CHAPTER 5
DESCRIPTION OF TRACE FOSSILS

5.1 INTRODUCTION

5.1.1 HISTORICAL BACKGROUND:

The work of Linnaeus (1758) invented binomial nomenclature which, among the nomenclatures yet invented, is the excellent and most practical system for the classification of organisms. However, this system was invented for the animals and not for their behavior. This statement is therefore important while classifying and naming trace fossils with the help of ICZN. Secondly, trace fossils are a reflection of behavior; they are the sedimentary structures resulting from their behavior. Trace fossils are made by organisms; they have morphology and for morphology we have classification scheme but it seemed to be nearly impossible to fit sedimentologic remains of behavior into this scheme because it was not meant for this purpose. Finally after the one and the other additional smaller fights, ichnology came under the shade of the law of the ICZN. In 1999, with the fourth edition of the ICZN, ichnology fully became integrated into the zoological system of nomenclature. Thus, although the rules of the ICZN deal only with the nomenclature, yet it is the fundament, on which ichnotaxonomy has been built. The nomenclatures used in this chapter also deals according to I.C.Z.N. rules.

The International Code of Zoological Nomenclature defined trace fossil” as the “fossilized work of an animal” which sound convincing but was insufficient. Bertling et al (2003) proposed a new definition for trace fossils but did not found general acceptance among the ichnologists and zoologists. Later the definition was emended, refined and discussed for years by several authors (Genise et al, 2004; Bertling et al, 2004) which defined trace fossils as “Morphologically recurrent structure resulting from the life activity of an individual organism (or homotypic organism) modifying the substrate”. Studies depicted clearly that various morphologies may be produced by one particular animal and various different animals may produce morphologically identical structures. These facts build the foundation of the modern ichnology and as a consequence the trace fossil nomenclature and
ichnotaxonomy shall be producer-independent but recognizing/identifying possible producer should affect the evaluation of ichnotaxobases.

5.1.2 CLASSIFICATIONS:

A trace fossil description should provide a clear picture of its preservational aspects. This preservational facet can be distinguished into two: (1) Toponomy and (2) Physiochemical processes of preservation and alteration (Frey and Pemberton, 1985). “Toponomy” comprises of description and classification of biogenic structures with respect to their mode of preservation and occurrence; including the mechanical processes involved in the fabrication of the structure and its alteration. (Buatois and Mángano, 2011). The fabrication of the structure is termed as the “stratinomy” and its alteration is termed as the “taphonomy”.

5.1.2.1 Stratinomic Classification

The fabrication of the structures is classified through schemes proposed by Simpson (1957), Seilacher (1964) and Martinson (1970). Simpson (1957) established four preservational categories: (1) Bed-junction preservation, for trace fossils preserved in relief at a bed junction; (2) Concealed bed-junction preservation, for individual burrow that appear to be isolated within an interval of different lithology; (3) Diagenetic preservation, for trace fossils preserved as nodule or nodule protuberances formed during early diagenesis; and (4) Burial preservation, for the filled burrows that have been subsequently exhumed by currents winnowing away the associated soft matrix.

Seilacher (1964) represented a modification of the previous classification and proposed a preservational scheme that comprised of “descriptive” (based on the relationship of the trace fossil to a casting medium; usually sandstone) and “genetic” (based on the assumed relationship of the trace fossils to the contemporary surface rather than that of the trace maker) terms (Seilacher, 1953a). The descriptive set defined two main subdivisions of structures, viz., the “full relief” (preserved within the stratum) and the “semirelief” (preserved at lithological interfaces) along with the third category, “biodeformational” structures. The semirelief structures are further subdivided into “epirelief” (preserved at the top) or “hyporelief” (preserved at the base) of the sandstone bed, along with the additional terms
"concave" for positive and "convex" for negative relief of the trace fossil. The biodeformational structures are referred to the sediment disturbances of biological origin. The genetic terms include "exogenic" (surficial traces covered by sediment different from the host), "endogenic" (actively or passively filled structure within the host bed) and "pseudoexogenic" (traces formed in homogeneous medium, but subsequently uncovered by erosion and recast with sand).

Martinson (1970) also proposed a similar classification to that of Seilacher (1964b) based on the relationship of trace fossils to a casting medium. He introduced four preservational categories: (1) "epichnial preservation", if preserved at the upper surface of the casting strata; (2) "hypichnial preservation", if preserved at the lower surface of the casting strata; (3) "endichnial preservation", if preserved within the casting medium; and (4) "exichnial preservation", if preserved outside the casting medium.

Among these classifications, Simpson (1957) is not used nowadays, since it incorporates the diagnostic aspects and is thus not strictly stratinomic while the classification proposed by Seilacher (1964) and Martinson (1970) met with the most acceptance.

5.1.2.2 Ethological Classification

The ethological system of classification is based on the evidence of animal behaviour and was first proposed by Seilacher (1953a). The original system consists of five categories, viz., (1) "Cubichnia", the resting trace; (2) "Repichnia", the locomotion trace; (3) "Pascichnia", grazing traces; (4) "Fodinichnia", the feeding trace; and (5) "Domicnichia", the dwelling traces; which are the basic building blocks of behavioural interpretations in ichnology.

Later refinements have been suggested to take account of additional behaviors and new ethological categories were added viz., "Fugichnia", the escape traces (Frey, 1973); "Agrichnia", farming traces and trap (Ekdale et al, 1984); "Praedichnia", predation traces (Ekdale, 1985); "Equilibrichnia", equilibrium traces (Bromley, 1990); "Calichnia", nesting traces (Genise and Bown, 1994); "Pupichnia", pupation chambers (Genise et al, 2007); "Fixichnia", fixation/anchoring traces (Giber. et al, 2004); "Impedichnia", bioclaustration structures (Tapanila, 2005); "Mortichnia", death traces (Seilacher, 2007). Apart from these
categories, the others are categorized as the subdivision of the major ones (e.g. “xylichnia” for wood boring is kept under category “fodinichnia”).

5.2 SYSTEMATIC ICHNOLOGY

The classification scheme proposed by Książkiewicz (1977) which was further emended by Uchman (1995) and Schlirf (2000, 2005) is used to classify the trace fossils in the present study, due to its sole based on the morphological patterns. The invertebrate trace fossils are differentiated into two general categories as burrows and trails, and borings. There are five major approaches to the classification and interpretation of trace fossils: (1) the descriptive approach, in which the morphologies of traces are described in detailed; (2) the preservational approach, in which traces are categorized by their mode of preservation and host sediment; (3) the behavioral approach, in which the general activities of the trace-makers are inferred; (4) the organism approach, in which the traces are ascribed to the organisms which created them; and (5) the taxonomic approach, in which formal Latinized names are given to the traces themselves.

Ideally, all five approaches have been employed simultaneously to provide a complete description and interpretation of the trace fossil fauna from the Patcham Island. However, it is briefly studied and classified into six morphological groups (i.e. with descriptive approach) as (1) circular and elliptical structures, (2) simple structures, (3) branched structures, (4) rosette structures, (5) spreiten structures and (6) winding and meandering structures. This classification has some difficulty in assigning few traces to any of the given groups and thus they are taken as the additional information and are devoid of any taxonomical rank. The ichnotaxonomy concept based on the significant (related to distinct behavior) and accessory features (reflecting minor behavioural changes) as introduced by Fürsich (1974b) is used here. The significant features of each trace fossils are regarded for the diagnosis of the ichnogenera and the accessory features for the diagnosis of the ichnospecies.

5.2.1 BURROWS:

5.2.1.1 Circular and Elliptical Structures

5.2.1.1.1 Plug shaped forms

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**Ichnogenus**: *Bergaueria* PRANTL, 1945

**Type ichnospecies**: *Bergaueria perata* Prantl, 1945

**Diagnosis**: Cylindrical to hemispherical vertical burrows possessing smooth, unornamented walls, circular to elliptical in cross-section, infillings essentially structureless, rounded base, with or without shallow central depression and radial ridges (Pemberton et al., 1988).

**Ichnospecies**: *Bergaueria* cf. *hemispherica* CRIMES, LEGG, MARCOS and ARBOLEYA 1977

    (Plate 5.1a)

**Diagnosis**: *Bergaueria* lacking a shallow, central depression (Pemberton et al. 1988).

**Description**: Hypichnial mound with hemispherical smooth termination, oval in outline. The diameter of the burrow is 2.1 to 2.5 cm and depth is 2.3 cm, the walls of the burrow are unornamented and the fill of the burrow is essentially structureless.

**Occurrence**: Micritic sandstone of Babia Cliff Sandstone member of Kaladongar Formation, Kaladongar range.

**Remarks**: The general shape, the hemispherical termination, resembles to the ichnogenus *Bergaueria hemispherica* though it varies by the larger size of this specimen. *Bergaueria* is probably a cubichnial or domicchnial form produced by suspension feeders (Fürsich, 1975), occurring in the shallow water deposits (Narbonne, 1984; Crimes and Anderson, 1985) and in flysch deposits (Prantl, 1945, Książkiewicz, 1977; Crimes and Crossley, 1991; Uchman, 1995). The producers of this trace are coelenterates, chiefly sea anemones (Alpert, 1973; Chamberlain, 1971).


    (no generic name assigned)

    (Plate 5.1b)

**Diagnosis**: Convex hypichnial semi-relief, consisting of an uneven, elongate, oval cast, which is higher on one side, with steep, overturned wall at the higher side (Uchman, 1995).

**Description**: Oval shaped cast with one side steep, overturned higher wall, preserved as convex hypichnial semi-relief. The structure is 5 cm long, 3 cm wide and 2.5 cm high.
**Occurrence:** Allochemic sandstone of Dingy Hill member of Kaladongar Formation, Kaladongar range.

**Remarks:** The name plug-shaped was introduced for peculiar resting burrows (cubichnia) preserved commonly but not exclusively as under traces (Savrda 2001; Seilacher 2001) and probably produced by suspension-feeders such as sea anemones (Pemberton et al., 1988; Uchman 1995). The present ichnospecies resembles the “plug shaped form B” of Uchman (1995) but differs in having comparatively smaller dimensions of the specimen. According to him, the trace resembles *Lockeia* JAMES or may be made by a small burrowing ray in larger dimensions making it difficult to commend on the trace maker.

### 5.2.1.1.2 Circles

**Ichnogenus:** *Laevicyclus* QUENSTEDT, 1879

**Type Ichnospecies:** *Cyclozoon philippi* Wurm 1912

**Diagnosis:** Approximately cylindrical bodies perpendicular to the bedding planes; diameter variable in same specimen; perforated by central canal; visible on bedding planes as regular concentric circles with diameter of several cm (Häntzschel, 1962).

**Discussion:** Quenstedt (1879) firstly reported and named this type of fossil as *Laevicyclus* but he interpreted it as a coral and did not erect any species. Häntzschel (1962, 1965) placed genus *Cyclozoon* in synonymy with *Laevicyclus* and kept the forms of two different origins in the genus *Laevicyclus* as “Form A” (large cylindrical, vertical burrows with small central cylinder) and “Form B” (vertical burrows with concentric scrape marks on the upper bedding surface). Later, Alpert and Moore (1975) restricted “Laevicyclus” to Form B and named Form A as “Dolopichnus”. Accordingly, they placed *Laevicyclus mongraensis* Verma (1970:38, PL 1:6; Chiplonkar and Badwe 1970:9, Pl. 3:4, 4a) apparently in *Dolopichnus* and placed *Cyclozoon philippi* Wurm 1912 as the type species of *Laevicyclus* ichnogenera.

**Ichnospecies:** *Laevicyclus* isp.

(Plate 5.1 c and d)

**Description:** Endichnial, full relief, vertical cylindrical body making right angle to bedding plane and appear as regular concentric circles. The burrow shows maximum outer diameter of 2.35 cm, the central knob is large and prominent with diameter of 1.2 cm.
**Occurrence:** Micritic sandstone of Dingy Hill member of Kaladongar Formation, Kaladongar range and pelloidal packstone of Raimarlo Limestone member of Goradongar Formation, Goradongar range.

**Remarks:** It is regarded as the feeding burrow of trace fossil comparable with dwelling shaft and scraping circles of recent annelid *Scolecolepis squamata* (Seilacher, 1953).

**Ichnogenus:** *Lockeia* JAMES, 1879

**Type Ichnospecies:** *Lockeia siliquaria* James, 1879

**Diagnosis:** Bilaterally symmetrical, elongated, commonly almond-shaped, heart-shaped, club-shaped to dumbbell-like or rarely of triangular shape, with smooth margin; predominantly preserved as isolated or row-like arrangements of hypichnial mounds; single segments commonly with a distinct median crest. Vertical spreite may be present (Schlirf et al, 2001)

**Ichnospecies:** *Lockeia amygdaloides* SEILACHER 1953

(Plate 5.1 e and f)

**Diagnosis:** Stout, high-standing, almond shaped ridges with a smooth surface, tapering at both ends; sometimes showing tall vertical spreite (Schlirf, 2000).

**Description:** Hypichnial, small, stout, high standing, almond shaped ridges with smooth surface, tapering at both end. The trace length is 1.1-1.4 cm, width is 0.3-0.7 cm and height is 0.2-1.1 cm, and occurs in crowded form.

**Occurrence:** Micritic sandstone of Babia Cliffs Sandstone member of Kaladongar Formation, Kaladongar range and in sandy allochem limestone of Raimarlo Limestone member of Goradongar Formation, Goradongar range.

