CHAPTER - 5

ICHNOLOGY

5.1 INTRODUCTION

Ichnology is the study of fossilized structures produced on or within the sediments by biological activities such as feeding, locomotion, dwelling, fecal pellets, etc. (Bromley, 1996). The fossilized work of an animal reflects the past life activity of an individual organism resulting in modification of the substrate. Ichnology deals with all aspects related to modern (neoichnology) and fossil traces (paleoichnology), bioturbation, and bioerosion, and is interdisciplinary in combining sedimentological, paleontological, biological, and ecological methods (Bromley, 1996). The application of ichnology to sedimentological investigations, particularly the reconstruction of depositional environments, is largely dependent on the exact recognition of ichnotaxa (Knaust, 2012). However, recognition of exact taxa is puzzling until the commendable contribution of Häntzschel (1975) by working on the chaos of synonymy and repetition in the nomenclature and laid the foundation for further studies.

5.2 HISTORICAL BACKGROUND

The concept of ichnology has gained its significance as it is attached to trace fossils in the environmental and diagenetic interpretation of rock units and reconstruction of ancient life and benthic behavioral patterns (Frey and Seilacher, 1980). The application thus does not restrict to the only ichnologist, but paleontologists, palaeobotanists, paleoecologists, sedimentologist, stratigrapher, and petrographer (Pemberton and Frey, 1982). Ichnology, therefore, requires a proper nomenclature system, systematic classification, and ichnotaxonomy. The development of the present nomenclature, however, is not a smooth transition. There are lots of obstacles and hindrances especially the inclusion under the International Commission on Zoological Nomenclature (ICZN) as trace fossils are not bio taxa.

The ICZN ruled that 'names based on the work of an animal that was established after 1930 were to be accompanied by a statement that purports to give characters differentiating the taxon while the taxon identified before shall be retained and treated as body fossil at the 15th International Zoological Congress in 1961 (Article 13(a)(i) of the 1964 edition of the ICZN).

Since the specific affinity of a trace fossil taxon is anonymous, post-1930 names became essentially unavailable which marks the beginning of the Dark Age of ichnotaxonomy (Bromley, 1996).

The debate on the inclusion or exclusion of trace fossils under the domain of ICZN continued. Several zoologists opined the complete removal of trace fossils from ICZN as trace fossils do not perpetuate themselves in natural populations by sexual or asexual reproduction, as do the other objects covered by the code nor are they parataxa in the sense of names applied to parts of an animal, that ultimately can be worked out when the anatomy becomes fully known (Bromley, 1996). Meanwhile, Sarjeant and Kennedy (1973) drafted a completely separate code for trace fossils nomenclature based on ICZN and ICBN which was republished by Sarjeant (1979). However, such an independent trace fossil code has never gained acceptance (Miller, 2007). Häntzschel and Kraus (1972) adopt an alternative route by proposing amendments to the existing code. Finally, the ICZN in its fourth edition, 1999 recognized trace fossils of all kinds including trace fossils of animals, plants, fungi, and microorganisms. Such traces should be treated the same as animal taxa and referred them as ichnotaxas they are not true bio taxa (Miller, 2007). This marks the end of the Dark Age of ichnotaxonomy.

5.3 CLASSIFICATION OF TRACE FOSSILS

Trace fossils are sedimentary structures formed by the activities of organisms mainly invertebrates. These biogenic structures are highly sensitive to ecological changes and a particular suite of trace fossils tends to occur preferentially in a particular environment. As a result, they are highly important in the field of sedimentology, stratigraphy, and paleoenvironment analysis. There are different approaches to studying trace fossils and accordingly they are classified. Preservational classification (Seilacher 1964, Martinson, 1965), ethological classification (Seilacher 1953a, 1964), and morphological classification (taxonomic classification under the International Code of Zoological Nomenclature) are the most widely used classification and are discussed briefly as under.

5.3.1 Preservation classification

Frey and Pemberton, (1985) describe two main preservation facets which include toponomy and physiochemical processes of preservation and alteration. Toponomy is the description and classification of biogenic structures with respect to their occurrence and mode of preservation.

Mode of occurrence defines the position of the structure on or within the stratum, or relative to the casting medium. Toponomy also includes stratinomy – mechanical processes involved in the fabrication of the structure and taphonomy – its alteration.

Stratinomic classification is proposed by Simpson (1957), Seilacher (1964), and Martinsson, (1970). Simpson's Classification (1957) describes four preservational categories: (i) bed junction (trace fossils preserved in relief at a bed junction); (ii) concealed bed junction (individual burrows that appear to be isolated within an interval of different lithology); (iii) diagenetic (ichnofossils preserved as a nodule or nodule protuberances formed during early diagenesis), and burial preservations (filled burrows that have been subsequently exhumed by currents winnowing away the associated soft matrix).

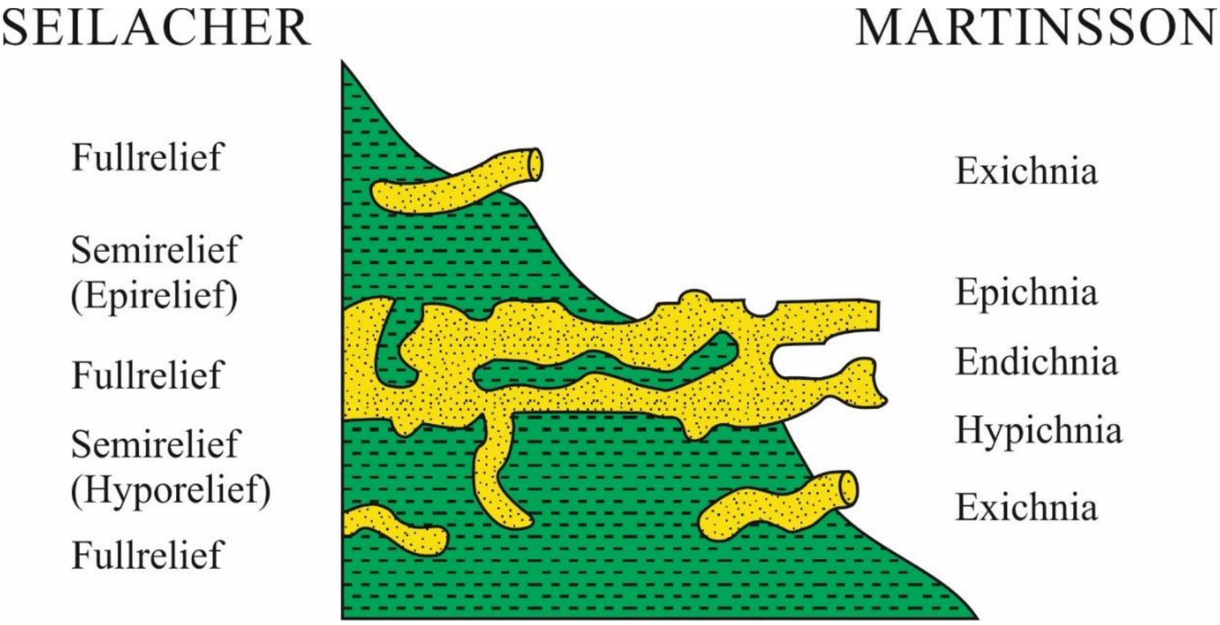

Fig. 5.1 Stratinomic classification of trace fossils (Seilacher, 1964; Martinsson, 1970)

Martinsson's Classification (1965, 1970) is based on the relationship of the trace fossil to the casting medium (Fig. 5.1) (Bromley, 1996). It includes epichnia (preservation in the upper surface), hypichnia (preservation in the lower surface), endichnia (preservation within the casting medium), and exichnia (preservation outside the casting medium).

Seilacher (1964) describes the preservation of trace fossils in two separate sets, descriptive (Fig. 5.1) and genetic terms. Descriptive terms describe the relationship between the trace fossils and the host rock. It includes mainly two categories – full relief (within the sediment) and semi-relief (at the sediment-sediment interface). Semirelief is further subdivided into epirelief (preserved at the top) and hyporelief (preserved at the base). Biodeformation structures are also often used to describe the biogenic disturbance in the sediments. Genetic terms refer to the assumed relationship of the trace fossil to the contemporary surface rather than that of the trace maker which includes exogenic (surficial traces covered by sediment that differs from that of the host layer), endogenic (structures actively or passively filled within the host bed), and pseudoexogenic (traces formed in a homogeneous medium).

Physiochemical processes of preservation and alteration fall within the realm of diagenesis, and can be quite variable and complex (Buatois and Mángano, 2011). The diagenetic effect of the trace fossils is poorly understood hitherto, however, it gained an increased recognition of their importance (Simpson, 1957; Frey, 1975; Bromley and Ekdale, 1984; Frey and Pemberton, 1985; Bromley, 1990, 1996; Schieber, 2002; McIlroy et al.,2003; Pemberton and Gingras, 2005; Needham et al., 2006).

Trace fossils provide a tangible animal behavioral activity and are the most natural way to classify them according to their behavioral pattern (Bromley, 2012). It is one of the most commonly used methods of classification in ichnological studies. The ethological classification was originally proposed by Seilacher (1953) consisting of five behavioral categories representing the basic building blocks of behavioral interpretations. These categories include 'cubichnia' for resting traces, 'repichnia' for locomotion traces, 'pascichnia' for grazing traces, 'fodinichnia' for feeding traces and 'domichnia' for dwelling traces. However, this classification often overlaps and with additional information, constant modifications and alterations have been proposed by several workers to include additional behavioural categories. The additional major behavioral categories include fugichnia, (Frey, 1973) for escape traces, agrichnia (Ekdale et al.,1984) for farming traces and traps, praedichnia (Ekdale, 1985) for predation traces, equilibrichnia (Bromley, 1990) for equilibrium traces, chemichnia (Bromley, 1996), calichnia (Genise and Bown, 1994a), aedifichnia (Bown and Ratcliffe, 1988) for nesting traces. Behavioral categories such as pupichnia (Genise et al.,2007) for pupation chambers, fixichnia (Gibert et al., 2004) for fixation/anchoring traces, xylichnia, and mortichnia (Seilacher 2007) for death traces, etc. are considered subcategories.

5.4 ICHNOTAXONOMY

The description and identification of objects (biological and paleontological) based on taxobases is called taxonomy. In the case of trace fossils, it is called ichnotaxonomy. Ichnotaxonomy, the manner in which to name and classify trace fossils, has been the subject of many proposals and discussions (see Miller,2012; Rindsberg, 2012). The lack of a consistent classification scheme for trace fossils often hinders integrated studies in which ichnological information is fully employed in sedimentological analysis (Knaust, 2012). Häntzschel (1975) attempted systematic ichnology by listing ichnogenera in alphabetical order while other workers attempted based on ethology (Chamberlain, 1971; Gibert et al.,2004; Krejci-Graf, 1932), supposed producers (Dzik, 2005, 2007; Lessertisseur, 1956; Vialov, 1968), preservation (Martinsson, 1965, Seilacher, 1964), overall morphology (Książkiewicz,1970, 1977; Richter, 1927; Simpson, 1975), or a combination (Seilacher,1953; Zherikhin, 2003). Workers like Gong and Si (2002) attempted to use topological parameters as the basis for the classification and evolution of metazoan traces.

The ethological approach for ichnotaxonomy gain popularity as purely morphological classification, without references to any ethological model and without taphonomic interpretation, which seems to be one of the dead ends of ichnotaxonomy (Uchman, 1998). Some workers (Schlirf, 2000; Seilacher, 2007; Trewin, 1994; Uchman, 1995, 1998) continue the morphological approach as the morphological characteristics have the advantage of being descriptive and independent from the behavioural interpretation and promote morphological grouping toward higher ichnotaxonomic levels (Knaust, 2012).

An ichnotaxobases approach is also applied by workers (see Bromely, 1990, 1996; Knaust, 2012) and it attempts to establish and apply the specific criteria for naming trace fossils, the so-called ichnotaxobases (Bromley, 1990). The most commonly used bases of ichnotaxa are (1) general form; (2) wall and lining; (3) branching; and (4) fill (Bromley, 1996). Bromley (1996) coined that the general form describes shape and orientation such as vertical, meandering, spreite, etc; Wall and lining describe the details of the burrow boundary such as no lining, dust film, constructional lining, zoned filled, wall compaction, diagenetic haloes, etc.; branching includes true branch, false branch and intersection (Bromley, 1974); while fill describes filling material and structure either passive or active. For tracks, detailed criteria include internal versus external width, number, and angle of a foot or claw imprints (Anderson,

Sub Horizontal	**Sub Vertical**	**Complex**
Asterosoma isp.	*Arenicolites* isp	*Hillichnus lobosensis*
Curvolithus isp.	*Arenicolites carbonarius,*	*Ophiomorpha annulata*
Curvolithus multiplex	*Chondrites targionii*	*Ophiomorpha rudis*
Curvolithus simplex	*Chondrites intricatus*	*Ophiomorpha* isp
Didymaulichnus cf parallelum	*Diplocraterion* isp.	*Thalassinoides* isp.
Didymaulichnus lyelli,	*Laevicyclus parvus*	*Thalassinoide horizontalis.*
Gyrochorte comosa	*Lockeia silliquaria,*	*Thalassinoides paradoxicus.*
Halopoa imbricata,	*Monocraterion tentaculatum*	
Helicolithus sampelayoi,	*Skolithos* isp.,	
Megagrapton irregular	*Skolithos linearis,*	
Palaeophycus anulatus	*Skolithos verticalis*	
Palaeophycus heberti?		
Palaeophycus tubularis,		
Phycodes curvypulmatum,		
Phycodes palmatus		
Planolites baverleyensis		
Planolites montanus		
Protovirgularia isp.		
Protovirgularia oblitrata,		
Rhizocorallium commune var auriform *Rhizocorallium commune* var *irregulare,* *Rhizocorallium commune* isp.		
Rhizocorallium, isp		
Taenidium isp		
Taenidium serpentinum		

Table 5.1 Trace fossils are classify based on ichnotaxobases approach (Knaust, 2012).

