

Article

## **Paleoenvironmental significance of ichnofossils from the Mesozoic Jaisalmer Basin, Rajasthan, north western India**

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### **Abstract**

The Mesozoic rocks are well exposed in the Jaisalmer basin of the Indian Subcontinent. These sediments are classified into six formations as Lathi Formation, Jaisalmer Formation, Baisakhi Formation, Badasar Formation, Pariwar Formation and Habur Formation. The sediments are mainly represented by limestone, sandstone and shale. The sediments of the Jaisalmer Formation, the Baisakhi Formation, the Badasar Formation and the Pariwar Formation are examined for ichnological investigation and their significant role during the deposition of those sediments. The present paper documents seventeen ichnofossils such as *Acanthorhapha* isp., *Asteriacites* isp., *Cylindrichnus* isp., *Keckia annulata*, *Laevicyclus mongraensis*, *Ophiomorpha borneensis*, *O. nodosa*, *Paleomendron* isp., *Palaeophycus heberti*, *P. tubularis*, *Planolites annularis*, *P. berverlensis*, *P. montanus*, *Thalassinoides horizontalis*, *T. paradoxicus*, *T. suevicus*, and *Skolithos verticalis* from the Mesozoic marine sediments of the Jaisalmer basin. The ichnofossil assemblage have proved major role for the paleoenvironmental interpretation of these sediments and accordingly depositional paleoenvironments of Jaisalmer Formation, the Baisakhi Formation, the Badasar Formation and the Pariwar Formation have been drawn.

**Keywords** paleoenvironment; ichnofossils; Jaisalmer Basin; Rajasthan; India.

### **1 Introduction**

Ichnofossils are of paleoenvironmental significance (Mude, 2012a, 2012b, 2011; Kundal and Mude, 2008; Badve, 1987; Pemberton and Fery, 1982; Chiplonkar et al., 1981; Haentzschel, 1975; Simpson, 1975; Seilacher, 1964, 1967, etc). Marine sedimentary rocks deposited in the Jaisalmer basin during the Mesozoic Era are represented by siliciclastic and carbonate rocks. The rocks of the Jaisalmer basin are grouped into six namely, Lathi Formation, Jaisalmer Formation, Baisakhi Formation, Badasar Formation, Pariwar Formation and Habur Formation. The Lathi Formation consists of various sandstones with fossilized wood and tree trunk, the Jaisalmer Formation is represented by marine arenaceous limestone, calcareous sandstone and marly limestone, the Baisakhi Formation consists of shale and sandstone, the Badasar Formation consists of sandstone and sandstone-shale intercalation, the Pariwar Formation is represented by sandstone –shale intercalation with fossil wood and the Habur Formation consists of limestone, sandy limestone and calcareous sandstone .

Mesozoic rocks of the Jaisalmer basin are studied for palaeontological aspects by various researchers such as Sahni and Bhatnagar (1958), Subbotia et al. 1960), Krishna (1987), Dave and Chatterjee (1996), Kachhara and Jodhawat (1999), Khosla et al. (2006) and Rai and Gurg (2007). Ichnological investigations have been carried out by researchers like Kumar (1979), Chiplonkar et al. (1981), Sudan et al. (2000), Borkar and Kulkarni (2001, 2002) , Rai and Gurg (2007) and Kulkarni et al (2008).

Seventeen ichnofossils from the Mesozoic Jaisalmer sediments have been documented, analyzed, described and used for the palaeoenvironmental interpretation. These ichnofossils are represented by *Acanthorhapha* isp., *Asteriacites* isp., *Cylindrichnus* isp., *Keckia annulata*, *Laevicyclus mongraensis*, *Ophiomorpha borneensis*, *O. nodosa*, *Paleomendron* isp., *Palaeophycus heberti*, *P. tubularis*, *Planolites annularis*. *P. berverlensis*, *P. montanus*, *Thalassinoides horizontalis*, *T. paradoxicus*, *T. suevicus*, and *Skolithos verticalis* .

**2 Geological Setting**

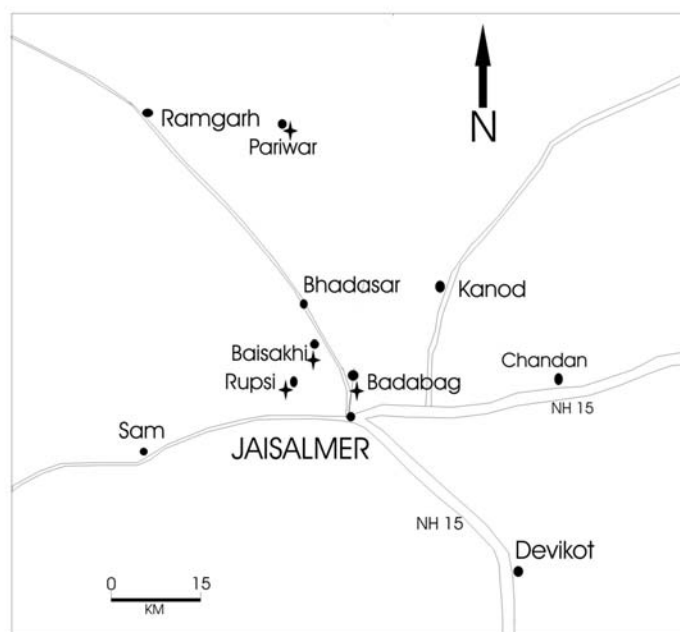
Marine Mesozoic rocks are widespread in the Jaisalmer basin, Rajasthan (Fig. 1). The rock successions in the basin are represented by Siliciclastic rocks interspersed with Carbonates of shallow, neritic facies in a southerly extending embayment of the Tethys. Mesozoic rocks of the Jaisalmer basin are classified as Lathi Formation, Jaisalmer Formation, Baisakhi Formation, Badasar Formation, Pariwar Formation and Habur Formation (Table 1).

**Table 1** The Mesozoic Stratigraphy of the Jaisalmer Basin ( Based on Dasgupta, 1974; Krishna, 1987)

Formation	Gross Lithology
Habur Formation (Aptian)	Marine coquinoidal limestone and sandy limestone -----Unconformity-----
Pariwar Formation (Cenomanian )	Sandstone and shale alternations with plant fossils and fossilized tree trunk
Badasar Formation (Portlandian)	Coarse to fine grained sandstone, marine to non-marine from top to bottom
Baisakhi Formation ( Kimmeridgian )	Marine shale alternating with sandstone and ammonites -----Unconformity-----
Jaisalmer Formation (Oxfordian-Callovian)	Alternations of marine arenaceous limestone and calcareous sandstone with a fossiliferous oolite bed at the top -----Graded contact-----
Lathi Formation (Bathonian-Lias)	Terrestrial to deltaic sandstone with fossil wood and fossilized tree trunk

**3 Systematic Taxonomy**

This study of paleo-ichnology follows the Treatise on Invertebrate Paleontology, (Haentschel, 1975). The morphological classification of Simpson (1975), ethological classification of Seilacher (1964) and facies classification of Seilacher (1964, 1967) are adopted.