**Remarks:** This ichnospecies of the ichnogenus *Lockeia* differs from the other ichnospecies in having an almond-like stout nature. *L. amygdaloides* represents short lived resting traces of small burrowing bivalves, perhaps semi-sessile forms (Häntschel, 1975).

**Ichnospecies:** *Lockeia siliquaria* JAMES 1879

(Plate 5.1 g and h)

**Diagnosis:** Same as for ichnogenus.
Description: Convex, hypichnial, relatively small, almond shaped oblong parallel to sub parallel bodies; with tapering to sharp and obtuse points at both ends. Short, inclined or vertical endichnial shafts may also be present. They occur as isolated and their dimension varies in different burrow populations, with observed length is 1.1-1.6 cm, width 0.4-0.6 cm and height of 0.9-1.0 cm.

Occurrence: Allochemic sandstone of Dingy Hill member, and micritic sandstone and micritic mudrock of Babia Cliff Sandstone member of Kaladongar Formation, Kaladongar range; and in pelloidal packstone of Raimarlo Limestone member of Goradongar Formation, Goradongar range.

Remark: This ichnospecies differs from the other ichnospecies of Lockeia by lack of a) plump nature of L. amygdaloides Seilacher, 1953; or L. avalonensis Fillion and Pickerill, 1990; b) thin and elongate as L. elongata, Yang, 1984; and c) asymmetrical as L. czarnockii Karasewski, 1974. The ichnospecies Lockeia siliquaria either represents the dwelling structure of suspension feeders or the fugichnial response to changing environmental conditions, rather than short lived resting traces (Mangano et al 1998).

Ichnogenus: Margaritichnus BANDEL, 1973

Type Ichnospecies: Cylindrichnus reptilis, Bandel 1967

Diagnosis: Trail made of ball-like structures which are either unconnected or connected by ridge of same width as diameter of balls.

Ichnospecies: Margaritichnus reptilis BANDEL, 1973

(Plate 5.1 i)

Diagnosis: Ball-like structures of 15 to 30 mm. diameter, commonly aligned like string of pearls, rarely connected by ridge with crescentic transverse grooves; thought to be trail of large wormlike, sediment feeding animal which packed its fecal pellets in mucus.

Description: Convex, hypichnial, semirelief ball shaped structures compressed, joint together with not very visible tube forming pearl like structure. The dimension of each ball structure is approximately 1.2 cm in diameter forming the pearl like structure of about 5-6 cm long.

Occurrence: Allochemic sandstone of Dingy Hill member of Kaladongar Formation, Kaladongar range.
Plate 5.1 Circular and Elliptical Structures (Bar length = 1 cm)
(a) Bergaueria cf. hemispherica, smooth hemispherical mound like structure; Micritic sandstone of BCSM; (b) Plug shaped form cf. B; Hypichnial, semi relief, mound like structure; allochecmic sandstone of DHM; (c) Laevicyclus isp., vertical cylindrical structure with concentric rings; micritic sandstone of DHM; (d) Laevicyclus isp., vertical cylindrical structure with concentric rings; bioclastic packstone of RLM; (e) Lockeia amygdaloides, stout almond shaped ridges with tapering ends, micritic sandstone of BCSM; (f) Lockeia amygdaloides, stout almond shaped ridges, sandy allochem limestone of RLM; (g) Lockeia siliquaria, almond shaped oblong ridges, pelloidal packstone of RLM; (h) Lockeia siliquaria, almond shaped oblong ridges, micritic sandstone of BCSM; (i) Margaritichmus reptilis, ball-shaped structure forming pearl-like form, allochecmic sandstone of DHM.

Remarks: Balls are interpreted as the fecal pellets probably made by large wormlike sediment-eating animals; trails possibly formed below the sediment surface (Häntzschel, 1975).
5.2.1.2 Simple Structures

5.2.1.2.1 Vertical forms

Ichnogenus: *Monocraterion* TORELL, 1870

Type ichnospecies: *Monocraterion tentaculatum* TORELL, 1870

**Diagnosis:** Funnel-shaped negative epirelief with a raised knob on the floor of the funnel; this knob is continuous with a short, vertical, centrally located tubular structure. Essentially with numerous small, horizontal, slightly curving, rarely branching, occasionally lined, tubular, full-relief structures with smooth outer surface going out from the raised knob (Schlirf, 2000).

![Plate 5.2 Vertical forms](Image)

(Plate 5.2 Vertical forms (Bar length = 1 cm; coin diameter = 2.5 cm)

(a) *Monocraterian tentaculatum*, vertical cylindrical burrow with funnel-shaped opening; micritic sandstone of DHM; (b) *Skolithos linearis*, cylindrical burrow inclined to the bedding, Sandy allochem limestone of KSM; (c) *Skolithos linearis*, cylindrical burrow inclined to the bedding, sandy allochem limestone, DHM; (d) *Skolithos linearis*, cylindrical burrow inclined to the bedding, micritic sandstone, DHM; (e) *Skolithos linearis*, vertical cylindrical burrow, bioclastic packstone, MHM; (f) *Skolithos linearis*, vertical cylindrical burrow, bioclastic packstone, MHM.)
Ichnospecies: Monocraterian tentaculatum TORELL, 1870

(Plate 5.2 a)

**Diagnosis:** Same as for ichnogenus

**Description:** Straight to slightly curved, unbranched cylindrical burrows, filled with surrounding substrate. Closely spaced or isolated on bedding plane, normal to steeply incline to the bedding plane, passing upward into ovate funnel, and downward into straight vertical and cylindrical. Several specimens show funnels with raised rims, which may reflect lining to the funnels. Funnel height is varying in different burrow population, diameter of the widest part varies from 2.0 to 3.0 cm and shaft diameter is 2.0 cm.

**Occurrence:** Micritic sandstone and sandy allochem limestone of Dingy Hill member of Kaladongar Formation, Kaladongar range.

**Remark:** Monocraterion occurs with conditions of relatively rapid sedimentation and is considered to be the dwelling structure of a worm like organisms (Myers 1970, Barwis, 1985).

**Ichnogenus: Skolithos HALDEMAN, 1840**

**Type ichnospecies:** Skolithos linearis HALDEMAN, 1840

**Diagnosis:** Unbranched, vertical to steeply inclined, straight to slightly curved cylindrical to subcylindrical, lined or unlined structures with or without funnel-shaped top. Wall distinct or indistinct, smooth or rough, some specimen annulated; fill massive; burrow diameter in some individuals slightly inconstant (Schlirf, 2000).

Ichnospecies: Skolithos linearis HALDEMAN, 1840

(Plate 5.2 b-f)

**Diagnosis:** Cylindrical to subcylindrical, perfectly straight and vertical to slightly curved or inclined burrows. Burrow wall distinct to indistinct, may be annulated (Schlirf, 2000).

**Description:** Endichnal, full relief, cylindrical to sub-cylindrical, unbranched vertical to inclined pipes with distinct or indistinct walls commonly closely crowded or showing widely space gradation. The depth varies from 4 to 6 cm and diameter is about 10 to 15 mm. The burrow fill is sandy and the wall is thinly lined by fine sediments.
Occurrence: Micritic sandstone and sandy allochem limestone of Dingy Hill member and sandy allochem limestone of Kaladongar Sandstone member of Kaladongar Formation, Kaladongar range; and sandy micrite and pelloidal packstone of Modar Hill member of Goradongar Formation, Goradongar range.

Remarks: The *Skolithos linearis* is distinguished from the *S. verticalis* because the former is longer and sandy type of fill of the burrow, which is the characteristic distinguishing factor in them (Carmona et al, 2008). *Skolithos* is widely recognized in shallow water, intertidal deposits (Seilacher, 1967) and in various shallow marine environments (Fillion and Pickerill, 1990; Alpert, 1974), probably thought to be produced by annelids or phoronids (Alpert, 1974) and suspension feeding polychaetes like *Amphinomoerostrata* and *Nereticostoe* (Patel and Desai, 2009).

5.2.1.2.2 Horizontal forms

**Ichnogenus:** *Bifungites* DESIO, 1940

**Type Ichnospecies:** *Bifungites fezzanensis*, Hall 1852

**Diagnosis:** Structures dumbbell-like or arrow-shaped, ends commonly hemispherical, on bedding planes respectively an erosional interface, preserved as positive hyporelief or positive epirelief.

Ichnospecies: *?Bifungites* isp.

(Plate 5.3 a)

**Description:** Preserved as positive epirelief, horizontal, blunt hammer-like structure. Burrow represents cylindrical tube (central cord) with nearly spherical end or dumbbell like structure. The length of the central cord is 8 mm and diameter of 9 mm; the hemispherical structure having maximum diameter of 20 mm.

**Occurrence:** Allochemic sandstone of Raimalro Limestone member, Goradongar Formation, Goradongar range.

**Remarks:** The specimen shows only one hemispherical structure with central cord, other part may be collapsed or eroded. *Bifungites* is interpreted as the domicnial burrow of some filter feeder such as polychaete/annelid (Pickerill and Forbes, 1977)
Plate 5.3 Horizontal forms (Bar length = 1 cm; Coin diameter = 2.5 cm.)
(a) ?Bifungites isp., cylindrical tube with nearly spherical end, allochemic sandstone, RLM; (b) Palaeophycus alternatus, annulated and striated cylindrical burrow, micritic sandstone, GSM; (c) Palaeophycus annulatus, Horizontal lined burrow with annulations, micritic sandstone, DHM; (d) Palaeophycus striatus, Horizontal lined striated burrow, allochemic sandstone, BCSM; (e) Palaeophycus striatus, striated cylindrical lined burrow, micritic sandstone, GSM; (f) Palaeophycus tubularis, Horizontal lined burrow, allochemic sandstone, DHM; (g) Palaeophycus tubularis, Horizontal lined burrow, micritic sandstone, DHM; (h) Palaeophycus tubularis, Slightly curved lined burrow, sandy allochem limestone, KBM; (i) Palaeophycus tubularis, cylindrical lined burrow, micritic sandstone, MHM; (j) Palaeophycus tubularis, cylindrical lined burrow, micritic sandstone, MHM; (k) Planolites beverleyensis: Horizontal unlined branched burrow; (l) Planolites beverleyensis; Horizontal unbranched burrow; Scale: Hammer length = 40 cm; (m) Planolites beverleyensis, Micritic sandstone, MHM; (n) Planolites beverleyensis, Micritic sandstone, MHM.

Ichnogenus: Palaeophycus HALL, 1847

Type ichtnospecies: Palaeophycus tubularis Hall, 1847

Diagnosis: Straight to slightly curved to slightly undulose or flexuous, smooth or ornamented, typically lined, essentially cylindrical, predominantly horizontal structures interpreted as originally open burrows; burrow-fill typically massive, similar to host rock; where present, bifurcation is not systematic, nor does it result in swelling at the sites of branching (Fillion and Pickerill, 1990).

Ichnospecies: Palaeophycus alternatus PEMBERTON AND FREY, 1982

(Plate 5.3 b)

Diagnosis: Alternately striate and annulate Palaeophycus of periodically varying diameter (Pemberton and Frey, 1982).

Description: Horizontal, subcylindrical, thinly lined, unbranched, straight to slightly curved, striated and annulated burrow; elliptical in cross-section with largest diameter of the burrow 18 mm; observed length of the burrow 50 mm.

Occurrence: Micritic sandstone of Gadaputa Sandstone member of Goradongar Formation, Goradongar range.

Remarks: The specimen with striae and annulations differentiates the ichtnospecies Palaeophycus alternatus from the other ichtnospecies of Palaeophycus. Palaeophycus is an
open burrow and a eurybathic facies-crossing form, probably produced by polychaetes (Pemberton and Frey, 1982).

**Ichnospecies**: *Palaeophycus annulatus*, BADVE 1987.

(Plate 5.3 c)

**Diagnosis**: Simple, straight or slightly curved horizontal to inclined, unbranched cylindrical to sub cylindrical lined burrow filled material is identical to matrix. Commonly unbranched though may be branched occasionally; there is development of annulus on the surface of burrow.

**Description**: Cylindrical, unbranched, distinctly lined, relatively long burrow, with fine, continuous, parallel annulations on surface. The length of the burrow is 8.3 cm while the diameter varies from 1.7-1.9 cm.

**Occurrence**: Micritic sandstone of Dingy Hill member of Kaladongar Formation, Kaladongar range.

**Remarks**: The specimen is similar to the diagnostic characteristics of annulations of the *Palaeophycus annulatus* by Badve (1987) and the absence of transverse lines along with the annulations makes it to differ from the ichnospecies *P. alternatus*.

**Ichnospecies**: *Palaeophycus striatus* HALL, 1852.

(Plate 5.3 d and e)

**Diagnosis**: Thinly lined burrows ornamented with fine, continuous, parallel, longitudinal striae (Pemberton and Frey, 1982).

**Description**: Horizontal to slightly inclined, slightly curved, unbranched, distinctly lined, relatively long burrow, with fine, continuous, parallel and longitudinal striae. Burrows predominantly elliptical in cross-section; burrow diameter 2.5-2.7cm. Burrow length is 6.2 cm.

**Occurrence**: Allochemic sandstone of Babia Cliff sandstone member of Kaladongar Formation, Kaladongar range; micritic sandstone of Gadaputa Sandstone member and micritic sandstone of Modar Hill member.

**Remark**: The burrows are classified as *Palaeophycus striatus* because of their distinct lining showing fine, longitudinal striae. The striae are interpreted as produced by the organism’s setae or bristles, which scratched the burrow wall as the animal moved (Schlirf, 2000). The
ornamentation on the wall also suggests the sediments have had certain stiffness in order to preserve such structures.

