

# **CHAPTER-6**

## **NEOICHTNOLOGY**

## 6.1 INTRODUCTION

In marine environment, animals living on or in the sediments alter surrounding habitat by burrowing, building tubes, feeding and defecating. As a result substrate landscape is in a constant flux with disturbance-rates dependent on the abundance and activity of the organisms (Wilson, 1990). Depending upon the life styles of an organisms, it may require a given range of grain size for burrowing, feeding or tube building (Wieser, 1959) and this sediment range represents only a portion of the fitness curve for that organism (Levins, 1968). Numerous infaunal organisms like crustacean, polychaetes, bivalves and gastropods are usually dominating the assemblages in the intertidal zone of the Mandvi area, of which, crustaceans and polychaetes are relatively short-lived in comparison with bivalves (Thorson, 1957; woodin, 1974), therefore, they are most suitable for neoichnological investigations.

Biogenic sedimentary structures are autochthonous in nature and characterize a biotope readily than any other organic constituents. Trace fossils primarily reflect adaptation to the biotope and are less influenced by taxonomic positions of the organisms producing them (Hertweck, 1972). For a long time biogenic structure have been studied only in fossil examples. Based on a classification of organism behavior in relation to biotope, Seilacher (1953, 1967) suggested a relative depth zonation for trace fossil communities (=ichnofacies). Starting with shallow water biotopes, however, additional observations on animal trace communities were made in modern marine environments by Richter (1924, 1926) and Schafer (1956). Author has also attempted to study present day intertidal ichnology of the Mandvi coast in the Gulf of Kachchh, Western India.

## 6.2 RECENT BIOGENIC SEDIMENTARY STRUCTURES

The intertidal zone of the Mandvi coast is marked by numerous "Bioturbational structures" of invertebrate animals. The term Bioturbational structures denotes the structures produced by the activity of living animals within the sediment or on the sediment surface (Richter, 1936, 1937, and 1952). The bioturbational structures provide more adequate and certain record of benthonic communities than the hard part; as such they are always autochthonous and cannot be concentrated by reworking. Schafer (1956; 1972) divided the Bioturbational structures in to two major groups (i) Fossitextura-

deformativa and (ii) Fossitextura-figurativa. The earlier groups consist of deformative bioturbative structures, without any distinct recognizable form of any trace. The later group consists of distinct recognizable bioturbational structures such as track, trails, burrows, etc. The figurative groups consist of biogenic sedimentary structures that reflect the organism activities like crawling, grazing, feeding, dwelling and tube building (Frey and Howard, 1969).

In recent intertidal zone, Fossitextura-deformativa bioturbational structures can be recognized either by absence of well developed, broken, disrupted, partly pulled apart laminations or formless mottled sediments and structureless sediments. To enhance the structure relief casts of sands, X-ray radiography etc., like techniques were used. While the figurative type bioturbational structures can be easily recognized as distinct burrows, trails etc. The burrow dimensions are known by simple techniques like wax casting, or by sequential trenching along the burrows with the help of scapula.

Recent biogenic sedimentary structures from the study area are classified according to the Toponomic classification, along with taxonomic, ecological and stratonomic as suggested by Seilacher (1953a). The taxonomic and ecological approach helps in identifying the tracemakers and their ecological constraints along with the morphological characteristics of the lebensspuren. The stratonomic approach involves the relation of the trace in regard to the sediment. Based on the ecological factors, Seilacher (1953a) suggested five groups of lebensspuren (i) Resting trace, (ii) Crawling trace, (iii) Grazing trace, (iv) Feeding structures, (v) Dwelling structures. The classification was further modified as ethologic classification (Seilacher, 1953a; 1964). Ethological aspects of Seilacher (1953a) was modified and new categories were added by other workers, compiled by Bromley (1996). These includes (i) Resting trace (Cubichnia); (ii) Crawling traces (Repichnia); (iii) Grazing traces (Pascichnia); (iv) Feeding traces (Fodinichnia); (v) Dwelling traces (Domichnia); (vi) Trap and Gardening traces (Agrichnia); (vii) Predation traces (Praedichnia); (viii) Equilibrium traces (Equilibrichnia); (ix) Escape traces (Fugichnia); (x) Edifices constructed above the substrate (Aedificichnia) and (xi) structures made for breeding purposes (Calichnia). All the traces found are classified according to the ethological classification.

### 6.3 PROBLEMS WITH RECENT NEOICHTHOLOGICAL TAXONOMY

In 1961 the International Zoological congress made a strange decision. It ruled that "names based on work of an animal that were established after 1930 were to be accompanied by a statement that purports to give characters differentiating the Taxon [Article 13(a)(i) of the 1964 edition of the ICZN] i.e. the causative organism has to be identified. Those names established before 1931 were to be treated as the same basis of body fossils. This was the Dark Age of ichnologist. Two courses of action were debated; first course was taken by Sarjeant and Kennedy (1973) and Sarjeant (1979), proposed separate code for trace fossils. Many zoologists also advocated the removal of trace fossils from the domain of ICZN (e.g. Lemech 1973). But Hantzschel and Kraus (1972) adopted an alternative course by proposing the amendments to the existing code and were largely implemented in the code. Due to constant agitation from the ichnologist, status of the trace fossil in the next revision of the ICZN in 1985 was done.

- The 1930/31 status was removed ichnogenus and ichnospecies have been received genus-group and species-group status respectively [Article 10d].
- A type species is not required and, where one has been designated should be disregarded [Article 42b, 66].

In this proposal, the modern traces were excluded and it is clearly stated that after 1930 only fossil traces were covered. The reason for this was one trace-one animal relation is the normal situation and 'traces of living animals can always be related to their causative organism, and there is no need to name them separately' (Melville 1979). When dealing with the traces of the modern organism the problem is the fossilization barrier. When does the work of the animal become fossilized? At what stage does the backfill of an organism becomes trace fossils? According to ICZN (1985) ichnotaxon are valid for the fossilized work of an animal including burrows, borings, galls, nests, worm tubes, cocoons, tracks; but not for modern specimen, unless the name was proposed before 1931 [Article 1a(7); Glossary, p267, 276] (Rindsberg 1990). This exclusion of the modern traces from consideration under code was intended to prevent flow of new and useless ichnogenera based on modern sedimentary structures (Melville 1979; Bromely and Fursich 1980). Bromely and Fursich (1980) and Rindsberg (1990) suggested the solution.



- When erecting the ichnotaxa, type specimen should be chosen from unequivocal fossil material.
- When material deemed to be unfossilised, but which nevertheless can be referred to an ichnotaxon, the adjective 'incipient' should precede the name.
- To exclude ichnospecies based on modern type specimens but allow ichnotaxa based on fossil types to be applied to modern specimen.

The intertidal zone is one of the most active zones of the shallow marine environment. Organisms living in intertidal are adapted not only to seasonal changes but also sharp daily changes in environments. Thus their body and resultant behavior and traces are adapted to these sharp changes. In recent ecological studies of benthic organisms, equilibrium (K-selected) species have been distinguished from opportunistic (r-selected) species (Pianka 1970). In general opportunistic species can respond to an open or unexploited niche and are characterized by (1) lack of equilibrium population size, (2) density-independent mortality (3) the ability to increase abundance (4) and high proportion of resource devoted to reproduction (Grassle and Grassle, 1974; Pemberton et al, 1992). This concept was adapted in trace fossils community and thus facies breaking traces, which are highly localized in low diversity, high density trace fossil are termed as Opportunistic traces (r-selective) while the Equilibrium traces are termed as those restricted to particular sedimentary facies, and characterized by high diversity of low dominance of trace fossil association in sediments reflecting stable, predictable environmental control. Thus the often-sited Opportunistic to Equilibrium end member classification of benthic marine communities does not represent full range of possible adaptive types. Vermeij (1978) recognized a third end member called stress tolerant, which is representative of species that predominantly inhabit physiologically stressful area such as intertidal zone. Due to stress tolerant nature the species are often subjected to change in their behavior and feeding styles. As observed earlier the dual feeding nature of the *Nephtys* and *Nereis* are result of their adaptation and their incorporation in third end member-Stress tolerant. Not only these two polychaete, but other polychaete like *Oniphus* also shows two distinct feeding styles and resultant biogenic structures. The burrows thus formed by these species are of dual nature, either, dwelling/feeding, or deposit-suspension feeding, nature, they are termed as complex burrow systems (Miller, 1998).

## 6.4 CRUSTACEANS ACTIVITY

Activities of crustaceans on the Mandvi coast are chiefly found in the form of locomotion, burrowing and feeding. Among crabs, *Ocypodes* species are most common and one of the primary bioturbators and their changing sediment characteristics on surface by grazing the surfacial sediments and disturbed the subsurface physical laminae by making burrow with variable depth and also bringing excavated materials to the surface and mixing with them. The burrows are lined or unlined with mucus and may be used for dwelling purposes. Following are the bioturbational structures as resulted from the behavior of these organisms.

### 6.4.1 Pellet Making Activity

The surfacial activities of the crabs are envisaged from the surfacial spreads of pellets (Plate 10 to 13) and less likely trackways, which are constructed mainly for feeding purposes. The medium to fine freshly deposited sediments on the beach and bar surfaces are completely covered with feeding pellets at places. This are characteristically scattered around the burrows of young and juvenile *Ocypodes* to form varieties of pelletal designs. These pellets are found in different forms, shape and size and are mainly found on the freshly deposited sediment layer. These activities were observed in all crabs except swimming forms. The fiddler crab feeds freshly deposited sediments surface; first they scrap the layer and place it into the mouth cavity by minor chaela. The non-ingested

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Plate-10 Rounded feeding pellets, (a) Feeding pellets neatly arranged in lobate form near the burrow opening. (b) Mound of feeding pellets and semi radiating pattern of feeding pellets around the burrow opening. (c) Freshly deposited upper sediment layer, completely churned and transformed into feeding pellets by young *Ocypodes* species. Few *Ocypodes* again feeds on discarded pellets around the burrow opening. (d) Grazing activity of crab around the burrow opening showing the scraping of the freshly deposited sediments.

