CHAPTER-7
PALAEOICHNOLOGY

7.1 INTRODUCTION

This chapter deals with the boring and burrowing activities of crustaceans and polychaetes in the frozen intertidal/subtidal sediments. These activities are formed as a part of the fossil record of the Holocene time of the coastal zone of the Mandvi area and can be distinctly separated and delineated from the "Fossilization barrier" (Seilacher 1967a) or the "Modern to fossil transition" (Curran 1994). Unlike the body fossils, whereby the taphonomic filter separates living organisms from the equivalent body fossil, the recognition of ichnologic transition from the "active" to "abandoned" or fossilised state is yet to be fully understood. The purpose of this study to identified and classified the trace fossils that form same area in similar environmental conditions and their preservation in their original state, either occurring in the uplifted or submerged sediments along with boring structures.

The Kachchh coast have experienced various phases of tectonic episodes in Quaternary times (Biswas, 1982), causing differential upliftment along the Kachchh coastline (Patel et al, 2001). The upliftment episodes during the Holocene have caused formation of (i) uplifted tidal mudflats and (ii) raised beaches along the Mandvi coast. The trace fossils content of these raised geomorphic units are distinct and comparable to modern structures produces by the similar kind of the organisms in the same area. Raised beaches and tidal mud deposits are intensely bioturbated comprising of abundant traces of invertebrate organisms of crustaceans, polychaetes and bivalves of subtidal/intertidal origin. Ichnologically these deposits are characterised by abundant but etholgically less diverse groups of ichnospecies like *Skolithos, Ophiomorpha, Polykladichnus, Thalassinoides* and *Gastrochaenolites*.

7.2 SYSTEMATIC ICHNOLOGY

The large number of interest has been attached for studying trace fossils in clastic sediments, like the reconstruction of ancient life or palaeocommunities and benthic behavioural patterns, palaeoecological and environmental interpretation of the marine strata of the different geological periods. To satisfy the diverse interest for studying trace fossils many workers has proposed different classification schemes for example Ethological/Behavioural classification (Seilacher, 1953 1964), Stratinomic (Seilacher,

1953), Preservation or Toponomic (Martinsson 1965,1975), Phylogenetic (Seilacher, 1953) and Morphologic affinity (Ksiazkiewicz 1977) classification scheme which was modified later by Uchman (1995). The author has applied all the classification schemes separately or in combination but for systematic description of the trace fossils, Ksiazkiewicz (1977) classification scheme and modified version (Uchman 1995) is followed.

The Trace fossils are classified on the basis of morphological affinity, whereby a few main morphological groups related to the general shape of trace fossils are distinguished, with subdivisions into smaller groups typified by the most characteristic ichnogenus (Uchman, 1995). The scheme related to classification schemes by Lessertisseur (1955) and Vialov (1972), is based mostly on the scheme of Ksiazkiewicz (1977) with respect to the main morphological groups. Uchman (1995) distinguished eight morphological groups: i) circular and elliptical structures, ii) simple structures, iii) branched structures, iv) radial structures, v) spreiten structures, vi) winding and meandering structures, vii) branched, winding and meandering structures and viii) networks. Two general divisions are used in Uchman's (1995) work, the burrows and borings. This classification scheme is simple and readily applicable considering the morphological criteria. The possible producers are also discussed and are compared with the known present day data from the same area.

7.2.1 Burrow Structures

7.2.1.1 Simple Structures

Diagnosis: - Cylindrical to subcylindrical, predominantly straight, rarely slightly sinuous traces with no or few lateral branches. Surface either smooth or sculptured.

7.2.1.1.1 Vertical forms: This form includes more or less straight, vertical to sub-vertical cylindrical burrows such as *Skolithos*

Ichnogenus

Skolithos HALDEMAN, 1840

Type Ichnospecies: *Fucoides? linearis* HALDEMAN, 1840

Diagnosis: Unbranched, vertical or steeply inclined, cylindrical or subcylindrical lined or unlined burrows, with or without funnel shaped top. Wall distinct or indistinct, smooth or rough possibly annulated; fill massive; burrow diameter may vary slightly along its length.

