CHAPTER-8
ICHNOCOENOSES

8.1 INTRODUCTION

"An ichnocoenoses is an association of lebensspuren reflecting life activity of the individuals of a biocoenoses" (Dorjes and Hertweck, 1975). Thus, the term is strictly confined to the Neoichnologic realm, though some of the workers have used them in fossil context and have modified it as " an ecologically pure assemblages of traces and trace fossil, deriving from the work of a single endobenthic community" (Ekdale et al, 1984, and Bromley, 1990). Looking in to this confusion, the author have restricted the term to the neoichnologic context, and have extended it upto some extent to sub-fossil traces. The term "Ichnocoenoses" and "Ichnofacies" reflects two different aspects of Ichnology. An ichnocoenoses is an association of traces that can be related to one definite biocoenoses. Dorjes & Hertweck (1975) suggested the fossil equivalent of the ichnocoenoses to be ichnofacies, and later Frey and Pemberton (1987) treated it as the unfossilised equivalent of the recurring, global, seilacherian ichnofacies. The shallow marine environment of the Mandvi region is characterised by variety of substrate characteristics and traces. This has thrown light on the various aspects including succession and transition of trace fossils in intertidal zone and its relevance to the tectonic evolution of the Mandvi region (Desai and Patel. *communicated*).

The intertidal marine environments are characterised by mobile and dynamic substrates, which are populated by diverse groups of endobenthic communities. Most of the lebensspuren found in this environment originates from the benthic organisms. The traces may include surface traces, dwelling structures, feeding structures, micro-coprolites or other traces, as well as preserved traces originating from a previous or emigrate community. Seilacher (1967) noted that in marine environments many parameters which govern the abundance and distribution of trace makers tend to change progressively with water depth, therefore it is important to define physical environment of an ichnocoenosis and its depositional setups. The physical environment of an ichnocoenosis or a character lebensspuren has therefore to be defined by its particular sedimentologic criteria, substrate and seawater conditions, etc; while the depositional conditions can be postulated by sedimentary structures, and associated bedforms in which the traces occur. Moreover the characteristics ichnofossils are usually not the only bioturbatation structures in an ichnocoenoses.

In ichnologic explorations, the main way to determine characteristic lebensspuren according to Frey (1975) is to investigate profiles consisting of a considerable number of representative samples from different environments. Then by comparing ichnocoenoses related to different substrate one can evaluate biogenic structures, which are common to several or to a single environmental along the profile. The individual trace fossil thus then reflects ethological and ecological response of the trace-making organism in a specific environmental condition.

Despite the rarity of physical re-deposition, there are certain factors that readily cause lebensspuren assemblages to be ecologically impure groupings. One of the most fundamental tenets of ichnocoenoses analysis is that all-available evidences-physical, chemical or biological- could be integrated and utilised in interpretations. Thus, ichnocoenoses analysis of the recent traces becomes powerful tool for understanding the environmental gradient of the shallow marine rock records.

The biogenic structures in the recent intertidal zone and raised beach and tidal flats of the study area demonstrates wide range of animal behaviour and can be interpreted with known ecology, behavioural patterns, adaptations, and other physical parameters. Thus would be of great help for paleobiology and paleoenvironmental constrains of the shallow marine intertidal zone. The individual traces studied in the intertidal zone exhibits a distinct non-random pattern, some traces occur together recurrently whereas others are never found in same geomorphic units. Naming the individual ichnocoenoses is necessary for their identifications as recurring entities. The simplest method is to identify the ichnocoenoses by its characteristics dominating ichnogenus. The eponymous for dose not necessarily need to be abundant in every occurrences of its ichnocoenoses and still, it might also appear on the other ichnocoenoses. The seven distinct ichnocoenoses found in the present day intertidal zone, whereas three distinct ichnocoenosis were found in the palaeo tidal flats and raised beach environments. The present day intertidal zone ichnocoenosis includes *Psilonichnus* ichnocoenosis; *Skolithos* ichnocoenosis; *Ophiomorpha* ichnocoenosis; *Chondrites* ichnocoenosis; *Balanoglossites* ichnocoenosis *Entobia*/*Meandropolydora* ichnocoenosis and *Faecichnia* ichnocoenosis.

The names of the ichnocoenoses are named after the dominant ichnogenus, but as per the ICZN (1985) rules, Article 1a(7) which indicates exclusion of the modern traces from naming fossilised trace fossils names; for this Bromley and Fursich (1980) and Rindsberg (1990) suggested "When material deemed to be unfossilised, but which nevertheless can be refereed to an ichnotaxon, the adjective 'incipient' should preceed the name. Therefore the names of assemblages of modern traces can be based on fossils, but applied to "Incipient fossils" (or Modern or subfossil) material by convention (*Per. Comm*, Andrew Rindsberg). Therefore all the names of ichnocoenoses in following sections are based on incipient fossils.

8.2 PRESENT DAY ICHNOCOENOSES

8.2.1 *Faecichnia* Ichnocoenosis

Various Faecichnia activities of the crustaceans and polychaetes in the forms of surfacial workings dominate the ichnocoenosis (Figure-34). It is characterised by traces like rod shaped faecal pellets; rounded, elongated, oblong, pseudo-faecall pellets, string pellets, etc. The pseudo faecal pellets were restricted only to the top of the freshly deposited surface, created by young and juvenile *Ocypode ceratopathalma, Ocypode roundata, O. platyrsis, Uca marionis, etc.* These crabs created structures in specific designs, surrounding their burrow opening, and were abundant on the beach, ridge and runnels of the Wind Farm and Rawal Pir sites and less abundant in Modwa Spit sites. Ethologically these traces represent the feeding activity, in which the pellet is never passed from its body, except its mouth grazes the pellets, and leaves it aside. This

