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Sedimentary structures and depositional environment of the Ashin Formation in Nakhlak area, Central Iran

S. H. Vaziri*

Department of Geology, Faculty of Basic Sciences, North Tehran Branch, Islamic Azad University,P.O. Box 19585-851, Tehran, Iran
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Abstract

Middle to Upper Triassic (Upper Ladinian to Lower Carnian) deep-sea sedimentary rocks crop out across a large area west of Nakhlak village, Central Iran and have been named Ashin Formation. The up to 304m thick, turbiditic, siliciclastic Ashin Formation consists of alternating turbiditic, thin- and medium-bedded calcareous sandstones, purple, fine-grained volcaniclastic sandstones, and mostly green and violet, very thin-bedded volcaniclastic shales that can be subdivided into three members. Ammonoids collected from members 1 and 3 of the Ashin Formation indicate a Late Ladinian to Early Carnian age for the formation. 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, brush casts and chips and protraction traces indicating A to E parts of the Bouma cycle. Septarian nodules occur repeatedly. The lower surfaces of sandstones contain abundant trace fossils belong to the deep-sea Nereites ichnofacies. Numerous signs of strong current activity such as groove casts, flute casts and prod marks associated with trace fossils such as Paleodictyon, Protopaleodictyon, Megagrapton and Lorenzinia indicate that the Ashin Formation represents a deep marine environment. The field and petrographic studies show that the Ashin Formation was deposited in distal parts of submarine fans, on the abyssal plain.

Keywords*: sedimentary structure, Triassic, Ashin Formation, Nakhlak, Central Iran.*

1. Introduction

A distinctive succession of Triassic sedimentary strata is well exposed in the Nakhlak area of central Iran. These rocks are subdivided into three formations: the Alam, Baqoroq and Ashin formations with Late Scythian to Early Carnian age that have been named as the Nakhlak Group [3, 15]. Lithological, paleontological and depositional environments of the Triassic strata of Nakhlak are completely different from the Triassic shallow carbonate and platform successions of Iran. The only Triassic succession correlative to the Nakhlak Group is the Triassic succession of Aghdarband area [11] in northeastern Iran.

The Upper Ladinian to Lower Carnian Ashin Formation [3, 15] consists of a siliciclastic turbidite facies, which contains moderately diverse sedimentary structures that have not been recorded previously. The main objective of this paper is to introduce sedimentary structures and the depositional environment of the Ashin Formation in the Nakhlak area of Central Iran.

2. Material

During field work in the Nakhlak area in the context of a sedimentological, ichnological, biostratigraphic and paleo-oceanographic study of the Ashin Formation 80 samples of sedimentary structures, 70 trace fossil samples, 26 rock samples for making thin sections, 66 shale samples for radiolarians, and some bivalves and ammonoids were collected. The material was studied at Würzburg University, Germany within the framework of a DAAD-sponsored research stay.

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*Corresponding author.
E-mail address (es): h_vaziri@iau-tnb.ac.ir

3. Study area

The Nakhlak area is located in the 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? ophiolitic rocks and Triassic (Alam, Baqoroq and Ashin formations), Upper Cretaceous (Sadr unit), and Paleocene (Khaled unit) sedimentary deposits with considerable thicknesses that were deposited in various sedimentary environments (Fig. 1).

4. Geological setting

The Triassic rocks of the Nakhlak area attain a thickness of up to 2724 meters and are bordered by two unconformities [15, 16, and 19]. Lithologically, the succession differs completely from time-equivalent lithostratigraphic units in the surrounding regions.These rocks have been termed Nakhlak Group and are subdivided into three formations [3, 15]:
(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 upward shallowing and coarsening 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 sequence, mostly composed of volcaniclastic sandstones and shales deposited in a deep marine environment.

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 [14-17].

Stahl [13] was the first geologist who studied the area between 1929 and 1969. Davoudzadeh and Seyed-Emami [3] studied the stratigraphy and paleontology of the Triassic rocks of the Nakhlak area and introduced the Nakhlak Group.

Vaziri [15] carried out a lithostratigraphic and biostratigraphic study of the Triassic rocks and reconstructed their sedimentary environments. Vaziri [22] also prepared a geological map of the Nakhlak area on a 1:25,000 scale. Vaziri and Soleimani [20] reported Triassic radiolarians from the Ashin Formation for the first time.