**Fig. 1** Location map of the study area (Fossil localities are marked by star)

**Ichnotaxonomy:** *Acanthorhapha* Książkiewicz, 1970 (*In* Haentzschel, 1975)

**Diagnosis:** Thin trails, 1 mm in width; twisting in somewhat irregular curves of small amplitudes, with short thorn like branches, usually on convex side of curves.

**Ichnospecies:** *Acanthorhapha* isp. (Pl. III-(1))

**Material:** DG/FCP/IF/103

**Description:** Tree like network of trails, parallel to bedding plane and the diameter of the trails ranges from 1 to 2 mm. It gives branch like appearance.

**Remark:** The present trails are disposed parallel to the bedding plane and they are very thin with tree / branch like appearance. Thus, this specimen is described as *Acanthorhapha* isp.. It is interpreted morphologically as tunnel and ethologically as pascichnia.

**Occurrences:** Marly limestone of the Jaisalmer Formation in a dry rivulet near Badabag.

**Ichnotaxonomy:** *Asteriacites* Von Schlotheim 1820 (*In* : Haentzschel, 1975)

**Diagnosis:** Impressions in the form of asteroids or ophiuroids, with sculptured arms; their striae produced by activity produced by digging tube feet.

**Ichnospecies:** *Asteriacites* isp. (Pl. III-(5))

**Material:** DG/FCP/IF/91

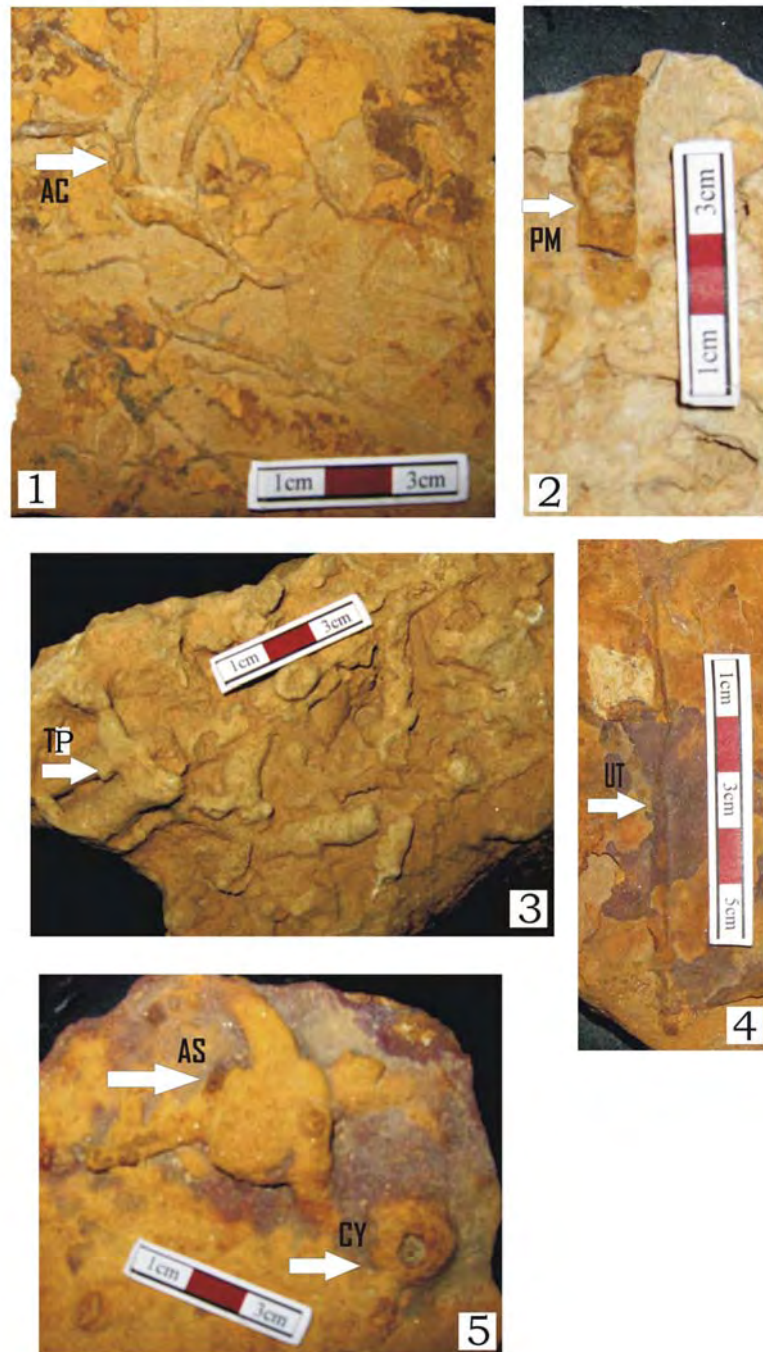
**Description:** The central circular to semicircular body consisting of 4 arms having thickness 6 mm and the width of arms decreases from centre towards outward. The diameter of the core varies from 16 to 20 mm and the diameter of the arms is 6 mm.

**Remark:** The present trace fossil has impression in the form of asteroids or ophiuroids, with transversely sculpted arms which may be produced by diggings tube feet. Chamberlain (1971) has been documented *A. lumbricalis* which is interpreted by Seilacher (1953 b, *In* Haentzschel, 1975 ) as resting traces of Asterozoa produced by ophiuroids. Seilacher (1953 a, *In* Haentzschel, 1975) has described *Asteriacites* from Lower

Jurassic sediments of Germany. As the present resting trace fossil has a central circular body with four arms, this is described and identified as *Asteriacites* isp. it is ethologically interpreted as cubichnia.