*Ichnospecies: Palaeophycus tubularis* HALL, 1847 
(Plate 5.3f-j)

**Diagnosis:** Smooth, unornamented burrows of variable diameter, thinly but distinctly lined (Pemberton and Frey, 1982).

**Description:** Endichnial or hypichnial, cylindrical to slightly flatted, straight to slightly curved more or less smooth, thin walled burrow, parallel to slightly oblique to the stratification. Branching is rare, burrow walls are irregular and the burrow fill is structureless and identical to host rock. Width and length of the burrow tubes are variable in different burrows population. Maximum observed length is 10 cm with diameter of 1.2 cm.

**Occurrence:** Sandy allochem limestone of Kuar Bet member, micritic sandstone, allochem sandstone and sandy allochem limestone of Dingy Hill member of Kaladongar Formation, Kaladongar range; micritic sandstone of Gadaputa Sandstone and Modar Hill members of Goradongar Formation, Goradongar range.

**Remarks:** *Palaeophycus* Hall (1847) has confusing taxonomic nomenclatural history; and thus it is recognized on the basis of wall lining and burrow sculpting by Pemberton and Frey (1982). The given specimen *P. tubularis* is distinguished from other ichnospecies of *Palaeophycus* by the absence of striae and annulations.

**Ichnogenus:** Planolites NICHOLSON, 1873.

**Type ichnospecies:** Planolites vulgaris Nicholson and Hinde, 1875

**Diagnosis:** Unlined, rarely branched, straight to tortuous, smooth to irregularly walled or ornamented, horizontal to slightly inclined burrows, circular to elliptical in cross-section, of variable dimensions and configurations. Burrow fill biogenic, essentially massive differing from host rock; where present, bifurcation is not systematic, nor does it result in swelling at the sites of branching (Fillion and Pickerill, 1990).
Ichnospecies: *Planolites beverleyensis* BILLINGS, 1862.

(Plate 5.3 k-n; Plate 5.5 b (ii))

**Diagnosis:** Relatively large, smooth, straight to gently curve or undulose cylindrical burrows (Pemberton and Frey, 1982).

**Description:** Hyporelief, predominantly cylindrical, smooth walled, unlined, unbranched to rarely branched, straight to gently curved burrows, more or less parallel to bedding plane. Dimension varies from different burrows population; length of burrow varies from 18 to 23 cm and diameter from 0.8 to 1.3 cm.

**Occurrence:** Micritic sandstone and allochemic sandstone of Dingy Hill member, micritic sandstone, allochemic sandstone and micritic mudrock of Babia Cliff sandstone of Kaladongar Formation, Kaladongar range; sandy allochem limestone of Goradongar Flagstone member, micritic sandstone and allochemic sandstone of Gadaoputa Sandstone member, allochemic sandstone, sandy allochem limestone and pelloidal packstone of Raimalro Limestone member and micritic sandstone and sandy micrite of Modar Hill member.

**Remarks:** According to Häntschel (1962) and Crime and Anderson (1985), *Planolites* is a broad ichnogenus ranging from Precambrian to Recent. *Planolites* is a eurybathic, extremely facies-crossing form, interpreted as pascichnion and referred to polyphyletic vermiform deposit-feeders producing active backfilling (Rodríguez-Tovar and Uchman, 2004).

### 5.2.1.2.3 U-shaped forms

**Ichnogenus:** *Arenicolites* SALTER, 1857

**Type ichnospecies:** *Arenicola carbonaria* BINNEY, 1852

**Diagnosis:** Vertical U-tubes without spreite (Fürsich 1974c)

Ichnospecies: *Arenicolites carbonarius* SALTER 1857.

(Plate 5.4, a and b; Plate 7.7a (ii))

**Diagnosis:** Simple, U-tubes without spreite, perpendicular to bedding plane (Häntzschel, 1975).
Description: Endichnial, full relief, vertically oriented, U-shaped, paired burrows. Burrow diameter is about 0.5-0.9 cm and burrow arms are about 1.5-2.5 cm apart. The burrows occur as paired, circular opening on the bedding surface; fill identical to the host sediment.

Occurrence: Micritic sandstone of Dingy Hill and Babia Cliff Sandstone members; and sandy allochtho limestone of Dingy Hill and Kaladongar Sandstone members of Kaladongar Formation, Kaladongar range.


Ichnospecies: Arenicolites statheri BATHER, 1925
(Plate 5.4 c)

Diagnosis: Straight, symmetrical, U shaped burrows (Fürsich, 1974b)

Description: Endichnial, full relief, vertically oriented, unlined, slightly curved, U-shaped burrow. Burrow diameter is about 10 mm and burrow arms are 3 mm apart, fill is identical to the host sediment.

Occurrence: Sandy micrite of Modar Hill member of Goradongar Formation, Goradongar range.

Remarks: Arenicolites statheri differs from other ichnospecies of Arenicolites because of their straight, vertical, closely spaced symmetrical U shaped tube. It is generally interpreted as domicnion of a suspension-feeding polychaete (Fürsich 1974c). Arenicolites are found in sediments ranging in age from Early Cambrian (Narbonne et al, 1987) to Holocene (Chamberlain, 1978).

Ichnospecies: Arenicolites isp.
(Plate 5.4 d and e; Plate 5.6 b (i))

Description: Endichnial, full relief, vertically oriented, lined as well as unlined burrows with paired opening with funnel shaped apertures. Burrow diameter is about 3-4 mm and burrow arms are about 2-4 mm apart. The burrows occur as paired, unfilled, funnel openings on the bedding surface.

Occurrence: Sandy micrite and pelloidal packstone of Modar Hill member of Goradongar Formation, Goradongar range.
Remarks: The vertical morphology of the paired burrow is not determined and therefore the identification to ichnospecies level is problematic. Ethologically, *Arenicolites* represents dwelling burrow of suspension-feeders (e.g. Fürsich 1975; Hakes 1977; Howard and Frey 1984; Pickerill et al. 1984; Læger et al. 1985). The occurrence of wall lining or lack reflects the difference in the sediment cohesiveness/consistency, as the wall gives more stability to the burrow.

5.2.1.3 Branched Structures

5.2.1.3.1 Dichotomously branching forms

**Ichnogenus:** *Chondrites* VON STERNBERG, 1833

**Type Ichnospecies:** *Fucoides antiquus* Brongniart, 1828

**Diagnosis:** Dendritic, smooth walled, regularly ramifying small burrow systems that normally do not interpenetrate or interconnect. Diameter of components within a given system remains essentially constant (Pemberton and Frey, 1984).

**Ichnospecies:** *Chondrites targionii*, BRONGNIART, 1828

(Plate 5.4 f and g)

**Diagnosis:** *Chondrites* characterized by well expressed primary successive branching, which are commonly slightly curved. The angle of branching is usually sharp or obtuse. Most of the tunnels are few millimeters wide (Uchman, 1999)

**Description:** Endichnial, tree like branched tunnel system with slightly sinuous branches. The specimen shows slightly winding, negative epirelief, dominated by second order branching at an angle of $50^\circ$ to $60^\circ$. The color of the sediment fill is different from the color of the host rock.

**Occurrence:** Micritic sandstone of Dingy Hill member of Kaladongar Formation, Kaladongar range; and sandy micrite of Modar Hill member of Goradongar Formation, Goradongar range.

**Remark:** According to Seilacher (1990) and Fu (1991), the trace maker of *Chondrites* may be able to live at the aerobic/anoxic interface as chemo-symbiotic organism.
Plate 5.4 U-shaped forms (Bar length = 1 cm, Coin diameter = 2.5 cm).
(a) Arenicolites carbonarius; vertical U-shaped paired burrow; (b) Arenicolites carbonarius; U-shaped paired burrow; (c) Arenicolites statheri, Sandy micrite, MHM; (d) Arenicolites isp., Sandy micrite, MHM; (e) Arenicolites isp. Micritic sandstone, MHM; (e) Chondrites targionii, endichnial, full relief, parallel to bedding plane; (f) Chondrites targionii, Muddy micrite, MHM; (g) Chondrites intricatus; small, endichnial, full relief, parallel to bedding plane; (h) Chondrites intricatus, Sandy allochonic limestone, RLM; (i) Dactylophycus isp; branching bilobate burrow; (j) Pilichnus dichotomus; endichnial full relief, Horizontal winding branched strings; (k) ?Pilichnus isp., Allochonic sandstone, GSM.

Ichnospecies: Chondrites intricatus, BRONGNIART, 1823
(Plate 5.4 h and i)

Diagnosis: Small burrow system with numerous downward radiating branches (FU 1991).
Description: Small tree-like burrow system with numerous downward radiating branches of flattened tunnel filled with lighter material than the host rock. The tube diameter is of 1 mm.

Occurrence: Micritic sandstone of Dingy Hill member of Kaladongar Formation, Kaladongar range and in sandy allochem limestone of Kaimarlo Limestone member of Goradongar Formation, Goradongar range.

Remarks: Chondrites intricatus is mostly found in fine grained siliciclastic and carbonate rocks (Uchman, 1995). This ichnospecies differ from the rest in having small tube diameters.

Ichnogenus: Dactylophycus MILLER AND DYER, 1878

Type ichnospecies: Dactylophycus tridigitatum, Osgood, 1970.

Diagnosis: Delicately annulated bilobate burrows; small and radiate or randomly branching (Häntzschel, 1975).

Ichnospecies: Dactylophycus isp.

(Plate 5.4 j)

Description: Hypichnial, palmate branched with unevenly pinching and swelling short segments appearing as fusiform. The specimen shows full relief preservation, smooth ornamentation, and elliptical cross-section. The palmate branch length varies from 3.3-3.4 cm and maximum width increases at the centre varying from 0.7 to 1.2 cm. The palmately branching form joins each other by thin pinching segments of length and width of 0.65 cm and 0.25 cm respectively.

Occurrence: Allochemic sandstone of Dingy Hill member of Kaladongar Formation, Kaladongar range.

Remarks: Its phobotaxis and second order branching is typical of Chondrites, but the burrow tendency towards palmate rather than lateral branching led (Osgood, 1970) to relate Dactylophycus to Phycodes and Arthrophycus instead of Chondrites, and it is true that all of these are chondritids, i.e., radiating feeding burrows without a spreite (Rindsberg, 1994).

Ichnogenus: Pilichinus UCHMAN,1999

Type Ichnospecies: Pilichinus dichotomus Uchman 1999
**Diagnosis:** System of horizontal, straight, curved to irregularly winding, very thin sub-millimetric strings showing commonly dichotomous branches (Uchman, 1999)

**Ichnospecies:** *Pilichnus dichotomus* UCHMAN, 1999

(Plate 5.4 k)

**Diagnosis:** As for ichnogenus.

**Description:** Full-relief, System of horizontal, straight, curved to irregularly winding, branched string without wall, preserved in full-relief on parting surface of calcareous sandstone. The strings are 0.15-0.35 mm wide. They are filled with dark argillaceous substance. Dichotomous, Y-shaped branches are commonest and very characteristic. T-shaped branches however also occur. When crowded, trace fossil may occur in regular nets.

**Occurrence:** Sandy allochem limestone of Babia Cliff Sandstone member of Kaladongar Formation, Kaladongar range.

**Remarks:** This form is very thin and differs from ichnogenus *Trichichnus*, in the horizontal orientation of burrows (Uchman, 1999).

**Ichnospecies:** ?*Pilichnus* isp.

(Plate 5.4 l)

**Description:** Endichnial, horizontal to gently incline with straight to slightly curved course, branched unlined burrow preserved in full-relief on parting surface of allochemic sandstone. The trails are 0.15-0.35 mm wide. Burrow filled with calcareous substance.

**Occurrence:** Allochemic sandstone of Gadaputa Sandstone member of Goradongar Formation, Goradongar range.

**Remarks:** This ichnogenera differs from the *Palaeophycus* and *Planolites* being very thin and from ichnogenus *Trichichnus*, in the horizontal orientation of burrows (Uchman 1999).

**5.2.1.3.2 Y-T shaped branching forms**

**Ichnogenus:** *Ophiomorpha* LUNDGREN, 1891

**Type Specimen:** *Ophiomorpha nodosa* LUNDGREN, 1891

**Diagnosis:** Simple to complex burrow systems lined at least partially with agglutinated pelletoidal sediment (Howard and Frey, 1984).
Ichnospecies: *Ophiomorpha nodosa* LUNDGREN, 1891

(Plate 5.5 a-e)

**Diagnosis:** *Ophiomorpha* with burrow walls consisting predominantly of dense, regularly distributed discoid, ovoid, or irregular polygonal pellets (Frey and Pemberton, 1999)

**Description:** Endichnial, full relief; horizontal, vertical, sub-vertical, branched or unbranched burrow covered with ovoid pelletoidal knobs and having diameter of 1.9-2.9 cm and length is about 36-74 cm. Burrows are filled with sediments similar to the surrounding substrate, but unfilled tube segments are also very common.
Plate 5.5 Y-T shaped branched, and bundled forms (Bar length = 1 cm; coin diameter= 2.5 cm).

