CHAPTER 5

DESCRIPTION OF TRACE FOSSILS

5.1 INTRODUCTION

The earliest work on the Ichnology (=study of trace fossils) of the Mesozoic sediments of Kachchh basin was dealt by Badve and Ghare (1978) later on by Shringarpure (1986), Ghare and Kulkarni (1986), Kulkarni and Ghare (1989), Fürsich (1998), Patel et al. (2008a and b) and Desai et al. (2008). Seilacher (1967) described trace fossils epigrammatically as fossil behaviour. Biogenic sedimentary structures (trace fossils) originate through the behaviour of animals and clearly do not represent the burrowing animals themselves (Bromley, 1996). The main focus of the present study is to describe the taxonomy, morphology and ethology of the trace fossils and their corresponding occurrence in lithofacies which will assist in sequence stratigraphic analysis, and to decide probable environment of deposition. The trace fossils were identified and documented through photographs from the rock sequences of Jhura dome, Mainland Kachchh.

Principles in Ichnology (Bromley and Fursich 1980; Ekdale et al. 1984)

- The same individual or species can produce different structures corresponding to different behaviour pattern
- Different trace makers can produce identical structures when behaving similarly
- The same burrow or trace may be differently preserved in different substrate
- Multiple architects may produce a single structure
- Non-preservation of causative organisms
- They are largely facies dependent

Major strengths of Ichnology (Seilacher, 1964; Frey, 1975)

- Long temporal range
- Narrow facies range
- No secondary displacement
- Occurrence in otherwise non-fossiliferous rocks

The main interest associated with studying trace fossils in clastic sediments, is related to the reconstruction of ancient life or palaeocommunities and benthic behavioural patterns, paleoecology, paleobathymetry and environmental interpretation of the marine strata of the different geological periods. To satisfy the diverse interest for studying trace fossils many workers have proposed different classification schemes for example Ethological (behavioral) classification (Seilacher, 1953a, 1964; Frey and Seilacher 1980; and Frey and Pemberton 1985), Stratinomic (Seilacher, 1953b), Preservational (toponomic) classification (Simpson, 1957; Chamberlain, 1971; Martinsson, 1970; Frey, 1971, 1973), Phylogenetic (Seilacher, 1953b) and Morphologic affinity (Ksiazkiewicz 1977) classification scheme which was modified later by Uchman (1995). The author has applied all the classification schemes separately or in combination but for systematic description of the trace fossils, Ksiazkiewicz (1977) classification scheme and modified version (Uchman 1995) is adopted in combination with other classification schemes (Chamberlain 1971, 1977; Hantzschel 1975 and Seilacher 1953a).

The present Ichnological study of the Mesozoic (Middle Jurassic to Lower Cretaceous) rocks of the central Mainland Kachchh has revealed the presence of seventy one ichnospecies. These ichnofossils are typically well expressed at bed transitions, especially at intercalated shale–siltstone–sandstone and shale-limestone sequences. Trace fossils are classified on the basis of morphological affinity, whereby a few main morphological groups related to the general shape of trace fossils are distinguished with subdivision into smaller groups, typified by the most characteristic ichnogenus (Uchman, 1995). In the present study, ichnogenera and ichnospecies are named according to International Commission on Zoological Nomenclature (ICZN) Rules, using the binomial system of nomenclature.

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

borings. This classification scheme is simple and readily applicable considering the morphological criteria. The possible producers are also discussed and are compared with the known present day data from the same area.

5.2 TAXONOMY

In Ichnology, Taxonomy means the classification of trace fossils according to their systematics and nomenclature (Frey, 1973). Prevalent taxa include the ichnogenus and ichnospecies. Ichno-taxonomy was attempted in the present study based on the field data. Total 71 Ichnospecies of 36 Ichnogenera (Table 5.1) were identified and their preservational aspects, ecological probable producers and behavioural aspects are discussed further. Their brief description is as follows:-

Table 5.1 Ethology and Toponomy of Trace Fossils of the Jhura Dome.

Ichnogenera / Ichnospecies	**Ethology**	**Toponomy**
1. *Ancorichnus ancorichnus*	Crawling (*Repichnia*)	Endichnial
2. *Arenicolites carbonarius*	Dwelling (*Domichnia*)	Endichnial
3. *Beaconites antarcticus*	Grazing (*Pascichnia*)	Epichnial
4. *Beaconites coronus*	Grazing (*Pascichnia*)	Epichnial
5. *Bergaueria isp.*	Dwelling (*Domichnia*)	Epichnial
6. *Biformites isp.*	Dwelling and Feeding	Endichnial
7. *Chondrites intricatus*	Feeding (*Fodinichnia*)	Endichnial
8. *Chondrites isp.*	Feeding (*Fodinichnia*)	Endichnial
9. *Chondrites patulus*	Feeding (*Fodinichnia*)	Endichnial
10. *Chondrites recurvus*	Feeding (*Fodinichnia*)	Endichnial
11. *Chondrites targionii*	Feeding (*Fodinichnia*)	Endichnial
12. *Cochlichnus anguineus*	Crawling (*Repichnia*)	Epichnial
13. *Cosmorhaphe carpathica*	Grazing (*Pascichnia*)	Epichnial
14. *Calycraterion isp.*	Dwelling (*Domichnia*)	Epichnial
15. *Calycraterion Samsonowiczi*	Dwelling (*Domichnia*)	Epichnial
16. *Didymaulichnus isp.*	Crawling (*Repichnia*)	Epichnial
17. *Diplocraterion habichi*	Dwelling and Feeding	Endichnial
18. *Gordia marina*	Crawling (*Repichnia*)	Epichnial

19. *Gyrochorte comosa*	Grazing (*Pascichnia*)	Epichnial
20. *Gyrolithes polonicus*	Feeding (*Fodinichnia*)	Endichnial
21. *Keckia annulata*	Grazing (*Pascichnia*)	Epichnial
22. *Laevicyclus mongraensis*	Dwelling (*Domichnia*)	Endichnial
23. *Lockeia ornata*	Resting (Cubichnia)	Epichnial
24. *Lockeia siliquaria*	Resting (Cubichnia)	Epichnial
25. *Margaritichnus reptilis*	Dwelling (*Domichnia*)	Endichnial
26. *Monocraterion tentaculatum*	Dwelling (*Domichnia*)	Endichnial
27. *Ophiomorpha nodosa*	Dwelling (*Domichnia*)	Endichnial
28. *Ophiomorpha recta*	Dwelling (*Domichnia*)	Endichnial
29. *Palaeophycus annulatus*	Crawling and Feeding	Endichnial
30. *Palaeophycus heberti*	Crawling and Feeding	Endichnial
31. *Palaeophycus striatus*	Crawling and Feeding	Endichnial
32. *Palaeophycus tubularis*	Crawling and Feeding	Endichnial
33. *Parahentzschelinia ardelia*	Feeding (*Fodinichnia*)	Endichnial
34. *Phoebichnus trochoides*	Feeding (*Fodinichnia*)	Endichnial
35. *Phycodes circinnatum*	Feeding (*Fodinichnia*)	Endichnial
36. *Phycodes curvipalmatum*	Feeding (*Fodinichnia*)	Endichnial
37. *Phycodes palmatum*	Feeding (*Fodinichnia*)	Endichnial
38. *Phycodes pedum*	Feeding (*Fodinichnia*)	Endichnial
39. *Phymatoderma isp.*	Feeding (*Fodinichnia*)	Endichnial
40. *Pilichnus dichotomus*	Feeding (*Fodinichnia*)	Epichnial
41. *Planolites annularis*	Crawling and Feeding	Endichnial
42. *Planolites beverleyensis*	Crawling and Feeding	Endichnial
43. *Planolite isp.*	Crawling and Feeding	Endichnial
44. *Planolites montanus*	Crawling and Feeding	Endichnial
45. *Protovirgularia dichotoma*	Crawling (*Repichnia*)	Epichnial
46. *Rhizocorallium irregulare*	Dwelling and Feeding	Endichnial
47. *Rhizocorallium jenense*	Dwelling and Feeding	Endichnial
48. *Rhizocorallium uraliense*	Dwelling and Feeding	Endichnial
49. *Sabularia ramosa*	Feeding (*Fodinichnia*)	Epichnial
50. *Scolicia strozzii*	Crawling (*Repichnia*)	Hypichnial

51. *Skolithos linearis*	Dwelling (*Domichnia*)	Endichnial
52. *Skolithos verticalis*	Dwelling (*Domichnia*)	Endichnial
53. *Taenidium cameronensis*	Crawling and Feeding	Endichnial
54. *Taenidium satanassi*	Crawling and Feeding	Endichnial
55. *Taenidium serpentinum*	Crawling and Feeding	Endichnial
56. *Thalassinoides foedus*	Dwelling and Feeding	Hypichnial and Epichnial
57. *Thalassinoides horizontalis*	Dwelling and Feeding	Hypichnial and Epichnial
58. *Thalassinoides paradoxicus*	Dwelling and Feeding	Hypichnial and Epichnial
59. *Thalassinoides suevicus*	Dwelling and Feeding	Hypichnial and Epichnial
60. *Urohelminthoida dertonensis*	Grazing (*Pascichnia*)	Hypichnial
61. *Zoophycos brianteus*	Feeding (*Fodinichnia*)	Endichnial
62. *Zoophycos caudagalli*	Feeding (*Fodinichnia*)	Endichnial
63. *Zoophycos circinnatus*	Feeding (*Fodinichnia*)	Endichnial
64. *Zoophycos insignis*	Feeding (*Fodinichnia*)	Endichnial
65. *Zoophycos laminatus*	Feeding (*Fodinichnia*)	Endichnial
66. *Zoophycos villae*	Feeding (*Fodinichnia*)	Endichnial
67. *Zoophycos Type A*	Feeding (*Fodinichnia*)	Endichnial
68. *Zoophycos Type B*	Feeding (*Fodinichnia*)	Endichnial
69. *Zoophycos Type C*	Feeding (*Fodinichnia*)	Endichnial
70. *Zoophycos Type D*	Feeding (*Fodinichnia*)	Endichnial
71. *Zoophycos Type E*	Feeding (*Fodinichnia*)	Endichnial

5.3 DESCRIPTION OF TRACE FOSSILS

I. Burrows

I.1 Circular and Elliptical Structures – Circles

Ichnogenus: - *Margaritichnus* Bandel, 1973

Diagnosis: - Vertical, plugged tube, subcylindrical structures, circular to slight elliptical in cross section; perpendicular to the bedding; both proximal and distal ends are enlarged and joined by a poorly defined cylindrical shaft; rarely connected by ridges which show

crescentic transverse grooves. Walls are unornamented and fillings are essentially structureless.

Ichnospecies: - *Margaritichnus reptilis* Bandel, 1967

(Plate 5.1, a-i and Plate 5.4, f-ii)

Diagnosis: - As Ichnogenus

Description: - Small, flattened, sub-spherical structures commonly preserved in convex epirelief and rarely in convex hyporelief. Vertical plugged slightly inclined to the bedding; 5 to 7 mm. in diameter.

Remarks: - In the original interpretation, Bandel (1967) had suggested that *Margaritichnus* represented fecal strings of a sediment-feeding; worm-like organism. Hakes (1976), however, indicated that *Margaritichnus* more closely represents the *Domichnia* of a soft-bodied organism, possibly anemone-like. They associated with trails possibly formed below the surface of sediment (Hantzschel 1975). The overall geometry, the lack of symmetry, and the associated structures (e.g., depressions, tubercles) distinguish *Margarithichnus* from *Bergaueria, Mammillichnis*, and *Conichnus* (Pemberton et. al. 1987).

Occurrence: - It occurs in CSSL and GOs of Jhurio and RMCSSL of Jumara Formations.

Ichnogenus: - *Calycraterion* Karaszewski, 1971

Diagnosis: - Simple plug shaped structures. They are regular calyx shaped depressions. They are 15 to 40 mm in diameter and 5 to 15 mm in depth. Two or three small circular depressions on the bottom representing outlets of filled burrows; they are in 2 to 5 mm in diameter.

Ichnospecies: - *Calycraterion samsonowiczi* Karaszewski, 1971

(Plate 5.1, b)

Diagnosis: - Calyx shaped depressions with funnel shape.

Description: - Concave epirelief; this is a depression with funnel shaped outermost rim. Diameter of entire structure is about 10 mm with 2 to 7 mm depth. Two or three small circular depressions on the bottom representing outlets of filled burrows–almost 5 mm in diameter.

Remarks: - They are mainly associated with *Ophiomorpha*, *Diplocraterion* and *Arenicolites.*

Occurrence: - It occurs in CSSL and GOs of Jhurio and RMCSSL of Jumara Formations.

Ichnospecies: - *Calycraterion isp.* Karaszewski, 1971

(Plate 5.1, c-i)

Diagnosis: - A vertical calyx - shaped depressions

Description: - Concave epirelief, convex hyporelief; smooth inner walls. The traces are preserved along the bedding plane. Diameter ranges in different photographs from 12 to 40 mm with 15 to 20 mm depth.

Remarks: - *Calycraterion isp.* is distinguished from *C. samsonowiczi* by lack of typical funnel shaped structures at the top.

Occurrence: - It occurs in CSSL and GOs of Jhurio and RMCSSL of Jumara Formations.

Ichnogenus: - *Monocraterion* Torell, 1870

Diagnosis: - "Trumpet pipes", funnel structure penetrated by central straight or slightly curved plugged tube, perpendicular to bedding plane, never branched, diameter commonly 5 mm.; long, funnel simple or multiple, diameter of funnels usually 1 to 4 cm.; greatest depth about 2 cm.; tubes commonly abundant but never crowded like *Skolithos*. Funnel obviously constructed by upward migration of animal, inhabiting tube is reflected by downward warping of surrounding bedding planes toward central tube.

Ichnospecies: - *Monocraterion isp.* Torell, 1870

(Plate 5.1, d-i and e-i)

Description: - Vertical, more or less cylindrical shafts having a prominent ridge (collar) like at the periphery of the opening at upper end. Plane view of slab with a specimen possesses a central conical part surrounded by a collar. A positive epichnia, circular scour with resistant burrow consists of vertical to slightly curved cylindrical burrows, which are unbranched and filled with surrounding substrate. They occur as isolated on bedding plane, mostly seen as circular to sub-circular outline on the top surface or in vertical section in form of two dimensional tubes. Burrows oriented normal to steeply inclined to the bedding plane, which very often pass upward into ovate funnel, and downward into curvature with rounded almost horizontally oriented lower ends. Several specimens show funnels with raised rims, which may reflect lining to the funnels. Funnel diameter is variable; shaft diameter varies from 0.5 to 1.0 cm, Funnels vary in height in different burrow population.

Remarks: - *Monocraterion* was frequently found in association with *Skolithos* burrows. This confirms the view of Hallam and Swett (1966) that the difference between the burrows of these two ichnogenera is not due to different trace maker organisms but to different rate of sedimentation. *Skolithos* is formed under conditions of slow sedimentation and *Monocraterion* occurs with conditions of relatively rapid sedimentation. *Monocraterion* is considered to be the dwelling structures of a worm like organisms, possibly a polychaete, for which the tube of *Diapatra cuprea* may be a modern analog (Mayers 1970, Barwis 1985).

Occurrence: - It occurs in CSSL and GOs of Jhurio and RMCSSL of Jumara Formations.

Ichnogenus: - *Laevicyclus* Quenstedt, 1879

Diagnosis: - Approximately cylindrical bodies standing right to bedding plane, diameter variable, perforated by central canal, visible on bedding planes as regular concentric circles with varying diameter.

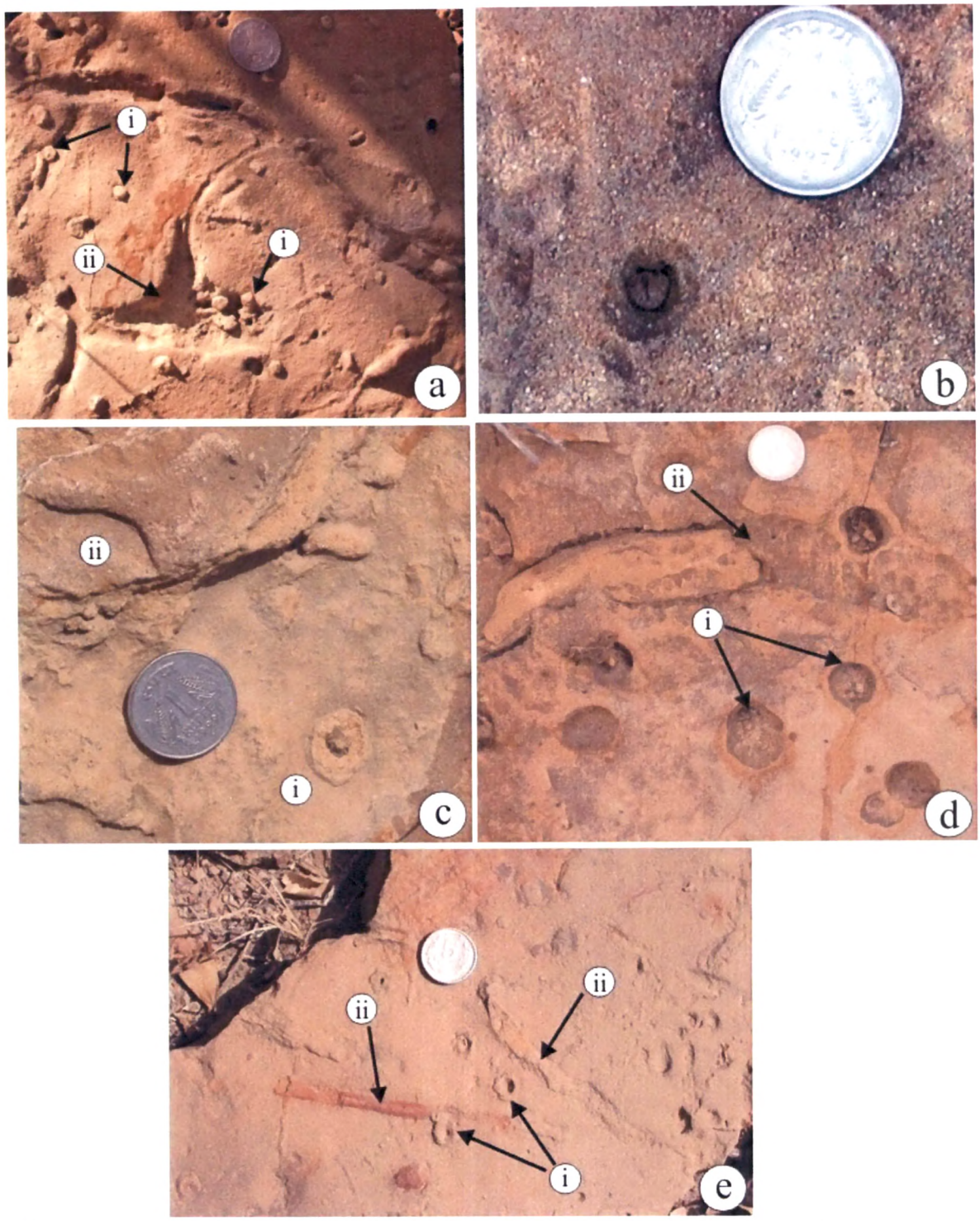


Plate 5.1 a-i) *Margaritichnus reptilis* and ii) *Thalassinoides suevicus,* CSSL, Jhurio Fm. b) *Calycraterion samsonowiczi*, RMCSSL, Jumara Fm. c-i) *Calycraterion isp.* and ii) *Thalassinoides suevicus,* CSSL, Jhurio Fm. d-i) *Monocraterion isp.* and ii) *Ophiomorpha nodosa* RMCSSL, Jumara Fm. e-i) *Monocraterion isp.* and ii) Locomotion trails, CSSL, Jhurio Fm.

Ichnospecies: - *Laevicyclus mongraensis* Chiplonkar and Badve, 1970

(Plate 5.2, a)

Diagnosis: - Approximately cylindrical bodies standing at right angles to the bedding plane perforated by central canal visible of bedding planes as regular concentric circle with diameter of several centimeters.

Description: - Endichinal, full burrow; circular bodies with central shaft and surrounded by concentric rings; maximum outer diameter is about 2 cm; shaft diameter is of 5 mm; visible on bedding planes as regular 1-2 concentric rings. Only the upper part of the burrow is preserved.

Remarks: - *L. mongraensis* is reported from the Cretaceous of Bagh beds (Chiplonkar and Badve, 1970) and Jurassic of the Habo dome (Patel et al., 2008a). However, *L. mongraensis* is also reported from the deep water flysch deposits, and is considered to be circular trace of the suspension feeding animals (Uchman, 1995).

Occurrence: - Their predominant presence was observed in RMCSSL and CSSL of Jumara and Jhurio Formations respectively.

I.2 Circular and Elliptical Structures - Elliptical structure

Ichnogenus: - *Lockeia* James, 1879

Diagnosis: - This ichnospecies is characterized by a greater length range, from relatively small sub spherical forms to large specimens reaching almost 5 cm in length. The ichnogenus *Lockeia* is usually interpreted as a resting trace (cubichnia) and considered the archetypical ichnologic expression of the activity of soft-substrate burrowing bivalves (Seilacher, 1953a; Osgood, 1970; Hantzschel, 1975; Kim, 1994).

Remarks: Lockeia commonly consists of smooth, oval to almond-shaped positive hyporeliefs that lack distinctive morphologic details. This has led to the implicit assumption that *Lockeia* is a simple trace that does not yield any relevant paleoecologic or ethologic information. *Lockeia* morphotypes, however, can be distinguished on the basis of morphologic details and

mode of occurrence, supplying relevant information on the ethology and auto-ecology of the tracemakers (Mangano and Buatois, 1998). The two types of *Lockeia* recognized, *L. ornata* and *L. siliquaria,* are discussed below.

