Iranian Journal of Science & Technology, Transaction A, Vol. 31, No. A1
Printed in The Islamic Republic of Iran, 2007

SHALLOW MARINE TRACE FOSSILS FROM UPPER DEVONIAN SEDIMENTS OF THE KUH-E ZARD, ZEFREH AREA, CENTRAL IRAN*

N. ABBASSI

Department of Geology, Faculty of Sciences, Zanjan University, Zanjan 45171, I. R. of Iran
Email: abbasi@mail.znu.ac.ir

Abstract – Upper Devonian sediments of the Kuh-e Zard area northwest of Zefreh, Central Iran, are composed mainly of brown and grey limestones with sandstone and shale intercalations. They contain trace fossils such as *Chondrites* isp., *Diplocraterion parallelum*, *Fustiglyphus annulatus*, *Lockeia* isp., *Phycodes* isp., and *Taenidium barretti*. These trace fossils indicate a shallow marine environment.

Keywords – Trace fossils, Systematic ichnology, Upper Devonian, Central Iran

1. INTRODUCTION

Ichnology is a field of research on biogenic structures that are preserved on the bedding planes or within the beds, and are produced by the life activity of organisms. These structures are called ichnofossils or trace fossils. Ichnologists can determine the ethology of trace fossils and distinguish ichnofacies and ichnocoenoses, though recognition of tracemakers is commonly problematic. Ichnology is very useful in studies of palaeoecology, determination of bathymetry of sedimentary basins and other palaeoenvironmental parameters [1-2].

Ichnological knowledge is based on data from the entire world. In Iran there is a great potential for ichnological studies because of the good exposure of sediments of different facies and ages. Some efforts have been made in this field in recent years [e.g. 3-5].

The current study was initiated when an interesting specimen of *Fustiglyphus* from Upper Devonian sediments of Kuh-e Zard in the Zefreh area, northeastern Isfahan, Central Iran (Fig. 1) was sent to the author by Isfahan (Esfahan) University. The author tried but did not find additional *Fustiglyphus* in the field. However, other trace fossils were collected or studied there, and their taxonomic analysis is the main aim of this paper. Sampled specimens were reposited in the National Natural History Museum of Iran in Tehran (Muze-ye Melli-ye Tarikh-e Tabi'i, prefixed as MMTT) with numbers MMTT-340-347.

2. THE UPPER DEVONIAN OF KUH-E ZARD

Middle-Upper Devonian sediments of the Zefreh area are composed of dolomitic limestones, sandy limestones and thin-bedded grey limestones. These are well exposed in the western flank of the Kuh-e Kaftar Mountain (15 km west of Kuh-e Zard). Brachiopods, corals, bivalves and trilobites indicate a Frasnian to Famennian age [6]. The Upper Devonian sediments of Kuh-e Zard mainly consist of medium to thick-bedded, grey-brown limestones. The lowest sediments consist of white to reddish, well-sorted and rounded quartz arenite (44 m), followed by light grey, fossiliferous limestones with sandstone and dark shale intercalations (Fig. 2) [7], which are middle to late Frasnian based on conodonts [8]. Upper Devonian sediments of east- and north-central Iran are known as the Bahram 2 and Shishtu 1

---

*Received by the editor January 23, 2005 and in final revised form September 30, 2006

Subformations [9]. The Bahram 2 Subformation contains bluish-grey and black limestone, partly nodular with intercalations of marly shales. The Shishtu 1 Subformation consists of dark-green shales interbedded with quartzitic sandstones [10]. These subformations crop out from the Tabas area to Lakar Kuh (north Kerman) in east-central Iran, and Jajarm, Torud and Jam areas in north-central Iran. The Upper Devonian sediments of the Zefreh area, like the other areas of central and western parts of central Iran have been reported without formal name(s) and correlated to Bahram 2 and Shishtu 1 Subformations. Bahram 2 and Shishtu 1 Subformations indicate two major system tracts, but the Upper Devonian sediments of the Zefreh area indicate only one system tract with regressive, highstand and transgressive tract conditions.