1981; Trewin,1994). Knaust (2012) applied Bromley's (1996) bases and proposed a nomenclature key to organized key ichnotaxa with respect to their ichnotaxobases for the determination of major groups of trace fossils down to the ichnogenus level. He highlighted the advantage of his proposed nomenclature key such as easing the identification of synonymous or established ichnotaxa when planning new descriptions or revisions, facilitating the assessment of the deployed ichnotaxobases for certain trace-fossil groups, and ease of continuously updating, improving, and extending in terms of ichnospecies, geological ages, key references, figures, locality information. This ichnotaxobases approach proposed by Knaust, 2012 will be adopted for describing the ichnotaxonomy of the study area as shown in Table- 5.1.

5.5.1 Orientation: Subhorizontal Burrows

Branching: Branched

Shape: Radial

Fill: Passive

Burrow Wall: Lined

Ichnogenus *Asterosoma* Von Otto, 1854

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

Ichnospecies: *Asterosoma* isp.

(Plate 5.1a)

Description: Sub-horizontal bulbs showing radial or star-like orientation with tapering ends; preserved as full relief; walls show longitudinal furrows with a sub-central inner tube. The bulbs are cylindrical with tapering ends with varying lengths of 3.3 cm to 3.5 cm; the width is 0.7 cm.

Plate 5.1 (a) Sub-horizontal protruding bulbus tubes of *Aesterosoma* isp. in sandy allochemic limestone facies of Hadibhadang Sandstone Member of Khadir Formation in the Chorar Island (Scale: coin diameter = 2.3 cm). (b) Faintly preserved trilobate *Curvolithus multiplex* (arrow) in sandy allochemic limestone of Hadibhadang Sandstone Member in Chorar Island (Scale: coin diameter = 2.3 cm). (c) *C. multiplex* (arrow) in sandy allochemic limestone of Ratanpur Sandstone Member in Khadir Island. (d) trilobate *Curvolithus simplex* in micritic sandstone of Bambhanka Member in Kakinda Bet. (e) Partially preserved trilobate *Curvolithus* isp. in sandy allochemic limestone of Hadibhadang Sandstone Member in Chorar Island (Scale: coin diameter = 2.3 cm).

Occurrence: Sandy allochemic limestone facies of Hadibhadang Sandstone Member of Khadir Formation in the Chorar Island (Plate 5.1a).

Remarks: The finger-like protruding resembles *Phycodes,* however the bulbous nature of the petal restricts it to *Asterosoma*. The present specimen shows sub-horizontal bulbs radiating but the five usually common petals of *Asterosoma radiciforme* are not visible due to lack of complete preservation, therefore the nomenclature for species has been kept open and the specimen is described here as *Asterosoma* isp. The tubular nature and manner of sediment working in *Asterosoma* are generally considered the feeding structures of deposit feeders (Dawson, 1890).

Branching: Unbranched

Shape: Trilobate

Fill: Active

Burrow Wall: No lining

Ichnogenus: *Curvolithus* Fritsch, 1908

Type ichnospecies: *Curvolihus multiplex* by subsequent designation (Häntzschel, 1962, p.W189).

Diagnosis: Straight to curved, horizontal, subhorizontal to rarely oblique, ribbon like or tongue like, flattened, unbranched, essentially endostratal traces with three rounded lobes on upper surface and up to four lobes on concave or convex lower surface. Central lobe on upper surface wider than outer lobes and separated from them by shallow, angular furrows. Faint, narrow central furrow dividing the central lobe in the upper surface may be present (Buatois, Mangano, Mikuláš, 1998).

Ichnospecies: *Curvolithus multiplex* Fritsch, 1908

(Plate 5.1b-c)

Diagnosis: *Curvolithus* with a smooth, trilobate upper surface and a convex, quadra lobate lower surface (Buatois, et al., 1998).

Description: Hypichnial, slightly curved, bilobate to trilobate sub-horizontal, ribbon-like structure. The median furrows are faintly visible. The trilobate annulation of the burrows is preserved locally and faintly visible in the distal end. The width of the burrow varies from 0.6 cm to 0.8 cm while the length varies from 4.7 cm to 6.2 cm.

Occurrence: It is observed in sandy allochemic limestone facies of Hadibhadang Sandstone Member of Khadir Formation in Chorar Island (Plate 5.1b) and Ratanpur Sandstone Member (plate 5.1c) of Gadhada Formation in Khadir Island,).

Remarks: *Curvolithus* is horizontal to sub-horizontal traces which can be distinguished from similar forms by its trilobate upper surface (Buatois et al.,1998). It is an endostratal structure commonly occurring parallel to the bedding plane and then obliquely inclined into another bedding plane (Buatois et al.,1998). *Curvolithus* is interpreted as a locomotory trace of carnivorous gastropods (Heinberg, 1973), flatworms (Seilacher, 1990), or scavenging gastropods (Buatois et al.,1998). *Curvolithus* locomotory trails of an infaunal predatory or scavenging gastropods. (Buatois et al.,1998).

Ichnospecies *Curvolithus simplex* Buatois, Mangano, and Mikuláš, 1998
(Plate 5.1d)

Diagnosis: *Curvolithus* with a smooth, trilobate upper surface and a smooth, unilobate to trilobate, concave or convex lower surface.

Description: Horizontal to subhorizontal, ribbon like winding trace fossil with trilobate upper surface from hypichnial view. The central lobes form the largest lobe and are slightly flattened upper surface while the side lobes have a partially convex upper surface. The width of the central lobe is about 3.6 mm while the side lobe is about 1- 2 mm.

Occurrence: *Curvolithus* is observed at different stratigraphic levels. In Khadir Island, it is observed in micritic sandstone of Bambhanka Member (Plate 5.1d) and sandy allochemic limestone of Ratanpur Sandstone Member.

Remarks: *Curvolithus simplex* can be differentiated from *C. multiplex* by the absence of quadralobe on the lower surface (Buatois et al.,1998). *Curvolithus* indicate the activity of worms (Heinberg, 1973) and carnivore gastropods, flatworms or nemerteans (Buatois et al.,1998),

Ichnospecies: *Curvolithus* isp.
(Plate 5.1e)

Description: Slightly curved, trilobate subhorizontal, ribbon-like structure. The trilobate structure is faintly visible due to thixotropic conditions. The tube is 4.6 cm in length with a width of 0.4 cm.

Occurrence: The specimen is observed in sandy allochemic limestone of Hadibhadang Sandstone Member of Khadir Formation in Chorar Island (Plate 5.1e).

Discussion: *Curvolithus* is interpreted as repichnia (locomotion trace) produced probably by carnivorous gastropods (Heinberg, 1973). *Curvolithus* are formed in shifting sediments with little cohesion, and thus have a little preservation potential (Buatois et al.,2017). Its occurrence is significant for palaeoenvironmental interpretation as it is restricted to shelf environment between fair-weather wave base and storm weather wave base which is the characteristic feature of *Cruziana* Ichnofacies (Buatois et al.,2017).

Branching: Unbranched

Shape: Bilobate

Fill: Passive

Burrow Lining: No lining

Ichnogenus: *Didymaulichnus* Young, 1972

Type Ichnospecies: *Fraena lyelli* Rouault, 1850.

Diagnosis: Smooth, furrow-like horizontal trails or burrows, bisected longitudinally by a narrow median groove if preserved in hyporelief (Fillion and Pickerill, 1990).

Ichnospecies: *Didymaulichnus lyelli* Rouault, 1850

(Plate 5.2a-b)

Diagnosis: Same as the Ichnogenus

Description: Long, straight to gently curved, simple, smooth bilobate trails consisting of two distinct lobes separated by a median depression. Preserved in convex hyporelief; lacks ornamentation and is parallel to the bedding plane. The length of the trail is 9.0 cm and the width is 0.4 cm.

Occurrence: *Didymaulichnus lyelli* is observed in sandy allochemic limestone facies of Hadibhadang Sandstone Member of Khadir Formation in Bela and Chorar Island (Plate 5.2a) while in micritic sandstone facies of Bambhanka Member (Plate 5.2b), in Kakinda Bet.

Remarks: This ichnospecies is assigned *Didymaulichnus lyelli* due to its lack of a) marginal bevels characteristics of *D. miettensis*, (Young, 1972); b) alternating burrow depths characteristic of *D. alternatus*, (Pickerill et al.,1984); c) lateral ridges characteristics of *D. rouaulti* (Lebesconte, 1883) and d) marginal bevels and larger size characteristics of *D.*

tirasensis with repeated deepening and shallowing and exhibit overlap and imbrication (Palij, 1974).

Ichnospecies: *Didymaulichnus alternatus* Pickerill, Romano and Meléndez 1984
(Plate 5.2c)

Diagnosis: Smooth, straight, gently curved to slightly sinuous *Didymulichnus* burrows composed of alternating deep and less deeply impressed sections giving the burrow a step-wise or castellated longitudinal section.

Description: Gently curved, long, bilobate structure with alternating deep and less deeply impressed sections. The burrow is preserved as hypichnial with a width of 0.15 cm each. The total length of the burrow is not preserved; however, the exposed burrow extends up to 14.1 cm long.

Occurrence: It is observed in sandy allochemic limestone facies of Bambhanka Member in Kakinda Bet (Plate 5.2c).

Remarks: *Didymaulichnus alternatus* can be differentiated from other ichnospecies by the presence of alternating high lows in the trail (Pickerill et al.,1984).

Branching: Unbranched
Shape: Bilobate
Fill: Active
Ichnogenus: *Gyrochorte* Heer1865

Diagnosis: Wall-like burrow with a top part (positive epirelief) consisting of two convex lobes with a median furrow and a bottom part (negative hyporelief) consisting of two grooves and a median ridge. The lobes on the top (and more rarely the grooves at the base) commonly exhibit transverse meniscus-like discontinuities and often obliquely aligned plaits. The internal structure (when recognizable) is constituted of repetitive biconvex-up modular units (spreiten). The burrow exhibits an irregular meandering or arcuate course, but more rarely it can be straight or gently curved. It is typically preserved as epichnial bilobate ridges associated with equivalent hypichnial bilobate grooves, both following the same path and corresponding to the same burrow. More rarely preserved as full reliefs (endichnia) (Gibbert and Benner 2002).

Plate 5.2 (a) *Didymaulichnus lyelli* with faint median groove observed in sandy allochemic limestone facies of Hadibhadang Sandstone Member of Khadir Formation in Chorar Island. (b) *D. lyelli* (Dy) with distinct median groove observed in association with *Rhizocorallium* (Rh) in micritic sandstone facies of Bambhanka Member. (c) Sinous, *Didymaulichnus alternatus* in micritic sandstone facies of Bambhanka Member in Kakinda Bet showing faintly preserved undulating bilobate structure as shown by the dashed line (Scale: coin diameter = 2.3 cm). and (d) Bilobate *Gyrochorte comosa* in Hadibhadang Sandstone Member of Khadir Formation in Chorar Island (Scale: coin diameter = 2.3 cm).

Ichnospecies: *Gyrocorte comosa* Heer1865

(Plate 5.2d)

Diagnosis: Same as ichnogenus

Description: Winding ridges and tunnels, bilobate trails consist of two lobes showing a biserial arrangement separated by a median furrow. Each lobe consists of uniformly developed obliquely aligned pads. The angle between the pads and the main furrow is 86°. The trails are winding straight and cross over each other frequently in such a way that the earlier formed ridges are not destroyed. The length is 10 cm and the width is 0.37 cm.

Occurrence: Micritic sandstone facies of Hadibhadang Sandstone Member of Khadir Formation in Chorar Island (Plate 5.2d) and Bambhanka Member in Kakinda Bet.

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

Branching: Unbranched
Shape: Cylindrical ridge like
Fill: Active
Burrow lining: Unlined
Ichnogenus: *Halopoa* Torell, 1870

Diagnosis: Long, generally horizontal trace fossils covered with longitudinal irregular ridges or wrinkles, which are composed of several imperfectly overlapping cylindrical probes (Uchman, 1998).

Ichnospecies: *Halopoa imbricata* Torell, 1870
(Plate 5.3a)

Diagnosis: Unbranched *Halopoa* with horizontal, relatively long, and continuous furrows and wrinkles (Uchman 1998).

Description: Hypichnial cylindrical full relief burrows, with hardly any terminations, 12cm long, straight, 0.83cm wide, covered with wrinkles irregularly along the length. The wrinkles are thin, continuous along the length of the burrows. They are then replaced by other wrinkles, not necessarily prolongation. The diameter of the tube is not constant.

Occurrence: Sandy micrite facies of Hadibhadang Sandstone Member of Khadir Formation in Chorar Island (Plate 5.3a).

Remarks: The longitudinal striation may be produced actively by locomotory organs and/or passively by body appendages of the trace maker (Uchman, 1998). The specimen appears similar to *Palaeophycus striatus,* however, it lacks a distinct wall and burrows opening. Therefore, it does not conform to the concept of *Palaeophycus* of Pemberton and Frey (1982). The burrow shows continuous horizontal furrows and wrinkles which are the characteristics of *Halopoa imbricata* (Uchman, 1998), produced by deposit-feeding annelids (Birkenmajer, 1959). *H. imbricta* can be differentiated from *H. annulata* by the absence of branch and perpendicular contraction.

Plate 5.3 (a) Irregularly wrinkled *Halopoa imbricata* in sandy micrite facies of Hadibhadang Sandstone Member in Chorar Island (Scale: coin diameter = 2.3 cm). (b) Equidimensional grooves arranged in linear fashion at equidistant of *Helicolithus sampelayoi,* in micritic sandstone facies of Ratanpur Sandstone Member in Bela Island (Scale: coin diameter = 2.3 cm)

Branching: Unbranched

Shape: Spiral

Fill: Passive

Burrow wall: Unlined

Ichnogenus: *Helicolithus* Azpeitia Moros, 1933

Type Ichnospecies: *Helicolithus sampelayoi* Azpeitia Moros, 1933

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

Ichnospecies: *Helicolithus sampelayoi*,Azpeitia Moros, 1933

(Plate 5.3b)

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

Description: Hypichnial, a small, horizontal, zigzag pattern that is twisted in a corkscrew pattern forming meandering right and left turns, in either the case it appears as parallel ridges or grooves, but another turn is always concealed, in some cases right and left turns exposed on the surface and appear as zigzag patterns. It consists of about 8-9 parallel grooves.

Occurrence: It occurs in the sandy allochemic limestone of Ratanpur Sandstone Member in Bela Island (Plate 5.3b).