(a) Ophiomorpha nodosa; Horizontal component of three dimensional maze structure; (b) Horizontal component of maze structure of (1) Ophiomorpha nodosa associated with horizontal unlined burrow of (2) Planolites beverleyensis; (c) Sub-vertical component of the Ophiomorpha nodosa; (d) Ophiomorpha nodosa, sandy micrite, MHM; (e) Ophiomorpha nodosa, sandy micrite, MHM; (f) Thalassinoides horizontalis, Horizontal Y-shaped burrow; (g) Thalassinoides horizontalis, Horizontal Y-shaped burrow; (h) Thalassinoides horizontalis, allochemic sandstone, GFM; (i) Thalassinoides suevicus, three dimensional Y-shaped burrows; (j) Thalassinoides suevicus, three dimensional Y-shaped burrows; (k) Thalassinoides suevicus, allochemic sandstone, GFM; (l) Thalassinoides suevicus, Sandy allochem limestone, RLM; (m) Thalassinoides isp.; a curved arm, Y-shaped burrow, allochemic sandstone of DHM; (n) Thalassinoides isp.; a curved arm, Y-shaped burrow, RLM; (o) Hartsella sursumramosa, Allochemic sandstone, GFM.

Occurrence: Micritic sandstone and allochemic sandstone of Dingy Hill member and sandy allochem limestone of Babia Cliff Sandstone member of Kaladongar Formation, Kaladongar range; and pelloidal packstone of Modar Hill member of Goradongar Formation, Goradongar range.

Remarks: Ophiomorpha occur predominantly in shallow water near-shore deposits (Weimar and Hoyt, 1964; Frey et al., 1978), but has also been reported, since the Mesozoic (Bottjer et al., 1987) from deep-sea deposits (Kern and Warme, 1974; Crimes, 1977; Crimes et al., 1981; Uchman, 1988, 1989, 1990, 1995). In Mesozoic-Cenozoic sediments, Ophiomorpha is produced mainly by shrimps comparable to recent callianassids (Weimar and Hoyt, 1964; Frey et al., 1978). Patel and Desai (2001, 2009) have also observed Ophiomorpha nodosa like burrows made by Stomatopodean (Squillidean) crustaceans, especially Oratosquilla striata in the runnels of the intertidal zone of the Mandvi area.

Ichnogenus: Thalassinoides EHRENBERG, 1944

Type Specimen: Thalassinoides callianassae Ehrenberg, 1944.

Diagnosis: Three dimensional burrow systems consisting predominantly of smooth-walled, essentially predominantly of smooth walled, essentially cylindrical components of variable diameter; branches Y- to T-shaped, enlarged at points of bifurcation (Howard and Frey, 1984).
Ichnospecies: *Thalassinoides horizontalis* MYROW, 1995
(Plate 5.5, f-h)

**Diagnosis:** Horizontal, branching framework of smooth-walled, unlined burrows, lacking vertically oriented offshoots. Burrow diameter consistent within individual specimens; constrictions or swellings at both junctions and inter-junction segments are notably absent.

**Description:** Smooth, unlined, three-dimensional Y-shaped branching horizontal burrows. Tunnels are straight to curve and burrows chiefly consist of horizontal tunnels that bifurcate at angle of $80^\circ$-$130^\circ$. The length of burrow is 10-12 cm and diameter varies from 0.6-1 cm.

**Occurrence:** Micritic sandstone and allochmnic sandstone of Dingy hill member of Kaladongar Formation, Kaladongar range; micritic sandstone of Gadaputa Sandstone member, sandy allochmnic limestone and oolitic packstone of Raimalro Limestone member.

**Remarks:** The specimen differs from the type material of Myrow (1995) in diameter and from *T. bacae* in the absence of the vertical shafts.

Ichnospecies: *Thalassinoides suevicus* REITH, 1932
(Plate 5.5, i-l)

**Diagnosis:** Predominantly horizontal, more or less regularly branched, essentially cylindrical burrow system; dichotomous bifurcations are more common than T-shaped branches (Howard and Frey, 1984).

**Description:** Endichnial, full relief, horizontal to slightly oblique three-dimensional burrow system, varying from 25 cm to 30 cm in length and from 1.5 to 3.5 cm in diameter. More or less regularly branched, connected to surface by more or less vertical shaft; dichotomous bifurcations are more common than T-shaped branches. The burrows fill differently as the colour, texture differ in the surrounding.

**Occurrence:** Micritic sandstone of Dingy Hill member; and allochmnic sandstone and sandy allochmnic limestone of Dingy Hill and Batia Cliff Sandstone members of Kaladongar Formation, Kaladongar range; and sandy allochmnic limestone of Goradongar Flagstone and Raimalro Limestone members of Goradongar Formation, Goradongar range.

**Remarks:** *Thalassinoides* is generally interpreted as a fodicichnial burrow, passively filled, usually related to oxygenated situations and soft but fairly cohesive substrates (Rodríguez-Tovar and Uchman, 2004). According to Follmi and Grimm (1990), the crustaceans producing *Thalassinoides* may survive transport in turbidity currents and produce burrows.
under anoxic conditions for a limited number of days. *Thalassinoides* is a facies-crossing form, most typical of shallow-marine environment, and is produced mainly by crustaceans (Frey et al. 1984).

Ichnospecies: *Thalassinoides* isp.
(Plate 5.5 m and n)

**Description:** Burrows showing Y-shaped branching. The arms are slightly curved to sinuous. Burrow diameter is about 2cm and the length of each branch varies. The tunnels are curved and shows angle of bifurcation of about 130-150°.

**Occurrence:** Allochemic sandstone of Dingy Hill member of Kaladongar Formation, Kaladongar range and sandy allochem limestone of Rimalro Limestone member of Goradongar Formation, Goradongar range.

**Remarks:** Ichnogenus *Thalassinoides* is classified based on the presence of horizontal elements and branching characteristics. Six ichnospecies are currently recognized, namely; *T. saxonicus* Geinitz, 1842 (characterised by its large form with tunnels; Kennedy, 1967); *T. ornatus* Kennedy, 1967 (consisting of smaller ovate, horizontal to gently inclined burrows; Kennedy, 1967); *T. paradoxicus* (that branches forming complex boxwork patterns, generally irregular in geometry; Howard and Frey, 1984); *T. suevicus* Reith, 1932 (which is predominantly a horizontal form consisting of enlarged Y-shaped bifurcations; Howard and Frey, 1984); *T. horizontalis* (a strictly horizontal form); and *T. foedus* Mikulás, 1990 (that forms polygonal frameworks. *Thalassinoides* isp., herein, does not exhibit any of the aforementioned attributes which precludes the definite identification to an ichnospecies level.

5.2.1.3.3 **Bundled forms**

**Ichnogenus:** *Hartsellea* RINDSBERG, 1994

**Type Ichnospecies:** *Hartsellea sursumramosa* Rindsberg, 1994

**Diagnosis:** Burrow system consisting of central shaft curving upward and outward branching palmately in proximal part and laterally in distal part. Branches recurved, with outermost branches most recurved and excavated first. Distal branches markedly sinuous, phobotactic. Burrow walls lined possibly pelleted; fill with transverse structure.
Ichnospecies: *Hartsella sursumramosa* RINDSBERG, 1994

(Plate 5.5 o)

**Diagnosis:** Same as for ichnogenus.

**Description:** Convex hyporelief, horizontal branched burrow, new branches issue from the outer curves of previous branches. The length of the burrow system is 84 mm and it covers an area of about 80 x 120 mm.

**Occurrence:** Allochemic sandstone of Goradongar Flagstone member of Goradongar Formation, Goradongar range.

**Remarks:** *Hartsella* is a system of upward-branching and thus the feeding appendages of its maker may be facing upward as shown by some scavenging and carnivorous polychaetes (Rindsberg, 1994). This specimen differs from *Chondrites* in having upward branching from a central shaft.

**Ichnogenus:** *Phycodes* RICHTER, 1850

**Type Ichnospecies:** *Phycodes cinctum* Richter, 1853

**Diagnosis:** Horizontal bundled burrows preserved outwardly as convex hyporeliefs. Overall patterns are reniform, fasciculate, flabellate, broom-like, ungulate, linear, falcate or circular. Some forms consist of a few main branches showing a spreite-like structure that gives rise distally to numerous free branches. In other forms the spreiten are lacking and branching tends to be second or more random. Individual branches are teeters and finely annulate or smooth (Fillion and Pickerill, 1990).

Ichnospecies: *Phycodes cinctum* RICHTER, 1853

(Plate 5.6 a (i))

**Diagnosis:** Same as for ichnogenus.

**Description:** Bundled structures of flabellate or broom-like pattern, consisting of horizontal tunnels. Proximal part of main tunnel unbranched while distally it divides into several cylindrical tunnels. Some annulations can be seen on the cylindrical tunnels. Tunnel fill is same as the substrate. Main tunnel is about 2-3 cm in diameter while the branches are 1-2 cm in diameter. The length of the tunnel ranges from 15-20 cm.
**Occurrence:** Allochonic sandstone of Dingy Hill member of Kaladongar Formation, Kaladongar range.

**Remarks:** *P. circinatum* is characterized by the bundled structures and annulations on the cylindrical tube.
Plate 5.6 Branched and Rosette structures (Bar length = 1 cm; coin diameter= 2.5 cm).
(a) Broom like horizontal smoothly curved burrow 1. *Phycodes circinatum* 1 and vertical paired burrows 2. * Arenicollites* isp. in allochemic sandstone, DHM; (b) * Phycodes palma tus*, palmate burrow; allochemic sandstone, DHM and BCSM; (c) * Phycodes palma tus*, sandy allochem limestone, BCSM; (d) * Phycodes cf. palma tus*, allochemic sandstone, GFM; (e) * Phycodes cf. palma tus*, Micritic mudrock, CFM; (f) * Phycodes cf. curvipalma tus*, sandy micrite, MHM; (g) * Asterosoma radiciforme*, radial bulbs from vertical shaft, BCSM; (h) * Asterosoma radiciforme*, radial bulbs from vertical shaft, BCSM; (i) * Asterosoma cf. radiciforme*, resembling bulbed * Asterosoma radiciforme*, micritic mudrock, GFM; (j) and (k) * Asterosoma ludwigae*, branching bulb form, allochemic sandstone, BCSM; (l) Bulbs of the * Asterosoma ludwigae*; allochemic sandstone, DHM; (m) * Ichnocumulus radiates*, pustule shaped with radiating projections in allochemic sandstone, DHM; (n) * Phoebichnus trochoidea*; irregular burrows radiating from central shaft; sandy allochem limestone, DHM; (o) and (p) * Phoebichnus trochoidea*, allochemic sandstone, GSM.

Ichnospecies: *Phycodes palma tus* HALL, 1852
(Plate 5.6 b and c)

**Diagnosis:** Few thick and rounded branches that originate in a palmate or digitate form from nearly the same point (Fillion and Pickerill, 1990)

**Description:** Burrow system is long, palmately branching close together, with branches terminating in fan-shaped structure. The burrow system shows length of 8.2-9 cm and the branch diameter is varies from 1-1.5 cm.

**Occurrence:** Allochemic sandstone of Dingy Hill and Babia Cliff Sandstone members and sandy allochem limestone of Babia Cliff Sandstone member of Kaladongar Formation, Kaladongar range.

**Remarks:** *Phycodes palma tus* is characterized by its palmate branching and differs from *P. curvipalma tus* by its larger size and lack of re-curvature.

Ichnospecies: *Phycodes cf. palma tus* HALL, 1852
(Plate 5.6 d and e)

**Description:** Horizontal, bundled burrows preserved outwardly as convex hyporelief. Overall pattern flabellate, consisting of a main stem that give rise to distally numerous free branches. The burrow system is 62 mm long with smooth or faintly developed transverse striae, individual branches varying in length from 20-22 mm and in width from 6-10 mm.
**Occurrence:** Sandy allochem limestone of Goradongar Flagstone member of Goradongar Formation, Goradongar range.

**Remarks:** Although the palmate branching style resembles the *Phycodes palmatum*, it is more regular in the type specimen and differs from *P. curvipalmatum* by its larger size and lack of curvature. Vermiform annelids are considered to be possible producers of *Phycodes* (Fillion and Pickerill, 1990).

**Ichnospecies:** *Phycodes cf. curvipalmatum* POLLARD, 1981

(Plate 5.6 f)

**Diagnosis:** Horizontal, cylindrical, or compressed burrows, 1-2 mm in diameter, which are curved and branched either dichotomously or palmately, like the fingers of a hand (Pollard, 1981).

**Description:** Horizontal, ramifying and branching intrasrtal burrows preserved outwardly as convex hyporelief. Burrow possesses a tube like form proximally that distally split into finger-like curved branches. The burrow system is 50 mm long with individual branches varying in width from 3-4 mm.

**Occurrence:** Sandy allochem limestone of Modar Hill member of Goradongar Formation, Goradongar range.

**Remarks:** These small sized, highly variable burrows with curved branches appear similar to the *Phycodes curvipalmatum* Pollard, 1981. Vermiform annelids are considered to be the possible producers of *Phycodes* (Fillion and Pickerill, 1990).

### 5.2.1.4 Rosette Structures

#### 5.2.1.4.1 Radial structures

**Ichnogenus:** *Asterosoma* VON OTTO, 1854

**Type Ichnospecies:** *Asterosoma radiciforme* Von otto, 1854

**Diagnosis:** Horizontal to inclined burrows, either with star-like arranged bulbs or bulbs that bud from a circular to elliptical tube in a dichotomously to fan-like pattern. Bulbs are concentrically to irregularly laminated with a small cylindrical, inner tube which lies in a sub-
central position or distinctly eccentric. Burrow wall with or without longitudinal, subangular furrows and striae (Schlirf, 2000).

Ichnospecies: *Asterosoma radiciforme* VON OTTO, 1854

(Plate 5.6 g and h)

**Diagnosis:** As for ichnogenus.

**Description:** Sub-horizontal bulbs showing radial or star like orientation with tapering ends; preserved as full relief; walls show longitudinal furrows and striae. The bulb length varies from 4.9-6.6 cm; width is 1.3-1.5 cm; the burrow system covers an area of 10×13 cm².

