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Trace fossils in Eocene flysch deposits of Saravan and Mehrestan, southeast of Iran

Kazem Shabani Goraji *

Department of Geology, College of Science, Zahedan Branch, Islamic Azad University, Zahedan, Iran

Abstract: Siliciclastic deposits in Saravan and Mehrestan area consists of turbidite units which forms rhythmic sequences of sandstones and shales. These sequences are very laterally extend and tracable at several kilometers in the field. These deposits are composed from sandstone, siltstone and shale with different sandstone:shale ratios in any parts. Sedimentary structures include of parallel lamination, parting lineation, cross lamination and bedding (planar and trough), graded bedding, ripple marks, load casts, groove and flute casts are obvious in these deposits. Diverse trace fossils are preserved on the bottom and top surfaces of sandstones and siltstones. These trace fossils are: Cochlichnus anguineus, Gordia arcuata, Granularia isp., Halopoa imbricate, Helminthoida crassa, Helminthopsis abeli, Lorinzinia apenninica, Nereites isp., Paleodictyon gomezzi, Paleodictyon majus, Paleodictyon (Ramidictyon) isp., Paleophycus sulcatus, Paleophycus tubularis, Planolites annularius, Spirorhaphe involute, Spirophycus involutissimus, Taphrhelmintopsis auricularis, Thalassinoides isp. Trace fossils are classified into six ichnofossils assemblages and consist of 15 ichnogenouse and 18 ichnospeices. Trace fossils of studied area mostly feeding and feeding-crawling traces and to belong to Nereites ichnofacies which formed in deep marine environment.

Key words: *Trace fossil; Ichnology; Ichnogenouse; Ichnospeices; Flysch; Saravan and Mehrestan; Southeastern Iran*

1. Introduction

Trace fossils provide valuable information about the characteristics of ancient sedimentary environments such as oxygen level, food supply, salinity, sedimentation rate, substrate, depth and turbulence of the environment (Pemberton et al, 2004; Bann and fielding, 2004; Gingras et al., 2002; MacEachern et al,. 2007; Vaziri and Fursich, 2007). They indicate episodes of sedimentation and erosion and also record gaps in sedimentation (Vaziri and Fursich, 2007; Malarkodi et al, 2009; Singh et al, 2010).

Trace fossils in various sediments are formed but one of the best conditions for the formation and preservation of this traces, is flysch deposits (Raghavendra et al, 2011). Major part of sediments outcropping in the studied area is considerable thickness of Eocene flysch deposits which prepare favor condition for preservations of trace fossils.

The main objectives of this paper are to describe and interpretation, the Eocene deep water trace fossils from the flysch deposits in Saravan and Mehrestan area in southestern part of Iran and to use the information for identification of sedimentary environment conditions in this region.

2. Regional geological

The Saravan and Mehrestan area is located in east flysch zone of Iran in Sistan and Baluchestan province (Fig.1). Have sharp bases and tops and Stow (2005) belived that this character is typical of ancient turbidites. Sandstone beds display T_{bcd}, T_{abc} and T_{abcd} Bouma divisions. Siltstone and shale are bright green and thin to thick layered. Siltstone has cross lamination, parallel lamination and symmetrical ripple marks with low amplitude are only a few millimeters.

3. Methods

In field studies, trace fossils has been collected and date such as shape, size and style of preservation respect to bed surface were determined. Required data includes lithology, texture and sedimentary structures to characterize the sedimentological and depositional properties of flysch deposits were also determined. Using the Hantzschel (1975) and Seilacher (2007) methodes, Ichnogenouse and Ichnospeices were identified.

4. Trace fossils description

The lower surfaces of turbidite sandstones in the flysch deposits of the Saravan and Mehrestan area, exhibit abubdant trace fossils. In the present study, a total 15 Ichnogenouse contains 18 Ichnospeices have been identified.

4.1. Cochlichnus anguineus

Description: Sinuous and wavy creep trace, preserved in the lower surface of the sandstone layer. The sinuous lines has average diameter of 15

* Corresponding Author.

mm and a length of 15 to 20 cm. Wavelength and amplitude of this traces are variable (Fig.4.1).

4.2. Gordia arcuata

This branched trace is Meandering and preserved in the form of a thin drilling tube with over crossing nature. This maze pipes has not any regular pattern and ornamentation. Tube width ranges between 1.0 to 2.0 mm (Fig.4.2).

