

Shallow Marine Trace Fossils from Mandai Formation of the Barmer Basin, District-Jaisalmer, Western Rajasthan, India

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Abstract

Thirteen well-preserved trace fossil species namely *Thalassinoides horizontalis*, *Thalassinoides suevicus*, *Ophiomorpha nodosa*, *Ophiomorpha borneensis*, *Palaeophycus heberti*, *Palaeophycus tubularis*, *Planolites*, *Planolites montanus*, *Planolites beverleyensis*, *Planolites annularis*, *Siphonites*, *Paleomeandron*, and *Phycodes palmatum* have been reported from Mandai Formation of the Barmer Basin at Mandai area, western Rajasthan, India. The present study area is located about 15 km southwest of Fatehgarh town on Fatehgarh–Jhinjinyali tar Road. The Mandai Formation is 27 m thick lithostratigraphic unit deposited in the north-western part of the Barmer Basin and overlies on Early Palaeocene Bariyara -Dharvi-Sajit Member of the Akli Formation and overlain by Giral-Thumbli Member of Akli Formation of Early Eocene. The Mandai Formation has mixed siliciclastic, minor carbonate and phosphorite facies and its starts with bioturbated medium to fine grained ferruginous sandstone at the base. These trace fossils are preserved of full relief in yellowish to dark brown medium to fine grained ferruginous sandstone and greyish yellow coarse and coarse to medium grained calcareous sandstone. The entire ichnogenes shows shallow marine depositional environment of Mandai Formation of Barmer Basin. No age can be assigned on the basis of these trace fossil as they have long range (Cambrian to Recent).

Keywords: Shallow marine; Trace fossils; Mandai formation; Barmer basin; Jaisalmer and Western Rajasthan

Introduction

Barmer Basin is mainly Tertiary basin, opened as narrow, roughly N-S trending linear graben and it has a maximum length 100 km; while the width is about 50 km [1]. Biswas et al. [2] opined that Barmer Basin considered as northern extension of Cambay Basin connected through the Sanchole Basin. The Barmer Basin is floored by Malani igneous suite, Lathi sandstone and Jaisalmer Formation [3]. The sediments of the Barmer Basin are classified into eight formations viz; Sarnu Formation, Fatehgarh Formation, Mandai Formation, Barmer Hill Formation, Akli Formation, Mataji ka Dungar Formation, Kapurdi Formation and Uttarlai Formation. The Sarnu Formation is represented by red siltstone and sandstone with plant fossils, the Fatehgarh Formation comprises siltstone, ferruginous sandstone, phosphatic sandstone having significant microvertebrates- magnetic spherule bearing bone bed and gastropod bed [4,5], the Mandai Formation is represented by bioturbated ferruginous sandstone and calcareous sandstone, medium to coarse grained sandstone, phosphatic bivalves bed, fine to medium grained sandstone, coarse grained sandstone and pebbly sandstone [6], the Barmer Hill Formation comprises sandy sandstone with chert and poorly preserved plant fossils and well -preserved *Asthenopodichium* wood bearing trace fossils [7], the Akli Formation is represented by bentonite, clay, lignite and ferruginous sandstone with gastropods, microvertebrates and plant fossils [8], the Mataji ka Dungar Formation is dominantly composed of coarse grained sandstone, ferruginous sandstone and clay and bentonitic clay at the base [6,9], the Kapurdi Formation is represented by fuller's-Earth, gypseous clay, bioclastic limestone and marl with plants fossils, crabs, shrimps, turtles, fishes and gastropods [10] and the Uttarlai Formation comprises salt, gypsum, gypseous clay and sands [1]. Many trace fossils have been already reported from the rocks of the Barmer Basin by various researchers such as Borkar et al. [11], recorded *Thalassinoides*, *Planolites* and *Planolites Montanus* from Fatehgarh Formation; nearshore – shallow marine trace fossils from Fatehgarh Formation reported by Parihar et al. [7,9] and trace fossils from Mandai Formation reported by Parihar

et al. [12]. The present investigation here deals with detailed study of shallow marine trace fossils from Mandai Formation of Barmer Basin at Mandai area viz; *Ophiomorpha nodosa*, *Ophiomorpha borneensis*, *Palaeophycus heberti*, *Palaeophycus tubularis*, *Planolites annularis* trace fossils found in yellowish to dark brown medium to fine grained ferruginous sandstone and *Thalassinoides horizontalis*, *Thalassinoides suevicus*, *Planolites*, *Planolites montanus*, *Planolites beverleyensis*, *Siphonites*, *Paleomeandron* and *Phycodes palmatum* trace fossils are occurred in greyish yellow coarse and coarse to medium grained calcareous sandstone in the lower phosphatic – carbonate dominated sequence of Mandai Formation. The objectives of present paper (i) To first reports of 13 trace fossils from Mandai Formation of the Barmer Basin. (ii) To the systematic ichnology of trace fossils and environment of deposition of trace fossils bearing facies of the Mandai Formation of Barmer Basin, Western Rajasthan, India.