**Occurrence:** Allochemic sandstone of Babia cliff sandstone member of Kaladongar Formation, Kaladongar range.

**Remark:** It is probably burrows with radiating feeding structures. The decapod crustaceans are the possible producers of the Mesozoic *Asterosoma* (Häntzschel, 1975; Altevogt, 1968).

Ichnospecies: *Asterosoma* cf. *radiciforme* VON OTTO, 1854

(Plate 5.6 i)

**Description:** Full relief, sub-horizontal bulbs showing 3-4 bulbs radiating from a central shaft normal to the bedding; the associated shafts are not well observable. The burrow system is 64 mm wide, while the individual bulb varies in length from 30-32 mm and diameter varies from 8-10 mm.

**Occurrence:** Sandy allochem limestone of Goradongar Flagstone member of Goradongar Formation, Goradongar range.

**Remarks:** It is probably a burrow with radiating feeding tubes. Decapod crustaceans are the possible producers of the Mesozoic *Asterosoma* (Altevogt, 1968; Häntzschel, 1975). The specimen shows only four bulbs radiating from the central shaft. This may suggest that the specimen belong to *A. radiciforme* which may be eroded or the specimen represents the 1st stage morphology of *Asterosoma* (Neto de Carvalho and Rodrigues, 2007).

Ichnospecies: *Asterosoma ludwigae* SCHLIRF, 2000

(Plate 5.6 j-l)

**Diagnosis:** *Asterosoma* with concentrically to irregularly laminated bulbs that bud form a circular to elliptical tube in a dichotomously to fan-like pattern.
Description: Various size of buds laterally dichotomously budding and bulbs are elliptical in cross-section and variable in shape; tapering at distally. The tube diameter is 0.6-1.1 cm. The long axis of bulbs is 2.3-4.3 cm, short axis 1.5-2.2 cm and height is 0.8 cm. The overall size of the burrow system is 10.2 cm in length and 2.2 cm in width.

Occurrence: Allochemic sandstone of Dingy Hill and Babia Cliff sandstone members of Kaladongar Formation, Kaladongar range.

Remarks: The concentric laminae represent the feeding behavior while the massive tubes represent the locomotion behavior (Schlirf, 2000). This ichnospecies differ from the other ichnospecies of the Asterosoma ichnogenus, in non-radiating and branching system.

Ichnogenus: Ichnocumulus, SEILACHER, 1956

Type Ichnospecies: Ichnocumulus radiatus SEILACHER, 1956

Diagnosis: Small pustule shaped bodies possessing straight, radiate projections (Häntzschel, 1975).

Ichnospecies: Ichnocumulus radiatus SEILACHER, 1956

(Plate 5.6 m)

Diagnosis: Same as for ichnogenus.

Description: Small pustule shaped bodies possessing straight, radiate projections. The body diameter varies from 1.5-2 cm and the radial projection varies from 0.75-1 cm in length.

Occurrence: Allochemic sandstone of Dingy Hill member of Kaladongar Formation, Kaladongar range.

Remarks: Ichnocumulus is reported from Jurassic sediments of south Germany as the resting traces made by an unknown animals hiding temporarily in sediments (Seilacher 1956).

Ichnogenus: Phoeibchnus BROMLEY AND ASGAARD, 1972

Type Ichnospecies: Phoeibchnus trochoides Bromley and Asgaard, 1972

Diagnosis: Central shaft, nearly vertical to bedding, with numerous, long, straight radial burrows oriented more or less parallel to bedding; radial burrows including distinct, annulated wall lining; concave towards central shaft (Häntzschel, 1975).
Ichnospecies: *Phoebichnus trochoide* BROMLEY AND ASGAARD, 1972

(Plate 5.6n-p)

**Diagnosis:** Same as for ichnogenus.

**Description:** Endichnial, full relief, with large, central vertical shaft from which irregular horizontal burrows radiate; burrow collapsed and central part appear as more irregular circular form with broken horizontal tubes. Diameter of the tubes are varies from 0.6-1 cm and length varies from 8-15 cm. The whole structure is affected by the erosional weathering processes leads to collapsed nature.

**Occurrence:** Sandy allochcim limestone of Dingy Hill member and allochemic sandstone of Babia Cliff Sandstone member of Kaladongar Formation, Kaladongar range; and allocheric sandstone of Gadaputa Sandstone member of Goradongar Formation.

**Remarks:** Central shaft has been interpreted as dominichnia while the radial burrows are interpreted as fodorichnia of some unknown animal (Hantschel, 1975).

5.2.1.5 Spreiten Structures

5.2.1.5.1 Vertical forms

**Ichnogenus:** *Diplocraterion* TORELL, 1870

**Type ichnospecies:** *Diplocraterion parallelum* TORELL, 1870.

**Diagnosis:** Vertical to oblique, U-shaped, single-spreite burrows; spreite may be unidirectional or bidirectional, continuous or discontinuous. Limbs unlined and smooth or with bioglyphs, sometimes with heavy lining; either parallel or diverging upward or downward; top of limbs sometimes with funnel-shaped opening (Schlief, 2005).

Ichnospecies: *Diplocraterion* isp.

(Plate 5.7 a (i), b)

**Description:** Vertical, smooth, unlined, U-shaped burrow appear as pair of circular openings on surface which is connected by spreite. The burrow tube is 0.5-1.8 cm apart, 0.6-2 cm in diameter; fill is identical to surrounding sediment.
**Occurrence:** Sandy allochem limestone of Dingy Hill member, pelloidial packstone of Kaladongar Sandstone member and micritic sandstone of Babia Cliff Sandstone member of Kaladongar Formation, Kaladongar range; and in micritic mudrock of Goradongar Flagstone member, allochemic sandstone of Gadaputa Sandstone member and pelloidial packstone of Modar Hill member of Goradongar Formation, Goradongar range.

**Remark:** The present trace fossil is kept under the *Diplocraterion* Torell, 1870 based on the essential diagnostic features but the vertical section could not be retrieved which makes it difficult to identify at ichnospecies level. It is the dwelling burrow of suspension feeding animal, probably living in environment of high wave energy (Goldring, 1962)

**Ichnogenus:** *Daedalus* ROUAULT 1850

**Type Ichnospecies:** *Vexillum desglandi* Rouault, 1850

**Diagnosis:** Subvertical spreiten structure made by lateral migration of a simple to spiral J shaped burrow; burrows commonly self-intersecting.

**Ichnospecies:** *Daedalus* cf. *verticalis* SEILACHER, 2000

(Plate 5.7 c)

**Diagnosis:** Deep arthropycid burrow resembling *Diplocraterion*, but made by protrusive vertical dislocation of a slightly inclined dead-end J-tube without a spiral turn.

**Description:** Deep burrow resembling *Diplocraterion*, but made by protrusive vertical dislocation of a slightly inclined dead-end J-tube without a spiral turn. The individual burrows are neither clustered into radial arrays, nor arranged parallel to each other. The burrow reaches a visible depth of 11 cm; diameter of the protrusive tube is 2.12 cm; and overall diameter of the tube is 8.13 cm.

**Occurrence:** Sandy allochem limestone of Dingy Hill member of Kaladongar Formation, Kaladongar range.

**Remarks:** It superficially resembles to *Diplocraterion* and lacks spirals but the origination from the vertical dislocation of a J- rather than a U-tube and larger vertical extension than its width clearly suggest as belonging to the arthropycids. Although, *Daedalus* has not previously been reported from rocks younger than Silurian except in the Carboniferous of Alabama (Seilacher, 2000), the present ichnospecies shows a clear resemblance with the *Daedalus verticalis* Seilacher, 2000.
5.2.1.5.2 Horizontal forms

Ichnogenus: \textit{Rhizocorallium} ZENKER, 1836

\textbf{Type Ichnospecies}: \textit{Rhizocorallium jenense}, ZENKER, 1836

\textbf{Diagnosis}: Wedge-shaped, double-spreite burrows, built up of U-limbs, oblique to parallel towards bedding plane, width of ‘U’ constant or distally increasing; limbs distinct. Exterior smooth, or with longitudinal or transverse ridges and grooves (Emended by Schlirf, 2005)

\textbf{Ichnospecies}: \textit{Rhizocorallium jenense} ZENKER, 1836
(Plate 5.7d-i)

\textbf{Diagnosis}: More or less straight, short U-shaped spreiten-burrows, commonly oblique to bedding plane and occasionally vertically retrusive (Fürsich, 1974c).

\textbf{Description}: Epichnial, positive semi relief, short, straight to slipper shaped, horizontal to sub horizontal, unbranched U-shaped tube containing spreiten. The tubes are filled with fine to medium grained sediments identical with the matrix; usually each arm of the tubes is 6.5 cm long and 1.2 cm wide.

\textbf{Occurrence}: Micritic sandstone of Dingy Hill member, allochemic sandstone of Babia Cliff Sandstone member of Kaladongar Formation, Kaladongar range; sandy allochem limestone of Goradongar Flagstone member, micritic sandstone, allochemic sandstone of Gadaputa Sandstone member of Goradongar Formation, Goradongar range.

\textbf{Remarks}: \textit{R. jenense} is interpreted as burrows of suspension feeders (Fürsich 1974a, 1974b) or scavenging organisms (Worsley and Mork 2001). The structure usually represents a fodiichnial behavior (Fürsich 1998). The Rhizocorallid modification represented by the slipper shaped \textit{Rhizocorallium} (Line drawing of Pl. VII, e) reflects a fixed two-stage program wherein the trace maker first increased the length of the tube by constructing inclined protrusive spreite and then switching to upward retrusive spreite (Seilacher, 2007).

\textbf{Ichnospecies}: \textit{Rhizocorallium irregularare} MAYER, 1954
(Plate 5.7 j-m)

\textbf{Diagnosis}: Long sinuous bifurcating or planispiral U-shaped spreiten burrows; mainly horizontal (Fürsich, 1974b).

\textbf{Description}: Epichnial semi-relief, long, more or less sinuous to curved, U-shaped, horizontal, branching and planispiral form of spreiten burrows with stout tubes about 1-2 cm
thick. Total burrow width is 6-10 cm. The spreite are less preserved, with tube representing pocket-like depressions. Burrow fill is identical to the host rock.

**Occurrence:** Micritic sandstone, allochemic sandstone and sandy allochem limestone of Dingy Hill; sandy allochem limestone, pelloidial packstone and sandy micrite of Kaladongar Sandstone; and allochemic sandstone and sandy allochem limestone of Babia Cliff Sandstone members of Kaladongar Formation; bioclastic grainstone of Goradongar Flagstone member, micritic sandstone of Gadaputa Sandstone member, sandy allochem limestone and pelloidial packstone Raimalro Limestone member, and sandy allochem limestone, pelloidial packstone, and sandy micrite of Modar Hill member.

**Remarks:** *R. irregulare* represents the fodinichnia of deposit feeding organisms. Fürsch (1974b) regarded *Rhizocorallium* to be produced by Crustaceans based on scratch marks. But no scratch marks were observed on any of the specimen. The relatively small dimension of the trace fossil in comparison to the large body dimension of the crustacean shows that this trace maker can be ruled out. Hence the question of the possible producer remains open (Schlirf, 2000). There are several stages of feedings observed in the sediments of the Kaladongar Sandstone member (Line drawing of Pl. VII, k)

Ichnospecies: *Rhizocorallium uliarense* FERTION, 1958

(Plate 5.7n and o)

**Diagnosis:** Long and coiled parallel U-shaped spreiten horizontal burrows with thick tubes

**Description:** Epichnial, long, U-shaped, horizontal, trochospiral spreiten burrows. Tubes are stout and parallel, 5 cm wide. Burrow fill is identical to the host rock.

**Occurrence:** Sandy allochem limestone of Kaladongar Sandstone member of Kaladongar Formation, Kaladongar range; Sandy allochem limestone of Modar Hill member of Goradongar Formation, Goradongar range.

**Remarks:** This ichnospecies differs from the other ichnospecies of this ichnogenus in the stout nature of tubes and coiling of the burrow on the bedding plane (Fürsch, 1974c).

5.2.1.5.3 Wall like forms

**Ichnogenus:** *Teichichmus*, SEILACHER, 1955

**Type ichnospecies:** *Teichichmus rectus* SEILACHER, 1955.
**Diagnosis:** Long, straight, sinuous to zigzag-shaped, unbranched or branched, wall-like spreite structures, formed by vertical displacement of horizontal or oblique, erect to undulose tubes without wall-lining, resulting in a unilobed (gutter-shaped) or bilobate (double gutter shaped) spreite in frontal view. Bioglyphs may be present (Schirr, 2005).
Plate 5.7 Spreiten structures (Bar length = 1 cm, Coin diameter= 2.5 cm)
(a) (i) U-shaped paired spreiten burrow Diplocraterion isp and (ii) U-shaped vertical paired burrow Arenicolites carbonarius; (b) Diplocraterion isp., allochemic sandstone, GSM; (c) Protrusive vertical J-tube Daedalus cf. Verticalis; (d) Horizontal, unbranched U-shaped spreiten burrow Rhizocorallium jenense; (e) Sub-horizontal, slipper shaped U-shaped burrow Rhizocorallium jenense, DHM; (f) Rhizocorallium jenense; horizontal U-shaped curved burrow; BCSM; (g) Rhizocorallium jenense, sandy micrite, MHM; (h) Rhizocorallium jenense, micritic mudrock, GFM; (i) Rhizocorallium jenense, micritic sandstone, MHM; (j) Long, more or less sinuous to curved U-shaped, horizontal burrow Rhizocorallium irregular; KSM; (k) Long, lobate, U-shaped horizontal burrow Rhizocorallium irregular; KSM; (l) Long, circular U-shaped horizontal burrow Rhizocorallium irregular; (m) Long hook-like U-shaped horizontal burrow Rhizocorallium irregulare, allochemic sandstone, RLM; (n) Coiled, u-shaped horizontal, spreiten burrows Rhizocorallium uraliense, sandy allochem limestone, KSM; (o) Coiled, u-shaped horizontal, spreiten burrows Rhizocorallium uraliense, micritic sandstone, MHM; (p) Sinuous, unbranched, horizontal stacked flat U-shaped retrusive spreiten burrow Teichichnus rectus, sandy micrite, KSM.

