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Late Devonian Fish micro-remains from Central Iran

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Abstract
Well exposed Famennian, mainly carbonate rocks of the Bahram Formation in the vicinity of Bagher Abad village, Central Iran, yielded chondrichthyan teeth some sarcopterygii and actinopterygii teeth and fragments. Three different genera were recognized among the chondrichthyan teeth represented by: *Phoebodus turnerae*, *Ph*. spp., *Deihim mansureae* (M2, M3), *Stethacanthus* sp.. Acanthodian and sarcopterygians teeth and fragments include: Dipnoi *indet.*, Onychodonthid tooth?, Osteichthyes bone and Paleonisciformes *indet*. This assemblage recovered from a shallow shelf environment on the northern margin of Gondwana during Late Devonian time.

Keywords: *Fish micro remains, Famennian, Shallow shelf, Central Iran.*

Introduction

Iranian platform was a part of northern Gondwana margin during Late Devonian time (Li *et al.,* 1993). It was situated in a tropical realm close to the southern tropic. At the middle Devonian sea level rise and caused flooding of large parts of Iranian platform (Wendt *et al.,* 2005). About 1200 m of carbonate and siliciclastic sediments were deposited over this area. The Bahram Formation is a part of these sequences where extended from southeastern Iran and western to eastern Central Iran. Devonian strata (Bahram Formation) in Isfahan province (Central Iran) were first studied by Djafarian and Brice (1973) who found Upper Famennian brachiopods in the Kaftari and Zard Mountains. After that several authors studied Devonian sequences in the area by biostraigraphy of conodonts, brachiopods and trilobites. The studied and dated sections in the area are as: Zefreh and Chahriseh sections (Zahedi, 1976; Hamedani, 1996; Mistiaen *et al*., 2000; Ghavidel-Syooki, 2001b; Morzadec, 2002; Gholamalian, 2003, 2007; Kebriaie, 2003), and Soh section (*e.g.,* Long & Adhamian, 2000; Adhamian, 2003). Fish micro-remains were first reported from the Upper Devonian sedimentary sequence of the Chahriseh region by: Hairapetian and Gholamalian (1998). Further investigations provided additional more diverse vertebrate material from these areas (Turner *et al*., 2002; Hairapetian *et al*., 2006, 2008; Hairapetian & Ginter, 2009). Habibi *et al*., (2012) reported the presence of fish micro-remains from the Bagher Abad section.

Geological setting

The Bagher Abad section is located 2 km east of Bagher Abad village and 60 km northeast of Isfahan (N 33º 3′ 57.1″, E 52º 2′55.5″) on the northeastern flank of Lamar Mountain (Fig. 1).The area constitutes the western sector of the Central Iranian structural zone and is confined to the east of the Zagros Range. Several faults have distributed the rock sequences of the area, acting as horst and graben structures, resulting in Paleozoic sediments being found adjacent to Triassic deposits (Fig. 1). The oldest rock until exposed in Bagher Abad area is a series of sandstone, dolomite, limestone and dolomitic limestone dated as Permian in Ardestan quadrangle (Radfar, 1999). After reconnaissance through these strata, the recovered fauna including: spiriferid brachiopods (*e.g*., *Cyrtospirifer* sp.), echinoids, bryozoans,... clarified the age of the lower part of these strata as Devonian. The results of this study allow us to separate Devonian and Permian sequences in Bagher Abad area. In this area Permian deposits (Jamal Formation) disconformably overlaie on Devonian sediments (Fig. 1). Devonian deposits in the area are equivalent to Bahram Formation in other parts of Iran. The base of Bahram Formation in the Central Iran Basin is diachronous, dated as Eifelian in Zefreh (Brice *et al*., 2006) and Howz-e-Dorah (Wendt *et al*., 2005), Early Givetian in Soh (Adhamian, 2003), Late Givetian in Hojedk

(Gholamalian & Kebriaei, 2008), Givetian in Neqleh section (Tabatabie & Yazdi, 2010) and Early Frasnian in Chahriseh (Turner *et al*., 2002). But it is younger in Bagher Abad section and dated as Famennian (this paper). It seems it can be related to the act of the faults which has been considered later.

