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Middle to Upper Triassic Deep-Water Trace Fossils from the Ashin Formation, Nakhlak Area, Central Iran

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Abstract

The up to 304 m thick, turbiditic, siliciclastic Ashin Formation (Upper Ladinian to Lower Carnian?) crops out widely in the Nakhlak area of central Iran. The rocks consist mainly of turbiditic volcaniclastic sandstones and shales that were deposited in distal parts of submarine fans of the continental slope to abyssal plain. Trace fossils occur commonly in the lower parts of the turbiditic volcaniclastic sandstones and belong to 17 ichnotaxa including ?*Chondrites* isp., *Ctenopholeus kutscheri*, *Helminthopsis abeli*, *H. tenuis*, *H. hieroglyphica*, *Laevicyclus rotaeformis, Lorenzinia nowaki*, *Megagrapton* isp., *Ophiomorpha* isp., *Palaeophycus* isp., *Paleodictyon* cf. *maximum*, *Protopaleodictyon incompositum*, *Protovirgularia* isp., and *Thalassinoides* isp. The trace fossil assemblage belongs to the deep-sea *Nereites* ichnofacies. In particular trace fossils such as *Paleodictyon*, *Protopaleodictyon*, *Megagrapton* and *Lorenzinia* indicate that the Ashin Formation represents a deep marine environment.

Keywords: Trace fossils; Triassic; Ashin Formation; Nakhlak; Central Iran

Introduction

Trace fossils provide important data about palaeoenvironmental parameters, such as oxygenation, food supply, rate of sedimentation, turbulence and palaeodepth [2,4,5,12,16,28]. They indicate episodes of sedimentation and erosion and also record gaps in sedimentation. The most significant environmental parameter governing the production, distribution, nature, and preservation of trace fossils, apart from food supply and hydrodynamic conditions, is the substrate and its properties. Substrate not only provides a primary control but also directly influences diagenetic processes which both enhances and masks specific traces depending on their original character [14].

The main objectives of this paper are to describe and interpret, for the first time, Middle to Upper Triassic deep-water trace fossil assemblages from the Ashin Formation in the Nakhlak area of central Iran and to use the information for corroborating the deep-water interpretation of this formation.

During field work in the Nakhlak area in the context of a sedimentological, ichnological, biostratigraphic and palaeo-oceanographic study of the Ashin Formation 70 trace fossil samples, 80 samples of sedimentary structure, 66 shale samples for radiolarians, and some

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bivalves and ammonoids were collected.

The samples were studied at the Institute of Palaeontology of Würzburg University within the framework of a DAAD-sponsored research stay.

Study Area

The Nakhlak area is located in a structural region called Central Iran, north of the Yazd Block, covering an area between longitudes 53°, 45′ and 53°, 54′N and latitudes 30°, 30′ and 33°, 37′E. It consists of pre-Triassic? ophiolite rocks and Triassic (Alam, Baqoroq and Ashin formations), Upper Cretaceous (Sadr unit), and Paleocene (Khaled unit) sedimentary rocks with considerable thicknesses that were deposited in various sedimentary environments (Fig. 1).

The Triassic sedimentary strata [7,35] are well exposed in the Nakhlak area. The Upper Ladinian-Lower Carnian? Ashin Formation [7,40] consists of a siliciclastic turbidite facies, which contains a moderately diverse trace fossil assemblage that previously has not been recorded.

Geological Setting

The Triassic rocks of the Nakhlak area attain a thickness of up to 2724 m [1,40,41]. Lithologically, the succession differs completely from time-equivalent lithostratigraphic units in the surrounding regions. These rocks have been termed Nakhlak Group and subdivided into three formations [7,40]: **(1)** The Alam Formation (Upper Scythian to Middle Anisian) consists, apart from some conspicuous carbonate intercalations in the lower and middle part, predominantly of a succession of shallowing- and coarsening-upward marine turbidites with common volcanic components, deposited on the forearc side of an active margin in a continental shelf to slope setting. **(2)** The Baqoroq Formation (Upper Anisian?-Middle Ladinian) is a succession of fine- to coarse-grained, polymict, fluvial conglomerates deposited on alluvial fans and in meandering and braided rivers. **(3)** The Ashin Formation (Upper Ladinian to Lower Carnian?) is a fine-grained turbidite succession, mostly composed of volcaniclastic sandstones and shales deposited as submarine fans on the continental slope to abyssal plain [7,40,41].

Ammonoids collected from different levels of the Alam and Ashin formations indicate an Early to Late Triassic (Late Scythian to Early Carnian?) age for the succession [35,40-42].

Stahl [34] was the first geologist who studied the area. Between 1929 and 1969 German geologists carried out some investigations on the rich mineral deposits of the region.

Davoudzadeh & Seyed-Emami [7] studied the stratigraphy and palaeontology of the Triassic rocks of the Nakhlak area and introduced the Nakhlak Group. Vaziri [40] studied the litho- and biostratigraphy of the Triassic rocks and reconstructed their sedimentary environments. He also prepared a geological map of the Nakhlak area on a 1:20.000 scale.

The comparison between the Triassic rocks of the Nakhlak area and other Triassic rocks of the Iran Plate shows that there is no similarity between them, because the latter are essentially carbonates (dolomite, limestone, and dolomitic limestone). These rocks were deposited in shallow marine environments on the continental shelf, whereas the Triassic rocks of Nakhlak (except for the Baqoroq Formation which represents

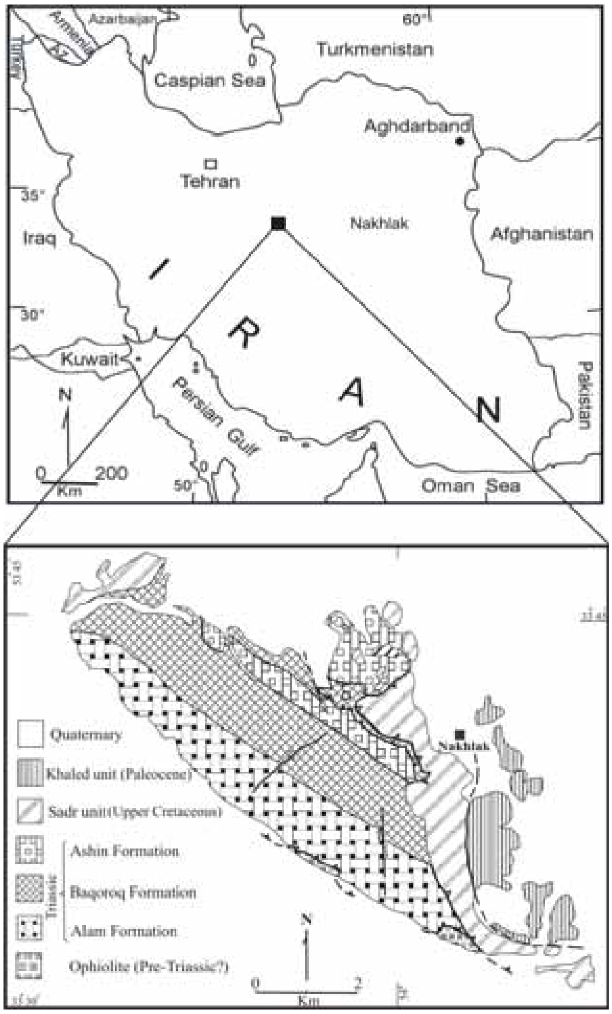

Figure 1. Location and geological map of the Nakhlak area, Central Iran.

continental environments) were deposited mostly in a continental slope to abyssal plain setting, and are mainly composed of siliciclastic turbidites, in most cases mixed with volcaniclastic fragments.