**Occurrences:** Shale-Siltstone intercalation at Badasar village, Badasar Formation

PLATE III



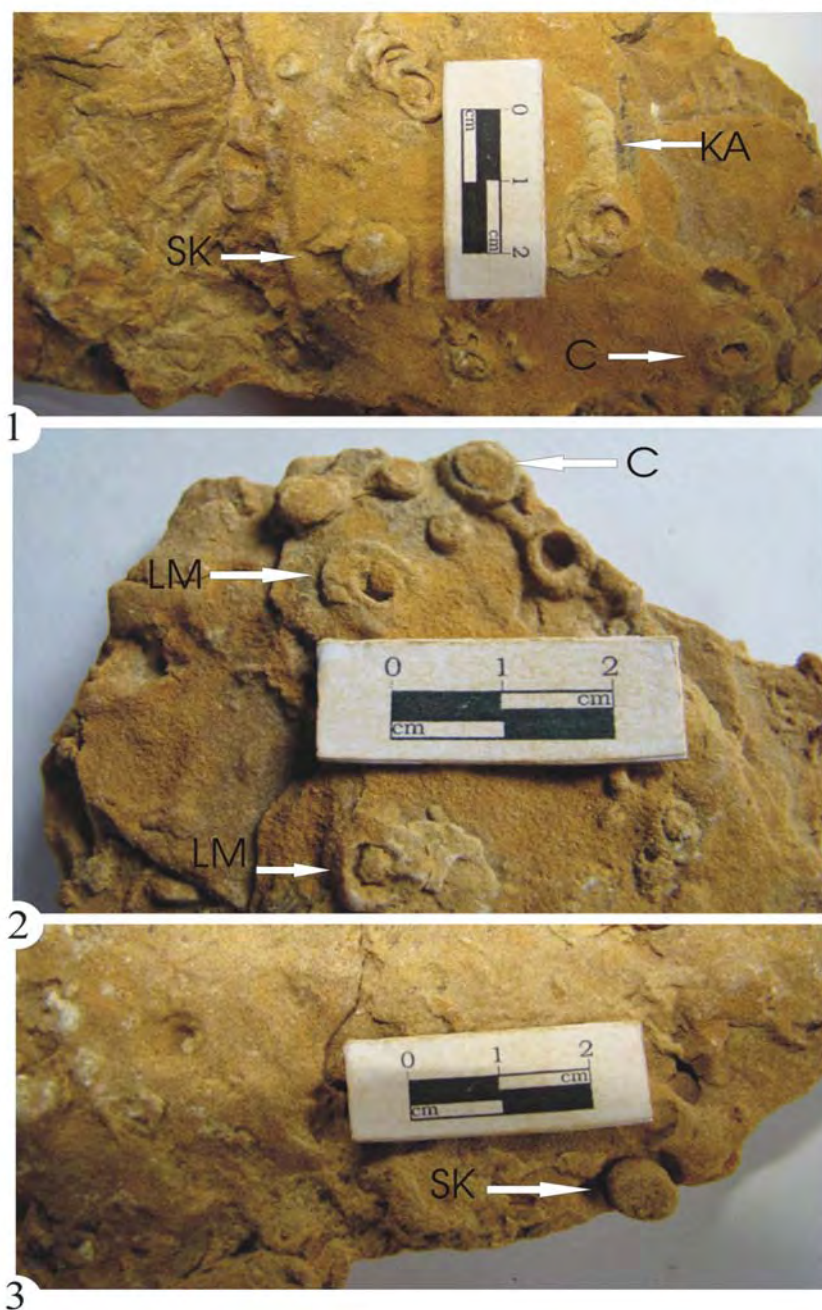
**Plate III** (1) *Acanthorhapha* isp; disposed horizontal to the bedding plane, network of very thin trails. (2) *Planolites montanus*; disposed perpendicular to the bedding plane, unlined very thin burrow. (3) *Thalassonoids paradoxicus*; disposed horizontal to the bedding plane, exhibiting simple branching. (4) *Unidentified Trail*; disposed parallel to the bedding plane. (5) i) *Asteriacites* isp , disposed horizontal to the bedding plane, arms visible, resting burrow. ii) *Cylindrichnus* isp, disposed perpendicular to the bedding plane, vertical burrow with central core.

**Ichnogenus :** *Cylindrichnus* Toots (*In* : Haward 1966)

**Diagnosis:** Vertical burrows, circular to semicircular in cross section, perpendicular to slightly inclined to the bedding surface having central core.

**Ichnospecies:** *Cylindrichnus* isp. (Pl. III-(5); Pl. V-(1))

## PLATE V



**Plate V** (1). i) *Keckia Annulata* ; disposed horizontal to the bedding plane exhibiting annulations. ii) *Skolithos verticalis*; disposed perpendicular to the bedding plane, vertical smaller and shorter burrow. iii) *Cylindrichnus* isp, disposed perpendicular to the bedding plane, vertical burrow with central core. (2) i) *Cylindrichnus* isp., disposed perpendicular to the bedding plane, vertical burrow with central core. ii) *Laevicyclus mongraensis*; disposed perpendicular to the bedding plane, vertical burrow with central shaft. iii) *Laevicyclus mongraensis*; disposed perpendicular to the bedding plane, vertical burrow with central shaft. (3) *Skolithos verticalis*; disposed perpendicular to the bedding plane vertical smaller and shorter burrow.

**Material:** Specimen Nos. DG/FCP/IF/3, 4, 76

**Description:** Burrows are vertical, semicircular in cross section having central core. Exterior wall of the burrows has crudely preserved concentric layers. The diameter of the burrows varies from 6 to 9 mm and the diameter of the central core is 4 mm.

**Remark:** *Cylindrichnus* is a permanent domichnial burrow of filter feeding organism (Haentzschel, 1975). Badve (1987) described *Cylindrichnus* isp. From top section of the Nimar Sandstone Formation exposed at Yalam, Madhya Pradesh. Kundal and Sanganwar (1998) documented this from the Nimar Sandstone Formation exposed at Hardaspur, Jobat of Jhabua district, M.P. Burrows are vertical, semicircular in cross section having central core, exterior wall of the burrows has crudely preserved concentric layers and more material with well preserved burrows is needed to describe up to specific level. Thus the present burrow is described as *Cylindrichnus* isp. It is interpreted morphologically as shaft and ethologically as domichnia.

**Occurrences:** Marly limestone of the Jaisalmer Formation in a dry rivulet near Badabag; Shale-Siltstone intercalation at Badasar, Badasar Formation.

**Ichnogenus :** *Keckia* Glocker, 1841

**Diagnosis:** Unbranched burrow, thinly lined, disposed horizontal to the bedding plane, districts annulations.

**Ichnospecies:** *Keckia annulata* Glocker, 1841 (Pl. V-(1))

**Diagnosis:** Unbranched burrow, thinly lined, disposed horizontal to the bedding plane, districts transverse annulations.

**Material:** Specimen Nos. DG/FCP/IF/1, 77

**Description:** Burrows unbranched, thinly lined with transverse annulations. The diameter of the burrows varies from 7 to 10 mm and 5 to 6 annulations per centimeter. The burrows are disposed horizontal to the bedding plane.

**Remarks:** Burrows are curved, unbranched and thinly lined with varying length and consists of transverse annulations. The present burrows are distinctly annulated and curved; therefore it is described as *Keckia annulata* Glocker. Chiplonkar and Ghare (1975), Badve (1987), Kundal and Sanganwar(2000) and Nayak (2000), recorded *K. annulata* from the Bagh Group. Kundal and Dharashivkar (2006) reported it from the bioclastic limestone of the Kalyanpur Limestone Member of the Dwarka Formation, Kundal et al.,( 2005) documented from Babaguru Formation, Cambay Basin. They are classified morphologically as tunnel and ethologically as fodinichnia.

**Occurrence:** Marly limestone of the Jaisalmer Formation in a dry rivulet near Badabag and Shale-Siltstone intercalation at Badasar, Badasar Formation

**Ichnogenus :** *Laevicyclus* Quensdete, 1879

**Diagnosis:** Vertical to slightly inclined burrows consisting of scraping circles surrounding a central vertical shaft, perpendicular to the bedding planes.

**Ichnospecies:** *Laevicyclus mongraensis*, Verma 1977 (Pl. V-(2))

**Diagnosis:** Vertical to slightly inclined burrows perpendicular to the bedding planes, scraping circles surrounding a central vertical shaft, two distinct circles visible in transverse section Verma (1971).