Remarks: *Heilicolithus* is described as graphoglyptid agrichnion similar to *Helicodromites* (Berger, 1957) but much smaller in size (Seilacher, 2007). It differs from *Helicolithus tortuous* (Książkiewicz 1970) as the latter is long with sigmoidal helicoidal turns (Seilacher, 2007). The *Helicolithus sampelayoi* is short and shows simple short helicoidal undulations in the deeper part (Uchman, 1999).

Branching: Complex

Shape: Network

Fill: Passive

Burrow wall: Unlined

Ichnogenus: *Megagrapton* Książkiewicz,1968

Diagnosis: Trace fossils are commonly preserved as hypichnial irregular nets (Uchman, 1998).

Ichnospecies: *Megagrapton irregulare* Książkiewicz, 1968

(Plate 5.4a)

Diagnosis: *Megagrapton* with meshes bordered by only slightly winding strings, which commonly branch at an approximately right angle (Uchman, 1998).

Description: Irregular networks consisting of hypichnial irregular polygons and rectangles which are never closed, formed by slightly curved or straight cylindrical strings 0.2 cm wide; branching at regular intervals at nearly right angles.

Occurrence: Sandy allochemic limestone facies of Hadibhadang Sandstone Member of Khadir Formation in Chorar Island (Plate 5.4a).

Remarks: *Megagrapton irregulare* can be easily differentiated from *M. submontanum* (Azpeitia Moros, 1933) as the later branch in acute angles with winding strings (Uchman, 1998). Siedlecka (1967) and Roberts (1969) interpreted as deep-water conditions based on sedimentological criteria. It is considered to be constructed as back-filled probes and spreiten by infaunal deposit-feeders (William Miller III, 1986) in a deep-water environment (Uchman et al.,2005).

Branching: Unbranched

Shape: Cylindrical, ridge-like

Fill: Passive

Burrow Wall: Lined

Ichnogenus: *Palaeophycus* Hall, 1847

Type ichnospecies: *Palaeophycus tubularis* Hall, 1847

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

Ichnospecies: *Palaeophycus tubularis,* Hall, 1847

(Plate 5.4b-d)

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

Description: Endichnial or hypichnial, straight, cylindrical, smooth, unbranched, long, unornamented, and thinly lined burrows which occur parallel to slightly oblique to the bedding plane. The length of burrows varies from 5.0 to 12.0 cm and the diameter remains constant throughout the burrow length.

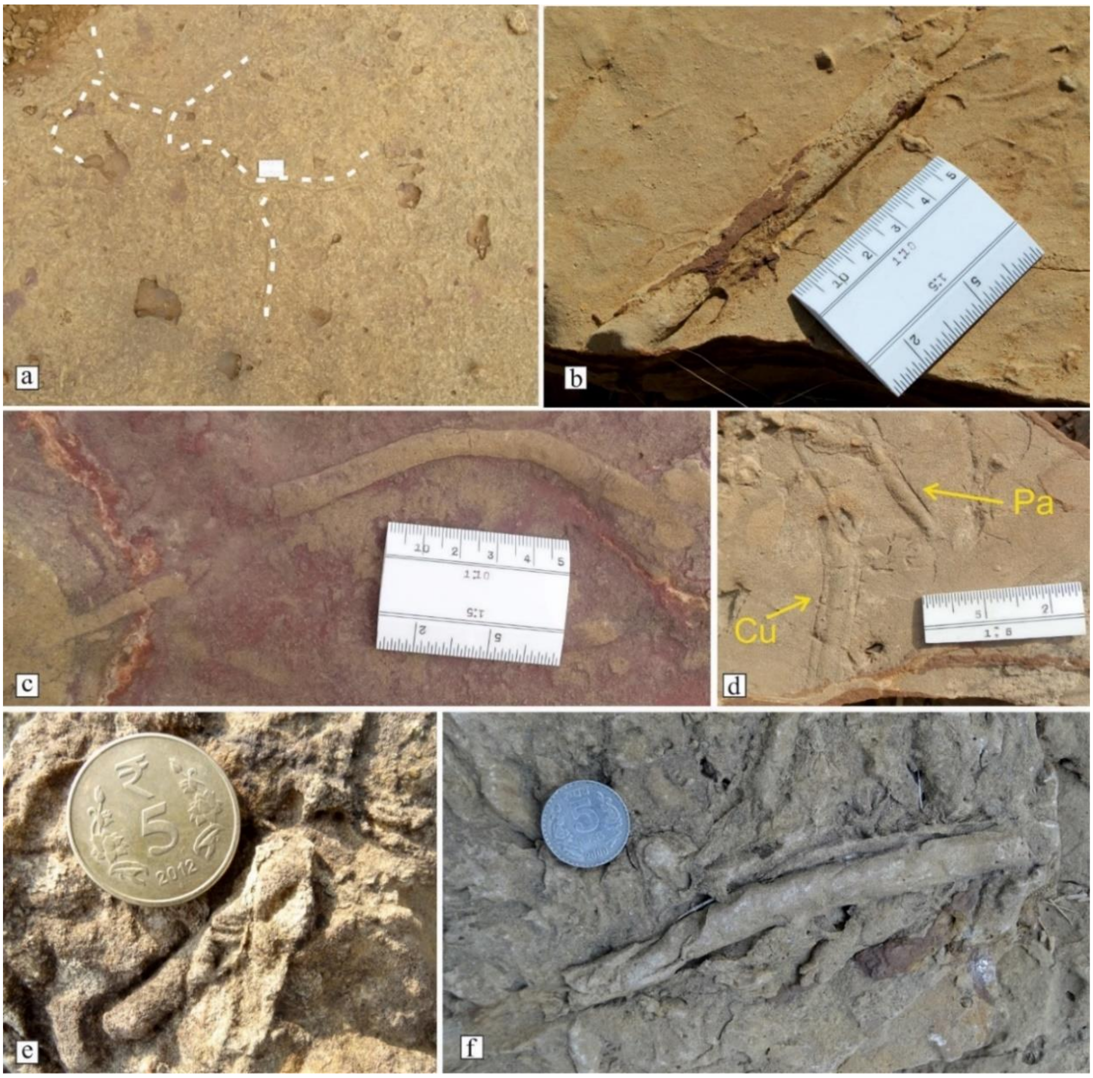

Plate 5.4 (a) *Megagrapton irregulare* branching almost perpendicularly in sandy allochemic limestone facies of Hadibhadang Sandstone Member in Chorar Island (represented by dotted lines). (b) Horizontal thin lining *Palaeophycus tubularis* (pa) in sandy allochemic limestone facies in Ratanpur Sandstone Member in Bela Island. (c) *P. tubularis* in ferruginous sandstone facies in Ratanpur Sandstone Member in Chorar Island. (d). *P. tubularis* (Pa) in association with *Curvolithus simplex* (Cu) in micritic sandstone facies of Bambhanka Member in Kakinda Bet. (e) Thickly lined *P. heberti* in sandy allochemic limestone of Hadibhadang Sandstone Member in Chorar Island (Scale: coin diameter = 3.2 cm). (f) Horizontal *P. heberti* with thick lining which is preserved as a groove around the central tube, observed in peloidal packstone/grainstone of Ratanpur Sandstone Member, in Khadir Island (Scale: coin diameter = 3.2 cm).

Occurrence: It is observed in sandy allochemic limestone facies of Ratanpur Sandstone Member in Khadir and Bela Islands (Plate 5.4b) and sandy allochemic limestone facies Hadibhadang Sandstone Member of Khadir Formation in Chorar Island (Plate 5.4c) and micritic sandstone facies of Bambhanka Member in Khadir Island (Plate 5.4d).

Remarks: The given ichnospecies *Palaeophycus tubularis* is distinguished from *P. striatus* (Hall 1852), *P. sulcatus,* and *P. alternatus* (Pemberton and Frey, 1982) by its thin wall-lining and absence of continuous parallel, anastomosing or alternate and annulate striae (Pemberton and Frey, 1982).

Ichnospecies: *Palaeophycus heberti* Saporta 1872
(Plate 5.4e-f)

Diagnosis: Smooth, unornamented, thickly lined cylindrical burrows.

Description: Endichnial or hypichnial, straight to slightly curved, unbranched, smooth-walled/ unornamented cylindrical burrows; with thick wall linings. The burrow lining may often form the major part of the structure. The length of the burrow extends up to 17.0 cm with a diameter of about 1.0 cm.
Occurrence: It is observed sandy allochemic limestone of Hadibhadang Sandstone Member in Chorar Island (Plate 5.4e) and peloidal packstone/grainstone of Ratanpur Sandstone Member in Khadir Island (Plate 5.4f).

Remarks: *Palaeophycus heberti* can be distinguished from other ichnospecies by the presence of thick wall lining (Pemberton and Frey, 1982).

Branching: Branched
Shape: Bifurcated or fork
Fill: Active
Burrow wall: No lining
Ichnogenus: *Phycodes* Ritcher 1850
Type Ichnospecies: *Phycodes circinatus* Richer 1853 by subsequent monotype

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

Ichnospecies: *Phycodes curvipalmatum*

(Plate 5.5a)

Diagnosis: Thin, short, rounded, horizontal palmate or digitate burrows that originate from the same point (Pollard, 1981).

Description: Small trifid-branched system of short burrows in convex epirelief and partial endorelief. Each tube bifurcating from the main tube slightly bulges or curved and extends only to a centimeter.

Occurrence: Micritic sandstone of Bambhanka Member of Khadir Formation in Kakinda Bet (Plate 5.5a).

Remarks: The specimen is assigned to *P. curvipalmatum* and not *P. palmatus* because the burrows are short and narrow, whereas *P. palmatus* Hall, 1852 has long and wide burrows (Hammersburg et al., 2018).

Ichnospecies: *Phycodes palmatus* Hall, 1852

(Plate 5.5b)

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

Description: Burrow system is long, palmately branching close together, with branches terminating in a fan-shaped structure. The main tube is about 2.5 cm. The total length is about 12.5 cm. branch tube diameter is nearly about 1.5 cm. maximum branch length is 5 cm.

Occurrence: It occurs in sandy allochemic limestone of Ratanpur Sandstone Member in Bela Island (Plate 5.5b).

Branching: Unbranched
Shape: Cylindrical ridge-like
Fill: Active
Burrow wall: No lining
Ichnogenus: *Planolites* Nicholson, 1873
Type species: *Planolites vulgaris* Nicholson and Hinde, 1875

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

Ichnospecies: *Planolites baverleyensis* Billings, 1862
(Plate 5.5c-f)

Diagnosis: Relatively large, smooth, straight to gently curved or undulate cylindrical burrows (Pemberton and Frey, 1982).

Remarks: The morphology of the burrow resembles the diagnostic characteristics of *Phycodes palmatum* and is thus considered as the ichnospecies. Ethologically, *Phycodes* represent feeding structures of most probably vermiform annelids (Fillion and Pickerill, 1990).

Description: Hyporelief, predominantly cylindrical, smooth-walled, unlined, unbranched, generally straight and rare gently curved burrows, and mostly parallel to the bedding plane with occasional slightly inclined to the bedding plane. *P. baverleyensis* vary in size from different assemblages or occurrences. The length of the burrow varies and can reach up to 22.34 cm and a diameter of about 2.3 cm.

Occurrences: It is observed in sandy allochemic limestone facies of Hadibhadang Sandstone Member of Khadir Formation (Plate 5.5c) and cross-bedded white sandstone facies and ferruginous sandstone facies of Ratanpur Sandstone Member of Gadhada Formation in Chorar Island; in Bela Island, it is observed in micritic sandstone (Plate 5.5d) and sandy allochemic limestone facies (Plate 5.5e) of Ratanpur Sandstone Member while in Khadir Island, *P. baverleyensis* observed peloidal packstone/grainstone facies, micritic sandstone and sandy allochemic sandstone of Ratanpur Sandstone Member and in micritic sandstone facies of Bambhanka Member (Plate 5.5f).

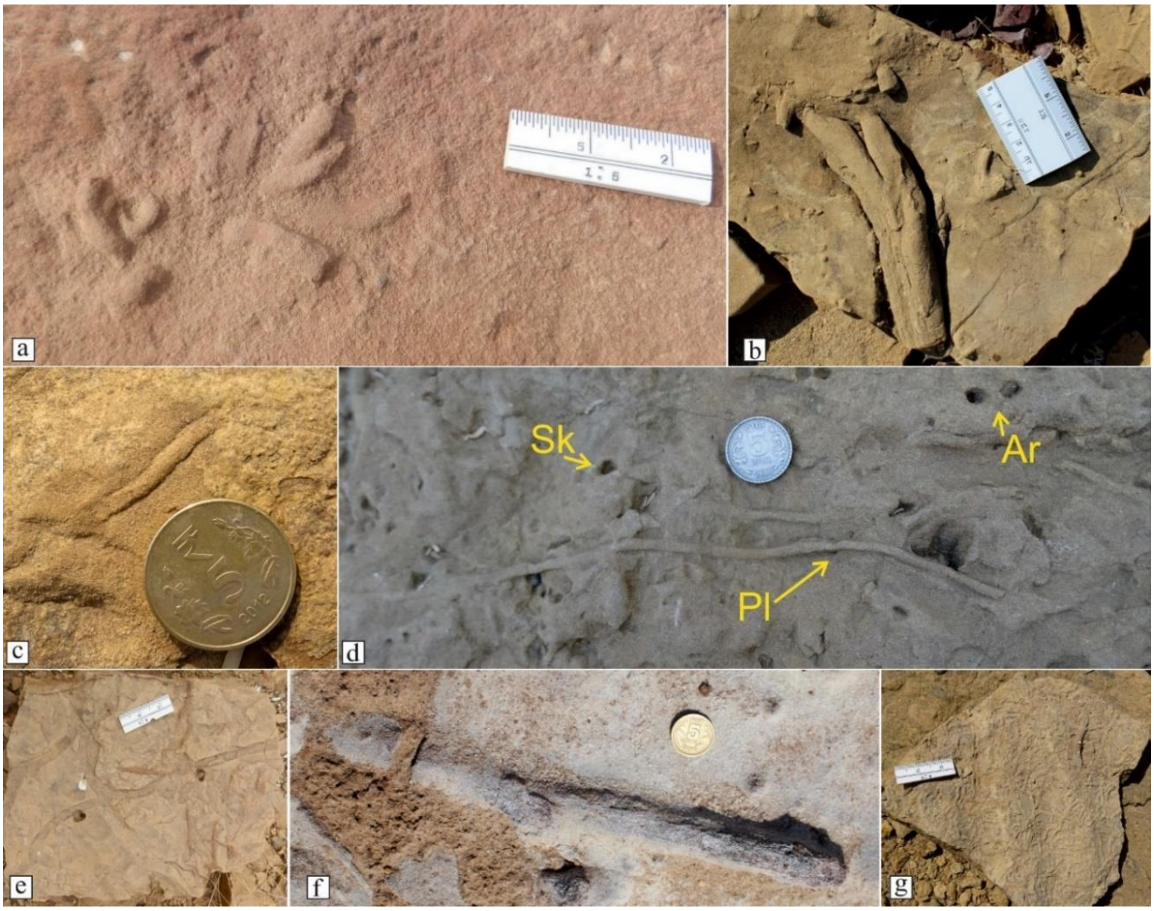

Plate 5.5 (a) Short and curvy bifurcating burrow *Phycodes curvipalmatum* in micritic sandstone facies of Bambhanka Member in Kakinda Bet. (b) Large digitating burrow *Phycodes palmatus* in sandy allochemic limestone of Ratanpur Sandstone Member in Bela Island. Horizontal, unlined burrows of *Planolites baverleyensis* in (c) sandy allochemic limestone facies of Hadibhadang Sandstone Member of Khadir Formation in Chorar Island (Scale: coin diameter = 3.2 cm) (d) micritic sandstone in association with *Skolithos* (Sk) and *Arenicolites* (Ar) and (e) sandy allochemic limestone facies (Scale: coin diameter = 3.2 cm) Ratanpur Sandstone Member in Bela Island and (f) micritic sandstone facies of Bambhanka Member in Khadir Island (Scale: coin diameter = 3.2 cm). (g) Contorted burrows of *P. montanus* in sandy allochemic limestone facies of Ratanpur Sandstone Member in Khadir Island.