Plate-11. Different types of pellets, (a) Lobate shaped arranged feeding pellets and oblong-burrowing pellets surrounding the burrow opening made during the burrow modification. (b) Blanket of feeding pellets made by young crab species of *Ocypodes* at junction of ridge-runnel. The size and abundance of the pellets indicates population of crabs. The size of the burrowing pellets indicates two different age group of the species. (c) Oblong, burrowing pellets of the *O. ceratopthalma* in the lower part of the beach. (d) Cylindrical to elliptical burrowing pellets of *Uca marionis*.

PLATE-10



(b)



(c)



(a)



(d)



PLATE-11



(b)



(c)



(a)



(d)

materials are throw aside into rounded pellets (upto 3mm) and are arranged on the surface in different patterns. These are found in varying proportion and diversity in all three sites. In the intertidal zone, the adults being restricted near the high water line while the young and juveniles in ridge-runnel systems as well as near the low water line. The structures made by young and juvenile crabs, consist of varying size of vertical cylindrical burrows and are surrounded by feeding and fecal pellets. They produce different kinds of beach structures like, concentric, radial, asteroid, mossy and pellet-mat design in a sequence arranging feeding pellets around their burrow. These pellets are of various size like-rounded, elongated, flat-topped, and rod shaped, depending upon the purpose. Rounded pellets are upto 12mm in diameter, typically arranged in lines (Plate-10 to 13). The young species of the *O. ceratopthalma* generally make elongated, asteroid design during the first few minutes of the exposure of the sediments during the low tide (Plate-10c). The *O. platyrsis* generally makes burrowing pellets, which are characteristically of flat; top shaped and arranged them around the burrow mouth in roughly asterical pattern. (Plate 12 a, b & c). The pelleted mat formed by *O. ceratopthalma* and *O. roundata* in the runnel and ridges are generally 1-8 mm thick and composed of rounded pellets of uniform size indicating all the makers are of same age group (Plate-11b). The pelleted mat is formed with prolonged time generally during the late hours of the exposed low water line (Plate-10 & 11). The other burrowing pellets of adult *O. roundata* and *O. platyrsis* are large, elongated, and is dumped around the burrow opening during the burrow modification (Plate-11a & c) in relatively low tide condition. The adult scraps the floor of the burrow by its major chaela and makes a ball between the two chaela and dumps the pellets near the surface. The size of the burrowing pellets depicts the size of the burrowing crabs (Plate-11d). These adults have different type of feeding habits, depending on the substrates and organic matter.

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Plate-12 Pellets. (a) Elliptical pellets with flat top surface of the burrowing pellets spread in all direction around the burrow opening. (b) Fecal pellets having flat top surface arranged in semi-circular pattern. (c) [i] Flat top surface of the burrowing pellets with rounded fecal pellets, [ii] rounded burrowing pellets along with small fecal pellets. (D) Rod shaped fecal pellets, note three types of sediment (i) Surficial sediments (ii) clean sand brought and dumped around the burrow opening, (iii) fecal pellets, a common element, which adds mud in the sand.



PLATE-12



(b)



(c)



(a)



(d)

*Uca* and *Macropathalma* are also important bioturbators but their abundance is less in the study areas. Their activity is similar to the activity of *Ocypodes*. The crustacean from this group excavates and inhabits in muddy-sand (Cladwell and Dingle 1975, 1976). They are suspension feeders and as a result, irrigate their burrow with the help of body and appendage movement. They make rod shaped fecal pellets, which are made up of mud. They can be easily recognized on the basis of rod shaped nature along with internal ramifications and structures (Plate 12c).

Other Crustaceans like *Matuta*, *Neptunus* and *Portunus* are not so efficient surfacial bioturbators. Out of these *Neptunus* and *Portunus* comprise of large carapace and cheale and are swimmers; rarely do they come to the intertidal zone. Species of the Genus *Matuta* are poorly bioturbators. They just scrap the surface for shelter purposes. The prawn *Peneas japonicus* is suspension feeder plankton and rarely works in sediment or occasionally get into sediments for protection purposes in the intertidal area.

Thus three different types of pellets are identified, Viz., feeding pellets; burrowing pellets and rod shaped fecal pellets and of which the rod shaped fecal pellet (Plate-12c) if preserved in fossil records can be identified as *Faverina*. The pelletal structures, when covered with sediment show structureless fills, of fossitexture deformative type of bioturbation. Similar biogenic deformations were also seen in the relief peels of the raised beach sections. Ethologically, this type of structures is classed under complex pascichnia-fodinichnia types. This is because the pellets represent fodichnia types, while the grazing mark on the surface represents pascichnia type.

#### 6.4.2 Burrowing Activity

The burrowing activity of the Crustacean along the Mandvi coast is varied and consists of three specialized techniques of burrowing, viz.- the back burrowing, side burrowing and the rotating burrowing. The purpose of burrowing can vary and may range from just temporary shelter to dwelling or to hide in order to predate. In the study area the crab burrows having a distinct zonation in the intertidal zone.

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Plate-13: Scratch marks with feeding pellets, (a) paired scratch marks of the chaela during pellet making activity in the wet fine sediment. (b) Scratch marks of the chaela in coarse-grained sediments. (c) Paired scratch marks of the chaela during pellet making activity in the watery sediments. Note the grazing activity is more pronounced in the watery sediments.



PLATE-13



(a)



(b)



(c)



6.4.2.1 Burrows of *Ocypode*

The *Ocypodes* are very efficient burrowers along the beaches of the Wind Farm, Rawal Pir and Modwa Spit sites. They are capable of making three dimensional burrow systems similar to their fossil equivalent *Thalassinoides* and *Psilonichnus*. They burrow in a wide zone parallel to the sea, extending from the lower part of the intertidal zone to the dunes and supratidal environments (Patel and Desai 1999). Adult species of *Ocypodes* burrows in limited zone ranging from upper intertidal zone to supratidal zone.

The burrows of these adult crustaceans are essentially characterized by three dimensional, cylindrical component of varying diameter with smooth, unlined walled, branched, burrows consisting of shafts and tunnels which joins at Y or T junctions. The shafts may be straight to slightly curved or twisted, with more than one oblique dead end branches. The morphology of young and juvenile crustaceans of the same species are very different from those described above, it consist of cylindrical, smooth, unlined walled, straight, and unbranched vertical shafts.

The crustacean burrow diameter shows considerable variation with prominence decrease in burrow diameter, towards the sea (Figure 26). The burrows near the sea are, simple unbranched burrows, while those near the land resembles English letters of Y, J, I

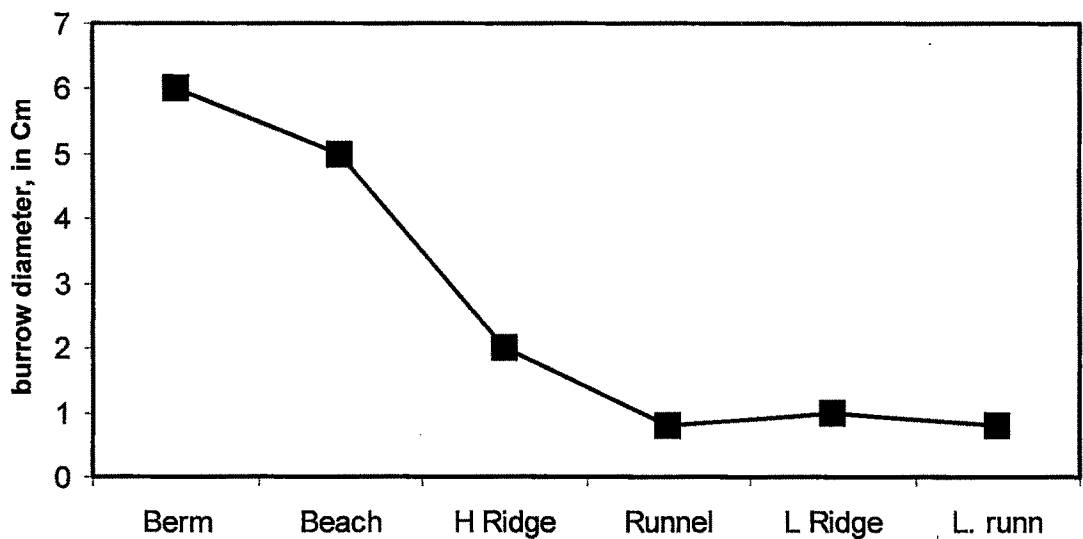


Figure-26 Burrow diameter of the *Ocypode* species across the intertidal zone.

and U shaped, bifurcates in upward direction (Plate-14) with its penetration, more than a meter deep into the sediment. The burrows of the adults have mean diameter varying form 4 cm to 7 cm (Figure-26) with the diameter at the joint nearly of about 8cm to 12cm.

The total length of the burrow may be nearly 2.5 ft. Few adults are resides on bar and lower part of the beach, their dimensions of the burrows are decreases, from 3 to 6 cm with the diameter of joint of ‘Y’ ranging from 6 to 8 cm and depth is more than 1 foot. The branched shaped burrows were peculiar, the depth of the branched burrows were nearly 23cm to 27cm, total length of burrows may vary from nearly 2ft to about 1/2 ft. In most of the cases, secondary arms of the ‘Y’ shaped burrows did not reached the surface and certain depth arm blinded off ranged from 11cm to 15 cm. In J-shaped burrows the depth of the turning was not found constant and ranged widely from 10 cm to 25 cm.