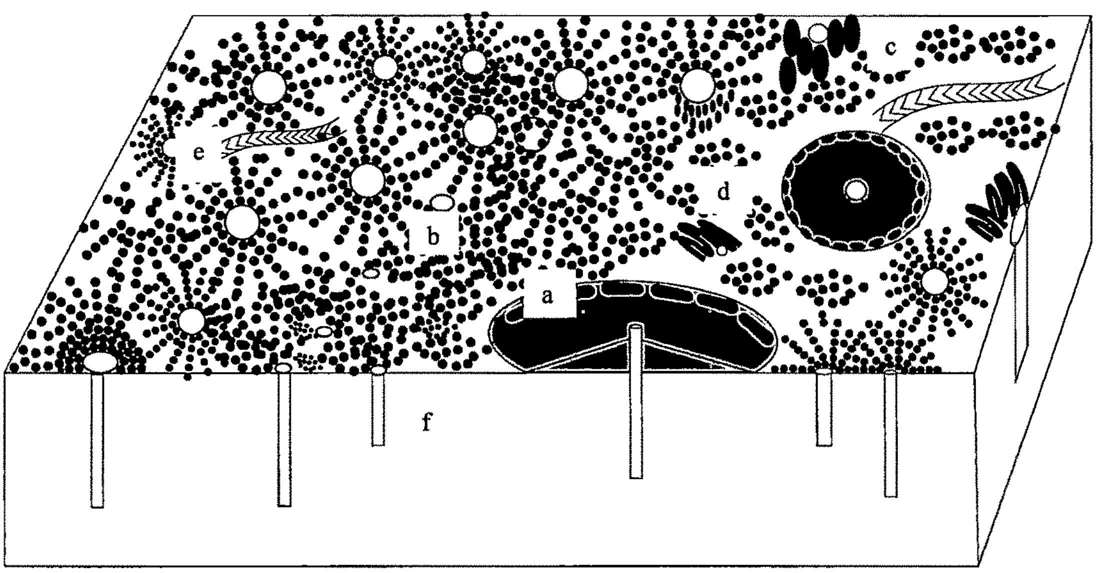


Figure- 34: Schematic diagram showing *Faecechnina* ichnocoenosis (a) rod shaped pellets, (b) feeding pellets of different designs, (c) burrowing pellets, (d) faecal strings, (e) hermit crab trail, (f) *Skolithos* burrow.

association often represents periodic exposures of the area. The true faecal pellets are rod and string shaped, made up of fine mud, excreted as a result of suspension feeder activity. They are abundant in the runnels of the Rawal Pir and Modwa Spit sites.

Interpretation

The importance of this ichnocoenosis is that the surfacial working often disrupts completely the original sedimentary structures, (Howard and Frey, 1975) and are only preserved as biodeformational structures. The ichnocoenosis is also well displayed in the relief peels of the raised beach sections, where the plane bed laminations are interrupted by biodeformational structures, and structureless sediments. These working are also important for sediment cycling and deposition of fine muds in coarse sands as observed in the study area and especially in deposition of argillaceous sediments in the form of biogenic pelletization (Pryor, 1975). This ichnocoenosis have poor potentials of preservations; but can accumulate as clay lenses in sand rich horizons.

8.2.2 *Entobia/Meandropolydora* Ichnocoenosis

This ichnocoenosis is dominated by circular, pouch shaped borings and small meandering tunnel occurring abundantly in calcitic shells of the bivalves. Such type of substrates has limited extension in the intertidal zone, and the boring organisms are locally abundant, includes polychaete worms, predaceous gastropods and some of the sponges. Included in this ichnocoenosis are other ichnogenus *Oichnus simplex*, *Talpina ramosa, Clinoides vestifica, Meandropolydora sulcans, and Entobia sp*. The ethology of borings suggest that it is made for dwelling purposes in either dead shells or symbiotically. In either case, the ichnocoenosis suggest dwelling nature of these trace makers of polychaete *Polydora*, or some sponge, which bore for protection or domicile rather than for food (Bromley, 1970; Warme, 1975; Howard and Frey, 1975). Sole feeding structures found in the assemblage is of the predation trace of the gastropod, which feed by drilling into the shell. The *Oichnus simplex* and *Entobia* isp. are closely associated and abundantly found on the gastropod (*Turritella*) shells; while *Meandropolydora sulcans* is usually found on gastropod (*Murex*) shell. *Entobia* alone as separate is found on thick oyster shell, which are abundant and well developed along the Modwa Spit shore platform. While *Cardium* and *Arca zebra* shells often bears dendritic tunnels borings of

Talpina ramosa and *Clinoides vestifica.* According to Bromley (1990), majority of the structures represents domichnia with equilibrichnia or fodinichnia, or simply praedichnia. All the traces have wide environmental preference, except for the type of substrate especially the *Entobia* specifically shows no general preference.

Interpretation

The main implication of this ichnocoenoses is the thorough knowledge of the post-mortem processes acting on the shells after the death of the organism can be known. It also helps in understanding shell breaking process occurring in the intertidal zone. Sedimentologically it helps in dissolving the calcium carbonate substrates by process of bioerosion and helps in production of fine-grained sediments. The ichnocoenosis indicates substrate stability (Howard and Frey, 1975), although many clasts are free of them and thus may have been rolled or tumbled periodically along the bottom, or were buried intermediately by migrating sand waves.