Tectonic Setting of the Nakhlak Area

The Triassic Nakhlak Group is an exotic succession in central Iran. Lithologically as well as palaeontologically the Triassic strata of Nakhlak differ completely from the shallow water carbonate platform successions of the Lower and Middle Triassic of Iran. The only correlative Triassic succession to the Nakhlak Group is the Triassic succession of the Aghdarband area in northeastern Iran. According to Alavi *et al.* [1] lithologic, palaeoenvironmental and palaeobiogeographic evidence suggests that both Triassic successions formed in a single tectono-sedimentary framework, at the southern active margin of the Turan Plate. The separation of the Triassic Nakhlak rocks from the rest of the Turan Plate and its transportation to the present position has been explained by the counterclockwise rotation of 135° of the East-Central Iranian Microcontinent since the Late Triassic [1,8,9,25,33,40,41]. However, this interpretation has recently been questioned, and a new model, postulating the existence of a small, short-lived oceanic basin in the area during the Triassic, has been put forth (A. Zanchi, pers. comm. Dec. 2006).

The Ashin Formation

Middle to Upper Triassic (Upper Ladinian to Lower Carnian?) deep-sea sedimentary rocks crop out across a large area west of Nakhlak and have been named Ashin Formation [7]. The formation consists of alternating thin- and medium-bedded calcareous sandstones, purple, fine-grained volcaniclastic sandstones, and mostly green and violet, very thin-bedded volcaniclastic shales that were deposited in distal parts of submarine fans, on the continental slope to abyssal plain [40]. These alternations fine upwards and exhibit some sedimentary structures and trace fossils that until now have escaped the attention of geologists.

Ammonoids collected from different levels of the Ashin Formation indicate a Middle to Late Triassic (Late Ladinian to Early Carnian?) age for the formation [35,40-42]. The formation includes the following ammonoids: *Proarcestes* sp., *Megaphyllites* sp., *Arpadites* cf. *szaboi* (BOECKH), and *Romanites simionescui* KITTL.

The Ashin Formation disconformably overlies the Baqoroq Formation and on the top is covered angular unconformable by the Upper Cretaceous Sadr unit [7,40,43].

Lithostratigraphy

The studied section of the Ashin Formation is situated west of Nakhlak village (backside of Nakhlak mine) (co-ordinates: N 33° 33′ 37″; E 53° 49′ 38″) and consists mainly of volcaniclastic sandstones and shales. The formation reaches a thickness of 304 m and can be subdivided into three informal members based on facies characteristics (Fig. 2).

Member 1 (17.5 m)

Alternating brick-red and green, thin- and very thin-bedded calcareous shales, siltstones and purple, medium-bedded sandstones with intercalations of light-red, medium-bedded conglomerates. The fossil content consists of crinoids and rare ammonoids (Fig. 3A).

These alternations become finer-grained up-section and exhibit sedimentary structures such as graded bedding, parallel lamination, and cross-bedding.

Member 1 has been named as the *first sedimentary ammonoid-bearing alternation*s of the Ashin Formation by Vaziri [40]. For the first time, Vaziri [40] reported *Proarcestes* sp. from these alternations. Previously, Davoudzadeh & Seyed-Emami [7] found this ammonoid only from the upper part of the Ashin Formation.

Member 2 (134.5 m)

Alternating green, thin- and very thin-bedded volcaniclastic shales and purple, medium-bedded volcaniclastic sandstones with crinoids and the bivalve *Daonella lomelli* WISSMANN (Fig. 3B, D-E).

These alternations fine upwards and exhibit sedimentary structures such as graded bedding, parallel lamination (with parting lineation) convolute bedding, small-scale cross-bedding, load casts, groove casts, prod casts, flute casts, bounce casts, chevron casts, and brush casts (Figs. 4A-F) indicating A to C parts of the Bouma cycle. Septarian nodules occur repeatedly. The lower surfaces of sandstones contain abundant trace fossils.

Due to the numerous trace fossils the member has been named *main sedimentary ichnofossil-bearing member* by Vaziri [40].

Member 3 (152 m)

Alternating green and violet, very thin-bedded volcaniclastic shales, purple, medium-bedded volcaniclastic sandstones, green, very thin-bedded

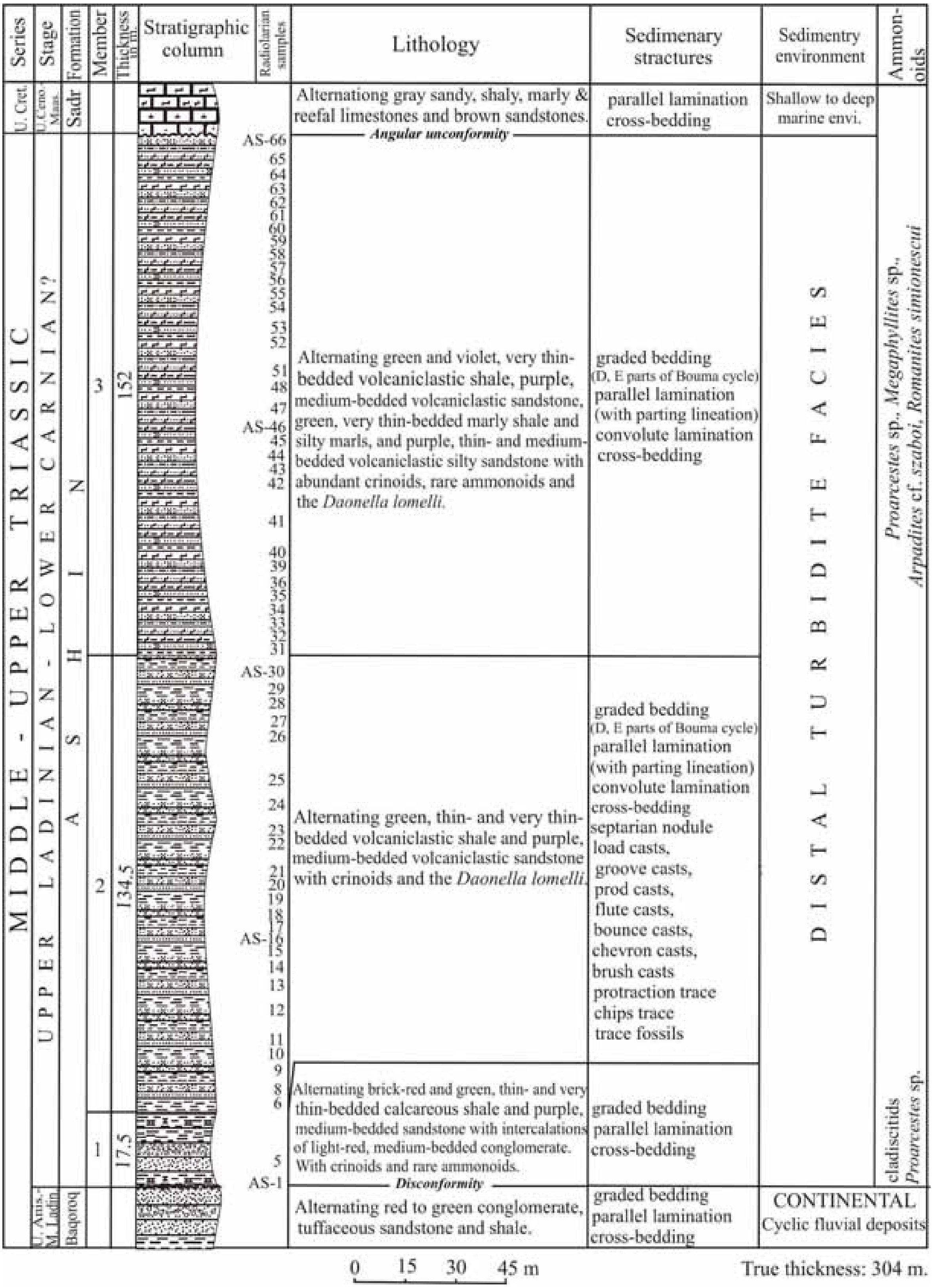

Figure 2. Lithologic and environmental characteristics of the Ashin Formation in the Nakhlak area, Central Iran.

