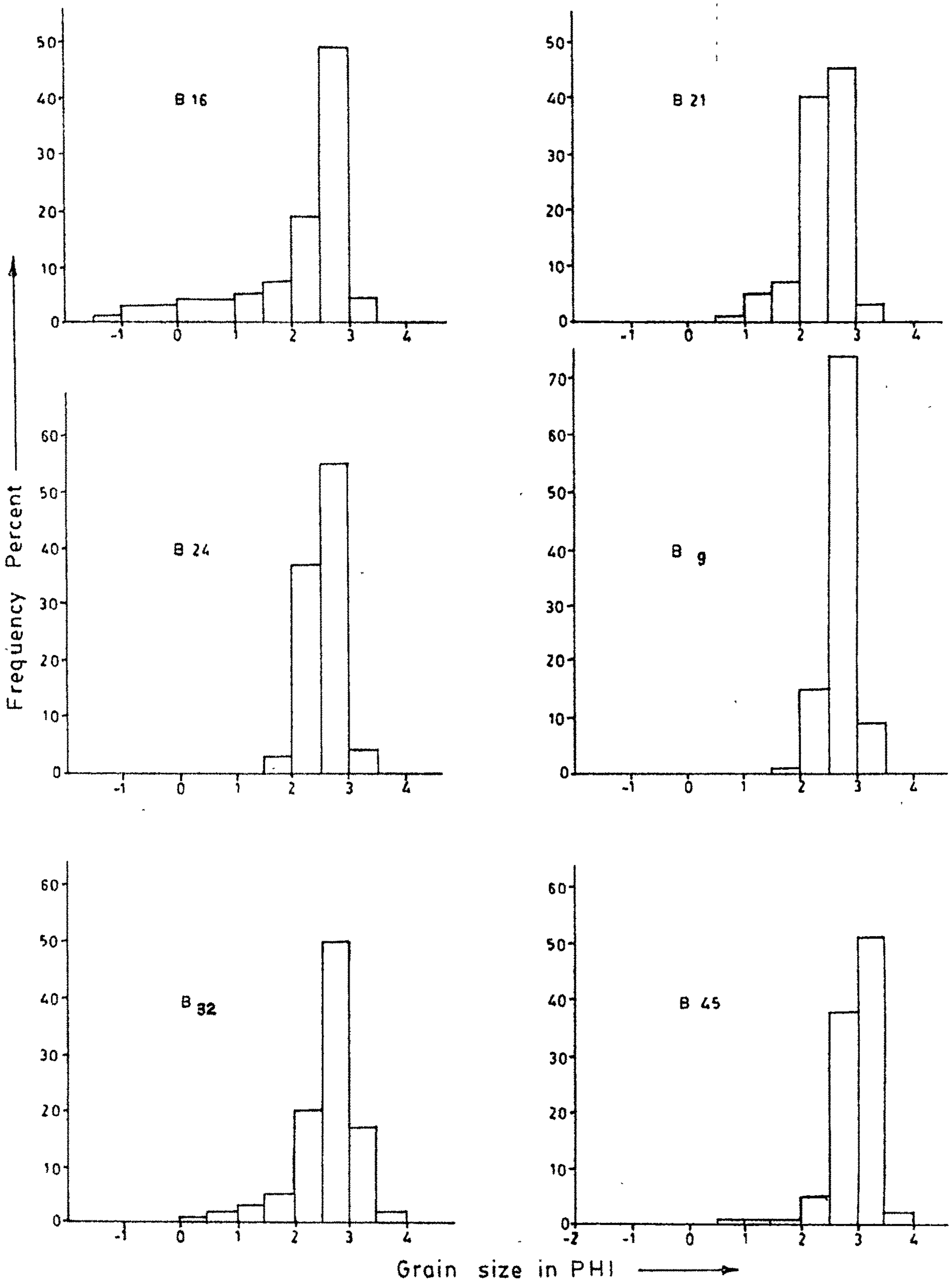
26.1 SEDIMENTOLOGICAL STUDIES

For the purpose of textural analysis samples were collected from the sand ridges (northeast of Abhya Mataji Mandir and south of Hanuman Mandir), and intertidal muddy sediments (from the west and southwest of Dhingeshwar Mandir). The various textural parameters of these sediments are computed as per the procedure adopted and described on page for the Piram Island. The graphic representation of the size analysis data has been presented in histograms (Fig.29) and cummulative curves (Fig. 30) using probability ordinate graphs. The statistical parameters so obtained are tabulated in the following Table no.18.

Table : 18 Textural Characteristics of Bet Shankhodhar Sediments

Locality	Sample No.	Mean Size (M_z)	Standard Deviation (σ_I)	Skewness (SK_I)	Kurtosis (K_G)
W and SW of Dhingeshwar	B9	2.70	0.24	0.03	1.29
	B16	2.12	1.44	-0.69	1.54
	B21	2.38	0.39	-0.20	1.19
	B24	2.53	0.28	-0.08	1.30
NE of Abhya Mataji Mandir	B32	2.62	0.53	-0.30	1.49
	B45	2.97	0.33	-0.25	1.09
	B46a	1.88	0.72	-0.15	0.82
	B46b	2.52	0.55	-0.37	1.60
	B46c	1.87	0.93	-0.19	0.79
	B47a	0.88	2.00	-0.49	0.87
	B47b	1.73	0.86	-0.05	0.75
	B47c	1.70	0.84	-0.05	0.72
	B47d	2.18	0.62	-0.32	0.91
	B47e	2.48	0.39	-0.36	1.28
South of Hanuman Mandir	B48a	1.62	1.25	-0.26	0.79
	B48b	2.03	0.82	-0.48	1.06
	B48c	0.92	1.32	-0.09	0.72
	B48d	1.53	1.08	-0.03	0.92
	B53a	2.33	0.77	-0.30	1.15
	B53b	1.65	1.14	-0.35	0.93
	B53c	2.47	0.32	-0.28	1.18
	B64c	2.55	0.36	-0.27	1.18

FIGURE 29. HISTOGRAMS: GRAIN SIZE DISTRIBUTION — BET SHANKHODHAR SEDIMENTS



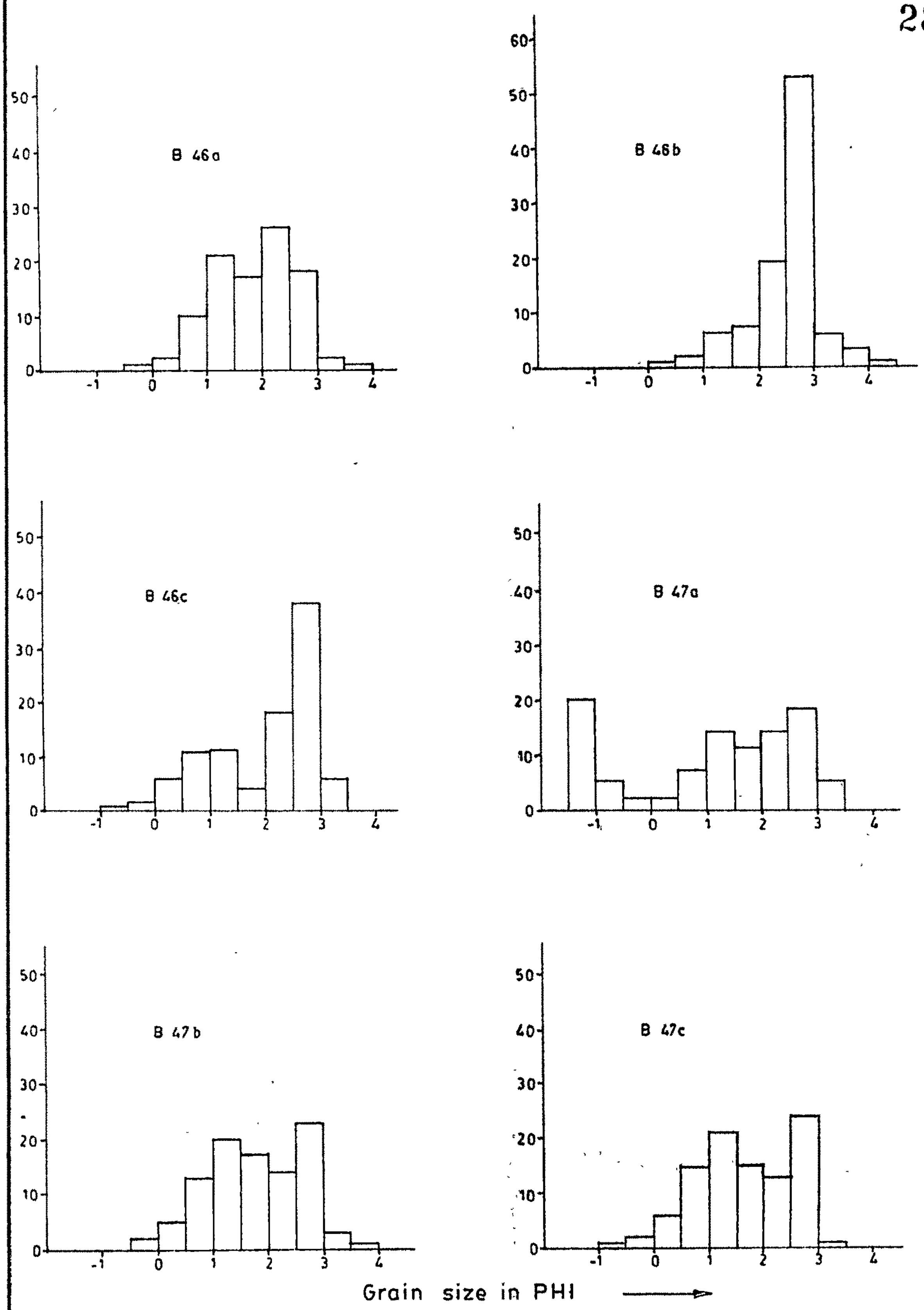
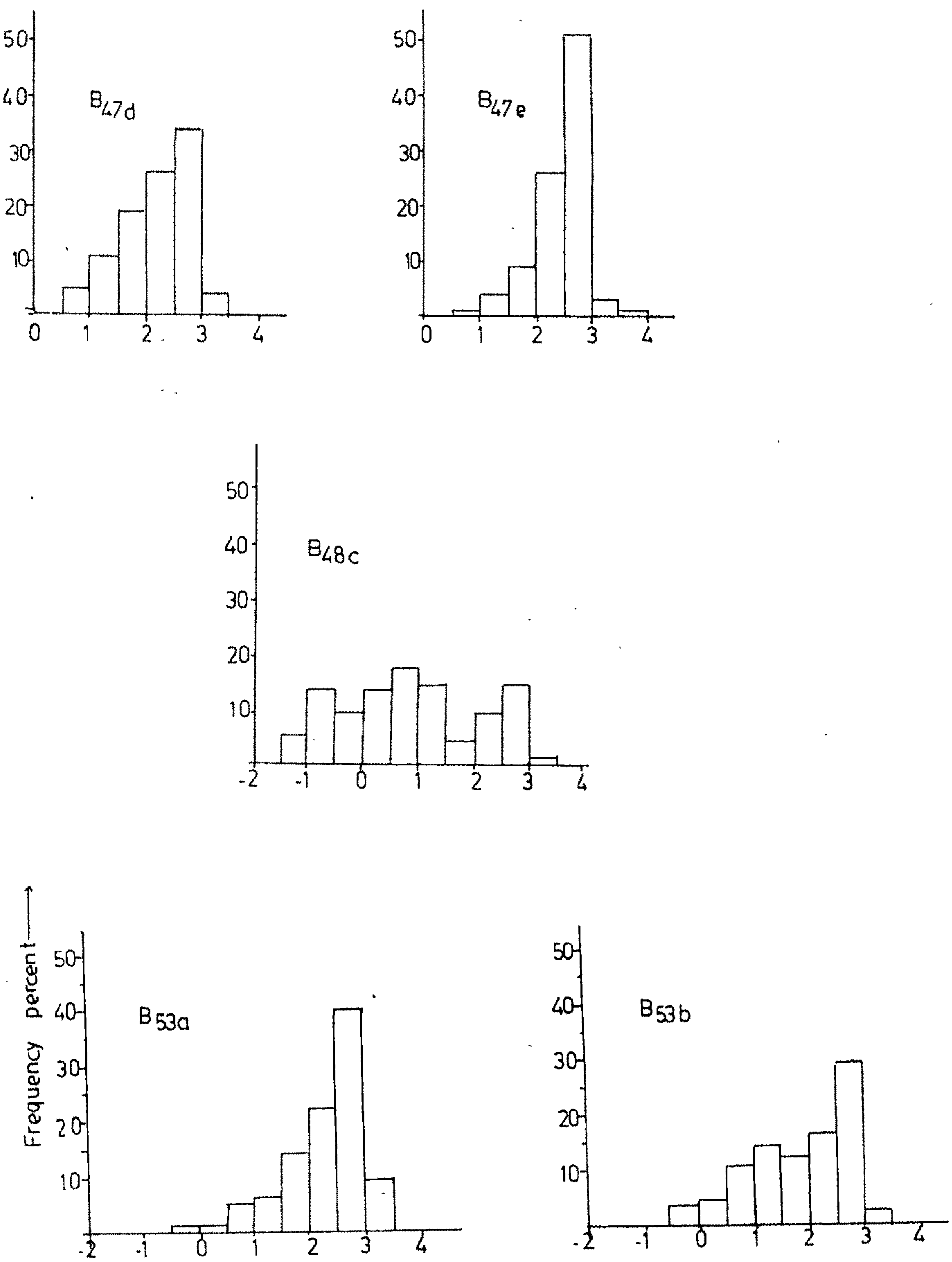
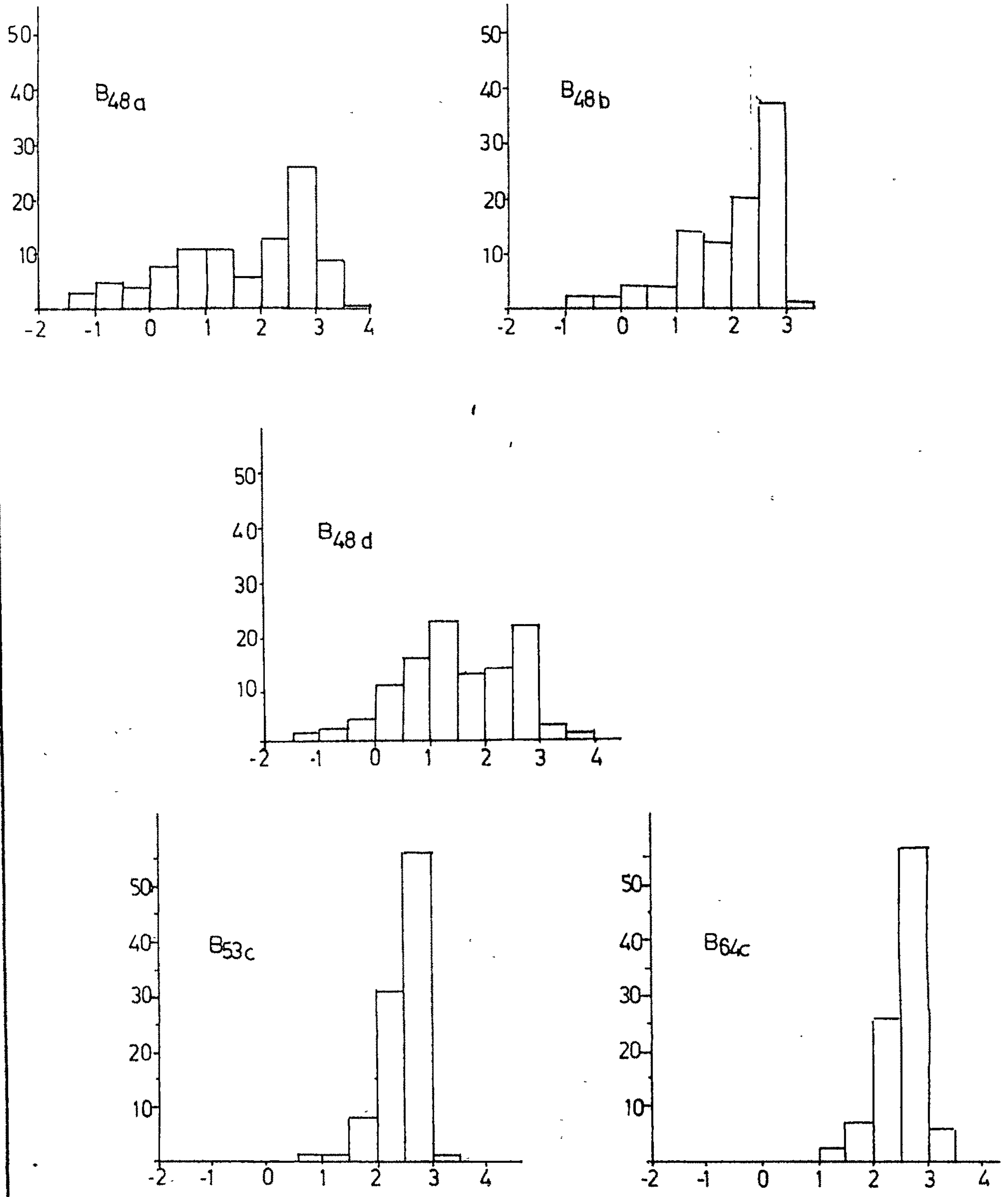