Remarks: *Planolites baverleyensis* can be differentiated from *P. montanus* (Richter, 1937) by its large size where the latter is small and sinuous, and from *P. annularis* (Walcott, 1890) by the absence of annulations in the burrows.

Ichnospecies: *Planolites montanus* Richter, 1937
(Plate 5.5g)

Diagnosis: Relatively small, curved to contorted burrows (Pemberton and Frey, 1982).

Description: Hypichnial ridges, irregularly cylindrical, sinuous, undulose, and meandrous small burrows exhibiting overlapping with no obvious pattern other than a general tendency toward horizontal development. The size of the burrows remains consistent throughout with a diameter of about 0.2-0.3 cm.

Occurrences: It is observed in sandy allochemic limestone facies of Ratanpur Sandstone Member in Khadir Island (Plate 5.5g).

Remarks: The irregularly cylindrical, small burrows with no preferential pattern, abundant cross-over or truncation distinguished *P. montanus* from the other ichnospecies *P. beverleyensis* (Billings, 1862) which is large, smooth, and straight to gently curve, or *P. annularis* (Walcott, 1890) which is annulated sub-cylindrical burrows (Pemberton and Frey, 1982).

Branching: Unbranched
Shape: Cylindrical ridge-like
Fill: Active
Burrow Wall: Unlined/ lined
Ichnogenus: *Protovirgularia* M‘Coy, 1850
Type ichnospecies: *Protovirgularia dichotoma* M‘Coy, 1850

Diagnosis: Horizontal or subhorizontal cylindrical trace fossil, trapezoidal, almond or triangular in cross-section, distinctly or indistinctly bilobate. The internal structure can be preserved; it is formed by successive pads of sediment which can be expressed on the exterior as ribs. The ribs are arranged in a chevron-like biserial pattern along the external or internal dorsal part. Exterior smooth mantle covering the structure and/or oval mound-like terminations of the trace fossil can be present (Uchman, 1998).

Ichnospecies: *Protovirgularia dichotoma* M'Coy, 1850
(Plate 5.6 a)

Diagnosis: Straight, bilobate trails with medial furrow and paired, coned, chevron-like wedge-shaped projections oblique from furrow (Hammersburg et al., 2018).

Description: Straight, elongated with prominent deep median furrow with a series of wedge-shaped appendages. The specimen is about 20.0 cm long and 3.0 cm wide with a deep median furrow. The cross-section shows a distinct bilobate ribs-like structure.

Occurrence: It is observed in micritic sandstone facies of Bambhanka Member in Kakinda Bet (Plate 6a).

Remarks: The specimen is assigned *P. dichotoma* due to the oblique and wedge-like lateral project and it differs from *P. rugosa* by the absence of a *Lockeia* like trace at the termination of *P. rugosa.*

Ichnospecies: *Protovirgularia oblitrata* Książkiewicz 1977
(Plate 5.6b)

Diagnosis: *Protovirgularia* having poorly expressed median groove and chevron markings (Książkiewicz, 1977).

Description: *Protovirgularia oblitrata* is characterized by thin median grooves and chevron straight markings. It is about 1.0 cm in breadth and has a length of about 9.8 cm.

Occurrences: It is observed in sandy allochemic limestone of Bambhanka Member in Kakinda Bet, south of Khadir Island (Plate 5.6b).

Remarks: *Protovirgularia oblitrata* can be differentiated from other ichnospecies such as *P. pennatus* (Eichwald, 1860), *P. vagans* (Książkiewicz, 1977), and *P. tuberculata* (Williamson, 1887) by its poorly expressed median groove and chevron markings (Uchman, 1998).

Plate 5.6 (a) Horizontal *Protovirgularia dichotoma* with prominent deep median furrow in micritic sandstone facies of Bambhanka Member in Kakinda Bet (bar = 5cm). (b) *Protovirgularia oblitrata* showing faint median groove in sandy allochemic limestone facies of Ratanpur Sandstone Member in Bela Island. (c) *Protovirgularia* isp. in sandy allochemic limestone facies of Hadibhadang Sandstone Member of Khadir Formation in Chorar Island (Scale: coin diameter = 3.2 cm).

Ichnospecies: *Protovirgularia* isp.

(Plate 6c)

Description: Straight, unbranched, hypichnial transverse ridges slightly inclined to the bedding plane. The trace is 1.4 cm in diameter in the wider part and is about 1cm in a relatively smooth and narrower, tapering part. The total length is about 2.6 cm and the maximum width of 1.5 cm. The central tube is smooth and surrounded by a thick annulated layer.

Occurrence: It is observed in sandy allochemic limestone facies of Hadibhadang Sandstone Member of Khadir Formation in Chorar Island (Plate 6c), sandy allochemic limestone facies of Ratanpur Sandstone Member in Bela Island, and micritic sandstone facies of Bambhanka Member of Gadhada Formation in Kakinda Bet.

Remarks: The burrow lacks chevron appendages which are commonly seen in *Protovirgularia rugosa* rather the ridges are parallel and closely spaced, however, the specimen is assigned *Protovirgularia* isp. due to lack of *Lockeia* like termination.

Branching: Unbranched

Shape: U-, J-shaped/laminar

Fill: Active

Burrow wall: No lining

Ichnogenus: *Rhizocorallium* Zenker, 1836

Type ichnospecies: *Rhizocorallium jenense* Zenker, 1836

Diagnosis: Horizontal to oblique, U-shaped spreite burrow (Knaust, 2013).

Ichnospecies: *Rhizocorallium commune* Schmid, 1876

Diagnosis: Unbranched, rarely branched burrows with a preferred subhorizontal orientation. The burrows are elongate, band-like, straight or winding, and may have subparallel longitudinal scratches on the wall. Fecal pellets (*Coprulus* isp.) are common within the actively filled spreite and the marginal tube (Knaust, 2013).

Subspecies: *Rhizocorallium commune* var. *auriform* Hall, 1843

(Plate 5.7 a-b)

Description: Epichnial, short and slightly curved, and inclined to the bedding surface. The matrix of the tube is identical to the host rock. The tube with a diameter of about 1.2 cm fan out towards the distal end and a pronounced spreiten structure filled the space between the tubes.

Occurrences: It is observed in peloidal packstone/grainstone of Ratanpur Sandstone Member (Plate 5.7a) of Khadir Island and micritic sandstone of Bambhanka Member in Kakinda Bet (Plate 5.7b) and it is also observed in sandy allochemic limestone facies of Ratanpur Sandstone Member in Bela Island.

Plate 5.7 (a) *Rhizocorallium commune* var. *auriform* showing faint spreiten structure in thinly bedded peloidal packstone/grainstone of Ratanpur Sandstone Member in Khadir Island. (b) Twisted *Rhizocorallium commune* var. *auriform* in thickly bedded micritic sandstone of Bambhanka Member in Kakinda Bet showing prominent spreiten structure. (c) Straight, elongated *R. commune* var. *irregularie* in sandy allochemic limestone facies of Hadibhadang sandstone Member in Chorar Island where the spreiten structures between the tubes have been obscured due to erosion. (d) *R. commune* var. *irregularie* horizontally preserved in sandy allochemic limestone facies of Ratanpur Sandstone Member in Bela Island. (e) Highly ferruginised *R. commune* var. *irregularie* observed in micritic sandstone facies of Bambhanka Member in Khadir Island. (f) Horizontal, partially preserved *R. commune* isp. in micritic sandstone of Hadibhadang Shale Member in Khadir Island.

Remarks: *Rhizocorallium commune* var *auriforme* is a relatively small form, which is distinguished it from a relatively large and horizontal form, *R. commune* var. *irregulare*; lack of trochospiral in the rare ichnosubspecies *R. commune uliarense* and lack of vertically retrusive spreite burrow of *R. commune problematica.*

Ichnospecies: *Rhizocorallium commune* Knaust, 2013

Subspecies: *Rhizocorallium commune var. irregularie* Knaust, 2013

(Plate 5.7c-e)

Description: Long, slightly curved, horizontal, U-shaped spreiten burrows. Tubes are positive epirelief separated by spreiten structure. The total length of the structure observed is 11.5 cm. The diameter of the tube is about 0.5 to 1.0 cm and the distance between the two tubes is about 3.9 cm.

Occurrence: Sandy allochemic limestone facies (Plate 5.7c) of Hadibhadang Sandstone Member in Chorar Island. In Bela Island, it is observed in sandy allochemic limestone of Ratanpur Sandstone Member (Plate 5.7d), while in Khadir Island it is observed in peloidal packstone/grainstone in Ratanpur Sandstone Member and micritic sandstone facies of Bambhanka Member (Plate 7e).

Remarks: The specimen is lacking pellets which are usually common however the slender and long nature of the horizontal U-shaped burrow of the present *R. commune* var. *irregular*e distinguishes it from the straight and parallel with abundant scratches nature of *R. jenense* and trochospiral nature of *R. commune* var. *uliarense* (Knaust, 2013). The trace maker is a deposit feeder probably crustacean (Rodríguez-Tovar and Pérez-Valera 2008).

Ichnospecies: *Rhizocorallium commune* isp.

(Plate 5.7f)

Description: Partially exposed spreiten structure with eroded marginal tubes preserved horizontal to the bedding plane. The sequential development of the tubed is clearly seen.

Occurrences: Micritic sandstone of Hadibhadang Shale Member in Khadir Island (Plate 5.7f).

Remarks: Horizontal shallow subsurface trace with active spreiten structures suggest *Rhizocorallium commune*. However, the length to width ratio (*R. commune* var. *irregulare* and *R. commune* var. *auriforme*), retrusive structure (*R. commune problematica*), and Trochospiral nature of *R. commune uliarense* could not be determined and hence the subspecies *Rhizocorallium commune* isp. is assigned.

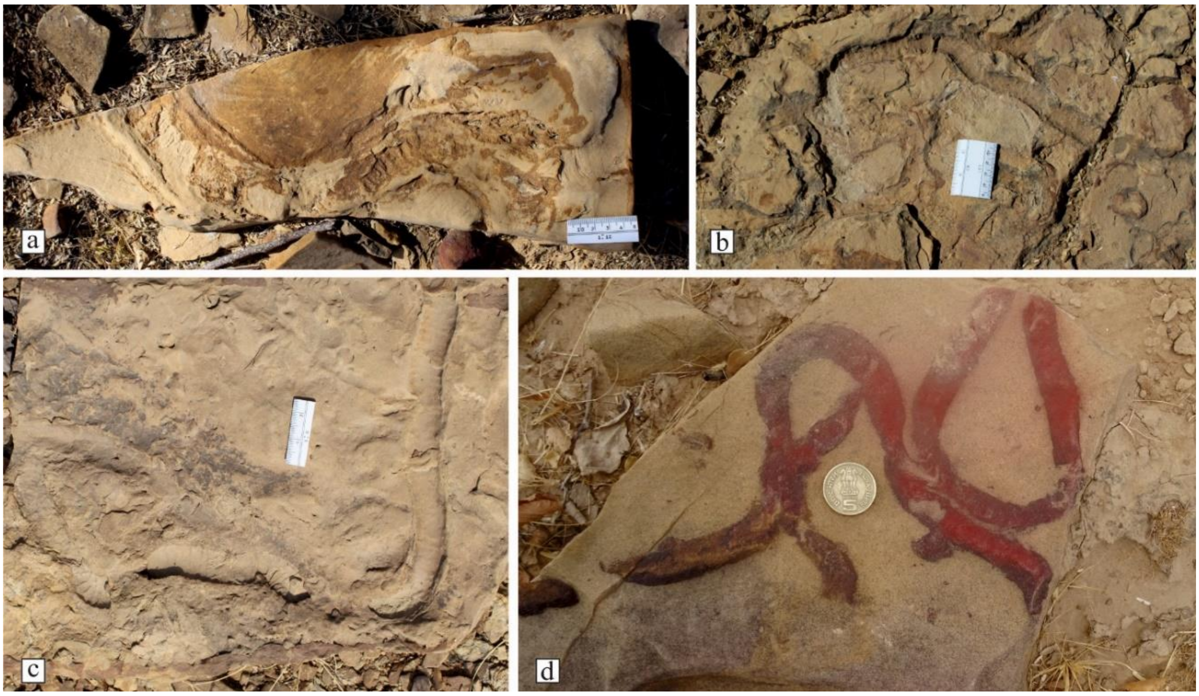

Plate 5.8 (a) Horizontal and sinuous *Taenidium serpentinum* in thinly bedded sandy allochemic limestone facies of Ratanpur Sandstone Member in Bela Island where the meniscate structure is perpendicular to the tube and is often obscure by erosion. (b) *T. serpentinum* in peloidal packstone/grainstone of Ratanpur Sandstone Member in Khadir Island with distinctly preserved meniscate structure while it is poorly preserved in micritic sandstone facies of Bambhanka Member. (c) in Khadir Island (d) Highly sinous *Taenidium.* isp. where the meniscate structure is obscure by ferruginous material in micritic sandstone of Ratanpur Sandstone Member in Khadir Island (Scale: coin diameter = 3.2 cm).