Ichnospecies: Teichichnus rectus, Seeilacher, 1955

(Plate 5.7 p)

Diagnosis: Simple, straight or sinuous Teichichnus (Fürsich, 1974b)

Description: The Kachchh specimen of T. rectus include consistently straight to sinuous, unbranched, horizontal stacked flat U-shaped, retrusive spreiten burrow. The maximum observed length of the burrow is about 20.0 cm and 3.0 cm wide; with vertical shift about 2.5 cm wide in cross section at the end of the trace. Burrow filled is identical to host sediments.

Occurrence: Sandy micrite of Kaladongar Sandstone member of Kaladongar Formation, Kaladongar range.

Remark: Seilacher (1955) interpreted Teichichnus as the result of the vertical shift of horizontal burrow which might be U-shaped with pipe at the top. Seilacher (1957) compared these forms to the modern structure made by the recent polychaete Nereis diversicolor.

5.2.1.6 Winding and Meandering Structures

5.2.1.6.1 Smooth forms

Ichnogenus: Circulichnus Vialov, 1971

Type ichnospecies: Circulichnus montanus Vyalov, 1971.

Diagnosis: A completed circular to oval interface trail or burrow (Vialov, 1971)
Ichnospecies: *Circulichnus montanus* VIALOV, 1971

(Plate 5.8 a)

**Diagnosis:** Same as for ichnogenus.

**Description:** Burrows wall smooth, unlined, cylindrical and circular in outline and preserved as full relief on bedding plane. The part of the photographed burrow is broken but it is essentially parallel to bedding plane. Diameter of the burrow varies from 1.0 to 1.2 cm. Burrow fill is different from the host sediments.

**Occurrence:** Allochomic sandstone of Gadaputa Sandstone member of Goradongar Formation, Goradongar range.

**Remarks:** It is a mono specific ichnogenus described by Vyalov (1971) from the Triassic of the Pamirs. The present specimens are included within *C. montanus* based on the ovate shape and their connectivity. It ranges in age from Ordovician to Paleocene and is considered to be eurybathic (McCann and Pickerill, 1988).

**Ichnogenus:** *Cochlichnus* HITCHCOCK, 1858

**Type Ichnospecies:** *Cochlichnus anguineus* Hitchcock, 1858

**Diagnosis:** Regularly meandering, horizontal trails and burrows resembling sine curves. Sinuosity of the trail may be extremely regular or somewhat irregular (Pemberton and Frey, 1984; Fillion and Pickerill, 1990)

Ichnospecies: *Cochlichnus anguineus* HITCHCOCK, 1858

(Plate 5.8 b)

**Emended Diagnosis:** Regular, sinusoidal, horizontal trails and burrows resembling a compressed and stretched corkscrew. Overall width of an individual trace may change progressively (Gluszek, 1995).

**Description:** Burrow preserved in convex hyporelief, sediment filled identical to host rock. Sinuous trails preserved as mould of burrows on the upper surface of beds. Wave lengths and amplitudes are constant within a single burrow. Maximum length is about 20 cm and diameter of the feeding trail is about 0.7 cm.

**Occurrence:** Allochomic sandstone of Dingy Hill member of Kaladongar Formation, Kaladongar range.
Remarks: Cochlichmus are the crawling trace and probably the feeding structures of small worms or worm-like animal (Eager et al, 1985) but the possible progenitors of this ichnospecies include annelids lacking well-developed parapodia (Hitchcock, 1858; Hakes, 1976), nematodes lacking circular muscles (Clarke, 1964), and in lacustrine deposits, insect larvae (Metz, 1987). It has been reported in sediments of supposed low-salinity paleoenvironment (Hakes, 1976).

Ichnospecies: Cochlichmus isp.

(Plate 5.8 c)

Description: Smooth, unbranched, lined, unornamented, regularly sinuously curved horizontal burrow preserved in full relief. Burrow circular to slightly elliptical in cross section; length is 170 mm. and diameter of 6 mm. Burrow fill is identical to surrounding rock. Wave lengths and amplitudes vary within a single burrow; mean wave length 55 mm and amplitude 0.4–0.6 (mean 0.5 mm).

Occurrence: Micritic sandstone of Gadaputa Sandstone member, Goradongar Formation, Goradongar range.

Remarks: Cochlichmus ranges in age from Precambrian to Holocene and has a wide facies range, including lacustrine (Mermia ichnofacies) and shallow marine (Cruziana ichnofacies) settings (Lucas and Lerner, 2005). It is regarded as the trace of annelids feeding within the sediment, locomotion trace of nematodes (Fillion and Pickerill, 1990).

Ichnogenus: Didymaulichmus YOUNG, 1972

Type Ichnospecies: Fraena lyelli Rouault, 1850

Diagnosis: Smooth, furrow-like horizontal trails or burrows, bisected longitudinally by a narrow median groove if preserved in hyporelief (Fillion and Pickerill, 1990)
Plate 5.8 Winding and meandering structures (Bar length= 1 cm; coin diameter=2.5cm)

(a) Circulichnus montanus, allochemic sandstone, GSM; (b) Moulds of sinuous trails Cochlichnus anguineus, allochemic sandstone, DHM; (c) Cochlichnus isp., allochemic sandstone, GSM; (d) Simple, smooth, gently curving bilobate trails Didymaulichnus lyelli, Micritic mudrock , BCSM; (e) Didymaulichnus lyelli, allochemic sandstone, DHM; (f) Long, smooth, unbranched arcuate & looped burrow Gordia arcuata, allochemic sandstone, DHM:
(g) Gordia arcuata, sandy allochem limestone, BCSM; (h) Gordia isp., sandy allochem limestone, RLM; (i) Helicolithus sampelayoi, bioclastic packstone, MHM; (j) (i) Helicolithus sampelayoi, & (ii) Planolites beverleyensis, bioclastic packstone, MHM; (k) Aulichnites parkerensis, bioclastic packstone, MHM.
Ichnospecies: Didymaulichnus lyelli ROUault, 1850
(Plate 5.8 d and e)

**Diagnosis:** Same as for ichnogenus.

**Description:** Simple, smooth, gently curving bilobate trails about 2.5 cm wide, preserved in convex hyporelief; parallel to the bedding; lobes separated by distinct furrow.

**Occurrence:** Allochemic sandstone of Dingy Hill member and micritic mudrock of Babia Cliff sandstone member of Kaladongar Formation, Kaladongar range.

**Remarks:** The present material is assigned to Didymaulichnus lyelli due to its lack of a) marginal bevels characteristics of D. miettenisis, b) alternating burrow depths characteristic of D. alternatus, c) lateral ridges characteristics of D. rouaulti and d) marginal bevels and larger size characteristics of D. tirasensis. This ichnogenus represents the crawling trail of molluscan origin (Hantzschel 1975).

**Ichnogenus:** Gordia EMMONS, 1844

**Type Ichnospecies:** Gordia marina Emmons, 1844

**Diagnosis:** Unbranched, predominantly horizontal trails or burrows that wind or loop but do not regularly meander, with a marked tendency to level crossing; burrow-fill structureless (Pickerill and Peel, 1991).

Ichnospecies: Gordia arcuata KSIAZKIEWICZ, 1977
(Plate 5.8f and g)

**Diagnosis:** Hypichnial, thread-sized meandering groove casts in which only apical arcuate bends are developed.

**Description:** Arcuate or looped, thick, usually long, smooth, thin rope sized, unbranched burrows having length about 30.0 cm and diameter about 1.8 cm. The burrow diameter is throughout constant and fill is identical to matrix.

**Occurrence:** Allochemic sandstone of Dingy Hill and sandy allochem limestone of Babia Cliff Sandstone members of Kaladongar Formation.

**Remarks:** This specimen is included in Gordia because they lack the regular sinuous curve of Cochlichnus, the loose meanders of Helminihopsis and regular meanders of Cosmorhaphe. Gordia is a feeding burrow of worm like animal (Crimes et al., 1977).
Ichnospecies: *Gordia* isp.

(Plate 5.8 h)

**Description:** Irregularly looping, long, slender, worm-like trail with small enlargement at wave crests. Trails of variable lengths, limbs representing positive amplitudes are long and gentle while limbs forming negative amplitudes (troughs) are short and steeper. The width of the string is about 5.4 mm and the length of the undulating string is about 238.7 mm. Preserved as convex hyporelief, and burrow fill is identical to host sediment.

**Occurrence:** Sandy allochem limestone of Raimalro Limestone member of Goradongar Formation, Goradongar range.

**Remarks:** The makers of the *Gordia* are probably priapulids, feeding on the nutrient-rich sediment (Wang et al., 2009). The hypichnial strings may be classified as feeding burrow or feeding trails while the hypichnial furrow as the locomotion trail of a polychaete worm (Książkiewicz, 1977). It differs from above described *Coehlichechnus* by lacking a regular sine curve.

**Ichnogenus:** *Helicolithus* AZPEITIA MOROS, 1933

**Type Ichnospecies:** *Helicolithus sampelayoi* Azpeitia Moros, 1933

**Description:** Small, horizontal, meandering trace fossils with horizontal second-order helicoidal turns. Changes of screw direction at every turn of first-order meanders (Uchman 1995)

**Ichnospecies:** *Helicolithus sampelayoi* AZPEITIA MOROS, 1933

(Plate 5.8i and j(i))

**Diagnosis:** *Helicolithus* with simple, short, regular helicoidal undulations (Uchman 1999)

**Description:** Small, horizontal, zigzags pattern with alternate right and left turn, in either of cases it appear as parallel ridges or grooves, but other turn is always concealed, in some case right and left turns exposed on surface and appear as zigzag patterns. Length of each turn is variable, 12 to 15 mm and diameter is constant, being 4 mm.

**Occurrence:** Pelloidal packstone of Modar Hill member of Goradongar Formation, Goradongar range.
Remarks: *Heilicolithus* is similar to *Helicodromites* but much smaller in size and interpreted as graphoglyptid agrichnion (Seilacher, 2007). At deeper part it shows simple short helicoidal undulations (Uchman, 1999). The specimen does not show change of sigmoidality and thus differs from the ichnospecies *Heilicolithus tortuosus* (Seilacher, 2007).

**Ichnogenus:** *Aulichnites* Fenton and Fenton, 1937

**Type Ichnospecies:** *Aulichnites parkerensis* Fenton and Fenton, 1937

**Diagnosis:** Preserved in convex epirelief with a bilobate upper surface. May show a unilobate convex-downward lower surface, in which case lateral margins of both surfaces intersect. Upper surface may show transverse, concave-convex striations. Lobes separated by median furrow (Fillion and Pickerill, 1990)

**Ichnospecies:** *Aulichnites parkerensis* Fenton and Fenton, 1937

(Plate 5.8k)

**Diagnosis:** Same as for ichnogenus.

**Description:** Horizontal, straight to sinuous, two closely spaced parallel trails separated by a deep furrow and preserved as epichnial ridges. Photograph shows specimen having annulations in the eroded part. Each trail has a width of about 3-6 mm and length of about 80 mm.

**Occurrence:** Pelloidal packstone of Modér Hill member of Goradongar Formation, Goradongar range.

**Remarks:** *Aulichnites* is considered as the crawling traces of gastropods and the annulated lobes are presumably related to the peristaltic movements (Frey and Howard, 1990).

### 5.2.1.6.2 Winding (helicoidal) structures

**Ichnogenus:** *Gyrolithes* Saporta, 1884

**Type ichnospecies:** *Gyrolithes davreuxi* Saporta, 1884.

**Diagnosis:** Systems built up of tubular structures with circular to elliptical cross section, more or less describing one or more dextral, sinistral or mixed circular helix structures (coils) essentially upright in the sediment; coils may be connected to each other by horizontal to
oblique or vertical unbranched or branched tubular structures; with or without wall-lining; exterior morphology smooth, knobb, with criss-cross ridges and grooves or longitudinal ridges and grooves; radius of individual whorls may increase, decrease or remain constant; diameter of tubular structures may vary.

Plate 5.9 Winding, and Plaited forms (Bar length= 1 cm, coin diameter = 2.5 cm)
(a) Endichnial, unornamented coiled burrow *Gyrolithes* isp., allochemic sandstone, DHM; (b) Biserially arranged plaited ridge burrow *Gyrochorte comosa*, allochemic sandstone, DHM, Chhappar bed; (c) *Gyrochorte comosa*, sandy allochem limestone, BCSM; (d) and (e) *Gyrochorte comosa*, bioclastic packstone, MHM; (f) Slightly curved small keel-like trail *Protovirgularia dichotoma*, DHM; (g) *Protovirgularia dichotoma* observed as (i) small keel-like slightly curved trail and (ii) fused appendages forming parallel ridges; DHM; (h) *Protovirgularia cf. dichotoma*, allochemic sandstone, GSM; (i) *Protovirgularia* isp., allochemic sandstone, RLM.
Ichnospecies: *Gyrolithes* isp.