B 46a
B 46b
B 46c
B 47a
B 47b
B 47c
Grain size in PHI

FIGURE 29. HISTOGRAMS : GRAIN SIZE DISTRIBUTION - BET SHANKHODHAR SEDIMENTS




B_{48a}
B_{48b}
B_{48d}
B_{53c}
B_{64c}

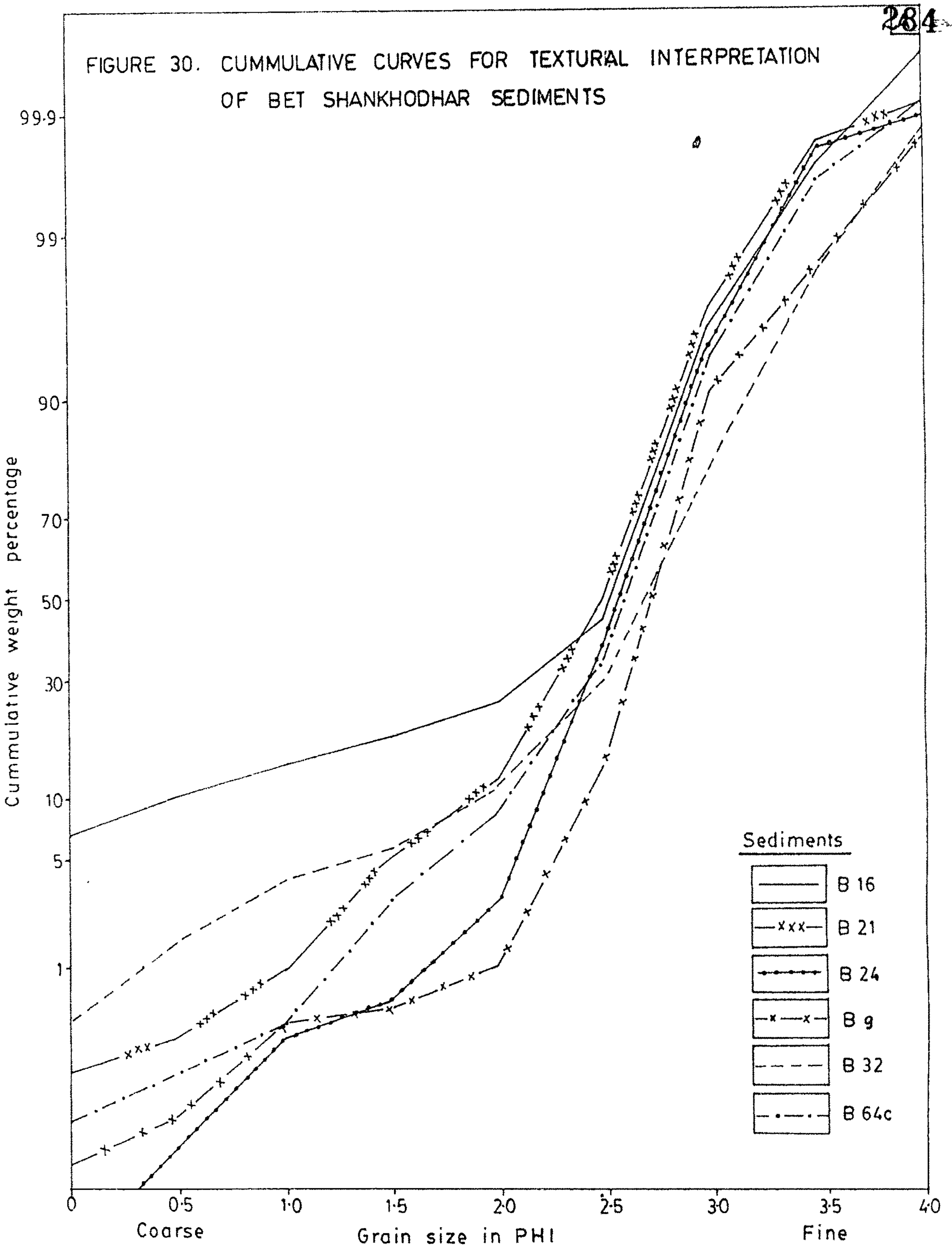
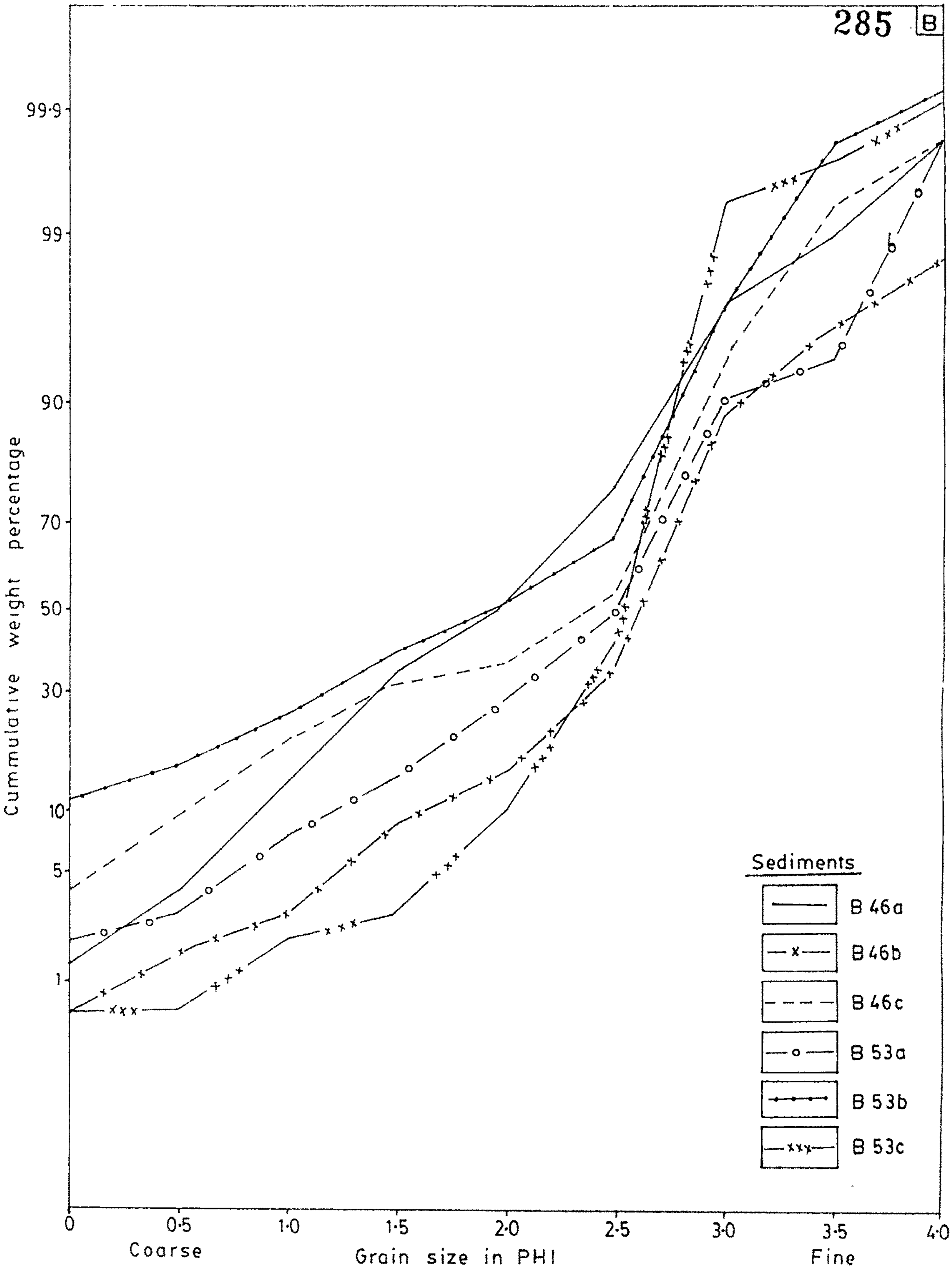
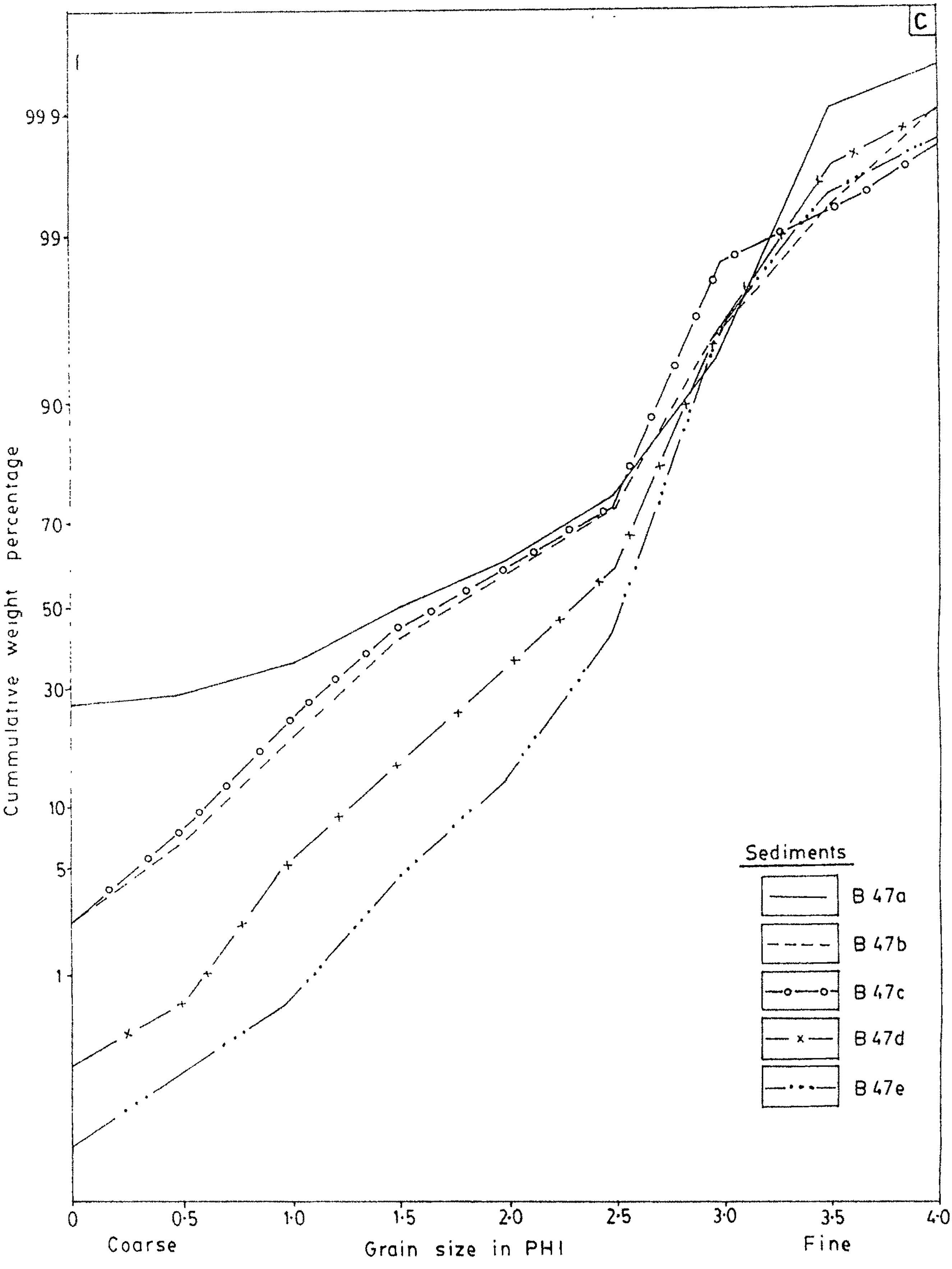


FIGURE 30. CUMMULATIVE CURVES FOR TEXTURAL INTERPRETATION OF BET SHANKHODHAR SEDIMENTS
Cummulative weight percentage
99·9
99
90
70
50
30
10
5
1
0
0·5
1·0
1·5
2·0
2·5
3·0
3·5
4·0
Coarse
Grain size in PHI
Fine
Sediments
B 16
B 21
B 24
B g
B 32
B 64c


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
B 46a
B 46b
B 46c
B 53a
B 53b
B 53c


C
99.9
99
90
70
50
30
10
5
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Cummulative weight percentage
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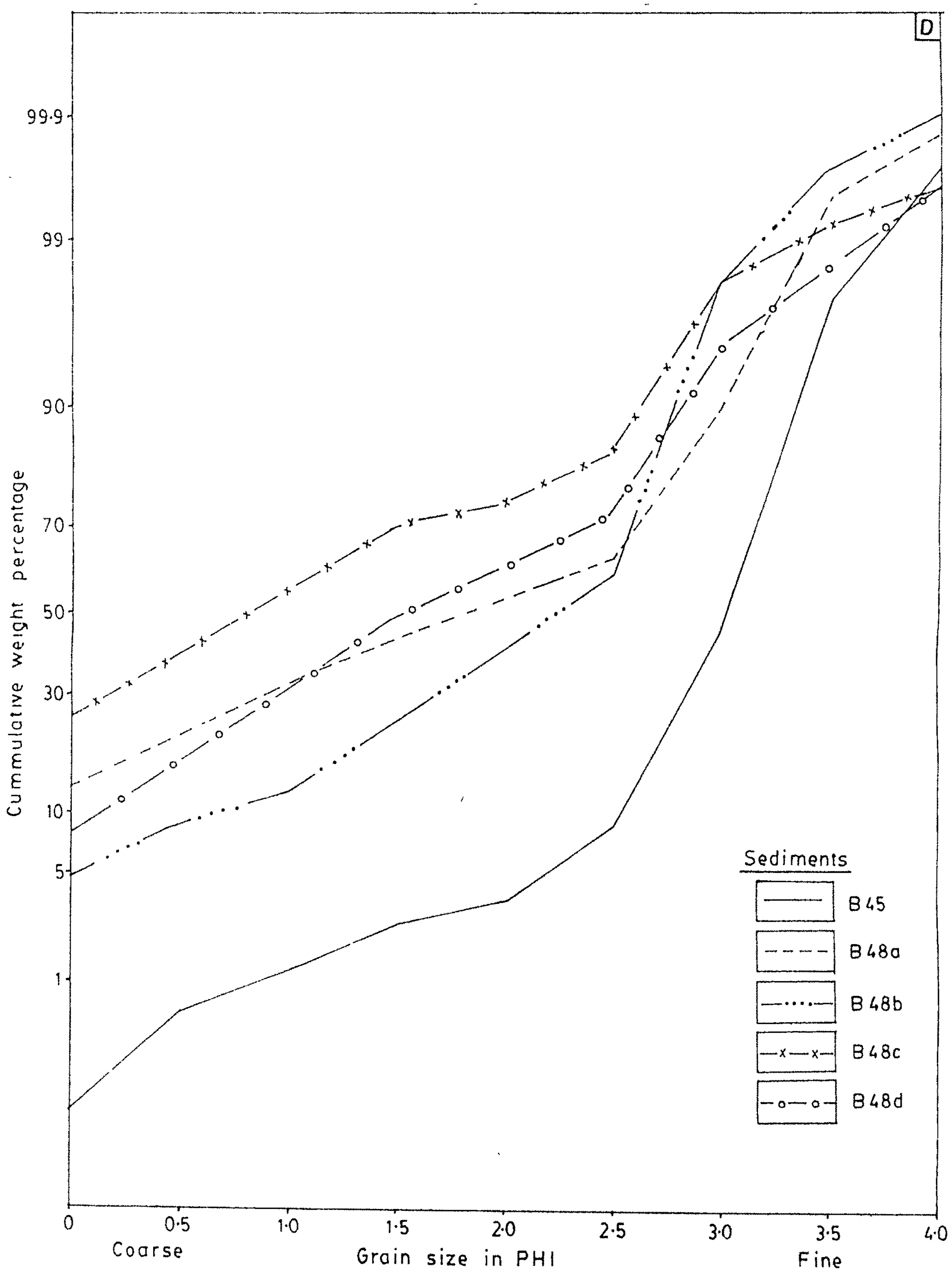
1·5
2·0
2·5
3·0
3·5
4·0
Coarse
Grain size in PHI
Fine
Sediments
B 47a
B 47b
B 47c
B 47d
B 47e


D
99·9
99
90
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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
B 45
B 48a
B 48b
B 48c
B 48d

26.2 CONCLUSIONS AND INTERPRETATION :

The graphic mean size of the sand ridge near Abhya Mataji Mandir range from medium sand (1.87 phi) to fine sand (2.97 phi), and farthest to northeast near light house it varies from coarse sand (0.88 phi) to fine sand (2.48 phi). The sand ridge south of Hanuman Mandir also shows the same characteristic in its graphic mean size and range from coarse sand (0.88 phi) to fine sand (2.55 phi), while the muddy sediment from the intertidal zone (west and southwest of Dhingeshwar Mandir) are fine sand (2.12 to 2.70 phi).