8.2.3 *Chondrites* ichnocoenosis

This association (Figure-35) is characterised by *Chondrites* like traces made by polychaetes *Nephthys* in the silty sand and sandy substrates of the Mandvi intertidal zone. The assemblage represents regularly branching burrow system constructed for combined feeding and dwelling purposes. The burrows represent three ramifying units consisting of straight vertical tunnel more than 10cm deep in to the sediments. Towards the sediment-water interface (SWI) that branches into an dichotomous` short tunnels, either straight or slightly arcuate, dendritic pattern tunnels, diverging are acute angle, which are placed just below the SWI that are produced as deposit feeder makes repeated probing in the sediments. Each tunnel end terminates at surface by creating surfacial feeding grooves. Sometimes the tunnel ends are also marked by faecal mound. This indicates that the structure is made for complex ethological purposes, which includes dwelling, and interface feeding. According to Bromley and Ekdale (1984), *Chondrites* indicates very low level of oxygen in interstitial waters within the sediment at the site and time of the burrow emplacement. But water samples taken from the *Chondrites* sites show normal dissolved oxygen 2.1mgl^{-1} to 1.25 mgl^{-1} and free CO_2 ranges from 25% to 73% in the water samples, at on average temperature of 88^{0} F,. This indicates that though the ichnogenus is considered to be opportunistic for oxygen deficient conditions, it can well adapted to normal conditions also. At all the sites including Wind Farm, Rawal Pir and Modwa Spit sites, no chemically reducing conditions were noticed below the biogenic

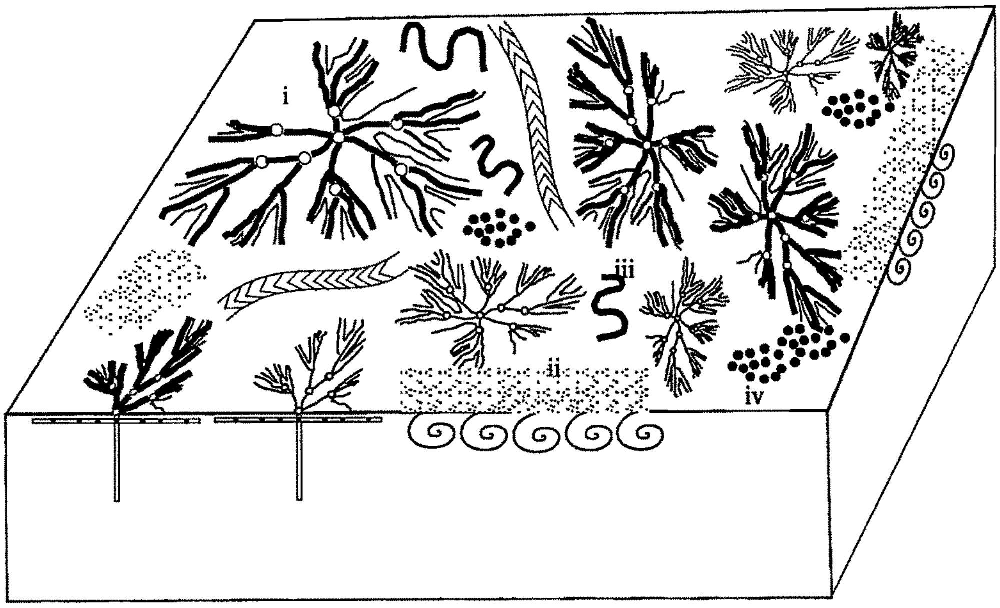


Figure-35: Schematic diagram of *Chondrite* ichnocoenosis (i) *Chondrites*, (ii) Gastropod siphonal burrows, (iii) gastropod trails, (iv) Faecal pellets.

structures. They are abundant on the flat, silty sand substrates of the ridge and flat intertidal zone, where the water flow after the low tides blankets the flat surface.

Interpretation

This association is characterised of the structures made by polychaetes *Nephtys inermis* and *Nephtys diabranchis* in the intertidal zone. Sedimentologically they are associated with plane laminations and antidunes, and characteristically absent from the rough hydrodynamic conditions necessary for producing ripples. Ethologically, the structure represents complex fodinichnial burrows (Ekdale, 1992) when its maker's behaviour changes as deposit feeders and also as a suspension feeders. Ekdale (1985) considered *Chondrites* as an opportunistic; while Bromley (1990) described the ichnocoenosis as non-vagile, deep deposit feeder structures. In contrast the Kachchh intertidal ichnocoenosis is non-vagile, interface deposit feeders, and opportunistic.

8.2.4 *Skolithos* ichnocoenosis

This ichnocoenosis (Figure-36) consist of different dwelling burrows of considerable length, which may be branched to unbranched, lined or unlined burrows made by polychaetes. Ethologically, they represent the domichnia group. The ichnocoenoses consist of biogenic structures of ichnogenus *Skolithos*, *Polykladichnus, Monocraterion, Diopatrichnus etc.* The assemblages are made in variety of substrates ranging from silty sand to mature sand to muddy gravel, but are restricted to the middle and lower intertidal zone of study area in the exposure level below 2. Some of the *Skolithos* which are concentrated on the ridges are made by small juvenile crabs of *Ocypode roundata, O. platyrsis*, and represents the first ontogenic phase of the *Psilonichnus* burrows, in which simple linear and non-branching burrows with single opening indicates very simple mode of inhabitation by young and juvenile crabs. These same crabs, when become adult make branched, Y-J shaped burrows known as *Psilonichnus*. While other structures are made essentially by deposit feeding polychaetes, except *Diopatrichnus*, which is a suspension feeding structure. The *Polykladichnus* are small cylindrical Y, to J shaped branched, unlined burrows made for dwelling by polychaetes like *Nereis costoe, N. unifasciata, N. diversicolour, N.* sp.; *Lycastis indica;*