Ichnospecies: - *Lockeia ornata* After Mangano and Buatois, 1998

(Plate 5.2, b-c)

Diagnosis: - Elongated, relatively large almond-shaped structures, whose diagnostic features are delicate, sharp, concentric ridges may be present that resemble growth interruptions in a bivalve shell. In some specimens, the presence of a longitudinal median ridge (carina) suggests the impression of the commissures of the valves. *Lockeia ornata* commonly is connected with chevron, smooth or roughly bilobate locomotion traces, and exhibits a gregarious mode of occurrence, with local patches of high density. Looping, radial, and rosary patterns formed by serial alignment of *Lockeia* are diagnostic of *L. ornata.*

Description: - Bilobate, elongated about 7 to 10 cm long; 2 cm wide and 0.5 mm high, relatively large and well associated with locomotion traces.

Remarks: - Bandel (1967) found *Lockeia* exhibiting similar ornamentation and proposed the ichnospecies *Pelecypodichnus ornatus* (= *Lockeia ornata*). *Lockeia*, the senior synonym of *Pelecypodichnus*, has been used by numerous authors, is well understood, and therefore should be used instead of *Pelecypodichnus* (Mapels and West, 1989). *Lockeia ornata* and associated *Protovirgularia* record dominant horizontal locomotion and suggest the activity of deposit- feeding bivalves.

Occurrence: - It occurs in NWWLs and BLs of Jhurio Formation.

Ichnospecies: - *Lockeia siliquaria* After Mangano and Buatois, 1998

(Plate 5.2, d)

Diagnosis: - *Lockeia siliquaria* is represented by bulbous, oval to almond-shaped structures that occasionally display more irregular outlines. Walls are commonly smooth with no apparent ornamentation. They may occur in clusters of a few individuals or as isolated specimens. This ichnospecies does not intergrade commonly with horizontal locomotion

traces, but can be connected to short, inclined or vertical endichnial shafts. They exhibit high density of structures with shallow epichnial depressions (after Mangano and Buatois, 1998).

Description: - Relatively small, circular to semi-circular, oval to almond-shape, and few individuals or isolated, more or less associated with locomotion traces. They are relatively 2 to 5 cm long; 1 to 2 cm wide and about 0.7 mm in height.

Occurrence: - It occurs in NWWLs and BLs of Jhurio Formation.

Remarks: - Overall morphology and mode of occurrence of these traces agree with the ichnospecies *Lockeia siliquaria* (James, 1879; Seilacher, 1953a), considered a senior synonym of *L. amygdaloidal* by Seilacher and Seilacher (1994), which comprises the majority of *Lockeia* recorded in the literature (e.g., Seilacher, 1953a; Osgood, 1970; Archer and Maples, 1984; Rindsberg, 1994). *L. siliquaria* either represents the dwelling structure of suspension feeders or the fugichnial response to changing environmental conditions, rather than short-lived resting traces (After Mangano and Buatois, 1998).

Two different bivalve life and feeding strategies have been analyzed. Hyporeliefs of *Lockeia siliquaria*, commonly connected with vertical to inclined shafts, represent relatively stable domiciles of filter-feeding bivalves rather than temporary resting traces. Overall morphology and size range of the structures suggest *Wilkingia* as the most likely tracemaker. On the other hand, specimens of the resting trace, *Lockeia ornata* connected to locomotion and locomotion/feeding structures (*Protovirgularia*) record the horizontal wandering activity of a deposit-feeding bivalve. Surficial morphology of *Lockeia ornata* imitates the ornamentation of Phestia, a nuculanid bivalve (After Mangano and Buatois, 1998).

I.3 Simple Structures

I.3.1 Vertical form

Ichnogenus: - *Skolithos* Haldeman, 1840

Diagnosis: - Simple, cylindrical to subcylindral, ordinary pipes, straight tubes or pipes perpendicular to bedding and parallel to each other, unbranched burrows, Burrow wall

distinct or indistinct, smooth or rough, possibly annulated; burrow diameter may vary slightly along its length.

Ichnospecies: - *Skolithos linearis* Haldeman, 1840

(Plate 5.2, e and Plate 5.3, d-ii)

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

Description: - Endichnial, full relief, cylindrical to sub-cylindrical, straight to slightly curved, unornamented, lined burrows of 5-10 mm diameter and observed depth about 7-10 cm. Burrow wall distinct and also appears as small ring-like projection on the top of the bed.

Remarks: - *S. linearis* is a facies crossing species and is found in Jurassic rocks of the Habo dome in central mainland Kachchh (Patel et al., 2008a). It is interpreted to be a domichnion of suspension feeding polychaetes like *Amphinome rostrata* and *Nereis costae* (Desai, 2003; Patel and Desai 2009). *S. verticalis* differs from *S. linearis* in having rough, annulated burrow walls.

Occurrence: - It occurs in GOs of Jhurio Formation.

Ichnospecies: - *Skolithos verticalis* Hall, 1843

(Plate 5.3, a)

Diagnosis: - Burrows vertical, burrow wall distinct or indistinct, smooth or rough, possibly annulated; burrow diameter may vary slightly along its length. Burrow fill structureless.

Description: - Epichnial, full relief, ordinary cylindrical to sub-cylindrical, unbranched pipes or straight tubes parallel to each other. Burrows are vertical, with rough and annulated walls which may be distinct or indistinct. The length varies from 3 to 10 cm with their diameter about 5 to 10 mm. Tubes commonly closely crowded, but also may show widely spaced gradations.

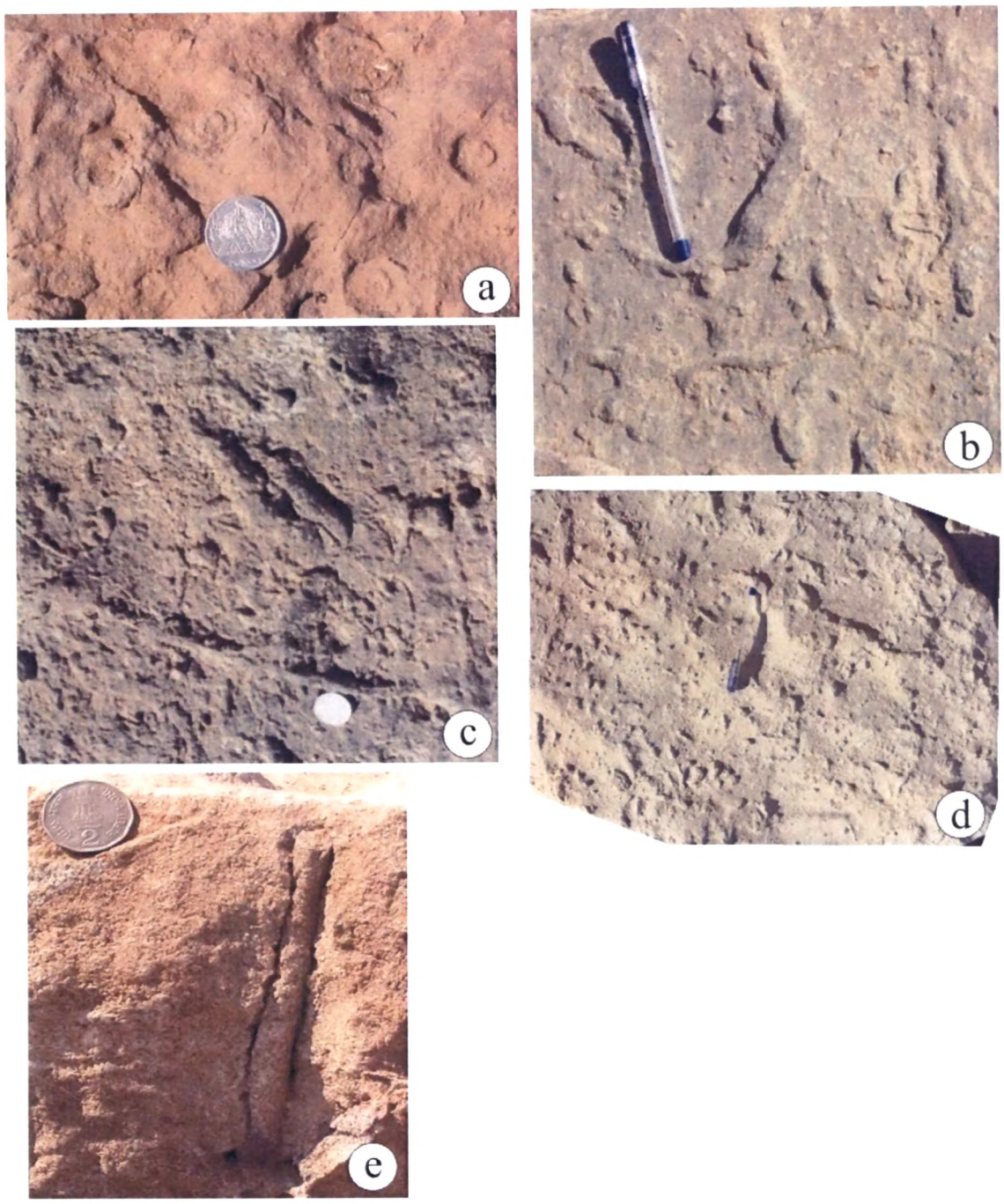


Plate 5.2 a) *Laevicyclus mongraensis*, CSSL, Jhurio Fm. b-c) *Lockeia ornata*, NWWLs, Jhurio Fm. d) *Lockeia siliquaria*, NWWLs, Jhurio Fm. e) *Skolithos linearis*, GOs, Jhurio Fm.

Remarks: - *S. verticalis* differs from *S. linearis* in having rough, annulated burrow walls. Although the diameter is narrow, the present specimens show a wider diameter. *Skolithos* is widely recognised in shallow water, intertidal deposits (Seilacher, 1967) and in various

shallow marine environments (Fillion and Pickerill, 1990; Alpert, 1974) and is thought to be produced probably by annelids or phoronids (Alpert, 1974).

Occurrence: - It occurs in DOs of Jumara Formation.

I.3.2 Plug shaped Form

Ichnogenus: - *Bergaueria* Prantl, 1946

Diagnosis: Cylindrical or buglike protrusive with smooth walls, lower rounded with shallow depressions and circular to elliptical in cross section. Fill essentially structureless.

Ichnospecies: - *Bergaueria isp.*

(Plate 5.3, b)

Diagnosis: As Ichnogenus

Description: - Occurs as epichnial, solitary, knob-like structures. Width of the specimen at the bed junction is about 2 cm, and the depth of the burrow is about 1.5 to 2 cm. The length and diameter are almost equal. The apical region is circular, with the sides of the burrow nearly parallel for 1/3 part of the burrow and later converging in a rounded lower end.

Remarks: - The present specimen differs from *B. prantl* Książkiewicz, 1977 in being circular, while the latter always slopes in one direction. More material is required for attempting to assign it at ichnospecies level.

Occurrence: - It occurs in CSSL of Jhurio and RMCSSL of Jumara Formations.

I.3.3 *U-shaped form*

Ichnogenus: - *Arenicolites* Salters, 1857

Diagnosis: Simple U-tube without spreiten, perpendicular to bedding plane. In the top sectional view it is appear as paired burrows.

Ichnospecies: - *Arenicolites carbonarius* Binney, 1852

(Plate 5.3, c and d-i)

Diagnosis: - Vertical to slightly oblique U-tube without spreiten. Tubes are cylindrical, smooth walled with mud lining or mud-sand filling. U-bend on one limb may show slight vertical or lateral migration but no true spreiten are formed. Dimensions vary in different burrow populations.

Description: - Vertically oriented, U–shaped, endichnial, paired burrows. Burrow diameter is about 2-4 mm and burrow arms are about 11-15 mm apart. Collapse structures are very common but at places burrow fill material is identical to the host sediments. The burrows occur as paired, circular openings on the bedding surface. In vertical view they occur as straight to curved 'U'- shaped tubes.

Remarks: - The burrows are assigned to *Arenicolites isp.*? because of their simple, symmetrical and vertical U-shaped tubes (burrow) without spreite. *Arenicolites* is generally interpreted as domichnion of a suspension-feeding polychaete. Though, Fursich (1974a) has assigned crustaceans as likely producers since scratch marks have never been observed, the studies on the recent intertidal zone of Mandvi (Patel and Desai, 2009) have revealed that suspension feeding polychaetes are undoubtful producers of the trace fossils. *Arenicolites* are interpreted as dwelling structures of suspension-feeding polychaetes.

Occurrence: - It occurs in CSSL and GOs of Jhurio and RMCSSL of Jumara Formations.

I.3.4 *Horizontal form*

Ichnogenus: - *Biformites* Linck, 1949,

Diagnosis: - Bimorphous form, consisting of narrow section, partly divided by longitudinal furrows, continuing into wider section with prominent transverse ribs. It resembles shafted hand grenade.

Ichnospecies: *Biformites isp.* Linck, 1949

(Plate 5.3, e)

Diagnosis: - It is bimorphous with prominent transverse ribs. One of the ends is narrow.

Description: -Preserved either as convex epirelief or full relief, endichnial burrow; these are having two distinct parts – narrower and wider. In the wider part, transverse ribs are distinct. Smooth narrow part is curved. It is preserved on a bedding plane with distinct lining. Diameter of the wider part is about 2 cm and of narrow part is about 6 mm. Total length of the burrow is 4 to 5 cm.

Remarks: - It is considered as dwelling burrow according to Seilacher (1955). They are mainly associated with *Keckia, Palaeophycus, Taenidium and Thalassinoides.*

Occurrence: - It occurs in RMCSSL of Jumara Formation.

Ichnogenus: - *Anchorichnus* Heinberg, 1974

Diagnosis: - Cylidrical, weakly sinuous, sub- to horizontal burrow containing a central meniscate fill and a structures mantle.

Ichospecies: - *Anchorichnus anchorichnus* Heinberg, 1974

(Plate 5.4, a-i)

Diagnosis: - As for Ichnogenus

Description: - Endichnial, full relief, meniscate burrow, inclined to the bedding plane. The menisci are 'V-shaped'. The burrow is characterized by backfill and presence of a mantle. This is demonstrated by the preferred orientation of sediment grain within the mantle resulting in fine striations. Length of the burrow varies and its diameter is about 3 to 5 mm.

Remarks: - *Ancorichnus*, considered to be a monospecific ichnogenus, is characterized by a distinct mantle. The mantle is only partly preserved in most specimens. The burrow is interpreted to be made in shifting sand by small juvenile crustaceans for dwelling purpose.

Occurrence: - It occurs in NWWLs and GOs of Jhurio and RMCSSL of Jumara Formations.

Plate 5.3 a) *Skolithos verticalis*, DOs, Jhurio Fm. b) *Bergaueria isp.*, RMCSSL, Jumara Fm. c) *Arenicolites carbonarius*, CSSL, Jhurio Fm. d-i) *Arenicolites carbonarius* and ii) *Skolithos linearis* RMCSSL, Jumara Fm. e) *Biformites isp.*, RMCSSL, Jumara Fm.

Ichnogenus: - *Palaeophycus* Hall 1847, Pemberton and Frey 1982.

Diagnosis: Cylindrical or subcylindrical burrows, usually sinuous, oriented more or less obliquely to bedding. Commonly unbranched, though may be branched occasionally. Surface of walls smooth or rarely with faint longitudinal striae. *Palaeophycus* is distinguished from *Planolites* by having a distinct wall lining and sediment fill typically same as the lithology of the host rock.

Ichnospecies: - *Palaeophycus annulatus* Badve, 1987

(Plate 5.4, b)

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 borrow.

Description: - Hypichnial and endichnial, full relief, slightly curved, thinly lined burrows of varying dimensions, in place distinctly annulated. Back fill identical to surrounding sediments. Length varies from 2 to 3 cm and diameter of tube is ~ 3-5 mm.

Remarks: - *Palaeophycus* has been interpreted as a crawling trace by Osgood (1970). The trace fossil is named as *P. annulatus*, though Buckman, (1995) considered the ichnospecies as *Nomia dubia*, and doubted its taxonomic position. The characteristic annulations occuring on the tubes supports its recognition as *P. annulatus* (Badve, 1987). The specimen differs from the type specimen of Badve, 1987 in ornamentation of annulated rings, regular and widely spaced, unlike the type specimen, which shows annulations of swelling types. These feeding structures seem to be associated with horizons rich in organic matter. Such horizons may have served as a food source attractive to the deposit feeding trace-maker organisms.

Occurrence: - It occurs in NWWLs; CSSL and GOs of Jhurio and RMCSSL and DOs of Jumara Formations.

Ichnospecies: - *Palaeophycus heberti* Saporta, 1872

(Plate 5.4, c-d and Plate 5.21, b-ii)

Diagnosis: Relatively small, smooth, unbranched, thickly lined cylindrical burrows.

Description: - Smooth, thickly lined, unornamented, slightly curved, epichnial burrows. Diameter constant in a specimen, ranging from 1 to 2 cm. Length varies from 2.5 to 6 cm though no complete specimen is preserved. Burrow fill structureless and identical to the host rock. Thick wall of the burrow can be seen along with smooth burrow fill inside, exposed due to differential weathering.

Remarks: - This species is distinguished from other species of *Palaeophycus* by its thick wall lining.

Occurrence: - It occurs in NWWLs; CSSL and GOs of Jhurio and RMCSSL of Jumara Formations.

Ichnospecies: - *Palaeophycus striatus* Hall, 1852

(Plate 5.4, e and f-i)

Diagnosis: Thinly lined burrows sculpted by continuous line of parallel striae.

Description: - Full, convex, hyporelief, horizontal, slightly curved, unbranched, distinctly lined, long burrow, about 5 mm in diameter with fine continuous, parallel longitudinal striae. Burrow fill massive, structureless and identical to the host rock. Burrow lining is thin.

Remarks: - The fine, continuous, parallel longitudinal striae are characteristic of *P. striatus* species and are considered to be the work of polychaetes (Pemberton and Frey, 1982). The striae are interpreted to be produced by organism's setae or bristles as a result of animal movement (Schlirf, 2000).

Occurrence: - It occurs in NWWLs; CSSL and GOs of Jhurio and RMCSSL of Jumara Formations.

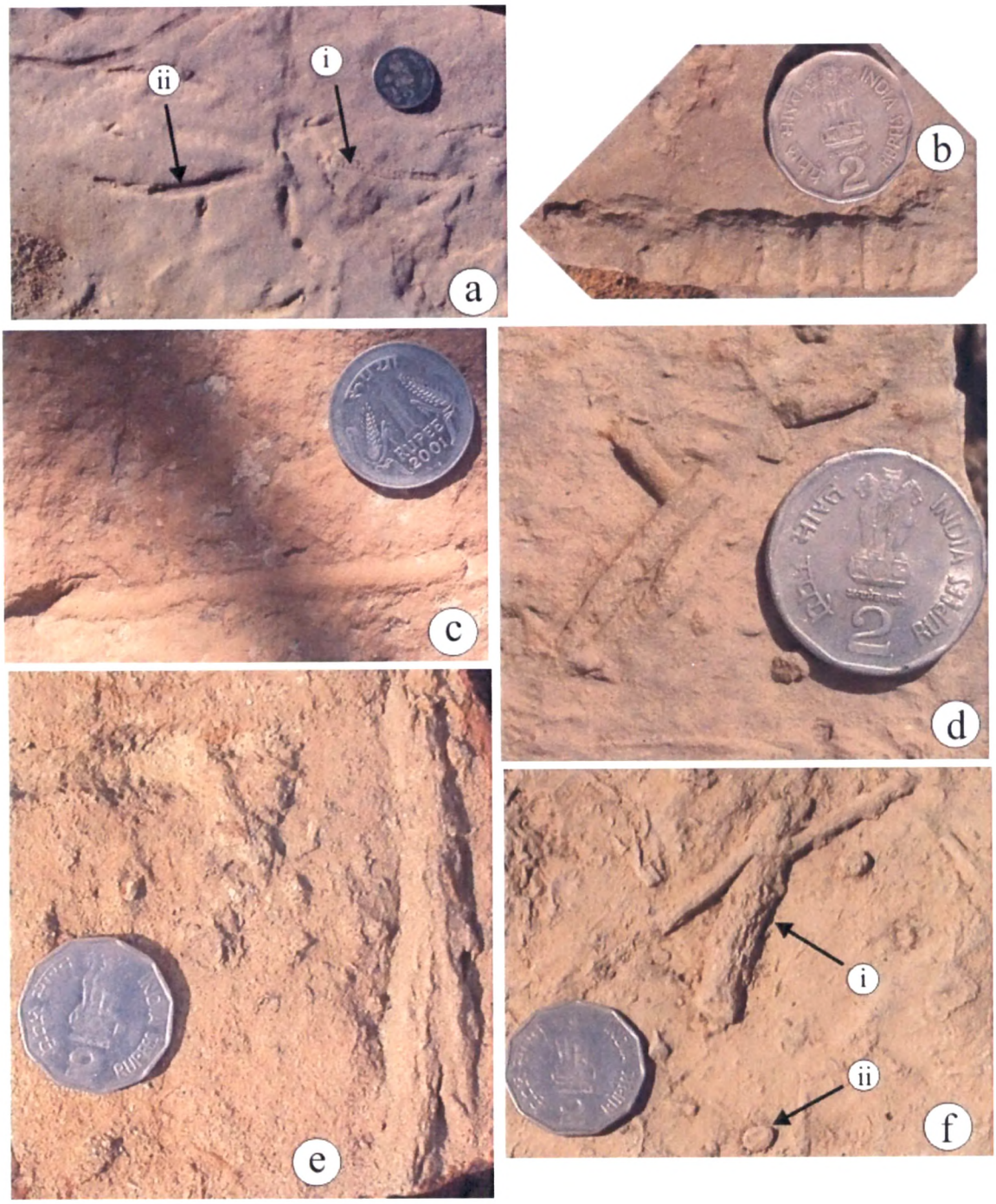


Plate 5.4 a-i) *Ancorichnus ancorichnus* and ii) *Planolites isp.* NWWLs, Jhurio Fm. b) *Palaeophycus annulatus*, RMCSSL, Jumara Fm. c) *Palaeophycus heberti*, GOs, Jhurio Fm. d) *Palaeophycus heberti*, CSSL, Jhurio Fm. e) *Palaeophycus striatus*, GOs, Jhurio Fm. f-i) *Palaeophycus striatus* and ii) *Margaritichnus reptilis* CSSL, Jhurio Fm.