In general, the variation in grain size shows northeastward decreasing trend as well as vertically it shows fining upward pattern in the sand ridges sediments.

The inclusive graphic standard deviation of the sand ridge sediments varies from very poorly sorted (2.00 phi) to very well sorted (0.32 phi) and that of the muddy sediments range from poorly sorted (1.44 phi) to very well sorted (0.24 phi).

The inclusive graphic skewness values of sand ridges and muddy sediments range from (-0.03 phi) nearly symmetrical to (- 0.32 phi) very negatively skewed.

The graphic kurtosis values reveals that the sand ridge northeast of Abhya Mataji Mandir comprises Platykurtic (0.72 to

0.87 phi) sediments, while the sand ridge south of Hanuman Mandir comprises platykurtic (0.72 phi) to leptokurtic ((1.18 phi) sediments. The muddy sediments are leptokurtic (1.29 to 1.54 phi).

On an average the sand ridge and muddy sediments of Bet Shankhodhar Island are bimodal in character (Fig.29), and show the values by traction as 19.7 %, by saltation, 77.9% and suspension as 2.4%.

HEAVY MINERAL STUDIES

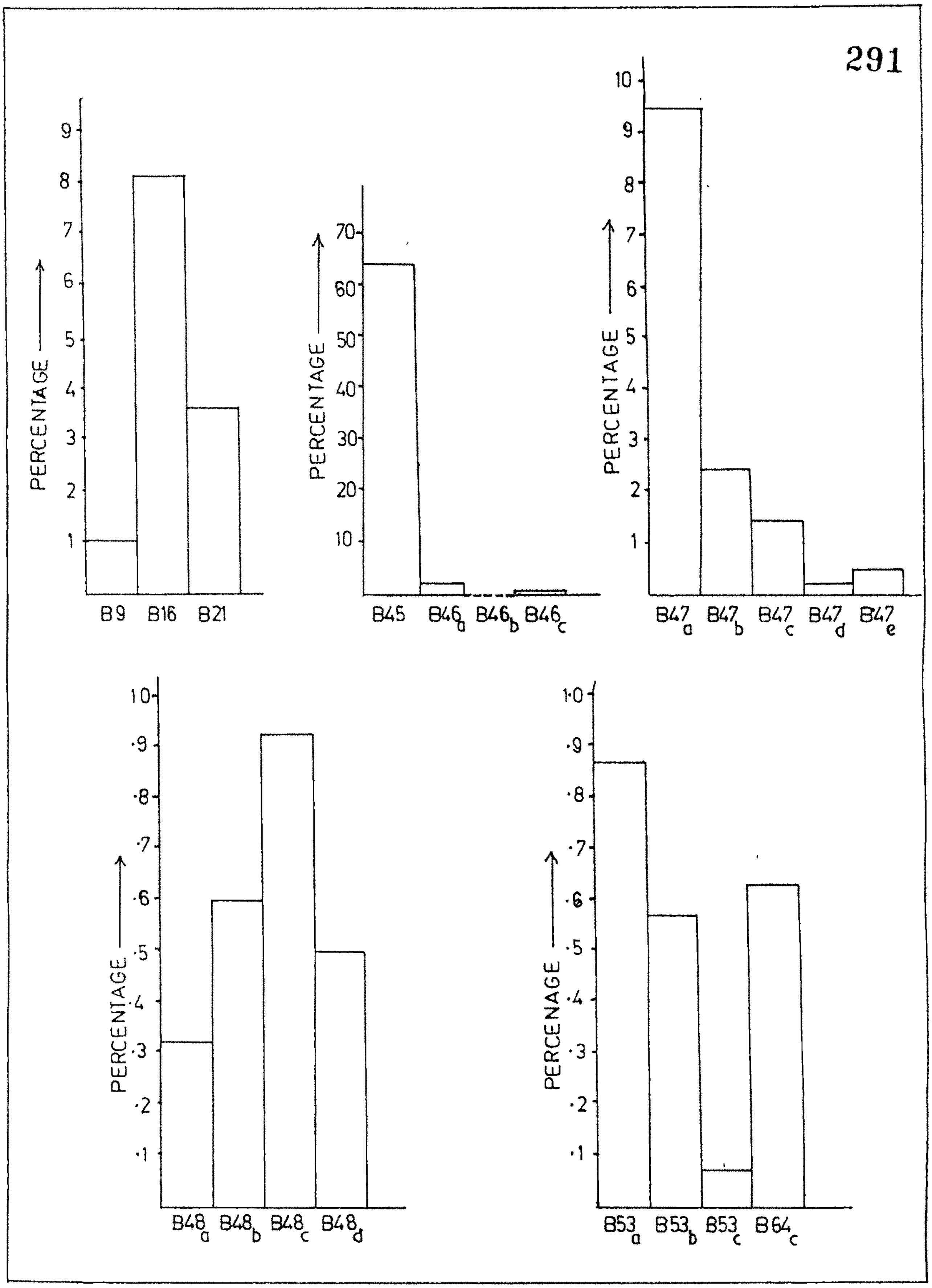
27.1 OCCURRENCE AND DISTRIBUTION

Concentrates of heavy mineral occur in the form of patches and layers along the intertidal zone, northeast of Abhya Mataji Mandir. It consists of minerals like magnetite, ilmenite, rutile, augite, glauconite and biotite. The magnetite occurs in relatively larger proportions. The percentage of heavies in different layers and patches, however vary. The values of the heavies were determined as per the procedure adopted and described on page for the Piram Island. The resulting values and weight percentages are tabulated in the following Table no.19 and shown in Figure 31.

Table : 19 Showing Weight Percentage of Light and Heavy Crops

Locality	Sample No.	Light Minerals Weight %	Heavy Minerals Weight %	Total Weight %
W and SW of Dhingeshwar Mandir	B9	98.97	1.03	100
	B16	91.83	8.17	100
	B21	96.35	3.65	100
NE of Abhya Mataji Mandir	B45	35.66	64.46	100
	B46a	97.47	2.53	100
	B46b	99.83	0.17	100
	B46c	99.03	0.97	100
	B47a	90.60	9.40	100
	B47b	97.60	2.40	100
	B47c	98.67	1.43	100
	B47d	99.80	0.20	100
	B47e	99.50	0.50	100
South of Hanuman Mandir	B48a	99.77	0.33	100
	B48b	99.40	0.60	100
	B48c	99.07	0.93	100
	B48d	99.50	0.50	100
	B53a	99.13	0.87	100
	B53b	99.43	0.57	100
	B53c	99.93	0.07	100
	B64c	99.47	0.63	100

FIG.31 DISTRIBUTION OF HEAVY MINERALS IN COASTAL ZONES - BET SHANKHODHAR ISLAND.



27.2 OBSERVATIONS AND INTERPRETATION

As seen from the foregoing Table 19, the maximum concentration of the heavy minerals is found in the sediments of the intertidal zone averaging about 64.5% . Such intertidal regions are actually the foreshore beach zones that are constantly exposed to the wave actions and exchange of sediments. The entire strip therefore extending north and northeast from the Abhya Mataji Mandir upto the eastern extremity of the Island is thus characterized by a concentration of heavies. In contrast along the beach sand ridge section, the percentage of heavy minerals is greatly low (2.5 to 0.2%). This possibly may be for two main reasons : (i) narrowness of the foreshore and backshore beach sections, (ii) steep slopes between the beach-sand ridge system which has no berm development and, (iii) for the reason that the narrow beach section is always kept wet by the uprushing and receeding tidal currents. Such a situation may not allow the wind to easily lift the heavy mineral particles to be associated with ridge system sediments, as is done during the dry phases.

The heavy mineral concentration likewise show lower values between 0.9 to 0.06% south of the Hanuman Mandir ridge sediments, but again get greatly improved near the mud flats averaging 8.2 to 1.0%.

Similarly, west and southwest of Dhingeshwar Mandir the values of the heavy mineral concentration vary between 50% to 8.1%. This improvement in value may possibly be for the open-sea conditions.

SEDIMENT TYPES

Broad sediment types are determined for most of the present day sedimentary environments described earlier. This include sediments from intertidal zone, mud flats, beaches, and beach ridges. In all three general categories of sediment types including foraminiferal/pelletoidal sand, gasteropod/ lamellibranch skeletal sand, and compound grain/foraminiferal sand, were confirmed associated in combinations within each of the above environments. There is however no distinct demarkation and in many occasions these categories are found overlapping each other in various fashions. The sediment types are :

(a) Foraminiferal/pelletoidal sand (Intertidal sediments-foreshore and backshore beaches).

(b) Gasteropod/lamellibranch skeletal sand (backshore beaches and intertidal regions).

(c) Compound grains/foraminiferal sand (foreshore, and backshore beaches and low sand dunes).

A brief description of all these types is given in the following paragraphs.

28.1 DESCRIPTION AND INTERPRETATION OF SEDIMENT TYPES

(a) <u>Foraminiferal/pelletoidal sand</u> : (Plate 50a).

Grain Size : medium to fine grained
Sorting : moderately sorted
Total foraminifera in the measured sample : 147

Sedimentological description : These sediments are extremely variable in character. Their most constant components are the foraminifera (dominated by Ammonia and Elphidium sp.), and elongated grains of pellets, in equal proportions with minor proportion of subangular to subrounded compound grains, coral fragments and broken shell fragments.

Relation to environment : These sand are not limited to or restricted to any particular microenvironment although they are usually found in moderate energy setting of the intertidal zones. The foraminiferal composition of these sand indicate their shallow water origin.

(b) Gasteropod/lamellibranch Sand : (Plate 50).

Grain Size : coarse to medium grained
Sorting : very poorly sorted
Total foraminifera in the measured sample : 114

Sedimentological description : The sediments of this type consist of very poorly sorted fine to medium grained sand, comprising mainly coarse grained broken skeletal parts of gasteropods (Turitella), and lamellibranch shells with coral fragments, foraminifera, faecal pellets and large compound grains. The skeletal parts and broken tests of gasteropods and lamellibranch show varying degree of borings, and abrasions.

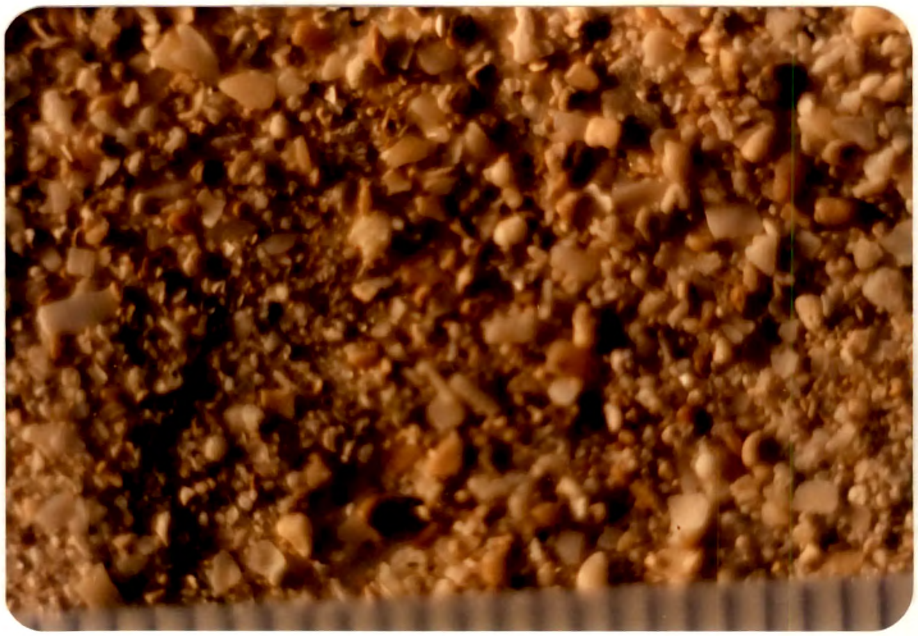
Relation to environment : The coarser fraction are generally concentrated in isolated patches in the upper tidal zones like backshore beach and supratidal zones. These sands possibly are laid down by the action of longshore currents and waves.

(c) Compound grains/foraminiferal sand (Plate 50c)

Grain Size : fine to medium grained
Sorting : moderately well sorted
Total foraminifera in the measured sample : 98

Sedimentological description : These sand consist of fine grained, angular to subangular compound grains of terrigeneous material, shell and coral fragments, and very little amount of foraminiferal test (Ammonia and Elphidium sp.). Shell fragments show varying degree of abrasions.

Relation to environment : The association of this type with backshore beach and dune indicate influence of wind over them. When the foreshore and backshore beach sediments dried the active winds possibly lifted many of such grains to be associated with the coastal dunes.



(a) Foraminiferal/pelletoidal sand x 6

(b) Gastropod/lamellibranch sand x 6

(c) Compound grain/foraminiferal sand x 6

MORPHOTYPE PATTERNS

For the morphotype studies of foraminiferal test, suitable samples were drawn mostly from the northern coastal block- especially from the foreshore backshore and dune ridge sections. Procedures described were once again followed while collecting and identifying the foraminiferal tests. The average composition of different morphotypes are as under :

(a) Biconvex trochospiral : 27%

(b) Milioline : 16%

(c) Plano-convex trochospiral : 18%

(d) Rounded planispiral : 36%

(e) Conical tapered : 3%

Morphotype pattern of various foraminiferal types obtained at the Abhya Mataji Mandir, and Hanuman Mandir foreshore backshore and beach - ridge sections are presented in the following Table 20 and shown in Figure. 32a,b.