4.3. Granularia isp.

This trace is prominent in the sole of the layer containing conserved and long, straight tubes and branches (two or three branches). Thin lining around the tube (spreite) may be seen. There are reliefs in the branching point. The thickness of the pipe is usually same to about 8 mm and a length of 25 cm. Texture of sediments filling the pipes similar the host (Fig.4.3).

Fig1: Location map of the studied area

Turbidite exposures in Saravan and Mehrestan area which contain thick flysch sequences have been deposited in the Sistan Ocean (as a branch of Neo-Tethys) during the Eocene (Fig. 2). The Sistan ocean which separated the Lut microcontinent at west from the Helmand microcontinent at east was already present in the Cretaceous (Cenomanian) and remained open and filled by a considerable thickness of turbidite sequences throughout the Eocene. This ocean finally closed at the end of the Eocene (McCall and Eftekhar-Nezhad, 1994).

These sediments generally comprise a rhythmic sandstone-shale sequences which are laterally extend. In this area the Eocene turbidites consist of fine to coarse-grained sandstones, pebbly sandatones, siltstones and shales. Sandstones are 10-200 cm thick and show, parallel lamination and bedding, cross lamination and bedding, graded bedding, ripple marks, flute casts, groove casts, prod and bounce marks and load structures (fig.3 a-d). In some thick bedded and structureless sandstone there are shale and mudstone clasts (3 to 10 cm) near the base of bed (fig.2e) probably due to complete erosion and break up of underlying mudstones. Generally, individual sandstone layers.

4.4. Halopoa imbricate

This trace can be seen like a relief on the lower or the upper surface of layer. These reliefs form straight or branching burrows with varying diameter that are preserved as positive epi- or hyporeliefs. Surface of these reliefs are wrinkled.

Fig. 2: Paleo-tectonic map of Eocene time of the Arabian Plate and adjacent blocks (McCall, 2003).

Margins of traces are irregular that may be caused by the organism in the form of digging to find food. They have in common that (1) the diameter may vary along one burrow; (2) the surface is ornamented by irregular longitudinal rugosities; (3) the adjacent sand surface is deflected around the burrow. All these features relate to the deformations implied in the expansion of a radial backfill around the generating tube. The makers were either wormlike animals able to hydraulically expand their bodies (i.e. they had no tough cuticles), or crustacean that could press their smooth carapaces against the burrow wall (Seilacher, 2007). In observed traces, diameter of burrow is 8 mm with length of 20 cm (Fig4.4).

4.5. Helminthoida crassa

This trace observed like the Meandering drilling reliefs on the sole of the bed. Meandering burrows are generally parallel and stretched with 1.5 to 2 mm in diameter. These meander has, 28 to 40 mm amplitude, 2 to 4 mm width, and 5 to 15 mm wavelength. Surface of the burrows is smooth. This burrows caused by grazing of animals such as worms for feeding within the sediments (Fig.4.5).