Ichnospecies: - *Palaeophycus tubularis* Hall, 1852

(Plate 5.5, a-b)

Diagnosis: Straight to slightly curved or more or less smooth-walled unornamented burrows variable, thinly but distinctly lined.

Description: - Long, horizontal, smooth, curved to straight, unbranched, unornamented, lined burrow, 4 to 9 mm in diameter; filled with the same sediment as the host rock. Diameter of the burrow is constant throughout the length of burrow.

Remarks: - The form is classified as *P. tubularis* on account of the horizontal, smooth, straight, long and unbranched burrows with distinct lining. The distinction between *Palaeophycus, Planolites* and *Macaronichnus* is partially controversial (Pemberton and Frey 1982; Fillion 1989, Fillion and Pickerill, 1990). *Palaeophycus* is a eurybenthic, facies-crossing form, produced probably by polychaetes or annelids (Pemberton and Frey, 1982).

Occurrence: - It occurs in NWWLs; CSSL and GOs of Jhurio and RMCSSL of Jumara Formations.

Ichnogenus: - *Planolites* Nicholson, 1873

Diagnosis: Unlined, rarely line, rarely branched, straight to tortuous, smooth to irregularly walled or annulated burrows, circular to elliptical in cross-section, of variable dimensions and configurations: fill essentially structureless, differing in lithology from host rock (after Pemberton and Frey 1982 and Fillion and Pickrill, 1990).

Ichnospecies: - *Planolites annularis* Walcott, 1890

(Plate 5.5, c-d)

Diagnosis: - Distinctly annulated, sub-cylindrical burrows.

Description: - Horizontal, straight to sinuous or undulose, semicircular burrows exhibiting prominent transverse annulations. Annulations are of almost equal size, pattern and regular spacing. Burrows tend to be of almost constant diameter.

Remarks: - The distinct annulations distinguish this species from *P. beverleyensis* and *P. montanus*. Annulations possibly reflect the peristaltic movements of the trace maker.

Occurrence: - It occurs in NWWLs; CSSL and GOs of Jhurio and RMCSSL of Jumara Formations.

Ichnospecies: - *Planolites beverleyensis* Billings, 1862

(Plate 5.5, e)

Diagnosis: Relatively large, smooth to sometimes irregularly walled, essentially cylindrical burrows, straight to gently curve or undulant (Frey and Howard 1990).

Description: - Predominantly cylindrical, smooth walled, unlined, straight to gently curved, unbranched to rarely irregularly branched burrow, oriented more or less parallel to bedding plane (Pemberton and Frey, 1982). Rare specimens display discontinuous, poorly developed annulations. Burrow occurs as a single isolated specimen to crowded masses, in which cross over, interpenetrations are common. Dimensions vary in different burrow population. Length of the burrow varies from 4 to 8 cm and diameter from 0.15 to 0.5 cm. Preserved as hypichnial, epichnial and endichnial ridges.

Remarks: - The observed burrows are exceptionally long and usually lack burrow wall or burrow lining. *Planolites* is generally regarded as the *Fodinichnia / Pascichnia*, product of vermiform deposit feeders actively of back-filling its burrow (Uchman, 1995).

Occurrence: - It occurs in NWWLs; CSSL and GOs of Jhurio and RMCSSL Jumara Formations.

Ichnospecies: - *Planolites montanus* Richter, 1937

(Plate 5.5, f)

Diagnosis: - Small, smooth-walled rarely branched, typically curved to undulant or contorted burrows (Frey and Howard 1990).

Description: - Irregular, cylindrical, curved, sinuous, small horizontal burrows oblique or variably oriented to the bedding plane. The burrow diameters are between 6 to 12 mm and length is ~30-50 mm.

Remarks: - The small size and tortuous appearance of the species differentiates it from *P. beverleyensis* and *P. annularis*. *P. montanus* is generally interpreted as an actively filled burrow of a deposit feeder (Uchman, 1995).

Occurrence: - It occurs in NWWLs; GOs and CSSL of Jhurio and RMCSSL of Jumara Formations.

Ichnospecies: - *Planolite isp.*

(Plate 5.4, a-ii and Plate 5.5, g)

Description: - Straight, very small, unlined, branching is absent, differing in lithology from host rock. Endichnial full burrow, very small, different filling material, straight having no wall and branching. It's about 0.1-0.3 mm wide and 0.5 to 3 cm long.

Remarks: - They are very distinct, not curved which differentiate them from *P.montanus*.

Occurrence: - It occurs in CSSL and GOs of Jhurio and RMCSSL of Jumara Formations.

Ichnogenus: - *Sabularia* Ksiazkiewicz, 1977

Diagnosis: - Horizontal, oblique or vertical, cylindrical full burrows, straight of feebly curved, rarely ramified simple burrow. Burrows are filled with sand or silt, coarser material than host rock.

Ichnospecies: - *Sabularia ramose* Ksiazkiewicz, 1977

(Plate 5.6, a)

Diagnosis: - Hypichnial, more rarely exichnial, cylindrical full burrows of somewhat irregular course, with few ramifications at obtuse angles (Ksiazkiewicz, 1977).

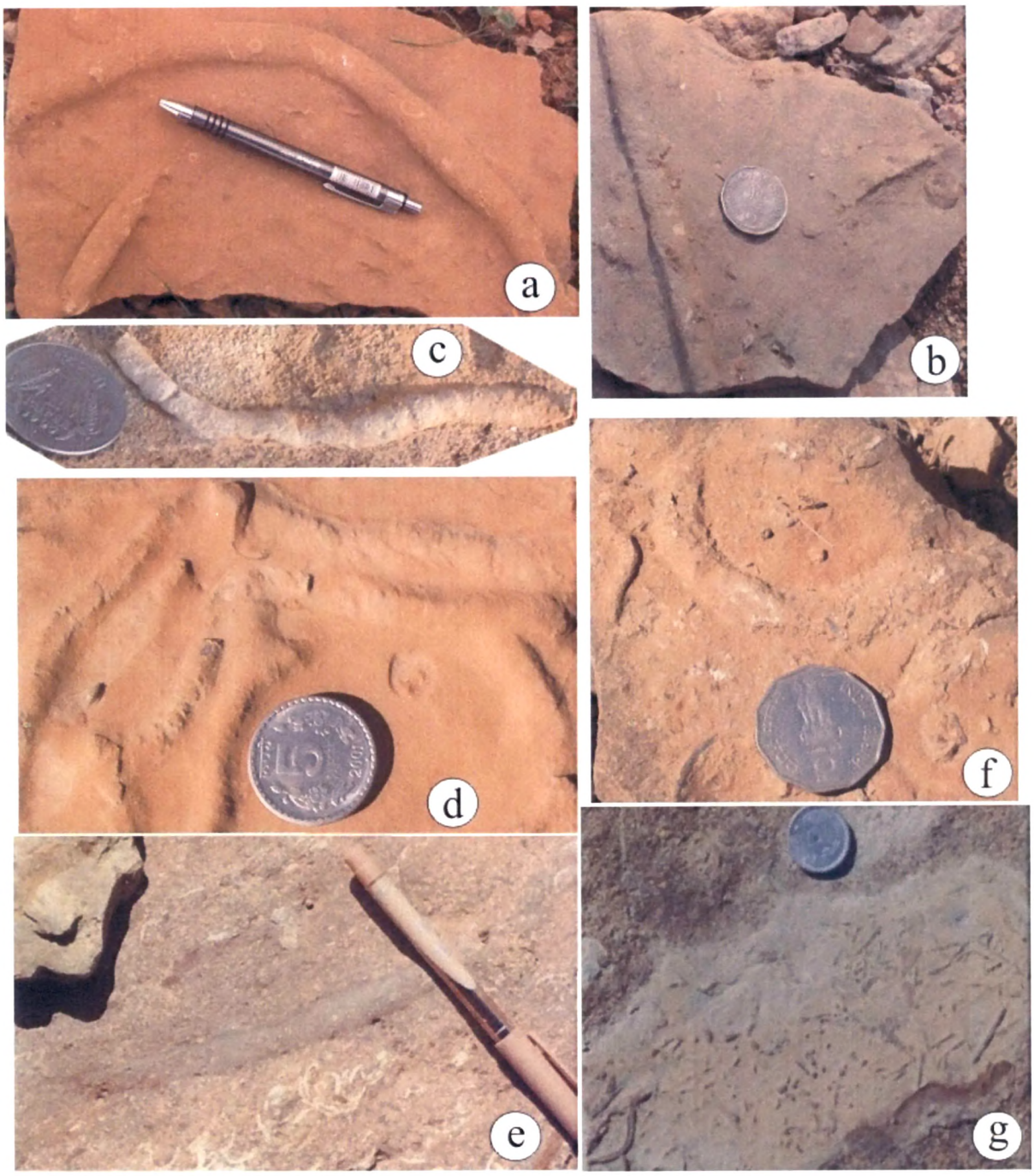


Plate 5.5 a) *Palaeophycus tubularis*, RMCSSL, Jumara Fm. b) *Palaeophycus tubularis*, CSSL, Jhurio Fm. c) *Planolites annularis*, RMCSSL, Jumara Fm. d) *Planolites annularis*, GOs, Jhurio Fm. e) *Planolites beverleyensis*, GOs, Jhurio Fm. f) *Planolites montanus*, GOs, Jhurio Fm. g) *Planolites isp.*, CSSL, Jhurio Fm.

Description: - The burrows are straight, cylindrical, slightly flattened, about 5 to 6 mm wide and 5 mm high. Most of the burrows do not enter the rock but are affixed to the sole. There are few ramifications, but many level crossings and interpenetrations. Burrows are filled with coarser silty material than host rock. Their course is somewhat irregular and curved.

Remarks: - In comparison with other species like *S. rudis, S. tenuis* and *S. simplex, S. ramose* having characteristic ramifications.

Occurrence: - It occurs in CSSL and GOs of Jhurio and RMCSSL of Jumara Formations.

1.4 Branched Structures

I.4.1 Dichotomously branched forms

Ichnogenus: - *Chondrites* von Sternberg, 1833

Diagnosis: - Regularly branching tunnel systems without wall, consisting of a small number of master shafts open to the surface which ramify at depth to form a dendritic network (After Osgood, 1970)

Ichnospecies: - *Chondrites intricatus* Brongniart, 1828
(Plate 5.6, b and c-i)

Diagnosis: - Small *Chondrites* composed of numerous downward radiating, mostly straight branches. The angle of the branches is usually less than 45^0. The branches are less than 2.0 mm wide. The burrow system is more than 20 mm wide.

Description: - Endichinal, full relief specimen having tree-like branching, downward penetrating, and markedly flattened tunnels. Width of tunnels, about 1-2 mm, is constant in all specimens. Angle of branching is less than 45^0 in all specimens. The specimens show one master shaft (Plate 5.6, b).

Remarks: - *Chondrites intricatus* is characterized by the fine branches and acute angle of branching. Fu (1991) mentioned a variety of organisms as possible producer of *Chondrites*:

sipunculids, polychaetes, arthropods, bivalves, or natulaceans and considered worms to be the most likely producers.

Occurrence: - It occurs in GOs; NWWLs; and CSSL of Jhurio and RMCSSL and DOs of Jumara Formations.

Ichnospecies: - *Chondrites patulus* Fischer-Ooster, 1858

(Plate 5.6, d-i and e)

Diagnosis: - Small *Chondrites* system with simple branches, which emanate concordantly at an obtuse angle from the main stem (Fursich, 1991)

Description: - Endichinal, full relief, horizontal to sub horizontal tunnels with simple branches, having diameter of about 0.2 to 0.3 mm. The diameter of the tunnels remains constant throughout. The specimens also show main branching at an obtuse angle with dominant second order branching and less prominent third order branching. The tunnels are filled with the host material.

Remarks: - *C. patulus* differs from *C. intricatus* in obtuse angle and up to third order of branching. The trace fossils occur as extensively bioturbated sandstone in which the overlying material has filled the tunnels, suggesting that the burrow might have remained open for long after it was vacated by the organism. Similar open burrows are also found in the recent intertidal zone of the Kachchh coastal plains (Patel and Desai, 2009).

Occurrence: - It occurs in GOs; NWWLs and CSSL of Jhurio and RMCSSL and DOs of Jumara Formations.

Ichnospecies: - *Chondrites recurvus* Brongniart, 1823

(Plate 5.6, f)

Diagnosis: - *Chondrites* in which branches arise only on one side of the master-branch and which are all bent in one direction in a lyre-shape into two, bilaterally opposed directions. There is commonly one or two orders of branching are present (after Uchman 1999).

Description: - Endichnial, horizontal, branched tunnels. The second-order branches arise from the convex side of a strongly curved first-order master-branch. Short, third-order and second-order branches are also present. The second order branches are 20-30 mm long where third order branches are just 2-5 mm long. All tunnels are about 1-3 mm wide without filling.

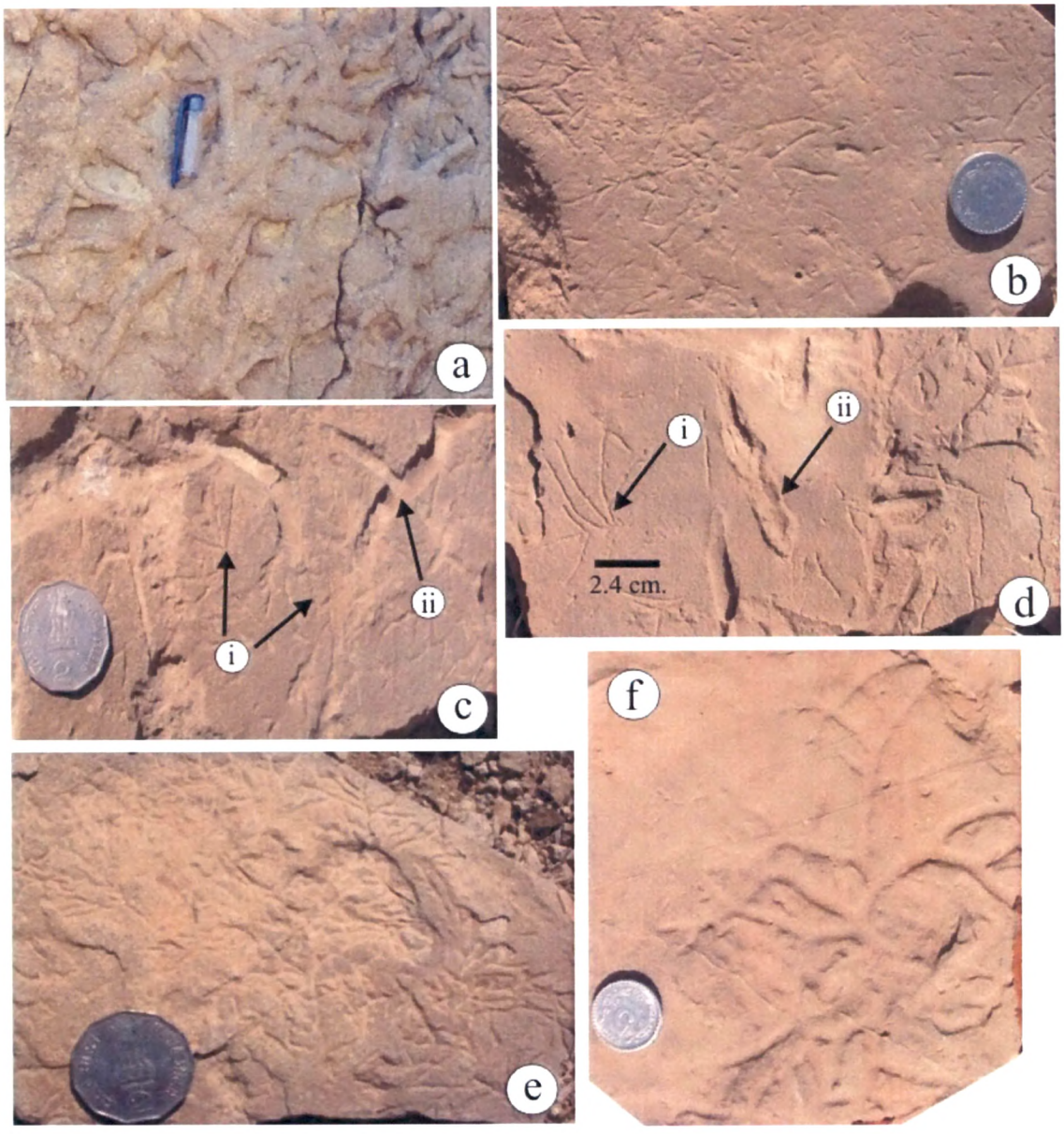


Plate 5.6 a) *Sabularia ramose*, CSSL, Jhurio Fm. b) *Chondrites intricatus*, GOs, Jhurio Fm. c-i) *Chondrites intricatus* and ii) *Thalassinoides suevicus* CSSL, Jhurio Fm. d-i) *Chondrites patulus* and ii) Biogenic groove, RMCSSL, Jumara Fm. e) *Chondrites patulus*, CSSL, Jhurio Fm. f) *Chondrites recurvus*, GOs, Jhurio Fm.

Remarks: - *Chondrites* is a feeding system of unknown trace makers related to infaunal deposit-feeder (e.g. Osgood 1970). *Chondrites* occur from the Tommotian (Crimes 1987) to the Holocene (e.g. Werner and Wetzel 1981).

Occurrence: - It occurs in CSSL and GOs of Jhurio and RMCSSL of Jumara Formation.

Ichnospecies: - *Chondrites targionii* Brongniart, 1828

(Plate 5.7, a-e)

Diagnosis: - The species is characterised by well expressed primary successive branching, which are commonly slightly curved. The angle of branching is usually sharp. Most of the tunnels are a few millimetre wide, thick and stout.

Description: - Endichnial, tree-like branched tunnel system with slightly sinuous branches. The specimens show slightly winding, negative epirelief, dominated by second order branching at an angle of 50^0 to 60^0. Tunnel width varies from 3-7 mm. Tunnels are filled with same or different sediment than the host rock.

Remarks: - The specimen differs from the earlier described forms in the stout tunnels of the *C. targionii* specimen. 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.

Occurrence: - It occurs in CSSL; NWWLs and GOs of Jhurio Formation.

Ichnospecies: - *Chondrites isp.*

(Plate 5.7, f-g)

Diagnosis: - regular thick curved branching in pair bilaterally opposed with equidistance without main stem.

Description: - Thick, branched tunnel system filled with material darker than the host rock. The branches emanate alternately from the main stem. The tunnels are slightly curved or sinuous. Width of the tunnels varies from 7-9 mm but is almost constant in one specimen.

Remarks: - The specimens differ from the other assigned species in the alternate mode of branching pattern and thick, stout branches. Further study of more specimens is required to assign it a specific name.

Occurrence: - It occurs in GOs of Jhurio and DOs of Jumara Formations.

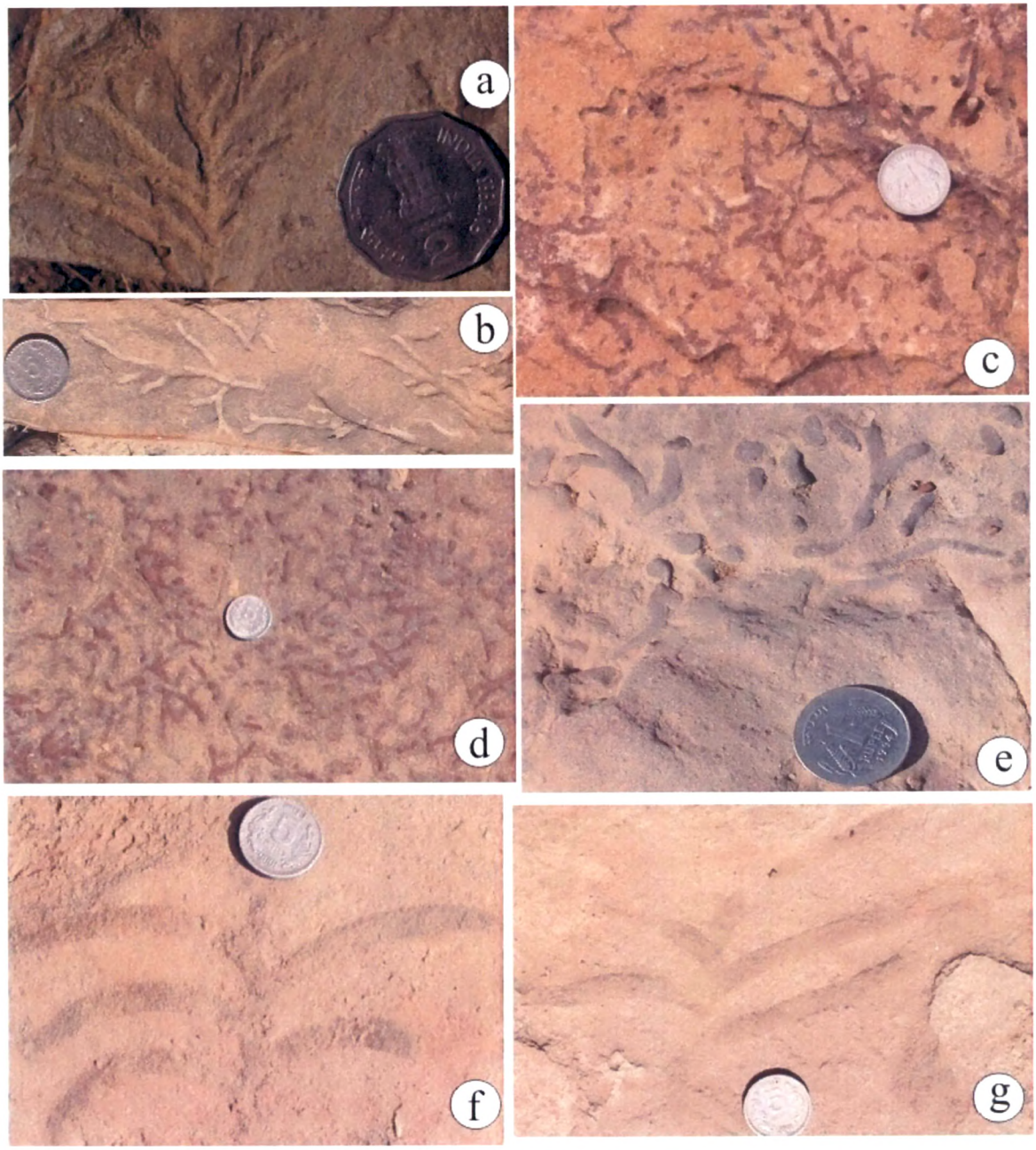


Plate 5.7 a) *Chondrites targionii*, CSSL, Jhurio Fm. b) *Chondrites targionii*, GOs, Jhurio Fm. c) *Chondrites targionii*, CSSL, Jhurio Fm. d) *Chondrites targionii*, RMCSSL, Jumara Fm. e) *Chondrites targionii*, CSSL, Jhurio Fm. f) *Chondrites isp.*, GOs, Jhurio Fm. g) *Chondrites isp.*, GOs, Jhurio Fm.