Geology of the Study Area

The Mandai Formation is located about 15 km south -west of Fatehgarh on Fatehgarh-Jhinjinyali tar Road (Figure 1). The Mandai Formation is 27 m thick lithostratigraphic unit deposited in the north -western part of the Barmer Basin. The various lithounits of the Mandai Formation forms low to high ridges and hillocks in and around Mandai Village. The Mandai ridge running from south of the Jatoni ki Dhani and up to Mandai in the south and the overall strike length of ridges is about 10 kms (Figure 2). The Mandai Formation

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Received April 29, 2015; Accepted May 31, 2016; Published June 08, 2016

Citation: Parihar VS, Nama SL, Mathur SC (2016) Shallow Marine Trace Fossils from Mandai Formation of the Barmer Basin, District-Jaisalmer, Western Rajasthan, India. J Ecosys Ecograph 6: 189. doi:10.4172/2157-7625.1000189

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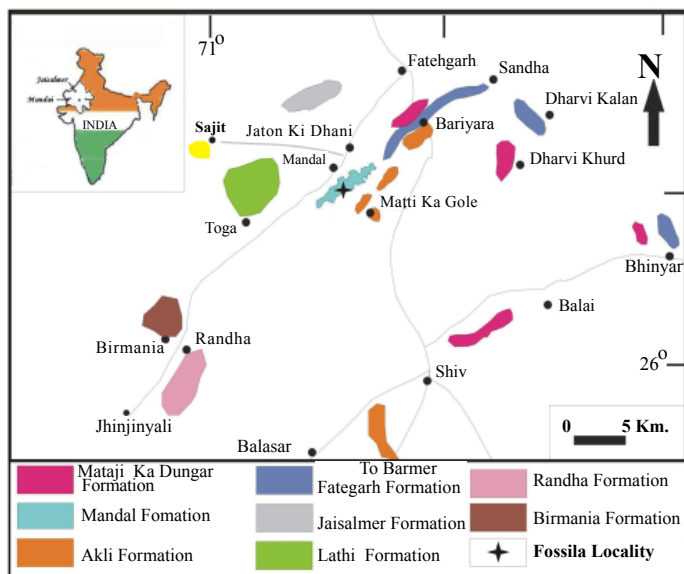


Figure 1: Location map of the Mandai Formation of Barmer Basin showing trace fossils locality [9].

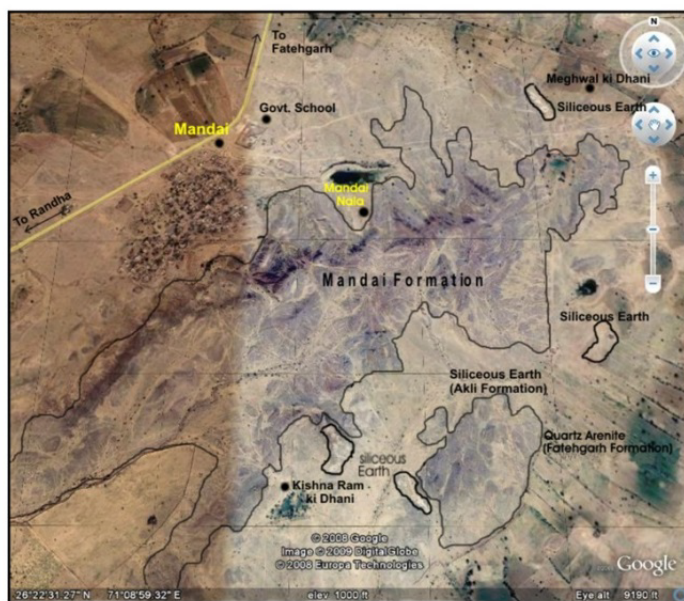


Figure 2: Interpretative geological map showing outcrops, hillock and ridges of Mandai Formation (based on field relationship and Landsat imagery) [9].

overlies on Early Palaeocene Bariyara-Dharvi-Sajit Member of the Akli Formation and overlain by Giral-Thumbli Member of Akli Formation of Early Eocene age. The lithology of the Mandai Formation of Barmer Basin are classified into two classes indicating two different sedimentary environments, they are mainly, the lower phosphatic-carbonate dominated lithofacies association comprised of ferruginous sandstone and calcareous sandstone have extension bioturbations, medium to coarse grained sandstone with boxworks and concretionary structures phosphatic bivalves bed and upper coarsening upward lithofacies association of siliciclastic sequences consists of fine to medium grained sandstone, coarse grained sandstone and pebbly sandstone mark the top of the Mandai Formation (Table 1) [6]. The *Ophiomorpha nodosa*,

Ophiomorpha borneensis, *Palaeophycus heberti*, *Palaeophycus tubularis*, *Planolites annularis* trace fossils found in yellowish to dark brown medium to fine grained ferruginous sandstone and *Thalassinoides horizontalis*, *Thalassinoides suevicus*, *Planolites montanus*, *Planolites beverleyensis*, *Siphonites*, *Paleomeandron* and *Phycodes palmatum* trace fossils occurred in greyish yellow coarse and coarse to medium grained calcareous sandstone in the lower phosphatic – carbonate dominated sequence of Mandai Formation at Mandai area (Figure 3).

Palaeontology

Trace fossils: The present paper here reports thirteen trace fossils from yellowish to dark brown medium to fine grained ferruginous

Mandai Formation (Middle to Late Paleocene (?))	Siliciclastic dominated lithofacies association	Pebbly sandstone, Coarse grained sandstone. Fine to medium grained sandstone.
	Carbonate – phosphate dominated lithofacies association	Phosphatic bivalve bed, Sandstone with boxwork structures, Calcareous and Ferruginous sandstone bearing trace fossils.
Akli Formation (Early Paleocene)	Bariyara – Sajit – Dharvi member	Repetitive sequence of Bentonite, clay and Fine to medium grained sandstone, Siliceous Earth.
Fatehgarh Formation (Cretaceous)	Upper siliciclastic facies	Quartz arenite, gastropod bed and sandstone.

Table 1: Generalized geological succession of the Mandai Formation [9].