**Material:** Specimen Nos. DG/FCP/IF/5, 6

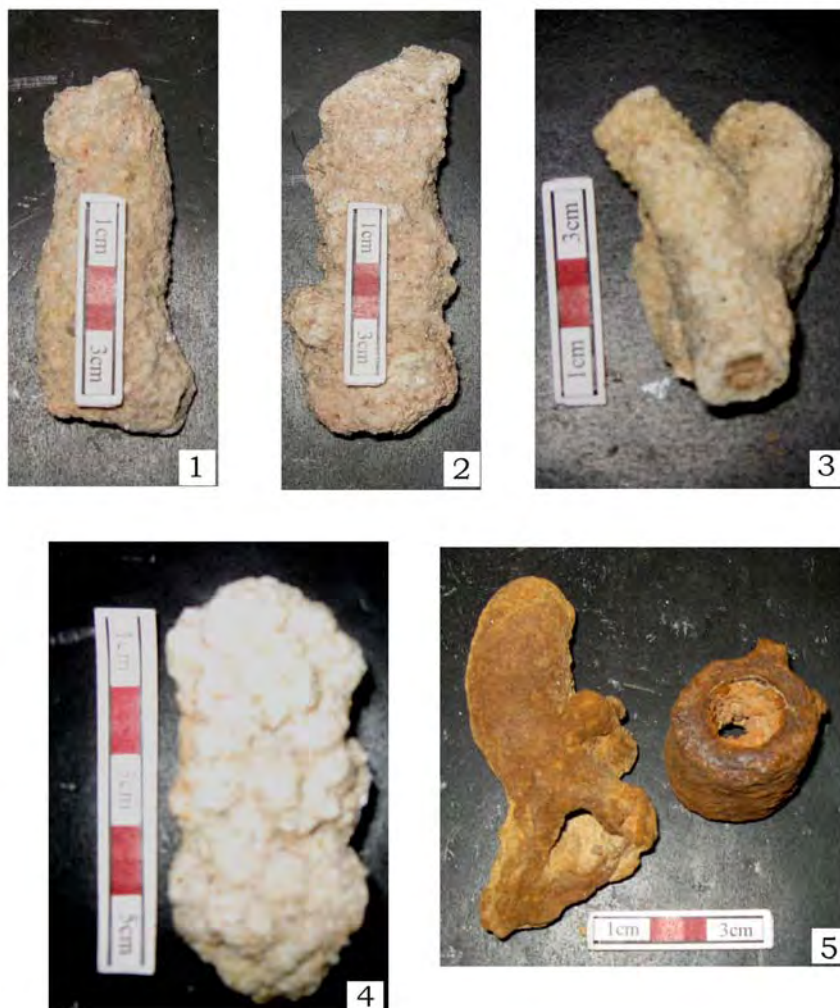
**Description:** Scraping circle surrounding a central vertical shaft, perpendicular to inclined to the bedding plane and preserved as positive epirelief. The diameter of the central shaft is 4 mm and 6 mm of scraping circle.

**Remarks:** Scraping circle surrounds a central vertical shaft. Burrow is perpendicular to inclined to the bedding plane and preserved as positive epirelief. Diameter of central shaft and scraping circles show close similarities

with *Laevicyclus mongraensis* Verma. They are morphologically shaft and ethologically domichnia. Verma (1971) originally described from Nimar Sandstone at Mongra, Amba Dongar area, Gujarat. This ichnospecies has been further recorded by various workers from India (Kundal and Sanganwar, 1998; Kundal and Dharashivkar, 2006). Recently, Mude (2012) documented it from the Babaguru Formation, Gujarat.

**Occurrence:** Marly limestone of the Jaisalmer Formation in a dry rivulet near Badabag.

## PLATE I



**Plate I** (1) *Ophiomorpha nodosa*; disposed perpendicular to the bedding plane and consisting of regularly distributed discoid, ovoid or irregular polygonal pellets. (2) *Ophiomorpha nodosa*; disposed perpendicular to the bedding plane and consisting of regularly distributed discoid, ovoid or irregular polygonal pellets. (3) *Ophiomorpha bornnensis*; disposed perpendicular to the bedding plane and consisting of regularly distributed bi-lobed pellets. (4) *Ophiomorpha bornnensis*; disposed perpendicular to the bedding plane and consisting of regularly distributed bi-lobed pellets. (5) *Palaeophycus heberti*; disposed perpendicular to the bedding plane and having thick wall.

**Ichnogenus:** *Ophiomorpha* Lundgren, 1891

**Diagnosis:** Vertical to horizontal shaft and tunnel, Simple to complex burrow systems, distinctly lined with agglutinated pelletoidal sediments. Burrow lining more or less smooth interiorly; densely to sparsely

mammalated or nodose exteriorly. Individual pellets or pelletal masses may be discoidal, ovoid, mastoid, bilobate, or irregular in shape, (Frey *et al*, 1978).

**Ichnospecies:** *Ophiomorpha borneensis* Keij (Pl. I-(3), (4))

**Diagnosis:** Burrow walls consisting predominantly of sparse, irregularly distributed, ovoid to mastoid pellets or pelletal masses, (Frey *et al*, 1978).

**Material:** DG/FCP/IF/62, 64

**Description:** Vertical to slightly inclined, lined burrows with bilobed pellets. The diameter of the burrows varies from 18 to 22 mm and the diameter of the pellets ranges from 2 to 5 mm.

**Remark:** These are horizontal and inclined burrows. Wall consists of dense regularly distributed bilobed pellets. The wall of burrows is composed of distinctly bilobed pellets and hence these are placed under *Ophiomorpha borneensis* Keij (Frey *et al.*, 1978). They are interpreted morphologically as shaft and ethologically as domichnia. This ichnospecies has been discovered by various ichnologists from different stratigraphic horizons from Indian Subcontinent (Kundal and Dharashivkar, 2006; Kundal and Mude, 2008).

**Occurrence:** Calcareous sandstone exposed at Pariwar village, Parivar Formation.

**Ichnospecies:** *Ophiomorpha nodosa* Lundgren (Pl. I-(1), (2); Pl. IV-(5))

**Diagnosis:** Burrow walls consisting predominantly of dense, regularly distributed discoid, ovoid or irregular polygonal pellets, (Frey *et al*, 1978).

**Material:** Specimen: DG/FCP/IF/ 61, 63, 68

**Description:** Lined, vertical to inclined burrows with discoidal and irregular polygonal pellets. Branching is also present. The diameter of the burrow ranges from 14-25 mm and the diameter of the pellets varies from 1-4 mm.

**Remark:** Burrows are straight to slightly curve and they are horizontal, inclined and perpendicular to the bedding plane. They exhibit branching habit while the wall of burrows consists of regularly distributed discoidal and irregular polygonal pellets. The present burrows are much similar to that of *Ophiomorpha nodosa* Lundgren and hence, they are identified as *Ophiomorpha nodosa* Lundgren. It has been discovered by various workers from the Indian subcontinent (Chiplonkar and Ghare, 1975; Kundal *et al.*, 2005; Kundal and Dharashivkar, 2006; Kundal and Mude, 2008). They are interpreted as shaft (morphologically) and domichnia (ethologically).