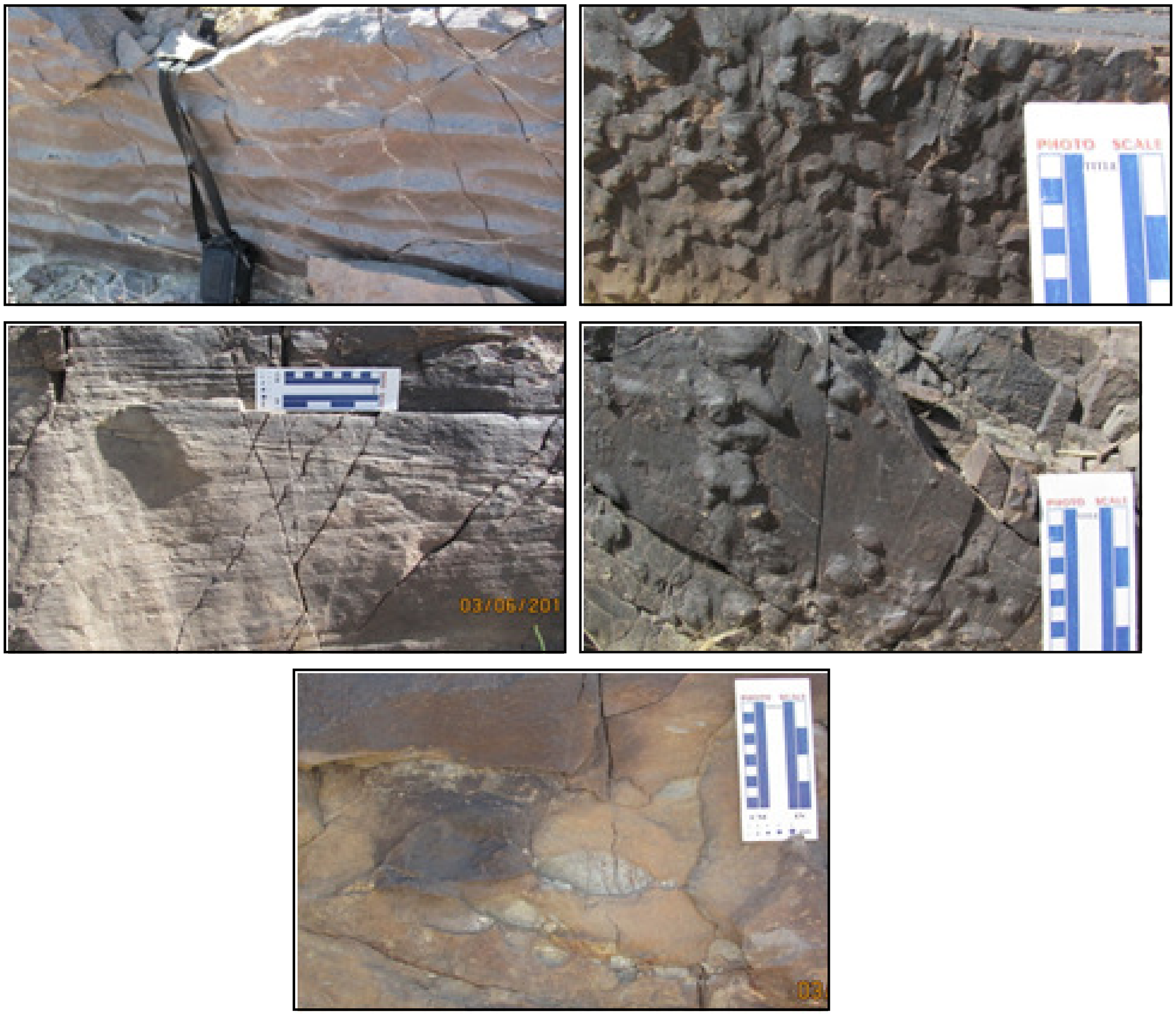

Fig.3: Field photographs showing features of the Eocene turbidite sandstones in the Saravan and Mehrestan area. (a) Flute casts clustered on base of sandstone bed (flow from bottom to top). (b) straight-crested current ripples preserved on the surface of sandstone bed (flow from bottom to top). (c) Cross-laminated sandstone showing tabular cross-bedding. The foresets dip at angle 30 with an angular basal contact with the horizontal bottom sets. (d) Load casts on the sole of sandstone bed. (e) Mudstone and shale clasts on the bottom of massive sandstone (A division of Bouma sequences).

4-6- Helminthopsis abeli

These traces are irregular, bulging, smooth and horseshoe-shaped meanders without branches preserved as positive hyporeliefs. Diameter of burrows is 1 to 2 mm and length of 35 to 180 mm which did not intersect (Fig.4.6).

4.7. Lorinzinia apenninica

Lorinzinia apenninica preserved as short and smooth hypichnial ridgs radiating from a central field. This trace form 5 to 8 radiating ridges. The ridges are 5 to 15 mm long and 5.2 mm average width which observed on the sole of the beds (Fig.4.7).

4.8. Nereites isp.

The name *Nereites* refers to the annelid worm *Nereis*, for whose body impression this trace was originally held. This trace observed like semirelief on the sole of the bed and is Meandering. Relief width is 5 to 8 mm. Nereites formation caused by grazing of animals such as worms, crustaceans and gastropod for feeding within the sediments (Fig.4.8).