Branching: Unbranched

Shape: Cylindrical, ridge-like

Fill: Active

Burrow wall: No lining

Ichnogenus: *Taenidium* Heer, 1877

Type ichnospecies: *Taenidium serpentinum* Heer, 1877

Diagnosis: Unlined or very thinly lined, unbranched, straight or sinuous cylindrical burrows containing a segmented fill articulated by meniscus-shaped partings (D'Alessandro and Bromley, 1987).

Ichnospecies: *Taenidium serpentinum* Heer, 1877

(Plate 5.8a-c)

Diagnosis: Serpentiform *Taenidium* having well-spaced, arcuate menisci; distance between menisci about equal to or a little less than burrow width. External moulds may show slight annulations corresponding to menisci, or fine transverse wrinkling. Secondary subsequent branching and intersection occur. Boundary sharp, lining lacking or insignificant (D'Alessandro and Bromley 1987).

Description: Slightly curved to meandering with no specific orientation, unbranched, meniscate burrow, parallel to slightly inclined burrows. The meniscate structures are widely spaced, roughly parallel to each other transverse to the axis of the burrow. The burrow remains parallel throughout with a diameter of 2.1 cm. The length of the burrow extends up to 34.1 cm.

Occurrence: It is observed in sandy allochemic limestone facies of Ratanpur Sandstone Member in Bela Island (Plate 5.8a) while in peloidal packstone/grainstone and micritic sandstone of Ratanpur Sandstone Member (Plate 5.8b), and micritic sandstone facies of Bambhanka Member (Plate 5.8c) in Khadir Island.

Remarks: *T. serpentinum* can be differentiated from *T. cameronensis* (Brady, 1947) by its less arcuate menisci and from *T. satanassi* (D'Alessandro and Bromley, 1987) by the lack of alternating meniscate shaped packets of two types of sediments.

Ichnospecies: *Taenidium* isp.

(Plate 5.8d)

Description: The specimen is sinuous, broad, often overlapped, and filled with secondary ferruginous material thereby masking the meniscate structure. The diameter of the burrow is about 2 cm while the length varies and extends up to 25.6 cm.

Occurrences: In Khadir Island, it is observed in micritic sandstone facies of Ratanpur Sandstone Member (Plate 5.8d).

Remarks: The three accepted ichnospecies of *Taenidium serpentinum* (well-spaced, arcuate menisci with spacing almost equal to the burrow width), Heer, 1877; *T. Cameronensis* Brady, 1947 (having intermeniscate segments and deeply concave menisci); and *T. Satanassi* D'Alessandro and Bromley 1987 (straight to weakly sinuous, with fill evenly alternating meniscus-shaped packets of two types of sediments; are differentiated by the shape of their menisci. The above attributes of the above species are not observed in the specimen. Hence, *Taenidium* isp. is assigned for the ichnospecies.

5.5.2 Burrow orientation: Sub-vertical burrows

Branching: Unbranched

Shape: U- and bow-shaped

Fill: Passive

Ichnogenus: *Arenicolites* Salter, 1857

Type ichnospecies: *Arenicola carbonaria* Binney, 1852

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

Ichnospecies: *Arenicola carbonarius* Salter 1857.

(Plate 5.9a-c)

Diagnosis: U-tubes without spreite, perpendicular to bedding plane (Häntzschel, 1975).

Description*:* U-shaped lined burrows with distinct walls, inclined or vertical to the bedding plane. The opening is circular. The diameter of the burrow greatly varies with a point size of 0.57 to 0.76 cm and burrow arms are about 0.11 to 0.41 cm apart.

Occurrence*:* It is observed in Ferruginous sandstone facies of Ratanpur Sandstone Member (Plate 5.9a), sandy allochemic limestone facies of Hadibhadang Sandstone Member of Khadir Formation, Gadhada Formation in Chorar Island (Plate 5.9b). It is also observed in micritic sandstone facies of Ratanpur Sandstone Member in Bela Island (Plate 5.9c).

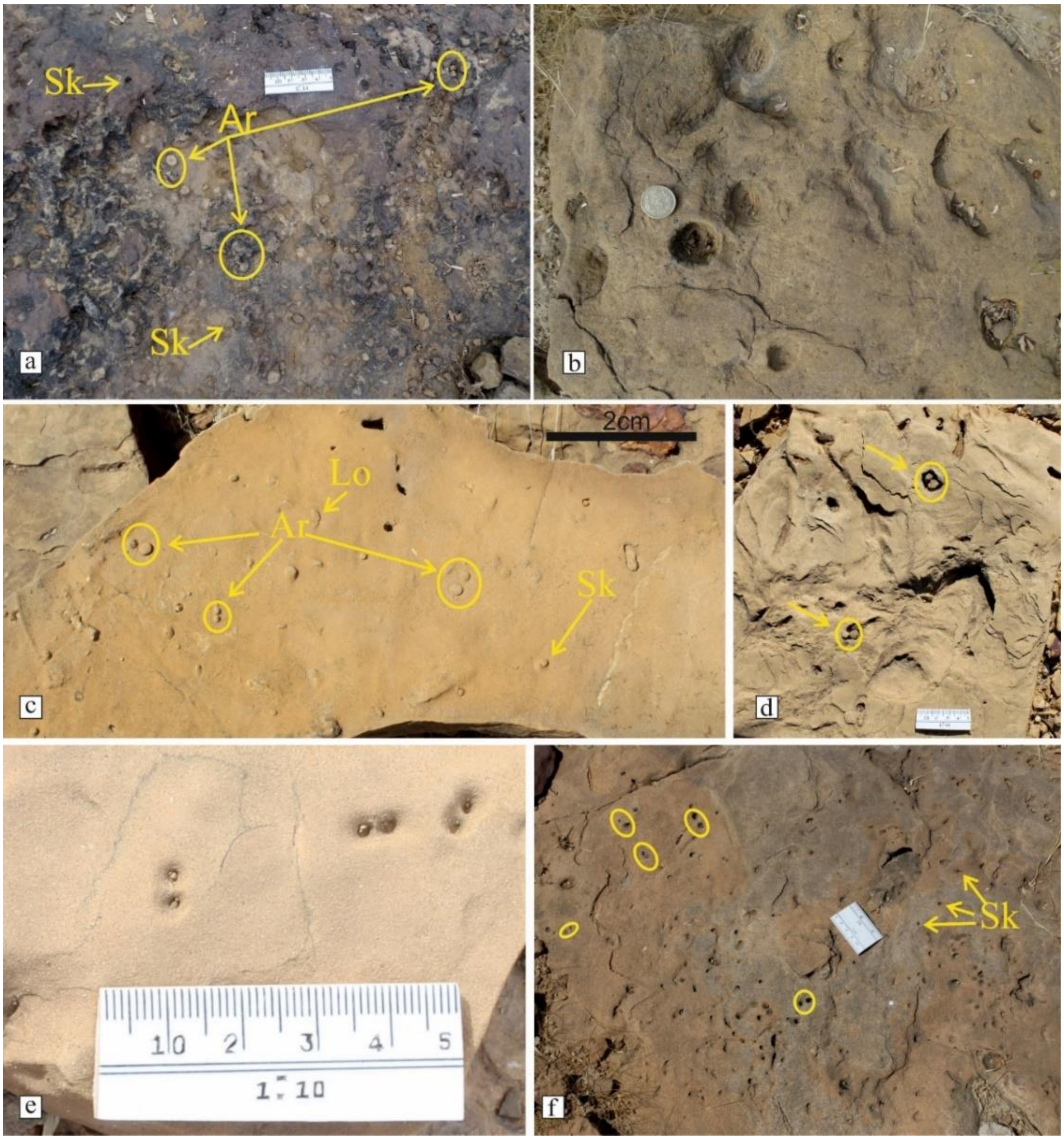

Plate 5.9 Vertical U-shapped burrows without spreiten structure *Arenicola carbonaria (*Ar*)*. (a) in association with *Skolithos* (Sk) in ferruginous sandstone facies of Ratanpur Sandstone Member in Chorar Island. (b) micritic sandstone facies of Ratanpur Sandstone Member in Khadir Island. (c) *Arenicola carbonaria* (Ar) in micritic sandstone facies in association with *Skolithos verticalis* (Sk) and *Lockeia* (Lo) *of* Ratanpur Sandstone Member in Bela Island. (d) Vertical lined pared tube *Arenicolites statheri* (indicated by an arrow) where the lining to the vertical is closely spaced or touch each other, observed in sandy allochemic limestone facies of Ratanpur Sandstone Member in Bela Island. (e) Very small size *Arenicolites* isp. represented by a circle in association with *Skolithos* (Sk), observed in micritic sandstone facies of Hadibhadang Shale Member Island and (f) Ratanpur Sandstone Member in Khadir.

Ichnospecies: *Arenicolites statheri* Bather, 1925.

(Plate 5.9d)

Remark: *Arenicolites* represent dwelling and feeding burrows of suspension-feeders (Fürsich, 1975; Hakes, 1977; Howard and Frey, 1984; Fillion and Pickerill, 1984). The lining of the burrows gives more stability to the burrows.

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

Description: Endichnial, full relief, lined U-shape burrow, perpendicular to the bedding plane. The burrow fill is similar to the host rock and the burrow lining shows darker colour. The individual arms are closely spaced with their lining touching each other. The diameter of the arms is 0.67 cm while the diameter of the whole tube is 1.8 cm.

Occurrence: It is observed in micritic sandstone and sandy allochemic limestone facies (Plate 9d) of Ratanpur Sandstone Member in Bela Island.

Remarks: *Arenicolites statheri* can be differentiated from other ichnospecies of *Arenicolites carbonaria* by its straight, vertical, closely spaced symmetrical U-shaped tube.

Ichnospecies: *Arenicolites* isp.

(Plate 9e-f)

Description: Paired burrows perpendicular to the bedding plane. The burrows are seldom lined and generally preserved as grooves.

Occurrences: In Khadir Island, it is observed in micritic sandstone facies of Hadibhadang Shale members (Plate 9e) and Ratanpur Sandstone (Plate 9f).

Remarks: The vertical burrow morphology of the trace fossil could not be determined, hence the *Arenicolites* isp. is assigned.

Branching: Branched

Shape: Bifurcated

Fill: Active

Burrow wall: No lining

Ichnogenus: *Chondrites* Sternberg, 1833

Type ichnospecies: *Fucoides antiquus* Brongniart, 1828

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

Plate 5.10 (a) Radiating branches of *Chondrites intricatus* in micritic sandstone facies of Ratanpur Sandstone Member in Khadir Island. (b) Meandering burrows *Chondrites targionii* in sandy allochemic limestone of Ratanpur Sandstone Member (Scale: coin diameter = 3.2 cm. (c) Vertical view of *C. targionii* in sandy allochemic limestone of Ratanpur Sandstone Member. (d) Close-up view of *C. targionii* bearing sandy allochemic limestone facies in Ratanpur Sandstone Member in Khadir Island (Scale: length of pen = 14 cm).

Ichnospecies: *Chondrites intricatus,* Brongniart, 1823

(Plate 5.10a)

Diagnosis: Small burrow system with numerous downward radiating branches (Fu, 1991)

Description: Endichnial, tree-like small burrow system with numerous branches radiating into the substrate. The branches are acute angles generally less than 45^{O}. The tube diameter is about 1mm. with most of its branched preserved as grooves.

Occurrences: Sandy allochemic limestone and micritic sandstone (Plate 5.10a) facies of Ratanpur Sandstone Member in Khadir Island.

Remarks: *Chondrites intricatus* can be differentiated from other ichnospecies by their small burrow nature. The trace maker of *Chondrites* may be able to live at the aerobic/anoxic interface as a chemo-symbiotic organism (Seilacher, 1990; Fu, 1991).

Ichnospecies: *Chondrites targionii,* Brongniart, 1828

(Plate 5.10b-d)

Diagnosis: *Chondrites* characterized by well-expressed primary successive branching, which are commonly slightly curved. The angle of branching is usually sharp or obtuse. Most of the tunnels are a few millimeters wide (Uchman, 1998).

Description: Preserved as an endichnial, dendritic branching tunnel system. The well express secondary branches up second order are fairly common. The secondary branches in acute angles varying from 40^{O} - 60^{O} mostly parallel the bedding plane. The burrow fill sediment contains high ferruginous content as compared to the host rock.

Occurrences: It is observed in micritic sandstone facies and sandy allochemic limestone facies of Ratanpur Sandstone Member in Khadir Island (Plate b-d). It is also observed in sandy allochemic limestone facies of Ratanpur Sandstone Member in Bela Island (Plate 5.10d).

Remarks: *Chondrites targionii* is differentiated from *C. intricatus* (Brongniart, 1823) by the absence of downward radiating straight branches, from *C. patulus* (Fischer-Ooster, 1858) by the lack of long and straight tunnels located at alternating positions from a central axis and obtuse angle between the main-branch and adjacent branches (Uchman, 1998, 1999); and from *C. recurvus* (Brongniart 1823) as the later branches only on one side of the main branch bending in only one direction (Fu, 1991).

Branching: Unbranched

Shape: U- or bow shape

Fill: Active

Burrow Wall: No lining

Ichnogenus: *Diplocraterion* Torell, 1870

Type Ichnospecies: *Diplocraterion parallelum* Torell, 1870.

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

Ichnospecies: *Diplocraterion* isp.

(Plate 5.11a)

Diagnosis: As per ichnogenus

Description: Straight and uniform U-tubes with spreiten structures, perpendicular to the bedding plane. Both the tubes are parallel with a narrow opening on the surface. Tube diameter is about 0.41 to 0.50 cm and tubes are 0.55 to 0.63 cm apart from each other.