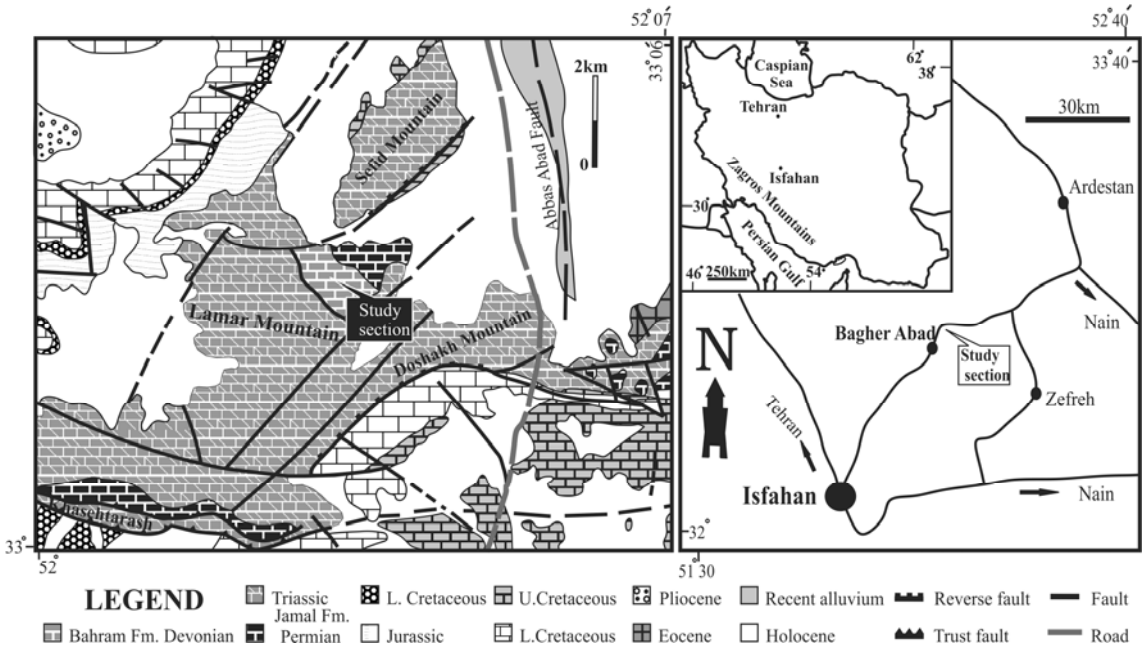

Figure 1: Geological map of the study area (simplified and modified after Radfar, 1999).

Two levels of biostromes, consisting mainly of tabulate and rugose corals (Mistiaen, 1999; Rohart, 1999; Brice *et al*., 1999) are diachronously exposed at the base of Bahram Formation in several sections in Central and Eastern Iran (*e.g*., Hojedk, Chahriseh, Ozbak-Kuh), but these levels were not encountered in Bagher Abad section.

Bahram Formation is disconformably overlain by oolithic and sandy limestones of Jamal Formation. A few meters red clay level is observed between Bahram and Jamal Formations in Bagher Abad section (Fig. 2-1). This erosional surface is reported from several localities in Central Iran and Alborz structural subzones (*e.g*., Wendt *et al*., 2002, 2005; Gholamalian, 2007). This phenomena may have resulted from deformation originated in an early pre-subduction compressional phase along the northern Gondwana margin of paleotethys (outer margin of Cimmeria) before rifting started in the Middle Permian (Sharland *et al*., 2001; Ruban *et al*., 2007).

Startigraphic succession and methods

The base of the Bahram Formation in Bagher Abad section begins with grey to red dolomitic limestone alternating with a few beds of grey limestone, dolomite and red sandstone containing fish micro-remains, conodont elements, brachiopods, sponge spicules, ostracods, echinoids and bryozoans (Fig. 2-2). The middle and upper parts of the succession comprises thin bedded grey limestones and medium to thick bedded grey limestone with gastropods, echinoids, brachiopods, sponge spicules and fish micro-remains (Figs. 2, 3). 34 samples were acid leached in order to recover conodont elements and fish micro-remains. Only one conodont element recovered from sample No. 7 but diverse fish micro-remains fauna was recovered mainly from lower part of the succession. The fish micro-remains fauna consists of chondrichthyan teeth and scales and some scales, teeth and fragments of sarcopterygii and actinopterygii (Fig. 4). The association is not well preserved. Most of the shark teeth are broken or abraded. This being the case, only their presence in the studied section is documented without much conclusion. Materials are hosted in Department of Earth Sciences, Shiraz University, 71454, Iran, under acronym SUIC.