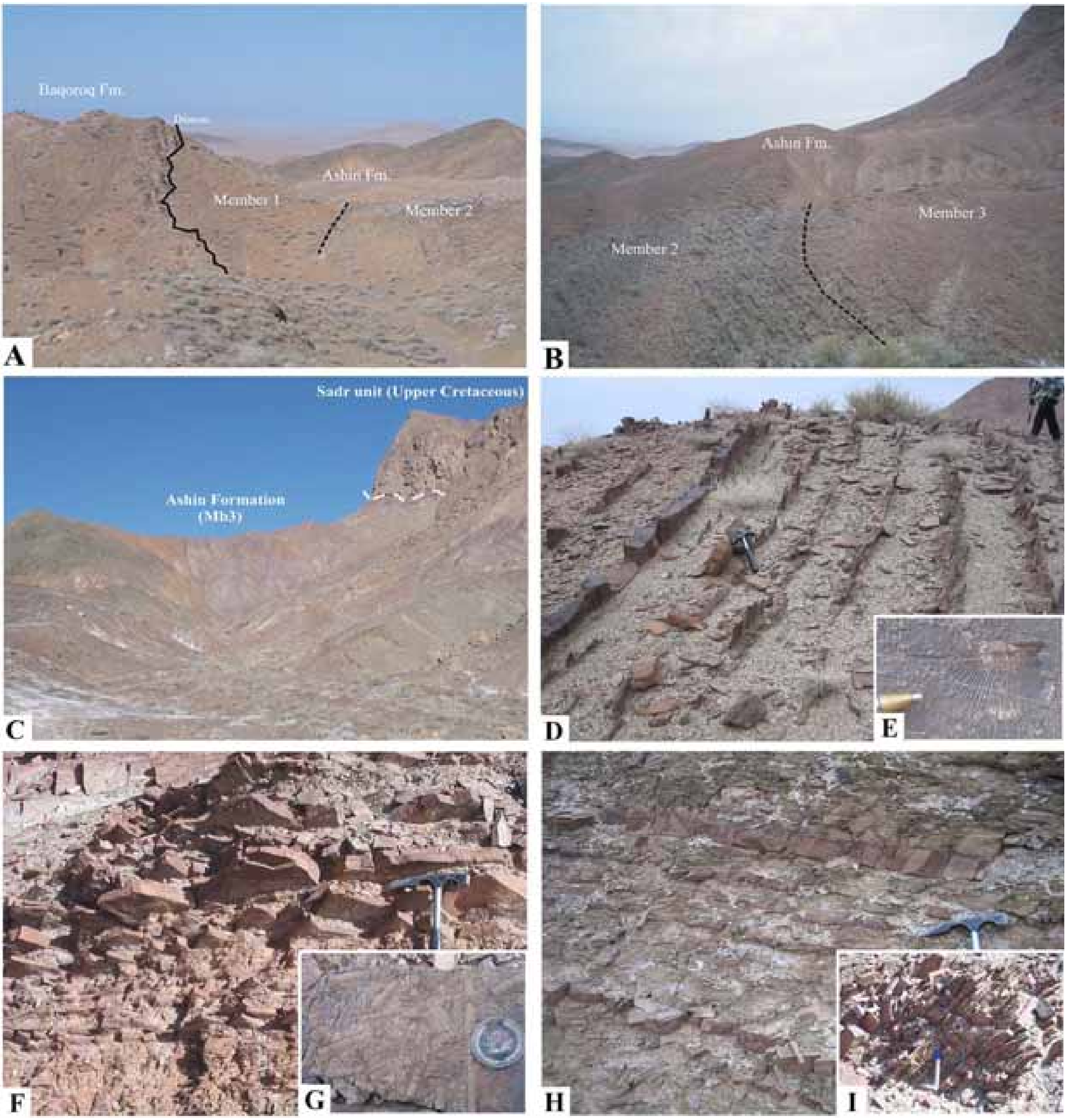

Figure 3. **(A)** Contact between the Baqoroq Formation and the Ashin Formation, member 1 and base of member 2. **(B)** Alternating volcaniclastic sandstones and shales in members 2 and 3 of the Ashin Formation. **(C)** Member 3 of the Ashin Formation and its unconformity contact with the Upper Cretaceous Sadr unit. **(D)** Alternating purple volcaniclastic sandstones and green volcaniclastic shales of member 2. **(E)** *Daonella lomelli* in sandstones of member 2. **(F)** Alternating violet, thin- and medium-bedded volcaniclastic sandstones and shales of member 3. **(G)** Crinoids in sandstones of member 3. **(H, I)** Alternating violet, thin- and medium-bedded volcaniclastic sandstones and green, very thin-bedded volcaniclastic marly shales and silty marls in the uppermost part of member 3.

marly shales and silty marls, and purple, thin- and medium-bedded volcaniclastic silty sandstones with abundant crinoids, *Daonella lomelli* WISSMANN (Figs. 3B-C, G-I) and the ammonoids *Megaphyllites* sp., *Arpadites* cf. *szaboi* (BOECKH), and *Romanites simionescui* KITTL [35,40]. The ammonoid assemblage suggests a Late Ladinian to Early Carnian? age for the member. Member 3 has been named as the *second sedimentary ammonoid-bearing alternation*s of the Ashin Formation by Vaziri [40]. Trace fossils are represented by ?*Chondrites* and *Palaeophycus*.