Ichnospecies

Skolithos linearis HALDEMAN, 1840
Plate- 31a

Diagnosis: Cylindrical to subcylindrical, straight to slightly curved and vertical to slightly curved or inclined burrows. Burrow wall distinct or indistinct, may be annulated and smooth or rarely corrugated.

Description: Predominantly straight to slightly curved, cylindrical to subcylindrical, vertical to steeply inclined, unbranched, burrows with a smooth thin lined to unlined. Very often collapsed structures and tapering of the burrows were observed. Observed burrow depth of upto 15 cm and diameter varies from 0.5 to 2 cm. and fills massive structureless fine to medium grain sand size particles. It is densely populated and completely exposed to wind blasting action over the raised beach section, while in muddy sediments it preserved as ring like projections on top of the layers.

Discussion: *Skolithos* is generally interpreted as the dwelling burrows of the suspension feeding worms or phoronid (Fursich, 1974). The present forms are observed in the raised beach section, which could be possibly made by the polychaetes. The walls are binded by mucus of the trace making animals. The intertidal zone of the study area comprise of many different type of polychaetes, especially *Oniphus, Heteromastus, Nereis, Lycastis,*

Plate-31: Burrows in raised beach, (a) different generations of the mucus bound, and vertical to inclined *Skolithos* burrows. (b) Branched pelleted walled, *Ophiomorpha* burrow.

PLATE-31

(a)

(b)

Amphinome et. are constructing the mucus bound vertical cylindrical burrows and they are thickly populated in the runnels and also observed in small pools in the lower part of beaches and ridges.

Preservation: Full relief, endichinal burrow

Locality: It occurs in raised beach and tidal muds of the Rawal Pir and Modwa Spit site and also raised beach of the Wind Farm site.

Remarks: The diagnosis of the *Skolithos linearis* and *S. verticalis* discussed by Alpert (1974), there is no significance difference (*Sensu* Fursich, 1974a) exist between both ichnospecies. Therefore, a synonymitization of *S. linearis* (Hall, 1847) and *S. verticalis* (Haldman, 1840), in which the latter would be priority is suggested. The prismatic contact in *S. linearis* described in Alpert (1974) and Fillon and Pickerill (1990) seems most likely to be an effect of burrow density and dose not reflect a primary behavioural pattern.

Ichnogenus

Monocraterion TORELL, 1870

Ichnospecies

Monocraterion sp. TORELL, 1870

Figure-33

Diagnosis: "Trumpet pipes"; funnel shaped structures penetrated by central straight, or slightly curved plugged tube, perpendicular to bedding plane, never branched; funnel simple or multiples

Description: Unbranched, vertical to near vertical, funnel shaped cylindrical to subcylindrical burrows. Funnel collapsed structures are very common, top funnel diameter is of 3 cm and depth of around 3.5 cm. Length of the burrows are upto 15 cm but very often tapering structures were also observed. Burrow fills are massive and structureless and identical to surroundings material

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Discussion: Westergard (1931) suggested that two tubular burrows forms *Monocraterion* and *Skolithos* were products of separate organisms. Hallam and Swett, (1966) later concluded that burrowers that were exposed to variable sedimentary conditions created the two traces. Barwis (1985) concluded that *Monocraterion* are dwelling tubes of polychaete *Diopatra cuprea* and forms at higher areas, with higher rate of sedimentation. The dwelling burrows similar to *Monocraterion* are found in the ridges and runnels of the Rawal Pir and Modwa Spit sites, where population of the *Diopatra* are quite noticeable which also constructed mucus bound cylindrical tubes with greater diameter at top.