Occurrence*:* It is observed in micritic sandstone facies of Ratanpur Sandstone Member and Hadibhadang Shale Member in Khadir Island and Bela Island (Plate 5.11a).

Remarks: The spreiten paired burrows are perpendicular to the bedding plane with no visible vertical component, hence the ichnospecies *Diplocraterion* isp. is assigned. It is the dwelling burrow of polychaete annelids, crustaceans, or other suspension-feeding animals (Fillion and Pickerill, 1990), probably living in an environment of high wave energy.

Branching: Unbranched

Shape: Circular

Fill: Active

Burrow wall: Lined/Unlined

Ichnogenus: *Laevicyclus* Quenstedt, 1879

Type ichnospecies: *Sabellarifex parvus* Desio, 1940, by subsequent designation.

Diagnosis: Cylindrical vertical burrows with an actively filled mantle and a passively filled core. The aperture can be funnel-shaped enlarged (Knaust, 2015).

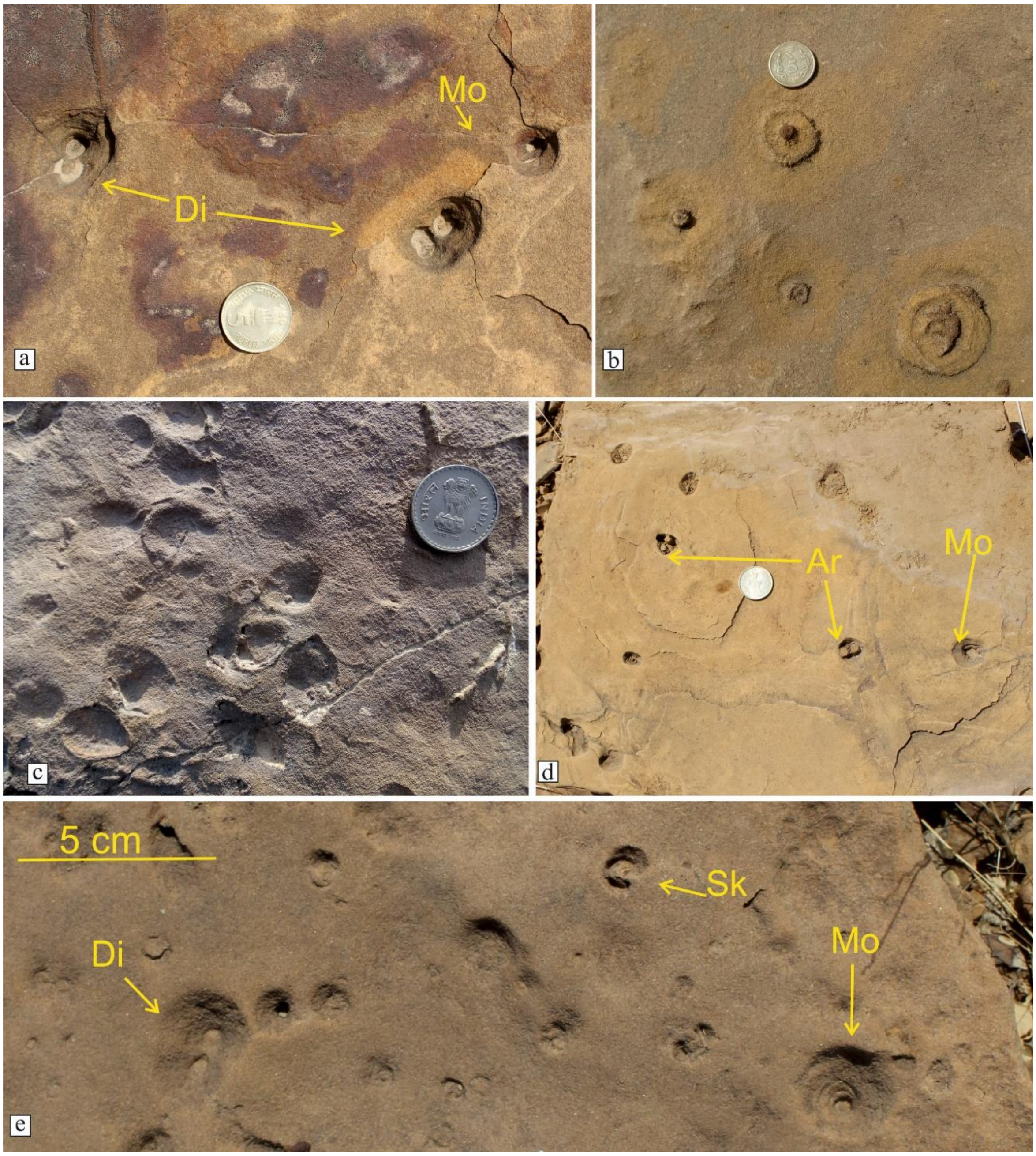

Plate 5.11(a) Vertical paired burrows of *Diplocraterion parallelum* (Di) in association with *Monocraterion* (Mo) in micritic sandstone facies of Ratanpur Sandstone Member in Bela Island (Scale: coin diameter = 2.3 cm). (b) *Laevicyclus parvus* showing the concentric ring in micritic sandstone of Ratanpur Sandstone Member (Scale: coin diameter = 2.3 cm) (c) Almond-shaped *L. siliquaria* observed in ferruginised sandy allochemic limestone of Ratanpur Sandstone Member in Khadir Island. (Scale: coin diameter = 2.3 cm). (d) Funnel-shaped vertical tube, *Monocraterion tentaculatum* (Mo) in association with *Arenicolites statheri* (Ar) in sandy allochemic limestone of Ratanpur Sandstone in Bela Island. (e) Funnel-shaped *M. tentaculatum* (Mo) observed in micritic sandstone of Ratanpur Sandstone Member in Khadir Island in association with *Diplocraterion* (Di) and *Skolithos* (Sk).

Ichnospecies: *Laevicyclus parvus* Desio, 1940

(Plate 5.11b)

Diagnosis: As for ichnogenus, by monotype (Knaust, 2015).

Description: Full relief, cylindrical, vertical to steeply inclined, with an actively filled mantle passively filled core burrows. Shallow circular depression surrounding the central tube/core perpendicular to the bedding plane. The circular depression is surrounded by an elevated ring with a diameter of 2.7 cm while the central tube has a diameter of 0.6 cm.

Occurrence: Peloidal packstone-grainstone and micritic sandstone facies of Ratanpur Sandstone Member (Plate 5.11b) in Khadir Island and micritic sandstone facies of Bambhanka Member in Kakinda Bet.

Remark: Knaust (2015) designated *Laevicyclus parvus* as a monotypy and also included *Lepocraterion, Calycraterion, Dolopichnus, Cylindrocraterion, Endaulites, Heterocongeridopsisichnium* and *Monticulichnus* within the same genera *Laevicyclus. L. parvus* is produced by the burrowing activity of bivalves.

Branching: Unbranched

Shape: Plug shape

Fill: Passive

Burrow Wall: No lining

Ichnogenus: *Lockeia* James, 1879

Type Ichnospecies: *Lockeia siliquaria* James, 1879

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

Ichnospecies: *Lockeia siliquaria* James, 1879

(Plate 5.11b-c)

Diagnosis: Same as ichnogenus

Description: Convex, hypichnial, relatively small, almond-shaped, oblong parallel to sub-parallel bodies; with tapering to sharp. They occur as isolated and their dimension varies in different burrow populations, with an observed length of 0.5 – 2.0 cm and a width is 0.3 -1.9 cm.

Occurrence: Sandy allochemic limestone (Plate 5.11b) Hadibhadang Sandstone Member in Chorar Island, micritic sandstone facies of Ratanpur Sandstone Member in Khadir Island (Plate 5.11c), and sandy allochemic limestone facies of Ratanpur Sandstone Member in Bela Island.

Remarks: Based on the experiment carried out by Schlirf et al. (2001), the shape and orientation of various species of *Lockeia* are the results of various orientations of the trace maker bivalve. Thus, the triangular forms of *Lockeia* described by Kim (1994) as *L. triangulichnus* appear to be preservational variants of *L. amygdaloides* rather than the proposed new ichnospecies. Thus, they regard *L. amygdaloides* Seilacher,1953, *L. avalonensis* Fillion & Pickerill, 1990, and *L. triangulichnus* Kim, 1994 as junior synonyms of *Lockeia siliquaria* James, 1879.

Branching: Unranched

Shape: Cylindrical

Fill: Passive

Burrow Wall: Lining/ No lining

Ichnogenus: *Monocraterion* Torell, 1870

Type Ichnospecies: *Monocraterion tentaculatum* Torell, 1870

Diagnosis: Funnel-shaped negative epirelief with a raised knob on the floor of the funnel; this knob is continuous with a short, vertical, centrally located tubular structure. Essentially with numerous small, horizontal, slightly curving, rarely branching, occasionally lined, tubular, full-relief structures with smooth outer surfaces going out from the raised knob (Schlirf, 2005).

Ichnospecies: *Monocraterion tentaculatum* Torell, 1870
(Plate 5.11a, d, e)

Diagnosis: As for ichnogenus because of monotypy (Schlirf, 2005).

Description: A single, tube-like, vertical burrow that has a series of stacked funnel structures that point towards the top surface of the bed. Diameter is 0.65 cm to 1.67cm.

Occurrence: It is observed in micritic sandstone (Plate 5.11a) and sandy allochemic limestone facies (Plate 5.11d) of Ratanpur Sandstone Member in Bela Island and Hadibhadang Shale Member; micritic sandstone facies of Ratanpur Sandstone in Khadir Island in association with *Diplocraterion* and *Skolithos* (Plate 5.11e).

Remarks: Frey and Howard (1985) suggested that *Monocraterion* should be viewed as an ichnospecies of *Skolithos*; however, multiple authors consider the funnel-shaped morphology as distinct and characteristic of a separate ichnogenus. Eroded specimens of *Monocraterion* may be diagnosed as specimens of *Skolithos*, while from upper bedding plane views, specimens may be diagnosed as *Rosselia* and/or *Laevicyclus* (Fillion and Pickerill, 1990; Jensen, 1997). It is produced by marine worms or worm-like organisms.

Branching: Unbranched
Shape: Cylindrical
Fill: Passive
Burrow wall: Lining/No lining
Ichnogenus: *Skolithos* Haldeman, 1840
Type ichnospecies: *Fucoides? linearis* Haldeman 1840

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

Plate 5.12 (a) Vertical *Skolithos linearis* in cross-bedded white sandstone facies of Ratanpur Sandstone Member in Chorar Island (Scale: Bar = 5 cm). (b) Straight and vertical *S. linearis* in cross-bedded white sandstone facies of Ratanpur Sandstone Member in Chorar Island (Scale: Bar = 5 cm). (c) Short, curved, and densely populated *Skolithos verticalis* in sandy allochemic limestone facies of Ratanpur Sandstone Member in Bela Island (Scale: Bar = 5 cm). (d) Vertical *Skolithos* isp. in micritic sandstone facies of Bambhanka Member in Kakinda Bet (Scale: coin diameter = 3.2 cm).

Ichnospecies: *Skolithos linearis* Haldeman, 1840

(Plate 5.12a-b)

Diagnosis: Unbranched, vertical or steeply inclined, cylindrical, lined or unlined burrows, with or without funnel-shaped top. Wall distinct or indistinct, smooth to rough possibly annulated; fill massive; burrow diameter may vary slightly along its length (Schlirf, 2000).

Description: Endichnial, burrows are straight, vertical to slightly curved, and perpendicular to the bedding plane. Burrows walls are distinct measuring about 1cm in diameter and depth of about 8.5 cm.

Occurrence: It is observed in friable sandstone facies of Ratanpur Sandstone Member in Chorar Island (Plate 5.12a) and in sandy allochemic limestone facies of Ratanpur Sandstone Member in Bela Island (Plate 5.12b).

Remarks: *Skolithos linearis* includes various forms that include straight and crowded to slightly curved and less crowded (Alpert, 1974). *Skolithos* lacks funnel shape aperture that differentiates it from ichnogenus *Monocraterion* Torell, 1870.

Ichnospecies: *Skolithos verticalis* Hall, 1843
(Plate 5.12a)

Diagnosis: Burrows cylindrical to sub- cylindrical, vertical, may curve slightly. Diameter 6 to 12 mm. Burrow wall indistinct, somewhat irregular.

Description: These are cylindrical, straight, vertical, or gently inclined, crowded burrows, that appear as a circular ring on the bedding surface. The tubes are unbranched with smooth walls. The diameter of the tubes varies from 0.57 to 0.67 cm. The maximum observed length of the tube is 15.22 cm.

Occurrence: It is observed in friable sandstone facies of Ratanpur Member, Gadhada Formation in Chorar Island (Plate 5.12c).

Discussion: The *Skolithos verticalis* burrows are generally shorter and smaller, more commonly inclined and curved (and to a greater extent) than *S. linearis*, and are never extremely crowded (Alpert, 1974); considered as dwelling burrows of annelids or phoronids (Alpert, 1974).

Ichnospecies: *Skolithos* isp.

(Plate 5.12d)

Description: Cylindrical to sub-cylindrical burrow with oval to circular on surface occurring in large numbers. The burrow wall is distinct and it appears as small ring-like projections on the bedding plane ranging in diameter from 0.6 to 1.03 cm.

Occurrence: Ferruginous sandstone facies of Ratanpur Member, Gadhada Formation in Chorar Island, micritic sandstone in Bela Island (Plate 5.12d), and micritic sandstone in Bambhanka Member in Kakinda bet.

Remarks: The sediment in the burrow fill tends to weather out readily, leaving the burrows as holes in the rock. The crowded nature of the present specimen of *Skolithos* suggests it to be *Skolithos linearis* however due to non-visible vertical sections it cannot be refrained from the other ichnospecies of *Skolithos* and thus kept under open nomenclature.

2.5.3 Burrow Orientation: Complex

Branching: Branched

Shape: Tunnel and serial shafts

Fill: Active

Burrow wall: No lining

Ichnogenus: *Hillichnus* Bromley, Uchman, Gregory, Martin 2003.