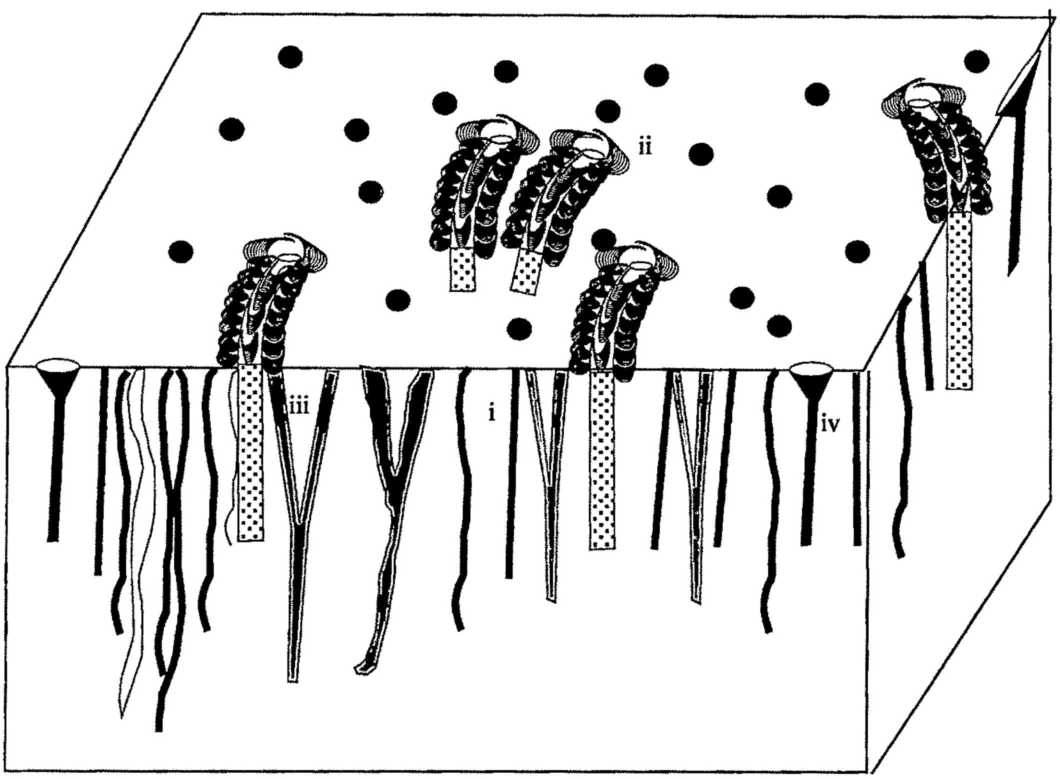
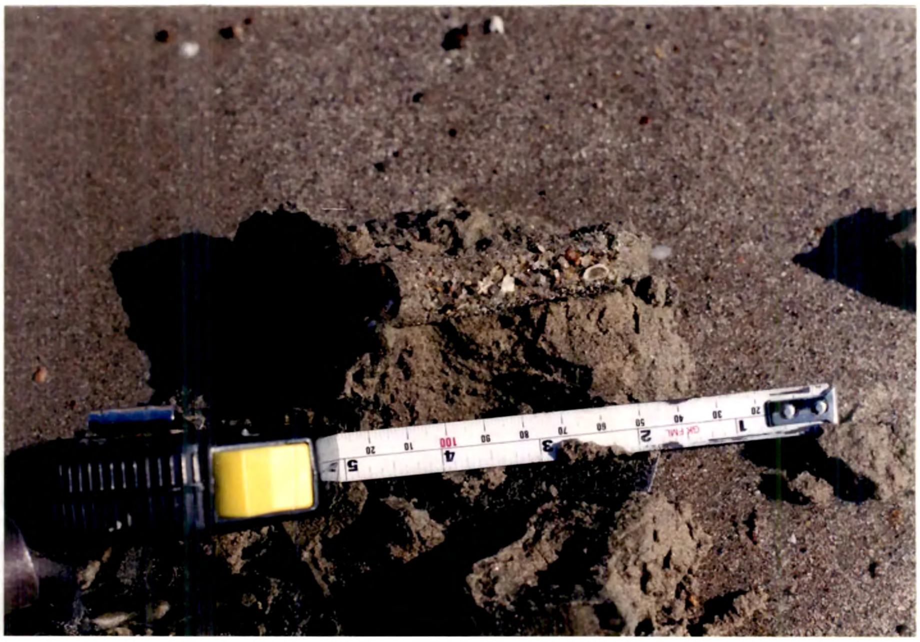


Figure-36 Schematic diagram of *Skolithos* ichnocoenosis (i) *Skolithos*, (ii) Diopatrichnus. (iii) Polykladichnus. (iv) Monocraterion.

Plate-35 Present day abandoned burrows, (a) Thinly lined, passively filled coarse sediment in abandoned burrow idnetical to ichnospecies *Skolithos*. (b) Domicile structure of the Oratosquilla striata in runnels. Tube showing mammaliated exterior surface of *Ophiomorpha nodosa* burrow.

PLATE-35



(a)

(b)

Lumbriconereis pseudobifilaris and *Amphinome rostrata*.

Interpretation

Skolithos ichnocoenosis is characterised by dwelling tubes of mucus linings and filled with coarse-grained materials (Plate-35a). Sedimentologically they are found to be abundant in the plane bed laminations (*Skolithos, Polykladichnus, and Monocraterion*), while in rippled, muddy gravelled substrates (*Diopatrichnus*). It indicates medium to high-energy settings, with moderate to high degree of bioturbation in clastic shifting substrates. The zonation of the structures indicates they are absent in the higher intertidal zone (i.e. exposure level 1, of CTL's). Similar conditions were also found favourable for *Skolithos* and its modern analogue tubes of *Diopatra cuprea* across modern tidal flats (Skoog et al, 1994).

8.2.5 *Psilonichnus* ichnocoenosis:

This ichnocoenosis (Figure-37) is characterised by dwelling burrow of three dimensional, branched, unlined burrow systems, which are either in the shape of the English letter Y, J, or I shaped or similar to the ichnogenera *Thalassinoides*. The burrows are made by adults *Ocypode roundata*; *O. ceratopathalma*; *O. platyrsis; Uca marionis* in the beach and backshore of the study area. They are restricted in the intertidal zone upto CTL's exposure level 0 & 1, and often extend more than meter deep into the sediment.