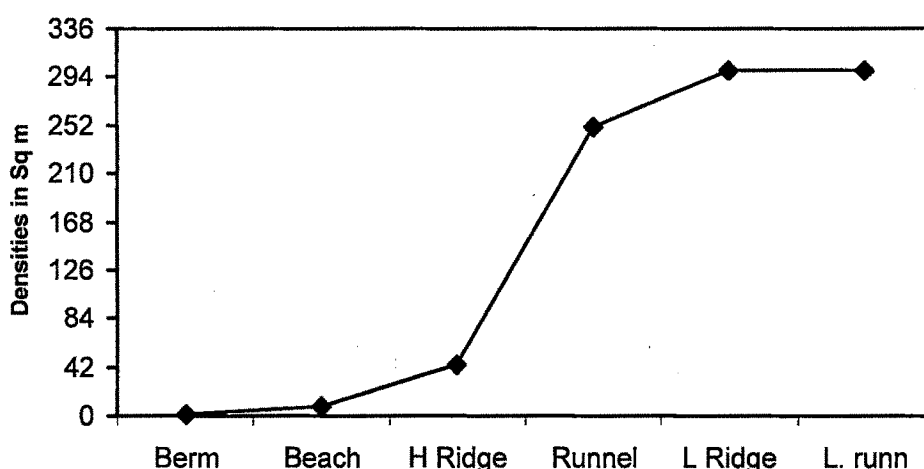


Figure-27 Crustacean burrow densities across the intertidal zone

Plate-14 Wax cast of the burrows (a, b, c, d) of adult *Ocypode ceratopathlam* showing different types of ‘I, J, U and Y shaped’ burrow morphologies (Rawal Pir).

Plate-15 Different type of mound with burrow, (a) Extensive development of the conical mound of the adult *Ocypode ceratopathalma* on the upper beach, apex of the cone consist of wet sediments (Modwa Spit). (b) Crab hole surrounded by thick rim of excavated loose sediments. (c) Half rim near burrow opening consisting of gravels and shell fragments. (d) Burrow opening associated with conical mounds consisting of excavated materials, ~45 cm apart from the opening. (e) Burrow opening with broad, thin, rim of the loose sediments modified by the appendages.

PLATE-14



(b)



(c)



(a)



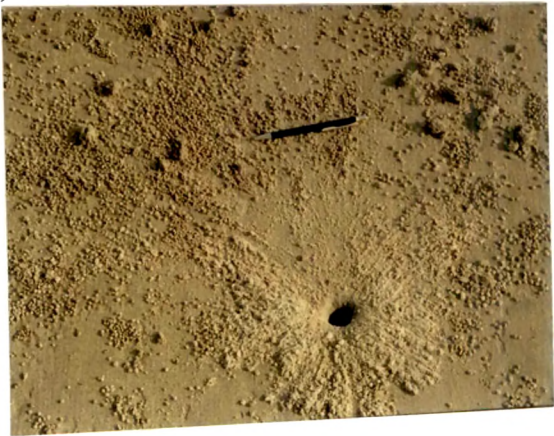
(d)



PLATE-15



(a)



(d)



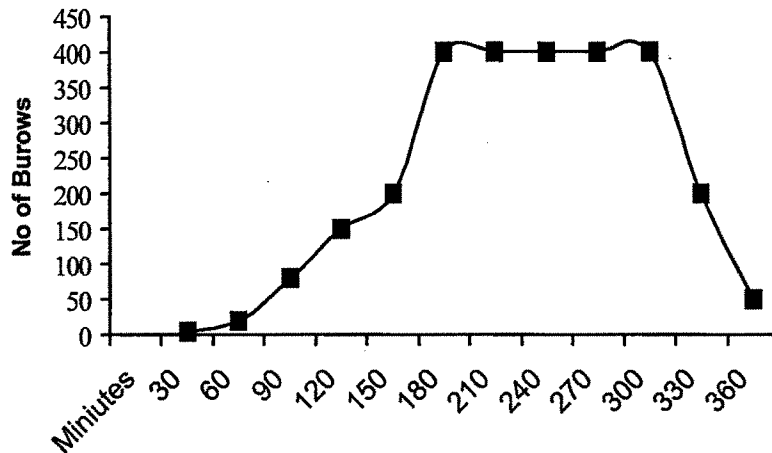
(b)

(c)



(e)

All the burrows of the *Ocypodes* were consists of different type of sand mounds



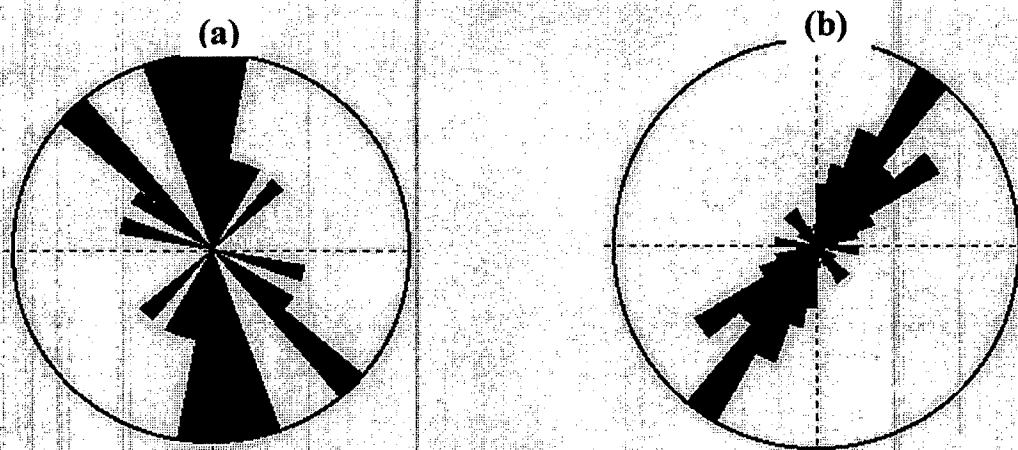
**Figure 28: Graph showing the number of burrows opening against the minutes during low tide.**

were made during the burrow modification. The adult crabs make conical mounds along the beaches of Modwa Spit (Plate-15a). The conical mounds are nearly 45-55 cm away from the burrow opening with the height of the mound around 10-20 cm, and occasionally found in pair and situated on the seaward side of the burrow mouth (Plate 16a). The inter-area of burrow mouth and conical mound are straddled with appendage markings on account of the constant movement for depositing the excavated materials from the burrow to the mound (Plate-15&16). A thick rim of excavated loose sediments (Plate-15b) surrounds the burrow mouths. The excavated material depends on the type of sediments present in the subsurface, i.e. sand or gravel size particles (Plate-15b & d). Some times few of the crabs spread the sediments in the form of thin films surrounding the burrow opening (Plate 15e). The burrows of young and juvenile crabs have circular cross-section. The vertical section shows tubular nature with rounded or tapering end. The inclination of the burrow varies from  $60^{\circ}$  to  $90^{\circ}$  with average observed length of 35 cm with diameter of 5 cm. However, observed dimension of the burrow is governed by the size of the crabs that makes it. These burrows are simple, vertical, unbranched and unlined. The burrows are more densely populated near to the low water line (Patel and Desai 1999) as well as in the ridge and runnel system (Figure-27). In contrast with the burrow diameter (Figure-26), the crustacean burrow densities increase towards the seaward direction. The high burrow densities, in lower ridge and runnel are mainly on account of increase in population of younger and juvenile *Ocypodes* near low water line.

The activity of Young and Juvenile crabs in the intertidal zone increases slowly (Figure 28) for initial 30-90 minutes of the low tide, but soon, the activity reaches maximum upto 400 burrows per sq. meter. This number is reached when the low tide phase is in peak, with onset of high tide the burrows sharply decreases on account of washing away by sediments.

The straight nature of the young and juvenile crab burrows probably indicate the simple biology and temporary usage during low tide. They are known for high bioturbational rates and burrowing in rotating fashion.

The making of the mound or a pyramid out side a burrow by species of *Ocypode* is a sort of social behavior for the territory or attracting the opposite sex, much similar to other behavior like movement, combat and sound (Warner 1977). Individuals for number of weeks can hold such territory to a single low tide period. In *Uca* the adults build porches outside the burrow (Plate-15b), displaying its territory much more similar to status of the ownership. Sometimes agnostic behavior in the *Uca* has also been observed. Burrow orientation of the crustaceans was studied following method suggested by Frey and Mayou (1971). A meter long wooden stick was inserted in the burrow openings and the direction was measured. It was found that most of the burrow openings near the high water line were towards the seaward direction and this also confirms the similar study done by Chakrabarti (1982). The rose diagram (Figure-29) indicates the orientation of burrow openings. The burrows of the supratidal zone did not showed any distinct orientation (Figure-29a). While, the foreshore burrows with mound shows marked



**Figure-29: Burrow orientation of *Ocypode* burrows (a) Orientation of backshore burrows without mound; (b) Orientation of foreshore burrows with mound.**

orientation towards the seaward direction (Figure-29b).

In some cases the mounds near the burrow opening consist of linear ridges or pair mound (Plate-16 a & b). It is envisaged from the nature of the sediment that the burrows were probably modified and have remained unaffected from the previous tidal cycle. The species of *Uca* are also efficient burrowers and make large burrows in the muddy sediments and their surfacial activity of the young are represented by feeding pellets.

Burrowing and locomotion activity of the juvenile form of *O. platytarsis* is observed on the Wind Farm and Rawal Pir Sites. During receding tide, gently slopping beach surface becomes free from residual water flow; juvenile crab comes out from the sediments and wanders on the surface for food, making trail in groove form. After walking few centimeter distances, it feeds on organic rich sediments and throwing waste in the form of rounded feeding pellets. Repeated activity in rotating fashion at one-place results in burrow form, which are few millimeters deep.