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

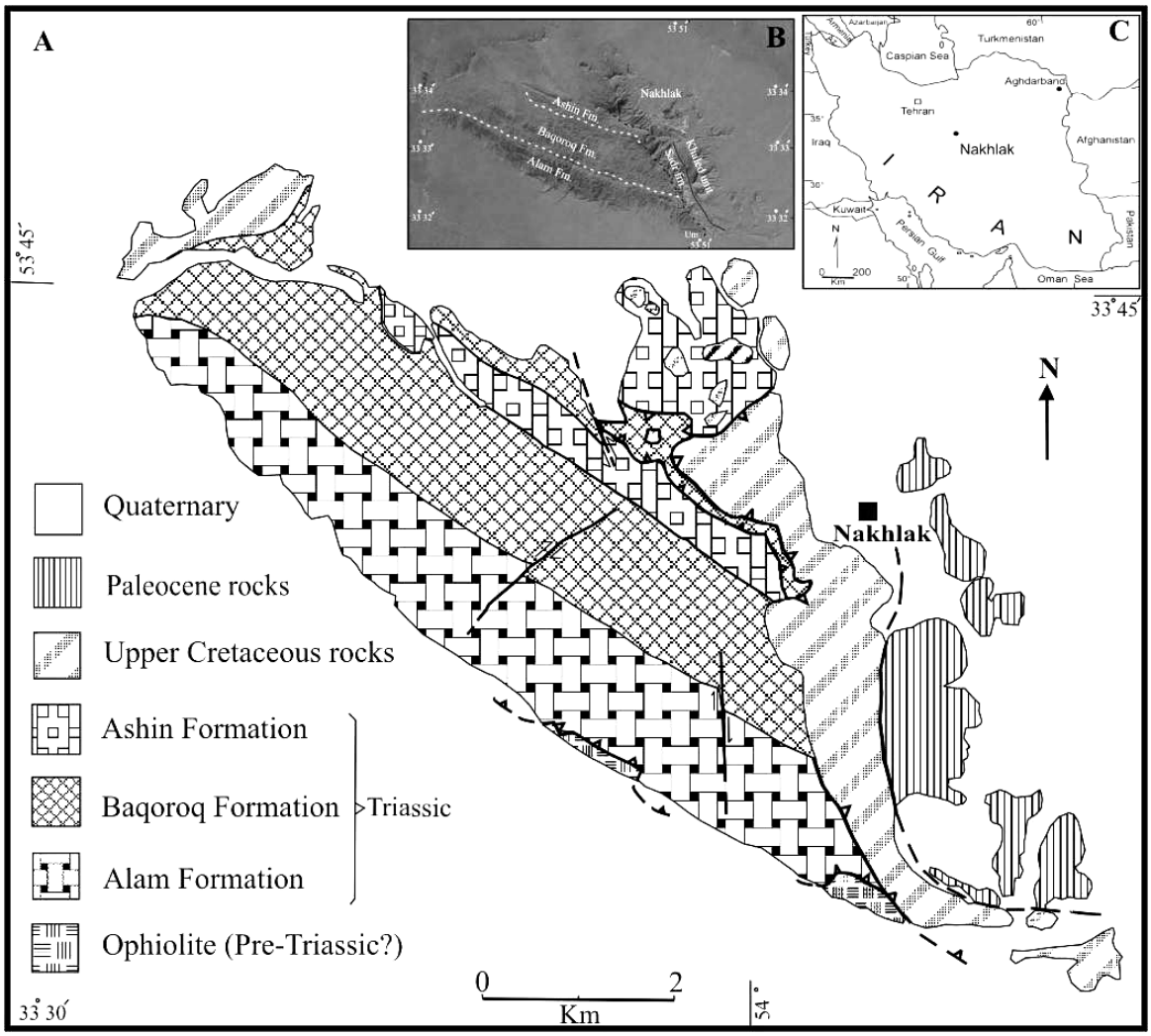

Fig. 1. Geological map (A), satellite image (B, from Google Earth) and location (C) of the Nakhlak area, Central Iran.

5. Tectonic setting of the Nakhlak area

The Triassic Nakhlak Group is an exotic succession in central Iran. Lithologically as well as paleontologically, the Triassic strata of Nakhlak differ completely from the shallow water carbonate platform successions of the Lower and Middle Triassic of Iran. The only Triassic succession which can be correlated to the Nakhlak Group is the Triassic succession of the Aghdarband area in northeastern Iran [1,2,3,11and15]. Lithologic, paleoenvironmental and paleo-biogeographic evidence suggests that both Triassic successions were deposited 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, 4, 5, 10, 12, 15, and 16]. 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 [23].

6. 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 as the Ashin Formation [3]. This formation with a thickness of 304 meters consists of alternating thin- and medium-bedded calcareous sandstones, purple, fine-grained volcaniclastic sandstones, and mostly green and violet, very thin-bedded volcaniclastic shales. The present study indicates it was deposited in the distal parts of submarine fans, on the continental slope and abyssal plain. These alternations fine upwards and exhibit some trace fossils that were studied by Vaziri and Fürsich [19] but until now their sedimentary structures have escaped the attention of geologists.

Ammonoids collected from different levels of the Ashin Formation indicate Middle to Late Triassic (Late Ladinian to Early Carnian) age for the formation [14, 15, 21].

The Ashin Formation disconformably overlies the Baqoroq Formation and on the top it is covered by the Upper Cretaceous Sadr unit [2, 3, 16, 18, 19] separated by an angular unconformity (Fig. 3J, K).

7. Stratigraphy

The studied section of the Ashin Formation is situated west of Nakhlak village (behind the 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).

Member 1 has been named as the *first sedimentary ammonoid-bearing alternation* of the Ashin Formation and the *third of sedimentary ammonoid-bearing alternation*s in the Triassic rocks of the Nakhlak region by Vaziri [15]. For the first time, he reported *Proarcestes* sp. from these alternations. Previously, Davoudzadeh and Seyed-Emami [3] 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). The lower surfaces of sandstones contain 17 ichnotaxa including ?*Chondrites* isp., *Ctenopholeus kutscheri*, *Helminthopsis abeli*, *H. tenuis*, *H. hieroglyphica*, *Laevicyclus rotaeformis*, *Lorenzinia nowaki*, *Megagrapton* isp., *Ophiomorpha* isp., *Paleophycus* isp., *Paleodictyon* cf. *maximum*, *Protopaleodictyon incompositum*, *Protovirgularia* isp., and *Thalassinoides* isp. (Fig. 5A-H). The trace fossil assemblage belongs to the deep-sea *Nereites* ichnofacies [19]. Due to the numerous trace fossils the member has been named *main sedimentary ichnofossil-bearing member* by Vaziri [15].