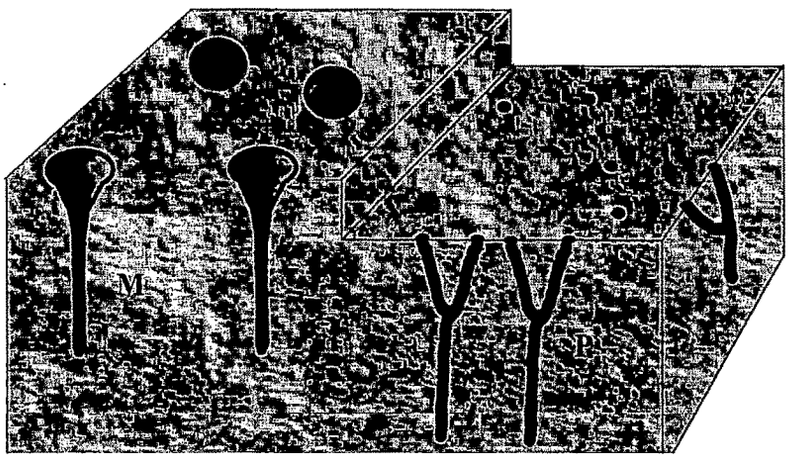


Figure-33 Schematic diagram showing *Monocraterion* (M) and *Polykladichnus* (P).

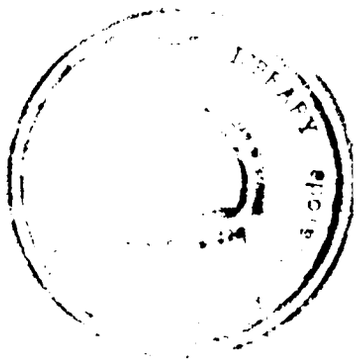
Preservation: Full relief, endichinal burrow

Locality: Raised beach of Rawal Pir site.

Remarks: Several, unbranched sand binded burrows occur in raised beach section, generally associated with the *Skolithos* and *Polykladichnus* structures.

7.2.1.2 Branched Structures

7.2.1.2.1 Small Y and T- Shaped Branching Group: This form group includes irregularly to regularly branching, horizontal to vertical burrows, typically showing Y and T shape.



Ichnogenus

Polykladichnus FURSICH, 1981

Ichnospecies

Polykladichnus irregularis Fursich, 1981

Figure-33

Diagnosis: Vertical tubes with Y-shaped bifurcation, usually connecting to the bedding surface. Number of bifurcation variable, usually between 2 and 4.

Description: The burrow morphology, ornamentation, dimensions and fill materials are similar the above-described *Skolithos* and *Monocraterion* ichnospecies, but it branched and have pair openings.

Discussion: *Polykladichnus irregularis* burrows are similar *Skolithos* in feeding mode and made by the suspension/deposit feeder polychaetes (Fursich 1981). Similar kind of mucus bound tubes/burrows are constructed by *Lumbriconereis, Nereis, Amphinome,* etc., observed in ridges and runnels of the middle and lower intertidal zone of the Rawal Pir and Modwa Spit sites.

Preservation: Full relief, endichinal burrow

Locality: Raised beach sections of the Rawal Pir and Wind Farm sites.

Remarks: The burrows are almost straight and always branched in Y-shaped fashion.

7.2.1.2.2 Ophiomorpha Group: The group embraces relatively large horizontal and vertical branching burrows. They have commonly swellings at branching points and are interpreted as Crustaceans burrows. This group corresponds partially to VIALOV'S (1970) Crustolithida.

Ichnogenus

Ophiomorpha LUNDGERN, 1891

Type Ichnospecies: *Ophiomorpha nodosa* LUNDGERN 1891

Diagnosis: Simple to complex burrow systems distinctly lined with agglutinated pelletoidal sediments. Burrow lining more or less smooth interiorly; densely to sparsely mammalated to nodose exteriorly. Individual pellets or pelletal masses may be discoid, ovoid, mastoid, bilobate, or irregular in shape. Burrow systems three dimensional, vertical and horizontal, cylindrical, tunnels dichotomy, simple to complex burrow systems (Modified after Howard and Frey, 1984).