Table : 20 Showing Distribution of Morphotypes in Nearshore Zone

Sample Location	Sample No.	Microenvironments	Morphotypes in % BT	M	PT	RP	CT
NE of	B46a	Foreshore	41	22	22	16	-
Abhya	B47b	Beachshore	37	14	13	37	-
Mataji	B47e	Dune-Ridge	23	21	23	32	2
Mandir	B47d	Dune-Ridge	24	21	21	31	3
	B47e	Dune-Ridge	22	20	20	33	5
South of	B53a	Beachshore	14	10	21	49	5
Hanuman	B53b	Dune-Ridge	30	10	14	42	4
Mandir	B53c	Dune-Ridge	22	10	13	50	5

FIG. 32 a. DISTRIBUTION AND RELATIVE ABUNDANCE OF FORAMINIFERAL TYPES BET SHANKHODHAR ISLAND

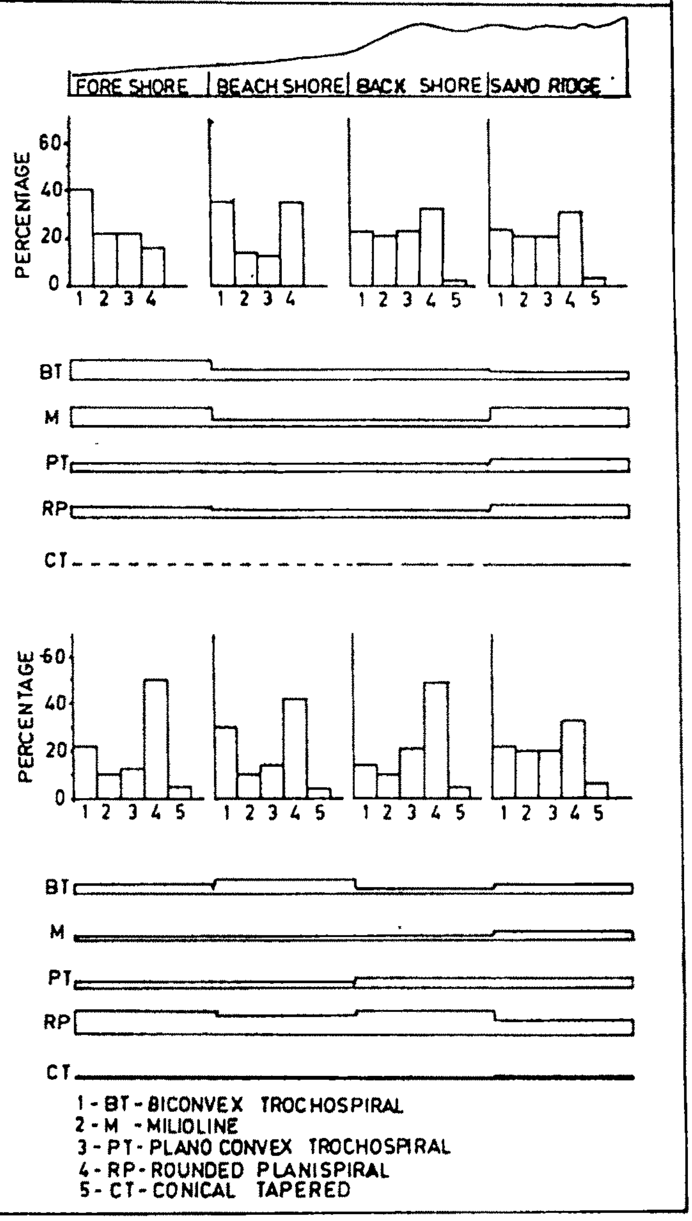
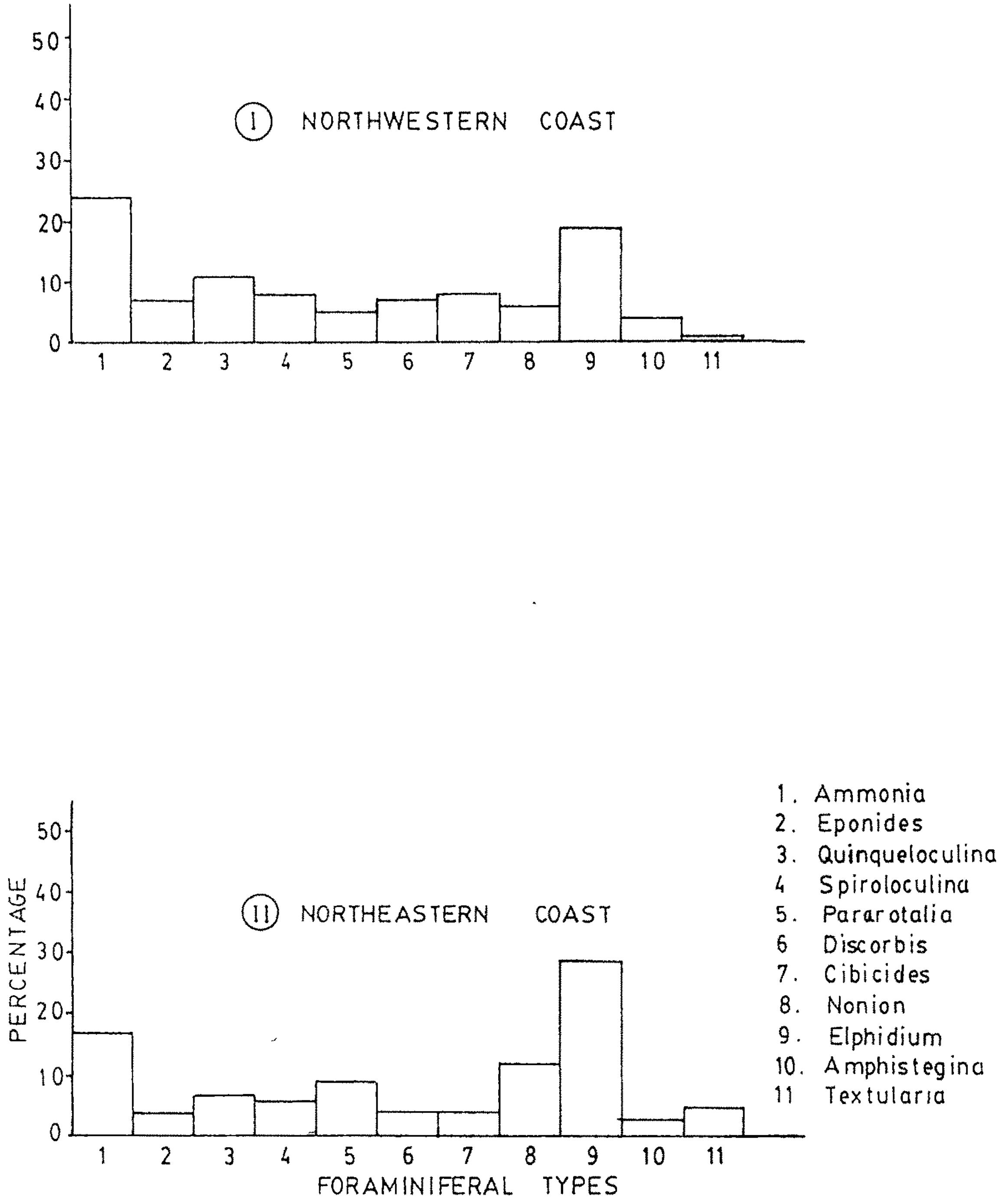


FIG 32 b HISTOGRAM SHOWING VARIATION IN PERCENTAGE OF FORAMINIFERAL TYPES IN BET SHANKHODHAR SEDIMENTS



29.1 OBSERVATIONS AND INTERPRETATION

From the above table it becomes clear that the general trend of the biconvex trochospiral (BT) morphotypes including Ammonia and Eponides has been to decrease in their number from the beach foreshore to the backshore and over the dune ridge surfaces. Such a trend, however is slightly inconsistant in the samples collected from the south of Hanuman Mandir in northeast. The possible reason for such a difference could be that the beach sections at this locality are greatly narrowed and most of the processes that bring gradual reduction in the biconvex trochospiral (BT) morphotype numbers are in all possibly overlapping and intermingling at the Hanuman Mandir Region.

The milioline (M) including Quinqueloculina and Spiroloculina by far maintain a constant rate of their distribution. Their percentage is slightly higher near the foreshore, may be for the wet conditions there, but in the drier localities of the Abhya Mataji beach section and the Hanuman Mandir sections their ratios are almost comparable.

The plano-convex trochospiral (PT) Pararotalia, Discorbis and Cibicides show almost similar trends like the milioline in their overall distribution patterns.

The distribution pattern shown by the rounded-planispiral (RP) Nonion, Elphidium and Amphistegina are rather interesting.

Their occurrence is found to be maximum at the beach-ridge top (around 50% and more). They, however show a gradual (Hanuman Mandir samples) or a sudden (Abhya Mataji Mandir samples) decrease in their percentage ratios. Such an aspect could be attributed to the rounded nature of their tests which can be easily transported by aqueous or aeolian processes of transport.

The conical tapered (CT) varieties Textularia and Bolivina have very insignificant presence, but show consistancy in their overall distribution patterns.

ANIMAL SEDIMENT RELATIONSHIPS

30.1 TRACE FOSSILS-LEBENSSPUREN AND BIOTURBATION

Animal sediment relationships in Bet Shankhodhar Island can best be studied by considering both the ichnological and neoichnological aspects in the sediments. The ichnological aspects involve the study of some excellent biogenic sedimentary structures or trace fossil varities preserved in the older rock strata; while the neoichnology takes into account the various biogenic sedimentary structures of the present day animals living on the various coastal zones.

30.1.1 ICHNOLOGY :

Ichnological studies have been an important tool in the sedimentary facies analysis. The facies analysis these days are particularly benified on two different levels - by wide spread acceptance of the importance of the trace fossils (ichnofossils) in sediment and the use of such structures in depicting the past environments and the depositional patterns. On a broad scale, spatial distributions of trace fossil assemblages have been correlated to their enclosing litho and bio-facies and thus, by inference, to the physico-chemical characteristics that further define the depositional environments. As claimed by Barwis (1985), most of these results have come from studies of ancient depositional sequences, not only because the older rocks lend themselves more easily to three dimensional observations, but also because fewer geologists have studied modern depositional environments, and their neoichnological characteristics.

In context to Bet Shankhodhar Island most of its lithofacies have preserved within them some excellent trace fossil forms. Such traces are represented by wide range of behavioral patterns including dwelling, Ophiomorpha, Thalassinoides, Skolithos, Palaeophycus, Phycodes, Cylindricum, and Monocraterion); feeding, (Zoophycos, Planolites Teichichnus, Rosselia); crawling (Scolicia), and resting (Bergaueria, and Conichnus) burrows. These traces and their densities and associations in the individual facies are likely to provide important clues to the animal sediment responses and the depositional systems as a whole.

In the following paragraphs detail study of all such traces found in Bet Shankhodhar Island has been presented by the author. For these studies the ichnogenera and ichnospecies have been named according to the recommandations of International Committee on Zoological Nomenclature (I.C.Z.N.), using the binomal classification terms used here as are in Chamberlain (1971;

1977); Fursich (1974); Hantzschel (1975); and Seilacher (1953). All these classifications have been applied to the present studies separately or in combinations.

30.1.2. SYSTEMATIC ICHNOLOGY

(I) Dwelling Burrows or Domichnia

ICHNOGENUS : OPHIOMORPHA LUNDGREN, 1871

Diagnosis : These are simple to complex burrow systems distinctly lined with agglutinated pelletoidal sediment. Burrow lining more or less smooth interiorly; densely to sparsely mammalated or nodose exteriorly. Individual pellets or pelletal masses are discoid, ovoid, bilobate or irregular in shape. Characteristics of the lining also may vary within a single specimen. Occasionally the Ophiomorpha burrows are found to be penetrating sediment for more than 1 meter in depth.

Ophiomorpha Ichnospecies in Bet Shankhodhar Island

Ichnospecies : Ophiomorpha nodosa LUNDGREN, 1871

Plate : 51a

Description : The Ophiomorpha nodosa in Bet are usually the large-scale burrow systems of straight to gently curved tunnels with both vertical and horizontal components preserved in full relief. The walls of the burrow are usually smooth on their interior surfaces and distinctly mammalated on the exterior surfaces. The burrow walls consist predominantly of dense, regularly distributed single pellets of construction. Burrow diameter of the large forms is about 4.0 cm and measurable length of about 40 cm (Horizontal burrows). No apertural neck constrictions are observed. Burrows are filled with sediment like that of the surrounding matrix.

Occurrence : It is most common form and occurs in practically all of the litho-facies in Bet Shankhodhar.

Discussion and Interpretation :

The *Ophiomorpha* burrows described here are assigned to the ichnospecies *Ophiomorpha nodosa* on the basis of their predominant single pellet mode of wall formation following the diagnosis of Frey et al. (1978). Pellet form somewhat, ranging from discoid to oval are also found sometime in Bet Shankhodhar sediments. According to Frey et al. (1978), *Ophiomorpha nodosa* burrows are formed by *Callianassa major* and other callianassid species, which live in nearshore sub-environments.

Ichnospecies : *Ophiomorpha borneensis* KEIJ, 1967

Plate : 31a, 46a

Description : *Ophiomorpha borneensis* are characterized by intrastal, irregularly meandering burrows. At times they are found to be vertical or steeply inclined (at places their tubes marking 'U' shaped burrows, cause confusion with *Arenicolites*, but can easily be distinguished from them by their bilobate pelletoidal sediments on the exterior surface). The burrow wall are lined with concentration of bilobate pellets, that form distinct rim which is lighter than the burrow fill material and the surrounding matrix. Rare to scattered ovoid or "single" pellets are also found with the bilobed pellets but these are usually subordinate in their number. The burrow diameter range from 2.0 to 3.5 cm, with an average diameter of 3.0 cm. Length of individual burrows are different at neighbouring burrow populations. The maximum observed length in the Bet sequence is about 45 cm.

Occurrence : Most widely developed burrow in cross-stratified calcareous sandstone (facies - B) and laminated sandstone - shale - claystone (facies - E).

Discussion and Interpretation :

According to Frey et al. (1978) the morphology of this form overlaps with other forms of Ophiomorpha like O.nodosa, and O.borneensis which could be genetically related to each other. Fursich (1974) considered Ophiomorpha borneensis as synonym of Spongiliomorpha saxona, but failed to consider the biobate pellets.

Ichnospecies : Ophiomorpha irregularie

Plate : 51b

Description : These include large, horizontal, straight, unbranched cylindrical burrows. The walls of these burrow forms are usually thick and lined with irregular pellets. Burrow diameter is constant throughout. Length of burrow is of 40 cm and diameter of 4.0 cm. Burrow line is distinct and commonly filled with surrounding matrix. Burrow collapse structures are very common in the Bet sequences.

Occurrence : Occurs in laminated sandstone - shale - claystone facies (facies - E & G).

Discussion and Interpretation :

This form of Ophiomorpha exhibits pelleted to rugose exterior wall surface where the patterns of pellet arrangement is not nearly as regular and distinct as that is found in specimens of Ophiomorpha nodosa (single pelleted wall) or O.borneensis (double pelleted wall).

Ichnospecies : Ophiomorpha sp. LUNDGREN, 1871

Box-Work Burrows

Plate : 32b, 52a,b

Description : These include the large, pelletoidal (single or double) horizontal net-work burrow systems that branch in an orderly manner to form polygonal patterns in the horizontal plane and is confined to a single level in the individual facies. Branches in such burrows are seen typically enlarged at the point of their bifurcation. Individual burrow tubes are 3.5 to 4.0 cm in diameter. The total net-work diameter is about 40 cm. Most of the burrows in the net-work are circular in cross-section and have fills identical to their matrix.

Occurrence : Occurs in cross-stratified calcareous sandstone (Facies - B), and also in facies - A.

Discussion and Interpretation :

The burrow morphology are identical with single pelletoidal forms of Ophiomorpha (O.nodosa) and net work burrow systems probably were constructed to form support of combined dwelling/feeding activities by the crustacean animals.

PLATE : 51

(a) Ophiomorpha nodosa

(b) Ophiomorpha irregularie

PLATE : 52

(a) (i) *Ophiomorpha* box-work burrows, (ii) *Monocraterion*.

(b) Close-up of *Ophiomorpha* box-work burrows.

ICHNOGENUS : PALAEOPHYCUS HALL, 1847

Diagnosis : Palaeophycus are infrequently branched, distinctly lined, essentially cylindrical, predominantly horizontal to inclined burrows in which the sediment fill is typically of the same lithology and texture as the host stratum. Palaeophycus is distinguished from Planolites by having a distinct wall lining and sediment fill typically different from the lithology of the host stratum.

Palaeophycus Ichnospecies in Bet Shankhodhar Island

Ichnospecies : Palaeophycus tubularis Hall, 1847

Plate : 39a

Diagnosis : Thinly lined unornamented, straight to sinuous cylindrical burrows of variable diameter.

Description : The Bet specimens are cylindrical, straight or less frequently branched burrows, parallel or slightly oblique to the stratification. Whenever, branched the branching is irregular with angles varying from 10 to 70. Burrow walls are irregular and the burrow fill is structureless and lithologically identical to the surrounding matrix. At a few locations the burrow segments exhibit physical collapse feature, representing incomplete filling by sediments. Width and length of the burrow tubes in different specimens were found to be varying from a few millimeters to 1 to 4 cm respectively.

Occurrence : Occurs in the laminated sandstone-shale-claystone flacies (facies - C).

Discussion and Interpretation :

Palaeophycus tubularis is distinguished from *Planolites* primarily by wall linings and the character of the burrow fill. Infills of *Palaeophycus* represent passive, gravity induced sedimentation within open lined burrows. Collapse features show that segments were incompletely filled by this process.