Time lapse photographic technique was employed to study the behavior activity of the *O. platytarsis* (Plate-17a). Plate-17a represents initial churning of sediments at a place and push aside feeding pellets to a rim like structure on the surface. This activity is repeated for many times and excavated material is continuously thrown in circular fashion forming pelletoidal wall structure. Burrow deepens downward and at same time animal piles up pellets raising rim above the surface. Photographs (Plate17a) were taken after 135 second after it starts burrowing. The burrow further deepens downward at same time diameter increases and rim is further raised (Plate17b), for constructing this structure, animal took another 150 seconds. After require depth is reached (2cm) animal covers the burrow by adding more pellets (Plate17c) from inside to the top of the burrow wall, and

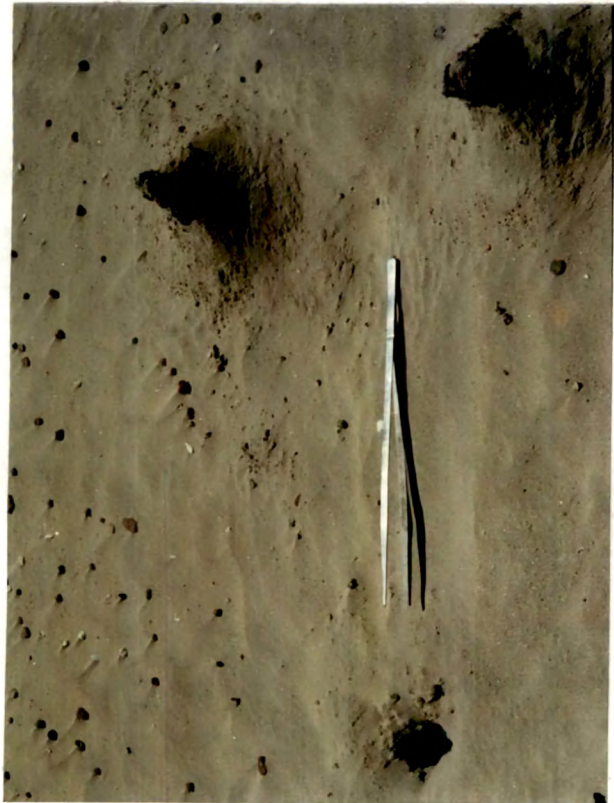
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Plate-16 Different type of mounds in supratidal zone, (a) Burrow with ridge of loose excavated sediments with appendage markings. Note the cone shaped structures at the extreme left side of the heap (Forecep=45 cm). (b) Burrow with paired conical mound, equi-distance apart from the holes. (c) Burrow mouth plugged with the burrowing pellets. (d) Burrow of *Ocypode roundata* with the heap of loose sediments, with appendage markings.

Plate-17 Rotating burrowers:- Time lapse photograph sequence (a, b, c, d,) showing burrowing activity of young *Ocypode platytarsis*.



PLATE-16



(b)



(c)



(a)



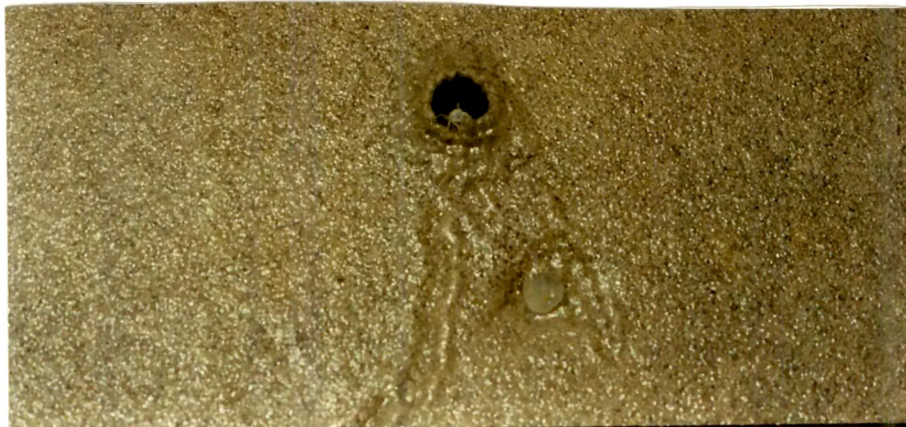
(d)



PLATE-17



(a)



(b)



(c)



(d)

form roof like structure. To complete this structure (Plate-17d), animal further took 180 seconds. During the construction of pelletoidal roof, a small hole as the size of the animal is left open. But due to noncohesiveness and watery nature of the sediment, the pelletoidal roof collapses and animal gets covered with the pelletoid structures (Plate-17d).

The burrows of all the crustaceans if preserved are definitely *fossitextura figurative*, and ethologically corresponds essentially to the Domichina group. The wax casts of the burrows of the adult species taken from Rawal Pir site suggest its morphological similarity to the *Psilonichnus* and *Thalassinoides* ichnogenus suggesting more of a semi-permanent nature of the burrows. The burrow morphology of the juvenile crabs is identical to the *Skolithos* or *Monocraterion* and may not even last more than one tidal cycle. Moreover the direction of the burrow openings are definitive suggestive of the seaward directions. Several small, vertical burrows are also covered by chimneys of pelleted walls, this if preserved may correspond to the ichnogenus *Ophiomorpha*, and are indicative of composite fodinichnia/domichnia, or to hide from predation by birds and other animals.

#### 6.4.2.2 Burrows of *Oratosquilla*

The stomatopods *Oratosquilla striata* Manning, 1978, are found in abundance in the runnels of the Rawal Pir and Modwa Spit sites. These are known for its voracious and carnivores nature that predate's on passing prey (Cladwell and Dingle 1976). They also feed on fine grained food particles in suspension-feeding mode and rarely do they come to the sediment-water interface (MacGinitie and MacGinitie 1949). The burrows of the *O. striata* are simple, generally consist of vertical shafts (Hamano *et al.* 1994,) which are lined and consists pelleted lined wall (Plate-18 a, b & c), these are identical to ichnospecies *Ophiomorpha nodosa* (Vaugelas, 1991). These are represented as simple to complex, inclined to vertical, three dimensional burrow systems. The pelleted walls are of nearly 2-5mm in thickness (Plate-18d). Two types of pelleted wall structure can be delineated

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Plate-18 Pelleted wall burrows, (a) Pelleted wall burrow in a tidal channel. (b) Cross sections of the abandoned burrows showing thick, pelleted wall lining. (c) Chimney of the pelleted wall burrows, with nodose appearance identical to ichnospecies *Ophiomorpha nodosa*. (d) Pseudo-*Ophiomorpha* colony of the protruded, pelleted rimed burrows.



PLATE-18



(b)



(c)



(a)



(d)

from the study area. One having compact packing of predominantly regular distributed, discoid, ovoid or irregular-polygonal pellet, while the other having loose packed small pellets of about 0.3-1mm diameter size and its height is about 1-4 cm appearing like chimney (Plate-18d). They may be more than meter deep and secreted gelatinous mucus to stabilize the loose sediments of the wall.

#### **6.4.2.3 Trauma behavior**

Trauma behavior of the *Oratosquilla striata* (Patel and Desai 2001) was observed in the intertidal zone during ebb tide condition along the Rawal Pir site on 26<sup>th</sup> January, 2001, when an earthquake (7.7 magnitude on Richter scale, USGS) occurred at 8.46 a.m. With the epicenter at Lat. 23° 39' N and Long. 70° 32' E.

It was observed that the *O. striata* started pumping water through the burrow perhaps due to the initial tremors. Subsequently, an increase in the intensity of the tremors caused fluidization of the subsurface sands, which started flowing through the burrow (Plate-19a) made by *O. striata*. The intensive shocks led to the intrusion spout phenomena similar to one observed by Otsuka et al. (1997) in the late Quaternary Tephra layers of the Karasu River valley of Japan. The intrusion spout phenomena occurred in this case through the cylindrical pelleted lined burrow forming a crater with a broad flat circular rim structure (Plate-19a). At this stage, *O. striata* either escaped in panic from its dwelling structure or was forcibly pushed towards the surface by the injected fluidized sand. Possibly, it got shocked and started moving in a circular motion (two to three rounds) around the burrow opening and presumably wandered for shelter on the surface and made a crawling trail (Plate-19a); this is abnormal to its usual behavior. The trail is horizontal, long, and circular to meandering, bilaterally symmetrical with flat ribbon (3.75 cm wide) like surfaces of negative epirelief. Two prominent grooves on either side of the trail and longitudinal median ridge with closely spaced transverse pads (Plate- 19a &b). While moving on the surface, the animal was unable to burrow and protect itself. Ultimately it became unconscious and died (Plate-19b).

#### **6.4.3 Crawling Traces (Repichnia)**

Two type of Crustacean crawling traces was observed, one made by adults of *Ocypode*, and other made by Hermit crabs. The crawling traces of *Ocypode* are mainly confined to the beach and backshore of Rawal Pir and Modwa Spit sites. *Dactylus*

imprints, consisting of sets parallel-arranged grooves make these traces. Appendage markings are also present around the burrow during the burrow modification for throwing the sediments in the form of mounds (Plate-16 a & b). Such types of the traces are often formed by side burrowers (Frey et al., 1984).

Hermit crabs on the Mandvi coast shows preference for gastropod shells like *Turritella*, *Cerithium*, *Murex* and *Telescopium* for protection and concealment. Two species of the Hermit crabs characterize the intertidal zone; they are *Clibanarius infraspinatus* and *Clibanarius* sp. Indeed, a close relationship exists between shell distribution and the autecology of the Hermit crabs. These species are mainly detritivores and may some time prefer organic rich watery sediment (Patel and Desai 1999). Ichnologically, the best evidence for the hermit crab activity is the telltale of the shell imprint left along the animal's trail, together with the tracks reflecting the peculiar style of locomotion. Generally the anterior legs pull and posterior ones push (Frey 1987). Locomotion may be continuous for long distances and comprises mainly of trails made by heavy gastropod shells (Plate-19c). The hermit crab are important bioturbators of the modern biocoenoses, especially they are abundant in the ridge-runnel systems.