(Plate 5.13-5.16)

Diagnosis: Complex trace fossil comprising several contrasting parts. Two concentric structures, a basal segmented structure and within this a basal tube, run axially along the base and give rise to lateral spreiten or feather-like structures. The individual spreiten or feather-like structures arise alternately on either side of the basal segmented structure. Arising by branching from the basal tube, a series of sand- and mud-lined tubes curve upward into a nearly vertical position. These rising tubes may stand in a straight line, as a zigzag line, or in irregular groups. The general course of the trace fossil is horizontal, straight to curving or rarely looping (Bromley et al., 2003)

Ichnospecies: *Hillichnus lobosensis* Bromley, Uchman, Gregory, Martin 2003.

Diagnosis: Same as ichnogenus.

Description: Complex multilevel morphological structure exhibits five morphological Levels from A to E; Level C-D in the Khadir Island, Level A-E in the Bela Island, and Level B-D in the Chorar Island. The specimens observed at two different stratigraphic levels show variation in dimension and preservation.

Level A

Level A is characterized by segmented series of alternate arcs preserved as negative hyporelief in the sandy allochemic limestone of Bela Island (Plate 5.13a). It is rarely preserved due to its delicate structure, and thixotropic nature of the substrate and is later affected by solution activity thereby making it difficult to recognize.

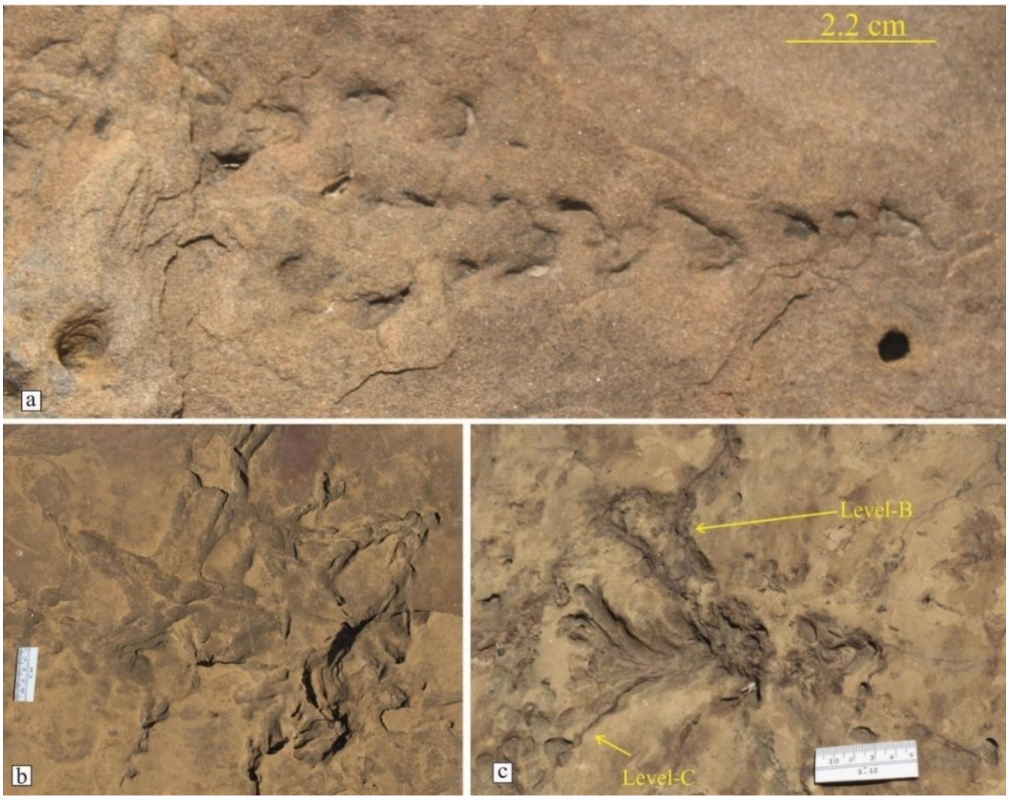

Plate 5.13 (a). Level A of *Hillichnus lobosensis* shows the basal segmented structure in sandy allochemic limestone of the Bela Island. (b). *H. lobosensis* shows the basal tubes of Level B. (c) Level B of *H. lobosensis* shows dark brown lined, undulated, wrinkled, irregular, and elongated tubes overlapping with leaf-like branches of Level C.

Level B

Level B is well preserved and comprises centrally placed thinly lined straight to curve 10.0 cm long basal tubes with a diameter of 2.0 cm (Plate13b), preserved as shallow groove and characterized by transversely well-developed wrinkle; occur as straight to wavy lined tubes filled with host sediments partly eroded forming grooves and shows prominent lined tubes with moderately developed transverse wrinkle. The infill sediments of the tube are similar to the host separated by the dark-colored lining of the tube. It often occurs in association with other levels like level C (Plate 13b and c).

Level C

Plate 5.14(a). Level C of *H. lobosensis* shows well-developed horizontal leaf or feather branches with prominent undulated and wrinkled basal tubes (Scale: coin diameter = 3.2 cm). (b). Leaf-like branches are smoothened by erosion in the Chorar Island. (c and d) Less prominent leaf-like Level C of Khadir (Scale: coin diameter = 3.2 cm). (e). Overlapping of Level C of *H. lobosensis* with a prominent basal tube with the overlying sediments and the crowded nature masking the leaf-like branches in the Bela Island (f) Level C with remnants of a broken basal tube.

Level C is leaf/feather-like branching basal tubes that become distally slenderer and shows maximum variation in morphological features and dimensions. It also overlaps with other morphological levels, representing the complexity of the structure. In Chorar Island shows a well-developed leaf or feather-like structure with individual branches alternating on either side of the basal tube parallel to the bedding plane and often eroded and smoothening the burrows (Plate 5.14a-b). The tube length varies from 16.2 to 26.4 cm. and has a diameter of 2.0 cm. Some specimens of the Khadir Island show a similar side branching tube pattern to the Chorar Island but majority of the specimens show comparatively less prominent and smoother basal tubes and lamellar branches with variation in tube length from 5.0 cm to 8.0 cm. and diameter of 1.0 to 1.5 cm (Plate14 c-d). Bela Island specimens also show overlapping feather-like structures however, the lateral branches are rather shorter, gently curving towards the distal end; the basal tube is prominent, length is 19.0 cm with a diameter of 1.0 cm (Plate 5.14e-f).

Level D

At this level, the feather-like branches disappear and the structure is dominated by short inclined tubes with a diameter of 1.0 - 1.2 cm (Plate 5.15c-e). Chorar Island specimen shows the presence of a slightly inclined tube that shows zig-zag nature (Plate 5.15f) with or without basal tube as well as the transition from Level C to Level D (Plate 14g), tube diameter ranges from 0.8 cm to 1.6 cm. Plate (5.15h) shows the level C as long, and narrow, with variable dimensional horizontal tubes on the vertical face of sandy allochemic limestone and inclined vertical pair burrows of level D in series at the top surface.

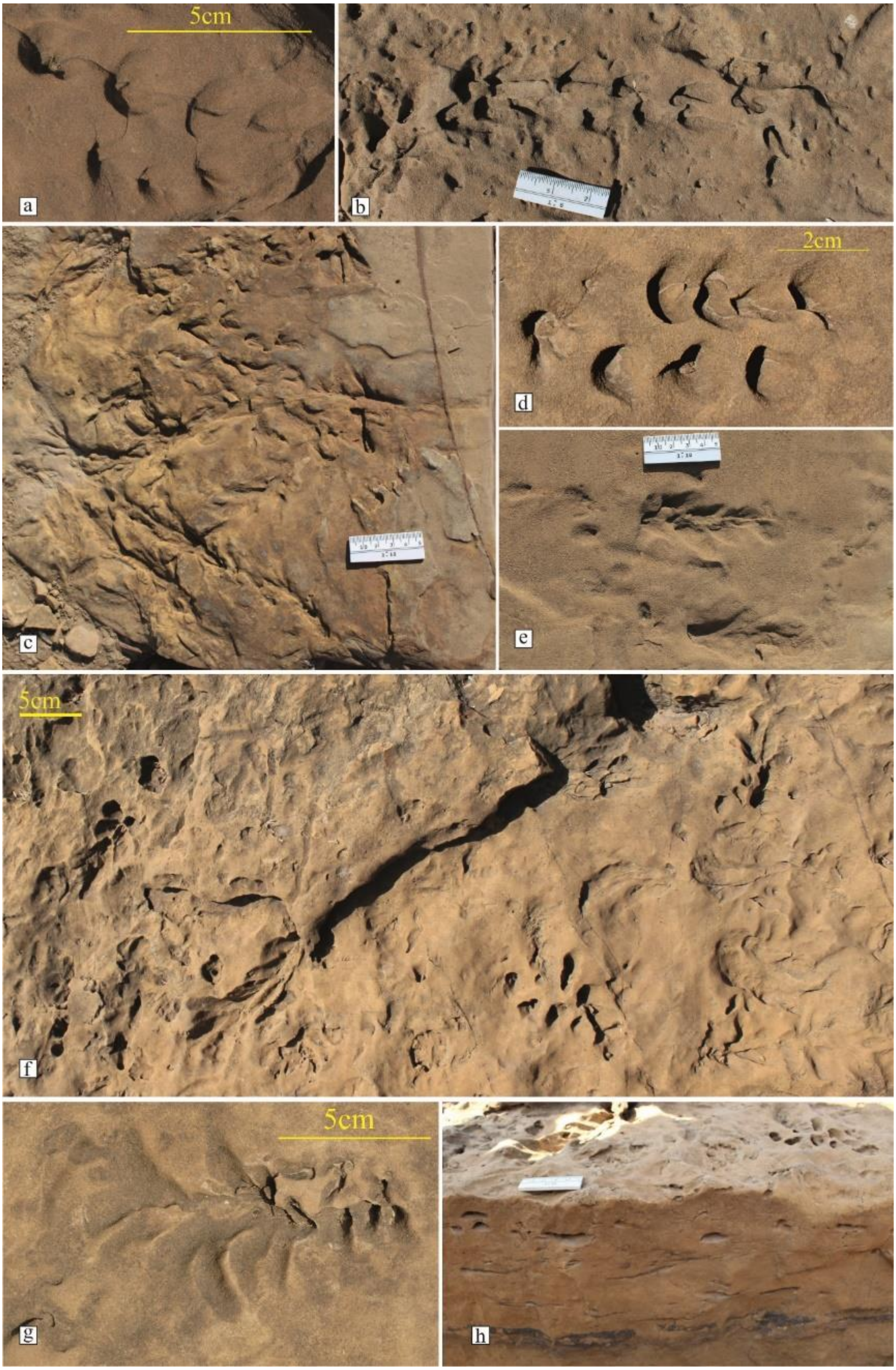
5cm
a
b
c
2cm
d
e
5cm
f
5cm
g
h

Plate 5.15 (a) Level D of *H. lobosensis* (a) the rising tube arises in pairs and (b) with prominent basal tube where the rising tubes arise from the side in an alternate pattern in the Khadir Island. (c) Crowded Level D of *H. lobosensis* with the prominent basal tube but eroded inclined tube, (d) Level D of *H. lobosensis* occurring parallel with a series of vertical tubes belonging to Level E. (e) Level D of *H. lobosensis* showing prominent basal tube with the inclined tube arising from the side in the Bela Island. (f) Crowded Level D of *H. lobosensis* where the basal tube is concealed while the inclined tube occurs in pair or zigzag. (g). The transition of level C to Level D. (h) Vertical view of *H. Lobosensis* in Chorar Island showing level D on top with the basal tube appearing as horizontal tubes and the feather-like protrusion from Level C appearing as thin curved lines.

Level E

It is characterized by linear or zigzag vertical tubes occurring in single, or in pairs resembling *Arenicolites*. The tubes are small, vertical, unlined, appear as single or pair burrows and arrange in series or in isolated forms in Khadir Island (Plate 5.15a). It has variable downward extension and diameter from 0.2 cm to 1.1 cm. The 0.6-1.2 cm diameter tubes occur in series; sometimes it is parallel with inclined tubes of Level D in Bela Island (Plate 5.15b).

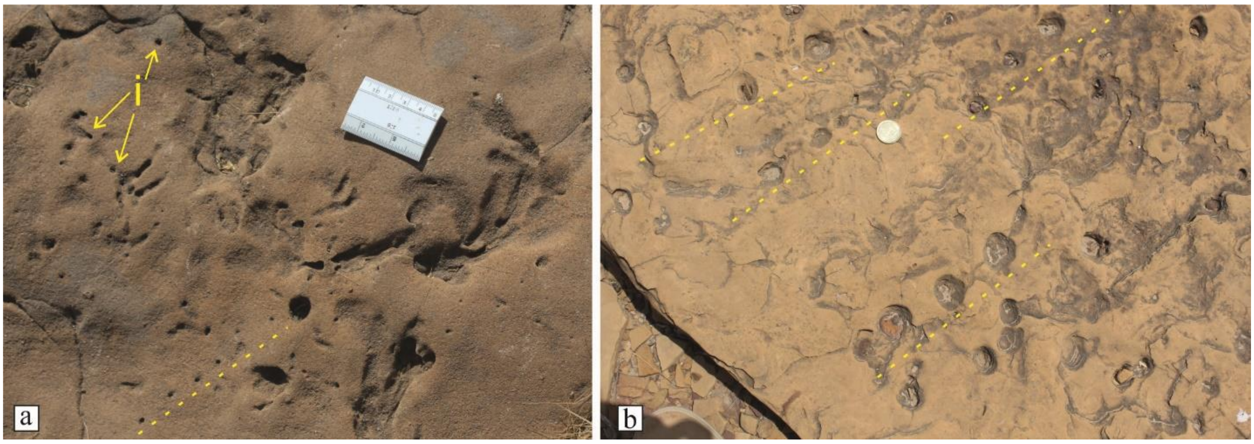

Plate 5.16 (a) Isolated (i) or series (dash line) of small vertical tubes belonging to Level E of *H. lobosensis* in Khadir Island. (b) Series of vertical tubes occurring in a straight line or in pairs, Bela Island (Scale: Coin diameter = 2.3 cm).

Occurrences: Micritic sandstone facies of Ratanpur Sandstone Member in Khadir Island (Plate 16a); sandy allochemic limestone facies of Ratanpur Sandstone and Hadibhadang Sandstone members in Bela (Plate 16b) and Chorar Islands.