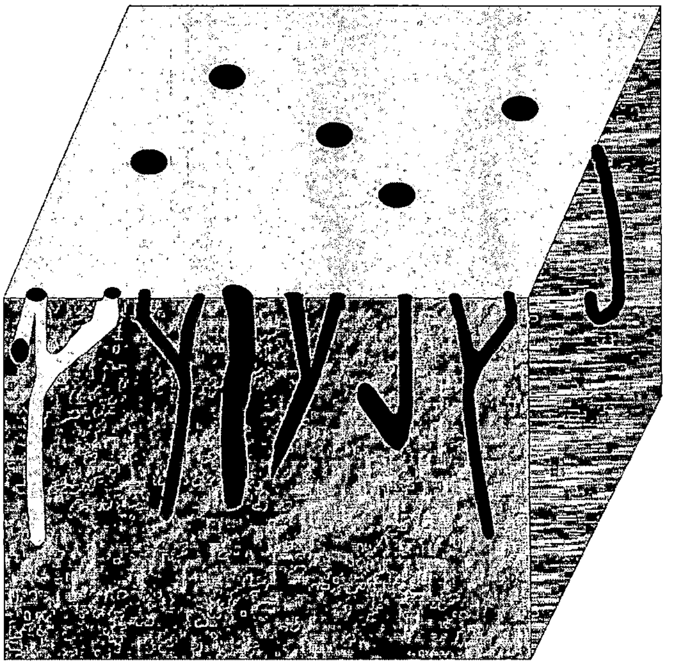


Figure-37 Schematic diagram of the *Psilonichnus* ichnocoenosis

The lower extends of the burrow marks the lowest limit of the ground water fluctuation during the low tides. The burrows are often renewed after the high tides, and the renewal processes are done by bringing the inner and deeper sediments to the surface. These excavated sediments are deposited in the form of mounds, thick rims or spreads, marking the territory of the adult crabs. This process is very effective in bioturbating the beach and backshore sediment, which are otherwise not bioturbated by any other organisms.

The same species that makes this *Psilonichnus* burrows during their young stage also make unbranched-small burrows similar to the *Skolithos*. The process and intentions, involved in making the burrows are same, i.e. for dwelling and protection and exhibits an earlier ontogenic phase of the *Psilonichnus* burrows. The intermediatery phase consists of gradation between fully developed *Psilonichnus* and *Skolithos*. Characteristically towards the low water line, the burrow diameter decreases, while density increases. In the Wind Farm and Rawal Pir sites, *Psilonichnus* burrows occurred in low density, far spaced, indicating territorial behaviour of the crabs. At in back shores of Rawal Pir and Modwa Spit site the burrow opening were characteristically directed and opens towards the sea ward sites. The beach burrows showed mixed directions, but majorities of them were directed towards the sea.

Interpretation

The presence of the *Psilonichnus* ichnocoenosis is clear indication of the beach-backshore environment in clastic sediments, and its range extends even to the dunal areas of the study area. Curran (1992) also described similar ichnocoenosis, in carbonate setting, the burrows are confined to the upper foreshore and backshore zones only. They have great potentials for preserving, and are good indicators of the past sea level positions (Curran, 1990).

8.2.6 *Ophiomorpha* ichnocoenosis:

This ichnocoenosis (Figure-38) is characterised by monodominant species of *Ophiomorpha nodosa*. Ethologically, it represents dwelling burrows constructed by squilidiean crustacean species of *Oratosquilla striata* (Patel and Desai, 2001). The ichnocoenosis is abundant in the lower intertidal zone, at exposure level 4 & 5, with substrate conditions of fine silty sand. The thick wall of the burrow indicates stability of the structure and is often found keeping in pace with the sediment-water interface. The structure is made by suspension feeding stomatopodean crustaceans. Density of the burrows varies according to the populations of the Squillidean, but high density, closely packed, burrows are found to be occurring close to the subtidal boundary or in runnel having some considerable water column during the low tide conditions. The burrows are abundant in the lower runnels of the Rawal Pir site, where the substrates are of silty sand

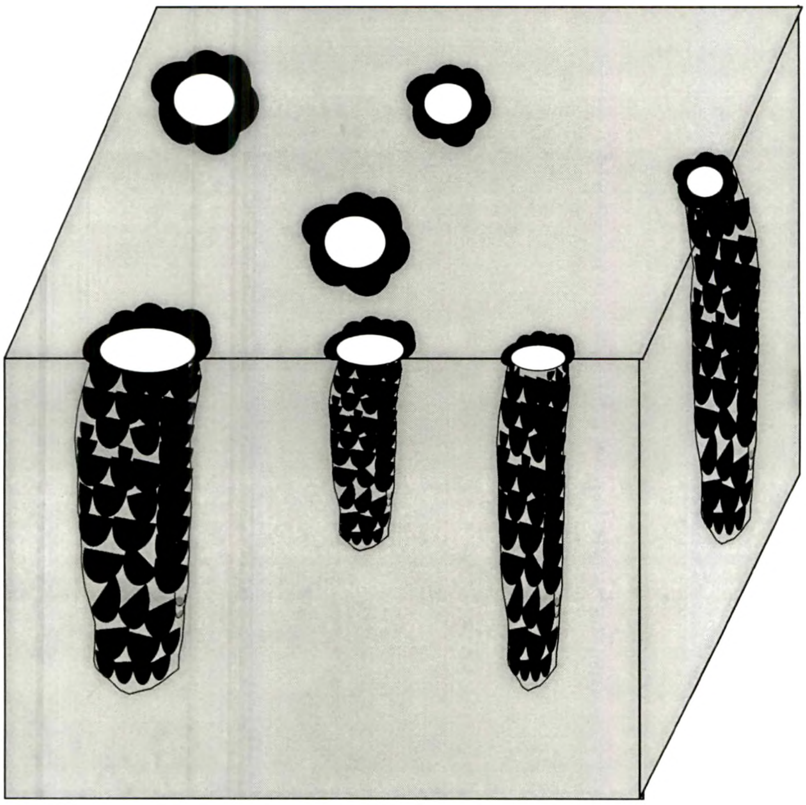


Figure-38 Schematic diagram of the *Ophiomorpha* ichnocoenosis.

type. Sometimes the inner walls are also lined by mud, or by different materials. The ichno-zonation of the recent crustacean traces of the intertidal zone shows, that they are abundant near the low tide level. Similar to the *Ophiomorpha* burrows occur pelleted chimneys, which are constructed by certain juvenile intertidal crabs, above the sediment surface to serve as tubular entrance to their burrows. Similar types of chimneys were considered, if preserved, by Frey et al., (1978) to be *Ophiomorpha*. However, ethologically and feeding styles does not match with those of *Ophiomorpha* constructed by squilidiean *Oratosquilla striata*.