The hermit crabs are also one of the prime surfacial bioturbators of the intertidal zone and are abundant in the Rawal Pir and Modwa Spit sites. The traces appears to be trails, but close examination reveals them to be as trackways. These are maximum of 2-cm wide, which may be meandering to winding, often cross cutting each other. They comprise of series of oblique grooves in V-shaped arranged scapes and gouges along with sharp mid-line. Similar trails are also made by gastropods but differs in morphology. The gastropod trails are flat, structureless, with mounds. These are made in small residual pools in the intertidal zone. Ethologically, the trackways of the hermit crabs represents crawling traces (repichnia).

## 6.5 POLYCHAETE TRACES

Polychaetes are second important bioturbators group of the Mandvi coast. Their abundance are found in fine-grained watery sediments, especially pools and runnels of the

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Plate-19 Crawling trails, (a) Crawling trail made by the *Oratosquilla striata* in trauma condition around the burrow opening, (i) crater with flat broad rim, (ii) crawling trail, arrow indicate the direction of movement and (iii) numerous small craters formed due to fluidization of subsurface sands. (b) *Oratosquilla striata* lying on the surface soon after the Bhuj Earthquake. (c) Irregular frill like trails made by *Clibanarius* (Hermit crab) on lower part of beach.



PLATE-19



(a)



(b)



(c)

intertidal zone, while they are scarce or absent on the extreme reaches of beach and dunal region. These animals further modified the substrate by employing specialized techniques like peristaltic movement of the body for feeding, grazing and dwelling purposes, produces different kind of bioturbational structures. Most of the bioturbational work; especially the burrowing is dependent on the fluidity and consistency of the substrate in which they inhabit. The polychaete taxocenosis in the study area is characterized by the presence of wide range of species and trophic strategies. Majority of the species are burrowing and modify their structures deep in to the sediment. The highest structural complexities of the polychaete taxocenosis may be directly related to the higher environmental stability and to the higher degree of microhabitats like clastic oxygenated sediments and enough food (Martin et al 1993).

#### **6.5.1 Burrowing Activity**

Burrowing activities of the polychaetes are found essentially on, ridges, runnels and lagoons of the study area. Morphologically, the burrows are cylindrical, vertical to inclined, branched to unbranched and mucus bounded. They usually occur as sand bounded small tubes, generally of 1-15 mm in diameter and upto to 50 cm deep and are densely populated in ridges, runnels and lagoons. They also occur as isolated tubes on the beach near the high water line. These forms are similar to pipes, made by mucus secreting polychaetes. Majorities of the polychaetes are suspension feeders, but combine suspension/deposit feeding activities were also observed.

##### **6.5.1.1 Dichotomously Branched Forms**

This structures occur as 3 ramifying forms consisting of vertical tubes, which are systematically branched, horizontally 2-3 cm below the sediments-water interface (Plate-20, 21 & 22). The horizontal components further open up on surface and appeared as dendritic pattern or plant root like structures (Plate-20 & 21). The vertical component is cylindrical, unbranched mucus lined tubes of 40-50 cm deep with constant diameter of 3mm. The horizontal component are multiple branched burrows that consist of an extensive series of short tunnels, either straight or slightly arcuate (Plate-20 and 21a). The X-radiograph shows first order, second order and even third order ramifying tunnel systems; each bifurcates at an acute angle (Plate-22a), with constant diameter of 3 mm.

These tunnels open to the surface trending upward across the sediment-water interface, each one consisting of numerous feeding grooves surrounding the opening. Very often these grooves are dichotomously branched forming tight network, to open system and some times tassel like, but all these structures have similarity of having internal tunnels joining the main shaft (Plate-22a).

The two polychaete species *Nephtys inermis* and *N. diabbranchis* are found to trace makers of these structures. During the receding tide, sediment surface covered with veneer of water, animal comes out from the semi-permanent tunnels to feed on freshly deposited organic rich sediments. While exploiting surfacial sediments animals leave behind varied form of network. Thus the whole ramifying structures indicates two distinct type of the behavioral activity i.e. first, domicile and protection purpose during high tide and secondly grazing activities- exploiting the freshly deposited organic rich sediments.

#### 6.5.1.2 Fecal Strings/Mounds

The surfacial activity of the Polychaetes are limited and represented as fecal strings and mound forms (Plate-23a) all along the Mandvi coast. This structure consists of conical fecal mounds, showing different kind of shapes, and at places they are represented as multiple mounds. These structures are small, circular and conical mound consisting of fecal casting having height of upto 2 cm and diameter of a centimeter.

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Plate- 20 Surficial feeding structures of Polychaetes, (a) Tassel like structures in organic rich sediment, made by interface-deposit feeding polychaete *Nephtys*. (b) Surficial expression of *Chondrite* like trace made by polychaete *Nephtys* in the intertidal zone of Wind Farm Site. (c) Dichthonomously branched feeding furrows in fine grained organic rich sediment along with mound of excreted sediments. (d) Large, branched structures made by polychaete *Nephtys*. Note the difference in the sediment colour, indicating structures were made in freshly deposited materials.

Plate- 21 *Chondrite* traces, (a) Surficial expression of *Chondrite* and horizontal tunnel network, few milimetre below the surface. (b) Vertical section of the mucus lined burrow showing horizontal branched network parallel to the surface. Holes indicates branching points. (c) Initial stage development of the burrow in the watery sediments, note the polychaete *Nephtys* in action. (d) Fully developed burrow. (e) Composite structures made up of mounds and surfacial feeding furrows along with the trackways of hermit crab.

Plate-22 X-ray radiograph polychaete burrow, (a) Plate core showing surfacial traces of the *Nephtys*. (b) X-radiograph showing subsurface horizontal tunnel network of the same plate core.



PLATE-20



(b)



(c)



(a)



(d)



PLATE-21



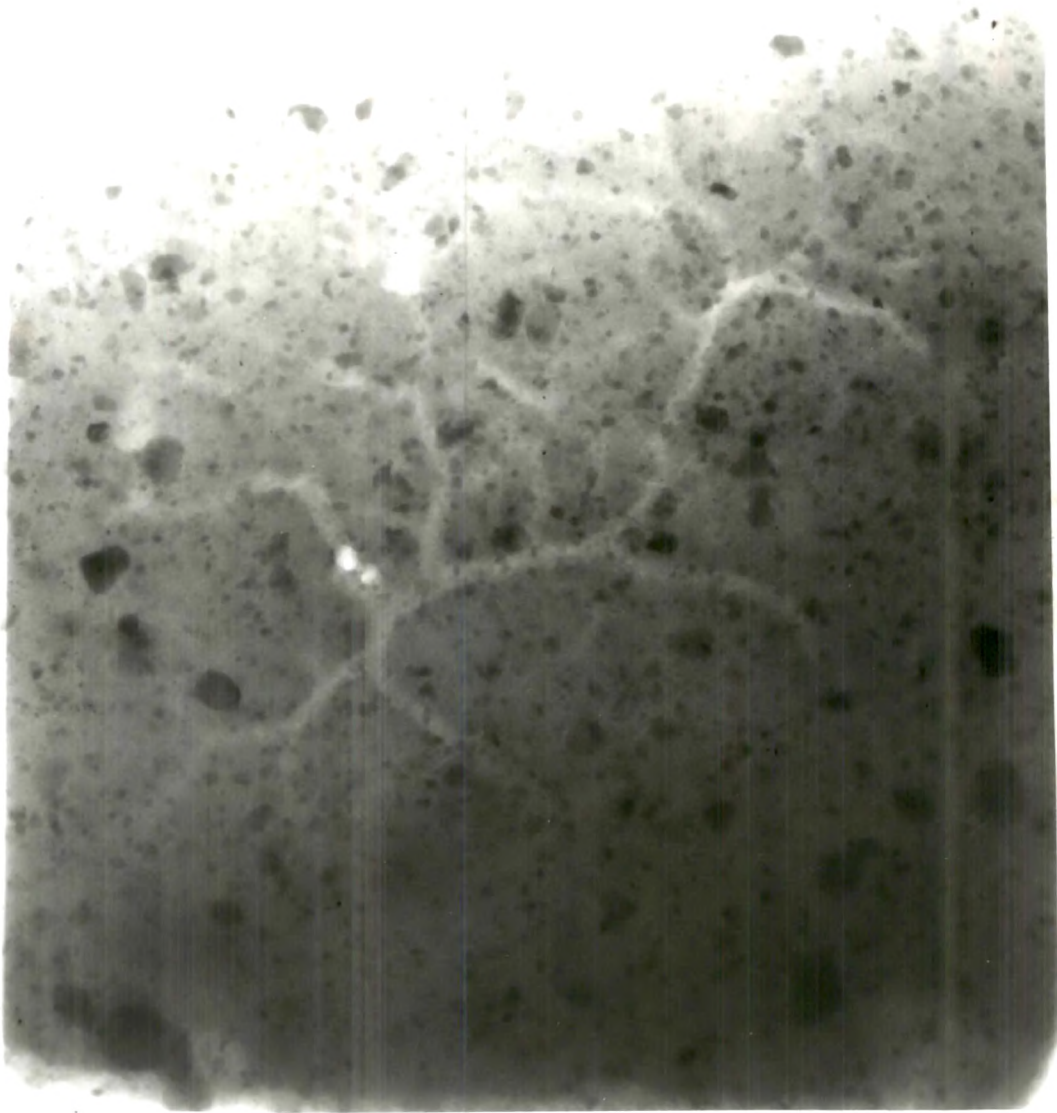
(a)

(b)

(c)

(d)

(e)



(a)



(b)

These are generally associated with vertical burrows, and also with paired opening burrows. These are similar to the fossilized form, first described by Donaldson and Simpson (1962) as ichnogenus *Chomatichnus*. Rawal Pir lagoon site, polychaetes *Chloeia flava*, is found to be making mound structures consisting of fecal materials. *Nephtys inmeris* and *N. dibranchis* are also found making similar structures. While *Nereis diversicolour* and *Nereis* sp, also make conical mound of fecal string. The shedding of the fecal material at the top of the burrow mouth (Plate-23a) is indicative of the worm adapted in working in anoxic conditions or in low oxygen conditions. The paired burrows made by *Arenicola* sp, consist of mound at one end and other end as funnel shaped opening (Plate-24 c & d). This funnel end is used for irrigating the burrow while the other end is used for throwing out the fecal material, which accumulates near the mouth of the burrow.