**Occurrence:** Calcareous sandstone exposed at Pariwar village, Parivar Formation.

**Ichnogenus:** *Paleomendron* Peruzzi, 1881

**Diagnosis:** Meandering trail, disposed horizontal to the bedding plane, double pointed corners at mender.

**Ichnospecies:** *Paleomendron* isp. (Pl. IV-(7))

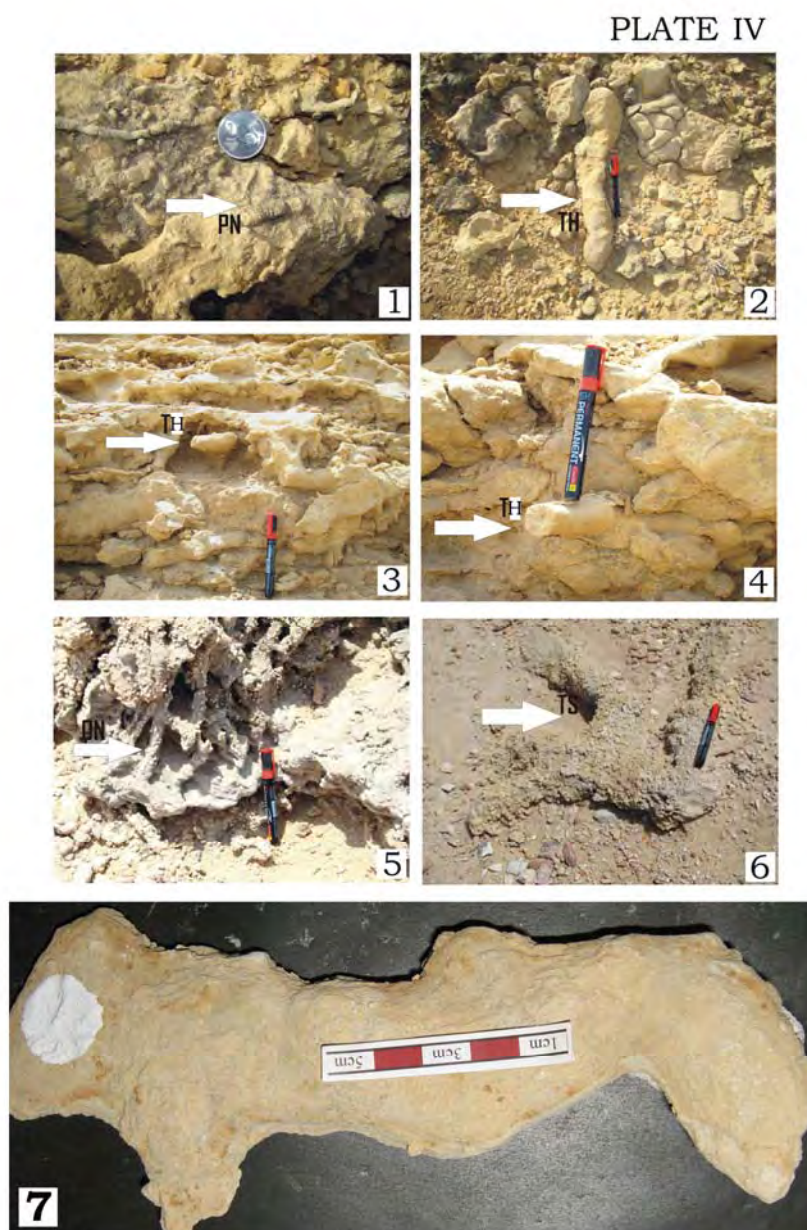
**Material:** Specimen Nos. DG/FCP/IF/52,109,110, 111

**Description:** Horizontal trail with meandering and meanders with double pointed corner. The average diameter of the trail is 35 mm and the diameter at meander varies from 40-50 mm.

**Remark:** Trails are disposed horizontal to the bedding plane with meandering. Double pointed corners are distinctly seen at portion of meandering. Thus, the present trails are identified and described as *Paleomendron* isp. (Haentzschel, 1975). Ksiazkiewicz (1968) has documented *Paleomendron rubustum* as a grazing trail in Flysch deposits (Late Cretaceous to Early Tertiary) from Australia, Italy, Spain and Poland. They are interpreted as tunnel (morphologically) and paschichnia (ethologically). This ichnospecies has been discovered from late Cretaceous Lameta Formation of Jabalpur area, Madhya Pradesh, India (Saha *et al*, 2010).



**Occurrence:** Shale-Siltstone intercalation at Badasar, Badasar Formation and Calcareous sandstone exposed near Mata Temple near Baisakhi, Baisakhi Formation.