Up-section, these alternations become very fine-

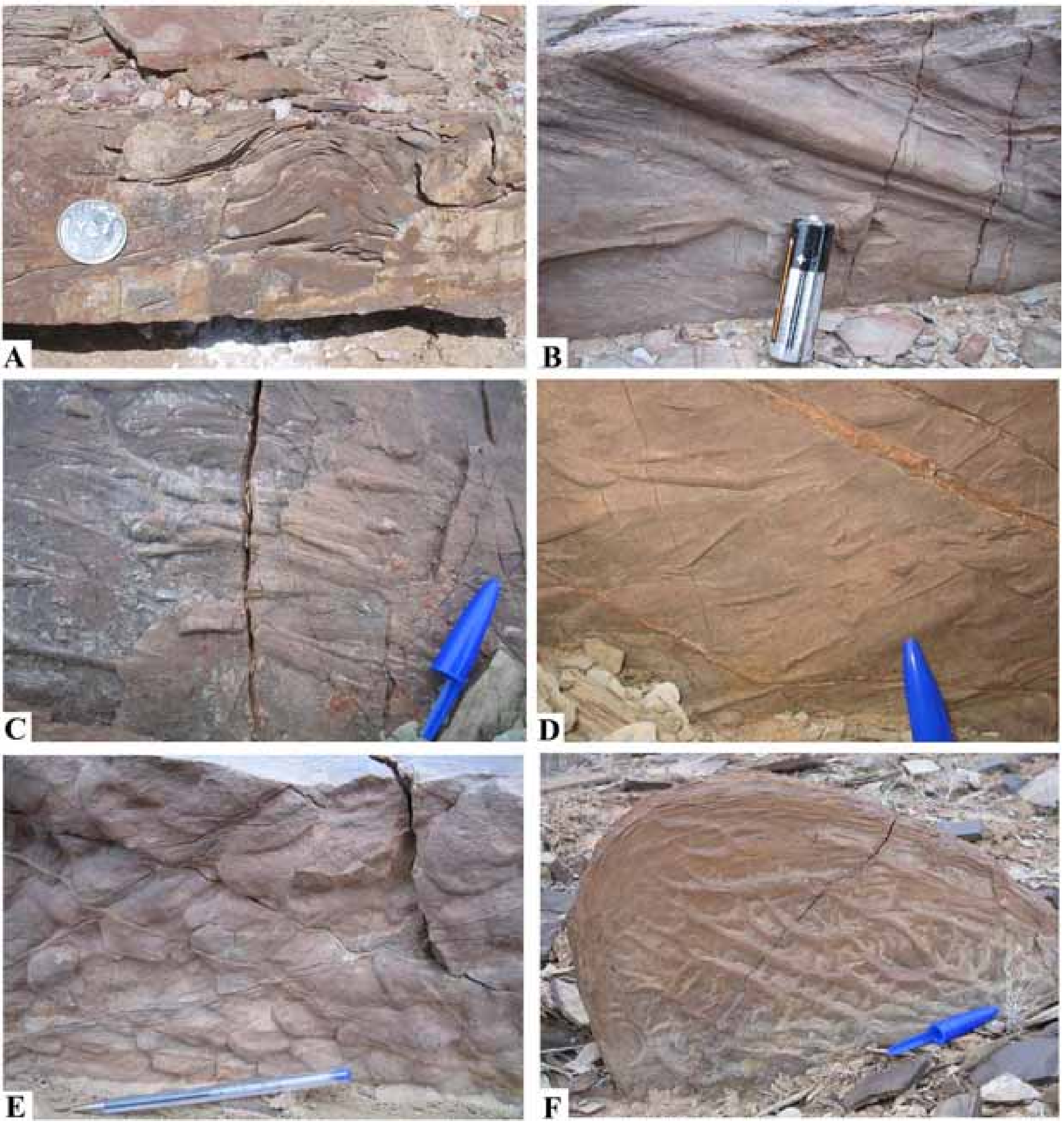

Figure 4. Some sedimentary structures in volcaniclastic sandstones of member 2 of the Ashin Formation include convolute bedding **(A)**, groove casts **(B)**, tool marks and flute casts **(C)**, prod marks and bounce casts **(D)**, load casts **(E)**, and septarian nodules **(F)**.

grained and thin-bedded, and exhibit sedimentary structures such as parallel lamination with parting lineation, convolute bedding, and cross-bedding indicating B to C parts of the Bouma cycle.

The bivalve *Daonella lomelli* WISSMANN in members 2 and 3 (Fig. 3E) confirms a Late Ladinian age. This bivalve has been reported from the Aghdarband area (Sina Formation) in northeastern Iran, from northwestern Afghanistan, and from the northernmost, westernmost and southernmost shelf regions of the Tethys.

Trace fossils of the Ashin Formation

The lower surfaces of turbiditic volcaniclastic sandstones of the Ashin Formation, especially in member 2, exhibit abundant trace fossils. In the present study, the best outcrop of the Ashin Formation has been analysed and a total of 17 trace fossil taxa have been identified (Fig. 5).

The trace fossils belong to the ethological groups Agrichnia (*e.g., Paleodictyon, Ctenopholeus*), Pascichnia (*e.g., Helminthopsis, Lorenzinia*), Chemichnia (*Chondrites*), and Domichnia (*e.g., Ophiomorpha*, *Thalassinoides*). Some ichnotaxa such as *Laevicyclus, Helminthopsis, Protopaleodictyon incompositum*, *Megagrapton* and *Paleodictyon* are pre-depositional forms, while others such as *Ophiomorpha* are post-depositional forms.

The trace fossil assemblage is typical of the *Nereites* ichnofacies [17,28], with a characteristic contribution of graphoglyptids (*Protopaleodictyon*, *Paleodictyon).* The ichnotaxa ?*Chondrites*, *Ctenopholeus*, *Helminthopsis*, *Palaeophycus*, *Thalassinoides*, and *Ophiomorpha* singly do not indicate typical sedimentary environments, because they have been recorded from both shallow- and deep-water facies. However, the presence of characteristic ichnotaxa of the *Nereites* ichnofacies such as *Paleodictyon*, *Protopaleodictyon*, *Megagrapton* and *Lorenzinia* indicate a deep marine origin of the Ashin Formation. Altogether, the trace fossil assemblage of the Ashin Formation confirms the sedimentological interpretation of the Ashin Formation as a continental slope to abyssal plain turbidite facies. The distribution and abundance of trace fossils in the Ashin Formation are shown in Figures 5 and 6.

Ichnotaxonomy

Ichnogenus *Chondrites* STERNBERG, 1833

?Chondrites isp.

Pl. 1, Fig. 1, Pl. 4, Fig. 1

Description: Branching, downward penetrating, and markedly flattened tunnels, 0.2-0.3 mm in diameter, preserved as positive hyporeliefs. Branches have sharp angles.

Material: two specimens (T 39).

Remarks: The characteristic feature of *Chondrites*, dichotomous branching, is only poorly developed. For this reason, the specimens are referred to *Chondrites* with doubt. Originally interpreted as the burrow system of a deposit-feeder [26,32], *Chondrites* is nowadays thought to be a trace produced by a chemosymbiotic organism [29]. This would explain its wide occurrence in dysaerobic environments [3], although being by no means restricted to it.

Occurrence: On the sole of turbiditic sandstones, Ashin Formation, member 3.

Ichnogenus *Ctenopholeus* SEILACHER & HEMLEBEN, 1966

Ctenopholeus kutscheri (SEILACHER & HEMLEBEN, 1966)

Pl. 1, Figs. 2, 3

Description: Short, curved, single row composed of up to seven circular knobs. Row up to 31 mm in length, preserved as positive hyporelief. The diameter of the knobs is 1.6-2.8 mm, the distance between kobs (from centre to centre) 3.8-6.8 mm.

Material: Two specimens (T 7, 32).

Interpretation: *Ctenopholeus* is interpreted as the bedding plane expression of a three-dimensional burrow system consisting of a straight, curved to looped horizontal tunnel, from which vertical to subvertical

Figure 5. Distribution of trace fossils in the Ashin Formation of the Nakhlak area.

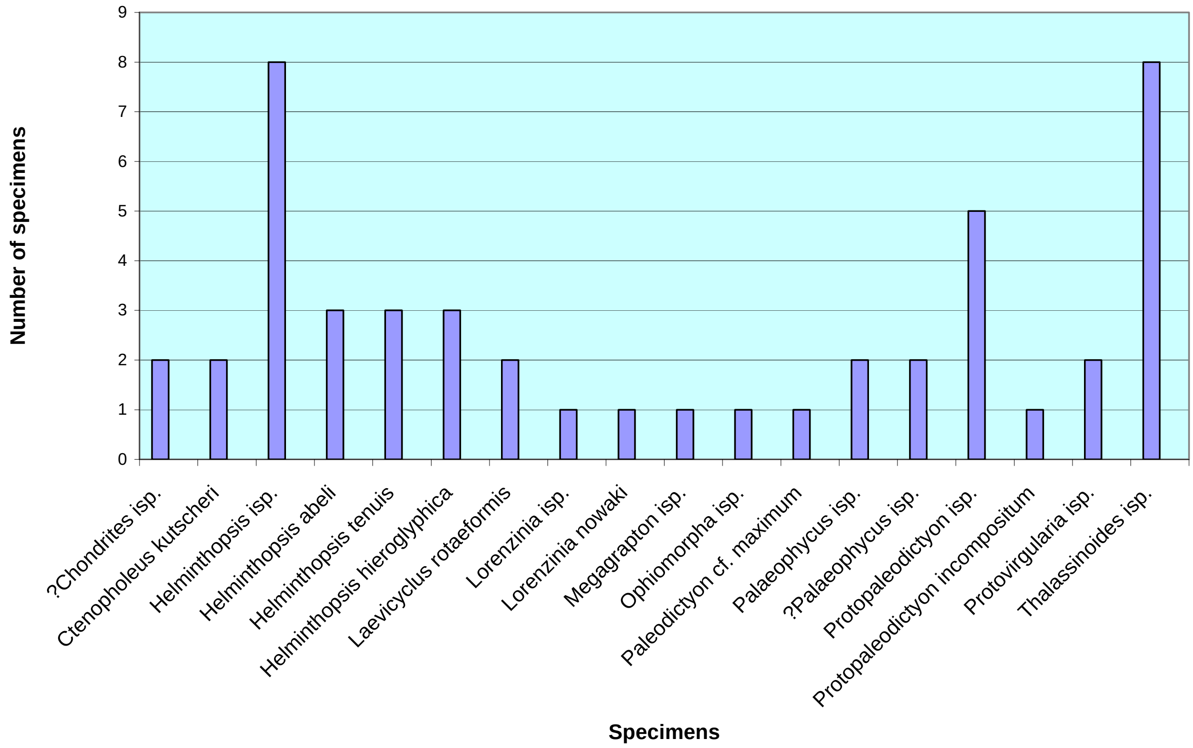

Figure 6. Abundance of trace fossils of the Ashin Formation.