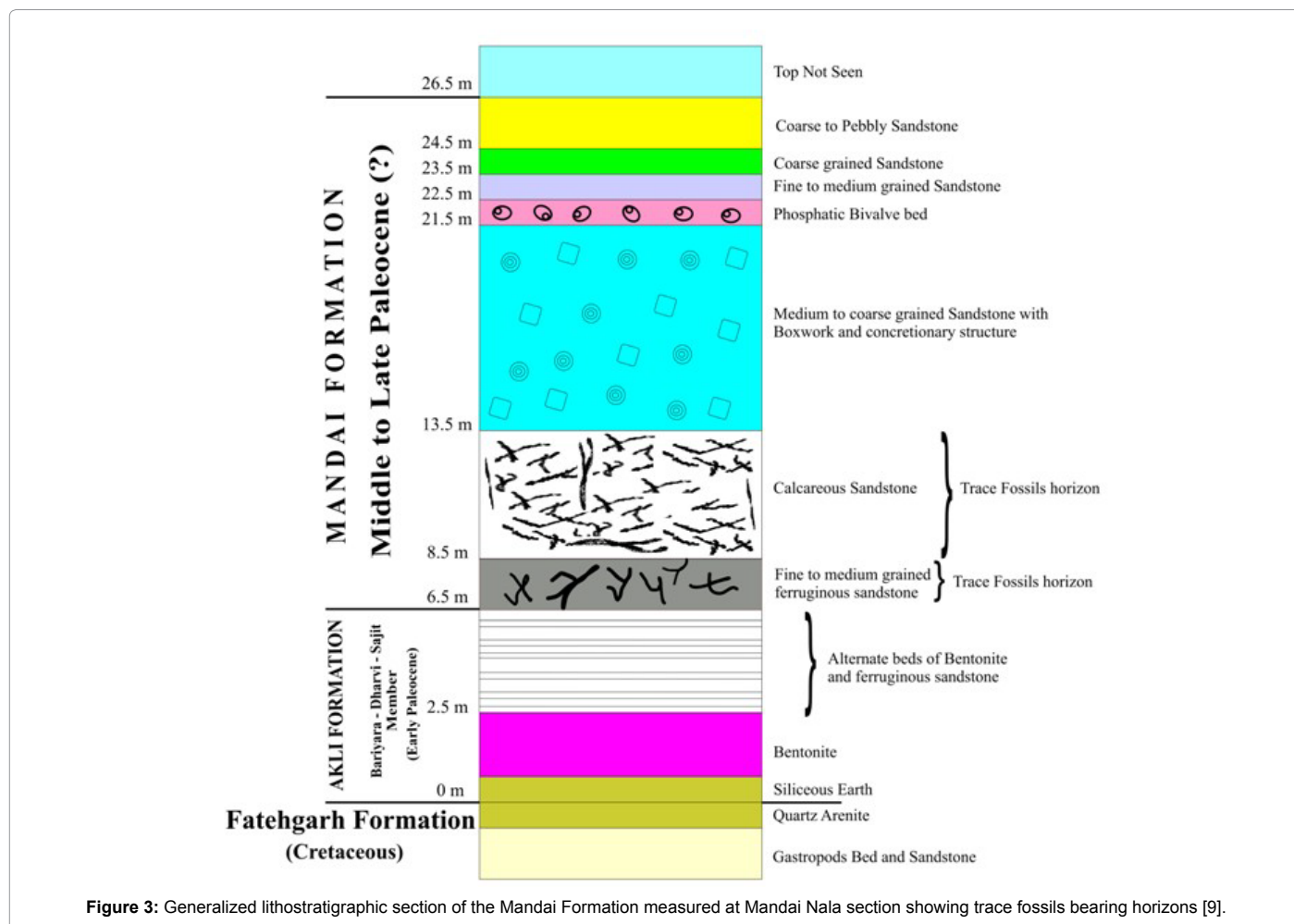


Figure 3: Generalized lithostratigraphic section of the Mandai Formation measured at Mandai Nala section showing trace fossils bearing horizons [9].

sandstone and greyish yellow coarse, coarse to medium grained calcareous sandstone of Mandai Formation of Barmer Basin. They are identified as *Thalassinoides horizontalis*, *Thalassinoides suevicus*, *Ophiomorpha nodosa*, *Ophiomorpha borneensis*, *Palaeophycus heberti*, *Palaeophycus tubularis*, *Planolites*, *Planolites montanus*, *Planolites beverleyensis*, *Planolites annularis*, *Siphonites*, *Paleomendron*, and *Phycodes palmatum*. All these trace fossils are well-preserved and abundant nature in Mandai Formation of Barmer Basin in Mandai area.

Methodology

The sedimentological, ichnological variation and responses of Trace fossils to sediments have been studied from the present Mandai Formation section in the field and accordingly lithostratigraphic section has been prepared. All the measurements of the trace fossils

have been done in the field. All ichnological interpretations are based on field observations and collected specimens kept for repository in our palaeontology lab. The present study of ichnology follows the Treatise on invertebrate Palaeontology [13]. The morphological classification of Simpson [14], ethological classification of Seilacher [15] and facies classification of Seilacher [15,16] are adopted.

Systematic ichnology

Ichnogenus: *Thalassinoides*

Ichnospecies: *Thalassinoides horizontalis isp* [17], (Plates 1B-1D)

Material: Specimen Nos. DG/JNVU/MF/TF/103,104,105 and Field Photos.