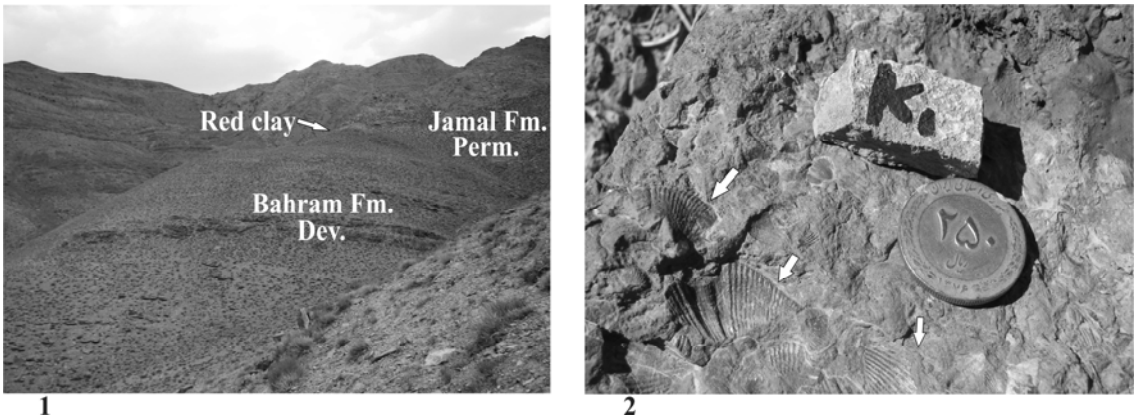

Figure2: Selected views of the study section. 1. View of Bagher Abad section showing Bahram and Jamal formations and red clay level at the top of Bahram Formation. 2. Brachiopod bearing bed at the lower part of the Bahram Formation (sample no. 2).

Systematic Paleontology

Class Chondrichthyes Huxley, 1880
Subclass Elasmobranchii Bonaparte, 1838
Order Pheobodontiformes Ginter, Hairapetian and Klug, 2002
Family Phoebodontidae Williams in Zangerl, 1981
Genus *Phoebodus* St. John and Worthen, 1875
Type species. *Phoebodus sophiae* St. John and Worthen, 1875

***Phoebodus turnerae* Ginter and Ivanov, 1992**
(Fig. 4-1)

1992, *Phoebodus turnerae* sp. nov.; Ginter and Ivanov, p. 68–70, figs 6B–C, 8A–H.
1995, *Phoebodus turnerae* Ginter and Ivanov. Ginter, fig. 4C.
1999, *Phoebodus turnerae* Ginter and Ivanov. Ginter and Turner, fig. 3H–I.
2000, *Phoebodus turnerae* Ginter and Ivanov. Ginter and Ivanov, p. 328, pl. 2, fig. A.
2002, *Phoebodus turnerae* Ginter and Ivanov. Ginter *et al*., text-fig. 6A–C.
2005, *Phoebodus turnerae* Ginter and Ivanov. Derycke, p. 63–64, pl. V, figs 1–2.
2009, *Phoebodus turnerae* Ginter and Ivanov. Hairapetian and Ginter, text- fig. 6F–H.
2010, *Phoebodus turnerae* Ginter and Ivanov. Hairapetian and Ginter, text- fig. 4F.
2011, *Phoebodus turnerae* Ginter and Ivanov. Ginter *et al.,* text-fig. 6J, K.

Material. One specimen from sample 8.

Description. The single tooth of *Ph. turnerae* from Bagher Abad is fairly complete. Tooth has a main cusp with two pairs of lateral cusps slightly arched lingually. Tooth has weak subparallel cristae on both sides (probably the result of abrasion) and a large oval button. The base has a lingually narrowing pentagonal shape. The large prominent button is located close to the lingual rim typical of the species. The main channel is located bellow the button slightly transferred to the lateral side. There are several foramina near the lingual rim and base.