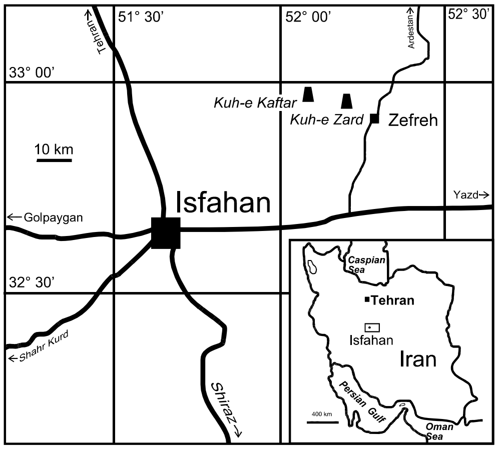

Fig. 1. Geographic map of the Kuh-e Zard area, northeast Isfahan

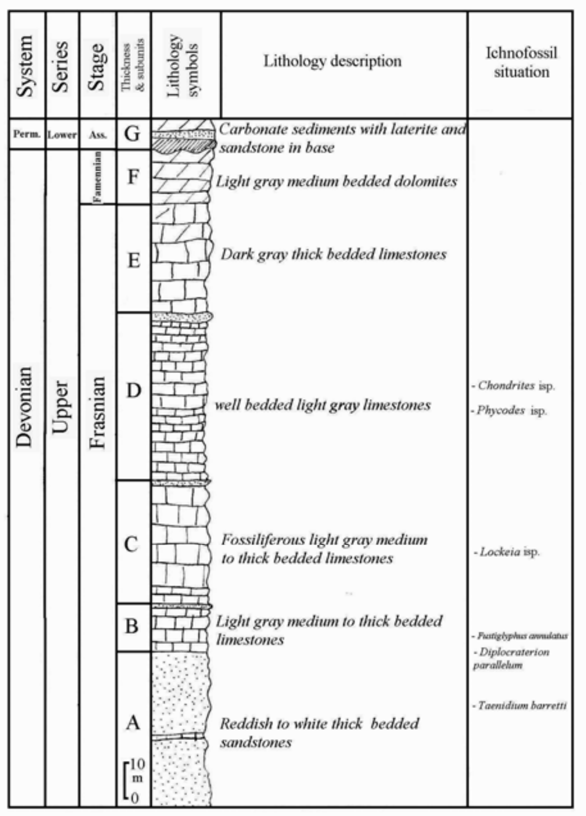

Fig. 2. Stratigraphy column of Upper Devonian sediments in the Kuh-e Zard with studied trace fossils situation (stratigraphy column and subunits from [7] with some corrections)

3. SYSTEMATIC ICHNOLOGY

a) Ichnogenus *Chondrites* Sternberg [11]

Type ichnospecies: *Fucoides antiquus* Brongniart [12].
Diagnosis: Dendritic, smooth-walled, regularly ramifying small burrow systems that normally do not interpenetrate or interconnect. The diameter of the components within a given system remains essentially constant (after Pemberton and Frey [13]).

Discussion: More than 170 ichnospecies have been established by different authors since the erection of *Chondrites* by von Sternberg in 1833, but these ichnospecies were based mainly on minor differences or negligible variations [14]. *Chondrites* need ichnotaxonomic review and it is possible that most ichnospecies can be omitted under the rules of synonymy. One ichnotaxonomic review was performed by Osgood [15]; he grouped *Chondrites* in types based on tunnel diameter, arrangement of branches, angle of bifurcation and nature of preservation related to bedding planes. Kotake divided *Chondrites* into two groups, one of large size (10-30mm) and the other of small size (0.5-2.5mm), classifying the small-sized group further based on tunnel form and angle of bifurcation into three classes (with A-C letters) and the large-sized group into two classes (D and E) [16]. Jordan classified his studied samples in four groups on the basis of the trace fossils' size, angle and rank of bifurcations [17]. Because of the considerable variation in *Chondrites* morphology, distinguishing its ichnospecies is difficult.

Chondrites is a facies-crossing trace fossil distributed in Cruziana, Zoophycos and Nereites ichnofacies [18]. At least some were produced by the chemosymbiotic action of a tracemaker in dysaerobic and reducing conditions [e.g. 19] or even anaerobic environments [20]. Sipunculoids, annelids, small arthropods, polychaetes and anthoptiloids have all been considered as a possible tracemaker of *Chondrites*. *Buthotrephis* [21] is synonym of *Chondrites* [14]. There are disagreements between some authors in the type ichnospecies selection. At first, this trace fossil was named *Fucoides*, but was later renamed *Chondrites* [11]. Häntzschel accounted *Fucoides targionii* [12] as type ichnospecies [22], but *Chondrites lycopodioides* [11] (=*Fucoides lycopodioides* [12]) is type ichnospecies in [18, 23]. Stanley and Pickerill, however, believe *Fucoides antiquues* is type ichnospecies based on the subsequent designation by Miller [14, 24].
Ichnospecies *Chondrites* isp.
Figs. 3A$_{1-2}$
Material: two specimens MMTT-340-341.

Description: Two specimens collected, persevered in full relief to concave epirelief in light brown to light grey limestone layers. Specimens consist of bifurcated tunnels with 3 to 4 orders of branching, and filled by structureless and distinctive lighter grey sediments then the host sediment. Burrow diameter ranges from 2 to 4 mm and the angle of branching is about 50º.

Discussion: Studied specimens show a different fill than the host sediment. This feature was noted by Kotake [25], and he postulated that *the Chondrites* fill resulted from surface sediment pumped downward by a tracemaker feeding at the seafloor.

b) Ichnogenus *Diplocraterion* Torell [26]

Type ichnospecies: *Diplocraterion parallelum* Torell [26].
Diagnosis: Vertical U-shaped spreiten-burrows (after Fürsich [27]).

Discussion: This trace fossil includes all U-shaped spreiten burrows that are perpendicular to bedding planes, differing in the latter from *Rhizocorallium. Corophioides* [28] is similar to *Diplocraterion*, but lacks funnel-like openings in U tubes, although these may be removed by erosion and thus are not appropriate diagnostic features [14]. *Bifungites* [29] and *Arthraria* [30] are dumbbell-shaped trace fossils with undisturbed sediments between the tubes, and therefore different from *Diplocraterion* [31]. Six ichnospecies have been recognized for *Diplocraterion*. *D. parallelum* [26] is distinguished by the parallel arms of a U-tube and unidirectional spreite. *D. biclavatum* [32] have extended arms below the base of the deepest U to form blind pouches. *D. habichi* [33] is distinguished by divergent arms. *D. helmerseni* [34] displays an expanded base and *D. polyupsilon* [28] has a bidirectional spreite. Finally *D. asymmetrium* [35] is a very asymmetrical U-tube and an incomplete, asymmetrical spreite that may be protrusive, retrusive or both. Its spreite, typically, is developed laterally as well as vertically. *Diplocraterion* is Cambrian to Oligocene [36] in age and is generally regarded as the dwelling burrow of a suspension-feeding organism [31] in high-energy environments.