Description: Cylindrical, horizontal burrow without any vertical offshoot shaft, disposed parallel to the bedding plane, more or less



Plate 1: A. Field photograph showing trace fossils bearing calcareous sandstone bed. B. Field photograph showing *Thalassinoides horizontalis* trace fossils are cylindrical, horizontal burrow without any vertical offshoot shaft, usually horizontal or parallel to bedding plane in grayish yellow coarse to medium grained calcareous sandstone bed. C. Field photograph showing *Thalassinoides horizontalis* trace fossils preserved in grayish yellow coarse to medium grained calcareous sandstone. D. Showing *Thalassinoides horizontalis* trace fossil preserved in grayish yellow coarse to medium grained calcareous sandstone. E. Showing *Thalassinoides suevicus* trace fossil preserved in grayish yellow coarse to medium grained calcareous sandstone.

regularly branched, unlined burrow system with smooth wall tube, burrow tubes length varying from 15-16 cm and diameter of burrow tube from 1.5-3.0 cm. Normally burrow tubes are filled with calcareous sediments.

Remark: They are mainly produced by crustaceans [18-20] and considered as a feeding burrow system created in water saturated cohesive substrate under oxygenated and energetic environments. The crustaceans producing *Thalassinoides* may survive transport in turbidity currents and produce burrow anoxic conditions for a limited time. The present burrows show much similarity with that of *Thalassinoides horizontalis*, [17] and also correlated the *Thalassinoides horizontalis* from the Palaeogene sediments of the Pondicherry area [21], from Kaladongar Formation, Patcham Island, Kachchh [22] and from Mesozoic sediments of Jaisalmer Basin [23].

Occurrences: Greyish yellow coarse to medium grained calcareous sandstone, Mandai Formation, Barmer Basin, Mandai Area, Jaisalmer.

Ichnospecies; *Thalassinoides suevicus* isp., (Plates 1E, 2A-2D)

Material: Specimen Nos. DG/JNVU/MF/TF/106,107,108,109 and Field Photo.

Description: *Thalassinoides suevicus* trace fossils are Y-shaped

branching, full relief, smooth wall tubes, horizontal to slightly oblique three dimensional burrow system (displaying a network of triple junction), burrow tubes length varying from 8-22 cm and diameter of burrow tube from 1-3 cm. Normally burrow tubes are filled with calcareous sediments.

Remark: *Thalassinoides* are typically recorded in shallow facies including beach, near-shore and shelf whereas *Thalassinoides suevicus* characterizes shallow marine environments as three-dimensional systems. They are mainly produced by crustaceans [18-20] and considered as a feeding burrow system created in water saturated cohesive substrate under oxygenated and energetic environments. The crustaceans producing *Thalassinoides* may survive transport in turbidity currents and produce burrow anoxic conditions for a limited time.

Occurrences: Greyish yellow coarse to medium grained calcareous sandstone, Mandai Formation, Barmer Basin, Mandai Area, Jaisalmer.

Ichnogenus: *Ophiomorpha*, [24]

Ichnospecies: *Ophiomorpha nodosa* isp., [24] (Plate 3A and 3B)

Material: Specimen Nos. DG/JNVU/MF/TF/ 110,111,112.

Description: Vertical and horizontal, branched and unbranched, cylindrical tunnel or burrow systems, ovoid or irregular polygonal pellets [18]. The diameter of burrow tube is about 1.5-2 cm while length is about 9-10 cm. The interior walls of burrow tubes are smooth whereas the burrow tubes are covered by elongated or irregular fecal pellets. The burrow tubes were filled with ferruginized sediments.

Remark: *Ophiomorpha* is feeding and dwelling burrow which normally occur in shallow water near-shore deposits [18,25], but also

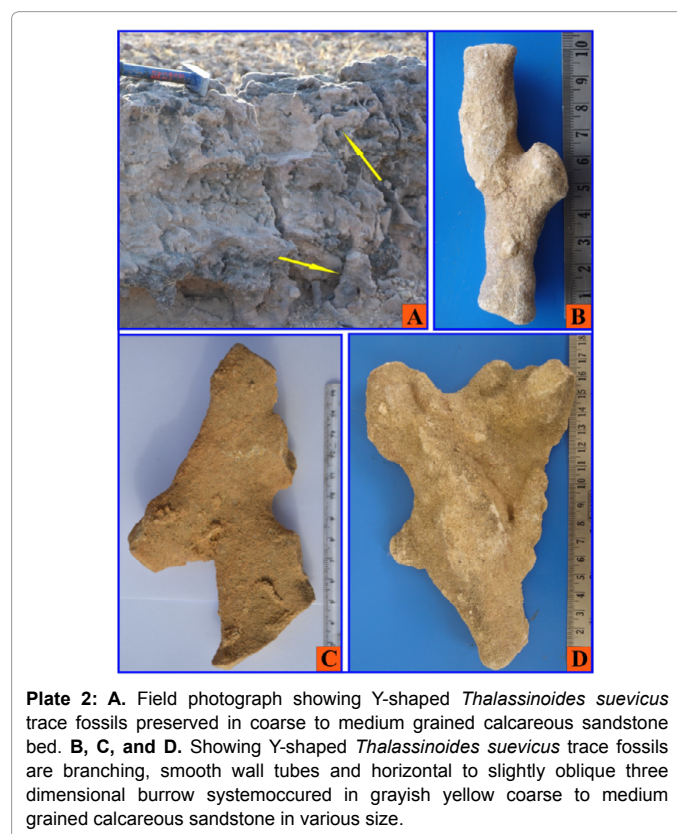


Plate 2: A. Field photograph showing Y-shaped *Thalassinoides suevicus* trace fossils preserved in coarse to medium grained calcareous sandstone bed. B, C, and D. Showing Y-shaped *Thalassinoides suevicus* trace fossils are branching, smooth wall tubes and horizontal to slightly oblique three dimensional burrow system occurred in grayish yellow coarse to medium grained calcareous sandstone in various size.

has been reported from deep-sea deposits [26-32], since the Mesozoic [33]. It is mainly produced by crustaceans, shrimps and ghost shrimps where as it is also formed by shrimps comparable to recent callianassids in the Mesozoic-Cenozoic sediments [18,25]. The present burrows are much similar to that of *Ophiomorpha nodosa* Lundgren and has been discovered by various workers from the Indian subcontinent [23,34-36].