Member 3 (152 m)

Alternating green and violet, very thin-bedded volcaniclastic shales; purple, medium-bedded volcaniclastic sandstones, green, very thin-bedded marly shales and silty marls, and purple, thin- and medium-bedded volcaniclastic silty sandstones with abundant crinoids, *Daonella lomelli* Wissmann (Fig. 3B-C, G-I) and the ammonoids *Megaphyllites* sp., *Arpadites* cf. *szaboi* (BOECKH), and *Romanites simionescui* Kittl [14, 15]. The ammonoid assemblage suggests a Late Ladinian to Early Carnian age for the formation. Trace fossils are represented by *Chondrites*? and *Paleophycus* [19]. 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.

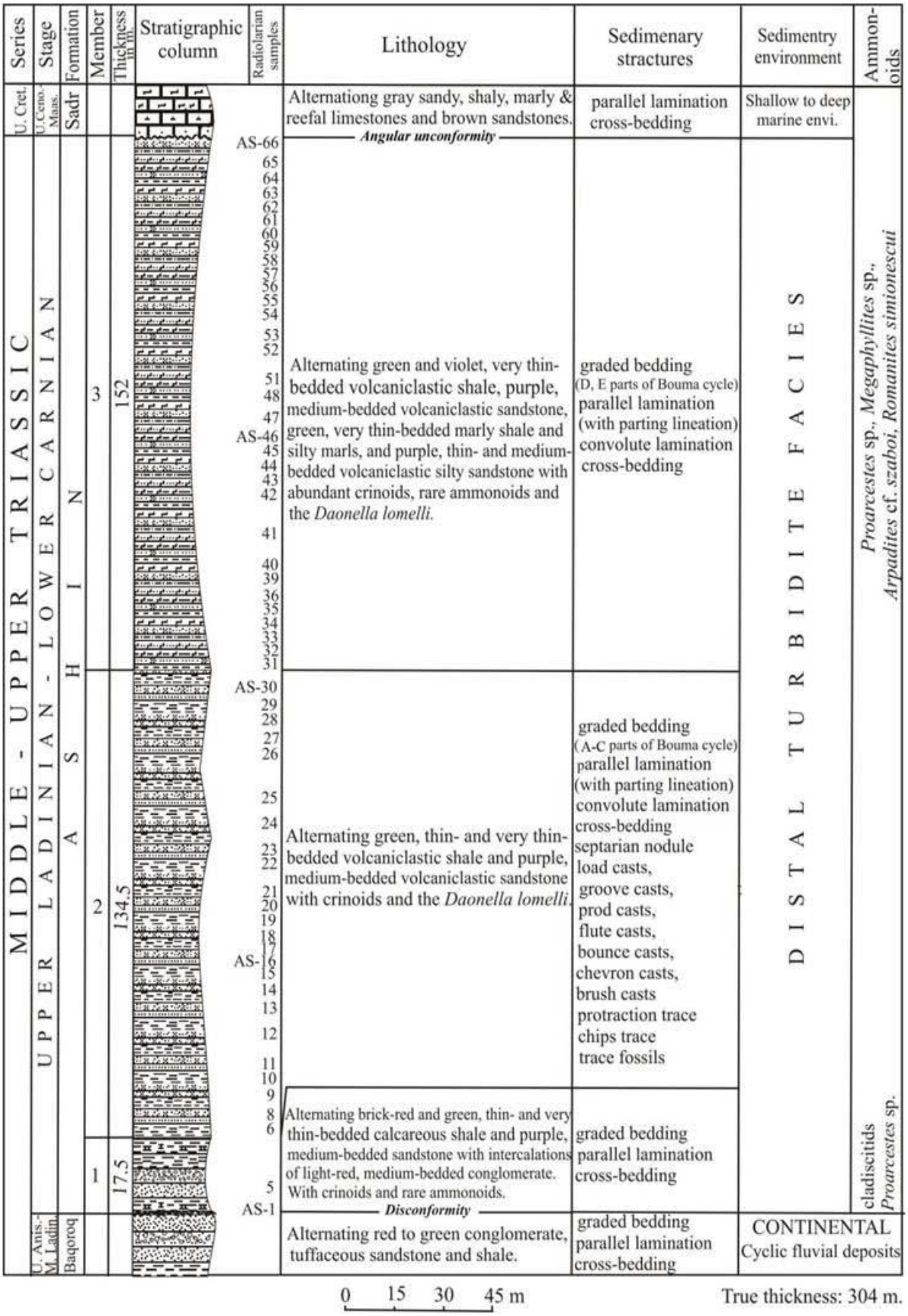

Fig. 2. Lithologic and environmental characteristics of the Ashin Formation in the Nakhlak area, Central Iran.