shafts extend upwards to the sea floor [19]. The existence of a horizontal burrow has been demonstrated in the case of the Devonian Hunsrück Slate [30], for material from the Lower Cambrian Mickwitzia Sandstone of south-central Sweden [22] and for material from the Lower Jurassic Shemshak Formation of the southern Alborz Mountains [19].
Occurrence: On the sole of turbiditic sandstones, Ashin Formation, member 2.

Ichnogenus *Helminthopsis* HEER, 1877
Helminthopsis isp.
Pl. 4, Figs. 3-4

Description: Single, smooth-walled irregularly meandering string, preserved as convex hyporelief. Diameter of string 2-4 mm. The meanders are sharp to gentle.
Material: Eight specimens (T 4, 6, 13, 15, 24, 27, 31, 33).
Remarks: *Helminthopsis* is a eurybathic, facies-crossing trace fossil, common in flysch deposits and produced probably by polychaetes or priapulids [13,23] The present specimens are too fragmentary to allow identification at the ichnospecies level.
Occurrence: On the soles of turbiditic sandstones, Ashin Formation, member 2.

Helminthopsis abeli KSIĄŻKIEWICZ, 1977
Pl. 1, Figs. 4-6

Description: Irregular, bulging and horseshoe-shaped, deep meanders, preserved as positive hyporeliefs. Diameter of string 1-3 mm.
Material: Three specimens (T 16, 28, 30).
Occurrence: On the sole of turbiditic sandstones, Ashin Formation, member 2.

Helminthopsis tenuis KSIĄŻKIEWICZ, 1968
Pl. 2, Figs. 1-3

Description: String forming meanders, which range from narrow to wide and from shallow to deep. Preserved as positive hyporeliefs. Diameter of string 2-4 mm. One of the specimens (T 10) is clearly pre-depositional in origin.
Material: Three specimens (T 10, 20, 21).
Remarks: Most specimens of *H. tennis*, including the holotype, display repeated, wide, shallow meanders and deeper narrow but obtuse meanders. *H. abeli* differs in commonly displaying relatively deep, bulged and

horseshoe-shaped meanders [38].
Occurrence: On the sole of turbiditic sandstones, Ashin Formation, member 2.

Helminthopsis hieroglyphica KSIĄŻKIEWICZ, 1968
Pl. 1, Figs. 7-8, Pl. 4, Fig. 1

Description: Wide, moderately deep and relatively regular meanders. String 2-5 mm in diameter. Preserved as positive hyporelief.
Material: Three specimens (T 5, 7-8).
Occurrence: On the sole of turbiditic sandstones, Ashin Formation, member 2.

Ichnogenus *Laevicyclus* QUENSTEDT, 1879
Laevicyclus rotaeformis D´ALESSANDRO, 1980
Pl. 2, Fig. 4

Description: Circular to slightly oval, ring-like structure, preserved as convex hyporelief. String 2-3 mm in diameter, inner diameter of the ring 13-14.5 mm. In the center, there is a sub-circular knob with a diameter of 3.2 mm.
Remarks: The specimens closely correspond to *L. rotaeformis* as figured by D'Alessandro ([6]: 369, pl. 43, figs. 1-2, pl. 44, figs. 1-2) from Miocene flysch of southern Italy and by Leszczyński & Seilacher ([24]: 296, Fig. 4) from Eocene flysch of Spain.
Material: Two specimens (T 3, 13).
Occurrence: On the sole of turbiditic sandstones, Ashin Formation, member 2.

Ichnogenus *Lorenzinia* GABELI, 1900
Lorenzinia isp.
Pl. 2, Fig. 5

Description: Short, hypichnial ridges radiating from a central field. The three radiating ridges probably are only part of the original structure, which possibly consisted of eight ridges. The ridges are up to 10 mm long and 1.6 mm wide. The central field measures 9 mm across.
Material: One specimen (T 8).
Occurrence: On the sole of turbiditic sandstones, Ashin Formation, member 2.

Lorenzinia nowaki (KSIĄŻKIEWICZ, 1970)
Pl. 2, Fig. 6

Description: Long, hypichnial ridges radiating from a central flat area. The five radiating ridges probably are only a part of the original structure, which might have had nine ridges. The ridges are up to 14 mm long and 3.4 mm wide. The central field measures 12 mm across.
Material: Two specimens (T 1, 40).
Remarks: Asymmetry in length of the ridges may be partially due to preferential scouring [28]. Uchman [38] believed the irregular morphology to reflect mainly the primary irregular distribution of elements of the burrow system. The trace fossil is interpreted as a wreath of asymmetric, wide U-tubes, which are radially arranged around a central area.
Occurrence: On the sole of turbiditic sandstones, Ashin Formation, member 2.

Ichnogenus *Megagrapton* KSIĄŻKIEWICZ, 1968
Megagrapton isp.
Pl. 2, Fig. 7, Pl. 4, Fig. 5

Description: Branching, winding strings with a diameter of 2 mm. Angles of branching commonly acute. The main ridges are up to 30 mm long. Preserved as positive hyporelief.
Material: One specimen (T 2).
Occurrence: On the sole of turbiditic sandstones, Ashin Formation. member 2 (T 4) and member 3 (T 40).

Ichnogenus *Ophiomorpha* LUNDGREN, 1891
Ophiomorpha isp.
Pl. 2, Fig. 8, Pl. 4, Fig. 5

Description: A simple, cylindrical burrow seen for 67 mm. Burrow 4 mm in diameter, flattened by compaction. Preserved as full relief. The characteristic knobby ornamentation is poorly preserved and consists of irregular, flattened peloids.
Material: One specimen (T 2).
Remarks: The occurrence of *Ophiomorpha*, a typical shallow-water ichnotaxon, in deep-sea turbidites has been discussed by several authors [36,37]. *Ophiomorpha* is particularly common in Paleogene and Neogene well-oxygenated, medium- and thick-bedded turbidite deposits, related to channel or proximal depositional lobe facies. However, it is also present in fan-fringe facies [39].
Occurrence: On the sole of a turbiditic sandstone, Ashin Formation, member 2.

Ichnogenus *Paleodictyon* MENEGHINI, 1850
Paleodictyon cf. *maximum* (EICHWALD, 1868)
Pl. 3, Fig. 8

Description: Fragment of a regular, hexagonal mesh with a string diameter of 1.7 mm. Mesh diameter approximately 8-10 mm.
Remarks: Although the regular, hexagonal shape of the mesh clearly identifies the trace as *Paleodictyon*, too little of the mesh is preserved to allow precise assignment to an ichnospecies. According to the classification scheme of Uchman [37], which uses string diameter and mesh diameter as diagnostic criteria, the trace may belong to *P. maximum* [10].
Material: One specimen (T 9).

Occurrence: On the sole of turbiditic sandstone, Ashin Formation, member 2.

Ichnogenus *Palaeophycus* HALL, 1847

Palaeophycus isp.