Ichnospecies *Diplocraterion parallelum* Torell [26]

Figs. $3B_{1-3}$

Material: One specimen MMTT-342.

Diagnosis: *Diplocraterion* having parallel arms and a unidirectional spreite (after Fürsich [27]).

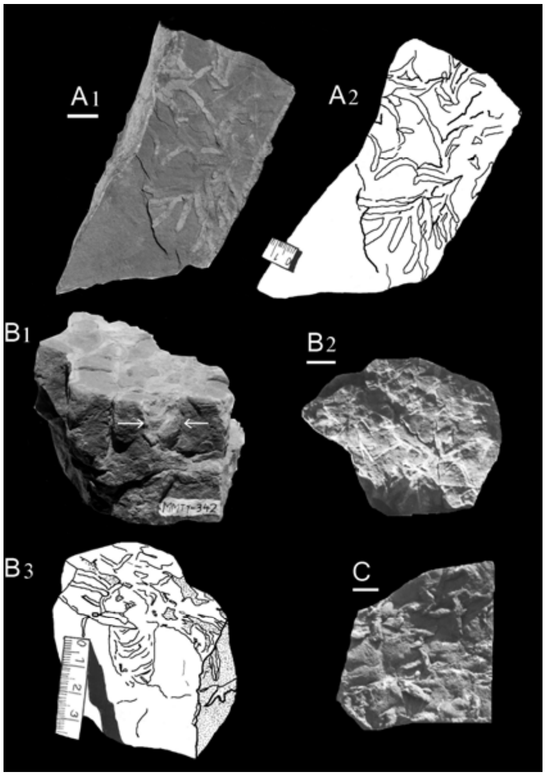

Fig. 3. Trace fossils assemblage of the Kuh-e Zard area, A) *Chondrites* isp., B) *Diplocraterion parallelum*; B_1 endichnial view, arrows show parallel arms and spreite; B_2, bedding plan view and B_3, drawing of B_1, scales are in cm, C) *Lockeia* isp., scale bar 2 cm

Description: Two specimens contain numerous *Diplocraterion* that are endichnial, spreite-bearing vertical U-shaped burrows. The trace fossils are randomly oriented and crosscut one another. They are filled with lighter sediment than the host rock. The limbs of the U-tubes are parallel. On average, the limbs are 23 mm apart and up to 25 mm long. Only protrusive spreiten are seen in vertical cut specimens and the causative burrow is indistinct in these *Diplocraterion*.

Discussion: The Zefreh *Diplocraterion* displays some peculiar features. One is the distinct color of the spreite, then the color of the host rock, and the other crosscut one another. The different color in the spreiten reflects the same feature as in *Chondrites* and it may be related to the similar action and strategy of the tracemaker.

c) Ichnogenus *Fustiglyphus* Vialov [37]

Type ichnospecies: *Fustiglyphus annulatus* Vialov [37].

Diagnosis: Horizontal, straight strings or narrow cylinders of varying length encircled at regular to irregular intervals by ring-like “knots” or well-defined swellings that display no bifurcation or invagination. It is rosary-like in shape, preserved as convex hyporelief or concave epirelief (after Stanley, and Pickerill [38]).

Discussion: *Rhabdoglyphus* [39] resembles *Fustiglyphus*, but it has bifurcating swellings, whereas swellings of *Fustiglyphus* are clearly rings or knots in shape. Some ethological interpretations have been provided about *Fustiglyphus*, evidently, peristaltic movements of organisms such as amphipods, gastropods or holothurians produce swellings [15, 23]. Stanley and Pickerill consider that swelling in *Fustiglyphus* may represent brood chambers [38]. *Fustiglyphus* ranges from Upper Cambrian to Eocene.

Ichnospecies *Fustiglyphus annulatus* Vialov [37]

Fig. 4A

Material: One specimen MMTT-343.