Interpretation

Bromley (1990) placed *Ophiomorpha* with the *Skolithos* ichnoguild because of its similarity with the suspension feeding animals. Ekdale (1992) criticise it and suggested *Ophiomorpha* as deposit feeding structure rather than suspension feeder. The Kachchh intertidal ichnocoenosis is purely the work of a suspension feeder, rather than of deposit feeders, the functional group and trophic group analysis of the trace maker also suggest similar conditions. Their associations in runnels suggest its adaptation to high energetic conditions of unstable substrates. The *Ophiomorpha* ichnogenus is considered to be of poor environmental indicators (Ekdale, 1992), when dealt with broad environments. The Kachchh intertidal ichno-zonation suggests that the ichnogenus is good indicators of the lower intertidal zone, where it occurs in the clastic, shifting substrates of moderate wave and current energy conditions.

8.2.7 *Balanoglossites* ichnocoenosis:

This ichnocoenosis is characteristically exposed in the Rawal Pir lagoon, where there are alternating layers of peat and sand. The ichnogenus is constructed by *Oniphus* polychaetes, which are suspension feeders. The burrows and its tunnels extend in to the anoxic layer, devoid of any interstitial oxygen. The sediments are of fine sand, and substrate is purely silty sand nature, often covered by algal mats that drastically cuts the oxygen supply in the sediments (Leszczynski et al, 1996). The burrows represent complex

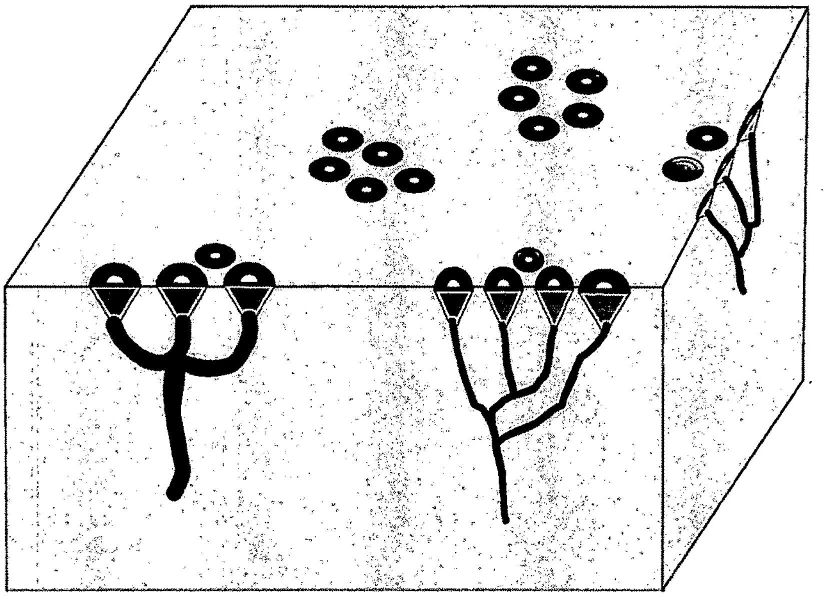


Figure-39 Schematic diagram of the *Balanoglossites* ichnocoenosis.

spatial configuration, consisting of horizontal segment from which vertical or somewhat oblique segments bifurcates upward towards the surface. The surfacial expression of the burrows are group of 5-7 funnels, connected by several U- shaped interconnecting tunnels, which are lined, of equal diameter and converge towards centre point. The branching and bifurcation are restricted only to the top few cm of the sediment. The worm is purely a suspension feeder, which feeds by irrigating the burrows, and suspension feeding from the water that is circulated. Due to the presence of the numerous funnels, the water that is circulated brings additional oxygen supply to the anoxic mud. Other common structures associated with the *Balanoglossites* were another funnel feeder-*Arenicolites*, which consist of a pair of funnels or a funnel and a mound, with U shaped interconnections. Both of the trace makers are well adapted to the harsh changing environment of the lagoon.

Interpretation

Ethologically, this ichnocoenosis is suggestive of fodinichinal burrows, with burrows modified to adapt to the low interstitial oxygen, and anoxic conditions. Sedimentologically, the biogenic structures are present on high viscosity flow deposits, indicating its adaptation to varied clastic environments of low energy to high-energy conditions. Palaeoecologically, the burrows are considered to be indicative of high organic matters in the sediments (Kazmierczak and Pszczolkowski, 1969). Recent ichno-zonation suggests the influence of the intertidal zone with exposure level of 2 &3. Barington, (1965) and Kazmierczak and Pszczolkowski, (1969) regarded the ichnogenus as indicative of lower intertidal zone. The occurrence of *Arenicolites* indicates that it must have acted as shelters only for short period of time and not as a permanent domiciles (Dam, 1990). Over all, the ichnocoenosis suggests major environmental changes like high water flow during spring tides in bottom substrate, followed by short period of well-aerated conditions in bottom water with no-sedimentation and abundant food supply.