Pl. 2, Figs. 7-8

Description: Slightly oblique cylindrical burrows, seen for up to 10 mm, with distinct wall. Burrow diameter 3.5 to 5.5 mm. Fill slightly softer than lining. Surface of burrows smooth. Preserved as positive hyporeliefs.

Material: Two specimens on a single slab (T 2).

Remarks: In contrast to the specimens described below, the present material can be identified as *Palaeophycus* without doubt, because of its conspicuous burrow lining.

Occurrence: On the sole of turbiditic sandstones, Ashin Formation, member 2.

?*Palaeophycus* isp.

Pl. 3, Fig. 5

Description: Simple, straight to slightly sinuous, cylindrical to sub-cylindrical burrows. Burrow diameter 5-6 mm, maximum observed length 75 mm. Surface of burrow smooth. Preserved as slightly washed out positive hyporeliefs. Pre-depositional in origin.

Material: Two specimens (T 19, 36).

Remarks: *Palaeophycus* is a eurybathic facies-crossing ichnogenus, produced probably by suspension-feeding polychaetes. It differs from the morphologically similar *Planolites* by the presence of a wall [27]. As the specimens are pre-depositional in origin, the nature of the burrow fill and the presence of a wall could not be verified.

Occurrence: On the sole of turbiditic sandstones, Ashin Formation, member 2.

Ichnogenus *Protopaleodictyon* KSIĄŻKIEWICZ, 1958

Protopaleodictyon isp.

Pl. 3, Figs. 2, 3, Pl. 4, Fig. 6

Description: Irregular, string-like meanders with ramifications at their apices. String diameter 2.5-3.5 mm. Branching commonly T-shaped. Preserved as positive hyporelief.

Material: Five specimens (T 11, 17, 18, 25, 29).

Remarks: *Protopaleodictyon* occurs almost exclusively in flysch deposits. Solely Gierlowski-Kordesch & Ernst [20] reported it from comparatively shallow-water deposits of Cretaceous age in East Africa.

Occurrence: On the sole of turbiditic sandstones, Ashin Formation, member 2.

Protopaleodictyon incompositum KSIĄŻKIEWICZ, 1970

Pl. 3, Fig. 4

Description: Irregular, deep meanders with side branches at apices. The string is 1.6 mm wide. Preserved as convex hyporelief. Pre-depositional.

Material: One specimen (T 9).

Remarks: *P. incompositum* occurs doubtfully since the Devonian [21], and with certainty since the Albian [23] in marine turbidites [38].

Occurrence: On the sole of a turbidite sandstone, Ashin Formation, member 2.

Ichnogenus *Protovirgularia* MCCOY, 1850

Protovirgularia isp.

Pl. 3, Fig. 6

Description: Slightly curved, keel-shaped positive hyporelief, seen for 51 mm. Diameter of trail 5-7 mm. With ornamentation of faint, transverse to chevron-shaped ridges.

Material: Two specimens (T 2, 12).

Remarks: Seilacher & Seilacher [31] demonstrated by neoichological experiments that *Protovirgularia* is a molluscan locomotion trace. A detailed discussion of *Protovirgularia* is found in Uchman [38].

Occurrence: On the sole of turbiditic sandstones, Ashin Formation, member 2.

Ichnogenus *Thalassinoides* EHRENBERG, 1944

Thalassinoides isp.

Pl. 3, Figs. 6-7, Pl. 4, Figs. 1-2

Description: Horizontal cylindrical burrows with Y-shaped branchings, preserved as washed-out positive hyporeliefs. Burrows occur in two size classes; diameters range from 8 to 10 mm, enlarged at points of bifurcation, and from 19 to 22 mm, respectively. Observed length from 65 to 170 mm. Pre-depositional.

Material: Eight specimens (T 8, 12, 14, 23, 34-35, 37-38).

Remarks: *Thalassinoides* is a facies-crossing trace fossil produced by crustaceans, and is most typical of shallow-marine environments [18]. The present specimens were found in deep-water turbidites.

Origin and palaeoenvironmental significance of *Thalassinoides* have been summarized by Ekdale [11]. According to Föllmi & Grimm [15], the crustaceans producing *Thalassinoides* may survive transport in turbidity currents and produce burrows under anoxic conditions for a limited number of days.

Occurrence: On the sole of turbiditic sandstones, Ashin Formation, member 2.

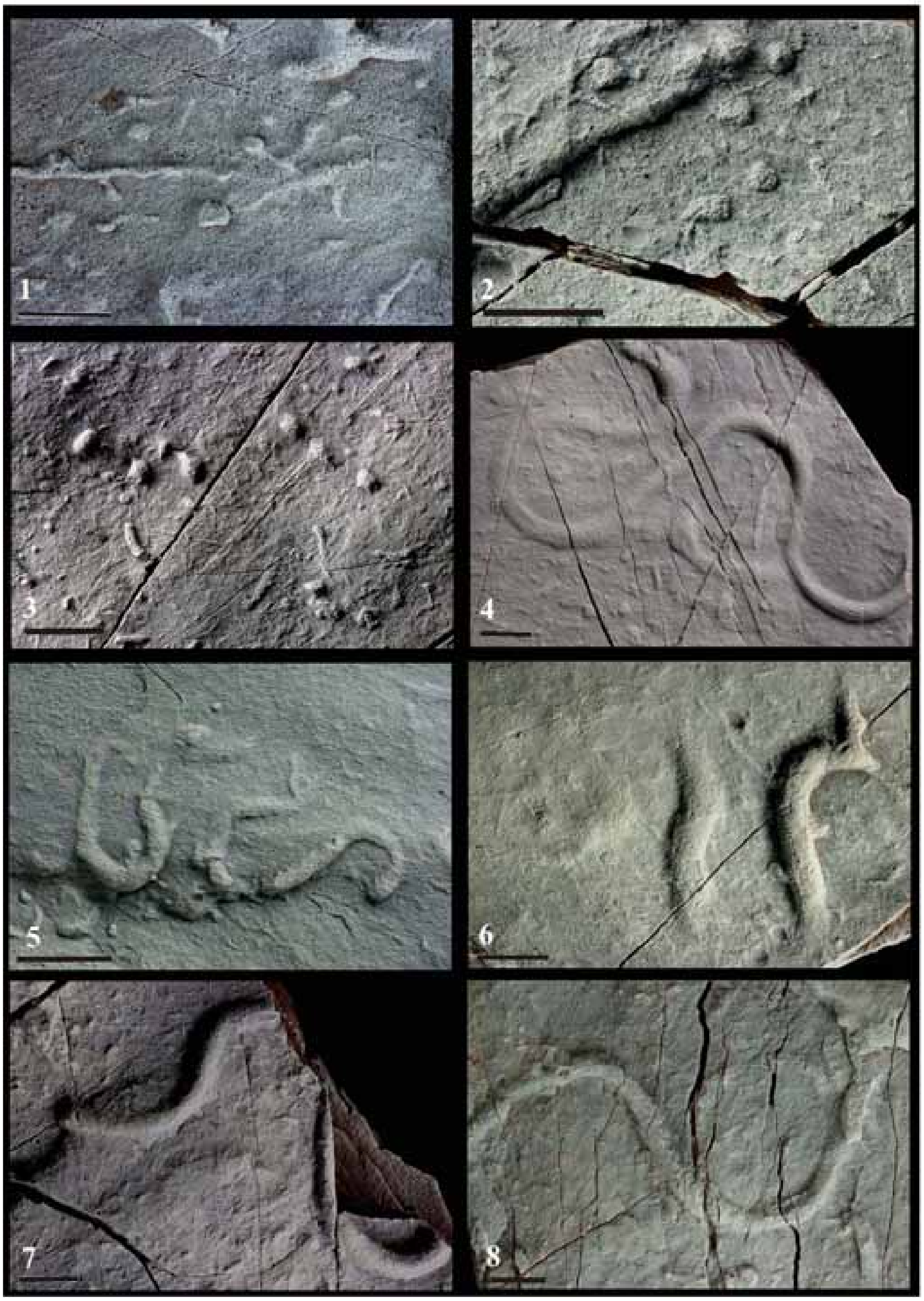

Plate 1.
Scale bars: 1 cm. All specimens are from the lower surfaces of sandy turbidites of the Ashin Formation.
Fig. 1: ?*Chondrites* isp., member 3, sample T39.
Figs. 2-3: *Ctenopholeus kutscheri* SEILACHER & HEMLEBEN, member 2, samples T7 (2) and 32 (3).
Figs. 4-6: *Helminthopsis abeli* KSIĄŻKIEWICZ, member 2, samples T16 (4), 28 (5) and 30 (6).
Figs. 7-8: *Helminthopsis hieroglyphica* KSIĄŻKIEWICZ, member 2, samples T7 (7) and 8 (8).