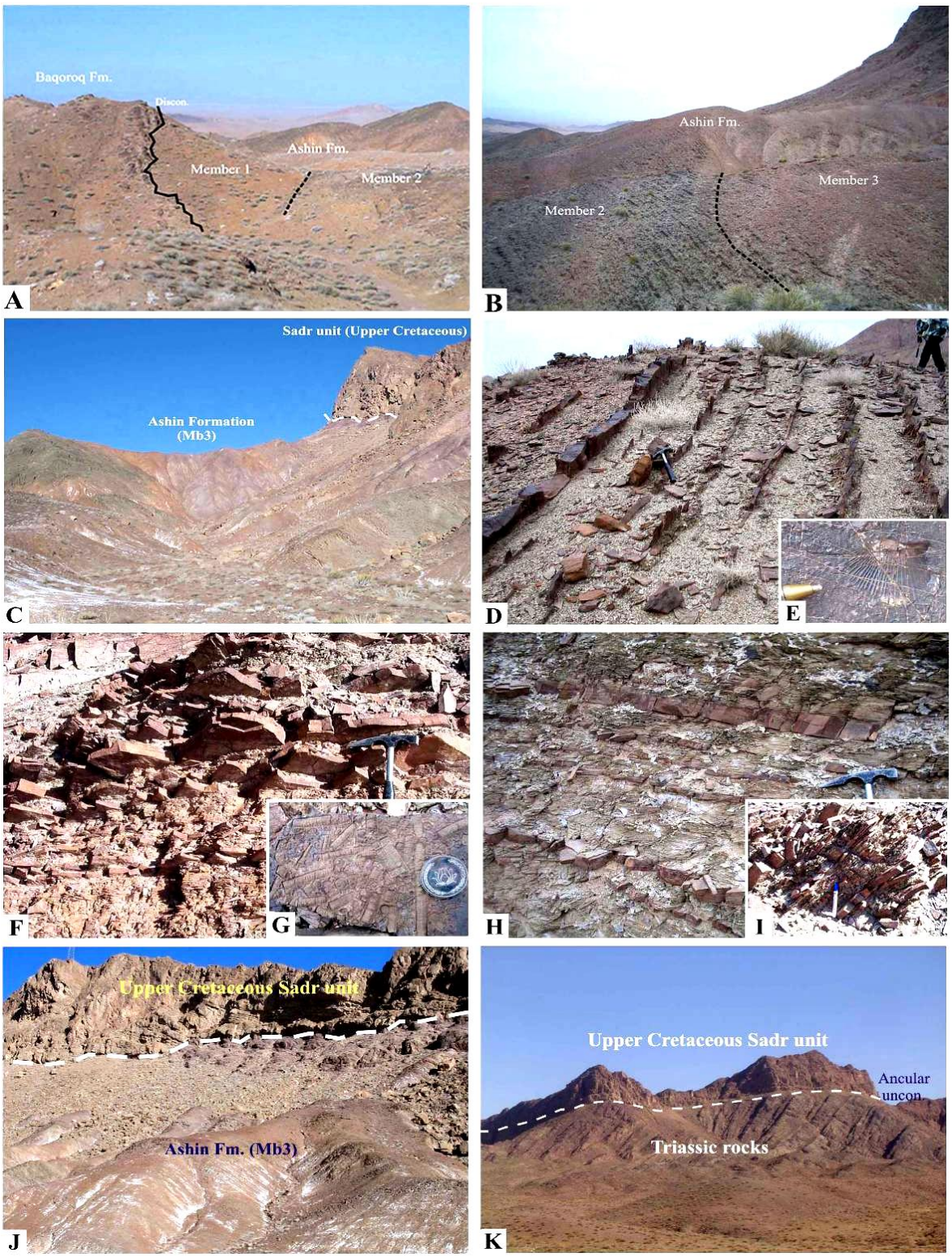

Fig. 3. (A) Contact between the Baqoroq Formation and the Ashin Formation, member 1 and base of member 2. (B) Alternating volcaniclastic sandstones and shales in members 2 and 3 of the Ashin Formation. (C) Member 3 of the Ashin Formation and its unconformity contact with the Upper Cretaceous Sadr unit. (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. (J) Contact between the Ashin Formation (Mb3) and Upper Cretaceous Sadr unit. (K) Angular unconformity between the Triassic and Upper Cretaceous rocks in the Nakhlak area, Central Iran.