Ichnospecies

Ophiomorpha nodosa LUNDGERN, 1891

Plate-31b

Diagnosis: Three-dimensional burrow systems, vertical and horizontal cylindrical tunnels, generally at acute angles; with local swellings. Burrow walls consisting predominantly of dense, regularly distributed ovoid pellets, internal wall smooth.

Description: Three-dimensional burrow systems preserved in full relief and consisting of shafts gently inclined or near vertical. The specimens have inner diameter of 3-5 cm, branched arms in upward direction, consisting of vertical to subvertical or horizontal burrows, outer wall covered with regular, dense ovoid pelletoidal knobs, generally associated with sandy substrates. Branching commonly occurs at acute angle in upward direction probably corresponding to irregular box work of Frey et al, (1978) showing lesser diameter of subsequent tunnels.

Discussion: *Ophiomorpha* usually occurs in nearshore deposits (Weimar and Hoyt, 1964; Frey et al., 1978) and are considered to be made by Callianasids shrimps. The present specimens are found to be associated with *Skolithos* and *Polykladichnus* ichnospecies, in the sandy raised beach sections of the Rawal Pir site. Association of these ichnospecies indicates that they are formed in the similar kind of environment but its trace makers are

different *Ophiomorpha nodosa* like burrows were observed in the runnels of the Rawal Pir and Modwa Spit sites and *in situ* trace maker *Oratosquilla striata* a mantis Shrimp of Stomatopodean crustaceans (Patel and Desai, 2001) found in the burrows.

Preservation: Full relief, endichinal borrows and fill identical to surrounding

Locality: Raised beach sections of Rawal Pir and Modwa Spit site.

Remarks: Occurs in sandy sediments, consisting of thick pelleted outer wall and inner fill are identical to surrounding.

Ichnospecies

Ophiomorpha isp. LUNDGERN, 1891

Plate-32 a &b

Diagnosis: Characterised by pelleted outer wall, with simple to complex burrow systems.

Description: Three dimensional burrow system consisting of branched vertical and horizontal arms, diameter of 3-5 cm, wall upto 7mm thick covered with irregular less dense, pelleted structures on outer side. Often observed as eroded pelleted structures by the present day wave and current action in the intertidal zone. Burrows vertical to subvertical, corresponding to shafts of Frey et al, (1978)

Discussion: *Ophiomorpha* usually occurs in nearshore deposits (Weimar and Hoyt, 1964; Frey et al., 1978) and are considered to be made by Callianasids shrimps. Structure observed with *Thalassinoides* in dewatered muddy substrates which correspond to as described by Frey et al., 1978. In the study area, at present day environment *Ophiomorpha* like burrows were observed to be made by Stomatopodean (Squillidean) crustaceans, especially *Oratosquilla striata*, (Patel and Desai, 2001), which are abundant in the runnels and lower intertidal zone. The present specimen found in the raised partially

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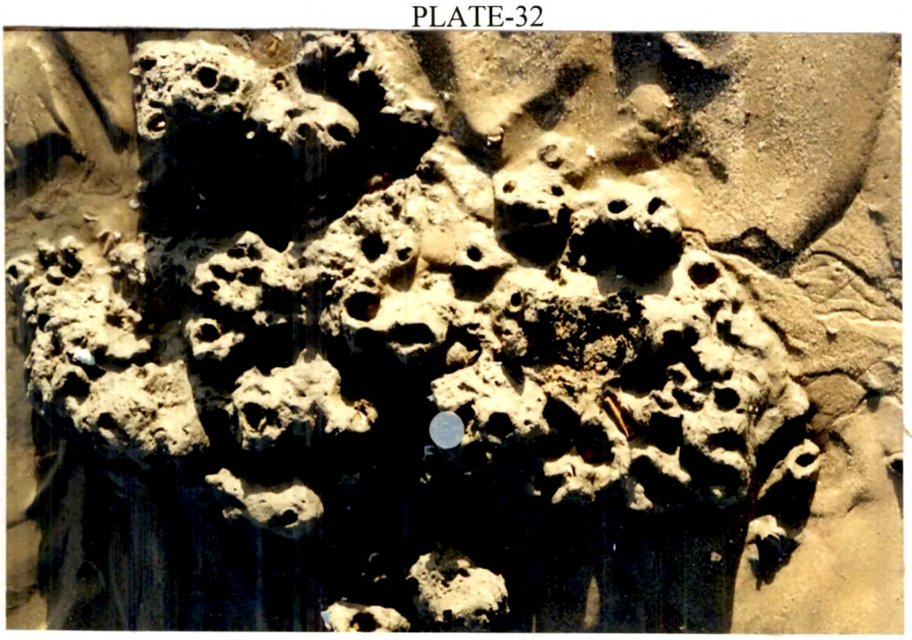
Plate-32 Pre-omission burrows, (a) Pre-omission suit comprising of thickly lined *Ophiomorpha - Thalassinoides* association in dewatered paleotidal mud (Rawal Pir). (b) close up of *Ophiomorpha* burrow showing warn-out nodose structure. (c) Smooth thinly lined *Thalassinoides* burrows occuring as exhumed forms.