Remarks. The speciemen from Bagher Abad is very similar to teeth of *Ph. turnerae* from *rhomboidea* and *marginifera* Zones of Ryauzyak, south Urals (Ginter & Ivanov, 1992; fig. 8A-C, G) and the tooth from Dalmeh, Central Iran (Ginter *et al*., 2002; text-fig. 6A-C). The teeth from Bagher Abad and Ryauzyak lack coarse striations on the cusps, but this is probably a matter of preservation. *Ph. turnerae* is already recorded from the Lower to Middle Famennian of the Chahriseh section (Hairapetian & Ginter, 2009; text-fig. 6F-H), and Kale Sardar section, Central Iran (Hairapetian & Ginter, 2010; text-fig. 4F). The Chahriseh specimens are of different sizes and show a wide base. The Kale Sardar specimen differs from our tooth in having a lingually narrowing pentagon base and only a large canal opening just below the button.

Stratigraphic range. Early to Middle Famennian (Early *crepida* through Late *marginifera* Zones) (Hairapetian & Ginter, 2010).

***Phoebodus* sp. 1**
(Fig. 4-2)

Material. One specimen from sample 1.

Description. Tooth contains five broken cusps. They are slightly arched lingually. Weak subparallel cristae observed on the both side of the cusps. Lateral denticles close to the main cusp are

much smaller than the others. Base and button are broken.

***Phoebodus* sp. 2**

(Fig. 4-4)

Material. One specimen from sample 18.

Description. Tooth has three main cusps. Only one of the lateral cusps is well preserved. Strong subparallel cristae ornamented the outer side of the cusps. Lingual side of the base is broken.

Remarks. Ginter *et al*., (2002; pl. 3, figs. D-G) described some tricuspid teeth with equal basal length and width and some other features as *Ph.* aff. *turnerae* as a transitional form between *Ph. turneare* and *Ph. gothicus,* from Mighan section, Iran. But at this case the base is broken.

***Phebodus* sp. 3**

(Fig. 4-5)

Material. One specimen from sample 17.

Description. The main and lateral cusps of this specimen are broken and rounded in cross section. It has a long lingually narrowing base with a rounded outline. There is a large canal opening, just below the button. The labio-lingual length of the base makes it similar to *Ph. gothicus*, but the button covers the whole base. However it resembles a juvenile tooth.

Order Symmoriiformes Zangrel, 1981

Family Stethacanthidae Lund, 1974

Genus *Stethacanthus* Newberry, 1889

Type species. *Physonemus altonensis* St. John and Worthen, 1875

***Stethacanthus* sp.**

(Fig. 4-6)

Material. One specimen from sample 12.

Description. This specimen has cladodont-type crowns. It is five cusped, with the lateral cusps being much smaller than the central one. Main cusp arched lingually. The only preserved lateral cusp is nearly straight and rounded in cross section. Strong longitudinal cristae are visible on the central and lateral cusps. The main cusp is elliptical in cross section. The base is quadrate – shaped in plan view and has numerous small foramina.

Remarks. Most stethacanthid teeth from Iran have five cusps, varied from slender cusps (*e.g*., Dalmeh section; Long & Hairapetian, 2000; figs. 4e, g, k) to slightly thicker and shorter cusps, like in protacrodonts (*e.g*., Hutk section; Ginter *et al*., 2002; pl. 1, figs. O-Q). The Bagher Abad specimen has a higher central cusp than the Hutk stethacanthid and a thicker central cusp than the Dalmeh teeth. It is rather similar to the stethacanthid teeth from the Late Famennian of Morocco (Ginter *et al*., 2002; pl. 10, figs. A-D).

Cohort Euselachii Hay, 1902

Superfamily Protacrodontoidea Zangerl, 1981

Family Protacrodontidae Cappetta, Duffin and Zidek, 1993

Genus *Deihim* Ginter, Hairapetian and Klug, 2002

Type species. *Deihim mansureae* Ginter, Hairapetian and Klug, 2002

2000, ?*Protacrodus* sp.; Long and Hairapetian, p. 217–218, fig. 4o.

2000, *Protacrodus* sp. cf. "*P. aequalis*" sensu Ginter and Turner. Yazdi and Turner, p. 226, fig 3: 4-7, 4.4 [non fig. 3. 8-10 = *Protacrodus* sp.]