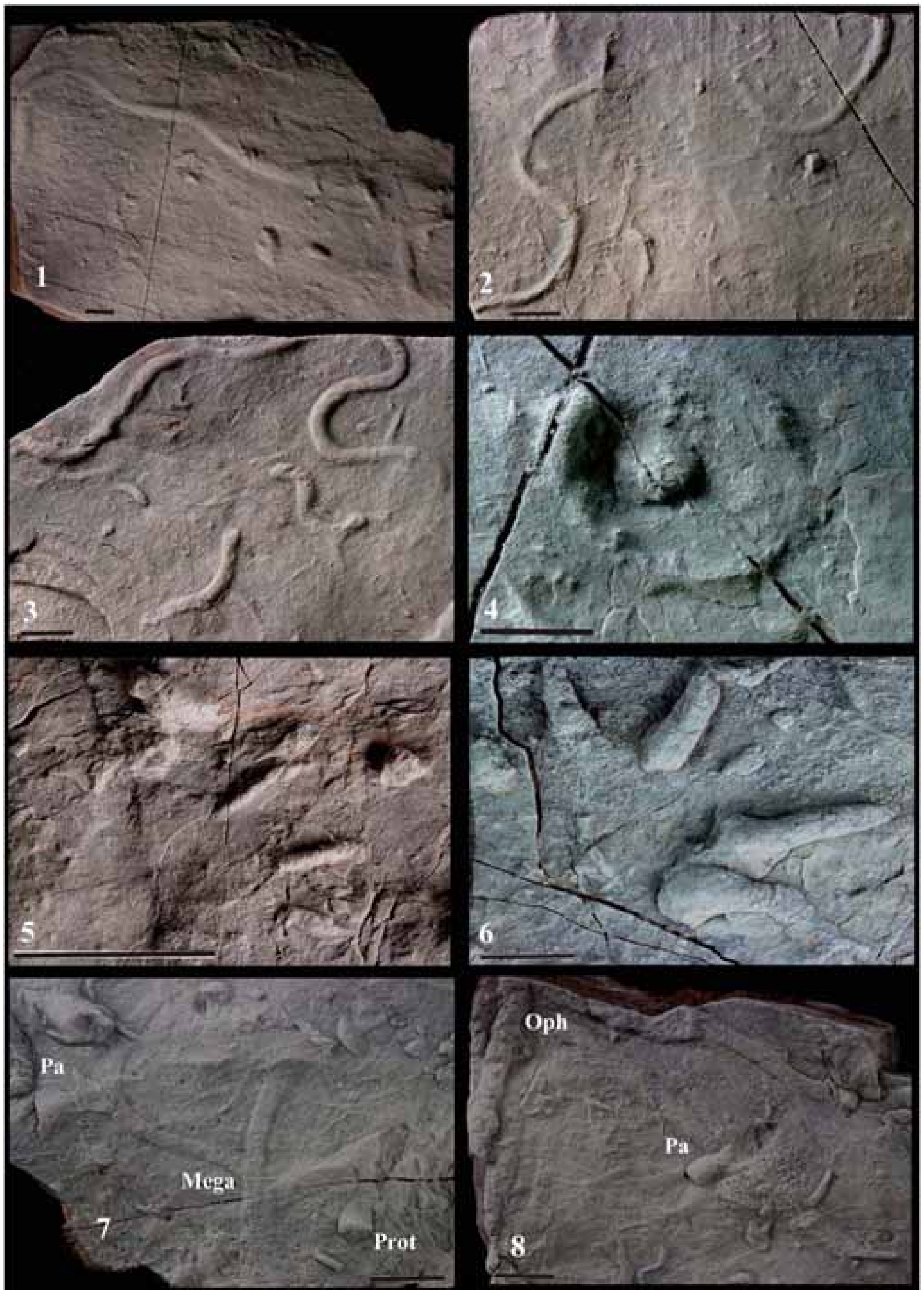

Plate 2.
Scale bars: 1 cm. All specimens are from the lower surfaces of sandy turbidites of the Ashin Formation, member 2.
Figs. 1-3: *Helminthopsis tenuis* KSIĄŻKIEWICZ, samples T10 (1), 20 (2) and 21 (3).
Fig. 4: *Laevicyclus* isp., sample T13.
Fig. 5: *Lorenzinia* isp., sample T8.
Fig. 6: *Lorenzinia nowaki* (KSIĄŻKIEWICZ), sample T1.
Fig. 7: *Megagrapton* isp. (Mega), *Protovirgularia* isp. (Prot) and *Palaeophycus* isp. (Pa), sample T2.
Fig. 8: *Ophiomorpha* isp. (Oph) and *Palaeophycus* isp. (Pa), sample T2.