(Plate 5.9 a)

**Description:** Full relief, endichnial, sinistrally coiled unlined burrow, without surface ornamentation. The burrow filled is identical to host sediment. The burrow diameter is about 2 cm.

**Occurrence:** Allochemic sandstone of Dingy Hill member of Kaladongar Formation, Kaladongar range.

**Remarks:** *Gyrolithes* isp. is differ from the other ichnospecies by lacking median furrow and probably made by decapods crustaceans (Hantzschel, 1975).

### 5.2.1.6.3 Plaited forms

**Ichnogenus:** *Gyrochorte* HEER, 1865

**Type ichnospecies:** *Gyrochorte comosa* HEER, 1865

**Diagnosis:** Epirelief, preserved as plaited ridges with biserially arranged, obliquely aligned pads of sediment, separated by median furrow. Hyporelief shows smooth biserial grooves separated by median ridge. Course straight to strongly winding, direction changes sharply. Parts of the trace may intersect. Ridges and their grooves separated by a vertical distance (Schirf, 2000).

Ichnospecies: *Gyrochorte comosa* HEER, 1865

(Plate 5.9 b-e)

**Diagnosis:** As for ichnogenus.

**Description:** Epirelief, long, sinuous and curved, horizontal trails consist of plaited ridges with biserially arranged long parallel ridges on the upper surface of the bedding plane, with width 0.4 – 0.6 cm and maximum observed length is 88.14 cm. Frequent crossing over in such a way that the earlier formed ridges are not destroyed.

**Occurrence:** Micritic sandstone, allochemic sandstone and sandy allochem limestone of Dingy Hill member; and micritic sandstone, sandy allochem limestone and micritic mudrock of Babia Cliff Sandstone member of Kaladongar Formation; and sandy allochem limestone of Goradongar Flagstone member, sandy allochem limestone of Raimalro Limestone member,
sandy allochem limestone, pelloidal packstone, and pelloidal grainstone of Modar Hill member of Goradongar Formation.

**Remark:** *Gyrochorte comosa* can be distinguished from other ichnospecies of *Gyrochorte* through its lack of a) oblique incisions characteristic of *G. burtani* Książkiewicz, 1971, b) imbricate asymmetrical riblets characteristic of *G. imbricate* Książkiewicz, 1977, and c) densely spaced irregular incisions characteristic of *G. obliterata* Książkiewicz, 1977. *Gyrochorte* producer must have been a cetritus-feeding worm-like animal, probably an annelid that created a bilobed, vertically penetrating and sometime plaited meandering trace (Gibert and Benner, 2002).

**Ichnogenus:** *Protovirgularia* M’COY, 1850

**Type ichnospecies:** *Protovirgularia dichotoma* M’COY, 1850.

**Diagnosis:** Horizontal or subhorizontal cylindrical trace fossil, trapezoidal, almond shaped or triangular in cross section, distinctly or indistinctly bilobate. Internal structure, if preserved, formed by successive pads of sediment that may be expressed as ribs on the exterior. Ribs arranged in chevron-shaped, biserial pattern along external or internal dorsal part. Occasionally with smooth mantle on exterior covering the structure and/or with oval mound-like terminations of the trace (Uchman 1998).

**Ichnospecies:** *Protovirgularia dichotoma* M’COY, 1850  
(Plate 5.9f and g)

**Diagnosis:** Unbranched, keel-like trail, typically, but not universally, with median ridge or furrow form where paired, lateral, wedge-shaped appendages, commonly only few millimeters in length and of even or variable spacing, originate. Lateral appendages normal or at acute angle to median ridge or furrow (Han and Pickerill, 1994).

**Description:** Horizontal to sub horizontal, straight to gently curved, small keel like trail. Burrows composed of biserially arranged, paired, lateral appendages (Pl. IV, i) originating normal or at acute angle to median furrow or lateral appendages fused together (Pl.IV, j) and forming parallel ridges. The length of the burrow is 6-7 cm; width of the burrow varies from 1-3 cm. The pads consist of same material as the surrounding matrix.

**Occurrence:** Micritic sandstone of Dingy Hill member of Kaladongar Formation.
Remarks: It is generally considered to be made by bivalves (Seilacher and Seilacher 1994, Ekdale and Bromley 2001).

Ichnospecies: Protovirgularia cf. dichotoma M’COY, 1850

(Plate 5.9 h)

Description: Positive hyporelief, small keel-like trail, wide, and slightly curved. Lateral appendages are normal or at acute angle to median ridge or furrow (Han and Pickerill 1994). The length of the burrow is 75 mm and 8 mm wide.

Occurrence: Allochemic sandstone of Gadaputa Sandstone member, Goradongar Formation.

Remarks: The present ichnospecies show a close resemblance with the Protovirgularia dichotoma. The producer of this trace is considered to be made by bivalves (Seilacher and Seilacher, 1994).

Ichnospecies: Protovirgularia isp.

(Plate 5.9 i)

Description: Slightly curved, small keel-like trail. Lateral pads show an acute angle to median ridge or furrow at the curving part of the burrow. The length of the burrow is 70 mm and the width ranges from 3-4 mm.

Occurrence: Allochemic sandstone of Raimalro Limestone member of Goradongar Formation, Goradongar range.

Remarks: Protovirgularia can be differentiated from biserial arthropod tracks by strict symmetry of impressions on the two sides, from bilobed, Scolicia by the angularity of the chevrons, from Cruziana by the cross-section and the non-scratched morphology of the chevrons and from Gyrochorte by being a positive hyporelief (Seilacher and Seilacher, 1994). This specimen differs from the rest ichnospecies of Protovirgularia, in respect to the width of the trail.

5.2.1.6.4 Meniscate forms

Ichnogenus: *Beaconites* Vyalov, 1962

Type Ichnospecies: *Beaconites antarcticus* Vyalov, 1962
Diagnosis: Small cylindrical, unbranched, walled, meniscate burrow. Straight or sinuous, horizontal or more rarely inclined or vertical. Weakly to strongly arcuate meniscate packets or segments enclosed by distinct, smooth and unornamented burrow linings (Keighley and Pickerill, 1994)

Ichnospecies: *Beaconites coronus* FREY, PEMBERTON and FAGERSTROM, 1984

(Plate 5.10 a-c)

Diagnosis: Predominantly horizontal, more rarely inclined to vertical, distinctly lined, gently winding, small meniscate burrow. Relatively short (with respect to burrow width) meniscate packets, or segments, of alternating sediment type. Menisci are gently to moderately arcuate (Keighley and Pickerill, 1994).

Description: Small, almost straight to gently winding, horizontal to slightly inclined, non branching, distinctly lined, meniscate burrow. Burrow diameter varies from 10 to 12mm, length varies from 70 to 90 mm and menisci 1 to 3 mm in width.

Occurrence: Allochem sandstone of Dingy Hill member of Kaladongar Formation; and allochem sandstone of Gadaputa Sandstone member and pelloidal packstone of Modar Hill member.

Remarks: The burrows are assigned to *Beaconites coronus* because of their distinct wall and almost straight to gently curved meniscate packets of various sediment composition. The possible producer of *B. coronus* needs body appendages in order to sort and move the sediment and thus arthropod seems to be more likely possible producers.

Ichnospecies: *Beaconites antarcticus* VIALOV, 1962

(Plate 5.10 d)

Diagnosis: Same as for ichnogenus

Description: Full relief, horizontal, sinuous, unbranched, thick-walled, meniscate burrow. Menisci form heterogeneous thick backfill of unequal thickness and merge laterally with each other but become distinct at burrow wall-sediment interface. The diameter of burrow is ~40 mm and the length is about 320 mm.

Occurrence: Pelloidal packstone and sandy micrite of Modar Hill member, Goradongar Formation, Goradongar range.
Remarks: The Kachchh specimen 'Beaconites antarcticus' is a lined burrow which is a prime characteristic of the ichnogenus Beaconites (Keighley and Pickerill, 1994) and can be distinguishes it from the other ichnosppecies by having thicker packets.

Ichnogenus: Bichordites PLAZIAT AND MAHMOUDI 1988


Diagnosis: Predominantly horizontal, cyindrical, straight to winding, unbranched, meniscate composite burrow, slightly concave along the base and the top, and with central cord. At least the upper part of the burrow contains a double row of menisci. The cord is preferentially preserved; it is heart-shaped to ovoid in cross-section, tapers locally and is interrupted. A longitudinal median shallow groove along the top of the cord locally passes into an indistinct crest. Locally, the cord is covered with external irregular constrictions or transverse striae (Emended by Uchman, 1995).

Ichnosppecies: Bichordites isp.

(Plate 5.10 e)

Description: Horizontal, cylindrical, unbranched, horizontal to gently inclined meniscate concave burrow with a central cord. The burrow is 15 to 20 mm in diameter and 30-40 mm long, central cord is about 20 mm long and diameter of 12 mm.

Occurrence: Sandy micrite of Modar Hill member, Goradongar Formation.

Remarks: Bichordites is produced by spatangoid echinoids with a single drainage tube, which belong to the so called Echinocardium group (Plaziat and Mahmoudi, 1988).

Ichnogenus: Nereites MAC LEAY, 1839

Type Ichnosppecies: Nereites cambriensis MacLeay, 1839

Diagnosis: Usually selectively preserved, winding to regularly meandering, approximately horizontal trails, consisting of median backfilled tunnel enveloped by even to lobate zone of reworked sediment. Generally, only external part of enveloping zone preserved as densely packed chain of uni-serial or multi-serial small depressions or pustules (Uchman, 1995).
Ichnospecies: *Nereites missouriensis* WELLER, 1899
(Plate 5.10 f)

**Diagnosis:** Variously preserved, loosely meandering to winding *Nereites* with wide, central backfilled tunnel and envelope zone of similar thickness, which occasionally displays low side lobes. The exterior may be expressed as uni- or multi-serial chain of closely packed sediment pustules. The interior may be preserved as a row of at least uniserial closely packed sediment depressions, or as strongly flattened burrows, which form usually colour-contrasted strips on parting surfaces with poorly preserved or not-preserved side lobes (Uchman, 1995).

**Description:** Shallow, epichnial, winding, exceptionally coiled grooves consisting of juxtaposed oval dimples surrounded by about 1 mm thick zone of disturbed sediments with occasionally elevated edges bordering the grooves. The grooves are 12-15 mm wide and up to 1 mm deep.

**Occurrence:** Sandy allochem limestone of Dingy Hill member of Kaladongar Formation.

**Remarks:** It is interpreted as the internal meandering grazing trails (Seilacher and Meischner, 1965). Various producers have been suggested: worms (Richter 1928), gastropods (Raymond 1931; Abel 1935), or crustaceans (Fraipont, 1915). *N. missouriensis* eurybathic form and has been reported mainly from flysch deposits from the late Precambrian (Crimes 1987) to the Miocene (D’Alessandro 1980).

**Ichnogenus:** *Rhabdoglyphus* VASSOEVICH, 1951

**Type ichnospecies:** *Rhabdoglyphus grossheimi* Vassoevich, 1951

**Diagnosis:** Cylindrical tubes consisting of short, closely spaced, invaginated “calyces,” some with short branches; preserved in convex hyporelief (Häntzschel, 1975).

Ichnospecies: *Rhabdoglyphus* isp.
(Plate 5.10 g)

**Description:** Convex hyporelief, cylindrical tubes consisting of uniformly shaped invaginated calyces. The length of the whole trace is 190 mm and diameter of 10 mm. Calyces vary in length from 15 to 20 mm and the diameter from 8 to 10 mm.

**Occurrence:** Allochem sandstone of Râimalro Limestone member of Goradongar Formation.
Remarks: *Rhabdoglyphus* is considered to have been produced by gastropods, amphipods or holothurians (Bouček and Elias, 1962). According to Osgood (1970), swellings of the burrow represent periodic anal constrictions and expansion by polychaete worm while advancing by bolting.
Plate 5.10 Meniscate forms (Bar length = 1 cm, coin diameter = 2.4 cm)
(a) Horizontal, unbranched, lined, meniscate burrow *Beaconites coronus*; (b) *Beaconites coronus*, allochemic sandstone, GSM; (c) *Beaconites coronus*, bioclastic packstone, MHM; (d) *Beaconites antarcticus*, bioclastic packstone, MHM; (e) *Bichordites* isp., sandy micrite, MHM; (f) (i) *Nereites missouriensis*, epichnial, winding with elevated edges bordering the grooves associated with (ii) *Palaeophycus tubularis*, sandy allochem limestone of DHM; (g) *Rhabdoglyphus* isp., allochemic sandstone, RLM; (h) *Scolicia prisca*; cylindrical body with arched dorsal side and a flat bottom; sandy allochem limestone, DHM; (i) Negative epirelief, bilaterally symmetrical long band-like surface trail *Scolicia prisca*, sandy allochem limestone, DHM; (j) Irregular, winding burrow *Scolicia* isp., allochemic sandstone, DHM; (k) Non-compartmentalized heterogeneous unbranched thin meniscate segmented burrow *Taenidium barretti*, sandy micrite, MHM; (l) Horizontal, slightly curved, cylindrical meniscate tubes *Taenidium serpentinum* having length equal to its width, Bar length = 4 cm; (m) Horizontal, cylindrical meniscate burrow *Taenidium serpentinum*; (n) *Taenidium serpentinum*, Bioclastic packstone, MHM; (o) *Taenidium serpentinum*, Bioclastic packstone, MHM.