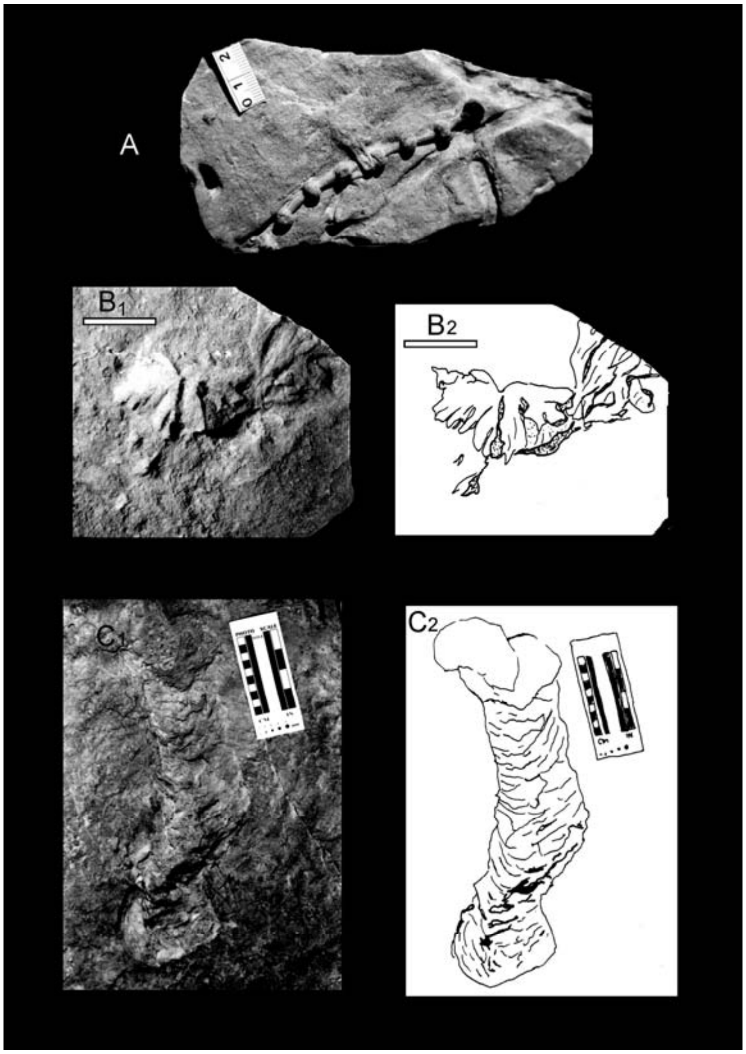

Fig. 4. Trace fossils assemblage of the Kuh-e Zard area (continue), A) *Fustiglyphus annulatus*, scale in cm. B) *Phycodes* isp., scale bar 2 cm, C) *Taenidium barretti* in bedding plane view

Diagnosis: Unbranched *Fustiglyphus* bearing spherical-, hemispherical-, heart-, or ring-shaped, singly or paired swellings. An individual specimen may be composed entirely of one type of swelling or else combinations of two or more.

Description: The specimen contains two *Fustiglyphus* preserved as concave epirelief and concave hyporelief on the bedding planes. The first of them is longer (80 mm) and distinctive, with a slightly curved string that is 2.5 mm in diameter, and displays eight spherical swellings. The swellings (6.8×4.7mm) occur in regular intervals (5 mm) along the same ridge. A poorly preserved knot is seen at one termination without joining the string, but with a furrow running to the next knot. The fill is identical to the host rock. A small appendage is present in one of the knots. The second *Fustiglyphus* is poorly preserved and shorter (28 mm), with two small spherical swellings that are 3 to 4 mm in diameter. It may become endichnial at one termination. Other indeterminate trace fossils are also present in the same slab.

Discussion: Described *Fustiglyphus* displays features of *Fustiglyphus annulatus* of Miller and Rehmer in [38], either in the same shape and intervals of swellings or string features. Stanley and Pickerill [38] listed and figured previously published examples of *Fustiglyphus annulatus.* Reported *Fustiglyphus annulatus* differs either in swelling shape or ratio of swelling diameters of and string width. However, according to an emended diagnosis [38], all are determinable as *Fustiglyphus annulatus*.

d) Ichnogenus *Lockeia* James [40]

Type ichnospecies: *Lockeia siliquaria* James [40].

Diagnosis: Small oblong horizontal bodies rounded or pointed at both ends, which resemble the end of an almond projecting above a surface. Preservation as convex hyporelief or concave epirelief. Surface normally smooth, although a longitudinal crest may be present. Vertical sections may reveal an overlying shaft of disturbed bedding conforming to the measurements of the specimen (after Osgood [15]).

Discussion: Ichnogenus *Pelecypodichnus* [41] is a younger subjective synonym of *Lockeia*. *Lockeia* contains diverse ichnospecies, and *L. siliquaria* [40] and *L. ornata* [42] are common among them. Bivalves are considered as tracemakers of *Lockeia*, and different living and feeding strategies of bivalves may cause different morphologies of *Lockeia* [43]. *Lockeia* occurs in shallow marine, deep marine and nonmarine sediments [44] and ranges from Ediacarian to Pleistocene.

Ichnospecies *Lockeia* isp.

Fig. 3C

Material: One specimen, MMTT-344.

Description: One sampled slab displays about 15 *Lockeia* in epireliefs. They are asymmetric and almond-shaped, and tapering at both ends to sharp points or elongate with a commissure. Delicate, fine, longitudinal ridges are present in some *Lockeia*. Slopes of *Lockeia* are commonly uneven.

Discussion: The described above trace fossils are somewhat similar to *L. siliquaria* [40], but have a different preservation. *L. siliquaria* is symmetrical, almond-shaped and moderately wide centrally, and *L. avalonensis* [44] typically lacks the commissure, sharp pointed ends and resulting boat-shape.

e) Ichnogenus *Phycodes* Richter [45]

Type ichnospecies: *Phycodes circinatum* Richter [45].