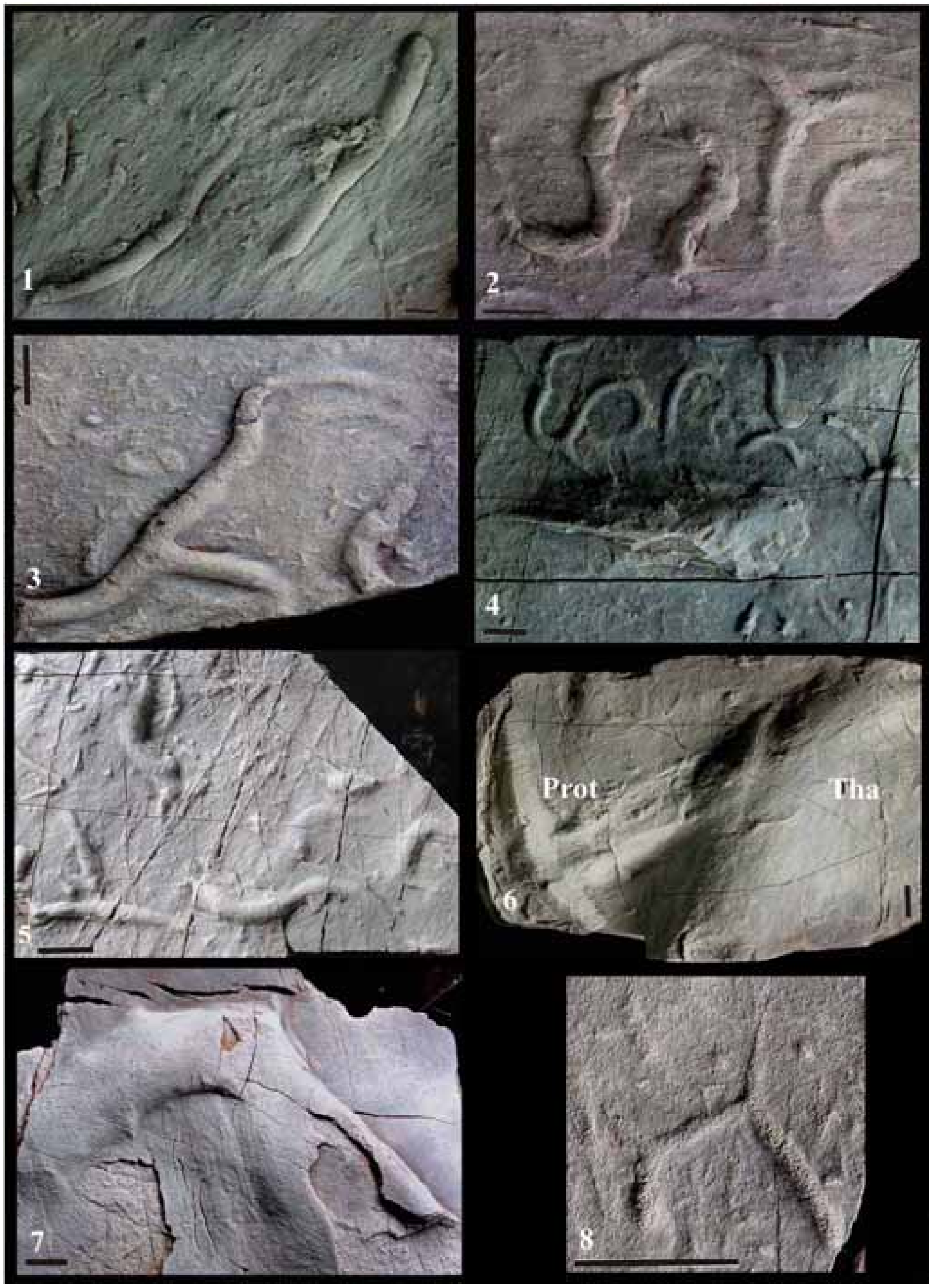

Plate 3.
Scale bars: 1 cm. All specimens are from the lower surfaces of sandy turbidites of the Ashin Formation.
Fig. 1: *Palaeophycus* isp., member 2, sample T19.
Figs. 2-3: *Protopaleodictyon* isp., member 2, samples T11 (2) and 17 (3).
Fig. 4: *Protopaleodictyo*n *incompositum* KSIĄŻKIEWICZ, member 2, sample T9.
Fig. 5: *Palaeophycus* isp., member 3, sample T6.
Fig. 6: *Thalassinoides* isp. (Tha) and *Protovirgularia* isp. (Prot), member 2. The washed-out nature of *Thalassinoides* indicates a pre-depositional origin, sample T12.
Fig. 7: Washed-out *Thalassinoides* isp., member 2, sample T34.
Fig. 8: Washed-out relict of *Paleodictyo*n cf. *maximum*, member 2, sample T9.

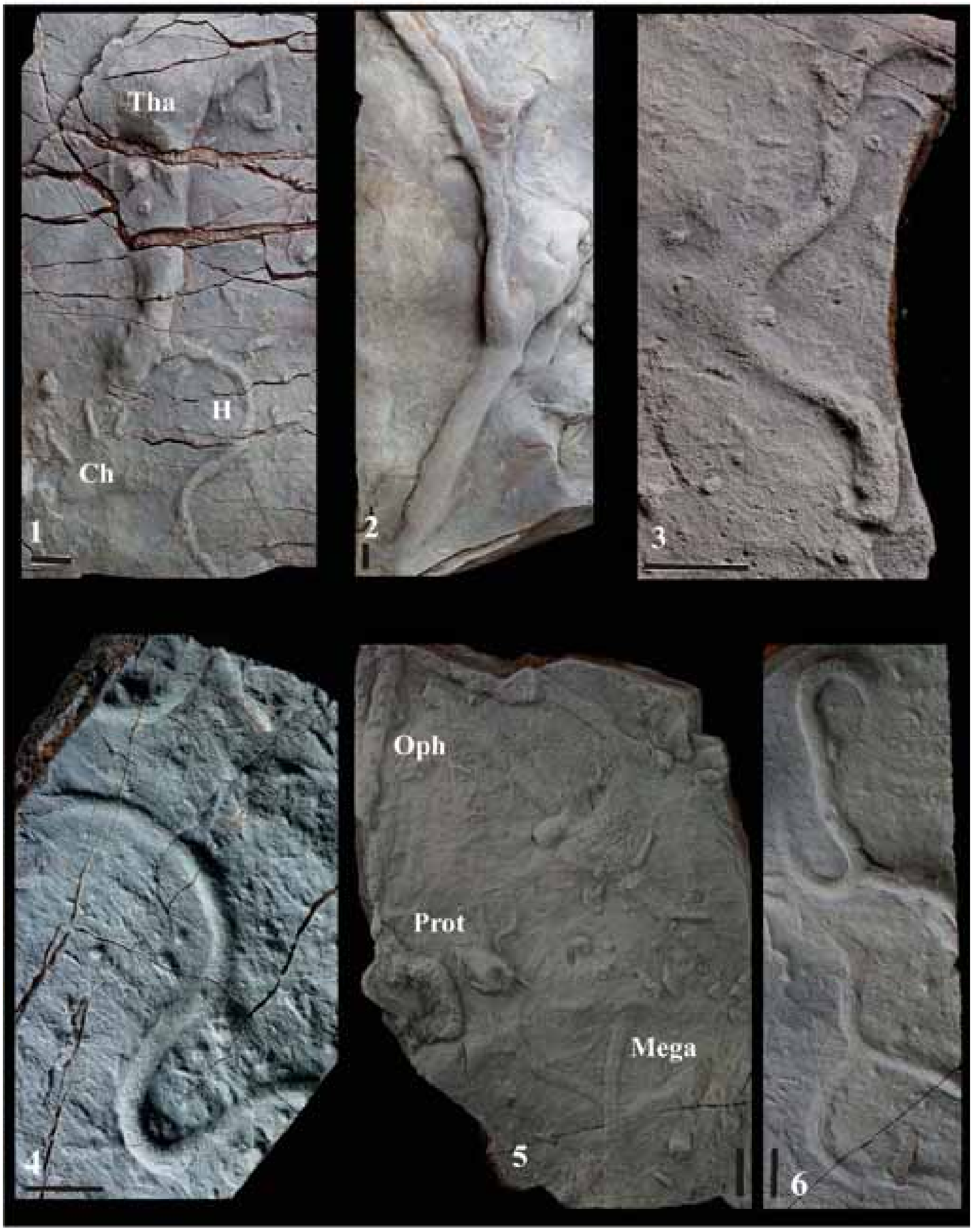

Plate 4.
Scale bars: 1 cm. All specimens are from the lower surfaces of sandy turbidites of the Ashin Formation, member 2.
Fig. 1: *Thalassinoides* isp. (Tha), ?*Chondrites* isp. (Ch) and *Helminthopsis hieroglyphica* KSIĄŻKIEWICZ (H), sample T8.
Fig. 2: *Thalassinoides* isp., sample T35.
Figs. 3-4: *Helminthopsis* isp., samples T4 (3) and 24 (4).
Fig. 5: *Ophiomorpha* isp. (Oph), *Protovirgularia* isp. (Prot) and *Megagrapton* isp. (Mega), sample T2.
Fig. 6: *Protopaleodictyon* isp., sample T18.

Conclusions

The Upper Ladinian to Lower Carnian(?) Ashin Formation of the Nakhlak area in central Iran exhibits a moderately diverse trace fossil assemblage. It contains several taxa, such as *Paleodictyon*, *Megagrapton*, *Protopaleodictyon*, and *Lorenzinia*, which are usually, albeit not exclusively, found worldwide throughout most of the Phanerozoic in deep-sea flysch successions and are characteristic of the so-called Nereites ichnofacies. The trace fossils occur on the soles of distal turbidites, associated with numerous signs of strong current activity such as groove casts, flute casts and prod marks. Both sedimentary structures and trace fossil composition thus support the deep-water character of the Ashin Formation.

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