In summary, *Nereites* are produced by animals that removed the sediment in front, but not by radial eversion of a voluminous proboscis. The finer and more nutritious fraction of the excavated sediment was ingested in each bite, passed through the gut and backfilled at the rear end. It is also clear that food was extracted from the sediment, because the reworked halo is relatively more voluminous in sand than in silt or foraminiferal ooze.

4-9- Paleodictyon gomezzi

By its regular meshwork, *Paleodictyon* is the most conspicuous of all flysch trace fossils and therefore most likely to appear in field reports. Specimens have been found has a regular hexagonal honeycomb mesh. This trace is a semi-relief on the sole of bed. Average diameter of networks is 7×5 mm and diameter of pipes is 1 mm. In comparison with *Paleodictyon majus*, the honeycomb mesh dimensions are smaller and more elongated (Fig.4.9).

4-10- Paleodictyon majus

This trace has a regular hexagonal honeycomb mesh and is a semi-relief on the sole of the bed. Network diameter is 20×12 mm and diameter of pipes is 1.5 mm. This meshwork trace is caused by grazing of animals on the sediment surface or at the interface between the clay and sand sediments (Fig.4.10).

4-11- Paleodictyon (Ramidictyon) isp.

Ramodictyon, whose name refers to the multiple ventilation shafts ascending from specified points of the net tunnels to the surface. In parts that were incompletely exhumed, these shafts are preserved as hypichnial knobs whose relationship to the net pattern can be inferred from more deeply eroded parts of the same system. This trace, form incompletely exhumed hexagonal pattern. Network diameter is 4×6 mm and diameter of pipes is 1 mm (Fig.4.11).

4-12- Palaeophycus sulcatus

This trace is semi-cylindrical, regular, horizontal, thin (1 to 2 mm), non-branching and straight to curved burrows. Surface of burrows is smooth. It differs from the morphologically similar *Planolites* by the presence of a wall. *Palaeophycus* often preserved as slightly washed out positive hyporelief on the surface of rippled sandstone or siltstone which formed during pre-depositional stage (Fig.5.1).

4-13- Palaeophycus tubularis

This trace consists straight, to slightly sinuous, cylindrical to sub-cylindrical burrows. Burrows diameter varies from 1 to 2 mm. These burrows intersect together and their density is higher in some areas. *Palaeophycus* is a eurybathic facies-crossing ichnogenus, produced probably by suspension-feeding polychaetes. According to the maker of this effect style of animal feeding (pending eater), the organism is more compatible with the energetic E sand-sized bed and high sedimentation rates (Fig.5.2).

4-14- Planolites annularius

Planolites form within the bed or preserved as semi-relief on the sole of the beds. These reliefs are filled cylindrical burrows that are horizontal and without branching and formed by sediment feeder organisms. Burrows diameter is 10 mm. Organism which makes this trace require the equilibrium conditions in terms of salinity, oxygen level, energy, low sedimentation rates, soft muddy substrate and high content of organic matters (Fig.5.3).

4-15- Spirorhaphe involuta

This trace formed as positive relief on the sole of sandstone bed with spiral pattern. Diameter of reliefs is 2 mm and diameter of the loop is 18 cm. This shape is a part of a ring and spiral burrow which formed by wormlike animal that lives on or within the muds (Fig.5.4).

4-16- Spirophycus involutissimus

Spirophycus formed as well preserved positive relief on the sole of sandstone bed with spiral pattern. In this trace, two starter spirals made by different individuals happened to be symmetrically arranged. Diameter of reliefs is 1 cm and diameter of the loop is 11 cm. This trace formed by polychaete worms (Fig.5.5).

4-17- Taphrhelmintopsis auricularis

This trace preserved as positive relief on the sole of sandstone bed and forms a curved, two-section ridge with a central groove. Width of trace is 7 cm, and width and depth of central groove is 10 mm and 5 mm respectively. This trace observed on the surface of the sandstone bed which has groove marks, and evidence of erosion by current to smooth the ridge is obvious. Trace was created on the sea bed and then sand deposited from turbidity currents casted the trace. In fact *Taphrhelmintopsis* can only be preserved by the exhuming and casting effect of the next turbidity current (seilacher, 2007) (Fig.5.6).

4-18- Thalassinoides isp.