8.3 RAISED BEACH AND TIDAL FLAT ICHNOCOENOSIS

8.3.1 Glossifunguites Ichnocoenosis

The *Glossifunguites* ichnocoenosis are exposed as firmground substrates in intertidal-supratidal zone (Figure- 40), typically showing characteristics of cohesive nature of the sediments, which have undergone compaction, dewatering and sub-aerial exposures. These ichnocoenosis were developed in intertidal/subtidal region of moderate energy settings of Rawal Pir site, where the semi-consolidated substrate offers resistance to erosion (Figure-40). This cohesive sediments of the intertidal / subtidal zones appears as an exhumed surface in the form of omission surfaces (Bromley, 1975; Pemberton & Frey, 1985). These traces are characterised by vertical, cylindrical, tear shaped pseudo-boring or sparsely to densely branching dwelling burrows. The sediments of the area are fine grained in nature consisting of mainly 70-80% silt size particle, with 15-40% of $CaCO_3$. They are characterised by two tier levels, essentially pre-omission and omission suits, the post-omission suit is conspicuously absent.

The pre-omission suits are characterised by soft ground burrows of *Ophiomorpha/Thalassinoides* (Plate-32) and *in situ* bivalve association of *Macoma/ Solen* (Plate-33). The pre-omission surface consists *Ophiomorpha-Thalassinoides* association, which characterised by presence of mud lined, branched burrow systems of intertidal/subtidal environments. These are dwelling/feeding burrows of the braychuryan and stomatopodean crustaceans (Patel and Desai, 2001). The *Macoma* and *Solen* is deposit feeding bivalves, adapted for burrowing in soft-silty-muddy sediments (Truemen and Ansel, 1969, Tasch, 1973) of the intertidal/subtidal zone. This association is found in dewatered mud, in which, the dead *Macoma* shells are represented in living positions with young *Solen* shells.

The omission suites are characterised by boring structures (Plate-33) of mechanical borer bivalve *Bernea truncata.* These structures are composed of clavete boring normally measures less than 10mm at the aperture and nearly 20-30 mm diameter at the base, and their length is identical to the *Bernea* shells (20-150mm).

Interpretation

The *Glossifunguites* ichnocoenosis, which present all along the coast as an exhumed surface indicates its phase change from soft ground to firm ground due to dewatering and sub-aerial exposures (Figure-40). The subtidal soft ground sediment surfaces provided hospitality for bivalves like *Macoma,* which flourished and colonised for successive generations. Due to changes in environmental conditions, *Solen* dominated as soft ground community represented as single generation of young shell. Finally, these communities have withdrawn from the omission surface due to aerial exposures and partial dewatering of the muddy sediment. These pre-omission surfaces were also hospitable for squilidiean and brachyuran crustaceans represented as dwelling/ feeding activities in the form of *Ophiomorpha* and *Thalassinoides* burrows.

In later stage, these sediments were uplifted, exposed aerially, squeeze out water from it and become firm and attracting the *Glossifunguites* association (Fursich, 1971). The firm substrates of the Kachchh coastline have been colonised by boring communities like *Barnea truncata*. The presence of bivalve dominated intertidal community clearly indicates the change, possibly due to seismic land uplift. This can be envisaged due to the shifting of the environment-specific substrate or the ichnological zones are momentary processes, and the parts of the subtidal area crosses the intertidal zone with being colonised by intertidal bivalve community. Hence the deposit indicates two tiering levels, one pre-omission and other omission. It appears that the pre-omission phase was within shallow marine, and a few meters (<2m) uplift have exposed them to subaerial lithification.

When compared with modern ichno-zonation from the same area, such type of high bioturbation is characterised by lower intertidal/subtidal environment. The presence of the dominant suspension feeding organisms also supports these views. They indicate initial (pre-lithification) colonisation of the organism into the soft substrate. The borings have typical style, wherein the individual borer activity avoids cross cutting of other borings. Similar case have also been observed for Miocene argillaceous limestone of Kachchh (Patel and Shringarpure, 1998) and are commonly observed in the lower to middle intertidal zone (Patel and Shringurpure, 1998; Gingras et al., 2001; Kozloff, 1996). The *Bernea* association are observed in comparatively firm substrates and their activity have overprinted the pre-omission suites of *Ophiomorpha/Thalassinoides* and thus shows two distinct tiering patterns indicating environmental condition change from subtidal to intertidal.