PLATE-32



(a)

(b)

(c)

dewatered mud of the Rawal Pir site may indicates two different type of trace makers which lived at same time of different geomorphic settings. Later on, tidal muds form the pre-omission suits and characterised by different generation of the trace fossils, i.e. bivalve borings.

Preservation: Full relief, endichinal burrows.

Locations and geomorphic units: It occurs in the raised partially dewatered muds of the Rawal Pir site.

Remarks: Occurs in muddy sediments, consisting of thick, pelleted outer wall, the outer walls seems to be worn out by physical agency. Thickly populated, usually occurs 20-25 burrows per square meter and indicating pre-omission surfaces in intertidal zone.

Ichnogenus

Thalassinoides EHRENBERG, 1944

Type Ichnospecies: *Thalassinoides suevicus* RIETH, 1932

Diagnosis: Three dimensional burrow systems consisting of predominantly smooth walled, essentially cylindrical components of variable diameter; branches Y to T shaped, enlarged at points of bifurcation. (After Howard and Frey, 1984)

Ichnospecies

Thalassinoides isp. EHRENBERG, 1944

Plate-32c

Diagnosis: Three-dimensional burrow systems consisting of predominantly smooth walled, essentially cylindrical components of variable diameter.

Description: Branched burrow system with vertical and horizontal cylindrical lined tube with iron oxide rim, smooth wall, 2-3 cm in diameter, some times shows transition from *Ophiomorpha* to *Thalassinoides*, indicated by the presence of less dense pelleted outer wall.

Discussion: *Thalassinoides* is generally thought to have made by *Uca*- adult decapod crustaceans. Which have burrows, more complex than that of *Ocypode,* unlike *Psilonichnus* burrows of no orientation can be noticed in the *Thalassinoides*. They are usually associated with *Ophiomorpha* and densely populated, indicating lower intertidal zone for the *Thalassinoides* as compared to the *Psilonichnus.*

Preservation: Full relief

Locality: In raised muds of Rawal Pir site.

Remarks: *Thalassinoides* Ehernberg 1944 is a common trace fossil in the partially dewatered muddy sediments characterised by pre-omission suites of the intertidal zone and closely associated with the *Ophiomorpha*. It is also differ from beach dominated ichnospecies *Psilonichnus* by the dominance of vertical and horizontal components with more complex branching pattern.

7.3 BORINGS

Borings are excavations in hard or semiconsolidated substrates. The borer attacks rocks, shells, calcareous tests, wood, peat, carbonate muds, and even man made materials. They belong to diverse taxonomic groups and through their activity they produce abundant and varied borings that are regarded as potential trace fossils. Marine borers often produce variety of borings from simple pit and blind tubes to ramifying complexes of interconnected voids.