Ichnogenus: - *Pilichnus* Uchman, 1999

Diagnosis: System of horizontal, straight, curved to irregular winding, very thin sub-millimetric strings showing commonly dichotomous branches (Uchman 1999).

Ichnospecies: - *Pilichnus dichotomus* Uchman, 1999
(Plate 5.8, a-b and Plate 5.16, a-ii)

Diagnosis: - As Ichnogenus

Description: - Horizontal, curved to irregularly winding, branched strings without wall. The branches are 1-2 mm wide and are filled with the same substrate as the host rock. Y and T-shaped branching is common where Y-shaped branches are commonest and very characteristic.

Remarks: - *Pilichnus*, typified by *P. dichotomous,* is much thinner than other small, tubular trace fossils, such as *Palaeophycos* and *Planolites,* which in addition do not display the characteristic dichotomous branches (Uchman,1999). *P. dichotomous,* when crowded, appears as irregular nets. *P. dichotomous* occurs in a very deep tier below the *Chondrites* tier (Uchman 1999).

Occurrence: - It occurs in CSSL and GOs of Jhurio and CSSL and RMCSSL of Jumara Formations.

1.4.2 Y- T shaped forms

Ichnogenus: - *Ophiomorpha* Lundgren, 1891

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

Ichnospecies: - *Ophiomorpha nodosa* Lundgren, 1891

(Plate 5.1, d-ii and Plate 5.8, c-f)

Diagnosis: Three-dimensional burrow systems, vertical and horizontal cylindrical tunnels, generally at acute angles; with local swellings. Burrow walls consisting predominantly of dense, regularly distributed, discoid, ovoid, or irregular-polygonal pellets (after Frey et al. 1978), internal wall smooth.

Description: - Vertical to oblique shaft passing to horizontal networks, horizontally branched as T and Y pelleted lining, three dimensional, sinuous burrow system, 15-25 mm in diameter. Outer wall covered with predominantly dense, regularly distributed discoid, ovoid, or irregular polygonal pellets (Frey et al., 1987). The knobs give a nodular appearance to the tubes. Burrow displays Y-shaped branching of second order, with the angle ranging from 90^0 to 100^0. Occasionally it also displays irregular box-work form.

Remarks: - The analogous relationship of the modern burrow of stomatopodean crustaceans especially *Oratosquilla striata* has been documented by Patel and Desai (2001, 2009) and *Callianassid major* by Weimer and Hoyt (1964). This burrow is interpreted to be the dwelling structure of the suspension feeding crustaceans of the shallow marine environments and ranges from Permian to Recent (Frey et al., 1978). The *Ophiomorpha* burrows described here are assigned to ichnogenus *O. nodosa* based on the predominant single-pellet mode of wall formation (Frey et al., 1987).

The burrows in *Ophiomorpha nodosa* shafts undoubtedly were constructed to support dwelling/feeding activity; possibly the shaft wall material was used by the secondary burrower as a food source. A precise taxonomic assignment for the wall burrower also is not possible, but small polychaetes or similar vermiform animals would seem to be the mostly likely trace-makers. In Mesozoic-Cenozoic sediments, *Ophiomorpha* is produced mainly by shrimps comparable to recent callianassids (Weimer and Hoyt, 1964; Frey et al., 1978). In addition, other organisms such as arthropods produce structures related to *Ophiomorpha* (Frey et al., 1978). Callianassids are partly suspension, partly deposit feeders (e.g. Pryor, 1975; Bromley, 1990). *Ophiomorpha* occurs predominately in beach; shallow-water near-shore upper shoreface deposits (Weimar and Hoyt, 1964; Frey et al., 1978; Bromley and Gerard 2008), but has also been reported, since the Mesozoic (Bottjer et al., 1987), from

deep-sea deposits (Kern and Warme, 1974; Crimes, 1977; Crimes at al., 1981; Uchman 1988, 1989, 1990a, b, 1995).

Occurrence: - It occurs in GOs and BLs of Jhurio and DOs and RMCSSL of Jumara Formations.

Ichnospecies: - *Ophiomorpha recta* Rischer-Ooster 1858

(Plate 5.8, g)

Diagnosis: - Mostly horizontal, rarely branched, sinuous to winding Ophiomorpha lined with small to medium size muddy pellets (Uchman 1999)

Description: - Horizontal to oblique, flattened tube which is 2 cm wide with simple lining. The interior of the tube (burrow) is lined with small, elongate to circular mud pellets, which are 0.6 to 2 mm long.

Remarks: - This trace fossil was described under different ichnogeneric names, Ksiazkiewicz (1977) noticed similarity of the discussed trace fossil to *Ophiomorpha*, but he designated the new ichnogenus *Tublichnium* (after Uchman 1999). This species has very identical feature of mud pellets within lining which distinguished from *O. nodosa* and *O. annulata.*

Occurrence: - It occurs in GOs of Jhurio Formation.

Ichnogenus: - *Thalassinoides* Ehrenberg 1944

Diagnosis: - Cylindrical burrows forming three dimensional branching systems consisting of horizontal network connected to surface by more or less vertical shaft. Regularly branching Y to T-shaped bifurcations in horizontal system forming polygons typical swelling at points of branching with smooth walled.

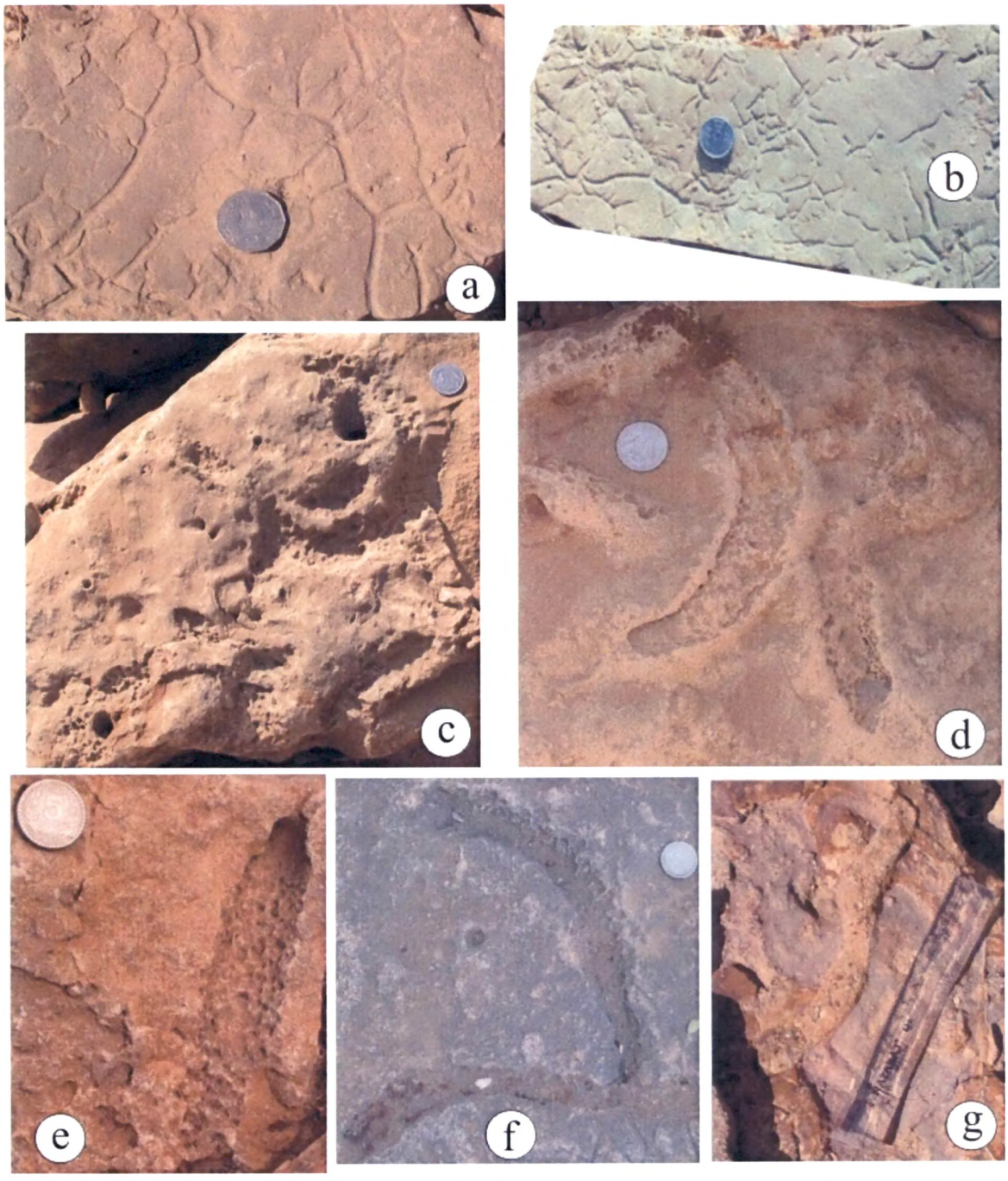


Plate 5.8 a) *Pilichnus dichotomus*, GOs, Jhurio Fm. b) *Pilichnus dichotomus*, CSSL, Jhurio Fm. c-d) *Ophiomorpha nodosa*, GOs, Jhurio Fm. e) *Ophiomorpha nodosa*, RMCSSL, Jumara Fm. f) *Ophiomorpha nodosa*, NWWLs, Jhurio Fm. g) *Ophiomorpha recta*, GOs, Jhurio Fm.

Ichnospecies: - *Thalassinoides horizontalis* Myrow, 1995

(Plate 5.9, a-e and Plate 5.15, b-ii)

Diagnosis: - Predominately horizontal, cylindrical more or less regularly branched, unlined burrow system with smooth wall. The diagnostic characteristic are (1) an entire bedding parallel oriented network, (2) absence of vertical oriented offshoots from polygon framework (3) diameter of the both inner and outer burrow wall is constant within the specimen, including lack of swellings at the junctions (Mayrow, 1995). (4) Horizontal burrow system viewing either Y or T shaped branching.

Description: - Smooth, unlined, three dimensional horizontal burrow system showing Y/T shaped branching. Tunnels are straight to curve and 20-35 mm in diameter. Burrows are chiefly consisting of horizontal tunnels that bifurcate at an angle of 80^0-130^0. Length varies from 10 to 25 cm. Some of the burrow walls show scratch marks. Its diagnostic features are: an entire bedding parallel oriented network, absence of vertical oriented offshoots from polygon framework and constant diameter of the both inner and outer burrow walls within the specimen.

Remarks: - The specimens differ from the type material of Myrow (1995) only in diameter. *T. horizontalis* resembles *T. bacae* but differs from it in entirely lacking the presence of vertical shafts. *T. horizontalis* from the Kachchh is robust and often occurs on the ripple marked ferruginous sandstone as -ve epirelief, suggesting it to be a deep tier trace of the overlying sediments. In many cases it was also observed to be formed at the under-surface of the shell concentrated beds. Some of the scratch marks on the burrow surface indicate its trace makers to be crustacean decapods. It differs from other ichnospecies in lacking the vertical component. Although the diameter of the burrow as suggested by Myrow (1995) is one of the prime factors in distinguishing the ichnospecies, in the present case, other morphological features strongly suggest it to be *T. horizontalis*.

Occurrence: - It occurs in NWWLs; GOs; and BLs of Jhurio and RMCSSL of Jumara Formations.

Ichnospecies: - *Thalassinoides paradoxicus* Kennedy, 1967

(Plate 5.9, f)

Diagnosis: - A burrow system consisting of smooth-walled essentially cylindrical. Branches are irregular and typically enlarged at points of bifurcation. Burrow dimensions variable within a given system.

Description: - Burrow system irregular, branched and spread on the bedding plane. Bifurcation is common within short distances and burrows show swelling/enlargement at the points of bifurcation. Burrow diameter ranges from 3 cm to 6-7 cm at the point of bifurcation.

Remarks: - This ichnospecies is characterized by its more or less H-shaped branching and enlargement at the point of bifurcation.

Occurrence: - It occurs in NWWLs; GOs and BLs of Jhurio and DOs of Jumara Formations.

Ichnospecies: - *Thalassinoides suevicus* Rieth 1932

(Plate 5.10, a-c and Plate 5.21.a)

Diagnosis: - Predominantly horizontal to slightly inclined, more or less regularly branched, essentially cylindrical burrow system consisting of horizontal network connected to surface by more or less vertical shaft; dichotomous bifurcations are more common than T-shaped branches (after Howard and Frey 1984). Burrows form three dimensional branching systems. Y-shaped bifurcations in horizontal system is forming polygons, typical swelling at points of branching or else where.

Description: - Endichnial, full relief, horizontal to slightly oblique three-dimensional burrow system, varying from 12 cm to 2 cm in length and from 3.5 to 0.5 cm in width. More or less regularly branched, connected to surface by more or less vertical shaft; dichotomous bifurcations are more common than T-shaped branches (Howard and Frey 1984). The burrows fill differently as the colour, texture differ in the surrounding. Convex back fill is rare. Often, the burrows form large networks seen as positive hyporelief. The smaller type species has three-dimensional network, horizontal parts of the burrow often are curved on bedding planes, the bends representing points where burrows branch in the third dimension.

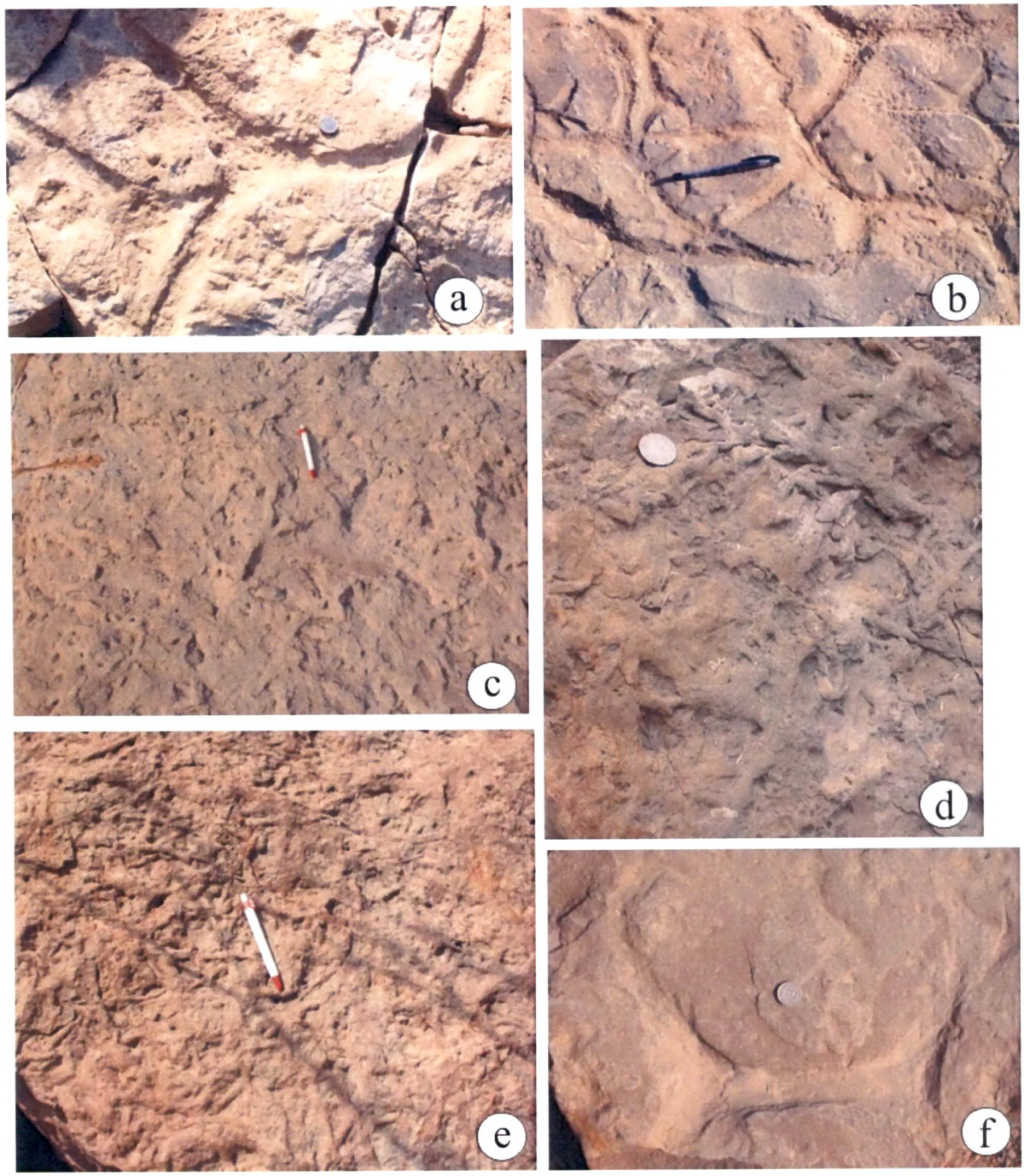


Plate 5.9 a-b) *Thalassinoides horizontalis*, NWWLs, Jhurio Fm. c) *Thalassinoides horizontalis*, DOs, Jhurio Fm. d-e) *Thalassinoides horizontalis*, GOs, Jhurio Fm. f) *Thalassinoides paradoxicus*, GOs, Jhurio Fm.

Remarks: - *Thalassinoides* is a facies-crossing form, most typical of shallow-marine environment, and is produced mainly by crustaceans (Frey et al. 1984). 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 sueivicus* is fairly ubiquitous in the Kachchh Basin occurring from nearshore settings down to the centre of the basin (Fursich, 1998). *Thalassinoides* is occurs with other facies crossing form *Chondrites* which mark the fluctuation of sea level in shallow water environment.

Occurrence: - It occurs in NWWLs; GOs and BLs of Jhurio and DOs of Jumara Formations.

Ichnospecies: - *Thalassinoides foedus* Mikulas 1990

(Plate 5.10, d)

Diagnosis: - Horizontal network of tunnels forming closed pentagonal and hexagonal meshes. Tunnels are of constant diameter with smooth surface and Y – branching regular tunnel system.

Description: - Endichnial, full relief tunnels forming horizontal more or less regular reticulations. Bifurcation of burrows Y – shaped. Single polygons are either hexahedral and regular in outline or pentagonal to septahedral and irregular in outline. Size of polygon is 15 to 17 cm and single hexagonal (benzene) form is well preserved. The species has exposed an angle of constant 120^0 branching of burrow system.

Remarks: - Regular structure, horizontal course and especially invariable diameter of the passages without a signs of widening are all features separating *T. foedus* from Mesozoic ichnospecies. These taxa have been described by Frey and Bromley (1985) and Viyalov (1966). The traces described above are generally like the ichnogenera *Paleodictyon, Meneghini* or *Protopaleodictyon* Ksiazkiewicz, but attain large size and sometimes have a more diversified surface. For this reason they are assigned to the ichnogenus *Thalassinoides* Ehrenberg described form Palaeozoic especially by Sheehan and Schieffelbenin (1984), Bottjer et al. (1984), and Gutschick and Rodriguex (1975) (after Mikulas 1990).

Occurrence: - It occurs in GOs and CSSL of Jhurio Formation.

I.4.3 Bundled forms

Ichnogenus: - *Phycodes* Richter, 1850

Diagnosis: - System of arched, palmately to laterally branching tunnels. Places of branching are well-defined, and the individual limbs are horizontal to incline. Bundled structures of flabellate or broom-like pattern, consisting of horizontal to slightly inclined tunnels; proximal part of the main tunnels unbranched, distal tunnels divide at acrute angles into several free cylindrical tunnels showing delicate annulations beneath thin smooth bark; main branches may show structure similar to retrusive spreiten; preserved as hyporelief as well as epirelief.

Ichnospecies: - *Phycodes circinnatum* Richter, 1853

(Plate 5.10, e)

Diagnosis: - Bundle structures of flabellate or broom like pattern, consisting of horizontal tunnels. Main tunnel is divided at different angles (20^0 to 40^0) into several tunnels showing articulated meniscate ridges.

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 tunnels ranges from 10-13 cm.

Remarks: - The specimens are characterized by the bundled structures and annulations on the cylindrical tunnels.

Occurrence: - It occurs in CSSL and GOs of Jhurio and RMCSSL of Jumara Formations.