Ichnospecies : Palaeophycus alternatus PEMBERTON and FREY, 1982

Plate : 39b

Diagnosis : Alternately striate and annulate burrows of periodically varying diameter.

Description : Palaeophycus alternatus burrows are slightly curved, thinly lined with regularly varying dimensions, finely striated longitudinally and in places distinctly annulated, striae consists of thin ridges and grooves, best developed where annulations are absent. Where annulie are well developed, 4 to 5 per cm, burrow diameter decreases. Palaeophycus alternatus preserved as epichnial ridges. Full relief; burrow fill identical with the matrix.

Occurrence : It occurs in facies laminated sandstone-shale-claystone (facie - C).

Discussion and Interpretation :

The periodic change from striate to annulate parts of burrows according to Pemberton and Frey (1982) reflects a change from direct locomotory to peristatic movements by trace marker.

ICHNOGENUS : CYLINDRICUM LINK, 1949

Diagnosis : Cylindricum are plug shaped burrows - like test tubes, rounded at lower end. Walls of the burrows are smooth. Burrows oriented perpendicular to bedding plane.

Cylindricum Ichnospecies in Bet Shankhodhar Island

Ichnospecies : Cylindricum sp. LINK, 1949

Plate : 45a, 53

Description : These are simple, straight, cylindrical burrows which are unbranched and perpendicular to bedding plane. These are preserved as hyporeliefs in lithofacies laminated sandstone shale claystone alternations. Diameter of the individual burrow varies with different burrow populations. The maximum observed diameter being 2.5 cm. Burrow sometime preserved on bedding plane appears as circular cross-cuttings (Plate 45a) and may be characterized by their raised rims. Most of the burrows in Bet sequence were found empty or partly filled, with fill identical to their host material. Many of these traces were found preserved on the ripple crests (Plate 45a,53).

Occurrence : These structure were found in facies - (E) laminated sandstone shale claystone alternations.

Discussion and Interpretation :

Link (1949; p. 19) interpreted, *Cylindricum* burrows are plugs shaped, like test tubes, rounded at lower end not pointed, walls smooth, diameter upto 5 cm; up to several cm long; preserved in groups in convex hyporelief oriented perpendicular to bedding plane. Following Link (1949) the author have interpreted his specimen of Bet as *Cylindricum*. Such structures are dwelling burrows of worm like animal.

PLATE : 53

Cylindricum in facies - E.

ICHNOGENUS : THALASSINOIDES EHRENBERG, 1944

Diagnosis : Thalassinoides include large burrow systems consisting of smooth-walled essentially cylindrical components. Branches 'Y' to 'T' shape and typically enlarged at points of bifurcation are characteristics of these burrow forms. Burrow dimensions are variable within a given system.

Thalassinoides Ichnospecies in Bet Shankhodhar Island

Ichnospecies : Thalassinoides sp EHRENBERG, 1944

Plate : 33b, 54

Description : These burrow systems are very thinly lined to unlined. The net work is largely horizontal and is confined to a single level in the sediment. Bifurcations are 'Y' shaped with noticeable enlargements at the junctions; some of the branches terminate after a short distance as blind tunnels. The walls are smooth with scratch marks at some place. The burrow diameter varies from 2-3 cm in some specimens.

Occurrence : It occurs in cross-stratified calcareous sandstone (facies - B), and also in laminated sandstone shale-claystone (facies - C).

Discussions and Interpretation :

The unlined burrow systems appear to be characteristic of cross-stratified calcareous sandstone and laminated sandstone-shale-claystone facies represents coherent substrates, in which wall reinforcement was not necessary. The burrows are interpreted as dwelling or combined feeding-dwelling structures of crustaceans.

PLATE : 54

(i) <u>Thalassinoides</u>, and (ii) <u>Teichichnus</u> in facies - C.

ICHNOGENUS : SKOLITHOS HALDEMAN, 1840

Diagnosis : *Skolithos* are straight, cylindrical to subcylindrical, vertical to i+nclined smooth walled burrows that are parallel to each other.

Skolithos Ichnospecies in Bet Shankhodhar Island

Ichnospecies : Skolithos sp. HALDEMEN, 1840

Plate : 37b

Description : *Skolithos* are straight, vertical, unbranched cylindrical burrows with a diameter ranging from 2.0-2.5 cm. The walls of the burrows are smooth and lack any ornamentation. No lining or funnel shaped apertures have been noticed in most of such burrow tubes. Burrow fill material is identical to matrix and mostly seen as circular to subcircular outlines on bedding plane. Some hard burrow tubes preserved as raised rim structure against resistance to erosion are also seen (Plate 37b).

Occurrence : Occurs in facies laminated sandstone-shale claystone alternations (facies - C & E).

Discussion and Interpretation :

According to Chamberlain (1977), *Skolithos* widely occurs in shallow water intertidal deposits, and in flood plain facies. *Skolithos* is interpreted as the dwelling burrow of a suspension feeding animal (Alpert 1974). According to Seilacher (1967) and Crimes (1975) it is common in sediments deposited under high energy tidal and nearshore conditions. The Bet species is envisaged to represent similar environmental conditions.

ICHNOGENUS : MONOCRATERION TORELL, 1870

Diagnosis : Vertical, more or less cylindrical shafts having a broad, funnel like opening at the upper end.

Monocraterion Ichnospecies in Bet Shankhodhar Island

Ichnospecies : Monocraterion sp. TORELL, 1870

Plate : 52a

Description : Monocraterion trace consists of straight, cylindrical unbranched tubes oriented normal to bedding which very often passes upward into an ovate funnel. The funnel is characterized by the central downward deflection of sedimentary laminae. Funnel width is variable, the maximum observed being 2 cm. Shafts 0.4 to 0.5 cm in diameter with maximum observed length of 4 cm.

Occurrence : Occurs in cross-stratified calcareous sandstone (facies - B).

Discussion and Interpretation :

The ichnogenus Monocraterion ranges in age from Cambrian to Recent and is typically found in shallow water sediments. These burrows have been interpreted as funnel-shaped tops to the Skolithos burrows. The funnel top being formed by the upward motion of a suspension feeding annelid in response to higher rates of sedimentation (Hallam and Swett, 1966).

ICHNOGENUS : PHYCODES RICHTER, 1850

Diagnosis : Phycodes are fan or radial system of horizontal branching burrows. Burrows essentially of uniform width throughout, and may be long, linear or slightly curving. Branching is close together.

Phycodes Ichnospecies in Bet Shankhodhar Island

Inchnospecies : Phycodes sp. RICHTER, 1850

Plate : 55

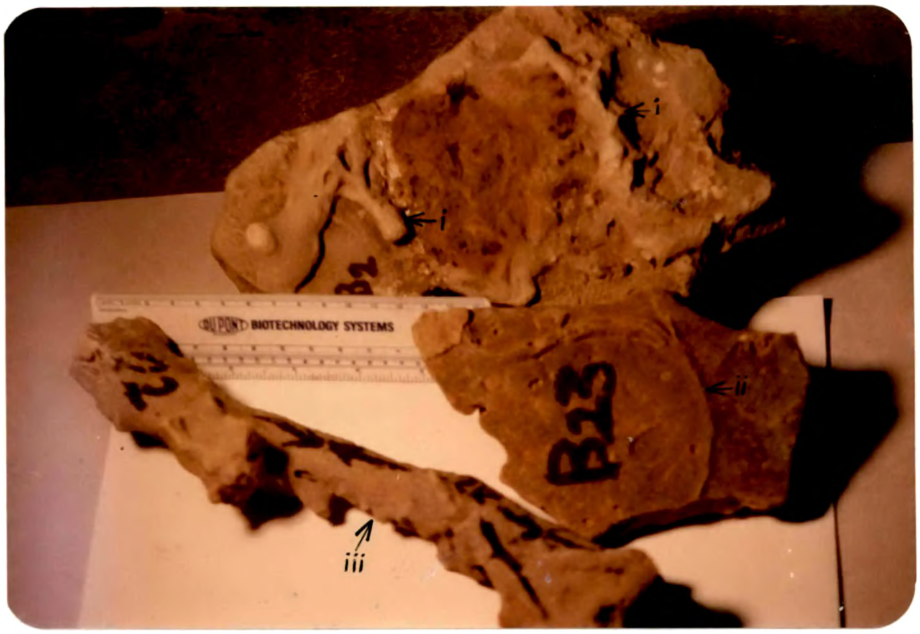
Description : Large bundles of burrows with minimal spreite development. Individual burrows mostly 1 to 1.5 cm in diameter, complete trace 7 to 8 cm in length. Burrows spread out from place of origin like a bunch of flowers.

Occurrence : Occurs in laminated sandstone-shale-claystone (Facies - C).

Discussion and Interpretation :

These are large burrow systems similar in size and form to examples described by Crimes and Anderson (1985) from the lower Palaeozoic of Newfoundland (Canada).

PLATE : 55



(i) Phycodes; (ii) Scolicia, and (iii) Thalassinoide in facies - C.

(II) Feeding Burrows of Fodinichnia

ICHNOGENUS : ZOOPHYCOS MASSALONGO, 1835

Diagnosis : Zoophycos is a variably shaped spreiten structure composed of numerous small protrusive more or less 'U' or 'J' shape burrows of variable length and orientation, with spreiten arranged as tabular or helicoid spirals giving an overall circular elliptical or lobate impression.

Zoophycos Ichnospecies in Bet Shankhodhar Island

Ichnospecies : Zoophycos sp. PLICKA, 1968

Plate : 45b

Description : The Bet specimen is typically planar or sub-horizontal with a planar imprint of an uncoiled spiral arrangement. The maximum observed length is about 9.5 cm and diameter of 2 to 3 cm. Cross section of the laminae displays lunate structures. Such structures are displayed by the addition of new segment constructed alongside the previous one as the animal rectracted and proceeded on its new course. This type of burrow indicate efficient mining of a nutrient rich substrate. Each course of the burrow represents the action of a vermiform organism as it moved in the substrate and ingested sediment.

Occurrence : Occurs in facies laminated sandstone-shale-claystone alternations (facies - G).

Discussion and Interpretation :

This trace fossil is regarded as a complex feeding structure, involving successive tunneling of a series of feeding probes by an unknown worm-like animal that probably lived in a shallow-marine environment (Simpson, 1970; p. 511).

ICHNOGENUS : TEICHICHNUS SEILACHER, 1955; 1957

Diagnosis : Blade-like and gently curved, rarely branched spreiten structures consisting of several closely cocentric, horizontal or inclined longitudinally nested burrows inosculating to simple, singular tunnels. Burrows within a given spreite displaced upward (protrusive) or downward (retrusive), and oriented at various angles with respect to bedding.

Teichichnus Ichnospecies in Bet Shankhodhar Island

Ichnospecies : Teichichnus sp. SEILACHER, 1955; 1957

Plate : 54

Description : Long, wall like burrows formed by vertical displacement of horizontal and oblique tubes. The retrusive part of the specimen (Plate 54) is very well preserved. This retrusive part is in straight to somewhat sinuous and does not show any signs of branching. It is found lying at an angle of about 35 to the horizontal in the sediment. The diameter of the final burrow on top of retrusive part is somewhat smaller than the diameter of the basal part. Teichichnus burrow preserved as full relief; fill identical with the matrix.

Occurrence : It occurs in facies laminated sandstone-shale claystone (facies - C).

Discussion and Interpretation :

Seilacher (1955, p. 122) interpreted *Teichichnus* as the result of the upward shift of a more or less horizontal burrow which might be 'U' shaped. Chisholm, 1970 (in Fursich, 1974; p. 41) described *Teichichnus* and found forms intermediate between *Teichichnus* and *Rhizocorallium* and suggested that these two ichnogenera and *Diplocraterion* are closely related to each other. Seilacher (1957, p. 203) has figured structures comparable to *Teichichnus* made by the Recent *Nereis diversicolor*.

ICHNOGENUS : ROSSELIA DAHMER, 1937

Diagnosis : Rosselia are cylindrical thick burrows, commonly oblique to bedding. In most of these burrows the lower end is seldom observed. Opening of the burrow tube is characteristically filled with concentric layers of matrix which as a rule are strongly weathered.

Rosselia Ichnospecies in Bet Shankhodhar Island

Ichnospecies : Rosselia socialis DAHMER, 1937

Plate : 56a,b

Diagnosis : Rosselia are typically conical to irregular bulbous structures, essentially vertical in nature. The central burrow is often surrounded by broad concentric funnel-like laminae, tapering downward to a concentrically walled stem.

Description : Rossellia socialis forming funnel shaped oblique or vertical burrows preserved in full relief are found in facies cross-stratified calcareous sandstone in Bet Shankhodhar Island. The characteristic upper flared portions of these burrows are 6 to 10 cm in diameter which exhibit concentrically laminated fill. Vertical burrows are found to extend downwards forming a cylindrical stem having maximum observed length of about 16 cm with diameter of 3.5 cm (Plate 56a,b) Most of the specimens are circular in cross-section, though a few are elliptical.

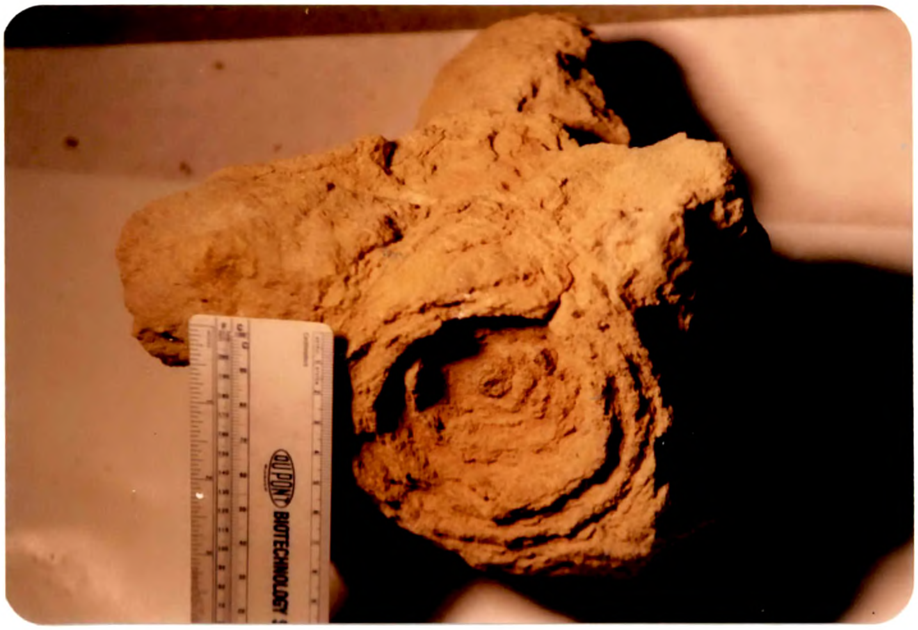
Occurrence : Occurs at the contact of facies cross-stratified calcareous sandstone (facies - B) and laminated sandstone shale-claystone (facies - C).

Discussion and Interpretation :

Funnel morphology of the Bet specimens resembles the Aasterosoma forms with helical funnels as described by Frey and Howard (1972). Seilacher (in Hantzschel, 1975; p. W 101), considered Rosselia to be a junior synonym of Asterosoma Chamberlain (1971) interpreted Rosselia as feeding or dwelling burrow of an annelid or worm like animal. According to Frey (1970) the structures can be attributed to crustacean. Ksiazkiewicz (1977) recognized such structures to have been made by sea anemone.

PLATE : 56

(a) Rosselia socialis in facies - B.



(b) Close-up of Rosellia socialis.

(III) Crawling Burrows or Repichnia

ICHNOGENUS : SCOLICIA DE QUATREFAGES, 1849

Diagnosis : Scolicia include horizontal bilaterally symmetrical trails of great variability. They are usually long, bandlike (depending on their origin as surface trails or internal trails), having varied sculptures caused by different methods of burrowing, creeping and removing sediment upto about 4 cm depth.

Scolicia Ichnospecies in Bet Shankhodhar Island

Ichnospecies : Scolicia sp. DE QUATREFAGES, 1849

Plate : 55 & 57

Description : The trace fossils interpreted as Scolicia sp. in Bet consist relatively large, sinuous, bilobed horizontal trails which often consist of median furrows that separate into two marginal ridges. The trails are preserved in concave and convex epirelief, typically 15 to 20 mm wide and 25 to 30 cm long. Sometimes median furrows get disappear and trails preserved are flat ribbon-like in their appearance.