#### 6.5.1.3 U-Shaped Forms

This structures are usually consists of two vertical to inclined tubes, converging downward and forming U-shaped burrows (Plate-24a). Tubes are cylindrical, unbranched, smooth, and mucus bounded. In field this structures are seen as paired funnel opening in plan view (Plate-24 a, c & d). Sometimes opening consists of conical mound at one end having diameter of the mound base ranging from 5 mm to 12mm and height upto 13mm. The other opening of the U-shaped structure consist of funnel-shaped opening. The dimensions of the funnel vary in different burrow population, the maximum diameter observed is of 20 mm and depth of 25 mm. These openings are joined by U-shaped mucus bounded tunnel, in which there is no vertical and lateral migrations. The two limbs are parallel with distance of two openings in the range of 7-10 cm apart, and have constant diameter of 5mm.

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Plate- 23-(a) Polychaete activity in shallow pool near the Rawal Pir site, consisting of excreted sediments in the form of pseudo-strings. (b) Orientated, agglutinated *Diopatra* tubes in fine grained sediments of the runnel.

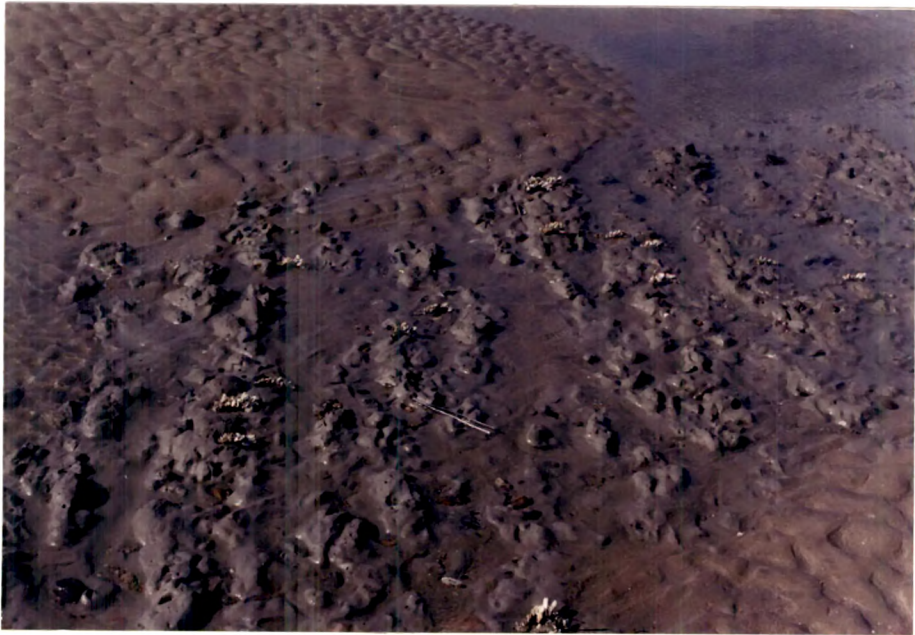
Plate-24: Funnel shaped burrow with mound, (a) Paired opening burrows consisting of funnel at one end and mound with opening on other end. The funnel acts to irrigate the burrow and the used water and waste is expelled from the other end in the form of mound (b) Funnel shape burrow opening with conical mound. (c) Paired funnel shaped burrows identical ichnospecies *Arenicolites* made by polychaete *Arenicola*.(d) Vertical section of the mucus lined burrow with mound.



PLATE-23



(a)



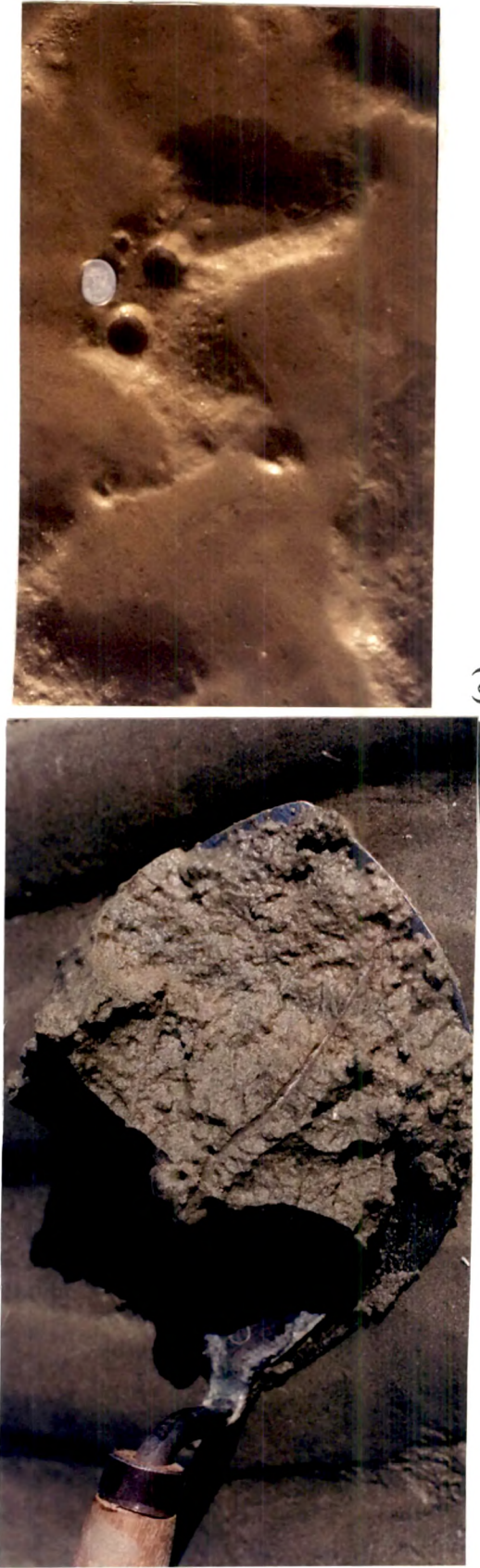
(a)





(a)

(b)



(c)

(d)

They are found commonly in the runnels of the Rawal Pir and Modwa Spit sites and also in lagoons of Rawal Pir sites. *Arenicola* Sp and *Amphinome rostrata* are the two polychaetes found to be making such types of structures. Though they both belong to separate family according to Rouse and Fauchald (1997); but their feeding behavior is similar. Their feeding guild is according to Fauchald and Jumars (1979) is CMX i.e. carnivore, mobile, and mouth structure consist of usually sac-like pharynges. This burrow is a suspension feeder, which are highly specialized. According to MacGinitie and MacGinitie (1949) this type of structures and the animals are well acquainted with the irrigation of the burrow by the peristaltic movement of the burrow. These burrows are identical to ichnogenus *Arenicolites franconocus*.

#### 6.5.1.4 Agglutinated Tubes

Lined, cylindrical tubes with diameter between 10-15 mm, depth of 50 cm and thickness of mucus lined are upto 2mm. Tube tops are semi rigid and protrude up to 16 cm above the surface. The protruded tube may be cylindrical to sub-cylindrical and diameter of the tube being increases in upward direction. The material attached to the tube can range from any sort of available material including shell fragments, sand grains, marine weeds, plastic cords, coir etc (Figure-30). Among these more than 80% of the material consists of shell fragments (Plate- 23b).

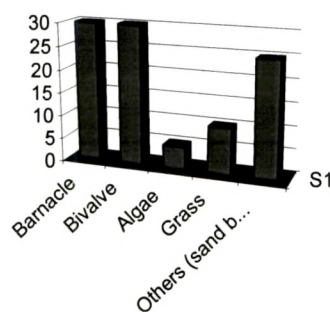


Figure-30: Percentage of the material used for constructing the *Diopatra* tubes, dominated by barnacles and bivalves.

*Diopatra neapolitana* is true suspension feeders and the undoubted constructor of this tube. The average armoured length of the tube is almost same ~10cm (Figure-31), this part of the tube remains on the surface. These animals are abundant in the runnels of



the Rawal Pir and Modwa Spit area. During the late stage of low tide their tube are directed according to the flow, with mean direction to be N 210° (Figure-32).