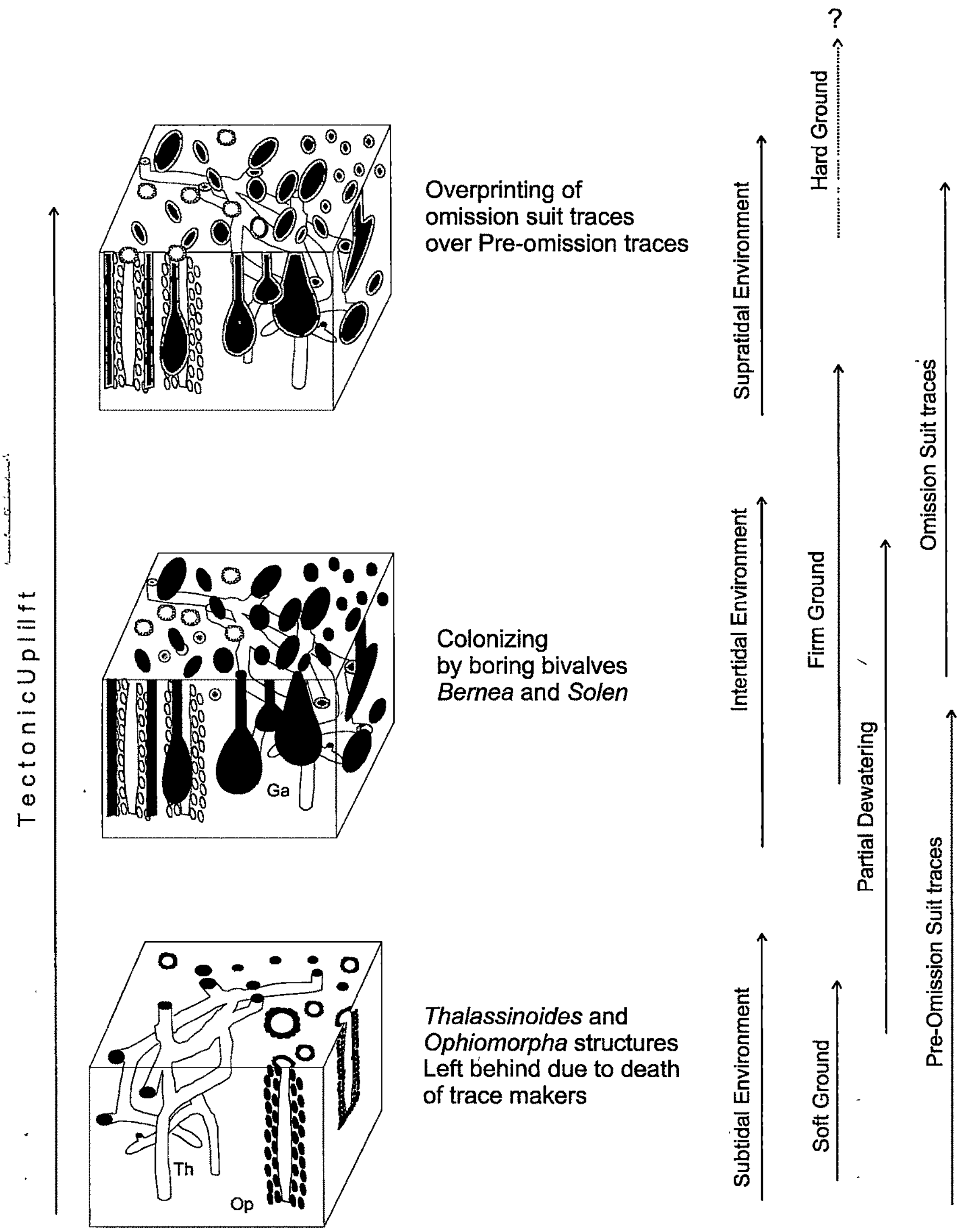


Figure-40 Sequence of development of *Glossifunguites* ichnocoenosis as an omission surface over pre-omission *Ophiomorpha-Thalassionides* ichnocoenosis.

8.3.2 *Skolithos* Ichnocoenosis

The *Skolithos* ichnocoenosis is well developed in the three-meter high raised beach cliff on either side of the Mandvi town and partially dewatered mud. The sediments comprises of coarse to fine grained sand size particles with plane laminated beds alternating with biodeformational-rippled laminated beds and seismic induced deformational structures. The distinct identifiable ichnogenera includes *Skolithos, Polykladichnus* and *Ophiomorpha*. It has bioturbational index of =5 and no discrete physical structures can be observed. The *Skolithos* and *Polykladichnus* structures are mucus bound sand structures made by marine polychaetes, often ranging in diameter from 5-20 mm and may be branched or unbranched. The *Ophiomorpha* present in these associations is made up of sandy pellets and sometimes lined by mud from inside. These ichno-structures represent the middle to lower intertidal zone, when compared with the present day profile of the Mandvi beach.

Interpretation

This association is characteristic of the lower intertidal/subtidal zone (Patel and Desai, 2001, Frey et al. 1978, Howard, 1972) and consist of *Skolithos, Polykladichnus,* and *Ophiomorpha* burrows. These burrows are made by suspension feeding animals in clastic, shifting substrates of the lower intertidal/subtidal environment, and are exposed as raised beach in the supratidal region, which indicates upliftment of the lower intertidal/subtidal sediments.

8.3.3 *Ophiomorpha* Ichnocoenosis

The *Ophiomorpha* ichnocoenosis is developed in sandy as well as in the pre-omission suits of the muddy sediments. The burrows developed in the mud are in the form of complex maze, with the burrow openings close to each other and in high density. The exposed burrows shows mucus lined smooth inner surfaces with iron oxide rim, while the outer nodose seems to have worn out by waves and currents of the intertidal zone. The burrows are monodominant and densely packed (15-20 burrows per sq. meter) with diameter of 3 to 5 cm; the Bioturbational Indices is =6, indicating complete bioturbation and obscure the physical sedimentary structures. In the sandy sediments of the raised beach, this ichnocoenosis consists burrows of *Ophiomorpha* with *Skolithos* and *Polykladichnus*. *Ophiomorpha* burrows are branched and lined with nodose structures exposed in cliff sections of the raised beaches. The prominent relief appears after sand blowing revealing the mucus binded structures.

Interpretation

The *Ophiomorpha* is a characteristic trace fossil of the subtidal region (Frey et al., 1978; Chamberlain and Baer, 1973) or of the lower intertidal zone (Patel and Desai, 2001). The creators of these burrows are stomatopodeans (Patel and Desai, 2001), or *Callianassa* shrimp (Weimer and Hoyt, 1964). These animals are subtidal dwellers, habituated to live in anoxic conditions. The presence of the iron oxide rim surrounding the burrow wall indicates the possibility of low oxygen conditions in muddy sediments and possibility of RPD layer near the surface cannot be ruled out. In such cases the burrows seems to be irrigated by overlying oxygenated waters, which causes oxidation in the burrow wall resulting into iron oxide rim. This indicates that the animal inhabiting regularly irrigated the burrow for feeding purposes. The raised beach burrow is devoid of any such type of rims, it may be due to high oxygen content in sandy sediments, and where the RPD layer may also be well below (>20cm) the surface (Pearson and Rossenburg, 1978). In present day environment *Ophiomorpha* like burrows are found in the lower intertidal zone (Plate-35b). Therefore the presence of these *Ophiomorpha* ichnocoenosis in the supratidal region, whether in muddy or sandy sediments, is probable indicator of the tectonic activity, which brought these sediment packages into the present status.