Occurrence : Occurs in facies laminated sandstone-shale-claystone alternations (facies - D).

Discussion and Interpretation :

Scolicia like trails are very widely variable in morphology because very often the trail making activity was controlled by substrate consistency and apparent movement of the animal on the substrate. In older sediments *Scolicia* generally attributed to gastropod activity because the specimens of *Scolicia* display a range of variation comparable to that of modern snail traces (Miller and Knox, 1985).

PLATE : 57

Scolicia in facies - C.

ICHNOGENUS : PLANOLITES NICHOLSON, 1873

Diagnosis : *Planolites* are characterized by unlined rarely branched, straight to tortuous, smooth to irregular wall or annulated burrows, circular to elliptical in cross-section of variable dimensions and configurations. Infilling of such burrows is essentially structureless, differing in lithology from host rock.

Remarks : *Planolites* is a broad ichnogenus ranging from Precambrian to Recent and is simple in form. According to Hantzschel (1962; 1975), and as suggested by Pemberton and Frey (1982) and Crimes and Anderson (1985) *Planolites* species can be broadly grouped into three distinct forms, based on size, curvature, and wall characteristics eg : *Planolites beverlyensis*, *P. montanus* and *P. annularis* respectively.

Planolites Ichnospecies in Bet Shankhodhar Island

Ichnospecies : *Planolites montanus* BILLING, 1862

Plate : 37a

Diagnosis : Planolites are back filled structures which are of variable sizes. The burrow structures are smooth, straight, slightly to gently curved or undulose cylindrical.

Description : Planolites observed in Bet sequence are variable in sizes, essentially horizontal, cylindrical, smooth walled, straight to gently curved, irregular branched to unbranched burrows, preserved on the bedding planes as positive hypichinal ridges. The occurrence of these burrows range from single isolated specimens to crowded masses in which crossovers interruptions and reburrowed segments are common (Plate 37a). In Bet specimen the length of the larger burrow varies from 6 to 10 cm and diameter of 0.7 to 1.0 cm. As suggested by by Pemberton and Frey (1982), Planolites can be distinguished from Palaeophycus primarily by having unlined walls and burrows fill differing in texture from that of the adjacent rocks. As suggested by these authors, burrow fill also differ in fabrics, composition and colour.

Occurrence : Occurs in facies laminated sandstone - shale - claystone alternations (facies - C)

Discussions and Interpretation :

The morphology of the traces is sufficient to distinguish them from the Palaeophycus. Planolites beverlyensis is distinguished from P. montanus primary by the large size and P. annularis, by the absence of annulation. Planolites are interpreted as produced by the deposit-feeding activities of worm -like animals (Hantzschel 1975).

(IV) Resting Burrows or Cubichnia

ICHNOGENUS : BERGAUERIA PRANTL, 1945

Diagnosis : *Bergaueria* are cylindrical protrusive burrows with smooth walls. Length and diameter of such burrows is subequal, lower ends rounded, with shallow depression which is sometimes subrounded by 6 to 8 very short radially arranged tubercles. Some species display biradially symmetrical impressions on ventral surface.

Bergaueria Ichnospecies in Bet Shankhodhar Island

Ichnospecis : *Bergaueria hemispherica* CRIMES et al 1977

Plate : 38a

Description : The *Bergaueria* trace fossil in Bet Shankhodhar is a vertical, hemispherical structure with positive hyporelief. The trace is randomely distributed. Such burrows are upto 15 cm in diameter and 8 to 10 cm in vertical length. Individual forms are circular in plane with their external margin smooth or slightly granular. Concentric ornamentation is absent. The base is smooth and rounded.

Occurrence : Occurs in cross-stratified calcareous sandstone (facies - B).

Discussion and Interpretation :

The structures found in Bet in further closely resemble Bergaueria Prantl (as figured by Hantzschel, 1975; Alpert, 1973). Bergaueria hemispherica differ from B. perata (Prantl, 1946), and B. radiata (Alpert, 1973) by the absence of a central depression and distinct radial ridges, Prantl (1946) as quoted by Fursich (1974) suggested that Bergaueria might represent the burrows of some anthozoans or allied forms. Bergaueria has been interpreted by various authors (Alpert, 1973) as the casts of burrows made by sedentary organisms such as coelenterates and anthozoans. Perhaps the suspension feeding coelenterates like the actinian anemones. Seilacher (1964) and Crimes et al. (1977) consider Bergaueria to be more common in shallow-water deposits.

ICHNOGENUS : CONICHNUS MYANNIL, 1966

Diagnosis : *Conichnus* burrows are fillings of conical or conelike hollows; mostly very regular forms circular in cross section; lower end round, without distinct mammaliform peak, thus differing from *Amphorichnus* MYANNIL.

Conichnus Ichnospecies in Bet Shankhodhar Island

Ichnospecies : *Conichnus* sp. MYANNIL, 1966

Plate : 38a

Description : These structure observed in Bet Shankhodhar include stumpy, cylindrical or conical bodies with apex directed upward; oriented subvertically in bed. Such conichnus display maximum observed length of about 12 cm, and diameter of about 8 cm, which gradually decrease upward. Preserved in full relief in facies - B.

Occurrence : Occurs in cross-stratified calcareous sandstone (facies - B).

Discussion and Interpretation :

Myannil (1966) described *Conichnus* as a dwelling burrows or resting trail produced by cerianthid sea anemone; somewhat similar "genera" as *Bergaueria* Prantl (1946).

30.2 NEOICHNOLOGICAL OBSERVATIONS IN BET SHANKHODHAR

Neoichnology includes study of present day organisms and their traces as claimed by Frey (1975). Neoichnology lays a foundation for consideration of fossil lebensspuren, as well as making palaeontological information gained from present-day traces useful without comparable fossil examples necessarily being considered. Seilacher (1953), Ladd (1959), Schafer (1972) have also stressed the importance of the study of present-day organisms and their habits in the interpretation, of body fossils and trace fossils. As suggested by Chamberlain (1975), the study of recent lebensspuren has same distinct advantages. The traces can be directly studied in modern beaches, salt marshes, tidal flats and coastal dunes etc. Another advantage as suggested by him includes many new, original observations that can be made on both the trace making organisms and their traces.

The main purpose of the author in presenting the neoichnological discussion here, will be to summarize the characteristics of lebensspurens observed by him on the nearshore sedimentary facies zones of the Bet Shankhodhar Island, and to discuss the implications of such lebensspuren with regards to their sedimentary environments.

A general review of ichnocoenoses (trace fossil assemblages) in Bet Shankhodhar indicate that the traces of marine animals here are both abundant and diverse in different environments viz.

the beaches, mud flats and the beach-ridge sections. The traces include dwelling structures, resting, and crawling traces, and feeding burrows. The animals originating such lebensspuren or traces are discussed by the author with these views and are separated into two major groups : - one that either lacks hard skeletal parts (worms), or does not rely exclusively upon hard parts (gastropods), and the other that uses spines or appendages in burrowing (decapods, echinoids).

30.2.1 LEBENSSPUREN IN THE BEACH SEDIMENTS

Beaches in Bet Shankhodhar Island are variously bioturbated by the lebensspuren of decapods, worms and gastropods. Their abundance and diversity, however is different at different beach sections viz. foreshore, backshore and beach dune sections.

(i) Decapod burrows : Deepod or crustacean burrows are represented in the Bet coastal zones and beaches by the burrows of the ghost shrimp Callianassa major, and the Ocypode quadrata burrows.

The beach foreshore area in Bet is invariably found characterized by the burrow systems of the shrimp Callianassa major. The highest density of such burrow openings is observed in the lower foreshore beach section, i.e. between mean-sea-level and mean-low-water-level; In the upper foreshore, the burrow openings are relatively low. As suggested by Frey (1975) C. Major burrows are characteristics of intertidal (i.e.

eulittoral) environments of high energy, such as tidal flats, shoals, and point bars in tidal streams.

In the beach backshore and lower dune proximities, burrows of the ghost crab <u>Ocypode quadrata</u> are the characteristics lebensspuren. The occurrence of this quassiterrestrial crab is rather limited approximately by mean high-water level. The greatest abundance of burrows, mainly related to adult individuals is observed in the upper backshore region (Plate 58a,b). Younger individuals on the other hand are found to prefer the lower backshore and the backshore - foreshore transition zones because the younger individuals apparently need more mositure for respiration than do the adults. Such observations are also reported by Frey (1975). Thus, an ichnological sub-zonation of the beach-backshore zone in Bet Shankhodhar Island based on abundance of ghost crab burrows is possible.

The burrowing mechanism adopted by both these decapod burrower is rather interesting. These organisms are found to depend almost totally on their appendages, which are used as levers in burrows. Very often the decapod burrow by its posterior end in the sediment, burying itself until only one or two antenae are left above substrate surface (Figure 33). After contact with the sediment, the first pairs of legs move back and forth, pushing the body backward and the sand through their antero-lateral margins upward.

The kinds of traces left by the decapods therefore depend on how the burrow has been constructed. In the fossil record the decapod burrows are variously referred to the trace fossils known as Thalassinoides, Ophiomorpha and a maze of large and small burrow system called the box work burrows.

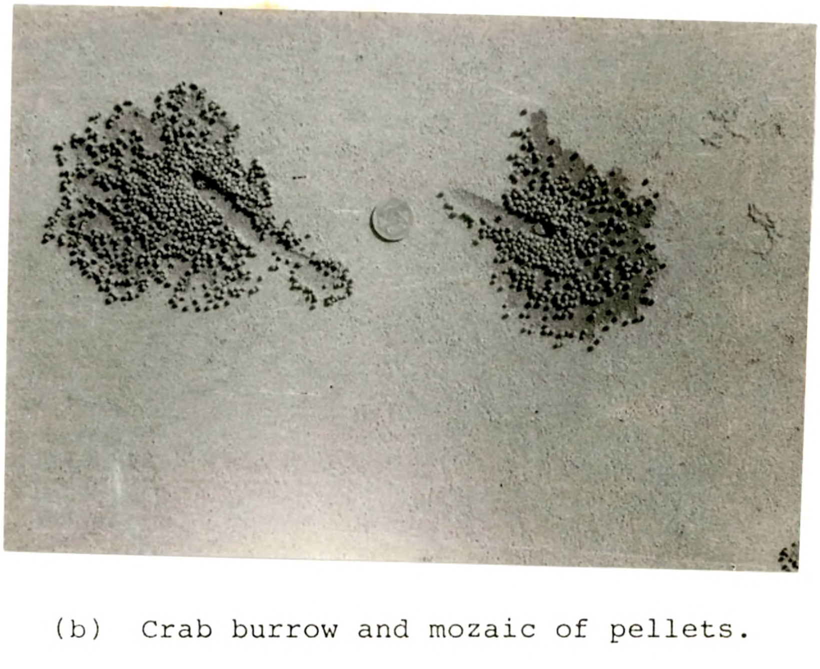
The substrate architecture of the decapod burrow systems observed in various coastal zones of Bet Shankhodhar Island is depicted (Plates 58a,b & 59b).

(ii) Polychaete annelid or worm burrow : Another important lebensspuren observed in Bet Shankhodhar include burrows of polychaete annelids especially on the beach foreshore and mud flat regions. In these zones such burrows are usually developed in great densities but are found to be destroyed very often after the death of the animal by sediment reworking and especially during the gradual shifting of beach ridges and runnels.

The beach foreshore and mud flat zones were the polychaete burrows prevail in larger quantities show variety of adaptations which result in numerous types of lebensspuren left in sediment. Significantly, the shape and structure of these traces depend on the morphology and life functions of the organisms. For example, the burrowing activity of the most common polychaete "Arenicola" results in a U-shaped burrows (Figure 33a) consisting of a sediment filled shaft, a gallery and an open shaft. The

PLATE : 58

(a) Mozaic of Crab pellets & food searching coastal bird track.



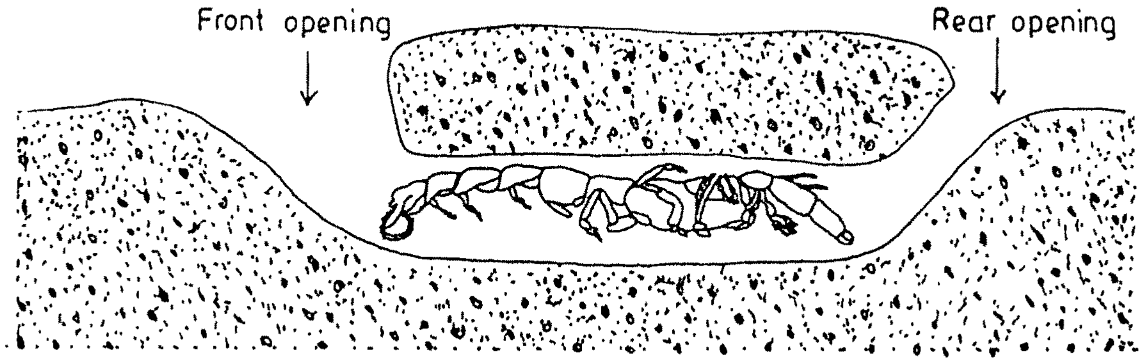
(b) Crab burrow and mozaic of pellets.

polychaete _Lanice_ penetrate the sediment leaving a simple cylindrical burrow (Figure 33b).

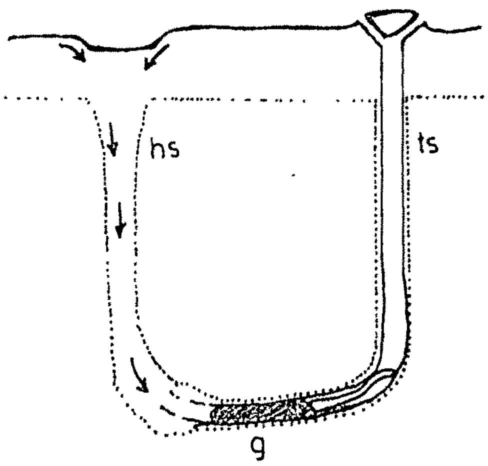
Tubes comparable to _Arenicola_ and _Lanice_ in the fossil record can be assigned to the trace fossil genera _Arenicolites_ and _Skolithos_ respectively.

(iii) _The Gastropod Lebensspuren_ : Gastropods of various types (identified only a few) are the other invertebrates that are found to develop some spectacular lebensspuren in the beach foreshore-backshore and the mud flat regions in the Bet Shankhodhar coastal zone. Such lebensspuren are variously represent by different kinds of trails, tracks and burrowing activities (Plate 59a, 60a,b, & 61a,b). The gastropod trails are observable only on or near the surface sediments. Howard (1968) found that movement in some gastropods creates sand ridges ahead and alongside the organism and a furrow behind. As observed by Frey and Howard (1972) in some gastropods (_Littorina littorea_) there exists a median band and two side walls. The median band is either smooth or segmented, and the side walls smooth, segmented, or absent. According to these authors six kinds of trail formation are possible in gastropods. These kinds will mainly depend on segmentation of the median band consisting of forward-convex cross-grooves and elevated intergroove areas. Sometimes a furrow or ridge may be seen in the middle of the median band; this is caused by the median line, which divide the sole of the snail foot into two halves.

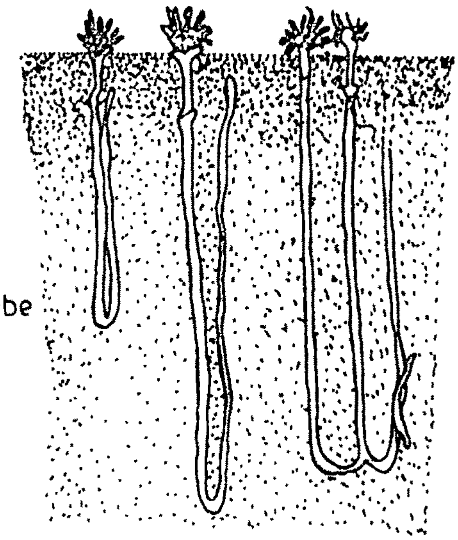
FIG. 33



(a) Burrowing Callianassa major.