The bioerosive role of borers is immense. Bioerosion is the most important local degrading agent in a number of modern and ancient habitats. Excavators are known to penetrate substrates for same reasons like those of the burrowers. Each borer usually adopts a strategy to bore the surface, either by mechanical, or by chemical methods. These significant groups of eroders and fabricators thus includes microborings by fungal, and algal species, sponges, siphunculids, polychaetes, arthropods, gastropods, bivalves, etc.

Since borings in shells of invertebrates occupy a special position in ichnology, the present work particular attempts to classify them in a system, though numerous ichnofamilies are valid like *Zapfellidea* Codez and Saint Seine 1958, in Rindsberg (1994) but are not sufficient to cover whole range of traces. Thus the different types of borings,

where majorities of them were in the shells of dead gastropods and bivalves studied in the present work are classified according to the classification of Vialov (1969). According to Martinsson (1970), in toponomic classification the borings have to be placed in Endichnia, although some can be classified as Exichina, however these concepts is not applicable to borings in pebbles or hard parts of the organism such as shells. Therefore Martinsson (1970, p. 328) suggested the terms *Ichnidia* or Endichnidia for these type of borings. According to Vialov (1972), the borings in hard substrates are termed as *FOROGLYPHIA*, which is further divided into *LITHOFORIDA* (borings in rocks and stones) and *CORPOFORIDA* (borings in organogenous substrates). The *CORPOFORIDA* is further divided based on the substrate types. The borings in woody substrates are known as *ARBOFOROIDEA;* while borings in calcareous shells are termed as *CONCHOFOROIDEA.* All the borings found in the study area falls under *CONCHOFOROIDEA* and *LITHOFORIDA* (Vialov, 1972). Usually wide varieties of boring morphology are found, because organism that bore into solid substrate uses large amount of energy in excavating the boreholes. Thus the dimensions of the borings reflect the size of boring organisms.

7.3.1 Lithoforida (Vialov, 1972): Borings formed in lithified substrates like rocks, pebbles, and partially dewatered mud

Ichnogenus

Gastrochaenolites Leymerie 1842

Ichnospecies

Gastrochaenolites torpedo Kelly and Bromley 1984
Plate-33 a & b

Diagnosis: Club shaped, slightly elongated borings with circular cross section. The borings are distributed in all available surfaces. Borings are produced normal to the surface.

Plate-33: Omission borings, (a) Monodominant boring traces-*Gastrocheonolites torpedo* in dewatered paleo-tidal muds (Rawal Pir). (b) *Insitu* bivalve shells of *Bernea truncata.*

PLATE-33

(a)

(b)

Description: Vertical, club shaped elongated borings with circular cross section, produced in the partially dewatered mud. The diameter ranges from 0.58 cm to 2.0 cm depending on the diameter of the shell. The height of the burrow also ranges from 5 cm to 25 cm.

Discussion: The borings of the ichnospecies *Gastrochaenolites* are generally shallow-water trace fossils, and where individuals are crowded and dominate the assemblage, only few meters of water may be inferred (Bromley, 1994). According to Bromley and D'Alessandro (1987) the *Gastrochaenolites* corresponds to the work of *Lithophaga lithophaga*; however, it is not possible to attribute the studied *Gastrochaenolites* to the same species, as such insitu shells of *Bernea truncata* are found in the borings.

Type of substrate: The borings are present in the dewatered mud of the Rawal Pir site.

7.3.2 Conchoforoidea (Vialov, 1972): Borings formed in shelly substrates.

Ichnogenus

Talpina VON HAGENOW, 1840

Ichnospecies

Talpina ramosa Hantschzel 1962
Plate-34 a

Diagnosis: Straight tunnel systems, commonly branched, numerous oval or circular opening towards the exterior, tunnel network having constant diameter with numerous circular openings.

Description: The specimen from the study area shows network of straight tunnel systems having constant diameter, branched, with circular openings.

Discussion: This trace fossil is thought to be the work of phoronida (Voigt, 1972, 1975) and are considered as domichnia traces.

Type of substrate: The borings are found on shell surfaces of *Cardita, Macoma* etc.