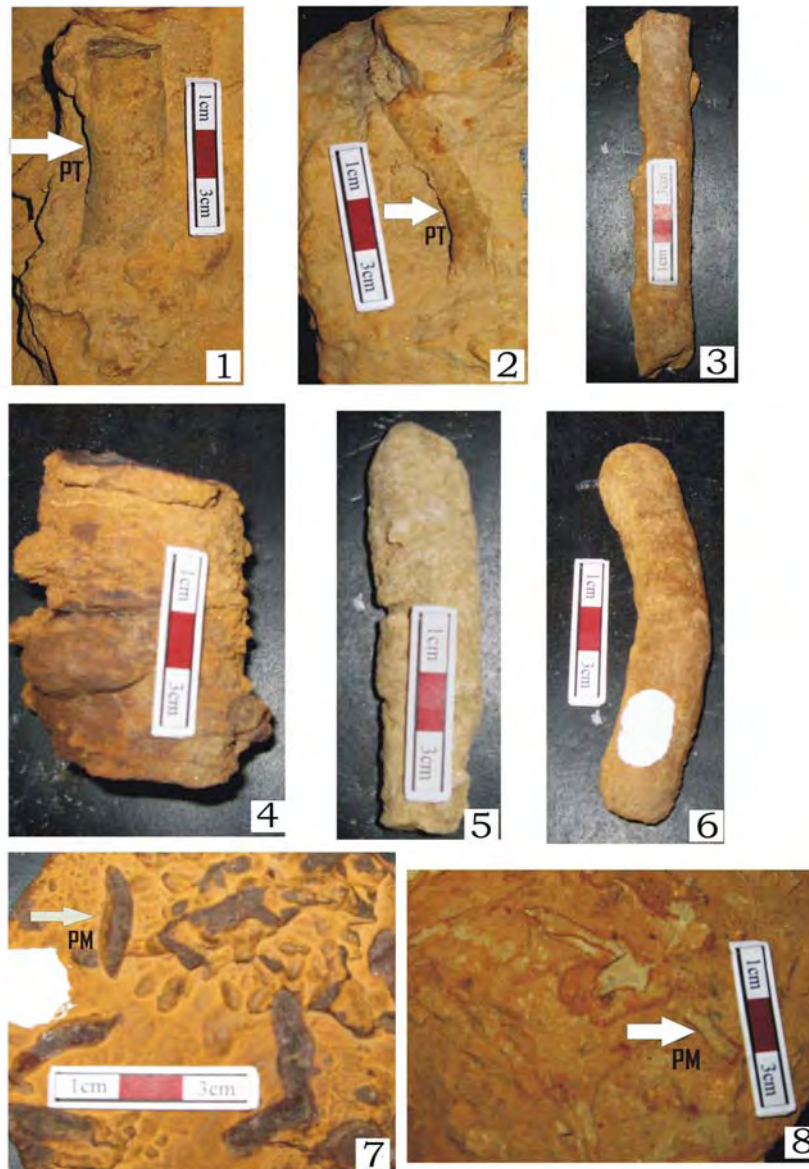


**Plate IV** (1) *Planolites annularis*; disposed horizontal to the bedding plane with transverse annulations. (2) *Thalassonoids horizontalis*; disposed horizontal to the bedding plane without any vertical offshoot / shaft. (3) *Thalassonoids horizontalis*; disposed horizontal to the bedding plane without any vertical offshoot / shaft. (4) *Thalassonoids horizontalis*; disposed horizontal to the bedding plane without any vertical offshoot / shaft. (5) *Ophiomorpha nodosa*; disposed perpendicular to the bedding plane and consisting of regularly distributed discoid, ovoid or irregular polygonal pellets. (6) *Thalassonoids suevicus*; disposed horizontal to the bedding plane exhibiting complex branching. (7) *Paleomeandron* isp. ; disposed horizontal to the bedding plane, meandering trail exhibiting double pointed corners at mender.

**Ichnogenus :** *Palaeophycus* Hall , 1847

**Diagnosis:** Lined, straight to tortuous, smooth to irregularly walled , elliptical to circular in cross-section, variable dimensions, burrow fill same to the host rock or colour of burrow identical to that of host rock (Pemberton and Frey, 1982).

**PLATE II**



**Plate II** (1) *Palaeophycus tubularis*; disposed perpendicular to the bedding, thickly walled, tube like appearance. (2) *Palaeophycus tubularis*; disposed perpendicular to the bedding ,thickly walled, tube like appearance. (3) *Palaeophycus tubularis*; disposed perpendicular to the bedding, thickly walled, tube like appearance. (4) *Palaeophycus heberti*; disposed perpendicular to the bedding plane and having thick wall. (5) *Planolites berberlensis*; disposed perpendicular to the bedding plane, unlined thick burrow. (6) *Planolites berberlensis*; disposed perpendicular to the bedding plane, unlined thick burrow. (7) *Planolites montanus*; disposed perpendicular to the bedding plane, unlined very thin burrow. (8) *Planolites montanus*; disposed perpendicular to the bedding plane, unlined very thin burrow.

**Ichnospecies:** *Palaeophycus heberti* ( Saporta) (Pl. I-(5), Pl. II-(4))

**Diagnosis:** Thickly Lined, straight to tortuous, smooth to irregularly walled , elliptical to circular in cross-section, variable dimensions, burrow fill same to the host rock (Pemberton and Frey, 1982).

**Material:** Specimen Nos. DG/FCP/IF/90, 125

**Description:** Unbranched burrows disposed horizontal to the bedding plane, lined burrow with thick wall, material infilled in the burrow similar to the host rock. The diameter of the burrow is 29 mm while the diameter of the wall is 9 mm.

**Remark:** Burrow is unbranched and horizontal to the bedding plane. The wall of burrow is considerably thick. Colour of burrow and host rock is same. It is cylindrical to subcylindrical in outer appearance and elliptical to roughly circular in cross section. It is a lined burrow filled with sediments typically identical to those of the host rock. As the present burrow has thick wall, this is described under *Paleophycus heberti* (Saporta) (Pemberton and Frey, 1982). They are interpreted morphologically as tunnel and ethologically as fodinichnia. Badve (1987) and Kundal and Sanganwar (1998) reported this species from Bagh Group of Madhya Pradesh. Kundal and Dharashivkar (2006) documented this species from Kalyanpur Limestone Member of Dwarka Formation. Recently, Mude et al., (2012) documented it from the Bhuj Formation, Kachchh.

**Occurrence:** Shale-Siltstone intercalation at Badasar, Badasar Formation

**Ichnospecies:** *Palaeophycus tubularis* (Pl. II-(1), (2), (3))

**Diagnosis:** Thickly lined, straight to tortuous, smooth to irregularly walled , circular in cross-section, variable dimensions, burrow fill same to the host rock, appears just like tube with uniform thickness (Pemberton and Frey, 1982).

**Material:** Specimen Nos. DG/FCP/IF/ 71, 84, 88

**Description:** Thinly lined unbranched burrows disposed horizontal to the bedding plane, infilled material is same as that of host rock, circular to semicircular in cross section. The diameters of the burrows vary from 6 to 24 mm and the diameter of the wall ranges from 1 to 2 mm.

**Remark:** Burrows are unbranched, thinly lined, cylindrical to tube like in appearance. They are preserved as positive epirelief and circular to semicircular in cross section and parallel to the bedding plane. Burrows are filled with material typically identical to that of surrounding matrix or host rock. The present burrows are, thinly lined and filled with material same to that of host rock. Therefore, they are described under *Paleophycus tubularis* Hall (Pemberton and Frey, 1982). They are interpreted morphologically as tunnel and ethologically as fodinichnia. Badve (1987) and Kundal and Sanganwar (1998) described this species from Bagh Group of Madhya Pradesh. Kundal et al., (2005) documented it from Babaguru Formation at Bhilod village, Broach district, Gujarat, Kundal and Dharashivkar (2006) recorded this species from Positra Limestone Member of Dwarka Formation. Recently, Mude et al., (2012) documented it from the Bhuj Formation, Kachchh.

**Occurrence:** Shale-Siltstone intercalation at Badasar, Badasar Formation.

**Ichnogenus:** *Planolites* Nicholson, 1873

**Diagnosis:** Unlined, rarely branched, straight to tortuous, smooth to irregularly walled , elliptical to circular in cross-section, variable dimensions, burrow fill different in lithology from host rock, colour of burrow differ from that of host rock. (Pemberton and Frey, 1982).

**Ichnospecies:** *Planolites annularis* (Pl. IV-(1))

**Diagnosis:** Straight to gently curved or tortuous cylindrical burrows with transverse annulations on the surface of the tunnel (Pemberton and Frey, 1982).

**Description:** The burrow is straight to slightly curved with distinct transverse annulations. The diameter of the burrow is 10 mm. the burrow infilled is identical to the host rock.

**Remarks:** The material of the burrow infilled is same to that of host rock and the burrow exhibits transverse annulations. The present burrow is much similar to *Planolites annularis*, Pemberton and Frey, 1982. Therefore it is identified as *Planolites annularis*. It is interpreted morphologically as tunnel and ethologically as fodinichnia.

**Occurrence:** Marly limestone of the Jaisalmer Formation in a dry rivulet near Badabag.

**Ichnospecies:** *Planolites beverleyensis* (Billings) (Pl. II-(4), (5))

**Diagnosis:** straight to gently curved or tortuous cylindrical burrows, smooth and thick (Pemberton and Frey, 1982).

**Material:** Specimen Nos. DG/FCP/IF/ 56, 82

**Description:** Straight to slightly curved burrow without lining, infilled material is different from the host rock, disposed parallel to the bedding plane, circular to semicircular in cross section. The diameter of the burrows varies from 15 to 24 mm.