2002, *Deihim mansureae* gen. *et* sp. nov; Ginter *et al*.. p. 191–193, text-fig. 10; pl. 1, fig. R; pl. 2, fig. K; pl. 4, figs F–G, J–M; pl. 5, figs A–M.

2005, Polyacrodontidae *insertae sedis*; Derycke, p. 76, pl.VII, figs 7–10.

2005, *Bobbodus* sp.; Derycke. p. 95–96, pl. XII, Figs 1–2.

2009, *Deihim mansureae* Ginter *et al*., Hairapetian and Ginter, text-figs 2D, 4H.

2010, *Deihim mansureae* Ginter *et al*., Hairapetian and Ginter, text-fig. 3A.

2011, *Deihim mansureae* Ginter *et al*., Ginter *et al*., text-figs. 8A-E, 11C.

***Deihim mansureae* Ginter, Hairapetian and Klug, 2002**

(Figs. 4-7, 9)

Material. Three specimens from samples 7, 8, 17.

Description. Ginter *et al*., (2002) introduced the new genus and species *Deihim mansureae* for sharks with clutching-crushing teeth whose crown

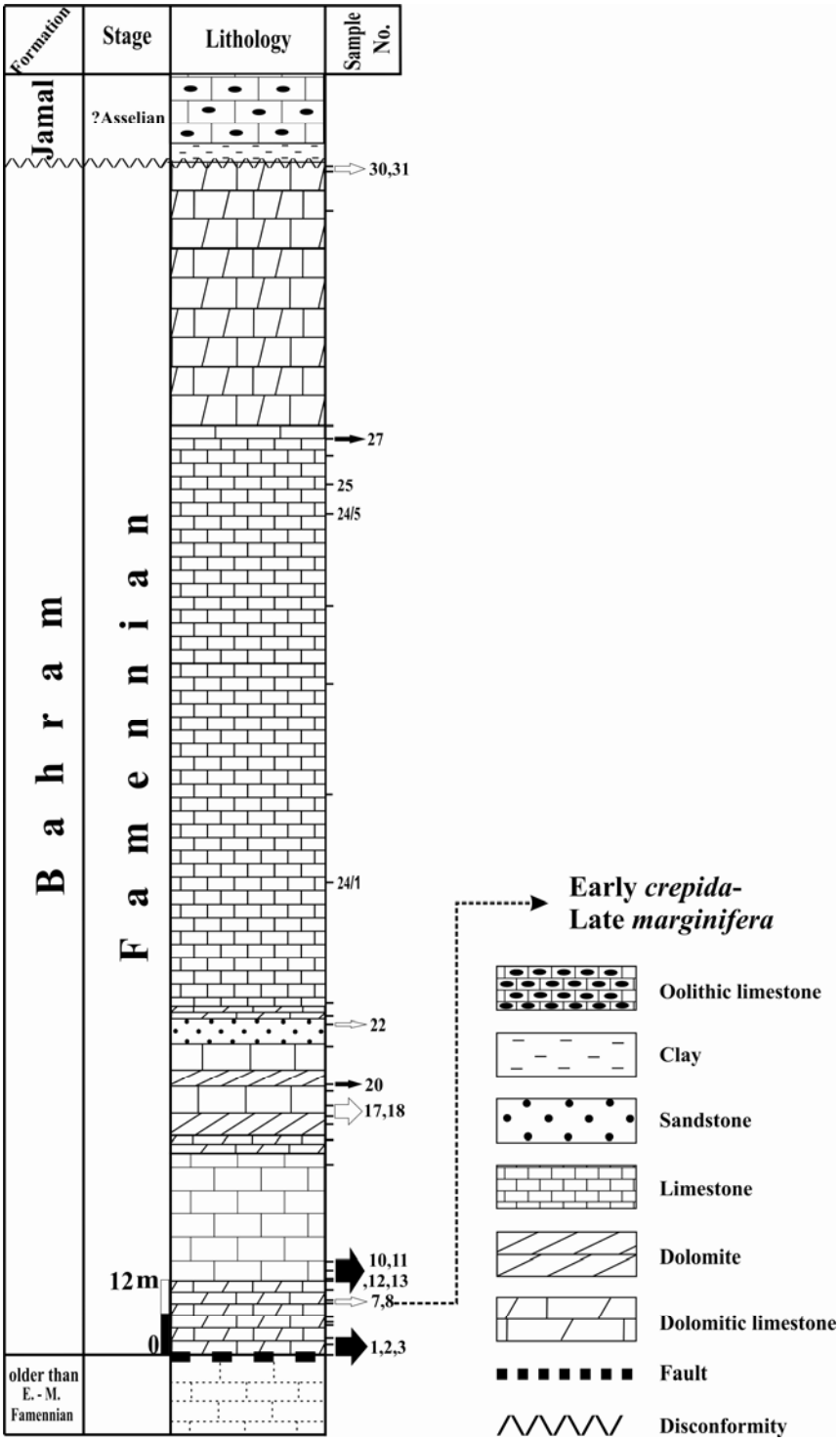

Figure 3: Lithology and stratigraphical column of Bagher Abad section showing fish-bearing horizons.

have a row of additional small cusplets just above the crown-base on the labial side. *Deihim mansureae* Morphotype 2 is characterized by a central cusp and three pairs of lateral cusps and more elongated mesio-distal side. Central lateral cusp is slightly curved lingually. Strong cristae are evident on the lingual, and rarely on the labial side. Five additional cusplets occur just above the crown-base interface on the labial side. Numerous perforations occur on the occlusal–lingual side of the base (Fig. 4-7). In *Deihim mansureae* Morphotype 3, no obvious size differences is seen between the teeth. The crown is asymmetric and the right lateral cusp is the largest. The size of

additional cusplets is smaller toward the larger cusps. Some weak cristae occur on the lingual and labial side. Several opening can be seen on the lingual side of the base (Fig. 4-9).