**Ichnogenus:** *Scolicia* DE QUATREFAGES, 1849

**Type Ichnospecies:** *Scolicia prisca* De Quatrefages, 1849

**Diagnosis:** Variably and commonly selectively preserved, simple, winding, meandering to coiling bilobed or trilobed back-filled burrows with two parallel, locally discontinuous, sediment strings along their lower side. Cross-section approximately oval in outline. Lower side between the strings flat or slightly concave up. Backfill laminae composite, may be biserial on the upper side. Washed-out forms preserved as hypichnial bilobate ridges (Uchman, 1995)

**Ichnospecies:** *Scolicia prisca* DE QUATREFAGES, 1849

(Plate 5.10 h and i)

**Diagnosis:** *Scolicia* preserved usually as epichnial trilobite furrow with concave, semicircular bottom and oblique slopes, densely packed fine transverse ribs at the bottom, more loose, asymmetrical and thicker ribs on the slopes. Two parallel strings may occur along the edges of the bottom. Proportion of bottom to slopes may vary in different specimens (Uchman, 1995)

**Description:** Horizontal bilaterally symmetrical surface trail of negative epirelief, consisting of great variability, long band-like morphology. Cylindrical bodies appear with an arched
dorsal side and a flat bottom. The washed out forms preserved as hypichnial bilobate ridges. The overall diameter of the trail is about 2.3-2.5 cm and is long about 65-70 cm.

**Occurrence:** Sandy allochem limestone of Dingy Hill member of Kaladongar Formation.

**Remarks:** This ichnotaxon is usually preserved in the middle part of turbidites at the transition from sandstone to mudstone. The substrate properties and degree of weathering may influence the expression of the ribs at the bottom (Uchmann, 1999). The specimen found in the Sandy allochem limestone of Dingy Hill member of Kaladongar Formation, differs from the *Subphyllochorda* in the taphonomic position and the kind of preservation (Fig. 5.1). It represents the characteristic of *Paleobullia* Gützinger and Becker, 1932, but it is kept under *Scolicia prisca* as suggested and regarded by Uchman (1995). The looped and unbranched trails typical of the grazing trails of the gastropods (Seilacher, 1953) and the bilobate with transverse markings typical of its surface trails (Schäfer, 1972) suggest gastropods to be the trace makers. This ichnogenus *Scolicia* is considered as a facies-crossing trace fossil (Seilacher, 1964).

**Ichnospecies:** *Scolicia* isp.

(Plate 5.10 j)

**Description:** Hypichnial shallow grooves, gently curved, cross-over crawling trails, feebly developed actively developed forward banding biogenic laminae; length of trails are variable and width of about 1-2 cm. Trail morphology varies in given specimen, broadening and narrowing of trails observed frequently as well as washed out leaving trails of cast.

**Occurrence:** Allochemic sandstone of Dingy Hill member of Kaladongar Formation.

**Remarks:** *Scolicia* isp., represents as shallow groove on the rippled surface, characteristic features may obscured by substrate consistency but overall morphology reflect the crawling trails which correspond to locomotion activity of echinoids (Uchman, 1995).

**Ichnogenus:** *Taenidium* HEER, 1877

**Type ichnospecies:** *Taenidium serpentinum* Heer, 1877.

**Diagnosis:** Varibly oriented, unlined, straight, winding, curved or sinuous, essentially cylindrical, meniscate backfilled trace fossils. Straight successive branching may occur, but true branching is absent (Keighley and Pickerill, 1994).
Figure 5.1 Different types of Scolicia burrow in relation to depth of burrowing/taphonomic position in the flysch deposits (redrawn from Uchman, 1995)

**Ichnospecies:** *Taenina burreri* BRADSHAW, 1981

(Plate 5.10 k)

**Diagnosis:** Straight to variably meandering, unbranched, unwalled, meniscate backfilled burrow. Menisci are commonly hemispherical, deeply arcuate to bell-shaped, tightly packed or stacked, forming non-compartmentalized backfill or thin meniscate segments (Schlirf, 2000).

**Description:** Full relief, straight to slightly sinuous, unbranched, unwalled, meniscate burrow with irregular boundary, subparallel to the bedding plane. Menisci are hemispherical to arcuate, tightly packed, forming non-compartmentalized heterogeneous backfill. The width of burrow range from 10 -12 mm and the length is about 73 mm.

**Occurrence:** Sandy micrite of Modar Hill member of Goradongar Formation
Remarks: The unwalled nature of the specimen differentiates it from *Beaconites*. *Taenidium baretti* show heterogenous fill similar to *Taenidium dieslingi* but differs from the latter in lack of compartmentalized and distinct packeting (Keighley and Pickerill, 1994).

Ichnospecies: *Taenidium serpentinum* HEER, 1877
(Plate 5.10 l-o)

Diagnosis: Serpentiform *Taenidium* having well-spaced, arcuate menisci; distance between menisci about equal to or little less than burrow width. External moulds may show slight annulations corresponding to menisci, or fine transverse wrinkling. Secondary subsequent branching and intersections occur. Boundary sharp and lacks lining (Keighley and Pickerill, 1994)

Description: Endichnial to hypichnial, concave and convex hyporelief burrows, active fill identical to matrix. Horizontal, straight, cylindrical tubes up to 8.0 cm long and 0.3 to 1.0 cm wide; having 0.5 cm diameter, symmetrically arranged distinct transverse annulations. Burrow typically unbranched having segmentation on surface by annular constrictions.

Occurrence: Allochemic sandstone of Babia Cliff Sandstone member of Kaladongar Formation; and micritic sandstone of Gadaputa Sandstone member, and sandy allochem limestone and pellowid packstone of Modar Hill member of Goradongar Formation.

Remarks: *Taenidium* has been reported from the Mesozoic and Cenozoic flysch of Europe (Heer, 1877) and from the Ordovician deposits of the Ouachita Mountain (Chamberlain, 1971). The cylindrical burrow exhibits typical periodic filling of tunnel in backward direction.

Ichnogenus: *Virgoglyphus* PATEL, JAQUILIN AND BHATT, In press

Type ichnospecies: *Virgoglyphus modari*

Diagnosis: Predominantly horizontal, segmented burrow consisting of overlapping cylindrical tubes with horn like extension on one side; extended up to emerging of the next tubes or beyond this tube; successive tubes progressively decreasing in dimensions, preserved as endichnia.

Remarks: Outwardly the burrow assigned here are similar to the *Rhabdoglyphus* VASSOEVICH, which also includes cylindrical tubes having invaginated calyces, but these
calyces are of uniform shape. According to Książkiewicz (1977), all short articulated rods consisting of uniformly shaped and relatively large limbs may be grouped as *Rhabdoglyphus*.

**Figure- 5.2** Comparison of *Virgoglyphus* Patel, Jaquilin and Bhatt, *in press* with the similar forms of *Rhabdoglyphus* Vassoevich, 1951 and the schematic representation of feeding pattern of the trace maker of *Virgoglyphus* n. gen.

Ichnospecies: *Virgoglyphus modari* PATEL, JAQUILIN AND BHATT, *In press*  
(Plate 5.11a)

**Diagnosis:** As for ichnogenus

**Description:** Essentially horizontal, segmented burrow consisting of overlapping tubes; each correspondingly fit in to next higher one and forming a bamboo-like structure. Each segment shows variable dimension and unevenly distributed for the entire length of the burrow. The horn-like structure is present on one side and extended up to or beyond the segment. The initial part of the burrow wall is pelleted but successive segments are unornamented. The
holotype is 120 mm long and diameter is varies from 15-18 mm. The burrow fill is identical to host sediment.

**Occurrence:** Pelloidal packstone of Modar Hill member of Goradongar Formation

**Remarks:** *Virgoglyphus modari* occurs in sandy micrite of the Modar Hill member of the Goradongar Formation at Modar hill. This new form of trace shows overlapping tubes which indicate periodically active fill of the burrow. The producer seems to start its move from “a” ending to “b” (Fig. 5.2) which shows an escape-like structure. Though the structure seems to be similar to the *Rhabdoglyphus* burrows, it does not follow its overall pattern of structure and has non-uniform calyces or segments no.1 to 8 (Fig.5.2). The burrow structure reveal an irregular pattern of feeding; wherein the producer might have moved, turned around and proceeded further to form a cover like structure overlapping the previous one, as depicted in the line drawing (Fig. 5.2). The overall structure and the size of the burrow suggest crustaceans to be its producer but to assign it particularly to this originator is difficult because of the paucity of the materials.

**Ichnogenus:** *Walcottia* GLOCKER, 1841

**Type Ichnospecies:** *Walcottia rugosa* Miller and Dyer, 1878

**Diagnosis:** Slender vermiform trace fossils preserved as convex hyporelief or convex epirelief that possess obliquely directed paired lobes. The closely spaced lobes are ridge-like and tend to obscure the body. The form tapers at one end and terminates at the other in a structureless ovoid mass. Alternatively, shell-like coverings composed of small plates or rings, or longitudinal grooves from which issue oblique striae may be present (Osgood, 1970)

**Remarks:** The *Walcottia rugosa* is considered as the junior synonym of *Protovirgularia rugosa* by Seilacher and Seilacher (1994) but the taxonomic status of other forms of ichnospecies of *Walcottia* ichtnogenus, namely, *W. cookana*, *W. sulcata*, *W. devilsdingli* and *W. imbricata*, remains equivocal (Rindsberg, 1994; Stanley and Pickerill, 1998). However, *Walcottia devilsdingli* is considered under separate ichtnogena “Walcottia” by Allington-Jones *et al.* (2010), and later taxonomy is retained and described considering the morphological similarities (Jaquilin *et al.*, 2012; Patel *et al.*, *In press*).

**Ichnospecies:** *Walcottia devilsdingli* BENTON AND GRAY 1981

(Plate 5.11 b-f)
**Diagnosis:** Unbranched horizontal burrow, circular to elliptical in cross-section, displaying symmetrically arranged irregular scratch marks at various points along the sides and behind the ovoid expanded burrow ends.

![Plate 5.11](image)

**Plate 5.11** Meniscate burrows and U-shaped borings (Bar length= 1 cm, coin diameter = 2.5 cm). (a) *Virgoglyphus modari* n. isp., Bioclastic packstone, MHM; (b), (c), and (d) Unbranched horizontal backfilled burrow *Walcottia devilsdingli*, allochecim sandstone, DHM; (e) Cylindrical chevron-like surface sculptured curved burrows *Walcottia devilsdingli*, allochecim sandstone, RLM; (f) Cylindrical chevron-like surface sculptured straight burrows *Walcottia devilsdingli*, allochecim sandstone, RLM; (g) Cylindrical boring bent in a narrow U shaped gallery *Caulostrepsis taeniola*, sandy allochem limestone, RLM.

**Description:** Hypichnial, cylindrical straight to curved full burrows with chevron-like surface sculpture is the characteristics of the ichnogenus. Burrow width in unscratched areas varies, maximum being of 60 mm; sculpture burrow length is 40 to 50 mm and diameter of 10-14 mm, and the cross-section is elliptical to circular. It consists of arcuate, uniformly bent
segments, each 6-12 mm long, separated by very narrow and shallow grooves; the figured specimen shows 5 to 10 scratch marks but numbers of scratch marks varies in different burrow populations.

**Occurrence:** Allochemic sandstone of Dingy Hill member and Raimalro Limestone member (Tuga village) of Kaladongar and Goradongar Formations respectively.

**Remarks:** The specimen differs in dimension from the *Beaconites* (smaller dimension) and *Imbrichnus* (larger dimension). The maker of the *Walcottia* was evidently slow-moving organisms that did not travel far before resting. The ovate to amygdaloid form of the resting trace strongly suggests bivalves as the chief makers (Rindsberg, 1994).

### 5.2.2 BORING:

#### 5.2.2.1 U-Shaped

**Ichnogenus:** *Caulostrepsis* Clarke, 1908

**Type ichnospecies:** *Caulostrepsis taeniola*, Clarke, 1908

**Diagnosis:** U-shaped tunnels with spreite, corresponding to tiny *Rhizocorallium*, sometimes radiating inward from commissure of brachiopods; commonly found in shells of brachiopods, mollusks, and echinoids (Häntzschel, 1975).

**Ichnospecies:** *Caulostrepsis taeniola*, Clarke, 1908

(Plate 5.11 g)

**Diagnosis:** Gallery cylindrical, bent in a narrow U which is sometimes enlarged in the shape of a tongue. The inward-facing margins of the limbs are always interconnected by a distinct vane. Limbs closer or partially fused towards the apertural extremity. Transverse section is dumbbell-shaped, aperture ‘8’-shaped (Bromley and D’Alessandro 1983).

**Description:** Cylindrical gallery bent in a narrow U-shape. The inward facing margin of the limbs of the U-shaped boring is interconnected by a distinct vane. Limbs closer or partially fused towards the apertural extremity. Dumbbell shaped in transverse section and 8-shaped aperture.

**Occurrence:** Sandy allochem limestone of Raimalro Limestone member of Goradongar Formation exposed near Dhorawar village.

**Remarks:** The ichnogenus *Caulostrepsis* are known to occur from numerous rockground and shells ranging in age from Devonian to Recert (Taylor and Wilson, 2003). Polychaetes like Spionid (Häntzschel, 1975) and small eunicid *Lysidiceninetia* (Bromley, 1978) are reported as the possible producer of the trace.