This trace is horizontal cylindrical burrows with Y-shaped branching preserved as washed-out positive hyporeliefs on the sole of sandstone beds. Diameter of burrows is approximately constant and about 2 cm, but subordinate branches are smaller in diameter. Their length varies from 5 to 20 cm. Thalassinoides is a facies-crossing trace fossil produced by crustaceans. Follmi and Grimm (1990) believed that the crustaceans producing this trace, may survive during transport by turbidity currents and produce burrows under anoxic conditions for a limited number of days (Fig.5.7).

5. Discussion and conclusions

Studied deposits, including flysch sequences, consisting of sandstone, siltstone and shale are exposed in the Saravan and Mehrestan area. Based on morphology (Table 1), type, frequency of trace fossils and the stratigraphic position of the traces in the beds, observed trace fossils are classified into 6 ichno-assemblages (Table 2). These ichno-assemblages represent paleoecological relations of animals, which had biological relationships and their activities create trace fossils.

Trace fossils, mostly observed in the sole of the sandstone beds. Activities of the trace maker organisms, focused on the surface of muddy sediments, followed by the deposition of sand and siltstone by the waning turbidity current, these traces have been casted. Therefore, trace fossils formed as post-event in a relatively quiet environment, along with the circulation of water provide sufficient oxygen to trace maker organisms.

The most important indicators of marine environments for benthic organisms are oxygen level and salinity of the water. Other factors, such as substrate stability, water turbulence and energy at the bottom of the basin, sedimentation rate, amount and type of organic matter also affect the biological activity of organisms. In the condition of low oxygen level, traces are small and scattered that formed by Deposit-feeder or Suspension-feeder organisms.