Diagnosis: Horizontal, bundled burrows preserved outwardly as convex hyporeliefs. Overall pattern reniform, fasciculate, flabellate, broomlike, ungulate, linear, falcate or circular. Some forms consist of a few main branches showing a spreite-like structure that gives rise distally to numerous free branches. In other forms the spreiten are lacking and branching tends to be second or more random. Individual branches are terete and finely annulate or smooth (after Osgood [15]).

Discussion: Ichotaxonomy of *Phycodes* at the ichnospecies rank is based on ethological and morphological features, so that tracemaker behavior influences the diverse morphology of *Phycodes*. The common feature of *Phycodes* is a master tunnel that is used by the tracemaker for the formation of other tunnels [18]. Ichnospecies of *Phycodes* differ in pattern, size, nature, style and rank of bifurcation and the presence or absence of spreite. It was formerly thought that *Phycodes* occurs exclusively in relatively consolidated sediments of low energy shallow marine environments. However, it was also reported from non-marine, brakishwater and deep marine environments [46]. *Phycodes* is interpreted as fodinichnion [47], and occurs from the Early Cambrian (*Phycodes pedum* zone in [48]) to Miocene [49].

Ichnospecies *Phycodes* isp.

Figs. 4B$_{1\text{-}2}$

Material: One specimen MMTT-345.

Description: Only one poorly preserved specimen was found which is preserved as concave epirelief on the sandy limestone bed. Its configuration is nearly symmetric, like a propeller. The master tunnel is not seen and other probes are radially arranged at one side and filled with light fine-grained sediment. The diameter of the probes range from 2 to 5 mm. Boundaries of probes are indistinct. Spreiten are not present. Other indeterminate concave epireliefs are also present.

Discussion: The studied specimen displays a radial semi-circular configuration. This arrangement is similar to that of *Phycodes auduni* [50] and *Phycodes bromleyi* [50], but these ichnospecies have wide and extended branches. Tunnels of *Phycodes palmatus* [51] radiate from a point and in one direction. The Zefreh *Phycodes* resembles *Phycodes* isp. from the Miocene Roksha unit of the Makran Zone in southeast Iran [52]. The latter, however, displays a narrow master tunnel.

f) Ichnogenus *Taenidium* Heer [53]

Type ichnospecies: *T. serpentinum* Heer [53].

Diagnosis: Variably oriented, unwalled, straight, winding, curved, or sinuous, essentially cylindrical, meniscate backfilled trace fossil. Secondary successive branching may occur, but true branching is absent [54].

Discussion: Three ichnogenera, i.e. *Taenidium*, *Beaconites* [55] and *Ancorichnus* [56], are meniscate backfill burrows. Their ichnotaxonomic problems and similar trace fossils such as *Scoyenia* [57] were discussed by previous authors [54, 58-59]. Backfill structure, boundary, branching, walled or unwalled, lining, mantle and nature of meniscus are significant features [60] for differentiating these trace fossils [54]. *Taenidium* is, essentially, an unwalled and unlined meniscate backfill burrow, and so is distinguishable from the other meniscate backfilled ichnogenera, *Beaconites* and *Ancorichnus*. *Beaconites* is a cindrical, unbranched, walled, meniscate burrow, and *Ancorichnus* is cylindrical, weakly sinuous, subhorizontal to horizontal burrow containing a central meniscate fill and a structured mantle. Ichnospecies of *Taenidium* are differentiated by the style of meniscate backfill, and *T. serpentinum* [53], *T. satanassi* [58], *T. cameronensis* [61] and *T. barretti* [62] are valid ichnospecies [54, 58]. *Taenidium* is a facies-crossing form ranging from Ordovician to Pleistocene.

Ichnospecies *Taenidium barretti* Bradshaw [62].

Figs. 4C$_{1\text{-}2}$

Material: One specimen, studied in the field.

Diagnosis: Straight to variably meandering, unbranched, unwalled, meniscate backfilled burrow. Menisci are commonly hemispherical or deeply arcuate, tightly packed or stacked, forming non-compartmentalized backfill or thin meniscate segments (after [54]).

Description: One specimen studied in the field, preserved as an epichnial meniscate, slightly meandering burrow on the bedding plane of a quartzite sandstone layer. It is about 430 mm long and 70 to 130 mm wide. Menisci are arcuate and variably compacted.

Discussion: The examined *Taeinidium* closely resembles *T. barretti* (in [54, plate 1, Figs. 5-6]). It is variably compacted; deep arcuate menisci are distinctive from other ichnospecies of *Teanidium*. *Taenidium barretti* has previously been reported only from non-marine environments [54, text-Fig. 5]. In Zefreh, however, it is associated with marine trace fossils.

4. DISCUSSION

Coenosis relates to a population that is held together by ecologic factors in a state of unstable equilibrium [63], and in ichnology, an *ichnocoenosis* is an assemblage of trace fossils attributable to a specified biocoenosis. Recognition of ichnocoenoses is difficult because of influences of diverse physical factors on the formation and fossilization of trace fossils. For example, where the rate of sedimentation is low, older traces can be obliterated by later thorough bioturbation and the ichnocoenosis is accordingly determined by only the younger and late trace fossils. *Ichnofacies* [1] reflect similar environmental conditions during the production of trace fossils. Ichnofacies mainly show different depths and may be useful for bathymetry. It is not always easy to ascribe a trace fossil to a particular ichnofacies, and therefore all factors must be considered [2]. The environmental range of some trace fossils can change through geological time, for instance migration of tracemakers from shallow marine to deep marine can occur [64]. Thus, for better determination of environmental conditions, all members of an ichnocoenosis must be considered. The author considers all the studied trace fossils of Kuh-e Zard as belonging to one ichnocoenosis whose most abundant and characteristic members are *Diplocraterion parallelum*, *Lockeia* isp. and *Chondrites* isp.