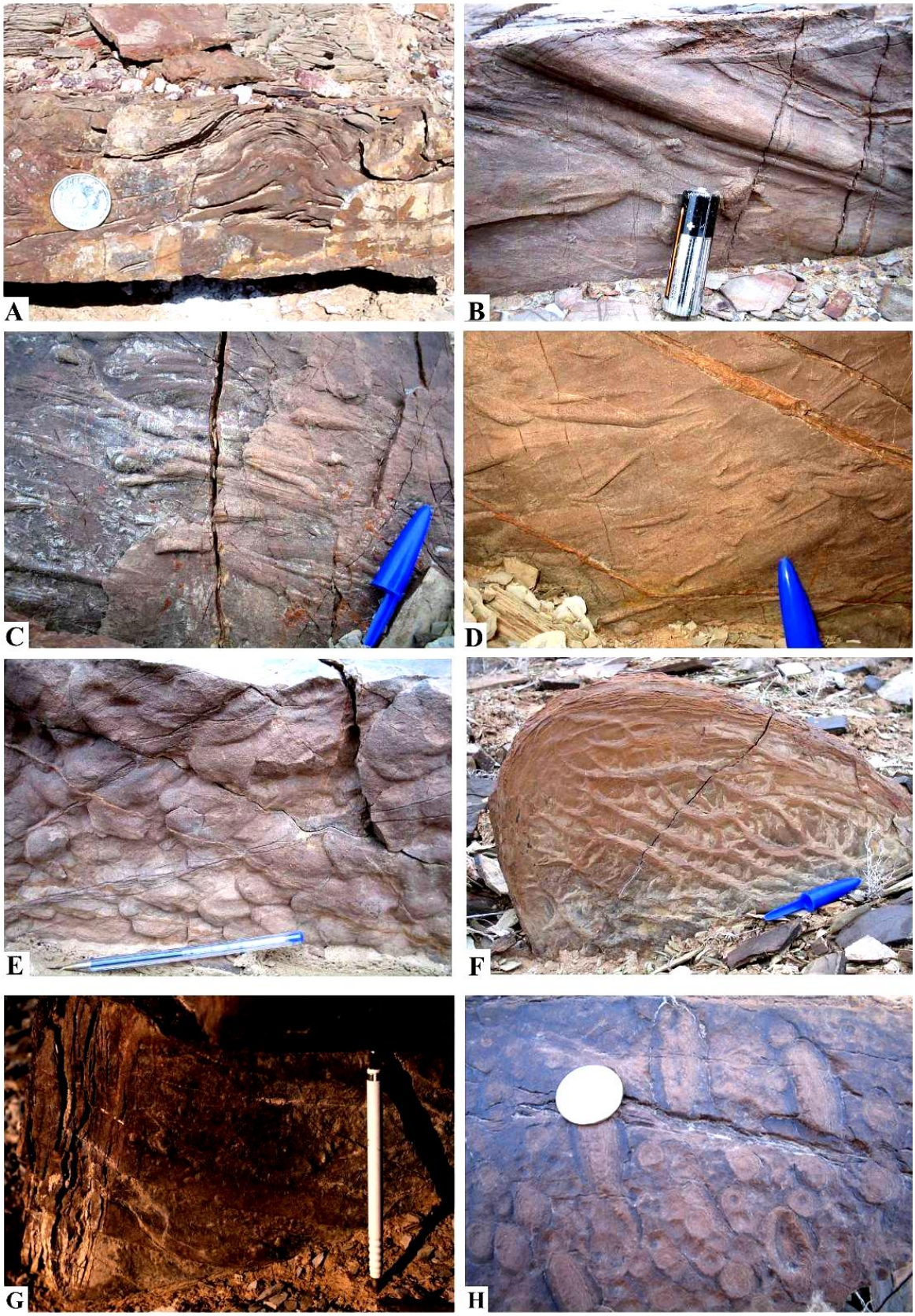

Fig. 4. Some sedimentary structures in volcaniclastic sandstones of member 2 of the Ashin Formation include convolute bedding (A), groove casts (B), tool marks and flute casts (C), prod marks and bounce casts (D), load casts (E), septarian nodules (F), Burrowing (G), and concretion (H).