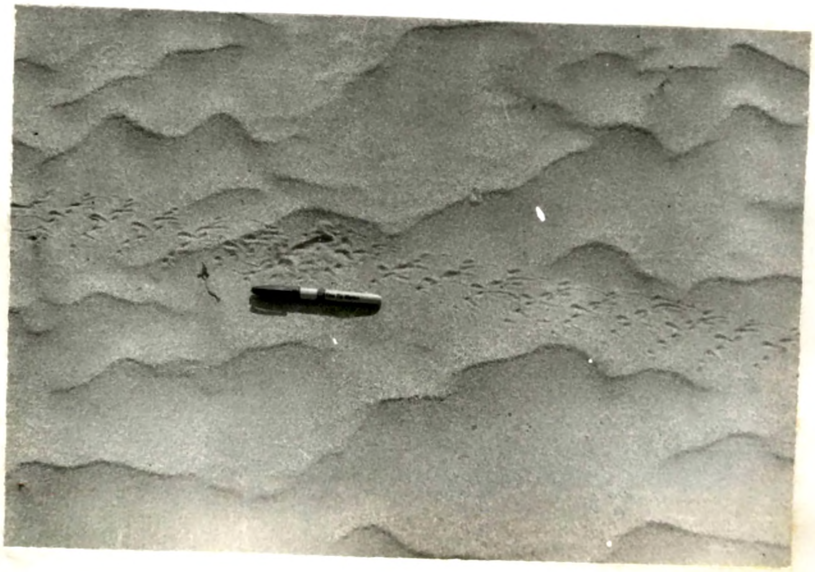
(b) Arenicola burrow, showing the head shaft (hs), gallery (g), and tail shaft (ts). Arrows indicate movement of sand down the head shaft, allowing Arenicola to feed inside its burrow. (Modified after Wells, 1945 & Frey, 1975)



(c) Dwelling burrow tube of polychaetes

PLATE : 59

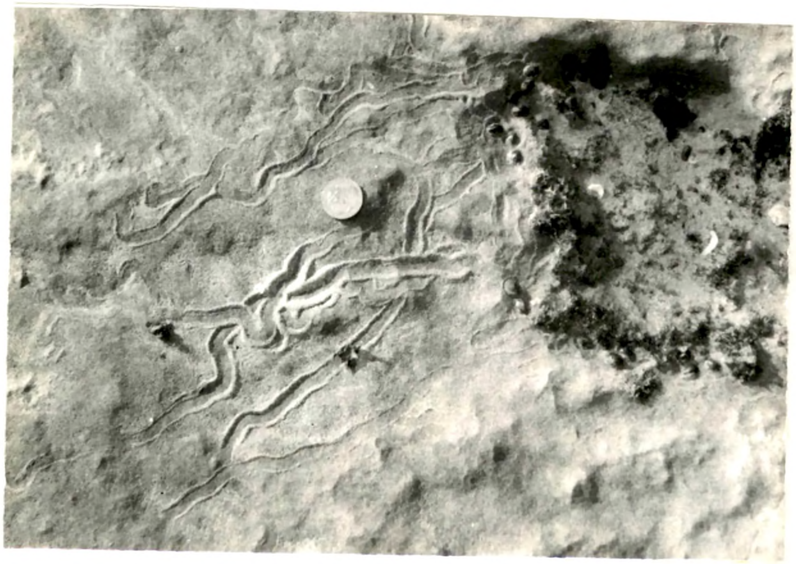
(a) Burrowing gastropods



(b) (i) Crustacean trails (ii) Swash marks in backshore beach.

PLATE : 60

(a) Gastropod trails in backshore beach.



(b) Gastropod trails in foreshore zone.

PLATE : 61

(a) Gastropod trails, faecal pellets and ripple marks in foreshore mudflat.

(b) Gastropod trails in foreshore zone.

In light of the above discussions the Bet Shankhodhar ichnofossils and neoichnological features of the gastropod trails are very significant. Following deductions regarding the mechanisms adopted by the gastropods in Bet sediments could be ascertained :

(1) In all possibilities the gastropod foot or the flat sole was mainly adopted by the organisms for creeping over the various substrates along the beach foreshore - backshore and near dune areas.

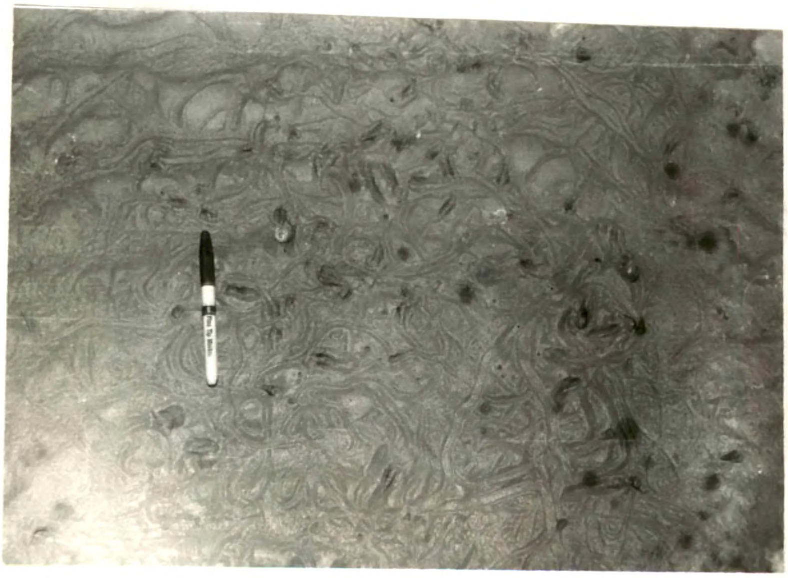
(2) The muscular creeps generating the waves (making trails) appear to be passing along the foot either in an anterior (direct) or a posterior (retrograde) direction (Plate 60b).

(3) Burrowing in Bet has been restricted to the naticid and turritelid forms (Plates 62a,b). This is achieved by continuation of normal surface motion or as being similar to the feature produced by a ball moving through the substrate (Plate 62a). The burrowing of turritellids (Plate 62b) in Bet appears to be comparable to the process described by Yonge, (1946). According to him, burrowing turritella create water currents to oxygenate the gills, and these currents are often passed through connections maintained with the substrate surface.

As further suggested by Yonge (1946), on burrowing the turritella's foot creats an inhalent depression by pushing mud to

PLATE : 62

(a) Gastropod trails in mud flat.



(b) Bioturbation by turritella gastropods in mud flat.

the right, the sediment then partly consolidated by its mucus and pedal glands, forms a low mound in front of the head.

Lastly, the gastropod lebensspuren in Bet can be compared with the following ichnofossil forms :

1. Helminothopsis Plate 62a
2. Cosmorhaphe Plate 60b,62b .
3. Neonereites Plate 61a

30.2.2 LEBENSSPUREN IN THE MUD FLATS : The mud flat zones in Bet Island are usually characterized by relatively low tidal ranges. In this zone a dense population of the worms having closely spaced vertical burrows, and complex burrow systems of decapods with irregularly branched interconnecting pattern is very often observed. The other lebensspuren which are found in this zone include some very dense gastropod trails (Plate 62b), burrowing gastropods (Plate 58a) and the mud scrapers nests (Plate 63).

30.2.3. LEBENSSPUREN ON THE DUNE, DUNE RIDGE SYSTEM

The marine or near shore aquem traces are greatly reduced in this zone, some crab pellet, mosaics, crab trails, and bird tracks are often found only at the low level dune regions (Plate 58a).. Contrary to these evidences the dune and dune ridge systems in Bet Shankhodhar are either completely barron of any lebesnsspuren or are sometimes found traversed by some unidentified insects and bird trails/and tracks.

PLATE : 63

Mud scrapers nests in foreshore zone.

IMPLICATIONS OF THE TRACE FOSSIL AND NEOICHNOLOGICAL RECORD IN BET SHANKHODHAR

The trace fossil record in Bet Shankhodhar Island as summerized in tables 21 and 22 indicate domination of the dwelling and feeding burrows by the crustaceans and polychaete worm burrows. The resting burrows although present in minor proportions are rather significant to indicate the presence of sea anemones living in the past.

As argued by Howard (1975) such a lebensspuren or trace fossil record which forms the actual part of the sediment substrate, can be advantageously used to furnish valuable information concerning (1) general depositional processes, (2) episodes of local deposition and erosion, (3) characteristics of currents, substrate consistency, and (4) in some cases causes of sediment sorting. The important point according to Howard (1975) is that within a depositional sequence, the biogenic structures or lebensspuren can be used as subtle indications of change in facies, which in turn indicate a change in the overall depositional environments.

In the above context it will now be worthwhile to examine the biosedimentary record available in the Bet Shankhodhar Island and test some of these concepts and ideas relating to the ichnological implications in general.

31.1 LEBENSSPUREN AS INDICATORS OF DEPOSITIONAL PROCESSES

The primary depositional features in any depositional system are characterized by the processes of erosion and sedimentation. As stated by Howard (1975), conditions of erosion and sedimenttion always occur when the rock is a part of a dynamic sedimentary environment. Specific clues to these processes as indicated by him could be found in the abrupt truncations of burrows and bioturbation textures. Ignorance to recognise these breaks according to him is likely to result in an interpretation of slow-continuous sediment accumulation, when in fact the sequence is resulted from intermittent deposition and erosion.

Following, the above line of thought, the best way to understand the depositional environments in Bet Shankhodhar Island according to the present author will be to consider various conditions under which the trace-making organisms could have existed in the depositional system. Such considerations could be made within a bedding unit or the sequence of bedding units representing the individual facies, and the break in deposition in such case may represent little or longer time. It is further felt by the author that towards such an understanding in context with the Bet situation following conditions are likely to be encountered.

(A) Continuous deposition :

(i) Slow rate of deposition : In case of continuous slow uninterrupted sedimentation, the record is likely to be one of complete biogenic reworking generally by a variety of biogenic organisms. In such cases as suggested by Howard (1975), the high degree of bioturbation has more to do with the amount of time available for biogenic activity per unit accumulation of sediment than with animal density or activity.

Examples of such relationship can be observed in Bet lithofacies A,B and C respectively (Plates 33a,33b & 37b, 44b). Here most of the organisms have not moved extensively through the substrate but have used it as an anchoring medium. These animals were dependent directly or indirectly on the overlying water for respiration, neutrients and food.

(ii) Fast rate of deposition : In this context, an essential provision is that following deposition, little or no erosion occurs, and in case of "catastrophic" event, conditions return more or less to what they were before the event occured (Howard; 1975).

Following these criteria the important considerations to be traced in Bet lithofacies in case of rapid sedimentation are that the organisms have reestablished themselves in the bed following deposition or have moved upward from below, or while given sufficient time (for the conditions to prevail) have destroyed the original biogenic structures.

Such relationships may be observed in facies 'B' and 'C' (Plates 36a,b, 37a & 46b). In facies B (Plate 36a) the chances for organisms to succeed in penetrating the new unit of sedimentation is probably related to the material laid down above them. In 'B' and 'C' (Plate 37a, & 33b) of rapid deposition, the abruptly deposited units are interbedded with units of considerably fine-grained textures. Because of this contrast, two additional factors have affected the ichnological record. First the contrasting texture permits preservation of many biogenic structures that were present in the preexisting subjacent with (facies-B) and on the upper surface of the depositional unit (facies - C) (Plates 37a, 33b).

(B) <u>Discontinuous</u> <u>deposition</u> :

(i) Variable rate of deposition - no erosion : Organisms in such conditions like the slow continuous sedimentation are able to keep pace with the addition of new sediments. As argued by Howard (1975) if thick beds are deposited rapidly, separated by intervals representing slow deposition but no erosion, stacking of essentially the same bedding types as those resulting from rapid continuous sedimentation would result. Under these conditions, the breaks in time can be recorded by bedding planes that form because of the setting out of finer materials between times of major sediment accumulation. In the absence of such silt or shale breaks as suggested by Seilacher (1964) features such as : horizons of concentrated burrows or feacal pellet accumulations in units otherwise lacking any evidence of change in sedimentation have to be considered. Also to be documented very carefully as per Seilacher (1964) are the absence of erosional indicators, such as truncated terminations of vertical burrows and bioturbation structures modified by scour.

Example of variable rate of deposition and no erosion in Bet can be cited from facies A,B, E and G, (Plates 32b, 44a, 45a, 46a, 53 & 64a).

(ii) Variable rates of deposition with erosion :

These are the most common depositional types in Bet Shankhodhar Island in which discontinuous periods of sediment accumulation are preceded and followed by erosion. This situation results in one of the most common kind of bedding units in facies A,B and F (Plates 31b, & 47). Here, the cyclic erosion and deposition produces a very specific type of stratification. Such a bedding type can be referred to as "parallel laminated to burrowed" (Plate 32a & 64b) characterized by an erosional upper and lower contacts. The lower part of the bed lacks or is improvised in recognisable biogenic features and is characterized by physical sedimentary structures in the form of parallel laminated sand. The biogenic structure in facies B and F are

PLATE : 64

(a) Trace fossils and substrate consistancy revealed by Ophiomorpha burrows.

(b) Ophiomorpha irregularie and some unidentified burrows indicating variable rates of deposition with erosion.

further observed to be generally increased upward within the bed and gradually have become the dominated sedimentary structures. The top of the bed can be recognised by erosional truncations of distinct horizontal *Ophiomorpha* burrows (Plate 64b).

The borings in hardground (facies D/E; Plate 65) also indicate discontinuity surfaces and distinctive evidences to indicate variable rates of sedimentation and erosion.

(C) Relative rates of sedimentation and erosion :

In addition to serving as indicators of overall general environmental conditions and subtle changes trace fossils as suggested by Howard (1975) can give important clues concerning local episodes of deposition and erosion.

Examples of animal response to both sedimentation and erosion are frequently observed in Bet Shankhodhar sedimentary sequence. These include some structures recording a combination of both events through life time of an individual (facies B,E and G; plates 42,46a & 65b). In another example (facie C, plate 54) vertical movement by organism in response to sedimentation is recorded. In the third case such episodes are recorded by an *Ophiomorpha* - the burrow reflects many periods of erosion and deposition within a vertical sequence of 20 cm.

It could thus be assumed that animals constructing the above cited forms were particularly adopted to environment of rapid deposition.

(D) Trace fossils and substrate consistency

The nature of the original fluid content of ancient sediment is frequently indicated by careful study of the associated trace fossils and bioturbation structures (Howard, 1975). As claimed by Purdy (1964), the type of burrowing itself can indicate something about the nature of the substrate. According to him, a textural continum exists in depositional environments from substrate composed completely of sand to those composed completely of clay-size material. Two examples of this range can be drawn as implied by him the "ends" of the textural continum. At the relatively high-energy end, clean, well-sorted sands and conditions of frequent erosion and deposition the environment is characterized by few species and few individual most of which are suspension feeders that commonly built deep well-constructed burrows. At the opposite end of the spectrum, the communites are composed of almost exclusively of deposit feeders, but here are also relatively few species and few individual because of the problem of locomotion and other activities in this type of muddy substrate (Purdy, 1964).

More direct evidences of such criteria can be observed in the lithofacies B,C and F (Plates 33b, 37a, 47, 51a & 65b). Here the <u>Ophiomorpha</u> burrows with thick burrow walls and boxwork type mazies net work are seen restricted to sandy to mixed sandy environments at the relatively high-energy end, while the bulk of the thinly walled Ophiomorpha tubes (facies A,B, Plate 32a, 45a & 64a) are found in the muddy and relatively muddy environment.

Bet examples (facies D/E Plate 65a) include discontinuity surfaces resulting in hardground borings indicating subaerial exposures and hard substrate conditions.