The trace fossil assemblage of Kuh-e Zard indicate shallow marine conditions. *Diplocraterion parallelum*, *Lockeia* isp. and *Taenidium barretti* are typical of shallow marine and high energy conditions. *Chondrites* isp., *Fustiglyphus annulatus* and *Phycodes* isp. are facies-crossing trace fossils that are mainly found in the Cruziana ichnofacies [65]. This ichnofacies reflects moderate to relatively low energy in infralittoral to shallow circalittoral substrates and below daily wave base, but not storm wave base environments. The Cruziana ichnofacies is most characteristic of subtaidal, poorly sorted unconsolidated substrates [65].

Acknowledgments- The author thanks Alfred Uchman, Roland Goldring and an anonymous reviewer, for their review of this manuscript. The *Fustiglyphus annulatus* specimen was collected by Vachik Hairapetian from Isfahan University, and the author would like to thank him for sending it to the author. Many thanks to M. M. Ataabadi for his help.

REFERENCES

1. Seilacher, A. (1967). Bathymetry of trace fossils. *Marine Geology*, *5*, 413-428.
2. Frey, R. W., Pemberton, S. G. & Saunders, T. P. A. (1990). Ichnofacies and bathymetry: A passive relationship. *J. Paleontology*, *64*, 155-158.
3. Uchman, A., Abbassi, N. & Naeeji, M. (2005). *Persichnus* igen. nov. and associated ichnofossils from the Upper Cretaceous to Eocene deep-sea deposits of the Sanandaj Area, west Iran. *Ichnos*, *12*, 141-149.
4. Crimes, T. P. & McCall, G. J. H. (1995). A diverse ichnofauna from the Eocene-Miocene rocks of the Makran range (SE Iran). *Ichnos*, *3*, 231-258.
5. Ataabadi, M. M. & Sarjeant, W. A. S. (2000). Eocene mammal footprints from eastern Iran: a preliminary study. *Earth and Planetary Sci.*, *331*, 543-547.
6. Zahedi, M. (1976). *Explanatory Text of the Esfahan Quadrangle Map 1:250000*. Geological Survey of Iran, Geological Quadrangle, No. F8, 49.

7. Kebriaei, M. R. (1997). *Conodonts biostratigraphy of Late Devonian in the Zefreh area, north-east of Esfahan*, unpublished stratigraphy & palaeontology M. Sc. Thesis (in Persian), Isfahan University, 122.
8. Kebriaei, M. R. (1998). Biostratigraphy of Late Devonian sequences based on recovery of conodont species in the Kuh-e-Zard, Zefreh area, north-east of Esfahan, Iran. *Nort Gondwanan Mid-Palaeozoic Bioevent/Biogeography Patterns in Relation to Crustal Dynamics, International Geological Correlation Program, Abstract Book Isfahan Meeting IGCP*, *421*, 18.
9. Stöcklin, J. & Setudehnia, A. (1991). *Stratigraphic Lexicon of Iran*, Geological Survey of Iran, report No. 18, 379, (Third edition).
10. Stöcklin, J., Eftekhar-Nezhad, J. & Hushmand-zadeh, A. (1965). *Geology of the Shotori Range (Tabas area, East Iran)*. Geological Survey of Iran, report No. 3, 69.
11. Sternberg, K. & Von Graf, M. (1833). Versuch einer geognostisch-botanischen Darstellung der Flora der Vorwelt. *Johann Spurny,* Prague, *5-6*, 1-80.
12. Brongniart, A. T. (1828). Histoire des végétaux fossiles ou recherches botaniques et géologiques sur les végétaux renfermés dans les diverses couches du globe. *G. Dufour & E. d'Ocagne, Paris*, *1*, 136.
13. Pemberton, S. G. & Frey, R. W. (1984). Ichnology of strom-influenced shallow marine sequence: Cardium Formation (Upper Cretaceous) at Seebe, Alberta. In Stoott, D. F. & Glass, D. J. (eds.) *The Mesozoic of Middle North America*. Canadian Society of Petroleum Geologists, memoir 9, 281-304.
14. Stanley, D. C. A. & Pickerill, R. K. (1998). Systematic Ichnology of the Late Ordovician Georgian Bay Formation of Southern Ontario, Eastern Canada. *Royal Ontario Museum, Life Sciences Contributions*, *162,* 56.
15. Osgood, R. G. Jr. (1970). Trace fossils of the Cincinnati area. *Palaeontographica Americana*. *6*(41), 281-444.
16. Kotake, N. (1993). Tiering of trace fossil assemblages in the Plio-Pleistocene bathyal deposits of Boso Peninsula, Japan. *Palaios*, *8*, 544-553.
17. Jordan, D. W. (1985). Trace fossils and depositional environments of Upper Devonian Black shales, east-central Kentucky, U. S. A. In Curran, H. A. (ed.) *Biogenic Structures*: Their Use in Interpreting Depositional Environment. SEPM Spec. Publ. *35*, 279-298.
18. Marintsch, E. J. & Finks, R. M. (1982). Lower Devonian ichnofacies at Highland Mills, New York and their gradual replacements across environmental gradients. *J. Paleontology*, *56*, 1050-1078.
19. Savrda, C. E. (1998). Ichnology of the Bridge Creek Limestone: Evidence for temporal and spatial variations in paleo-oxygenation in the Western Interior Seaway, in Stratigraphy and Palaeoenvironments of the Cretaceous Western Interior Seaway, U. S. A. *SEPM Concepts in Sedimentology and Paleontology*, *6*, 127-136.
20. Bromley, R. G. & Ekdale, A. A. (1984). *Chondrites*: A trace fossil indicator of anoxia in sediments. *Science*, *224*, 872-874.
21. Hall, J. (1847). Palaeontology of New York. Volume I. containing descriptions of the organic remains of the Lower Middle Division of the New York System, (equivalent in part to the Middle Silurian rocks of Europe). *C. van Benthuysen,* Albany. 338.
22. Häntzschel, W. (1962). *Trace fossils and problematica*. In Moore, R. C. (ed.) *Treatise on Invertebrate Paleontology*, Part W. Geological Society of America, New York, and University of Kansas Press, Lawrence, W177.
23. Häntzschel, W. (1975). *Trace fossils and problematica*. In Teichert, C. (ed.), *Treatise on Invertebrate Paleontology*, Part W. Miscellanea, Supplement I. Geological Society of America, Boulder, and University of Kansas Press, Lawrence. 269.
24. Miller, S. A. (1889). North American geology and palaeontology for the use of amateurs, students and scientists. *Western Methodist Book Concern*. 664.
25. Kotake, N. (1991). Packing process for the filling material in *Chondrites*. *Ichnos*, *1*, 277-285.
26. Torell, O. (1870). Petrificata Suecana Formationis Cambricae. *Lunds. Univ. Årsskr*, *6*, 1-14.
27. Fürsich, F. T. (1974). On *Diplocraterion* Torell 1870 and the significance of morphological features in vertical,