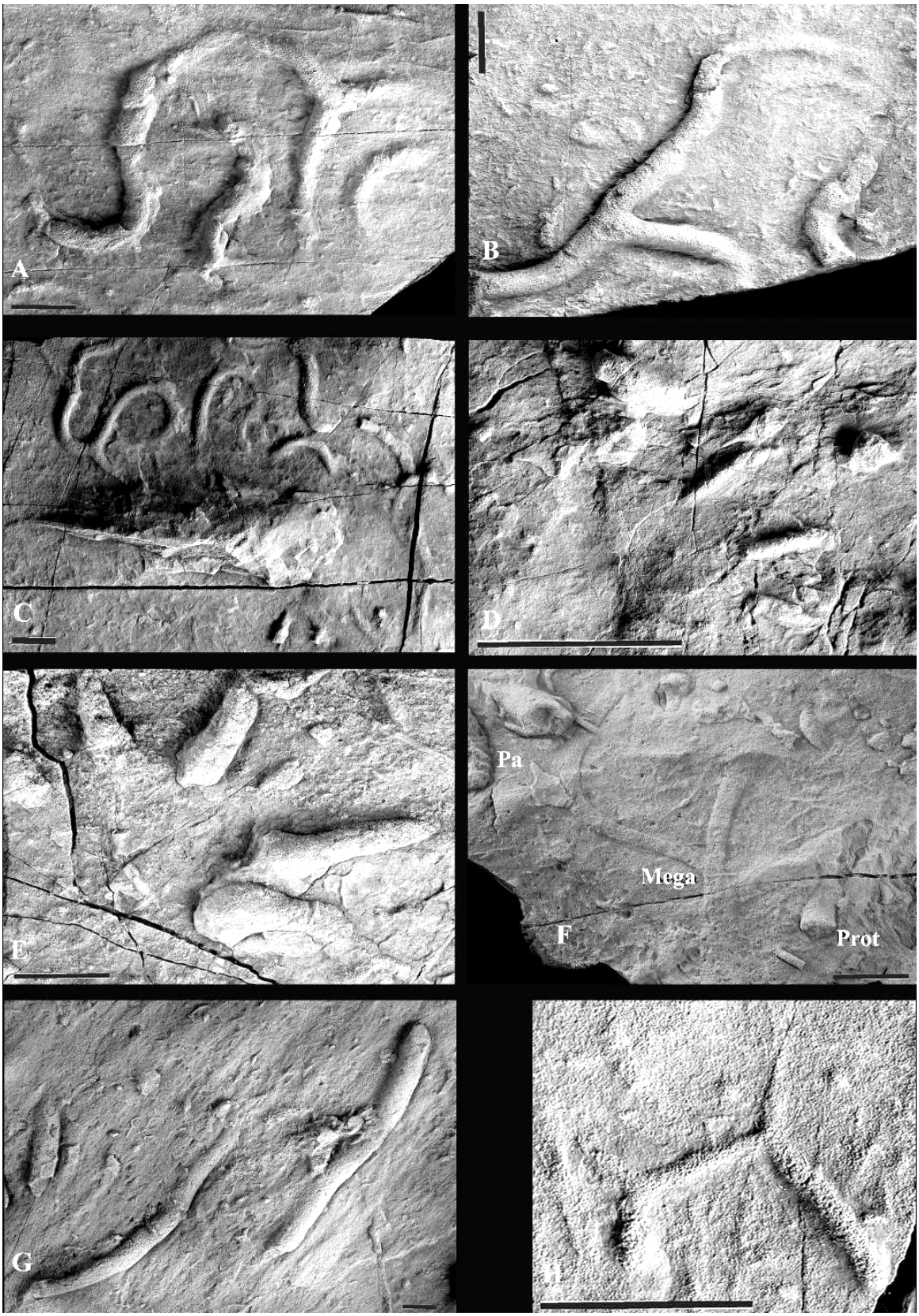

Fig. 5. (Scale bars: 1 cm.) Ichnofossils from the lower surfaces of sandy turbidites of the Ashin Formation (after Vaziri and Fürsich [19]) (A, B) Protopaleodictyon isp. (C) Protopaleodictyon incompositum KSIĄŻKIEWICZ (D) Lorenzinia isp. (E) Lorenzinia nowaki (KSIĄŻKIEWICZ) (F) Megagrapton isp. (Mega), Protovirgularia isp. (Prot) and Paleophycus isp. (Pa) (G) Paleophycus isp. (H) Washed-out relict of Paleodictyon cf. maximum

8. Sedimentary structures

The Ashin Formation as the youngest formation of the Nakhlak Group consists of thin to very thin-bedded turbidite alternations which fine upwards (dominantly volcaniclastic sandstone and shale) and exhibits some sedimentary structures. The alternations of member 1 of Ashin Formation become finer-grained up-section and have sedimentary structures such as graded bedding, parallel lamination, and cross-bedding.

The alternations of member 2 are fining 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, brush casts, burrowing and chips and protraction traces (Fig. 4A-H) indicating A to C parts of the Bouma cycle. Septarian nodules occur repeatedly. In member 3, the alternations become very fine-grained and thin-bedded up-section, and exhibit sedimentary structures such as parallel lamination with parting lineation, convolute bedding, and cross-bedding indicating D and E parts of the Bouma cycle.

9. Facies and sedimentary environment

The Ashin Formation consists of shaly, calcareous and sandstone facies. Microfacies studies were carried out on calcareous and sandstone facies. The Shaly facies of the Ashin Formation are pelagic argillaceous sediments that occur in the upper part of turbidite fine-grained sedimentary cycles. The most important microfacies include allochemical-microcrystalline limestone and lithic-arenite facies (Fig. 6A-D). For classification purposes the concepts of Folk [8] have been used for siliciclastic facies (especially sandstones) and those of Dunham [6] and Flügel [7] for carbonate facies.

9.1 Allochemical - microcrystalline limestone

This facies consists of abundant calcareous and detrital grains (quartz, feldspar) with ferric pigments and opaque minerals (less than 10%). It also has sponge spicules and radiolarians which occur in a fine-grained calcspar matrix. This facies has sparse fabric and shows sedimentation in a quite environment (Fig. 6A, B). Types of calcareous grains indicate deep and open marine (abyssal plain) environment. This facies has two sub-facies: micrite and sandy-biomicrite which includes abundant shell fragments compacted in a microcrystalline matrix.