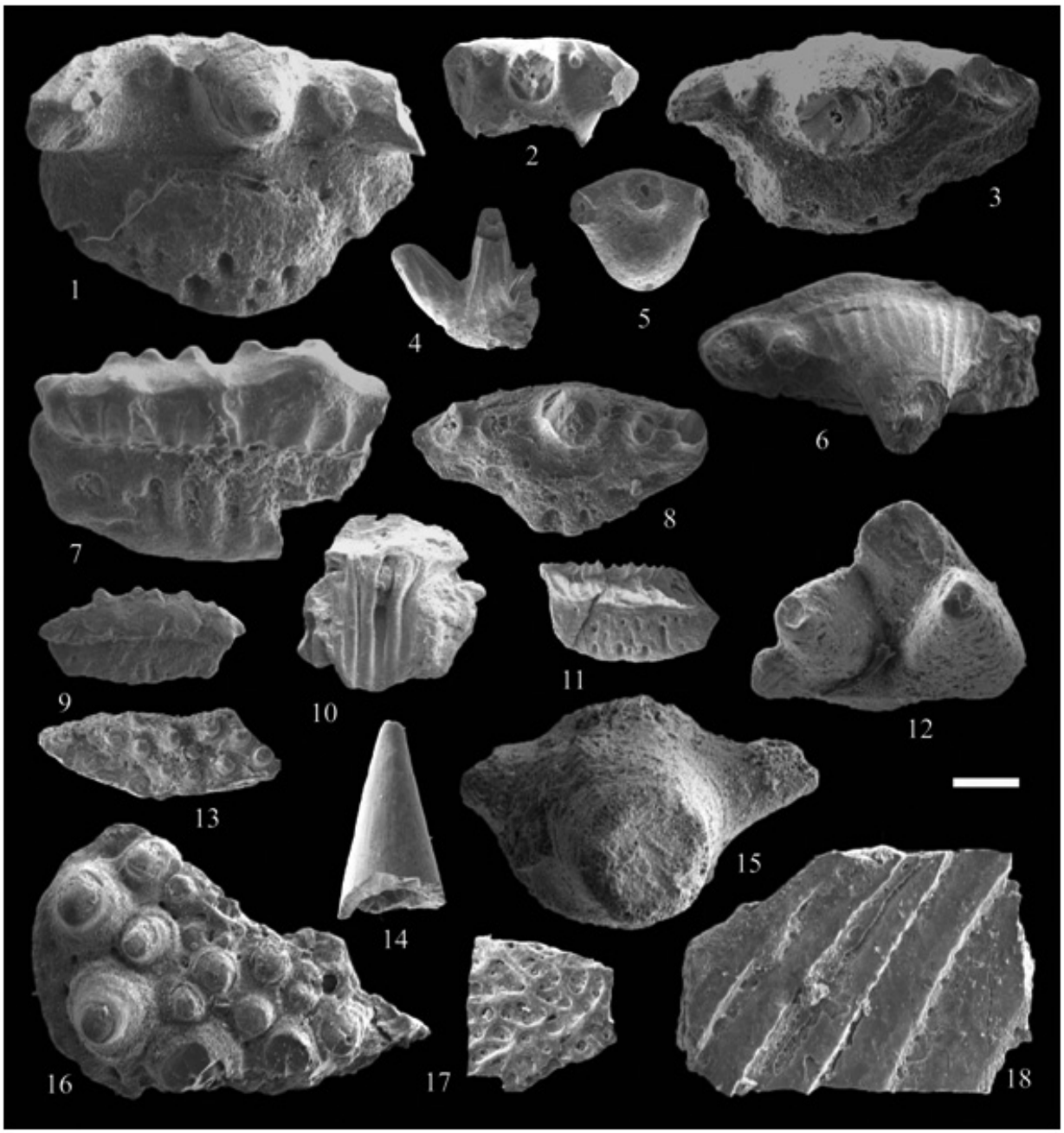

Figure 4: Fish micro-remains from the Bagher Abad section: 1. *Phoebodus turnerae* Long and Hairapetian 2000, SUIC 9115, sample 8, occlusal–lingual view. 2. *Phoebodus* sp. 1, SUIC 9106, sample 1, occlusal view. 3. Cladodont *indet.*, SUIC 9117, sample 17, occlusal view. 4. *Phoebodus* sp. 2, SUIC 9118, sample 18, labial view. 5. *Phoebodus* sp. 3, SUIC 9116, sample 17, occlusal–lingual view. 6. *Stethacanthus* sp., SUIC 9112, sample 12, occlusal view. 7. *Deihim mansureae* Ginter *et al*., 2002, SUIC 9109, (M2), sample 17, occlusal view. 8. Ctenacanthidae *indet*. SUIC 9119, sample 7, occlusal view. 9. *Deihim mansureae* Ginter *et al*., 2002, SUIC 9108, (M3), sample 7, occlusal-lingual view. 10. Ctenacanthus-type scale, SUIC 9105, sample 1, crown view. 11. Euselachii *indet*. SUIC 9111, sample 30, occlusal-lingual view. 12. Undefined, SUIC 9107, sample 1, occlusal view. 13, 16. Dipnoi *indet*., tooth plate, 13- SUIC 9101, sample 2, crown view, 16- SUIC 9102, sample 10, crown view. 14. Onychodontid tooth?, SUIC 9110, sample 12, lateral view. 15. Undefined, SUIC 9114, sample 27, occlusal view. 17. Osteichthyes, bone, SUIC 9103, sample 12, crown view. 18. Palaeonisciformes *indet*. scale, SUIC 9104, sample 12, crown view. Scale bar equal to 500µm.

Remarks. The *Deihim mansureae* Morphotype 2 from Bagher Abad resembles tooth holotype of *D. mansureae* Ginter *et al*., 2002, Morphotype 2 (figs. 10A-C), but central cusp is less prominent and

additional small cusplets are shorter (probably the result of abrasion). It is reported from Hojedk and Hutk sections (Ginter *et al*., 2002) and Chahriseh section (Hairapetian & Ginter, 2009). In contrast to the *Deihim mansureae* Ginter *et al*., 2002 Morphotype 3, the labio – lingual/mesio-distal dimension ratio is equal in Bagher Abad specimen. The teeth assigned to *Deihim mansureae* Morphotype 2 are positioned intermediately in the antero-lateral parts of the jaw and *Deihim mansureae* Morphotype 3 occur in the most postero-lateral regions. Both Morphotype 2, Morphotype 3 are catching and crushing teeth (Ginter *et al*., 2002).

Stratigraphic range. Ginter *et al*., (2002) suggested the age of Famennian (*crepida*-Early *expansa* Zones) for *Deihim mansureae*, but Ginter *et al.*,(2011) extended the age from Upper Frasnian to Upper Famennian in Iran.

Euselachii *indet.*

(Fig. 4-11)

Material. One specimen from sample 30.