spreiten-bearing, U-shaped trace fossils. *J. Paleontology*, *48*, 952-962.

28. Smith, J. (1893). Peculiar U-shaped tubes in sandstone near Crawfurdland Castle and in Gowkha Quarry, near Killwinning. *Geol. Soc. Glasgow*, *9*, 289-292.
29. Desio, A. (1940). Vestigia problematiche paleozoiche della Libia. *Ann. Museo Libico Storia Naturale*, *2*, 47-92.
30. Billings, E. (1872). On some fossils from the Primordial rocks of Newfoundland. *Canadian Naturalist and Quarterly Journal of Science with the Proceedings of the Natural History Society of Montreal*, *6*, 465-479.
31. Pickerill, R. K., Romano, M. & Meléndez, B. (1984). Arenig trace fossils from the Salamanca area, western Spain. *Geological Jour*., *19*, 249-269.
32. Miller, S. A. (1875). Some new species of fossils from the Cincinnati group and remarks upon some described forms. *Cincinnati Quart. Jour. Sci*., *2, 4*, 349-355.
33. Lisson, C. I. (1904). Los *Tigilites* del Salto del Fraile y algnues Sonneratia del Morro Solar. *Cuerpo Ingen. Minas del Perv́, Bol*., *17*, 64.
34. Öpik, A. (1929). Studien über das estnische Unter-Kambrium (Estonium). *I-IV, Acta Comment. Univers. Tartuensis*, *A., 15, 2*, 56.
35. Ekdale, A. A. & Lewis, D. W. (1991). Trace fossils and paleoenvironmental control of ichnofacies in a late Quaternary gravel and loess fan delta complex, New Zealand. *Palaeogeogr., Palaeoclimatol., Palaeoecol*., *81*, 253-279.
36. Leszczyński, S., Uchman, A. & Bromley, R. G. (1996). Trace fossils indicating bottom aeration changes: Folusz Limestone, Oligocene, Outer Carpathians, Poland. *Palaeogeogr., Palaeoclimatol., Palaeoecol*., *121*, 79-87.
37. Vialov, O. S. (1971). Redkie problematiki iz mesozoya Pamira I Kaukaza. *PaleontologicheskiĬ Sbornik*, *7*, 85-93.
38. Stanley, D. C. A. & Pickerill, R. K. (1993). *Fustiglyphus annulatus* from the Ordovician of Ontario, Canada, with a systematic review of the ichnogenera *Fustiglyphus* Vialov 1971 and *Rhabdoglyphus* Vassoievich 1951. *Ichnos*, *3*, 57-67.
39. Vassoievich, N. B. (1951). Usloviya *obrazovaniya flisha*. Gostoptekhizdat, Leningrad, 240.
40. James, U. P. (1879). Description of new species of fossils and remarks on some others from the Lower and Upper Silurian rocks of Ohio. *The Paleontologist*, *3*, 17-24.
41. Seilacher, A. (1953). Studien zur Palichnologie, II. Die fossilen Ruhespuren (Cubichnia): Neues Jahrb. *Geologie, Paläontologie, Abhandl*., *98,* 87-124.
42. Bandel, K. (1967). Trace fossils from two Upper Pennsylvanian Sandstones in Kansas. *Univ. Kansas Paleont. Contrib*. *18*, 1-13.
43. Mángano, M. G., Buatois, L. A., West, R. R. & Maples, C. G. (1998). Contrasting behavioral and feeding strategies recorded by tidal-flat bivalve trace fossils from the Upper Carboniferous of Eastern Kansas. *Palaios*, *13,* 335-351.
44. Fillion, D. & Pickerill, R. K. (1990). Ichnology of the Upper Cambrian? To Lower Ordovician Bell Island and Wabana groups of eastern Newfoundland. Canada. *Palaeontographica Canadiana*, *7*, 119.
45. Richter, R. (1850). Aus der thüringischen Grauwacke. *Deutsche Geologische Gesellschaft, Zeitschrift*, *2*, 198-206.
46. Han, Y. & Pickerill, R. K. (1994). *Phycodes templus* isp. nov. from the Lower Devonian of northwestern New Brunswick, eastern Canada. *Atlantic Geology*, *30*, 37-46.
47. Seilacher, A. (1955). Spuren und Fazies im Unterkambrium. In Schindewolf O. H., & Seilacher A. (eds.) *Beiträge zur Kenntnis des Kambriums in der Salt Range (Pakistan)*. Akademie der Wissenschaften und der Literatur zu Mainz, mathematisch-naturwissen-schafliche Klasse, Abhandlungen, *10*, 373-399.
48. Narbonne, G. & Hofmann, H. J. (1987). Ediacarian biota of the Wenecke Mountains, Yukon, Canada. *Palaeontology*, *30*, 647-676.
49. Bradley, J. (1981). *Radionereites*, *Chondrites* and *Phycodes*; trace fossils of anthoptiloid sea pens. *Pacific Geol*., *15*, 1-16.