**Remark:** Burrows are straight, unbranched and disposed parallel to the bedding plane. They are semicircular to circular in cross section. They are unlined burrows infilled with material different from that of host rock i.e. colour of burrow and host rock is different. The present burrows are considerably thick. Hence, they are placed under *Planolites beverleyensis* (Billings) (Pemberton and Frey, 1982). They are interpreted morphologically as tunnel and ethologically as fodinichnia. Borkar and Kulkarni (1992) and Kundal and Sanganwar (1998, 2000) recorded *Planolites beverleyensis* (Billings) from Wadhawan Formation of Gujarat and Bagh Group of Madhya Pradesh, respectively. Kundal et al., (2005) documented it from Babaguru Formation at Bhilod village, Broach district, Gujarat. Kundal and Dharashivkar (2006) recorded this species from Shankhodhar Sand-Clay Member Dwarka Formation. Recently, Mude et al. (2012) documented it from the Bhuj Formation, Kachchh. Further, Mude (2012) documented it from the Babaguru Formation, Gujarat.

**Occurrence:** Shale-Siltstone intercalation at Badasar, Badasar Formation and Calcareous sandstone exposed near Mata Temple at Baisakhi, Baisakhi Formation

**Ichnospecies:** *Planolites montanus* Nicholson (Pl. II-(7), (8); Pl. III-(2))

**Diagnosis:** straight to gently curved or tortuous cylindrical burrows, smooth thin and very small (Pemberton and Frey, 1982).

**Material:** Specimen Nos. DG/FCP/IF/ 93, 75, 76, 107, 112

**Description:** Straight, undulose, tortuous, unlined burrow, disposed parallel to the bedding plane, infilled material in the burrow is different than that of host rock. The diameter of the burrows ranges from 4 to 7 mm.

**Remark:** Burrows are straight, undulose, tortuous and isolated. They are disposed parallel to the bedding plane and preserved as positive epirelief. They are an unlined burrows infilled with sediments having textural and fabricational characters different from host rock. Present burrows are small in diameter and tortuous in nature. Hence, they are placed under *Planolites montanus* Richter (Pemberton and Frey, 1982). They are interpreted morphologically as tunnel and ethologically as fodinichnia. Many researchers like Badve and Ghare (1978, 1980); Sanganwar and Kundal (1997); Kundal and Sanganwar (1998, 2000) reported this ichnospecies from Bagh Group of Madhya Pradesh while Chiplonkar and Ghare (1979) documented from Trichinopoly Group, Tamil Nadu. Kundal et al., (2005) documented this from Babaguru Formation at Bhilod village, Broach district, Gujarat. Kundal and Dharashivkar (2006) reported this ichnospecies from Shankhodhar Sand Clay Member (Dwarka Formation) at Dingeshwar Mahadev cliff.

**Occurrence:** Marly limestone of the Jaisalmer Formation in a dry rivulet near Badabag and Shale-Siltstone intercalation at Badasar, Badasar 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 or elsewhere.

**Ichnospecies:** *Thalassinoids horizontalis* Myrow, 1995 (Pl. IV-(2), (3), (4))

**Diagnosis:** Cylindrical burrows, predominantly horizontal, more or less regularly branched, unlined burrow system with smooth wall, horizontal network without vertical shaft, lack of swelling at points of branching (Myrow, 1995).

**Material:** Specimen Nos. DG/FCP/IF/ 57 and field photographs

**Description:** Very thick horizontal burrow, disposed parallel to the bedding plane without any ornamentation, cylindrical in cross section, absence of vertical offshoots, the diameter of the burrows ranges from 45 to 50 mm (Lab specimens) and 45 to 75 mm ( field specimens).

**Remark:** The burrows are disposed parallel to the bedding planes without vertical offshoots and the length of burrow varies from 100 – 450 mm and diameter ranges from 45-75 mm. the present burrows show much similarities with that of *Thalassinoids horizontalis* Myrow (1995). It is interpreted morphologically as tunnel and ethologically as domichnia. Malarkoli et.al., (2009) recorded this from the Palaeogene sediments of the Pondicherry area, India.

**Occurrences:** Shale-Siltstone intercalation at Badasar, Badasar Formation and Calcareous sandstone exposed near Mata Temple at Baisakhi, Baisakhi Formation

**Ichnospecies:** *Thalassinoids paradoxicus*, Woodward 1830 (In Curran and Frey, 1977) (Pl. III-(3))

**Diagnosis:** Predominantly horizontal, isolated and unbranched, simple Y-shaped burrows, disposed horizontal to the bedding planes (Howard and Frey, 1984).

**Material:** Specimen Nos. DG/FCP/IF/76

**Description:** Y-shaped isolate burrow, swelling at the point of bifurcation with smooth surface and unornamented. The diameters of the burrows vary from 6 to 15 mm and the diameter at the branching is 10 to 18 mm.

**Remark:** the present burrows are isolated, Y-shaped and unornamented and thus they are identified and described as *Thalassinoides paradoxicus*. Morphologically it is interpreted as tunnel and ethologically as domichnia. Sanganwar and Kundal (1997) and Kundal and Sanganwar (1998) respectively documented this from the Nimar Sandstone Formation at Yelam, Barwah, Khargaon district, Madhya Pradesh and Hardaspur, Jobat, Jhabua district.

**Occurrence:** Shale-Siltstone intercalation at Badasar, Badasar Formation.

**Ichnospecies:** *Thalassinoides suevicus*, Kennedy, 1967 (Pl. IV-(6))

**Diagnosis:** Predominantly horizontal, Simple Y-shaped to complex branching, essentially cylindrical burrow system consists of a horizontal network connected to the surface by a more or less vertical shaft; dichotomous bifurcation are more common than T-branches (Howard and Frey, 1984).

**Material:** Specimen Nos. DG/FCP/IF/ 51, 80

**Description:** Y-shaped to complex burrow, swelling at the point of bifurcation with smooth surface and unornamented, parallel to the bedding plane. The diameter of the burrows ranges from 8 to 10 mm (Lab. Specimen) and 40 to 120 mm (Field specimen).

**Remark:** The burrows are Y-shaped to complex and disposed parallel to the bedding plane without ornamentation, exhibiting swelling at the point of bifurcation. The present burrows show most of the characters similar to that of *Thalassinoides suevicus*, hence these are described as *Thalassinoides suevicus*. It is interpreted morphologically as tunnel and ethologically as domichnia.

**Occurrences:** Shale-Siltstone intercalation at Badasar, Badasar Formation and Calcareous sandstone exposed near Mata Temple at Baisakhi, Baisakhi Formation.

**Ichnogenus :** Skolithos Haldemann, 1840

**Diagnosis:** Straight tubes or pipes perpendicular to bedding plane, shafts parallel to each other, subcylindrical to cylindrical, unbranched.

**Ichnospecies:** *Skolithos verticalis* (Pl. V-(1), (3))

**Diagnosis:** Straight to slightly curved, cylindrical burrow, vertical to inclined, usually shorter and smaller.

**Material:** Specimen Nos. DGFCP/IF/ 2, 7

**Description:** Vertical shaft, disposed perpendicular to the bedding plane without branching. The diameter of the burrows varies from 5-6 mm.