(E) Sediment sorting :

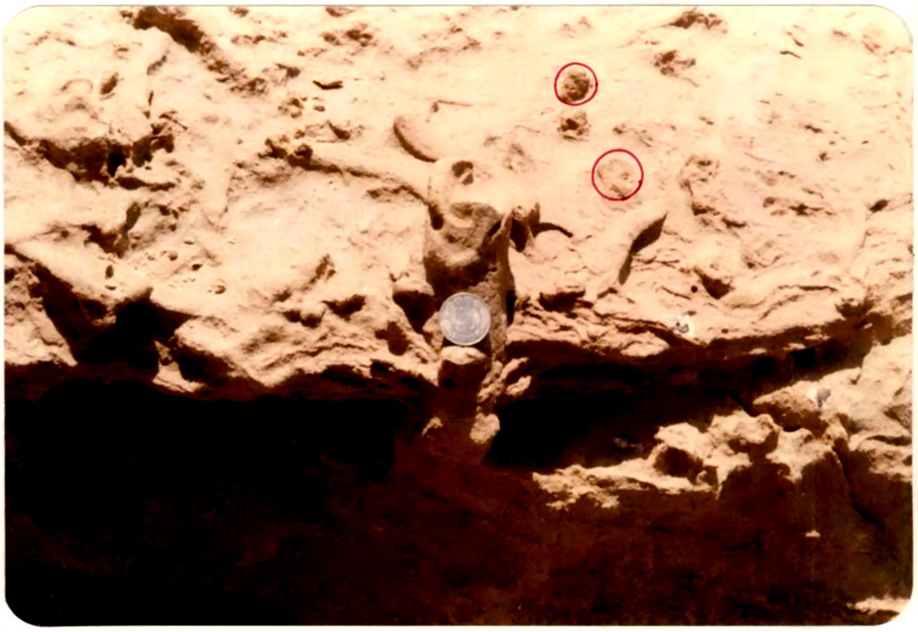
Although, reworked sediments does not itself constitute a trace fossil, the burrowing activity of organisms has been in several instances to be responsible for grain sorting - an important sedimentological process. Examples to such a criteria in Bet Shankhodhar include :

(i) Sediment ingesting by polychaete worms and gasteropods that pass large amount of sediment through their digestive systems and in the process extract nutrients from the substrate. As a result of this activity, a vast amount of material is likely to be transported and redeposited locally for example the back fill structures (plate 65a) and the gastropod bioturbation (plate 62b) in the recent supratidal and mud flat environments of Bet Shankhodhar. These sedimentary fragments are further left behind and if sufficient burrowing and sediment ingesting activity is accomplished, the particles eventually may become the phenomena of biogenic bedding.

(ii) A different kind of sediment sorting action initiated by <u>Callianassid</u> shrimps has been observed by the author in Bet Shankhodhar's recent sedimentary environments. It is found that <u>Callianassid</u> shrimp in the process of its building a complex system of burrow galleries, pumps considerable sediment out of the burrow to the sediment water interface. It is further observed that in the presence of even slight current, this excavated material is sorted during transport; the coarser material is deposited near the burrow and the finer clay fractions remains longer in suspension and is transported away from the immediate area of the burrow (Plate 58a,b & 61a).

PLATE : 65

(a) Rock borings in hard ground indicating substrate consistancy.



(b) (i) Vertical Ophiomorpha burrow. Note burrow reinforcements made by the burrowing animal keeping space with the rate of sedimentation, (ii) monocretarian burrow.

PLATE : 65

(c) Biogenic reworking of sediments, photograph shows the backfill structure which often contributes to the coastal sediments.

Table : 21 Distribution of trace fossils in different lithofacies in Bet Shankhodhar

Lithofacies	Ichnogenera	Relative abundance
A	*Ophiomorpha borneesis*	a
	Ophiomorpha box-work burrows	b
B	*Ophiomorpha borneesis*	a
	Ophiomorpha irregularie	b
	Thalassinoides sp.	b
	Rosselia socialis	b
	Bergaueria hemispherica	a
	Conichnus sp.	a
	Planotites montanus	b
	Monocraterion sp.	b
	Skolithos sp.	b
C	*Phycodes sp.*	b
	Palaeophycus alternatus	c
	Palaeophycus tubularis	d
	Skolithos sp.	b
	Thalassinoides sp.	b
	Planolites montanus	c
	Rosselia socialis	b
	Teichichnus sp	b
	Ophiomorpha sp.	b
D	*Ophiomorpha nodosa*	b
	Ophiomorpha irregularie	b
	Monocraterion sp.	a
	Skolithos sp.	b
	Palaeophycus alternatus	d
E	*Scolicia*	c
	Ophiomorpha irregularie	c
	Ophiomorpha nodosa	c
	Cylindricum sp.	b
	Skolithos sp.	b
F	*Ophiomorpha nodosa*	c
G	*Zoophcos sp.*	b
	Ophiomorpha nodosa	c
	Ophiomorpha irregularie	b
H	Trace fossils not observed	-
I	-do-	-
J	-do-	-
K	-do-	-

a - Rare 1 to 2, b - Common = 3 to 5, c - abundant = 6 to 10 and d - high = > 10

Table : 22 Ethologic, Ichnogeneric, Stratinomic and Phylogenetic classification of trace fossil in Bet Shankhodhar

Ethologic	Ichnogenera	Stratinomic	Phlogenetic
Domichnia : - Permanent shelters of vagil or hemisessile animals procuring food outside sediment.	Ophiomorpha	Endogenic; full relief	Crustacean
	Thalasinoides	"	"
	Skolithos	"	Worms
	Palaeophycus	"	Worms
	Cylindricum	"	Worms
	Monocraterion	"	Worms
	Phycodes	"	Worms
Fodinichnia - feeding patterns which also served as shelter	Zoophycos	Endogenic; full relief	Annelida ? Polychate
	Teichichnus	"	Crustaceans, like animals
	Rosselia	Endogenic; hyporelief	Annelida ? Polychate
Repichnia - Trails or burrow left during direct locomotion	Scolicia	Epi-, hypo-, full relief	Snail traces (gastropod like animals)
	Planolites	Epi, -endo, intergenic intergenic; hyporelief	Annelida ? Polychate
Cubichnia - shallow resting traces	Bergaueria	Positive; hyporelief	Actinian traces
	Conichnus	"	"

BET SHANKHODHAR ISLAND - PALEOTIDAL RANGE MODEL

As seen in the foreging discussion on the sedimentary facies and their interpretations (Part IV, 23.0), the lithological sequence in Bet Shankhodhar Island is dominated by tidal depositional events. Such sediments deposited by tidal currents in the entire Island zone are characterized by a distinct combination of sedimentary and biogenic structures, vertical and lateral facies changes, sediment textures, and lithologies reflecting nine phases (Table 17) of tidal sediment transport in clastic and semi-clastic environments. These sediments further comprise a distinct association which may be termed "tidalites". Tidalites as defined by Klein (1971) are the sediments deposited by tidal tractional currents, an alternation of tidal traction currents and tidal suspension deposition, tidal slack water suspension sedimentation, late stage emergence run off prior to exposure, and tidal scour in tide-dominated areas. According to Klein (1971) tidalite deposition occurs both in the intertidal zone and in shallow, subtidal, tide-dominated environments less than 200 meter in depth. Klein (1971) further defines a special subset of tidalites which he calls "intertidalite". 'Intertidalite' according to him is sediment and sedimentary rock sequence demonstrably deposited in the intertidal zone by the tidal processes listed above. As futher claimed by him in recognizing an intertidalite it is mendatory to document combinations of criteria indicating processes of exposure, evaporation, and late stage emergence run off prior to exposure. Once such processes are documented, it becomes possible to examine rock record for criteria of paleotidal range. Klein (1971) further warns that great care must be exercised in recognizing the combination of features present and in interpreting the flow processes responsible for them, since some of the biosedimentary features occurring in tidalites and intertidalites are also known to occur in sediment deposited in fluvial and other shallow marine environments by other processes.

32.1 **PALEOTIDAL RANGE MODEL :**

In light of the above mentioned criteria suggested by Klein (1971) it is now possible to present a paleotidal range model for the stratigraphical sequence exposed in the Bet Shankhodhar Island (Figure 26).

As depicted in the (figure 34) the intertidalite sedimentation in Bet Shankhodhar Island is characterized by a distinct zonation of sediment transport processes distributed in three prominant zones and two complete cycles of such zone sequences. These transport zones include : (1) a zone of bed load current transport in combination with late-stage, sheetlike runoff prior to exposure (facies A,B,C) producing low tidal flat sand, (2) a second zone where bed load transport current processes alternate with suspension deposition (transitional zone, producing mid flat interbedded sand and mud facies E,G); and (3) a third zone dominated by suspension (producing high tidal flat mud and clay facies H). These sediment transport zones are found to control the textural distributions of intertidalites in the Bet Shankhodhar Island.

As once again could be confirmed from the figure 34, base of each of the paleotidal cycle is represented by an intraformational conglomerate (facies A and F) and cross-stratified sands (facies B and G) with bimodal dip orientations indicating their depositions by reversing of tidal currents. These sands are further characterized by combinations of sedimentary structures including small scale current ripples superimposed on the crests of the sand wave ripples. Such orientation of ripples has generated a vertical sequence of cross-stratified sandstones overlain by thin beds of microcross-laminae in facies 'C' and 'G' respectively (Table 21). Similar sequences where interval 'B' represents tidal bed load transport and interval 'C' represents late stage emergence run off prior to exposure characterizing the low tidal flat environments.

These low tidal flat sequences in Bet Shankhodhar are further found to be grading into zones of flasser-bedded sand and clays, lenticular beds in claystone and interbedded 0.2 to 0.5 cm thick layers (facies C,D,E,G,H,I,J). Wunderlich (1970) has refered such layers as "tidal bedding". According to Klein (1971) such mixed lithologies and structures comprise the mid-flat environments which as suggested by him are often characterized by an alternation of both bed load sand transport and clay suspension sedimentation.

The Bet sequence is further terminated upward by silty clays deposited by suspension sedimentation and finally overlain by the supratidal marsh deposits or mudstone displaying typical mudcracks (facies E and J). The position of mean high tide as suggested by Klein (1971) in such sequence occurs at the boundary between high tidal flat clays and the overlying tidal marsh deposits.

The overall evidences on the intertidalite in Bet Shankhodhar Island thus indicate two fining upward sequences that contain within themselves the preserved record of mean tidal range possibly of the late Pliocene-Pleistocene time. The top of each sequence coincides, here with mean high water, while the position of mean low tides occurs within the intraforamational conglomerate and cross-stratified sandstone -shale sequence, with sandstone containing features indicative of bed load transport only (Table24,A,B) and feature indicating of combination of bed load transport and late stage emergence runoff prior to exposure (table 24,A,B,C).

Using the above criteria it is now possible to recognise intertidalite in Bet Shankhodhar Island by measuring the thickness of part of the preserved fining upward sequence as explained earlier. Accordingly the possible paleotidal ranges of the (1) first paleotidal cycle can be calculated as 9.5 meter and that of the (2) second cycles as 6.75 meter.

It will now be interesting to compare these paleotidal ranges so obtained in the above studies with the present day tidal elevations in the gulf of Kutch. Following table gives such an information.

Table : 23 Tidal Elevation in Gulf of Kutch

Stations	Mlws	Mlwn	Msl	Mhwn	Mhws (meters)
Okha	+ 0.41	+ 1.20	+ 2.04	+ 2.96	+ 3.47
Sikka	+ 0.71	+ 1.73	+ 3.04	+ 4.35	+ 5.38
Kandla	+ 0.78	+ 1.81	+ 3.88	+ 5.71	+ 6.66
Navlakhi	+ 0.78	+ 2.14	+ 4.15	+ 6.16	+ 7.21

The above tidal ranges covering tidal elevation data from stations in the gulf of Kutch mark the lateral tidal variations from the mouth to the head. It is further apparent from this data that the stations farthest from the mouth of the Gulf show maximum elevations in tidal heights as compared with the stations situated adjacent to the mouth of the gulf. In order words the tidal ranges are maximum in the areas where the embayment narrows down (head) and are relatively much lower where it widens (mouth). In case such an argument holds good, the palaeotidal ranges obtained by the author are extremely significant.

In the first place the tidal ranges during both the cycles indicate existence of very high tides 9.25 and 6.25 meters respectively.

Both the tidal ranges show considerable difference in their tidal heights (about 3.05 meter) and perhaps indicate a tendency to lower the tidal elevations during the later period.

Such a change could take place if the embayment may have a tendency to widening up in the process of its formation. Approximation to such a phenomena can presently be observed in the two extremities of the Gulf of Kutch where the tidal range indicate a considerable difference.

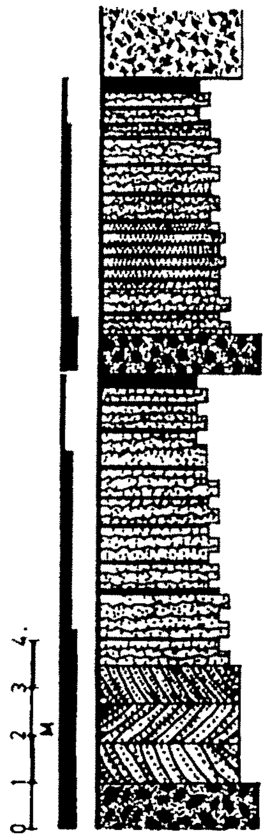
In all possibilities, therefore the late Pliocene-Pleistocene tidal ranges established by the author for the Bet Shankhodhar Island indicate a stage during which the gulf embayment was perhaps in its formative stage with the position of its narrowed embayment somewhere around the Bet region. As the embayment slowly widened the paleotidal ranges of the second cycle were significantly reduced. The present day tidal ranges of 7.21 & 3.47 near the head and mouth of the Gulf of Kutch can once again be markers to support such an argument.

Table 24 Bet Shankhodhar Island : Tidal Process - Response Model

(Modified after Klein, G.V. 1971)

Trasport Process	Criterion
A. Tidal Current bedload transport with bimodal reversals of flow directions	1. Cross-stratification with sharp boundaries (facies B,D,E,G,I,J) 2. Herringbone cross-stratification (facies - B) 3. Parallel laminae (facies - E,G,H 4. Complex internal organization of sand waves.
B. Time velocity asymmetry of tidal current bedload transport	5. Reactivation surfaces (facies -A 6. Unimodal distribution of orienta tion of maximum dip direction
C. Late stage emergence ebb outflow and emergence with sudden changes in flow directions at extremely shallow water depths (less than 2.0 m)	7. Flat-topped current ripples (facies - E) 8. Symmetrical ripples (facies - E) 9. Cross-stratification overlain by micro-cross-laminae (facies-E,I,
D. Alternation of tidal current bedload transport with suspension settlement during slack water periods	10. Cross-stratification with flaser (facies - B) 11. Flaser bedding, simple (facies - 12. Flaser bedding, bifurcated (facies - B) 13. Flaser bedding, wavy (facies - B 14. Wavy bedding (facies - D) 15. Lenticular bedding, connected thick lenses (facies - B) 16. Tidal bedding (facies - B,C,D,E, G,H,I,J)
E. Tidal Slack-water mud suspension deposition	17. Flaser bedding (facies - B) 18. Flaser bedding, wavy (facies- B, 19. Flaser bedding, bifurcated, wavy (facies - B,D) 20. Wavy bedding (facies - B,D)
F. Tidal Scour	21. Mud chip conglomerates (facies-A 22. Intraformational conglomerates (facies - A,F)
G. Exposure and Evaporation	23. Mud cracks (facies - D) 24. Intraformational conglomerates a rip-up clasts (facies - A,E,F)
H. Burrowing	25. Vertical and horizontal burrows many intermittent stages in betw A to E and F,G,H, facies
I High rates of sedimentation combined with regressive sedimentation	26. Fining upward sequence facies A E and F to I 27. Cyclic alternation of paleotidal sequences facies A to E and F to

FIGURE: 34. PALEOTIDAL RANGE SEQUENCE BET SHANKHODHAR ISLAND



FACIES No.	LITHOFACIES	SEDIMENTARY STRUCTURES	BIOTURBATION FREQUENCY	ENVIRONMENTS	SEQUENCE
K	Gritty sandstone	Large scale trough cross-stratification	—		
J	Laminated sandstone-shale-claystone alteration	Low angle planar and trough-cross-stratification	—	High tidal flat	PALEOTIDAL RANGE-II
I	Laminated sandstone-shale-claystone alterations	Low angle planar and trough-cross-stratification	—	Mid flat	
H	Sandstone-mudstone rhythmites	Rhythmites (parallel laminations)	—		
G	Laminated sandstone shale-claystone alterations	Linguid ripples	Low	Low tidal flat	
F	Round pebble conglomerates	Cross beddings	Very low		
E	Laminated sandstone-shale-mudstone alterations	Low angle cross-beddings, reactivation surfaces, flat-topped ripples, rip-up-clast, mudcracks	Low	High tidal flat	PALEOTIDAL RANGE-I
D	Laminated sandstone-shale-claystone alterations	Ripple marks, wavy beddings, rip-up-clast, clay drapes	Low	Mid flat	
C	Laminated sandstone-shale-claystone alterations	Low angle thin-laminations	High		
B	Cross-stratified calcareous sandstone	Low angle planar- and trough-cross beddings, herringbone-cross-stratification flaser, wavy, lenticular beddings	Very high	Low tidal flat	
A	Flat pebble conglomerates	Bimodal cross beddings, reactivation surfaces	Low		