Description. The base is lingually developed and displays multiple perforations. Crown consists of several unique cusps arranged in a straight row. It is narrowing labio-lingually. Strong cristae are observed on both lingual and labial sides of the crown. The lingual margins are straight.

Order Ctenacanthiformes Glikman, 1964

Family Ctenacanthidae Dean, 1909

Ctenacanthidae *indet*-tooth

(Fig. 4-8)

Material. One specimen from sample 7.

Description. Crown has a main cusp with two pairs of broken lateral cusps. Lingual margin is straight. Several perforations are observed on the base. At present the cusps are smooth but this is probably due to abrasion.

Cladodont indet.

(Fig. 4-3)

Material. One specimen from sample 17.

Description. The cladodont-type crown of this specimen has a high and thick central cusp. There are two pairs of the lateral cusps being smaller than the central one. Longitudinal cristae are observed on both sides. The large elliptical button is lingually developed and slightly moved sideward. The base shape and development is similar to that in *Phoebodus*.

Table 1: Distribution of chondrichthyan teeth and associated vertebrate micro-remains in the Bagher Abad section, Central Iran.

Taxa / Samples	1	2	3	7	8	10	11	12	13	17	18	20	22	27	30	31	TOTAL
Phoebodus turnerae					1												1
Ph. sp.1	1																1
Ph . sp.2											1						1
Ph . sp.3										1							1
Deihim mansureae (M2)					1					1							2
Deihim mansureae (M3)				1													1
Stethacanthus sp.								1									1
Euselachii *indet* .															1		1
Ctenacanthidae *indet* .				1													1
Cladodont *indet.*										1							1
Ctenacanthus type scale	1																1
Dipnoi *indet* .		1				1											2
Onychodonthid tooth?				1	2		1	2	1		2	2	1			4	16
Osteichthyes bone					2			1		1							4
Paleonisciformes *indet* .			1		3			1		1							6
unassigned	1						1							3			5
TOTAL	3	1	1	3	9	1	2	5	1	5	3	2	1	3	1	4	45

Remarks. Hairapetian and Ginter (2009; text-fig. 2G) described a tricuspid crown with a high central cusp and a base similar to that in *Phoebodus* from Middle *triangularis* - *crepida* Zones of the

Chahriseh section, Central Iran.

Class Osteichthyes Huxley, 1880
Subclass Sarcopterygii Romer, 1955
Order Dipnoi MÜller, 1845
Dipnoi gen. *et* sp. *indet.*
(Figs. 4-13, 16)

Materials. Two specimens from samples 2, 10.

Description. Teeth plate fragments are composed of several separated denticles of different sizes. Denticles are cone shape and are arranged irregularly. They are rounded in cross section. There are two fragments of this shape with similar characteristic, but the denticles in the larger one are bigger, and lateral space between denticles is smaller (Fig. 4-16). The outline of base cannot be determined with certainty, due to incomplete preservation.

Remarks. Some tooth plates of dipnoan fish were reported from *crepida* Zone, Early Famennian of Ertych section, Armenia (Ginter *et al*., 2011; text-fig. 9A-D). Ertych specimens are composed of some radiating denticulated ridges with each row consisting of separated denticles of varying sizes.

Chondrichthyan assemblages

Of all samples from the Famennian of Bagher Abad, sample 8 is the richest sample yielded an assemblage of chondrichthyan teeth, sarcopterigii teeth and scales and actinopterigii scales. The most important species within this sample include: *Ph. turnerae* and *D. mansureae,* suggest a time span from the Early *crepida* to Late *marginifera* Zones. This sample represents the contemporaneous occurrence of *Ph. turnerae* and *D. mansureae*. The synchronous presence of these species have been reported from Lower to Middle Famennian of Dalmeh, Central Iran (sample 39, Ginter *et al.*, 2002), Middle Famennian of Chahriseh, Central Iran (sample 114, Hairapetian & Ginter, 2009) and Lower Famennian of Hodjedk, Central Iran (sample R4, Hairapetian, 2008) and Ertych, Armenia (sample Er-7, Ginter *et al.,* 2011). There are not enough shark teeth from the Bagher Abad section to present further reasonable analysis of assemblage. It can only be concluded that with correlating to the other Central Iranian sections (*e.g.,* Chahriseh) the assemblage were recovered from Famennian shallow water successions.

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