The burrow linings are secreted as mucus by the worm and later stiffen to a thin parchment-like material. During the tube construction, exterior is reinforced with detritus picked up by the worm from the surroundings. This reinforcement not only increases tube strength, a necessary conditions for protection and adequate flushing (Myers, 1972), but also aids in predator detection by increasing the effective tube diameter (Brenchley,

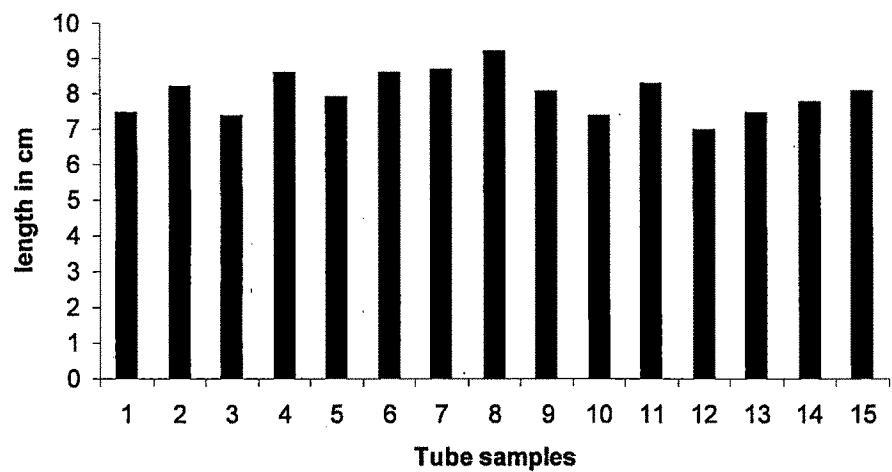


Figure-31 Armoured length of the Diopatra tubes.

1976). Reinforcement probably also increases feeding efficiency by aiding in the trapping

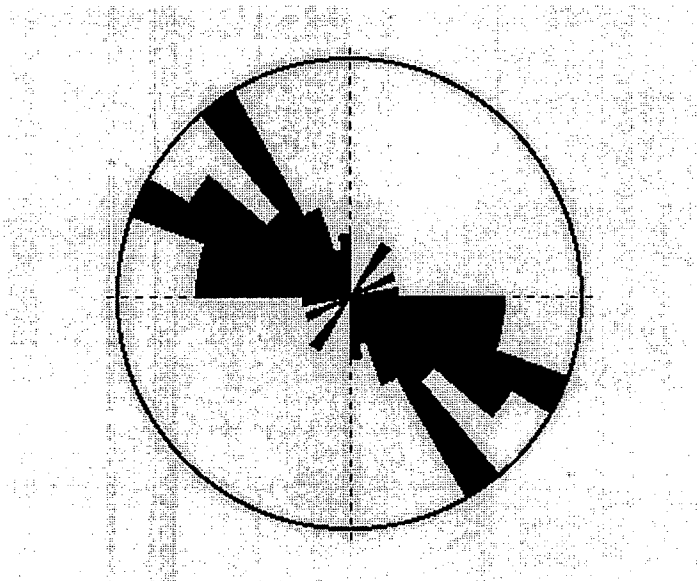


Figure-32 Rose diagram showing the orientation of the Diopatra tubes in the runnels.



of edible detritus. Tube tops have the shape of inverted J shaped, which helps in effective feeding (Mangum et al., 1968).

#### 6.5.1.5 Grouped Funnel Burrows

Grouped funnel burrows are the structures that are found in the lagoon of the Rawal Pir area. The burrows represents a system with a complex spatial configuration and on whole consisting of mucus bound vertical tube with horizontal to oblique segments, which further bifurcates in their upper parts and opens in the funnel shape at the surface (Plate-25). Individual structure therefore has many outlets on the surface, usually group of 4-7 funnels (Plate-25c) which are interconnected to each other. Each funnel converges in the middle of the structure (Plate-26a); usually the convergence point of all the burrows is below 3-5 cm of the sediment-water interface. The burrows are smooth, cylindrical, lined, branched, with constant diameter of 5mm. Observed depths of the structures are of 50cm and funnels diameter upto 40mm while depth of the funnel is about 30mm. These structures made by filter/suspension feeding *Oniphus eremita* and identical to ichnogenus *Balanoglossites triadicus*. These burrows extends upto the anoxic zone or algal/peaty layer in the lagoonal sediments of the Rawal Pir area.

#### 6.5.1.6 Y/I Shaped Burrows

These are the structures resembling English letter 'Y' and 'I' shaped, smooth, inclined to vertical, straight, cylindrical, branched or unbranched lined burrows. The arm of the "Y" shaped burrow bifurcates in upward direction at 10 cm below the sediment-water interface (Plate-27a & b). The diameter of the burrows are constant and of 8mm and depth of about 40cm. 'I' shaped burrows are steeply inclined to vertical (Plate-27b,c & d) and mucus bound with tube diameter ranges from 1-4mm and depth is variable, but

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Plate-25: Group funnel burrows in Rawal Pir lagoon, (a & b) *In situ* trace maker *Oniphus* in the burrow. Head with tentacles (a) and segmented body (b). (c) Grouped funnel burrows identical to ichnospecies *Balanoglossites*. (d & e) Cross section of a funnel burrow system showing central shaft with tunnels curving upward and outward, branching palmately in proximal part.

Plate-26 X-Ray radiograph of the group funnel burrow, (a) Three inch thick plate core showing surfacial expression of the grouped funnel burrows. (b) X-radiograph showing palmately converging tunnels from each individual funnel to the centre of the structure.

PLATE-25



(a)



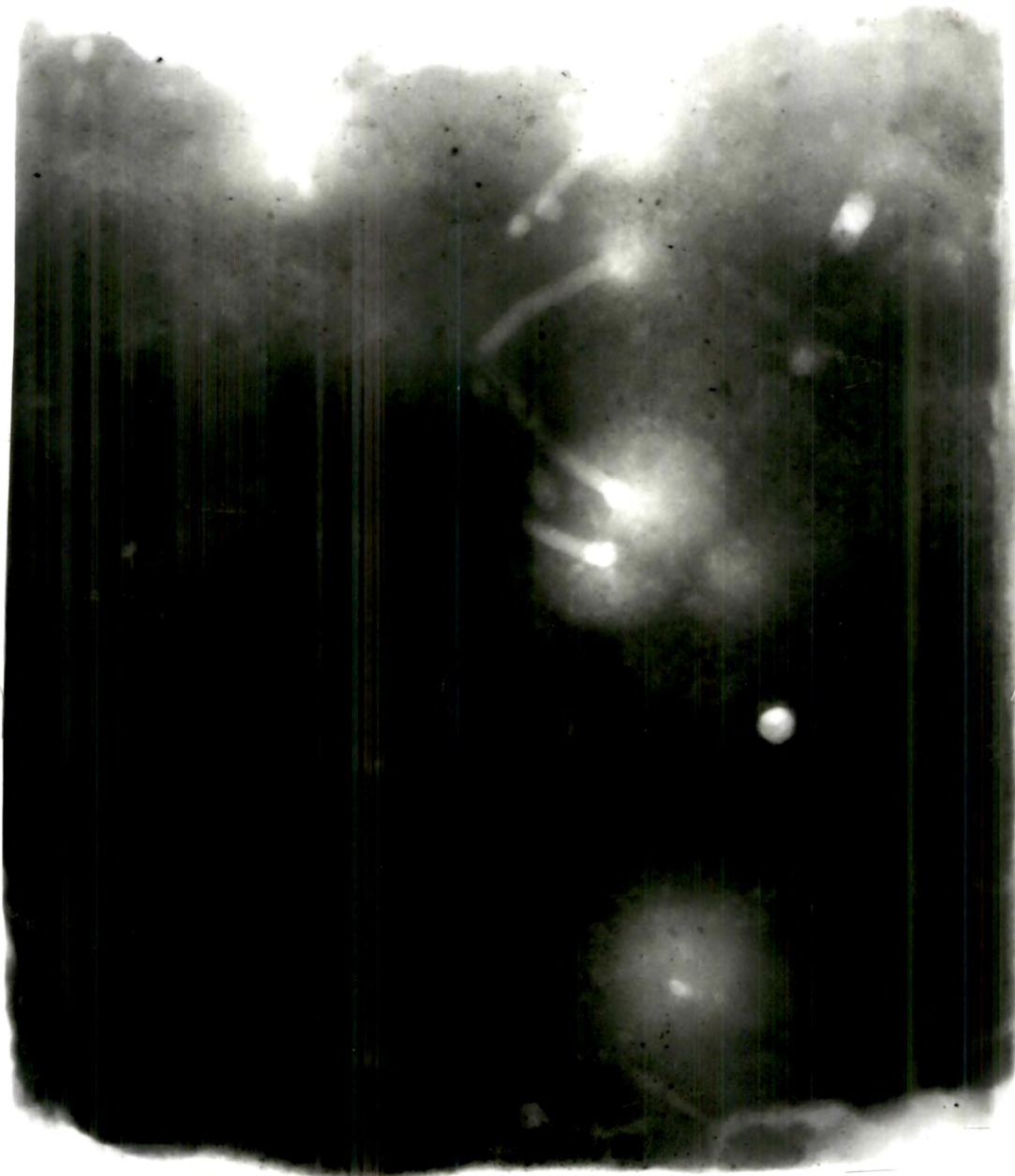
(d)



(c)



(e)



(a)



(b)

maximum observed depth of the burrow is upto 50cm (Plate 27 b&c). The mucus lining served to stabilize the burrow wall, to prevent collapsing of loose sand grains. The burrows are kept open by the producer and had a permanent connection to the sediment/water interface. The acute angles of Y-shaped branching indicate that the jointing did not serve as turning points for animals. These structures are very common in ridges of the Rawal Pir and Modwa Spit sites. 'Y' shaped burrow are made by *Heteromastus filiformis*, identical to fossil form *Polykladichnus irregularis* while 'I' shaped structures are constructed by *Amphinome rostrata*; *Nereis costoe*; and *Oniphus eremita*, identical to fossil form *Skolithos linearis*.