Occurrences: Dark brown medium to fine grained ferruginous sandstone, Mandai Formation, Barmer Basin, Mandai Area, Jaisalmer.

Ichnospecies: *Ophiomorpha borneensis* isp., (Keij) (Plate 3C and 3D)

Material: Specimen Nos. DG/JNVU/MF/TF/113 and Field Photo.



Plate 3: A. *Ophiomorpha nodosa* trace fossil is vertical and horizontal branched and unbranched, cylindrical tunnel or burrow tubes which are covered by elongated or irregular fecal pellets occurred in dark brown medium to fine grained ferruginous sandstone. B. Showing *Ophiomorpha nodosa* trace fossil found in yellowish brown medium to fine grained ferruginous sandstone. C. *Ophiomorpha borneensis* trace fossil is vertical and slightly horizontal to inclined, branched and unbranched, cylindrical burrow systems with regular bi-lobed pellets occurred in light brown fine grained ferruginous sandstone. D. Field photograph showing *Ophiomorpha borneensis* trace fossil is vertical and slightly horizontal to inclined, branched and unbranched, cylindrical burrow systems, covered by dense regularly distributed bilobed fecal pellets preserved in dark brown medium to fine grained ferruginous sandstone. E. *Palaeophycus heberti* trace fossil is having thick walled, horizontal to oblique, branched and unbranched, disposed parallel to the bedding plane, smooth burrow tube occurred in dark brown medium to fine grained ferruginous sandstone. F. Showing *Palaeophycus heberti* trace fossil is preserved in grayish yellow coarse to medium grained calcareous sandstone. G. *Palaeophycus tubularis* trace fossil is thick walled burrows, horizontal to oblique, branched and unbranched, disposed parallel to the bedding plane and smooth borrow shows tube-like appearance occurred in dark brown medium to fine grained ferruginous sandstone. H. Showing *Palaeophycus tubularis* trace fossil occurred in dark brown medium to fine grained ferruginous sandstone. I. *Palaeophycus tubularis* trace fossil occurred in yellowish to dark brown medium to fine grained ferruginous sandstone.

Description: Vertical and slightly horizontal to inclined, branched and unbranched, cylindrical tunnel or burrow systems with regular bi-lobed pellets, having diameter of burrow tube is about 1-2.5 cm and length is about 10-18 cm. The interior walls of burrow tubes are smooth whereas the burrow tubes are covered by dense regularly distributed bilobed fecal pellets. The burrow tubes were filled with host rock of ferruginized sediments.

Remark: These are horizontal and inclined burrows and its burrows wall consists of dense regularly distributed bilobed pellets hence these are placed under *Ophiomorpha borneensis*, Keij [18]. They are interpreted as feeding and dwelling burrows and mainly produced by crustaceans, shrimps and ghost shrimps where as it is also formed by shrimps comparable to recent callianassids in the Mesozoic-Cenozoic sediments [18,25]. This ichnospecies has been also correlated to *Ophiomorpha borneensis* found from different stratigraphic horizons from Indian Subcontinent [23,35-37].

Occurrences: Dark brown medium to fine grained ferruginous sandstone and greyish yellow coarse to medium grained calcareous sandstone, Mandai Formation, Barmer Basin, Mandai Area, Jaisalmer.

Ichnogenus: *Palaeophycus* [38]

Ichnospecies: *Palaeophycus heberti* isp., [38] (Plate 3E and 3F)

Material: Specimen Nos. DG/JNVU/MF/TF/114,115.

Description: Thickly lined, horizontal to oblique, unbranched and can be branched, disposed parallel to the bedding plane, smooth to sometime irregularly walled and having thick walled. The diameter of burrow tube is about 3-4 cm and length of about 9-10 cm. The burrow tubes were filled with ferruginized matrix.

Remark: *Palaeophycus* is considered as a combined dwelling and feeding burrows formed by worm like animals. The present burrows have thick walled therefore, they are described under *Paleophycus heberti* (Saporta) [19]. This *Palaeophycus heberti* also correlated to from Bagh Group of Madhya Pradesh [39,40], Kalyanpur Limestone of Dwarka Formation [35] and Bhuj Formation of Kachchh Baisn [23].

Occurrence: Dark brown medium to fine grained ferruginous sandstone, Mandai Formation, Mandai Area, Barmer Basin, Jaisalmer.

Ichnospecies: *Palaeophycus tubularis* isp., (Plate 3G-3 I)

Material: Specimen Nos. DG/JNVU/MF/TF/116,117,118, 119.

Description: Thinly lined, horizontal to oblique, unbranched thick walled burrows, disposed parallel to the bedding plane, smooth to sometime irregularly walled and borrow show tube-like appearance. The diameter of burrow tube is about 1-2 cm and length of about 5-8 cm. The burrow tubes were filled with ferruginized sediments.

Remark: *Palaeophycus* is considered as a combined dwelling and feeding burrows formed by worm like animals. The present burrows have thick walled with tube like appearance therefore, they are described under *Paleophycus tubularis* [19]. This ichnospecies also correlated to *Paleophycus tubularis* from Bagh Group of Madhya Pradesh [39,40] from Babaguru Formation at Gujarat [34] and from Positra Limestone of Dwarka Formation [35] and from the Bhuj Formation, Kachchh [23].