Ichnospecies: - *Phycodes curvipalmatum* Pollard, 1981

(Plate 5.10, f)

Diagnosis: - Curved cross-cutting pipe like burrows as branches forms mesh like structure from a main thick elliptical tunnel.

Description: - Horizontal, ramifying and branching burrow system. The tube-like burrows split into finger-like curved branches distally. Cross-cutting of the burrows forms a net-like pattern. Diameter of the burrows is 5-8 mm.

Remarks: - The curved, ramifying branches distinguish this ichnospecies from the others. It is interpreted to be feeding burrow (Eagar et al., 1985).

Occurrence: - It occurs in GOs of Jhurio Formation.

Ichnospecies: - *Phycodes palmatum* Hall, 1852

(Plate 5.11, a)

Diagnosis: - Fan or radial system of horizontal branching burrows. Burrows essentially uniform throughout, long, linear or slightly curving, branching close together in the proximal part.

Description: - Palmate branching burrows system. Burrows are long, branching close together in the proximal part, with branches terminating in fan-shaped structure. Branches are 1 to 1.5 cm in diameter; initial common part of the bunch (stem or tunnel) is collapsed. Each tubes of the burrow are having different diameter.

Remarks: - *Phycodes palmatum* is characterized by its palmate branching. It differs from *P. curvipalmatum* by its larger size and lack of re-curvature.

Occurrence: - It occurs in GOs of Jhurio and RMCSSL of Jumara Formations.

Ichnospecies: - *Phycodes pedum* Seilacher, 1955

(Plate 5.11, b)

Diagnosis: - Horizontal arch shape tunnels with feather stitch like pattern of branching tunnels. The cylinders branch from a common stem at small angles and almost touch one another.

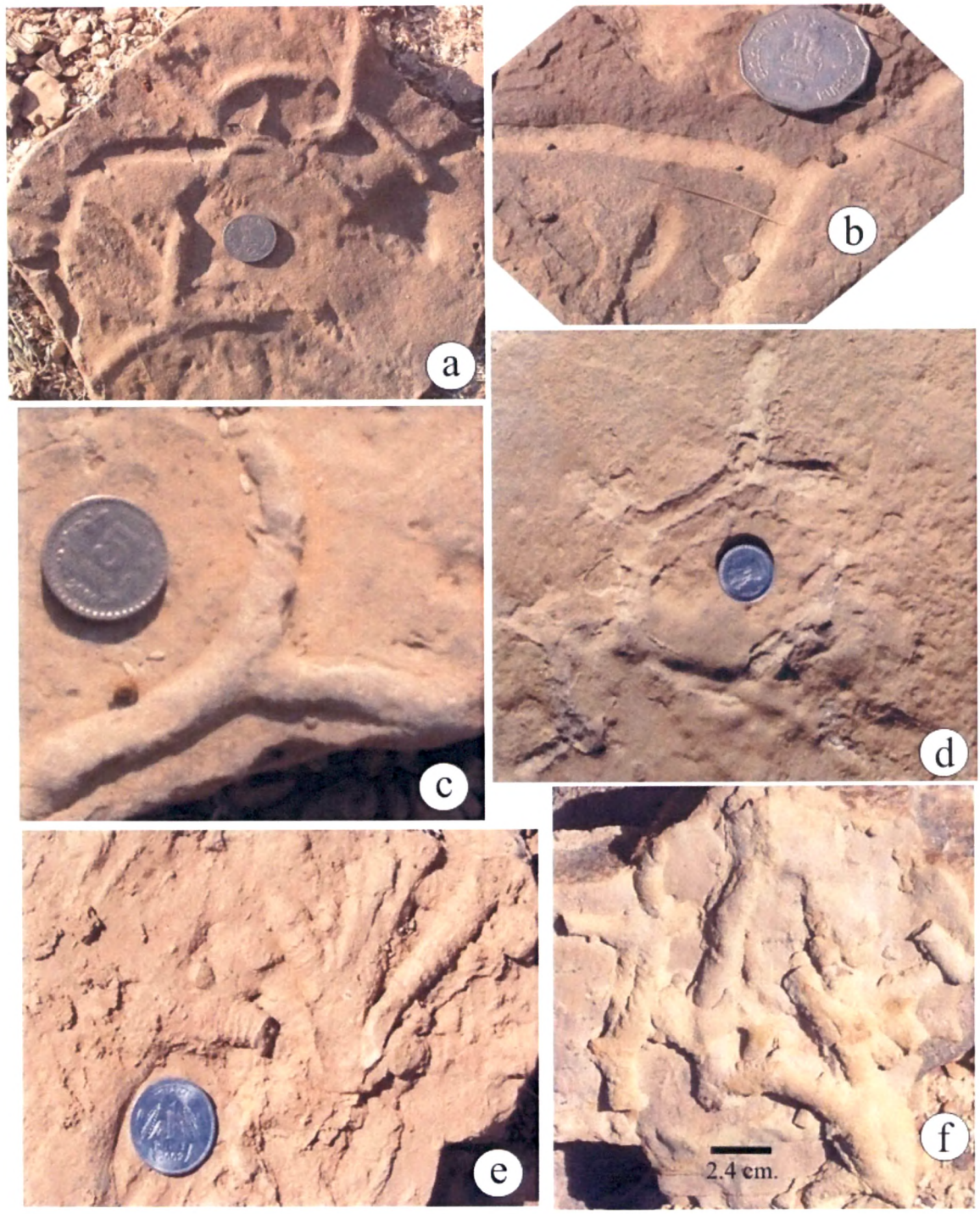


Plate 5.10 a) *Thalassinoides suevicus*, RMCSSL, Jumara Fm. b) *Thalassinoides suevicus*, NWWLs, Jhurio Fm. c) *Thalassinoides suevicus*, CSSL, Jhurio Fm. d) *Thalassinoides foedus*, GOs, Jhurio Fm. e) *Phycodes circinnatum*, GOs, Jhurio Fm. f) *Phycodes curvipalmatum*, GOs, Jhurio Fm.

Description: - Arch-shaped to sub-triangular burrow system with very small branches. The branches are tangential to almost parallel to the main stem except one at an approximate angle of 30^0. The distal end tapers to a rounded or sharp flat shape. Diameter of tunnels is between 3-5 mm.

Remarks: - The ichnospecies is characterized by the small, feather stitch-like branching pattern. It represents systematic mining by a worm-like animal having a fixed base and moving forward and outward through the sediments in the tidal zone where sufficient organic matter accumulates and supports deposit feeding endobenthos (Martino, 1989).

Occurrence: - It occurs in GOs of Jhurio and DOs of Jumara Formations.

Ichnogenus: - *Phymatoderma* Brongniart, 1849

Diagnosis: - Horizontal to subhorizontal trace fossil composed of irregularly branched lobes spreading out from the point. Edges of the lobes are irregular and can show palmate orientation fill with pellets arranged perpendicularly to the longer axes of the lobes (after Fu 1991).

Ichnogenus: - *Phymatoderma isp.*

(Plate 5.11, c)

Diagnosis: - As Ichnogenus

Description: - Horizontal to sub horizontal trace fossil made up of branched lobes radiating out from one point. Lobes are palmate. Diameter of the lobes is about 1 to 1.2cm.

Remarks: - The absence of pellets or spreiten distinguishes these specimens from other known ichnospecies of *Phymatoderma*. A few lobes exhibit some fine striations but it is a random feature. Although the pelletal feature of lobes is considered diagnostic for the ichnogenus (Fu, 1991) yet the overall morphology allows these forms to be placed under *Phymatoderma*.

Occurrence: - It occurs in CSSL of Jhurio Formations.

I.5 Meniscate form

Ichnogenus: - *Beaconites* Vialov, 1962

Diagnosis: - Small, cylindrical, unbranched, walled, meniscate burrows. 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 fillings (Keighley and Pickerill 1994).

Ichnospecies: - *Beaconites antarcticus* Vialov, 1962

(Plate 5.11, d)

Diagnosis: - Small, cylindrical, unbranched, lined burrows, straight to slightly sinuous. Burrows fill meniscate, typically heterogeneous packets of unequal thickness. Larges packets slightly thicker to slightly thinner than overall burrow width, meniscate interfaces weakly to moderately arcuate. Burrows lining is uniform, smooth and unornamented, commonly thick and very distinct (Keighley and Pickerill, 1994).

Description: - Cylindrical, mainly unbranched burrows parallel to bedding plane, somewhat sinuous, commonly crowded, distinct annulations (meniscate). Maximum observed length is about 28.0 cm, diameter of 5 cm, marginal welts is 0.5 to 2.5 cm. Burrow lining is distinct and fill identical with the matrix.

Remarks: - This species was designated as type ichnospecies of *Beaconites*. The present specimen differs from the original in having homogenous fill instead of heterogeneous fill.

Occurrence: - It occurs in NWWLs of Jhurio Formation.

Ichnospecies: - *Beaconites coronus* Frey et al., 1984

(Plate 5.11, e)

Diagnosis: - Predominantly horizontal, more rarely inclined to vertical, distinctly lined, gently winding, small meniscate burrow. A relatively short (with respect to burrow width)

meniscate packet, or segments, is of alternating sediment type. Menisci are gently to moderately arcuate (Keighley and Pickerill, 1994).

Description: - Horizontal, lined, gently winding meniscate burrow. Meniscate packets are shorter than wider and made of same sediment as the host rock. Menisci are gently to moderately arcuate. Burrow diameter 1-2 cm and burrow length variable.

Remarks: - This ichnospecies differs from the above described species in being more uniform and lined, having thin meniscate segments and gently arcuate menisci.

Occurrence: - It occurs in GOs; NWWLs and BLs of Jhurio Formation.

Ichnogenus: - *Keckia* Glocker, 1841

Diagnosis: - Filling of cylindrical tunnels with transverse annulations. Single "segments" bent. Burrow straight or slightly curved, branched, 1 to 2 cm wide, of varying length, lying in bedding plane.

Ichnospecies: - *Keckia annulata* Glocker, 1841

(Plate 5.12, a-c)

Diagnosis: - Cylindrical, gently curved with equidistant transverse annulations. Burrow diameters throughout constant.

Description: - Cylindrical burrows with transverse annulations. Burrows are straight or slightly curved, 1 to 1.5 cm wide. The annulations cover the burrow as segments, being wider in the centre and tapering to a point at both ends.

Remarks: - These burrows are divided into a series of segments which are very characteristic and differentiate them from other meniscate forms. It was originally described as a plant but later interpreted as stuffed burrows of sediment-feeding animals (Hantzschel, 1975).

Occurrence: - It occurs in NWWLs and GOs of Jhurio Formation.

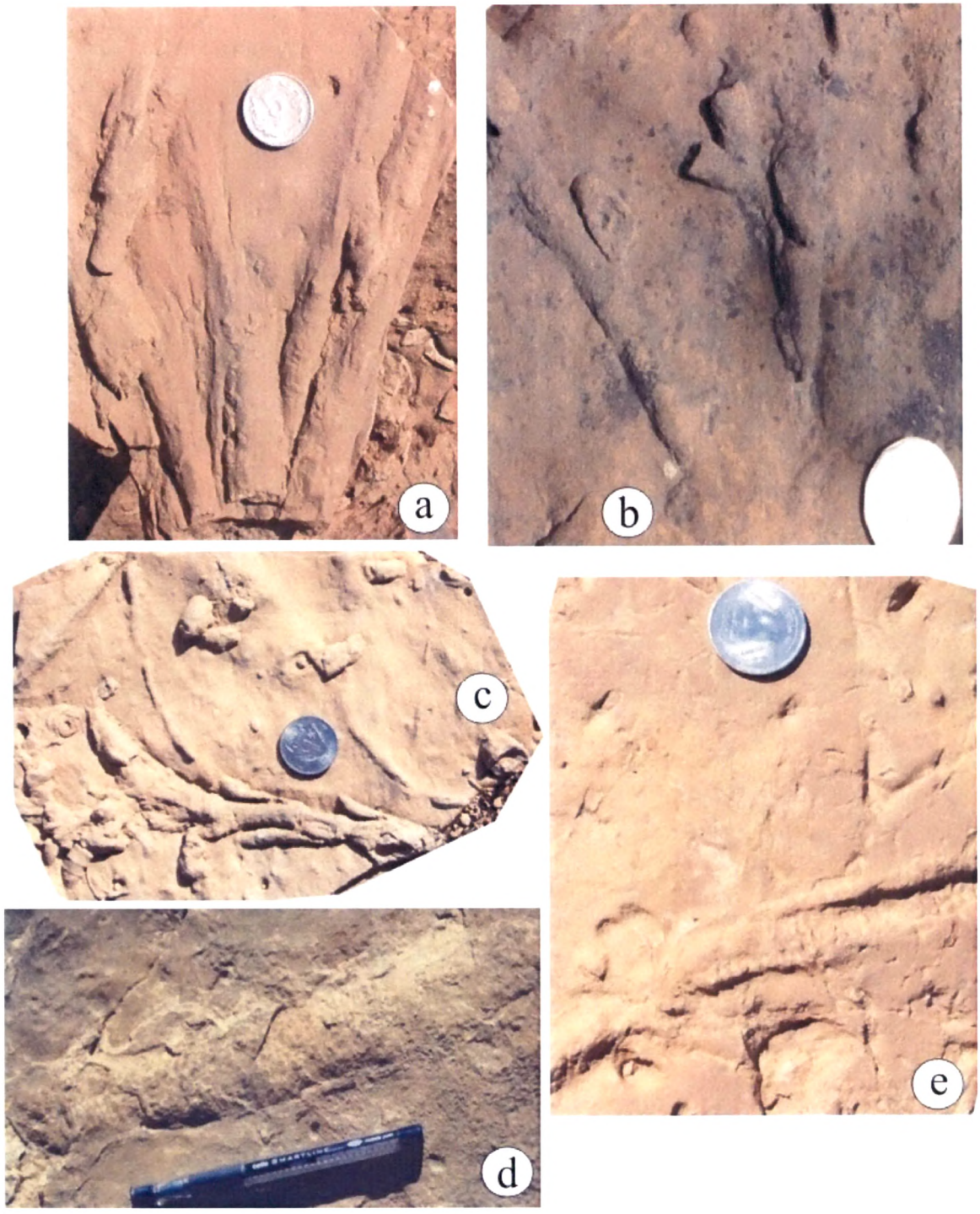


Plate 5.11 a) *Phycodes palmatum*, RMCSSL, Jumara Fm. b) *Phycodes pedum*, CSSL, Jhurio Fm. c) *Phymatoderma isp.*, CSSL, Jumara Fm. d) *Beaconites antarcticus*, NWWLs, Jhurio Fm. e) *Beaconites coronus*, GOs, Jhurio Fm.

Ichnogenus:-*Scolicia* de Quaterfages, 1849

Diagnosis: - Variably and commonly selectively preserved, simple, winding, meandering to coiling bilobate or trilobite back-filled burrows with two parallel, locally discontinuous, sediment strings along their lower side. Cross-section is approximately oval in outline and area between strings flat or slightly concave. Backfill laminae composite may be biserial on the upper side. Washed – out forms preserved as hypichnial bilobate ridges (Uchman1995).

Ichospecies: - *Scolicia strozzii* Savi and Meneghini, 1850
(Plate 5.12, d-e)

Diagnosis: - Straight to tightly meandering hypichnial bilobate ridge, preserved as semi-relief. Median groove separates the prominent zones of the ridge. The prominent zones and the groove are more or less semi-circular in cross-section. Tendency to meandering; width, depth, high, and proportions of the morphological elements may vary from specimen to specimen (Uchman 1995).

Description: - Concave epirelief, straight, bilobate smooth hypichnial trace, 5-9 mm wide, 2-3 mm high, 7-12 cm length (Plate 5.12, d), it is post depositional in origin. The trails contain two parallel lobes separated by median furrow. Lobes comprise evenly spaced series of oblique transverse fine pods preserved in concave epirelief. The median groove is wide and its base extends to the level of the surrounding lower surface of the bed. The side ridges are narrow and acute. The side ridges are asymmetric.

Remarks: - The varied sculpture may be caused by different methods of borrowing, creeping and removing sediments. Gotzinger and Becker (1932) ascribed the *Scolicia* traces to crawling gastropods. Simpson (1975) classified *Scolicia* as freely winding traces on bedding plane. The presence of narrow rims or cylindrical strings bordering the median lobe on either side is also difficult to account for, if the traces were produced by crawling gastropod. It may be assumed that a large polychaete was the producer of this trace (Ksiazkiewicz 1977).

Occurrence: - It occurs in NWWLs and CSSL of Jhurio Formation.

Plate 5.12 a) *Keckia annulata*, GOs, Jhurio Fm. b) *Keckia annulata*, CSSL, Jhurio Fm. c) *Keckia annulata*, NWWLs, Jhurio Fm. d) *Scolicia strozzii*, CSSL, Jhurio Fm. e) *Scolicia strozzii*, NWWLs, Jhurio Fm.

Ichnogenus:-*Taenidium* Heer, 1877

Diagnosis: - Variably oriented, unwalled (unlined, or very thin lined), winding, curved or sinuous, mostly un-branched, straight, cylindrical burrows containing a segmented fill articulated by meniscus shaped partings, meniscate backfilled trace fossil (modified after

D'Alessandro and Bromley 1987). Secondary successive branching may occur, but true branching is absent (Keighley and Pickerill 1991).

Ichnospecies: -*Taenidium cameronensis* Brady, 1947

(Plate 5.13, a-d)

Diagnosis: - Un-walled meniscate burrows, secondary successive branching and interaction are present. It has longer packets of sediment between successive menisci in the backfill, arc of the meniscus is also much deeper (D' Alessandro and Bromley 1987). All references to this ichnospecies have been from shallow water setting (e.g. Decourten 1978).

Description: - Endichnial, thinly lined, sinuous, cylindrical, meniscate burrows of about 1.8-2.0 cm in diameter. Meniscate packets are equal to or smaller than wide. The burrow contains segmented fill articulated by meniscus. The inter-meniscate segments are about 5-7 mm thick.

Remarks: - *T. cameronensis* Brady, 1947, differs from *T. serpentinum* and *T. satanassi* in having longer packets of sediment and arc of the meniscus is also much deeper (D'Alessandro and Bromley, 1987). *Taenidium* is interpreted as *Pascichnia*l trace produced by vagile, deposit feeding animals (D'Alessandro and Bromley, 1987).

Occurrence: - It occurs in GOs and NWWLs of Jhurio Formation.

Ichnospecies: - *Taenidium satanassi* D'Alessandro and Brady, 1987

(Plate 5.13, e)

Diagnosis: - Sinuous to nearly straight backfilled burros, the fill consisting of evenly alternationg meniscus-shaped packets of two types of sediment, more or less equal thickness; sediment packets considerably shorter than wide, Menici weakly arcuate (after D'Alessandro and Bromley, 1987).

Description: - Endichnial, unbranched, cylindrical, meniscate burrows of about 2-2.5 cm diameter. Burrows having well spaced menisci; distance between menisci less than burrow

width. The burrow contains thick segmented fills articulated by meniscus. The filled material and host material are identical.

Remarks: - D'Alessandro and Bromley (1987) and Decourten (1978) also considered this ichnospecies from shallow water settings. The species differs from other ichnospecies of *Taenidium* in its well spaced and arcuate shaped menisci along with homogeneous fill.

Occurrence: - It occurs in GOs of Jhurio Formation.

Ichnospecies: - Taenidium serpentinum Heer, 1877

(Plate 5.13, f-g)

Diagnosis: - Straight to variable meandering, serpentiform Taeinidum having well-spaced, unwalled, meniscate backfilled burrow. Menisci are commonly hemispherical, tightly packed or stacked, forming non-compartmentalized backfill or thin meniscate segments (Keighley and Pickerill, 1994). Secondary subsequent branching and intersections occur (D'Alessandro and Bromley, 1987).

Description: - Straight to meandering, branched, unwalled, meniscate backfilled burrow. Menisci are hemispherical, forming thin meniscate segments. At places the menisci are not well preserved and hence widely separated from each other. Diameter of burrow is about 0.5-0.6 cm and length is 6-7 cm.

Remarks: - The subsequent branching and intersections distinguish T. serpentinum from other species (D'Alessandro and Bromley, 1987). Although earlier considered as escape or equilibrium structures, they are also considered to be repichnial structures (Keighley and Pickerill, 1994).

Occurrence: - It occurs in GOs of Jhurio Formation.