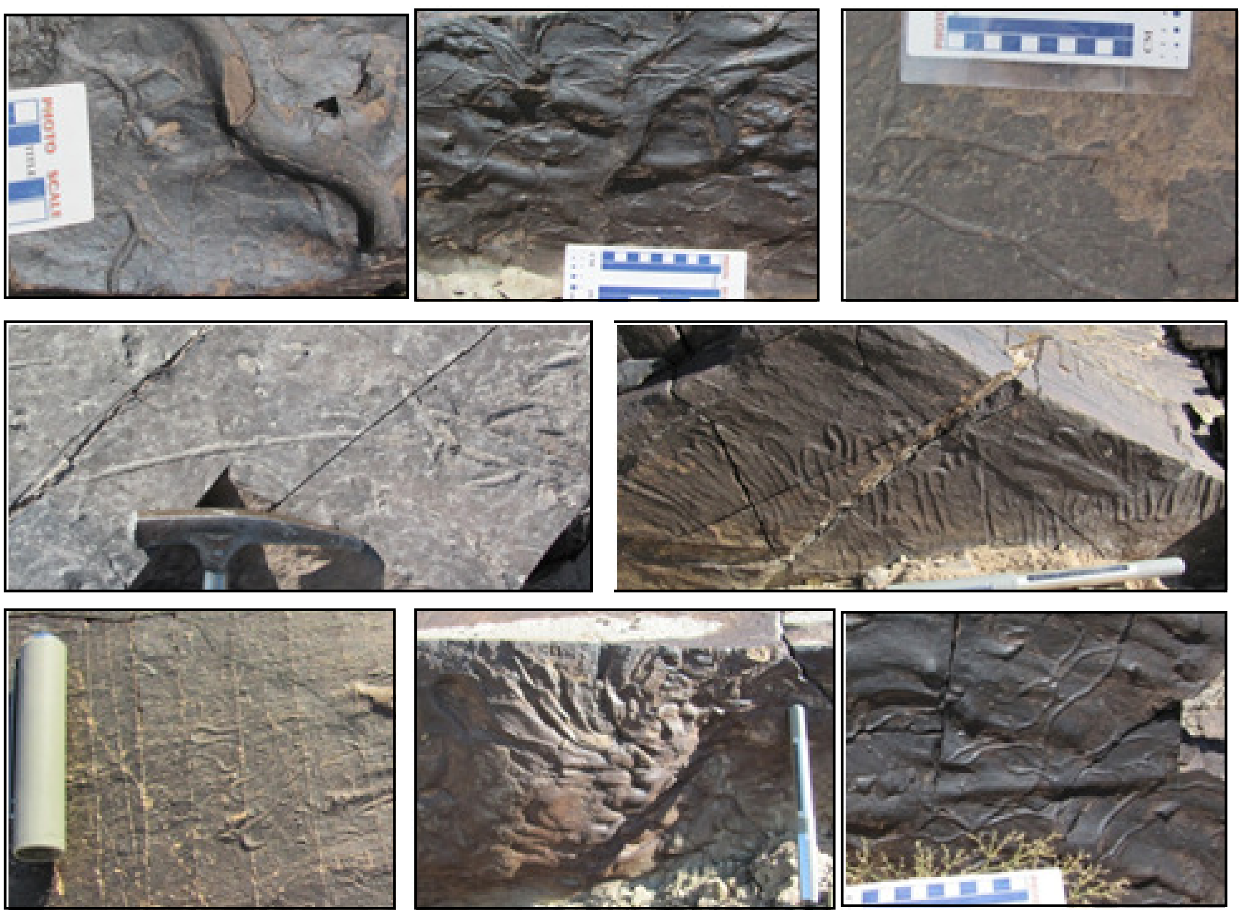

Fig.4: 1.Cochlichnus anguineus, 2.Gordia arcuata, 3.Granularia isp, 4.Halopoa imbricate, 5.Helminthoida crassa, 6.Helminthopsis abeli, 7.Lorinzinia apenninica, 8. Nereites isp, 9. Paleodictyon gomezzi, 10. Paleodictyon majus, 11.Paleodictyon (Ramidictyon) isp.