Occurrence: Dark brown medium to fine grained ferruginous sandstone, Mandai Formation, Mandai Area, Barmer Basin, Jaisalmer.

Ichnogenus: *Planolites* isp., (Plate 4A)

Material: Specimen Nos. DG/JNVU/MF/TF/120 and Field Photo.

Description: Single meandering, cylindrical, smooth walled, straight to gently curved, unbranched burrows tube, usually more or less horizontal or parallel to bedding plane. The diameter of burrow tube is 1 cm and length about 10-16 cm. The burrow tubes are filled with calcareous matrix.

Remark: *Planolites* are broad ranging from Precambrian to Recent [41,42]. It belonging to Paschinia/Fodichinia ethological group and interpreted as a product of vermiform deposit feeder actively back feeding its burrow [43]. It is considered as a feeding burrow system created in water saturated cohesive substrate under oxygenated and energetic environments. The crustaceans producing *Thalassinoides* and associated trace fossils may survive transport in turbidity currents and produce burrow anoxic conditions for a limited time.

Occurrences: Yellowish to dark brown medium to fine grained ferruginous sandstone and greyish yellow coarse to medium grained calcareous sandstone, Mandai Formation, Barmer Basin, Mandai Area, Jaisalmer.

Ichnospecies: *Planolites montanus* isp., (Plate 4B and 4C)

Material: Specimen Nos. DG/JNVU/MF/TF/121.

Description: Single meandering, straight to gently curved, unlined burrow, cylindrical burrows, usually more or less horizontal or parallel to bedding plane with very small and thin burrow. The diameter of burrow tube is 0.5-0.6 cm and length about 6 cm. The burrow tubes are filled with calcareous sediments.

Remark: *Planolites* are feeding and dwelling burrows and interpreted as a product of vermiform deposit feeder actively back feeding its burrow [43]. The present burrows are small and thin burrow and much similar to *Planolites montanus* [19]. It is also correlated to this ichnospecies from Bagh Group of Madhya Pradesh (Badve et al.; Sanganwaret et al.; Kundal et al.) [40,44-46] from Trichinopoly Group, Tamil Nadu from Babaguru Formation at Gujarat [34] and from Shankhodhar sand clay of Dwarka Formation [35].

Occurrences: Greyish yellow coarse to medium grained calcareous sandstone, Mandai Formation, Barmer Basin, Mandai Area, Jaisalmer.

Ichnospecies: *Planolites beverleyensis* isp., (Plate 4E)

Material: Specimen Nos. DG/JNVU/MF/TF/122.

Description: Straight to slightly curved burrow without lining, single meandering, cylindrical unbranched, usually more or less horizontal or parallel to bedding plane with thick burrow. The diameter of burrow tube is 2-4 cm and length about 9-10 cm. The burrow tubes are filled with calcareous sediments.

Remark: *Planolites* are feeding and dwelling burrows and interpreted as a product of vermiform deposit feeder actively back feeding its burrow [43]. The present burrows are considerably thick and much similar to *Planolites beverleyensis* [19]. This is also correlated to *Planolites beverleyensis* ichnospecies from from Wadhawan Formation of Gujarat, Bagh Group of Madhya Pradesh [40,46], from Babaguru Formation at Gujarat [34], from Shankhodhar Sand Clay of Dwarka Formation [35], Bhuj Formation, Kachchh and Babaguru Formation, Gujarat [23].

Occurrences: Greyish yellow coarse to medium grained calcareous sandstone, Mandai Formation, Barmer Basin, Mandai Area, Jaisalmer.

Ichnospecies: *Planolites annularis* isp., (Plate 4D)

Material: Specimen Nos. DG/JNVU/MF/TF/123.