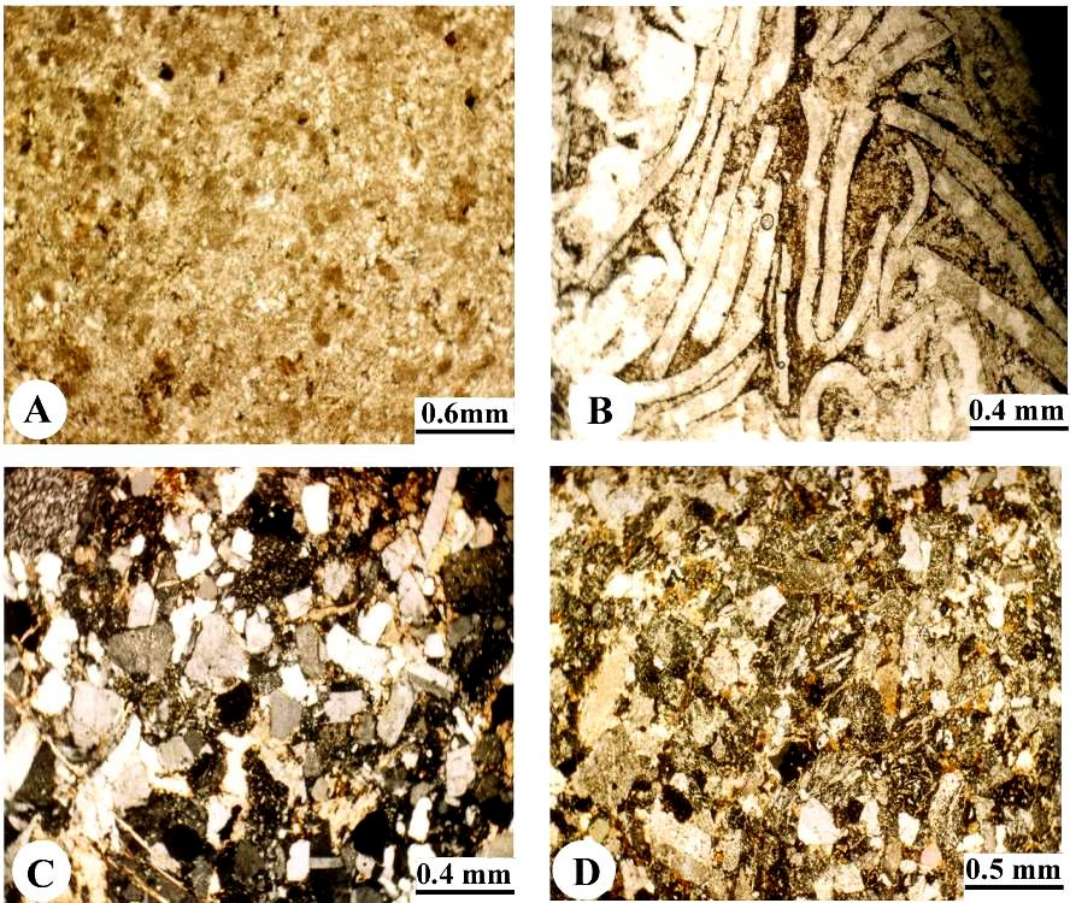

Fig. 6. (A) Allochemical-microcrystalline limestone. (B) Allochemical-microcrystalline limestone (bio-micrite sub-facies). (C) Lithic- arenite facies with iron oxide (D) Lithic-arenite facies with tuffaceous grains.

9.2. Lithic-arenite facies

This facies consists of quartz (7.5 to 55%), feldspar (1.5 to 2.5%), lithoclasts (20 to 68%) and ferric and opaque minerals. The lithoclasts of facies include meta-quartz, mica-schist and tuffaceous (35%) and cherty (5%) grains (Fig. 6). Feldspars include mainly orthose and lesser plagioclase. The clastic grains are very fine and their average diameter is 0.18 mm. They have a mature texture and calcite cement (rarely argillaceous cement) that is inoculated with hematite (Fig. 6C, D).

Lateral extension and vertical relation of beds and the sedimentary structures indicate fine-grained siliciclastic distal turbidite sediments. Wide lateral extension of beds, graded bedding, parallel lamination (with parting lineation), convolute bedding, small-scale cross-bedding, slumping, load casts, groove casts, prod casts, flute casts, bounce casts, chevron casts, brush casts, chips and protraction traces, and A to E parts of the Bouma cycle indicate that the Ashin was deposited in the distal parts of submarine fans, on the abyssal plain by turbidite currents (Fig. 9). The study of calcareous facies of Ashin Formation shows that these facies were formed in the abyssal plain. They formed when the entry of detrital material and spreading of fans were stopped and normal conditions for deposition of carbonates were established.

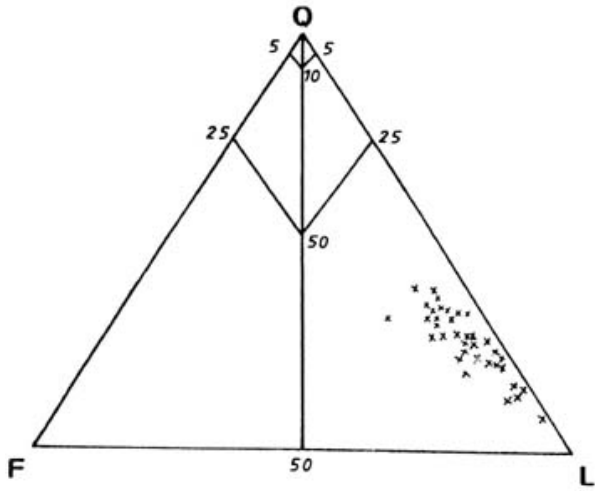

Fig. 7. Situation and compact place of sandstones (Lithic-arenite facies) of the Ashin Formation in method of Pettijohn et al. [9].