Remark: The complex trace fossil *Hillichnus* is characterized by lateral lamellae and tubules that differentiate it from *Jamesonichnites heinbergi* (Dam, 1990) by the presence of narrow splayed rising tubes; *Lophoctenium* (Fu, 1991) by basal tube and associated vertical structure. *Hillichnus lobosensis* of Bromley et al., (2003) comprises five distinctive morphological levels that differentiate it from *Hillichnus agrioensis* of Pazos and Fernández (2010) which is composed of 4 morphological levels. The feather-like branch with basal tubes is characteristic of Level C in *Hillichnus lobosensis* while similar structures are observed at level B in *Hillichnus agrioensis*.

Branching: Branched/Unbranched
Shape: Boxwork
Fill: Active/Passive
Burrow wall: Lining
Ichnogenus: *Ophiomorpha* Lundren, 1891
Type Specimen: *Ophiomorpha nodosa* Lundgren, 1891

Diagnosis: Simple to complex burrow systems distinctly lined with agglutinated pelletoidal sediment. Burrow lining more or less smooth interiorly; densely to sparsely mamillated or nodose exteriorly. Individual pellets or pelletal masses may be discoid, ovoid, mastoid, bilobate, or irregular in shape. Characteristics of the lining may vary within a single specimen (Frey et al.,1978).

Ichnospecies: *Ophiomorpha annulata* Książkiewicz, 1977
Plate (5.17a)

Diagnosis: *Ophiomorpha*, mainly horizontal or subhorizontal, cylindrical, rarely branched, covered with elongate pellets arranged perpendicularly to the long axis of trace fossil. Sharp angles prevail at branching points. Swellings are common. In flysch deposits, commonly hypichnial, smooth, and straight small specimens (usually 2-6 mm in diameter) (Uchman, 1995).

Description: Endichnial, slightly curved, branched/unbranched, pellet lined cylindrical burrows. The pellets are elongated and are arranged perpendicular to the long axis of the trace fossil. The inner walls of the burrows are smooth with a diameter of about 2.5 cm while the outer wall has saw-like sharp ridges due to the arrangement of the pellets.

Occurrences: It is observed in peloidal packstone/grainstone facies of Ratanpur Sandstone Member in Khadir Island and micritic sandstone facies of Bambhanka Member (Plate 5.17a) in Kakinda Bet.

Remarks: *Ophiomorpha annulata* is assigned to the specimens with crowded and elongated pellets The dense pellets covering the entire tube can differentiate it from *O. nodosa* Lundgren, 1891 as the latter lacks elongated pellets. *Ophiomorpha* is interpreted as the burrow of crustaceans such as *Callianassa* (Häntzschel, 1952).

Ichnospecies: *Ophiomorpha irregulaire* Frey, Howard and Pryor, 1978
(Plate 5.17b)

Diagnosis: Predominantly horizontal *Ophiomorpha* system having T-shaped and/or Y-shaped branch nodes; geometry of the system is a meandering maze having smoothly curved internodal tunnels; cross-section is oval; roof lining is pelleted with regularly or irregularly spaced, conical to attenuated, outwardly tapering pellets of nonuniform size; interior surface of this lining is smooth; floor commonly unlined, locally bearing longitudinal grooves (Bromley and Ekdale, 1998).

Description: Endichnial, horizontal burrows with T-shaped and/or Y-shaped branch nodes with gently curved inter nodal tunnels. The pallets that lined the burrow are irregular a with smooth internal burrow wall. The diameter of the burrows remains mostly constant at about 1.0 cm with swollen or enlarged at the nodes.

Occurrences: Micritic sandstone facies of Ratanpur Sandstone Member in Khadir Island (Plate 5.17b)

Remarks: *Ophiomorpha irregulaire* sufficiently resembles that of *O. nodosa* to allow *O. irregulaire* to be accommodated within that ichnogenus (Bromley and Ekdale, 1998). However, the irregular distribution of pellets wall of *O. irregulaire* and thick strongly developed lining on the roof of the burrow distinguished the trace fossils from other ichnospecies.

Ichnospecies: *Ophiomorpha nodosa* Lundgren, 1891

(Plate 5.17c)

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

Description: Endichnial, full relief; horizontal to sub-vertical, branched or unbranched burrow covered with ovoid pelletoidal knobs. The peloidal knobs are consistently regular, and dense, with single pellets in the wild. The length of the tube is 15.7 cm with a diameter of 3.4 cm. The burrow fill is similar to the host rock.

Plate 5.17 (a) Elongated pellets of *Ophiomorpha annulata* in micritic sandstone of Ratanpur Sandstone Member with elongated pellets (Scale: coin diameter = 2.3 cm). (b) T or Y-shaped *Ophiomorpha irregulaire* showing less dense pellets in micritic sandstone facies of Ratanpur Sandstone Member in Khadir Island. (c) *Ophiomorpha nodosa* showing regularly dense pellets in micritic sandstone facies of Ratanpur Sandstone Member in Khadir Island (Scale: coin diameter = 2.3 cm). (d) Highly ferruginised *Ophiomorpha* isp. in micritic sandstone facies of Ratanpur Sandstone Member in Khadir Island (Scale: coin diameter = 2.3 cm).

Occurrences: It is observed in micritic sandstone (Plate 5.17c) and sandy allochemic limestone facies of Ratanpur Sandstone Member of Gadhada Formation in Khadir Island as well as micritic sandstone of Ratanpur Sandstone Member in Bela Island.

Remarks: The wall of *Ophiomorpha nodosa* sufficiently resembles that of *O. irregulaire.* to allow to be accommodated within the ichnogenus (Bromley and Ekdale, 1998). The elongated pellets of *O. nodosa* are often regarded as the rework of *O. irregulaire* (Frey et al., 1975).

Ichnospecies: *Ophiomorpha* isp.

(Plate 5.17d)

Description: Endichnial, highly curved, unbranched, lined cylindrical burrows. The burrows are highly ferruginised masking the peloidal arrangement. The burrow length extends up to 39.7 cm with a diameter of about 3.4 cm.

Occurrences: It is observed in micritic sandstone faces of Ratanpur Sandstone Member in Khadir Island (Plate 5.16d).

Remarks: The trace fossil is poorly preserved and the peloidal arrangement of the specimen is masked by ferruginous material, hance *Ophiomorpha* isp. is assigned.

Branching: Branched/Unbranched

Shape: Boxwork

Fill: Active/Passive

Burrow Wall: No lining

Ichnogenus: *Thalassinoides* Ehrenberg, 1944.

Type Specimen: *Thalassinoides callianassae* Ehrenberg, 1944.

Diagnosis: Large burrow systems consisting of smooth-walled, essentially cylindrical components; branches are Y to T shaped, typically enlarged at points of bifurcation; burrow dimensions may vary within a given system (Howard and Frey,1984).

Ichnospecies: *Thalassinoides horizontalis* Myrow, 1995

(Plate 5.18a-b)

Diagnosis: The trace fossil *Thalassinoides horizontalis* generally consists of smooth-walled, unlined, horizontally branching burrows that form polygonal networks. The bedding parallel frameworks contain both Y- and T-junctions. The burrows are even in diameter, lacking swellings at junctions or elsewhere, and have inner diameters of 3-4 mm (Myrow, 1995).

Description: Horizontal cylindrical burrows which are Y- or T- shaped with no vertically oriented offshoot. Burrow walls are smooth and the angle of branching is 72°. The length of burrows is more than 31 cm and the diameter ranges from 0.33 to 1.6 cm.

Occurrences: In Khadir Island, it is observed in sandy allochemic limestone (Plate 5.18a) and micritic sandstone facies of Ratanpur Sandstone Member, micritic sandstone facies of Hadibhadang Sandstone Member in Bela Island, and sandy allochemic limestone facies of Hadibhadang Sandstone Member in Chorar Island (Plate 5.18b).

Remarks: The absence of vertical component distinguished *Thalassinoides horizontalis* from other species and the complete absence of features such as scratch marks, burrow swellings at junctions and elsewhere, three-dimensional branching systems) that would indicate construction by crustaceans (Myrow, 1995).

Ichnospecies: *Thalassinoides paradoxicus* Woodward, 1830

(Plate 5.18c)

Diagnosis: Sparsely to densely but irregularly branched, subcylindrical to cylindrical burrows oriented at various angles with respect to bedding; T-shaped intersections are more common than Y-shaped bifurcations, and offshoots are not necessarily the same diameter as the parent trunk (Howard and Frey, 1984).

Description: Smooth, irregularly branched burrow systems spreading over bedding plane, bifurcated in different dimensions. The angle of branching is 86.5° and swelling at the point of bifurcation. Burrow fill is identical to host sediments. The diameter of the burrow is about 1.24 cm and near the point of bifurcation is about 1.67 cm.

Occurrence: Sandy allochemic limestone facies of Ratanpur Sandstone Member in Khadir Island; micritic sandstone facies of Hadibhadang Sandstone Member in Chorar Island (Plate 5.18c).

Remarks: *Thalassinoides paradoxicus* is characterized by enlargement at the point of bifurcation, by which it is distinguished from the other ichnospecies and is interpreted as feeding and dwelling burrows of crustaceans (Myrow, 1995).

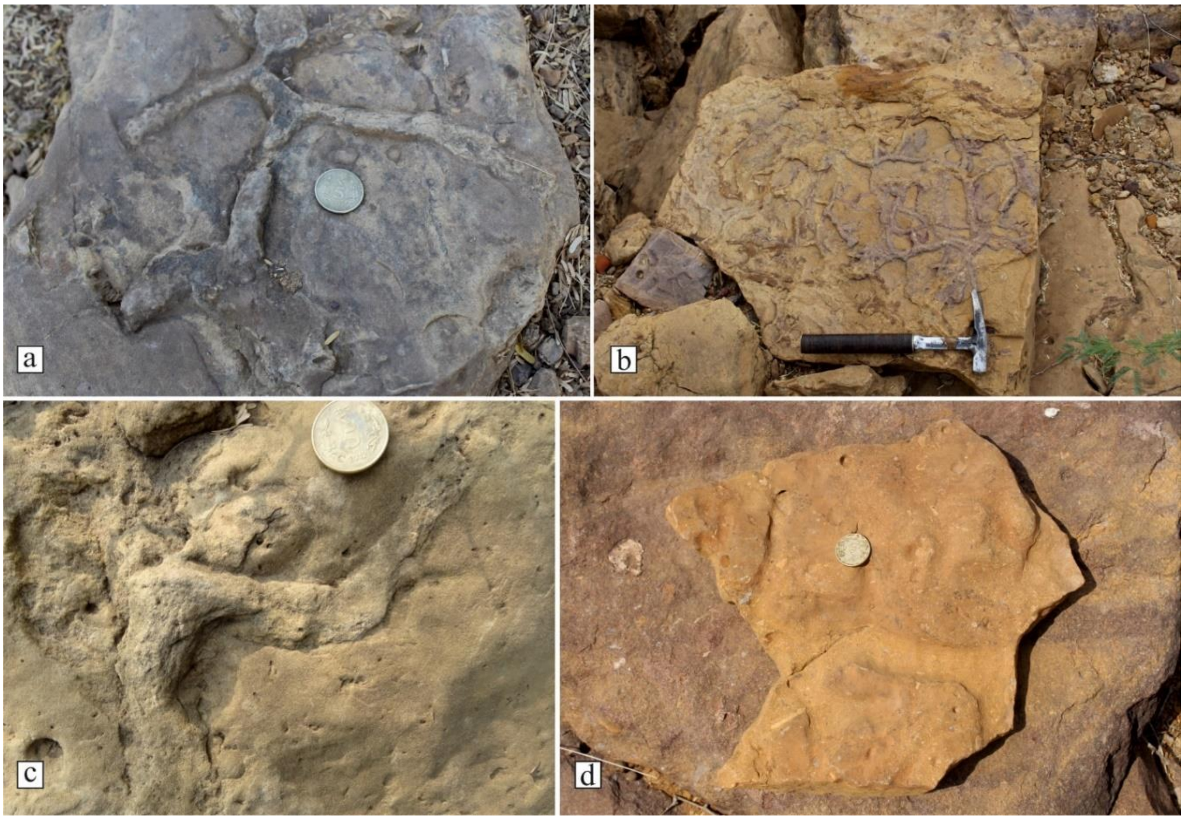

Plate 5.18 (a) T/Y shaped *Thalassinoides horizontalis* in sandy allochemic limestone facies of Ratanpur Sandstone Member in Khadir Island and (Scale: coin diameter = 3.2 cm). (b) Networks of *T. horizontalis* in sandy allochemic limestone facies of Ratanpur Sandstone Member in Chorar Island (length of hammer = 32 cm). (c) Horizontal Y-shaped *T. paradoxicus* with swollen nodes in micritic sandstone facies of Hadibhadang Sandstone Member in Chorar Island (Scale: coin diameter = 3.2 cm). (d) Field photograph of *Thalassinoides* isp. in Ratanpur Sandstone Member of Bela Island (Scale: coin diameter = 3.2 cm).

Ichnospecies: *Thalassinoides* isp.

(Plate 5.18d)

Description: Horizontal, Y-shaped burrows, preserved as groves. The actual burrow has been eroded. The diameter of the burrow is 3.6 cm branching at an angle of 106^{o}.

Occurrences: Sandy allochemic limestone facies of Ratanpur Sandstone Member of Gadhada Formation in Bela Island (Plate 5.18d) and cross-bedded white sandstone facies of Ratanpur Sandstone Member in Chorar Island.

Remarks: The trace fossils are poorly preserved, eroded, and do not exhibit the distinctive attribute of a particular ichnospecies such as *Thalassinoides saxonicus* Geinitz, 1842 due to lack of large form with tunnels (Kennedy, 1967); *T. ornatus* Kennedy, 1967 due to lack of smaller ovate, burrows (Kennedy, 1967); *T. paradoxicus* Woodward, 1830, due to that branches forming complex box work patterns (Howard and Frey, 1984); *T. suevicus* Reith, 1932 due to lack of enlarged Y-shaped bifurcations (Howard and Frey, 1984). It resembles *T. horizontalis* Myrow, 1995 which is strictly horizontal form but lacks other details. Hence, *Thalassinoides* isp. is assigned.