Ichnogenus

Clinoides FENTON AND FENTON, 1932

Ichnospecies

Clinoides vestifica Bromley, 1970
Plate-34 b

Diagnosis: Tubular borings, widely spaced, somewhat flexous or straight, irregularly branched, round perforation extending throughout the length of the tube.

Description: Widely spaced tubular borings branched in dendritic pattern widely spaced. Circular in cross section, diameter not constant, ranging from 0.5 mm to 2mm.

Discussion: The boring is thought to be of sponge *Cliona*, but can also be produced by polychaete living in commensalism (Jux, 1964) with the bivalves.

Type of substrate: *Cardita* shell.

Ichnogenus

Entobia BRONN, 1837

Ichnospecies

Entobia isp. BRONN, 1837
Plate-34 c, e & f

Diagnosis: Small scale borings consisting of globular chambers, mostly crowded, connected by very small slender canals; walls of the chambers with very few surface pores camerate, composed of networks of chambers, apophyses are short and wide at base. **Description:** Small-scale borings arranged parallel to the external oyster shell, usually of 0.1 to 0.8-cm in diameter. Connected by slender canals. Apertures of distinct size differing within the same samples. The shape of the sample varies from subrounded to

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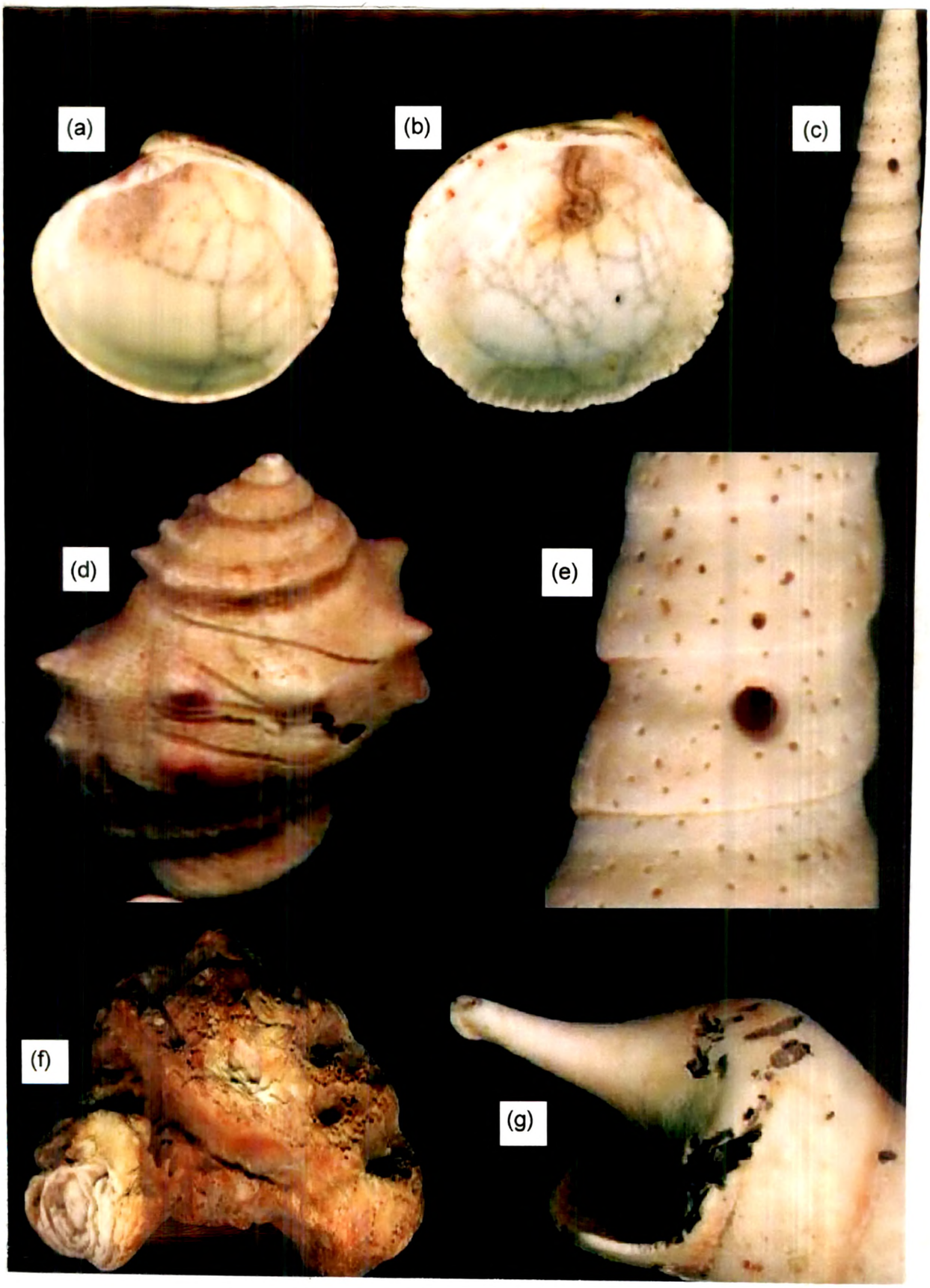
Plate-34 Borings in shells, (a) *Talpina ramosa* in *Macoma* shell. (b) Irregularly branched *Clinoides vestifica* in *Cardita* shell, polychaete *serpulid* tube under the umbonal region. (c, e & f) *Entobia* Sp. in *Turritella* and Oyster shell showing numerous camerated, smaller boring. (d) *Meandropolydora sulcans* boring on *Murex* and *Turritella* shells. (e) Close-up of (c), *Oichnus simplex* showing circular predatory bore hole.