#### 6.5.1.7 Calcitic Tubes

Cemented calcitic tubes are found on varied hard substrate including pebbles, bivalve shells, oysters reefs and rock platforms (Plate-28a). These tubes are spiral to tightly coiled, smooth from inside, sub-cylindrical to conical in shape and consist of ridges and ribs on the outer surface. In plan view these occur as circular from inside, the outer morphology is not reflected inside the tube. The diameter of these tubes are variable and may vary, generally the proto-tube diameter is less than 1mm and tubes opens to atmosphere have diameter upto 10mm and length of uncoiled tube is upto 15cm. Generally, single occupancy of the tubes are found on any sorts of hard substrates, but crowding of the tubes were also observed on oysters reefs (Plate-28 a & b) and rock platforms. They are found in symbiotic relation with the oyster reefs and indicate polarization of the fauna according to light intensity, rate of sedimentation and turbulence levels (Fursich et al., 1992).

Polychaetes species *Serpula vermiculris* and *Sabellaria* sp. secrets such calcareous tubes (Plate-28a) and grows larger by the addition of the anterior increments. They are abundant in the intertidal rocky platform of the Rawal Pir and Modwa Spit area, and also in the Mundra area colonized in mangrove trunks (Patel and Desai 1999). The structures

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Plate- 27: Polychaete burrows, (a) "Y" shaped polychaete burrows similar to ichnospecies *Polykladichnus irregularis* Fursich 1981. (b) Vertical, branched burrows in "Y" shaped fashion close to upper surface (c & d) Vertical burrows of *Nereis* identical to ichnospecies *Skolithos linearis*.



PLATE-27



(b)



(c)



(a)



(d)

are suggestive of the activity of the filter feeding animals, specialized in seston feeding or having ciliated tentacular crown by which they feed. The calcareous tubes are abundant in Kachchh sedimentary basin since Jurassic time.

#### 6.5.1.8 Polychaete Sand Reefs

Polychaete sand reefs (Plate-28c) building activities were observed on man made structures along the mouth of Rukhmavati River and shore platforms of Rawal Pir sites. *Scolopos latus*, a filter feeding polychaetes secreting the mucus on the burrow opening and binding the sand grains during the high tide condition. Tubes usually occur in the bunch, crowded, curved and randomly oriented with individual tubes having length of about 7 to 12 cm and constant diameter of 2 mm. Colony grows in all direction by binding size sorted grains and represent number of generations. It consists of agglutinated quartz grains, heavy minerals, broken small shell fragments of ostracods, foraminifers, faecal pellets, etc. The material found in the reefs is local and is extracted from the turbulent nearshore waters by *Scolopos latus*. These worms are filter feeders (Fauchald and Jumars, 1977) and usually incorporates the detrital material into the tube by sorting material of appropriate shape and size, and cementing it with mucus or special protein cement. The reefs consist of individual tubes, which the concomitantly glued to each other in reef mass with same cement, and subsequently synchronous growth produces individual reefs.

### 6.6 NEMERTEA

These are unsegmented worms found abundantly in the lagoon of the Modwa Spit area. They reside in the anoxic sediments of the lagoons and come to the oxic surface for feeding on algal covered sediments (Plate-29a). The small conical mound of extruded sediments often containing at center from which the worm comes on the surface and moves all around this hole making pentamerous form (Plate-29 a& b) surrounds the

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Plate- 28: Polychaete reefs, (a) calcareous tubes of the Sabellarid polychaete on the shore platform. (b) Extensive development of the live oyster reefs on the shore platform (Modwa Spit). Note the dense association of the oyster shells with symbiotical relationship of Sabellarid polychaete. (c) Sand binded polychaete reefs of *clymene* developed on anthropogenically formed barriers along the Rukmavati river mouth.



PLATE-28



(a)



(b)



(c)

burrow opening. These burrows are simple, straight, vertical, deep, lined and unbranched and often extended to anoxic zone. Their burrows are lined with reddish (iron) or black coloured muddy sediments, which implies that the animal during the high tide irrigates the burrow with overlying water which causes oxidation of ferrous and causes ferrous lining to the burrow walls of the anoxic mud (Plate-29d). While stretch out on the surface for feeding purposes animals making the biogenic curved laminae (Plate-29c).

## 6.7 GASTROPOD (*Archeotectonica laeviegata*)

Activities of the Gastropod *Archeotectonica laeviegata* were observed in the Modwa Spit lagoon, which showed wide range of morphological patterns. *Archeotectonica* lives in the aerobic environment just below the sediment-water interface about 1-2mm below surface. It communicates with the external environment by a pair of highly active siphons through which it performs all vital physiological processes. The presence of the gastropods can be seen by small-pitted appearance (Plate-30 a, b & c) of the surface, usually consisting of small cylindrical holes of about 0.5 to 1.5-mm diameter. Usually, more than 250 individuals are grouped together per sq. meter. Each burrow is associated with a gastropod shell *Archeotectonica laeviegata*, found buried on its sides with the axis parallel to the bedding plane and aperture nearly vertical. The animal excavates a tunnel by its slender foot, in an oblique manner. Thus the opening is located on the ground surface slightly away from the shell and linked to the surface by an inclined tiny tunnel of

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Plate- 29 Biogenic structures of unsegmented worms, (a) Unsegmented worm *Cerebratulus marginatus* stretching out from the burrow and pumping the water make the sediments watery around the burrow. (b) Pentamerous structure on the mound formed on account of pumping of water. (c) Animals stretch out in the watery, algal rich sediments for grazing. Note formation of the biogenic laminae because of peristaltic movement of the animal. (d) Black anoxic mud of the lagoon with oxidised lined burrow wall of the Nemertea formed due to irrigation of the burrows in anerobic condition.

Plate-30: Gastropod activity, (a) Surficial expression of *Archeotectonica laeviegata* activities in the form of small siphonal holes and their locomotary trails. (b) Insitu dense accumulation of the gastropod shells below the surface. (c) Scouped sediment showing population of *Archeotectonica laeviegata*.



PLATE-29



(b)



(c)



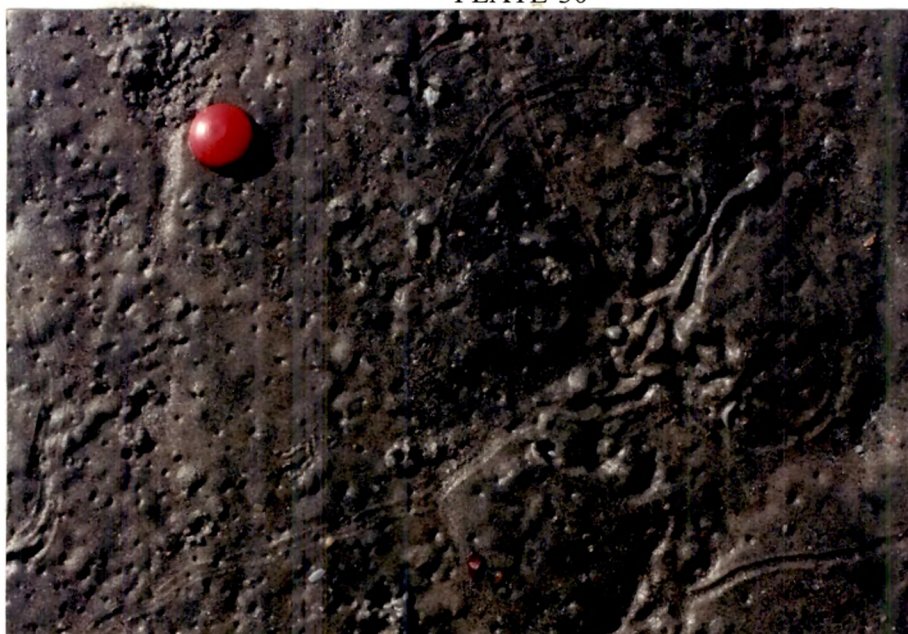
(a)



(d)



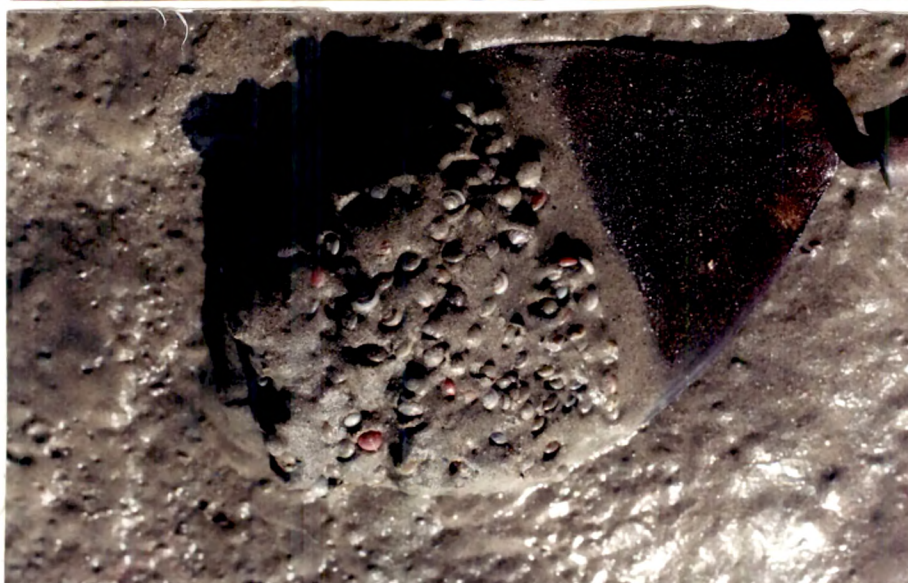
PLATE-30



(a)



(b)



(c)

0.5-0.8 cm in length. Field observations during various tides at Modwa Spit site suggested that gastropods during the high tides do not leave the sediments but remain at the same place, unless, eroded and relocated at some other place by stronger tides. Similar burrows can be produced by different organisms in different marine environments. Badve and Bhonsle (1987) reported similar type of burrows made in intertidal zone by gastropod *Umbonium vestiarium* along with fossil burrows of similar characteristic from sandstones of Jhuran formation from Rudramata area of Kachchh.