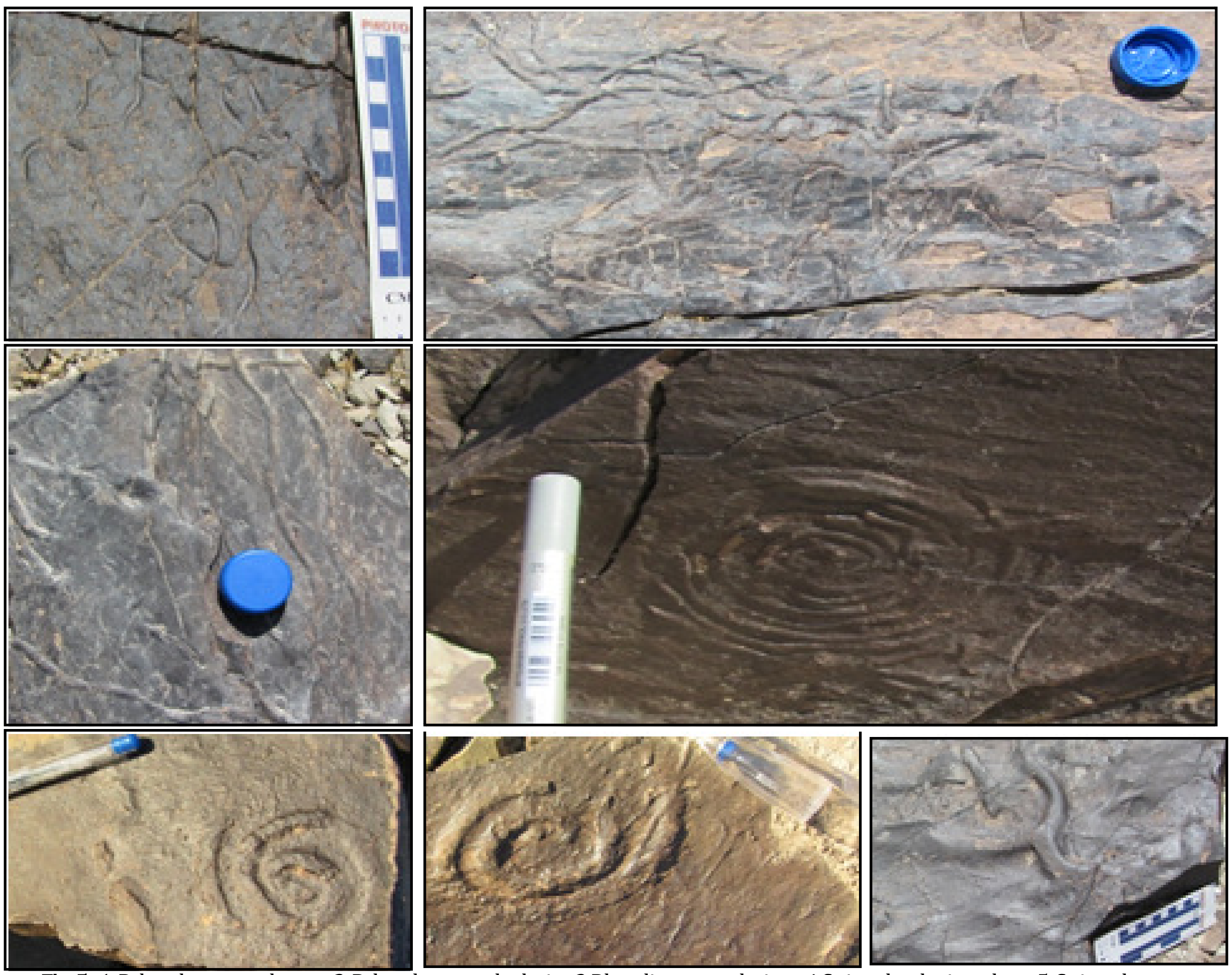

Fig.5: 1.Paleophycus sulcatus, 2.Paleophycus tubularis, 3.Planolites annularius, 4.Spirorhaphe involute, 5.Spirophycus involutissimus, 6.Taphrhelmintopsis auricularis, 7.Thalassinoides isp.

Table 1: Morphology of trace fossils found in the Saravan and Mehrestan area

Row	Morphology	Observed traces
1	Meandering trails	Helmithoida, Helminthopsis, Taphrhelminthopsis, Nereites, Palaeophycus
2	Patterned traces	Paleodictyon
3	Spiral traces	Spiroraphe, Spirophycus
4	Non-branching burrows	Planolites
5	Straight branching burrows	Granularia
6	Irregular burrow networks	Thalassanoides
7	Radiating burrow system	Lorinzinia

Table 2: Identified ichnoassemblages in the Saravan and Mehrestan area

Row	ichnoassemblage	Ichnofacies	Depositional environment	Trace Fossils
1	Taphrhelminthopsis-Planolites	Nereites	Abyssal	Thalassanoides isp., Planolites annularius, Granularia isp., Paleophycus sulcatus, Paleophycus tubularis, Taphrhelmintopsis auricularis
2	Paleodictyon	Nereites	Abyssal	Paleodictyon gomezzi, Paleodictyon majus, Paleodictyon (Ramidictyon) isp.
3	Palaeophycus	Nereites	Slop to Abyssal	Granularia isp. Helminthopsis abeli, Paleophycus sulcatus, Paleophycus tubularis, Planolites annularius, Thalassinoides isp.
4	Helmithoida	Nereites	Abyssal	Granularia isp., Helminthoida crassa, Helminthopsis abeli, Paleophycus sulcatus, Paleophycus tubularis, Planolites annularius, Thalassinoides isp.
5	Helminthopsis-Thalassanoides	Cruziana-Skolithos	Sublittoral	Granularia isp., Helminthopsis abeli, Paleophycus sulcatus, Paleophycus tubularis, Thalassinoides isp.
6	Granularia-Planolites	Nereites	Slop to Abyssal	Granularia isp., Paleophycus sulcatus, Paleophycus tubularis, Planolites annularius

By increasing the amount of oxygen in the environment, trace maker organisms are more abundant and during the more nutrients and oxygen consumption by them, other organisms that are capable of operating in low oxygen conditions are eliminating (Seilacher, 2007). Biological behavior and activity of trace maker organisms in the Saravan and Mehrestan flysch deposits, as shown in Table 3.

Table 3: Biological activity and behavior of trace maker organisms in flysch deposits of studied area

Behavior	feeding	feeding - crawling	crawling	feeding - resting	resting
Trace Fossil	Halopoa, Planolites, Cochlichnus	Helmithoida, Helminthopsis, Taphrhelminthopsis, Paleodictyon, Nereites	Palaeophycus, Cochlichnus	Thalassanoides	Granularia, Halopoa

Trace fossils in the Saravan and Mehrestan area, can be classify into 6 ichno-assemblages. These traces mainly related to feeding and feeding-crawling activities, which create after turbidity currents wanning and the availability of nutrients and oxygen in the environment. In general identified trace fossils in the Saravan and Mehrestan area belong to Nereites ichnofacies and represent sedimentation in a deep marine environment.

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