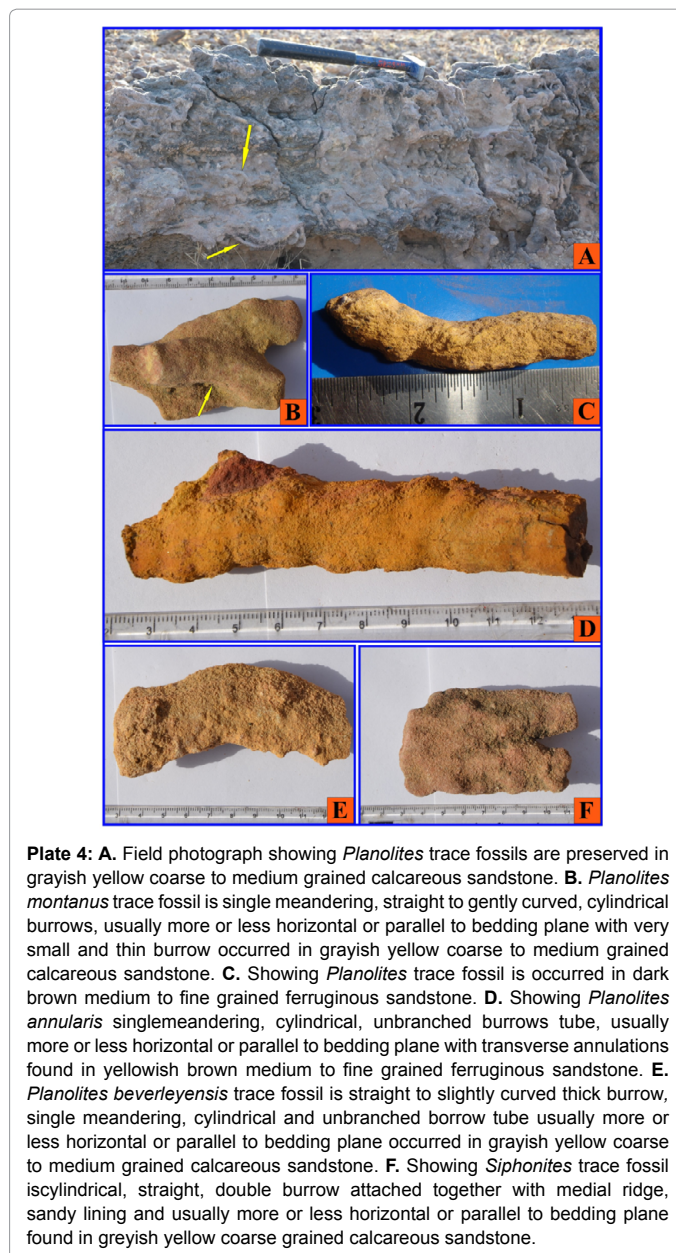


Plate 4: A. Field photograph showing *Planolites* trace fossils are preserved in grayish yellow coarse to medium grained calcareous sandstone. B. *Planolites montanus* trace fossil is single meandering, straight to gently curved, cylindrical burrows, usually more or less horizontal or parallel to bedding plane with very small and thin burrow occurred in grayish yellow coarse to medium grained calcareous sandstone. C. Showing *Planolites* trace fossil is occurred in dark brown medium to fine grained ferruginous sandstone. D. Showing *Planolites annularis* singlemeandering, cylindrical, unbranched burrows tube, usually more or less horizontal or parallel to bedding plane with transverse annulations found in yellowish brown medium to fine grained ferruginous sandstone. E. *Planolites beverleyensis* trace fossil is straight to slightly curved thick burrow, single meandering, cylindrical and unbranched burrow tube usually more or less horizontal or parallel to bedding plane occurred in grayish yellow coarse to medium grained calcareous sandstone. F. Showing *Siphonites* trace fossil is cylindrical, straight, double burrow attached together with medial ridge, sandy lining and usually more or less horizontal or parallel to bedding plane found in greyish yellow coarse grained calcareous sandstone.

Description: Single meandering, cylindrical, straight to gently curved unbranched burrows tube, usually more or less horizontal or parallel to bedding plane with transverse annulations. The diameter of burrow tube is 1-1.5 cm and length about 10-11 cm. The burrow tubes are filled with ferruginized sediments.

Remarks: *Planolites* are feeding and dwelling burrows and interpreted as a product of vermiform deposit feeder actively back feeding its burrow [43]. The present burrow is much similar to *Planolites annularis*, [19]. It is also correlated to *Planolites annularis* from Jaisalmer Baisn of Rajasthan [23].

Occurrences: Yellowish brown medium to fine grained ferruginous sandstone, Mandai Formation, Barmer Basin, Mandai Area, Jaisalmer.

Ichnogenus: *Siphonites* isp., (Plate 4F)

Material: Specimen Nos. DG/JNVU/MF/TF/124,125.

Description: Vertical and horizontal, straight, double burrow attached together with medial ridge, sandy lining and usually more or less horizontal or parallel to bedding plane. The burrow system shows length of 7-8 cm and the diameter of burrow tube is 1-2 cm. The burrow tubes are filled with calcareous sediments.

Remark: *Siphonites* is interpreted as a dwelling and feeding burrows formed by worm like sediment eating animals. Some authors are described it's as *Palaeophycus* Hall [38]. The present burrow structures are much similar to *Siphonites* ichnospecies.

Occurrences: Greyish yellow coarse grained calcareous sandstone, Mandai Formation, Barmer Basin, Mandai Area, Jaisalmer.

Ichnogenus: *Paleomendron* isp., [47] (Plate 5A)

Material: Specimen Nos. DG/JNVU/MF/TF/126.

Description: Vertical to horizontal, cylindrical to sub-cylindrical burrow tube with meandering and meanders double pointed corners having reduced diameter of burrow tube at the meander point. It is horizontal to the bedding plane and the average diameter of the burrow trail is about 1-3 cm and length of the trail of burrow tube is about 10-12 cm. The burrow tubes are filled with calcareous matrix.

Remark: *Paleomendron* is interpreted as dwelling burrow trails known only from deep-marine deposits [16], while Ksiazkiewicz [48] has documented *Paleomendron rubustum* as a grazing trail in Flysch deposits (Late Cretaceous to Early Tertiary) from Australia, Italy, Spain and Poland. The present burrow trail are horizontal to the bedding plane with meandering and its double pointed corners are distinctly seen at portion of meandering thus, the present trails are described as *Paleomendron* isp. [13]. This ichnospecies has been also correlated to *Paleomendron* isp. of Lameta Formation of Jabalpur area, Madhya Pradesh [49] and from Jaisalmer Basin of Rajasthan [23].

Occurrences: Greyish yellow coarse to medium grained calcareous sandstone, Mandai Formation, Barmer Basin, Mandai Area, Jaisalmer.

Ichnogenus: *Phycodes*

Ichnospecies: *Phycodes palmatum* isp., [38] (Plate 5B)

Material: Specimen Nos. DG/JNVU/MF/TF/127.

Description: Bundled splayed or broom-like pattern, horizontal burrow originating from a central base point. Its burrow system is long, palmately branching close together, with branches terminating in fan-shaped structure. The burrow system shows length of 11-12 cm and the branch diameter is 3-4 cm wide. The burrow tubes are filled with calcareous sediments.