PLATE-34



subrectengular. Some of the chambers are not spherical, but are irregular nodular and tend to occur in closely adjacent rows. Few chambers fuse in pair at a mature stage (Phase C; Bromley and D'Alesendro, 1989).

Discussion: Entobian forms are work of endolithic sponges. Similar borings are produced by present day, several species of *Cliona* (Bromley and D'Alesendro, 1989).

Type of substrate: The substrate types varied from oyster shell to other bivalves, and even *Turritella* (gastropods).

Ichnogenus
Meandropolydora VOIGT, 1970

Ichnospecies
Meandropolydora sulcans VOIGT, 1965
Plate-34 d

Diagnosis: Long, meandering furrow, sunk into outer or inner side of the shell, sinuous borings that extends as 'U' shaped pouches, resembling U-shaped tubes of polydora but without spreite. Pouches tend to run parallel with a tendency for a symmetrical mode of growth.

Description: Thread-sized long, smooth-walled, sculpted shallow tunnels, bilaterally symmetrical, gently curved, to winding sinuous furrows sunk on outer side of gastropod and bivalve shells, The maximum observed length is about 3 cm and width of about 1 to 2 mm. Probably made by polychaete worms of family Spionidae.

Discussion: Polychaete borings are very regular and characterised by single, blinded tubes, U-shaped and meandering furrows confined to the outer side of the shell of gastropod *Murex*. These traces are thought to be made by modern polychaete of genus *Polydora* probably as a post-mortem process.

Type of substrate: Gastropod (*Murex*) and bivalve shells.

Ichnogenus

Oichnus Bromley (1981)

Ichnospecies

Oichnus simplex Bromley (1981)
Plate-34 c

Diagnosis: They consist of circular to subcircular boreholes, piercing throughout the shell.

Description: Isolated, smooth, circular to subcircular boring having 3-4 mm in diameter and pierced through the gastropod and bivalve shells.

Discussion: The hemispherical shape allows interpreting it as the result of carnivorous gastropod activity (Bromley, 1981). These are commonest types of circular holes, found on the shells. A predatory habit is inferred for the vertical cylindrical bores as this morphology shows that the originator, in search of food attempted to gain entrance into the bivalve and gastropod shells rather than bore for its domicile (Patel and Shringarpure, 1989).

Type of substrate: Bivalve (*Oyster, Macoma*) and Gastropod (*Turritella, Conus*) shells.