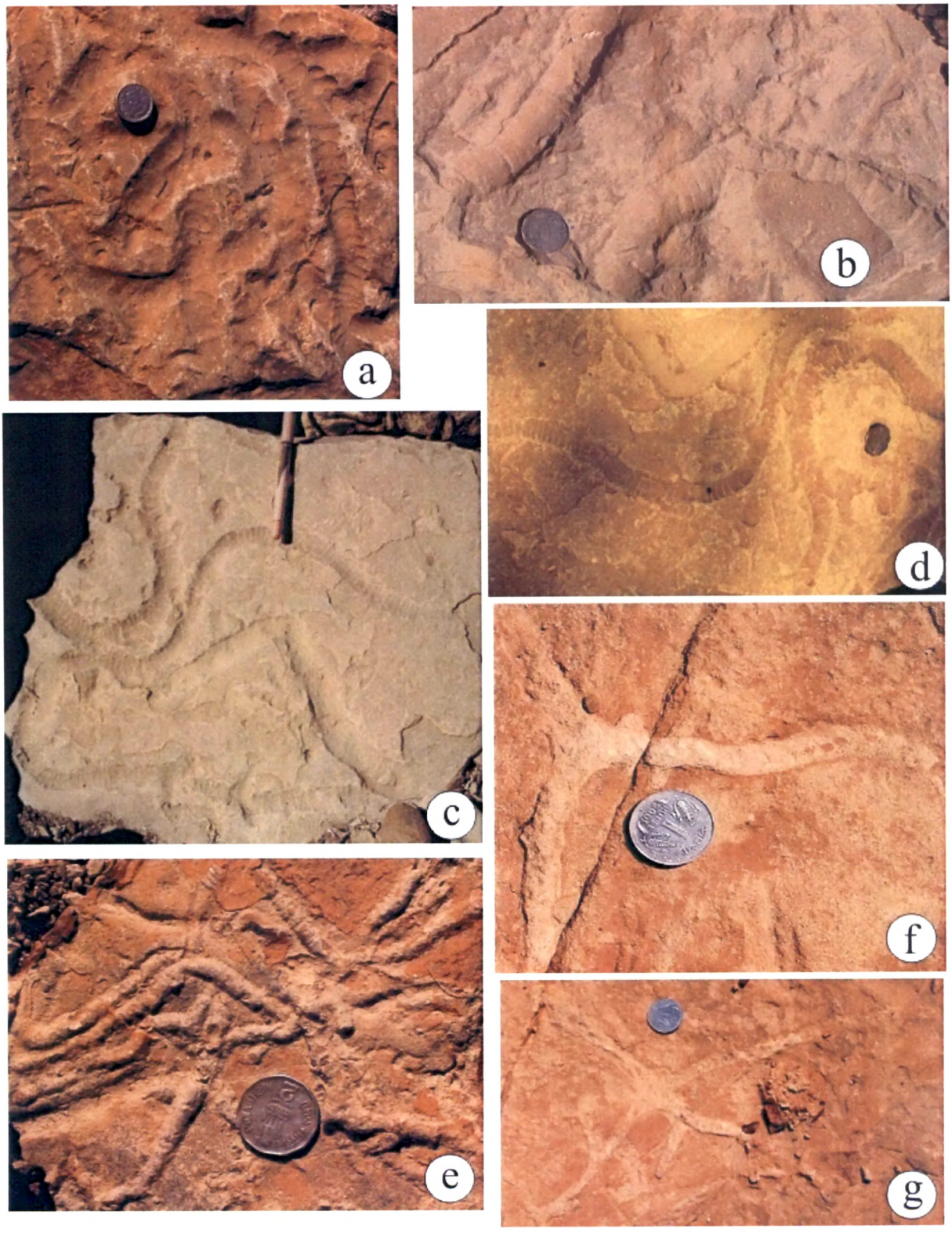


Plate 5.13 a-b) *Taenidium cameronensis*, GOs, Jhurio Fm. c) *Taenidium cameronensis*, NWWLs, Jhurio Fm. d) *Taenidium cameronensis*, BLs, Jhurio Fm. e) *Taenidium satanassi*, GOs, Jhurio Fm. f-g) *Taenidium serpentinum*, GOs, Jhurio Fm.

I.6 Winding and Meandering structures

I.6.1 Meandering structures

Ichnogenus: - *Didymaulichnus* Young, 1972

Diagnosis: - Smooth, straight and gently curving burrows consisting of two lobes separated centrally by distinct furrow and flanked laterally by bevels which are not continuous. Traces commonly crossing and occurring in profusion on bedding planes

Ichnospecies: - *Didymaulichnus isp.*

(Plate 5.14, a)

Description: - An irregular, curved to straight trail preserved as a positive hyporelief. The trace is 3-4 mm wide, smooth and bilobed with a very narrow median depression. Trails overlap and truncate one another.

Remarks: - These are generally regarded as surface trails, probably of a mollusc (Hakes, 1976), and are also regarded as of shallow water origin. Since these traces do not conform to the morphological description of any one ichnospecies of *Didymaulichnus,* they are described here as *isp.*

Occurrence: - It occurs in GOs of Jhurio Formation.

Ichnogenus: - *Gordia* Emmons 1844

Diagnosis: - Long, slender, smooth worm like trails of uniform thickness throughout, mostly bent but not meandering.

Ichnospecies: - *Gordia marina* Hantzschel, 1962

(Plate 5.14, b-c)

Diagnosis: - Long thread-sized smooth, arcuate or looped unbranched burrows.

Description: - Epichnial semi relief, long, slender, irregularly curve, smooth worm-like trails of uniform thickness. Mostly bent but not meandering; resembling hair-worm (Hantzschel, 1962). The specimen shows convex, thick thread-sized, meandering ridge casts in which smooth worm-like bends are developed. The most notable characteristic of the specimen is the uniform width and high length to width ratio. Length is about 6 to 8 cm and width is 0.3 to 0.4 mm.

Remarks: - The assignment of this species to *Gordia* may be open to question, since the actual shape of the meanders, never wholly developed, is unknown. It is included in the ichnogenus *Gordia* because it hasn't regular sinuous curves of *Cochlichnus*, loose meanders of *Helminthopsis* (Miller and Knox, 1985) and the regular meanders of *Cosmorhaphe* (Ksiazkiewicz, 1970).

Occurrence: - It occurs in GOs of Jhurio and RMCSSL of Jumara Formation.

Ichnogenus: -*Cochlichnus* Hitchcock, 1858

Diagnosis: - Regular meandering, un-branched, unlined, smooth trail resembling sine curve.

Ichnospecies: - *Cochlichnus anguineus* Hitchcock, 1858

(Plate 5.14, d)

Diagnosis: - Small, smooth, un-branched sinusoidal unlined burrows.

Description: - Epichnial, sinuous, regularly winding, unbranched, horizontal, string-like burrows. Burrows are circular in cross section, with diameter being 3-5 mm and show slight thickening at the meander.

Remarks: - *Cochlichnus* has been reported previously from the Jurassic of Kachchh by Fürsich (1998) and from Upper Jurassic of Boulonnais, France (Schlirf, 2000). The present specimen is robust as compared to those described by other workers (Fürsich, 1998; Schlirf, 2000; Książkiewicz, 1977) and interpreted as feeding structure of worm-like animals. It differs from other species in having unornamented surface and smaller burrow diameter.

Occurrence: - It occurs in NWWLs and CSSL of Jhurio Formation.

Ichnogenus: - *Cosmorhaphe* Fuchs 1896

Diagnosis: - Unbranched graphoglyptid burrow with two orders of meanders or undulations (after Seilacher 1977).

Ichnospecies: - *Cosmorhaphe carpathica* Uchman, 1999
(Plate 5.14, e)

Diagnosis: - First order meanders, fairly dense, amplitude of second-order meanders 2-3 times greater than wavelength, but suppressed for long stretches (after Seilacher 1977).

Description: - Meandering hypichnial string, 1 to 2 mm wide, preserved as semi-relief. The string forms pseudo circular pattern with fairly dense first order meanders and irregular, very shallow second order meanders.

Remarks: - The long, winding stretches are a characteristic feature of this material, which is not found in other ichnospecies of *Cosmorhaphe*. For this reason the new name *Cosmorhaphe carpathica* was proposed by Uchman (1999). *Cosmorhaphe* may be either pre- or post-depositional, produced by animals which could live either on the sea-bottom or close to it. Any worm-shaped animal or gastropod without external ornamentation could produce this trace (Ksiazkiewicz 1977).

Occurrence: - It occurs in NWWLs of Jhurio Formation.

I.6.2 Plaited Forms

Ichnogenus:-*Gyrochorte* Heer, 1865

Diagnosis: - Trace in epirelief preserved as pliated ridges with biserially arranged, obliquely aligned pads of sediments, separated by median furrow. Hyporelief shows smooth biserial grooves separated by median ridges. Course is strongly winding, direction changes sharply. Parts of the trace may intersect. Ridges and their grooves separated by a vertical distance.

Ichnospecies: - *Gyrochorte comosa* Heer, 1865

(Plate 5.14, f)

Diagnosis: - Trace up to 5.0 mm. wide in epirelief preserved as plaited ridges with biserially arranged, obliquely aligned pods of sediment, in hyporelief preserved as smooth beserial grooves separated by median ridges; course strongly winding and direction changing sharply, trace may intersect itself or other traces, ridges and other grooves may be separated by vertical distance of 1.0 cm; usually preserved in clastic sediments.

Description: - Epirelief, slightly sinuous, bilobed burrow preserved as plaited ridges with biserially arranged, obliquely aligned pads consisting of smooth ridges with a median furrow. Burrow width is 0.3 to 0.6 cm and maximum observed length is ~25 cm. The trace is strongly winding and parts of the trace may intersect frequently in such a way that the earlier formed ridges are not destroyed. The angle between the pads and the median furrow varies from 40 to 50 degree.

Remarks: - *Gyrochorte* is considered to be the burrow of an animal that selects food from the sediment over the entire length of its body (Powell, 1992). The producer must have been a detritus-feeding worm-like animal, probably an annelid that created a bilobed, vertically penetrating and sometime plaited meandering trace (Gibert and Benner, 2002).

Occurrence: - It occurs in DOs and RMCSSL of Jumara Formation.

Ichnogenus: - *Protovirgularia* M'Coy, 1850

Diagnosis: - Horizontal or sub-horizontal cylindrical trace fossil, trapezoidal, almond-shaped or triangular in cross section, distinctly or indistinctly bilobed. Internal structure (if preserved), formed by successive pads of sediments 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 is on exterior covering the structure and/or with oval mound-like terminations of the trace.

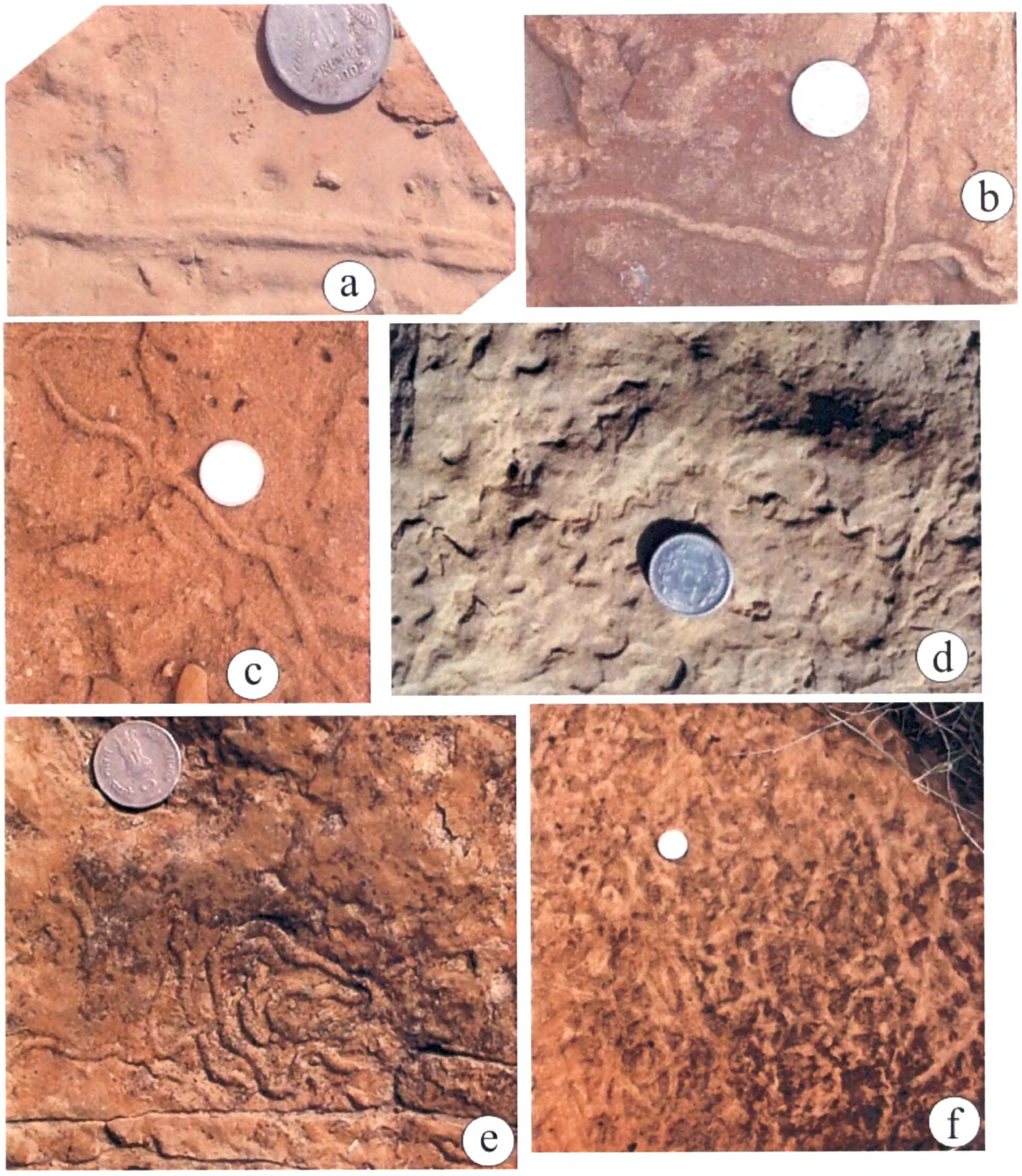


Plate 5.14 a) *Didymaulichnus isp.*, GOs, Jhurio Fm. b) *Gordia marina*, GOs, Jhurio Fm. c) *Gordia marina*, RMCSSL, Jumara Fm. d) *Cochlichnus anguineus*, NWWLs, Jhurio Fm. e) *Cosmorhaphe carpathica*, NWWLs, Jhurio Fm. f) Gyrochorte comosa, DOs, Jumara Fm.

Ichnospecies: - *Protovirgularia dichotoma* M'Coy, 1850

(Plate 5.15, a, b-i and c-e)

Diagnosis: - Unbranched, keel like trail typically but not universally, with median ridge or furrow from where paired, lateral, wedge-shaped appendages, cross-cutting, commonly few centimetres in length and of even or variable spacing, lateral appendages, normal or at acute angle to median ridge or furrow.

Description: - Epichnial, horizontal, cylindrical, distinctly bilobed trace with median ridge from where paired, lateral, wedge-shaped appendages originate. Total burrow diameter is 2.5-3 cm. Lateral appendages are almost normal to the median ridge or furrow.

Remarks: - The wedge-shaped appendages on either side of the median groove distinguish this genus from *Gyrochorte*. The trace is generally interpreted as made by annelids (Schlirf, 2000).

Occurrence: - It occurs in NWWLs and GOs of Jhurio Formation.

I.6.3 Branched winding and meandering structures

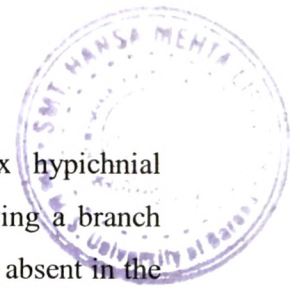
Ichnogenus: - *Urohelminthoida* Sacco, 1888

Diagnosis: - Burrow system preserved usually as string sized, deep, hypichnial branched meanders. Lateral appendages protrude outwardly from the curved segments of the meanders (after Uchman 1995). This ichnogenus is related to *Helminthoida* owing to its guided meanders, which have short appendages on the apical bends. Some meanders may have no appendages (Ksiazkiewicz 1977).

Ichnospecies: - *Urohelminthoida dertonensis* Sacco, 1888

(Plate 5.15, f-g)

Diagnosis: - It is a burrow system with hypichnial meanders and secondary branching. The strings are 0.5 to 1.5 mm wide with lateral appendages which pass straight into one arm of a meander, but form an angle with the second arm.



Description: - The specimen has half preservation of the form; convex hypichnial preservation which represents one main string with meandering and also having a branch with meander which is more or less parallel to the main string. Appendages are absent in the specimen.

Remarks: - *Urohelminthoida* is a typical araphoglyptid burrow (Seilacher 1977). Apart from numerous flysch occurrences it was found in Mesozoic shallow water deposits (Fursich and Heinberg 1983). Seilacher (1977) indicated that one of the characteristic features of *U. dertonensis* are the widely spaced meanders. However, the distance between meanders varies in the examined material from tight to widely spaced. Consequently, this feature is not regarded as diagnostic (after Uchman 1995).

Occurrence: - It occurs in CSSL and BLs of Jhurio Formation.

I.7 Spreiten structure

I.7.1 U- Shaped

Ichnogenus: - *Diplocraterion* Torell, 1870

Diagnosis: -U-shaped burrow with spreite, vertical to bedding plane, limbs of U-parallel, both limbs of successive U-tube confluent with limbs of preceding U-tube, opening of tubes mostly funnel shaped, commonly protrusive, but also retrusive forms observed, bottom of burrow semicircular, rarely straight, horizontal cross-section on bedding planes dumb-bell-shaped, diameter of tubes 5 to 15mm.; distance between limbs 1 to 7 cm., depth of burrow 2 to 15 cm.

Ichnospecies: - *Diplocraterion habichi* Torell, 1870
(Plate 5.16, a-i and b-c)

Diagnosis: - As Ichnogenus; narrow, vertical U-burrow with a spreite; the burrows having both limbs are curved dumb-bell shaped on the bedding surface in the top-view (sectional view).

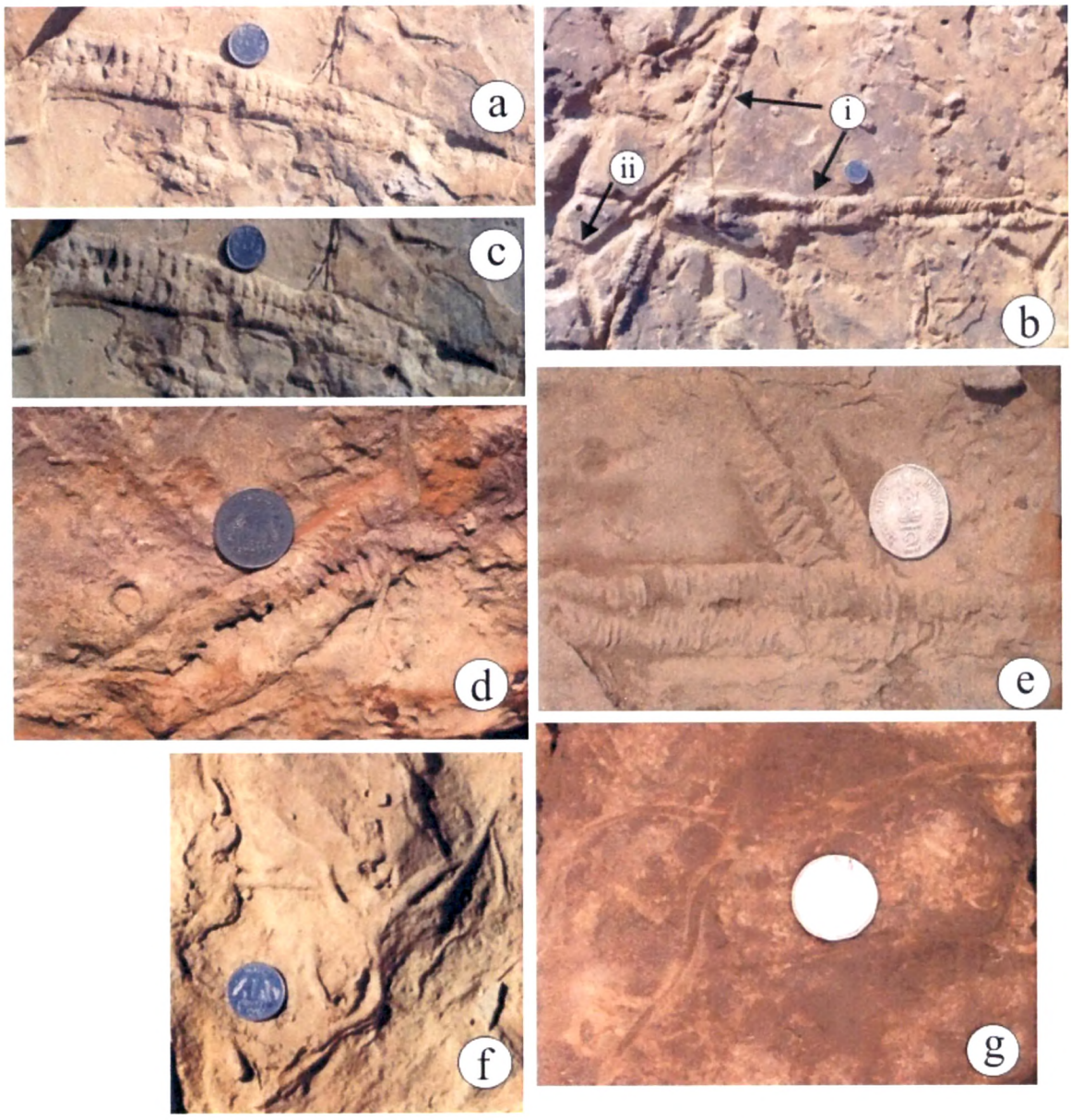


Plate 5.15 a-c) *Protovirgularia dichotoma* and b-ii) *Thalassinoides horizontalis* NWWLs, Jhurio Fm. d-e) *Protovirgularia dichotoma*, GOs, Jhurio Fm. f) *Urohelminthoida dertonensis*, CSSL, Jumara Fm. g) *Urohelminthoida dertonensis*, BLs, Jhurio Fm.

Description: - Narrow, vertical, U-shaped burrows with spreite, vertical or slightly inclined to the bedding plane. The arms of the burrow are parallel. The burrow opening is curved, dumb-bell shaped on the bedding surface and 2-3 cm apart.

Remarks: - Although the arms are parallel yet based on the smaller dimension and absence of width / depth ratio data, the above specimens are not assigned to *D. parallelum*. The limbs of the U-burrows have closely placed; they are narrow, while in the *D. parallelum* it is wide. They are thus being described as '*D. habichi*'. *Diplocraterion* is interpreted as domichnion of polychaete annelids, crustaceans or other suspension feeders (Fursich, 1974a; Fillion and Pickerill, 1990).

Occurrence: - It occurs in GOs and CSSL of Jhurio and RMCSSL of Jumara Formations.