50. Dam, G. (1990). Taxonomy of trace fossils from the shallow marine Lower Jurassic Neill Klinter Formation, East Greenland. *Bulletin of the Geological Society of Denmark*, *38*, 119-144.
51. Hall, J. (1852). *Palaeontology of New York. Volume II. Containing descriptions of the organic remains of the Lower Middle Division of the New York System, (equivalent in part to the Middle Silurian rocks of Europe).* C. van Benthuysen, Albany, 362.
52. Abbassi, N. (2000). Palaeoichnology, lithostratigraphy and sedimentary environments of Roksha and "Vaziri" units (Miocene) in Nikshahr-Ghasr Ghand areas (Makran). Univ. Sh. Beheshti. Unpublished Ph.D. Thesis, Tehran, Iran, 350, [In Persian, English and French abstracts].
53. Heer, O. (1877). Flora Fossilis Helvetiae. Die vorweltiliche Flora der Schweiz. *Jour. Würster & Co*., 182.
54. Keighley, D. G. & Pickerill, R. K. (1994). The Ichnogenus *Beaconites* and its distinction from *Ancorichnus* and *Taenidium*. *Palaeontology*, *7*, 305-337.
55. Vialov, O. S. (1962). Problematica of the Beacon Sandstone at Beacon Heights, West Antarctica. *New Zealand Journal of Geology and Geophysics, 5,* 718-732.
56. Heinberg, C. (1974). A dynamic model for a meniscus filled tunnel (*Ancorichnus* n. ichnogen.) from the Jurassic Pecten Sandstone of Milne Land, East Greenland. *Rapport Grønlands Geologiske Undersøgelse*, *62*, 1-20.
57. White, C. D. (1929). Flora of the Hermit shale, Grand Canyon, Arizona. *Carnegie Inst. Washington Pub*., *405*, 1-221.
58. D'Alessandro, A. & Bromley, R. G. (1987). Meniscate trace fossils and the *Muensteria-Taenidium* problem. *Palaeontology*, *30*, 743-763.
59. Frey, R. W. & Fagerstrom, J. A. (1984). Morphological, ethological and environmental significance of the ichnogenera *Scoyenia* and *Ancorichnus*. *J. Paleontology*, *58*, 511-518.
60. Pickerill, R. K. (1994). Nomenclature and taxonomy of invertebrate trace fossils. In Donovan, S. K. (ed.) *The Palaeobiology of Trace Fossils*. John Wieley & Sons Pub., 3-42.
61. Brady, L. F. (1947). Invertebrate tracks from the Coconino Sandstone of northern Arizona. *J. Paleontology*. *21*, 466-472.
62. Bradshaw, M. A. (1981). Palaeoenvironmental interpretations and systematics of Devonian trace fossils from the Taylor Group (Lower Beacon Supergroup), Antarctica. *New Zealand Journal of Geology and Geophysics*, *24*, 615-652.
63. Bates, R. L., Jackson, J. A. (1980). *Glossary of Geology* (2nd ed.), Ame. Geol. Inst., Virginia, 751.
64. Crimes, T. P. & Fedonkin, M. A. (1994). Evolution and dispersal of deepsea traces. *Palaio*s, *9*, 74-83.
65. Frey, R. W. & Pemberton, S. G. (1984). Trace fossil facies models. *In R. G. Walker* (ed.) *Facies Models*. Geoscience Canada, Reprint Series *1*, 189-207.