**Remarks:** Burrows are cylindrical, unbranched, and disposed perpendicular to the bedding plane. *Skolithos verticalis* are generally shorter in length and smaller in diameter as compare to *Skolithos linearis*. They are suspension feeder, ethologically domichnia and morphologically shaft. The genus *Skolithos* is widely known in near shore /shallow water marine environment (Seilacher, 1967). The suspension feeding burrows are the resultant of the feeding activities of polychaetes like *Amphinome rostrata* and *Nereis costoe* (Patel and Desai, 2009). Recently, Mude (2012) documented it from the Babaguru Formation, Gujarat.

**Occurrence:** Marly limestone of the Jaisalmer Formation in a dry rivulet near Badabag and Shale-Siltstone intercalation at Badasar, Badasar Formation.

**Ichnogenus :** ?

*Unidentified Trail* (Pl. III-(4))

**Material:** Specimen Nos. DGFCP/IF/ 104

**Description:** Thin trail more or less straight tapering at one end. The diameter of the trail ranges from 2 to 3 mm.

**Remark:** The present trail is very thin, straight and narrowing at one end disposed parallel to the bedding plane. As only one specimen is available and there is lack of literature, this is described as *unidentified trail* and it is open for discussion.

**Occurrence:** Shale-Siltstone intercalation at Badasar, Badasar Formation.

#### 4 Discussion

The palaeoenvironment of marine sediments can be interpreted by investigating lithology, primary structures, and faunal elements, but in modern days, ichnofossils and association of ichnofossils due to their autochthonous nature, have been proved very helpful in palaeogeographic investigations (Haentzschel, 1975). Seilacher has proved that the typical trace fossils assemblages occur in different location in sediments of different ages. Such assemblage belongs to a particular marine environment and is composed of typical association of ichnofossils, constituting ichnofacies (Haentzschel, 1975). Seilacher (1967) has introduced the

ichnofacies classification and he (op. cit) has grouped all known ichnofossils into six ichnofacies, namely, *Scoyenia Facies* (non-marine, commonly red-beds), *Skolithos Facies* (littoral; rapid sedimentation), *Glossifungites Facies* (littoral; with erosional surface), *Cruzian Facies* (deeper shallow water, below the true littoral zone), *Zoophycos Facies* (transitional to bathyal zone) and *Nereites Facies* (bathyal to abyssal; pelagic sediments and turbidites).

The first record of trace fossil (*Gyrochorte*) was made by Kumar (1979), Chiplonkar (1981) identified ichnogenus *Ichnyrica*, Borkar and Kulkarni (2001) documented presence of *Rhizocorallium karaiensis* from the Habur Formation and Borkar and Kulkarni (2008) recorded *Planolites* isp., *P. montanus* and *Thalassinoides* isp. from Fatehgarh Formation. Recently, Kulkarni et al. (2008) documented ichnospecies such as *Arenicolies tenuis*, (?) *Bichordites* isp., *Planolites* isp., *Rhizocorallium irregulare*, *R. jenense*, *Taenidium serpentinum* and *Thalassinoides ichnosp* the Ford Member of the Jaisalmer Formation.

## 5 Conclusions

The present paper documents seventeen ichnofossils such as *Acanthorhapha* isp., *Asteriacites* isp., *Cylindrichnus* isp., *Keckia annulata*, *Laevicyclus mongraensis*, *Ophiomorpha borneensis*, *O. nodosa*, *Paleomendron* isp., *Palaeophycus heberti*, *P. tubularis*, *Planolites annularis*, *P. berverlensis*, *P. montanus*, *Thalassinoides horizontalis*, *T. paradoxicus*, *T. suevicus*, and *Skolithos verticalis* from the Mesozoic marine sediments of the Jaisalmer basin and their formation wise occurrences are mentioned in Table 2.

**Table 2** Palaeo-environmental interpretation based on ichnofossils assemblage

<b>Ichnofossils from the Mesozoic Jaisalmer Basin</b>		
<b>STRATIGRAPHIC HORIZON</b>	<b>ICHNOFOSSILS</b>	<b>DEPOSITIONAL ENVIRONMENT</b>
HABUR FORMATION	Not Investigated	No Comments
PARIWAR FORMATION	<i>Ophiomorpha borneensis</i> , <i>O. nodosa</i>	Shallow water near-shore marine environment for the top of the formation.
BADASAR FORMATION	<i>Asteriacites</i> isp., <i>Cylindrichnus</i> isp., <i>Palaeophycus heberti</i> , <i>P. tubularis</i> , <i>Planolites annularis</i> , <i>P. berverlensis</i> , <i>P. montanus</i> , <i>T. paradoxicum</i> , <i>T. suevicus</i> ,	Shallow sub-littoral marine environment with moderate to low energy conditions.
BAISAKHI FORMATION	<i>Paleomendron</i> isp., <i>Planolites berverlensis</i> , <i>Thalassinoides horizontalis</i> , <i>T. suevicus</i> .	Shallow sublittoral (deeper shallow) marine environment.
JAISALMER FORMATION	<i>Acanthorhapha</i> isp., <i>Cylindrichnus</i> isp., <i>Keckia annulata</i> , <i>Laevicyclus mongraensis</i> , <i>Planolites montanus</i> and <i>Skolithos verticalis</i>	Littoral to sublittoral marine environment under high to moderate energy conditions.
LATHI FORMATION	Not Investigated	No Comments

The Jaisalmer Formation consists of six ichnofossils, namely, *Acanthorhapha* isp., *Cylindrichnus* isp., *Keckia annulata*, *Laevicyclus mongraensis*, *Planolites annularis* and *P. montanus*. The ichnofossils assemblage belongs to *Skolithos* ichnofacies which indicate that the Jaisalmer Formation was deposited in littoral to sub-littoral marine environment under high to moderate energy conditions. The Baisakhi Formation consists of 4 ichnofossils, namely, *Paleomendron* isp., *Planolites berverlensis*, *Thalassinoides horizontalis* and *T. suevicus*. The ichnofossils assemblage from the Baisakhi Formation belongs to *Cruziana* ichnofacies which point out that the Baisakhi Formation was deposited in shallow sublittoral (deeper shallow) marine environment. The Badasar Formation consists of ten ichnofossils, namely, *Asteriacites* isp., *Cylindrichnus* isp., *Paleomendron* isp., *Paleophycus heberti*, *P. tubularis*, *Planolites berverlensis*, *P. montanus*, *Thalassinoides paradoxicus* and *T. suevicus*. The ichnofossils assemblage belongs to *Cruziana* facies which indicates that the Badasar Formation was deposited in shallow sub-littoral marine environment with moderate to low energy conditions. The Pariwar Formation consists of two ichnofossils, namely, *Ophiomorpha borneensis* and *O. nodosa*. The ichnofossils assemblage belongs to *Skolithos* facies. The samples for the present study are collected from the surface exposures in the type locality where the top portion of the Pariwar Formation was exposed. Thus, the present ichnofossils point out that the top of the Pariwar Formation was deposited in shallow water near-shore marine environment and contacting the conclusion of non-marine environment for the deposition of the Pariwar Formation.

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