Ichnogenus:-*Rhizocorallium* Zenker, 1836

Diagnosis: - Horizontally protrusive U-burrows with spreite. Simple, parallel to sub-parallel U shaped tubes with spreite, generally protrusive or irregular retrusive asymmetrical spreite, and horizontal to somewhat oblique to bedding plane with a spreite often recording growth of trace makers. Arms/tubes several cm apart; very rarely branched, occasionally with lateral flaps or tubes relatively thick. They demonstrate high energy shoreface, backshore depositional environment and colonize transgressive and by-pass surfaces.

Ichnospecies: - *Rhizocorallium jenense* Zenker, 1836

(Plate 5.16, d-e)

Diagnosis: - Oblique to bedding, rarely branched, relatively thick tubes, horizontal to sub-horizontal, long sinuous parallel U-shaped spreiten burrow system. Limbs are more or less parallel and distinct with occasionally protrusive spreiten.

Description: - Simple, full relief U-tube, generally oblique to the bedding plane. Tubes are more or less parallel and distinct. Median line of 'U' often curved horizontally on bedding plane. Its width varies from 1 to 2 cm, filled with the identical matrix to the host sediments. Total burrow width is 4-6 cm.

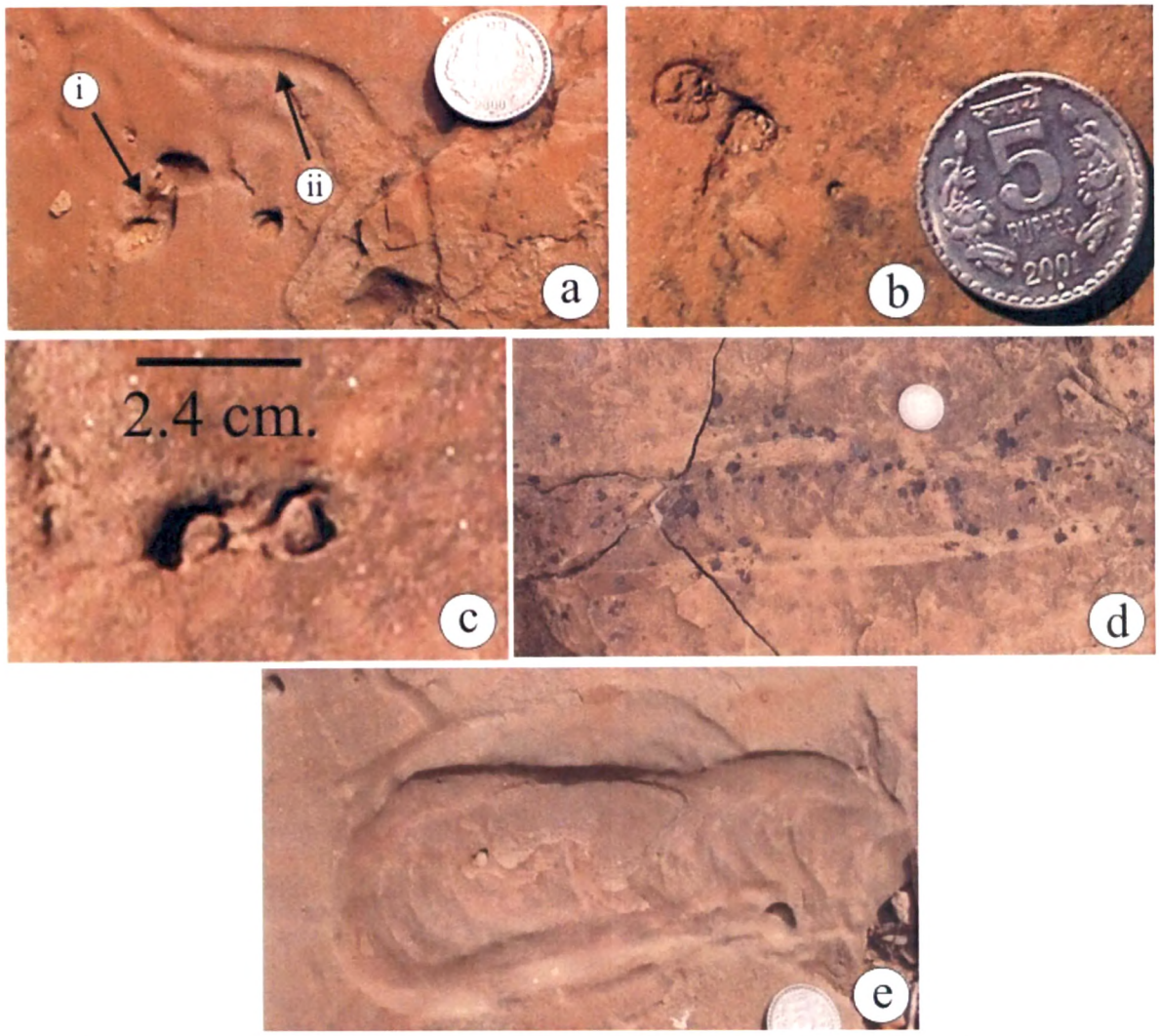


Plate 5.16 a-i) *Diplocraterion habichi* and a-ii) *Pilichnus dichotomus,* CSSL, Jhurio Fm. b) *Diplocraterion habichi*, GOs, Jhurio Fm. c) *Diplocraterion habichi*, RMCSSL, Jumara Fm. d) *Rhizocorallium jenense,* DOs, Jumara Fm. e) *Rhizocorallium jenense*, GOs, Jhurio Fm.

Remarks: - The parallel nature of tubes is characteristic of this ichnospecies. Taxonomic status of *Rhizocorallium* was extensively discussed by Fursich (1974a, 1974c) who concluded that short oblique, vertically retrusive forms should be interpreted as burrows of suspension feeders. However, the deposit feeding with back filling interpretation of the ichnofossil cannot be ruled out.

Occurrence: - It occurs in CSSL; GOs and BLs of Jhurio and CSSL, DOs RMCSSL of Jumara Formations.

Ichnospecies: - *Rhizocorallium irregulare* Mayer, 1954

(Plate 5.17, a-c)

Diagnosis: - Straight or slightly sinuous bifurcating or planispiral U-shaped, long, spreiten burrows; mainly horizontal (Fursich, 1974c). Most burrows are simple, straight or winding, but occasionally branched or spiral varieties occur (Fursich and Heinburg 1983). They contain irregular retrusive asymmetrical closely spaced spreiten with passive fill in the marginal tube.

Description: - Epichnial semi-relief, long, U-shaped, horizontal spreiten burrows with stout tubes about 1-2 cm thick. Total burrow width is 3- 7 cm. The spreite are less preserved, with tube representing pocket-like depressions. Burrow fill is identical to the host rock. In a few specimens the burrow ends in a sac-like cavity.

Remarks: - Variation in dimension and irregular curvature of tubes are typical of this ichnospecies. Fursich (1974c) 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).

Occurrence: - It occurs in CSSL; GOs and BLs of Jhurio and CSSL, DOs RMCSSL of Jumara Formations.

Ichnospecies: - *Rhizocorallium uraliense* Firtion, 1958

(Plate 5.17, d-f)

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

Description: - Epichnial, long and coiled, U-shaped, horizontal, spreiten burrows. Tubes are stout and parallel, 1.8-2 cm wide. Total width of burrow is 6-10 cm. The burrow width varies along the length, being wider at the terminal part.

Remarks: - *R. uraliense* differs from *R. irregulare* and *R. jenense* in the stout nature of tubes and coiling of the burrow on the bedding plane (Fursich, 1974c).

Occurrence: - It occurs in CSSL of Jhurio and Jumara Formations.

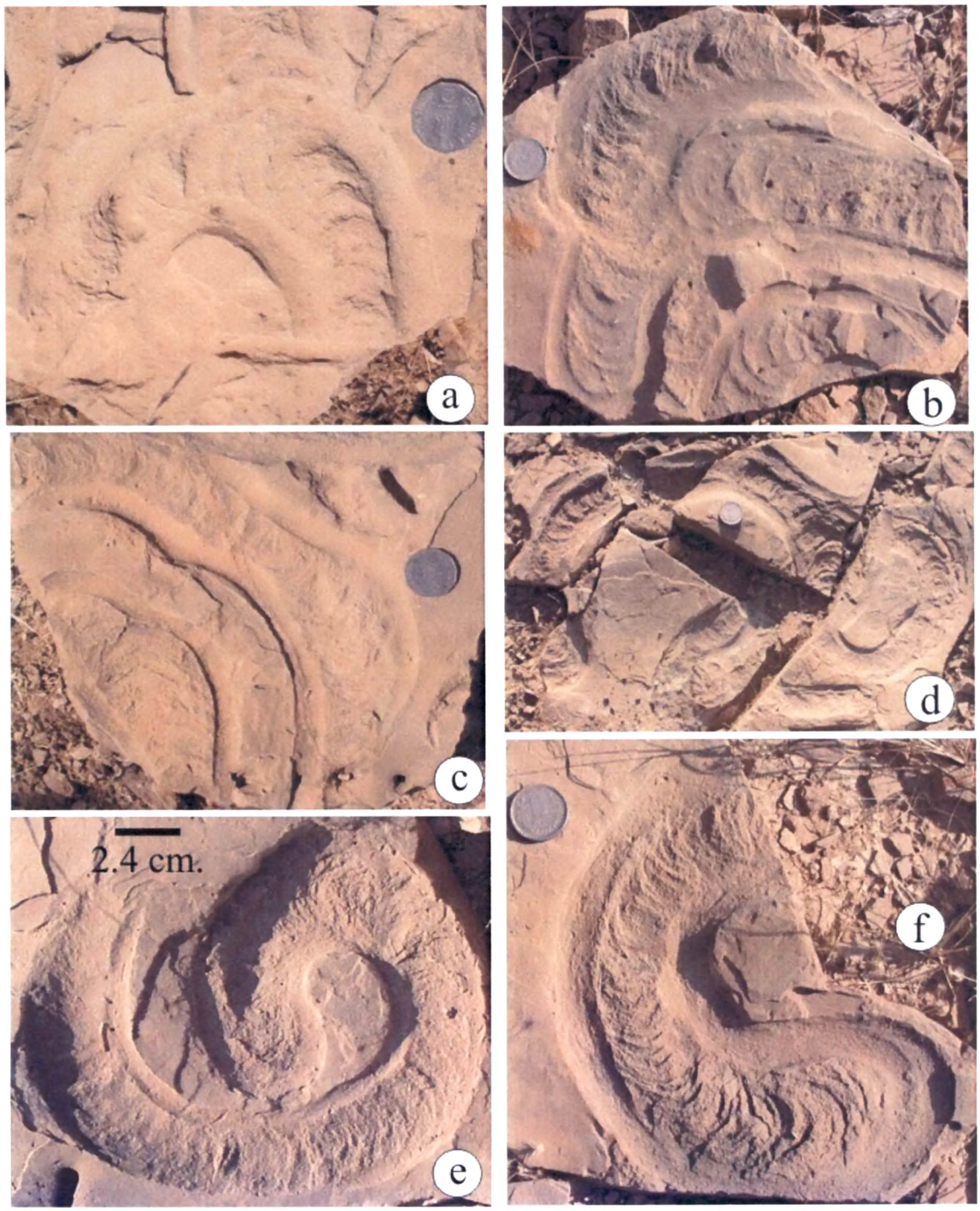


Plate 5.17 a-c) *Rhizocorallium jenense*, CSSL, Jumara Fm. d-f) *Rhizocorallium uraliense*, CSSL, Jumara Fm.

Ichnogenus: - *Zoophycos* Massalongo, 1855

Diagnosis: - Large single lobes to complex helical spreite structures; Spreiten structures composed of numerous small, more or less U-shaped or J-shaped protrusive burrows of variable length and orientation. Spreite arranged in helicoids spirals, overall outline circular, elliptical or lobate; central vertical tunnel or marginal tube may be present (after Uchman 1995). Shallowly conical, spiral form, consisting of three main parts; spirally coiled spreite, major and minor lamellae contained within the lamina, and a cylindrical tunnel, axis of spiral vertical to bedding, height small, single volutions cone like, sloping outward, diameter of successive whorls generally increasing downward, occasional inverse direction of coiling, base diameter of structure up to 50.0 cm or more, whorls comprising lamina variable in outline; circular, arcuate or lobate, occasionally first volutions lobate and larger and deeper ones nearly circular in outline, laminae exhibit major and minor lamellae, appear lunate in cross section, and curve radially from axis of spiral, major lamellae branch at acute angle toward axis forming minor lamellae, cylindrical tunnels with axial and marginal part forms the axis of spreite, has same thickness as spreite, may continue for a part or for whole length of lamina and then may be open to sediment at both ends, planar forms of *Zoophycos* similar to closed spiral spreite. Triassic to Cretaceous *Zoophycos* is showing shoreface to open shelf depositional environments (Gerard and Bromley 2008).

A variety of morphotypes of *Zoophycos* are recorded from the study area signifying a wide range of behaviour pattern. Five species are identified namely *Zoophycos brianteus, Zoophycos caudagalli, Zoophycos circinnatus, Zoophycos laminatus, Zoophycos insignis* and *Zoophycos* villae and others are described as *Zoophycos* Type A, B, C, D and E.

Ichnospecies: - *Zoophycos brianteus* Massalongo, 1855

(Plate 5.18, a-b)

Diagnosis: - *Zoophycos* is having a more or less circular to elliptical outline in planar view, without lobes (Uchman 1999). The whorls occur in cross-section in stairs, one above the other at intervals of .5 to 2 cm. the rays (lamellae) are about 1-2 mm wide. Dichotomy of rays is common. In some specimens there are elongated oval hollows between rays. Both small and large specimens have a circular outline (Ksiazkiewicz 1977).

Description: - Endichnial, helicoidal coiling, 30 cm in diameter which shows a circular to semi-circular outline in plan view. The traces show a raised apex in the centre from which the distinctive spreiten extend arcuately up to the burrow margin, forming several vertically stacked coils which are overlapping. The central part of the burrow is elevated by up to 0.8 to 1 cm. Burrow diameter increases toward the lower coils. Primary laminae are distinguishable. Marginal tube is absent. Dichotomy of ray is common. Although the majority of the structures exposed in the sections parallel to the bedding are planar, number of low cones and the filaments of these are arranged concentrically about a central point, rod or stalk which may be slightly raised. Many of the conical specimens are formed of several superimposed cones which may be spirally coiled. Distally, the filaments are curved either dextrally or sinistrally to give the *Zoophycos* swirled appearance.

Remarks: - There is considerable diversity in *Zoophycos* species of Dhosa Oolite. These variations are observed in the outline of the whorl as circular, lobed or multi-lobed, with or without marginal tube. In few cases laminate structures are also found, in either case single or double burrow openings. *Z. brianteus* is distinguished on the basis of its raised apex and circular to elliptical outline. The organisms producing this trace are not definitely known and great speculation abounds regarding the producing animal. There are various views regarding the nature of the trace although majority of the opinion favours a *Fodinichnia*l origin.

Occurrence: - It occurs in BLs of Jhurio and DOs of Jumara Formations.

Ichnospecies: - *Zoophycos Caudagalli* Hall 1863 (after Rindsberg 1994)
(Plate 5.18, c-d)

Diagnosis: - *Zoophycos* with sub-circular early stage, later horizontal, slightly inclined, tongue-like lobe is having spreiten structure along a bedding plane. It has an extension from a short vertical cylindrical shaft

Description: - A small *Zoophycos* with early sub-circular and later tongue like spreiten structure originating from a short vertical shaft, 3-4 cm in height, cutting across bed. Lobe is approximately 5-6 cm wide and 15-20 cm in length having spherical ending.

Remarks: - Only one specimen was observed. It has shown a typical originating vertical shaft, which hasnever been discussed earlier in this species group. While identifying, it could be mixed with Z. *laminatus;* Simpson 1957 or Z. insignis; Squinabol 1890; except it has characteristic early sub-circular and later tongue shaped extension lobe having spreiten structure with vertical shaft.

Occurrence: - It occurs in DOs of Jumara Formation.

Ichnospecies: - *Zoophycos circinnatus* Brongniart, 1828

(Plate 5.18, e-f)

Diagnosis: - A burrow consists of hemicircular or oval protrusive spreite filling large lobes that are slightly inclined to bedding. Total structure may consist of several endogenic, full relief loops developed about the central access galleries (chamberlain 1971).

Description: - Endogenic, full relief, dwelling/ feeding burrows with semi-circular planar spreiten showing wide U-shaped opening. It has large horizontal or inclined spirals or loops. Loops 20-40 cm across and spirals 10-25 mm high. The diameter of the whorls increases away from the openings. Within the whorl stacked arrangement of the laminae is present. Primary lamellae are prominent. Secondary lamellae also present. The successive whorls are deep and well-marked. An outer marginal tube binds the whorls. Major laminae are distinct but minor laminae are moderately distinct. In horizontal sections parallel to the bedding, the trace fossil consists of a number of laminae arranged concentrically, and some of laminae overlap one another.

Remarks: - The form is distinguished by two openings, large loops and thick laminae.

Occurrence: - It occurs in BLs of Jhurio and DOs of Jumara Formation.

Ichnospecies: - *Zoophycos insignis* Squinabol 1890

(Plate 5.19, g)

Diagnosis: - *Zoophycos* composed mostly of distinct U-shaped lobes, which may protrude from an oval or elongated ellipsoidal central spreiten (Uchman 1999).

Description: - Incomplete, Endichnial, planar spreiten structures. The spreiten of the specimen occurs at several levels within the sediment. It is filled with dark coloured spreiten laminae which is different than the host sediment. A distinct four U-shaped arcuate spreiten structures, about 20mm wide, occurs. All the spreiten structures are extended in all directions form a oval or elongated central spreiten. U-shaped spreiten structures have faint marginal lining and tunnel.

Remarks: - The U-shaped structures can be treated as the causative burrows, which are the characteristic element of Echinospira pauciradiata Girotti (1970) (Ekdale and Levis 1991a, Uchman 1995). They are also a characteristic element of Zoophycos insignis Squinabol (1980). For these trace fossils, the U-burrow model (Ekdale and Levis 1991a) can be applied. Ekdale and Levis (1991a) described *Zoophycos* (=Echinospira) from the tertiary rocks and suggested that it was produced by long organisms reworking sediment in a long U-shaped burrow. According to the model, Echinospira is formed by lateral /vertical shifting of a vertical (Diplocraterion like) to horizontal (Rhizocorellium like) U-shaped burrow with spreiten. This was earlier proposed as na alternative model by Bromley (1991), who suggested that the *Zoophycos* tracemaker fed on its own faecal pellets (authocoprophagy) and that, consequently *Zoophycos* is not a feeding structure, but a farming structure. Based on Ksiazkiewiczs (1977), the species Z.brianteus and Z.insignis can be distinguished for largely circular *or lobate and/or antler-shaped forms*. This difference is mostly discernible only in early stages and fully developed specimens must usually be referred to as *Zoophycos* isp indet (Mikulas 1990).

Occurrence: - It occurs in DOs of Jumara Formation.

Ichnospecies: - *Zoophycos laminatus* Simpson 1957

(Plate 5.19, a-b)

Diagnosis: - *Zoophycos* with horizontal long elongated spreiten burrow, curved lamellae, lobed ending having quiet faint lining.

Description: - Sheet-like laminated burrow composed of a series of horizontally arranged curved lamellae which are crescentic in sections and perpendicular to the bedding. It is

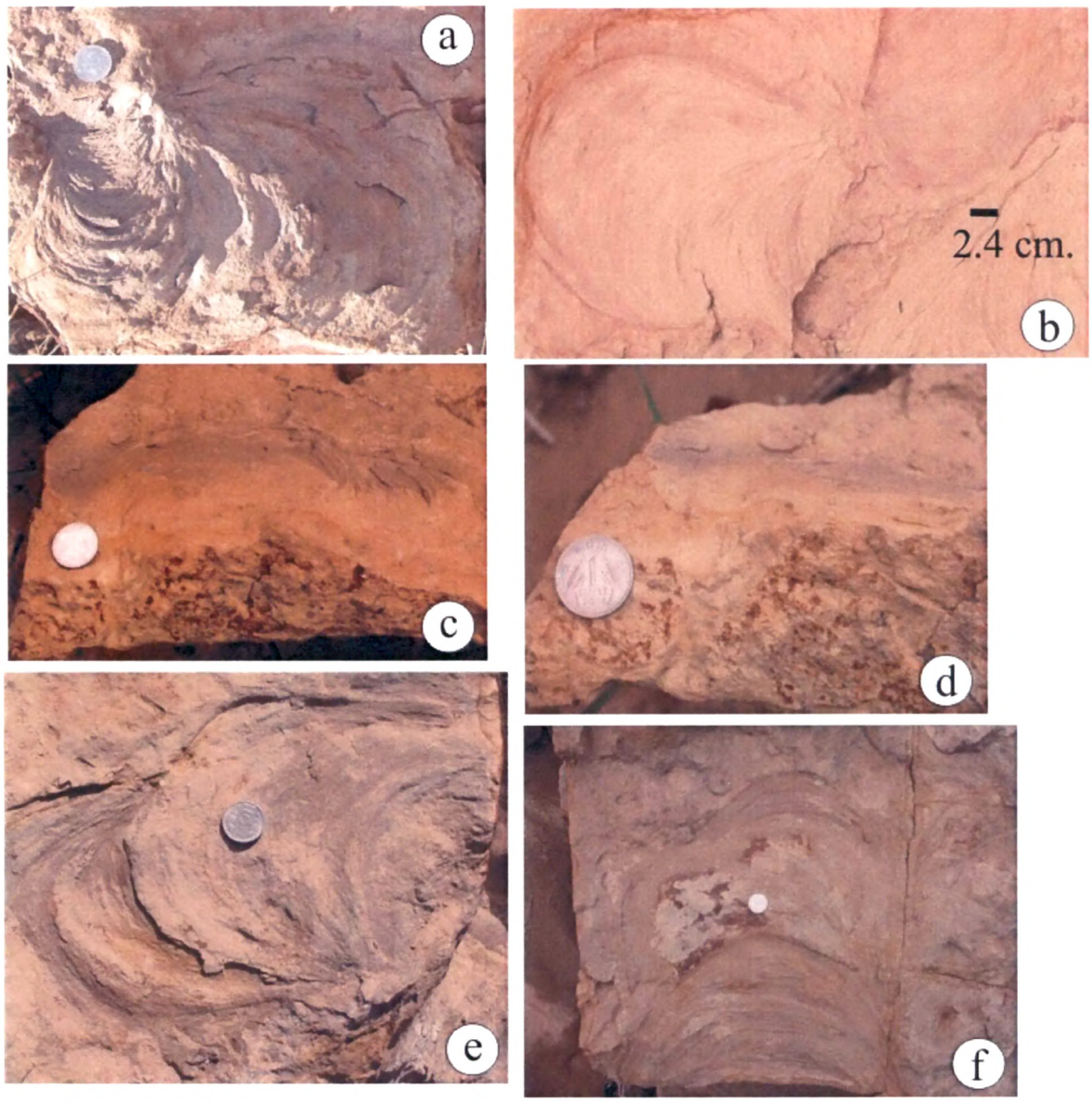


Plate 5.18 a-b) *Zoophycos brianteus*, DOs, Jumara Fm. c-d) *Zoophycos Caudagall*, DOs, Jumara Fm. e-f) *Zoophycos circinnatus*, DOs, Jumara Fm.

composed of a series of light and dark colour and slightly asymmetrical crescentic laminae which represent the outline of hemi-cylinders. The broader crescentic bands form a number of sub-parallel major laminae from which minor laminae are given off at an acute angle. The burrow, which is usually constant in diameter, terminates either by merging into the general mass of the rock or by coming to a rounded end. These arcuate laminae are usually between 0.5-2 mm wide but broader ones being 3-5 mm occur at irregular intervals. The width of the burrows is 8-10 cm and up to 60 cm in length. Many of the surfaces covered with *Z.*

laminatus were usually planar but occasionally they were gently curved or inclined a few degrees to the bedding plane.