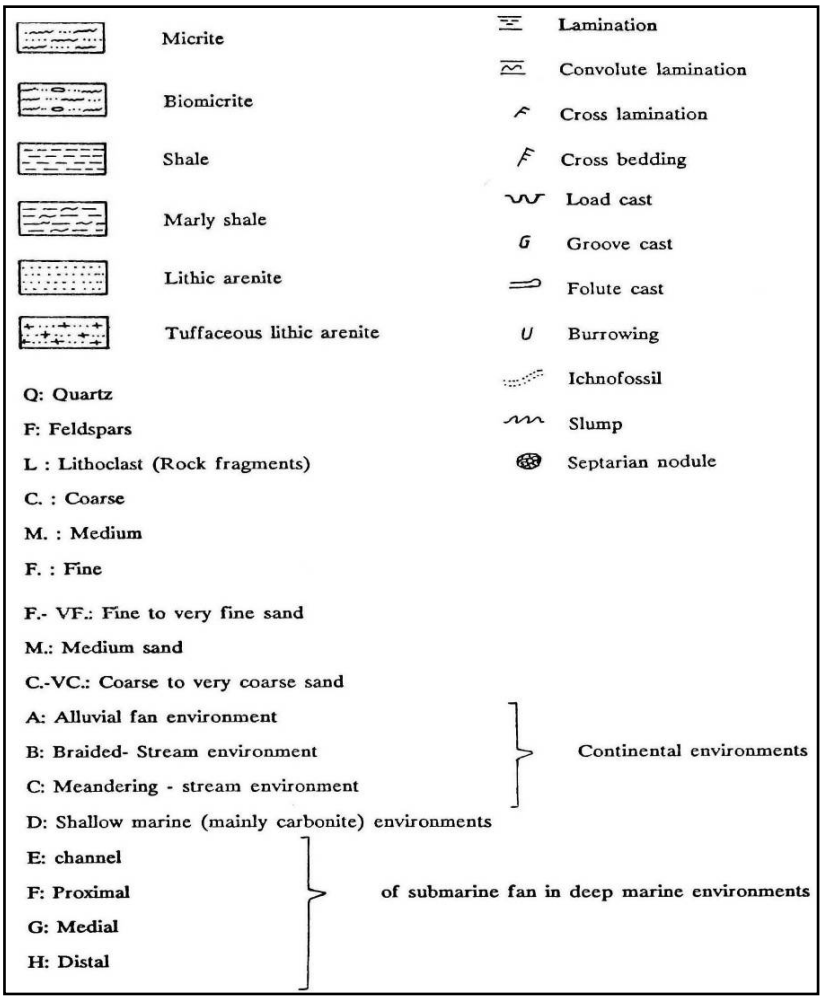

Fig. 8. Key of symbols

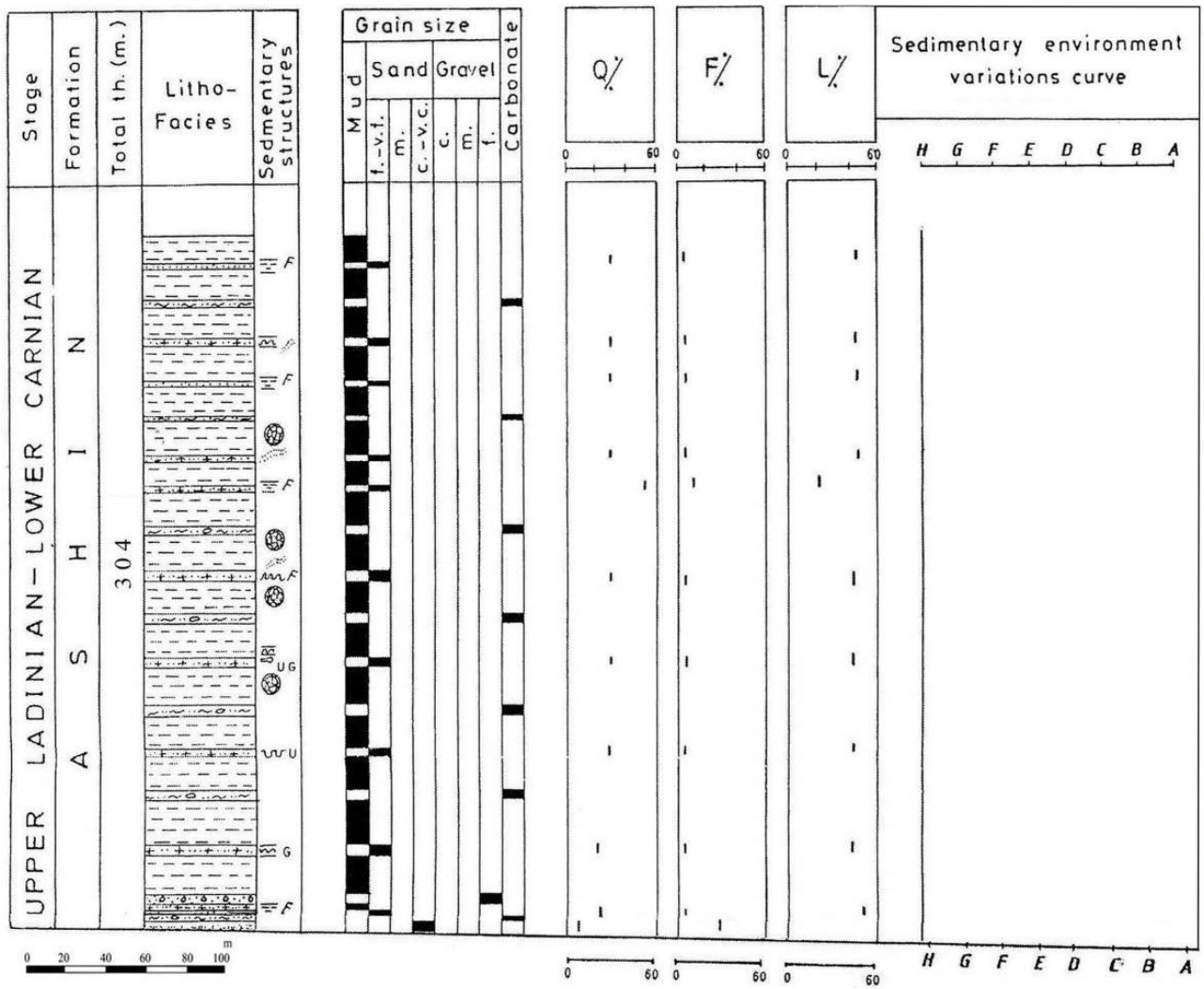

Fig. 9. Sedimentary succession, changes in grain size, distribution and components of lithofacies, and variations curve of sedimentary environment of the Ashin Formation (for key of symbols see Fig. 8).

10. Conclusions

- The Ashin Formation with a thickness of 304 meters consists of alternating thin- and medium-bedded calcareous sandstones, purple, fine-grained volcaniclastic sandstones, and mostly green and violet, very thin-bedded volcaniclastic shales. They include allochemical-microcrystalline limestone, shaly and lithic-arenite facies. 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, brush casts and chips and protraction traces indicating A to E parts of the Bouma cycle. Septarian nodules occur repeatedly.
- The lower surfaces of sandstones contain abundant trace fossils belong to the deep-sea *Nereites* ichnofacies. Numerous signs of strong current activity such as groove casts, flute casts and prod marks associated with trace fossils such as *Paleodictyon*, *Protopaleodictyon*, *Megagrapton* and *Lorenzinia* (Fig. 5) indicate that the Ashin Formation represents a deep marine environment.
- The field and petrographic studies show that the Ashin Formation was deposited in distal parts of submarine fans, on the abyssal plain.

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