Remark: *Phycodes* is considered as a feeding burrow made by repeated probes by a marine organisms such as worms into the sediments. *Phycodes palmatum* is characterized by its branching and fan-shaped structures or pattern [38]. This ichnospecies has been also correlated to *Phycodes palmatum* of Kaladongar Formation of Patcham Island, Kachchh [22].

Occurrences: Greyish yellow coarse to medium grained calcareous sandstone, Mandai Formation, Barmer Basin, Mandai Area, Jaisalmer.

Palaeoenvironmental Significance

Trace fossils are widely used for palaeoenvironmental interpretation of the rocks/facies because they have palaeoenvironmental significance [13-15,16,18]. The sediments of Mandai Formation are examined for ichnological investigation and their role during the deposition of those sediments. Thirteen trace fossils viz; *Thalassinoides horizontalis*, *Thalassinoides suevicus*, *Ophiomorpha nodosa*, *Ophiomorpha borneensis*, *Palaeophycus heberti*, *Palaeophycus tubularis*, *Planolites*, *Planolites montanus*, *Planolites beverleyensis*, *Planolites annularis*, *Paleomendron*, *Siphonites* and *Phycodes* have been reordered, analyzed, described and used for palaeoenvironmental interpretation. Palaeoenvironment of marine sediments can be interpreted by investigating lithology, primary sedimentary structures, and faunal elements. The typical trace fossil assemblages occur in different location in sediments of different ages and that assemblage belongs to a particular marine environment and is composed of typical association of trace fossils, constituting ichnofacies [13,15]. Seilacher [16] has introduced the ichnofacies classification and he has grouped all known trace fossils into six ichnofacies namely, *Scoyenia Facies* (non-marine commonly red beds), *Skolithos Facies* (littoral; rapid sedimentation), *Glossifungites Facies* (littoral; with erosional surface), *Cruziana Facies* (deeper shallow water, below the true littoral zone), *Zoophycus Facies* (transitional to bathyal zone) and *Nereites Facies* (bathyal to abyssal; pelagic sediments and turbidites (Figure 4). All these trace fossil species are belonging to *Skolithos* and *Cruziana* facies which indicate that sediments of the Mandai Formation of Barmer Basin was deposited in shallow sub-littoral marine environment under high to moderate energy conditions. Thus the ichnological investigations indicate shallow marine depositional environment of trace fossils bearing horizons viz; yellowish to dark brown medium to fine grained ferruginous sandstone and greyish yellow coarse and coarse to medium grained calcareous sandstone of Mandai Formation of the Barmer Basin.

Discussion and Conclusion

Thirteen trace fossils namely *Thalassinoides horizontalis*, *Thalassinoides suevicus*, *Ophiomorpha nodosa*, *Ophiomorpha borneensis*, *Palaeophycus heberti*, *Palaeophycus tubularis*, *Planolites*,



Plate 5: A. *Paleomendron* trace fossil is vertical to horizontal, cylindrical to sub-cylindrical burrow tube with meandering and meanders double pointed corners having reduced diameter of burrow tube at the meander point occurred in grayish yellow coarse to medium grained calcareous sandstone. **B.** Showing *Phycodes palmatum* trace fossil is bundled splayed or broom-like pattern, horizontal burrow originating from a central base point, palmately branching close together, with branches terminating in fan-shaped structure which is occurred in grayish yellow coarse to medium grained calcareous sandstone.

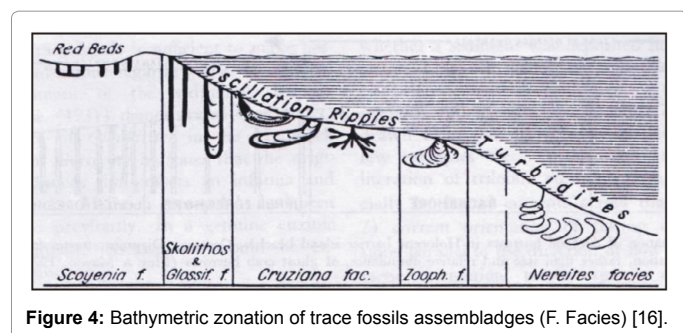


Figure 4: Bathymetric zonation of trace fossils assemblages (F. Facies) [16].

Planolites montanus, *Planolites beverleyensis*, *Planolites annularis*, *Paleomendron*, *Siphonites* and *Phycodes palmatum* are identified which reflects the presence of suspension and feeding animals. The trace fossils of the Mandai Formation of Barmer Basin are well-preserved and abundant in nature in Mandai area. All these trace fossil species belonging to *Skolithos* and *Cruziana* facies which indicate that sediments of the Mandai Formation of Barmer Basin was deposited in shallow sub-littoral marine environment under high to moderate energy conditions. Thus the sedimentological and ichnological investigations indicate shallow marine depositional environment of trace fossils bearing horizons viz; yellowish to dark brown medium to fine grained ferruginous sandstone and greyish yellow coarse and coarse to medium grained calcareous sandstone of Mandai Formation of the Barmer Basin.

All these above mentioned trace fossils have been already recorded from different stratigraphic sequences of USA, Russia, Austria, Poland, Australia, Canada, Italy, Germany, Spain and including India. No age can be assigned on the basis of these trace fossils as they have long range from Cambrian to Recent [13,41,50], but the stratigraphic status of Mandai Formation, it's overlies on Early Palaeocene Bariyara-Dharvi-Sajit Member of the Akli Formation and overlain by Giral-Thumbli Member of Akli Formation of Early Eocene can be assigned Middle to Late Palaeocene age (?) to Mandai Formation of the Barmer Basin [51-53].

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