Remarks: - Only two to three specimens were observed at bedding plane. It has quite identical morphological features of *Z. caudagalli* Hall, 1863 accept it hasn't showed sub-circular longue-like extension.

Occurrence: - It occurs in DOs of Jumara Formation.

Ichnospecies: - *Zoophycos villae* Massalongo, 1855

(Plate 5.19, c)

Diagnosis: - A burrow having planar spreiten structure with arcuate laminae bent in clockwise direction with fan-shaped outline.

Description: - Burrows are fan-shaped and consists of radiating arcuate laminae. Laminae branch at acute angle, distally become broad and bent in clockwise direction. Few specimens show bulging at end. Laminae exhibit major and minor ridges, radiating, curved from the axis of spiral. Major lamellae branch at acute angle expanding distally. Marginal tube is absent. Thickness and width of the lamellae varies from axis to the peripheral zone. Length of the structure is 35 cm and comprises a large number of filaments or bands of .5 to 4 mm in thickness.

Remarks: - Thick radiating laminae characterize this species.

Occurrence: - It occurs in DOs of Jumara Formation.

Ichnospecies: - *Zoophycos* Type A

(Plate 5.19, d)

Description: - Endichnial, full relief, large lobed, gently inclined, spreiten filled loops with single opening. U-shaped spreiten radiating outwards and forming loops which showing concentric pattern. The exterior boundary is lobed or undulatory, giving a floral appearance. Primary laminae are distinct. The successive whorls are deep and well marked. An outer

marginal tube binds the whorls. Structures enlarge exponentially and central margin of each spreiten shifts and forms curved axis which is parallel to the general growth of the structures.

Occurrence: - It occurs in DOs of Jumara Formation.

Ichnospecies: - *Zoophycos* Type B

(Plate 5.19, e)

Description: - The specimen shows endichnial, planar relief with multi lobes. The axial tube has a single opening along which the coils are occurring in spiral fashion. The first level of whorls is smaller in diameter while the next level becomes wider and longer as the animal moves further downward and outward to exploit the sediments. Marginal tube is prominent. Numerous arched lamellae are present. Irregular, circular and concentric striae form an assemblage in the form of a leaf; 8-10 cm in diameter.

Occurrence: - It occurs in DOs of Jumara Formation.

Ichnospecies: - *Zoophycos* Type C

((Plate 5.19, f and Plate 5.20, a)

Description: - Helicoidal form with 'U'- shaped, endichnial burrows. In Plate (5.20, a) the whorls emanate outward from a common point, moving in different and opposite directions. In Plate (5.19, f) the tube is U-shaped with wide spaced openings at a distance of ~ 12 cm. Laminae show a dotted texture which may be preservational or may be due to fecal pellets. Primary and secondary lamellae are present. Marginal tube is present but is not very distinct.

Occurrence: - It occurs in DOs of Jumara Formation.

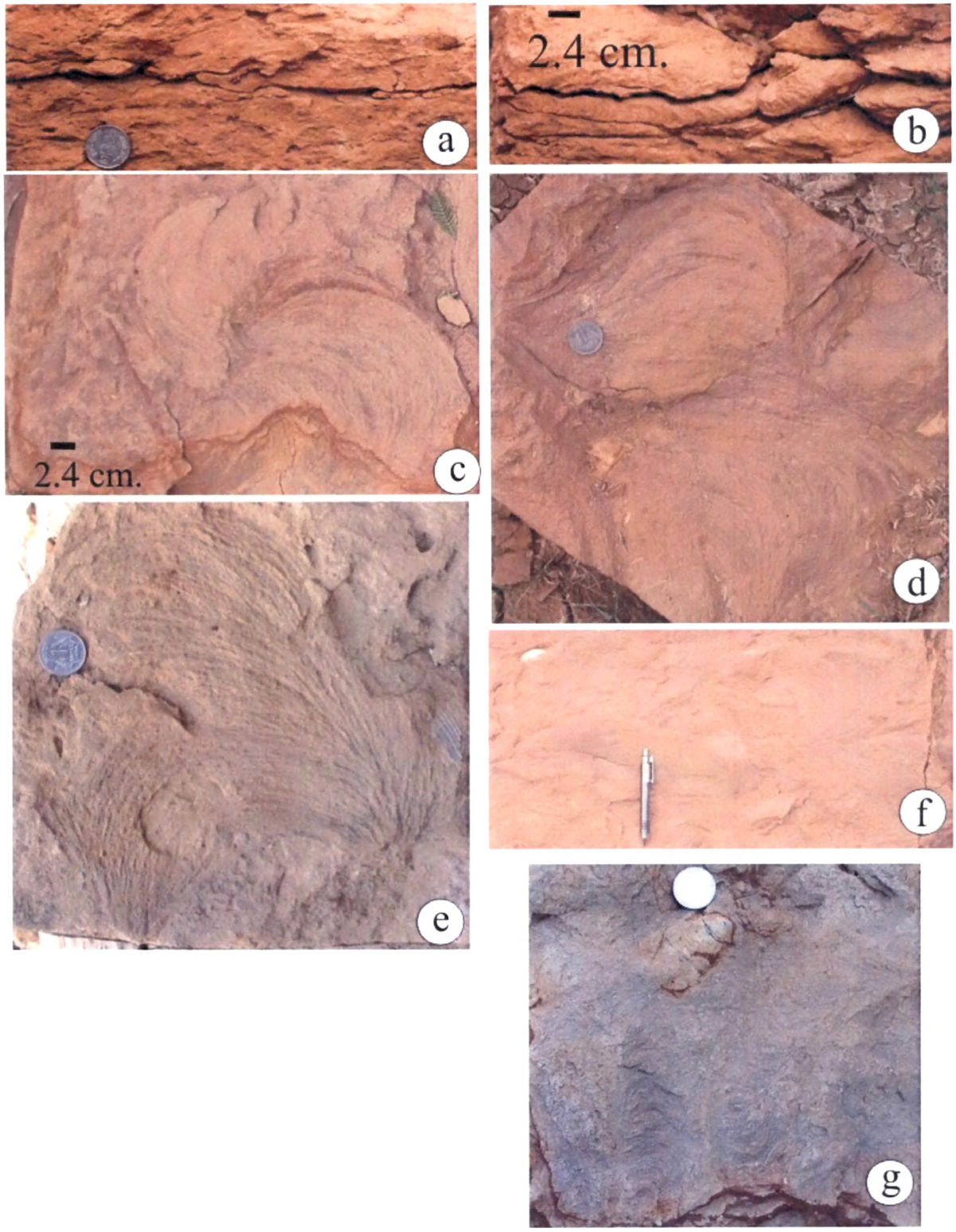


Plate 5.19 a-b) *Zoophycos laminatus*, DOs, Jumara Fm. c) *Zoophycos villae*, DOs, Jumara Fm. d) *Zoophycos Type A*, DOs, Jumara Fm. e) *Zoophycos Type B*, DOs, Jumara Fm. f) *Zoophycos Type C*, DOs, Jumara Fm. and g) *Zoophycos insignis*, DOs, Jumara Fm.

Ichnospecies: - *Zoophycos* Type D

(Plate 5.20, b)

Description: - Single opening, lobed large U-shaped spreiten loops, showing concentric pattern. The lobe is elongated, up to 20 cm long, usually rimmed by thin marginal tube. The exterior boundary is lobed or undulatory, giving a floral appearance. Primary laminae are indistinct. The successive whorls are deep and well marked. An outer marginal tube binds the whorls. Burrow fill is darker material than the surrounding.

Occurrence: - It occurs in DOs of Jumara Formation.

Ichnospecies: - *Zoophycos* Type E

(Plate 5.20, c)

Description: - Endichnial, full relief specimen showing two planar spreiten emanating from a single, oblique tube. The spreiten fan out in different directions at acute angles from the tube. Marginal tube is not present. Primary lamellae are prominent.

Occurrence: - It occurs in DOs of Jumara Formation.

General Remarks: - - The classification of *Zoophycos* on the specific level is not an easy task. Several authors have created many species, based on the shape of the lobes and whorls, and the width and the manner of branching. A variety of morphotypes of *Zoophycos* are recorded from the study area signifying a wide range of behaviour pattern. Some of the specimens are identifiable at the species level but most are described as Type A, B and so on within the genus. The organisms producing *Zoophycos* traces are not definitely known and great speculation abounds regarding the producing animal. There are also various views regarding the nature of the trace although majority of the opinion favours a *Fodinichnial* structures.

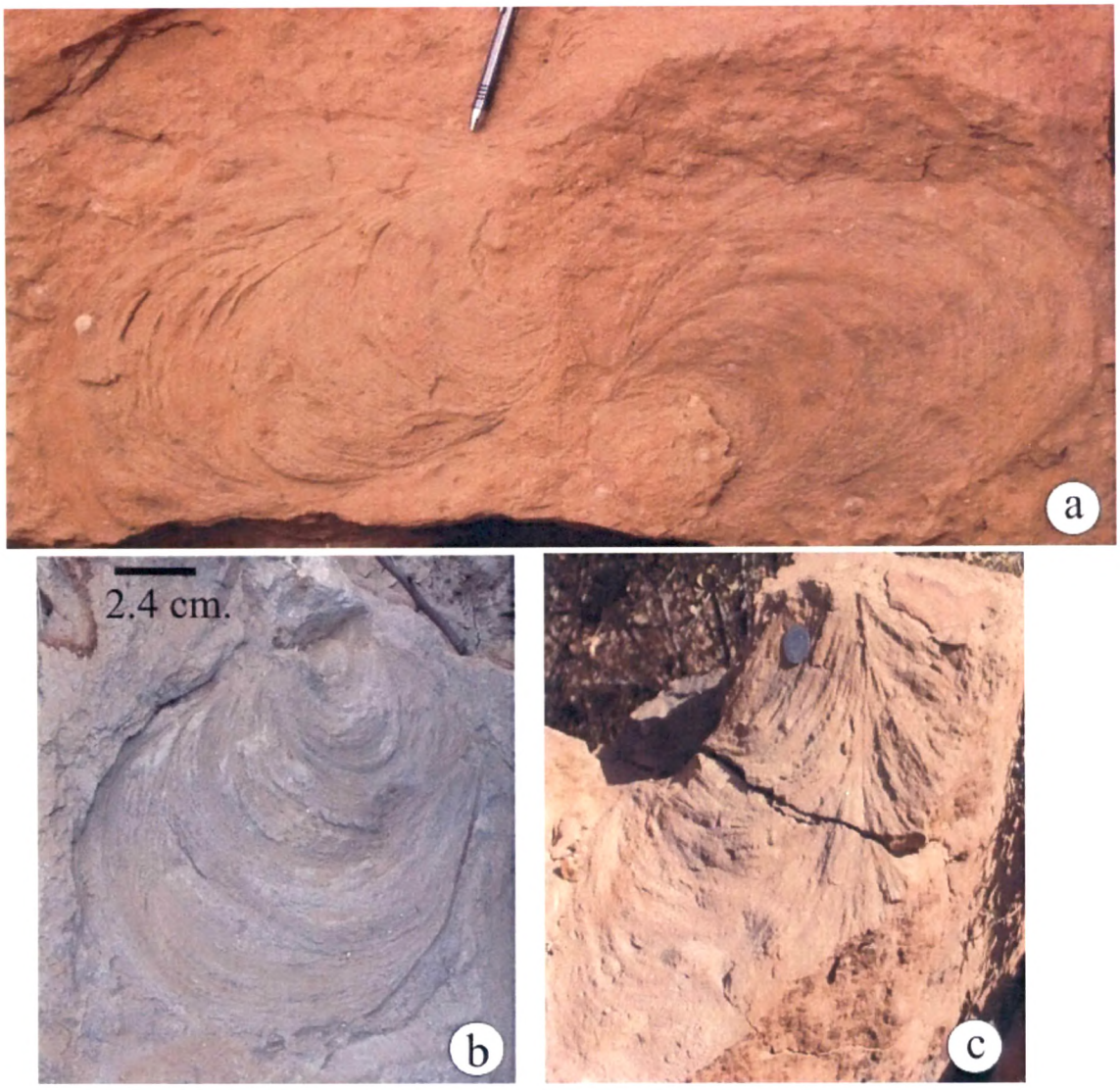


Plate 5.20 a) *Zoophycos Tpye C.*, DOs, Jumara Fm. b) *Zoophycos Type D*, DOs, Jumara Fm. And c) *Zoophycos Type E*, DOs, Jumara Fm.

I.8. Radial Structures

I.8.1 Radial Forms with Vertical Shafts

Ichnogenus: - *Parahentzschelinia* Chamberlain, 1971a

Diagnosis: - A burrow system composed of numerous vertical shafts radiating vertically from one master-shaft. It may be preserved on interfaces as group of oval to circular pits, mounds, bulbs and spots (Uchman 1995).

Ichospecies: - *Parahentzschelinia ardelia* Chamberlain, 1971a

(Plate 5.21, b-c)

Diagnosis: - A single vertical shaft is radiating vertically upwards making flower kind of structure.

Description: - Endichnial, full relief burrow system composed of numerous vertical shafts radiating vertically from one master shaft. Trace fossils occur as small, circular, light coloured spots of about 3-7 mm diameter, randomly distributed. The burrow fills are not identical to the host rock. The vertical shaft is about 2-2.5 cm and inclined to sub-horizontal; radiating shafts are about 2-3 cm in length. As such no filling material is observed. Radiating shafts end with irregular smooth surface without lining.

Remarks: - *P. ardelia* has been identified as Endichnial full burrow in Pennsylvanian deep-water deposits of U.S.A. (Chamberlain 1971). *P. surlyki* is known from Jurassic shallow-water deposits of Greenland (Dam 1990). The first ichnotaxon structure is interpreted as feeding-*Domichnia*l structure, the second one as domichnion (Uchman, 1995).

Occurrence: - It occurs in RMCSSL of Jumara Formation.

Ichnogenus: - *Phoebichnus* Bromley and Asgaard, 1972

Diagnosis: - Central shaft, nearly vertical to bedding with numerous, long, straight radial burros oriented more or less parallel to bedding, radial burrow about 0.5 to 1 cm in diameter without wall lining, total length of shaft and tunnels unknown.

Ichnospecies: - *Phoebichnus trochoides* Bromley and Asgaard, 1972

(Plate 5.21, d)

Diagnosis: - As Ichnogenus

Description: - Two distinct vertical shafts having 1 to 1.5 cm diameter contains straight radial furrows; specimen shows more radial pattern in the left side of vertical shafts rather than right side. Radial furrows are very distinct about 0.2 to 0.3 mm deep having elevated thin sharp ridges on both the sides. They are about 7 to 10 cm long and slightly curved in the end.

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

Occurrence: - It occurs in NWWLs of Jhurio Formation.

I.9 Coiled Structures

Ichnogenus: - *Gyrolithes* De saporta, 1884

Diagnosis: - Dextrally or sinisterly coiled burrows up to few centimetres in diameter, sometimes with rounded or elongate processes which may be branching near upper end; diameter of whorls mostly uniform; vertically oriented; up to several decimetres high (Hantzschel 1975).

Ichnospecies: - *Gyrolithes polonicus* Fedonkin, 1980

(Plate 5.21, e)

Description: - Positive relief traces, silt in filled on silty-sandstone sole consisting of a burrow forming an almost complete circle. In specimen burrow diameter about 20 mm and diameter of complete trace 2 cm. affected by current scour (Crimes and Anderson 1985).

Remarks: - Its coiled burrow lacking in preservation will insist author to describe as *G. Polonicus*

Occurrence: - It occurs in RMCSSL of Jumara Formation.

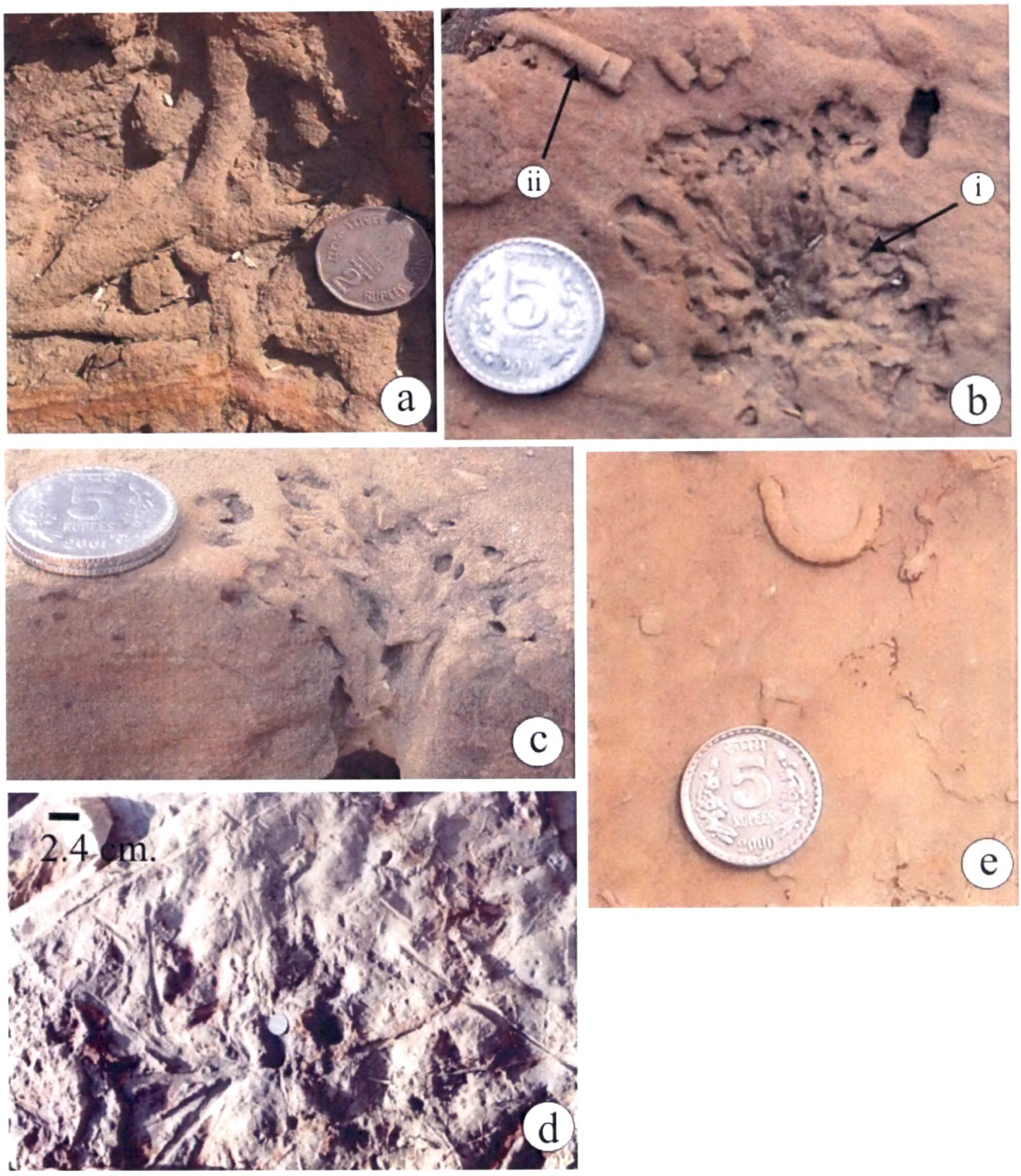


Plate 5.21 a) *Thalassinoides suevicus* GOs, Jhurio Fm. b-i) *Parahentzschelinia ardelia*, and ii) *Palaeophycus heberti,* RMCSSL, Jumara Fm. d) *Phoebichnus trochoides*, NWWLs, Jhurio Fm. and e) *Gyrolithes polonicus*, RMCSSL, Jumara Fm.