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Article

Ammonoids from the Carboniferous-Permian boundary of east-central Iran

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With 10 figures and 2 tables

Abstract: A small ammonoid assemblage from Carboniferous-Permian boundary strata of Kuh-e-Bagh-e-Vang in the Tabas region (east-central Iran) is reported. The new species *Agathiceras iranicum* Korn & Ghaderi n. sp. and *Eoasianites baghevangensis* Korn & Ghaderi n. sp. are described. Ammonoids from Frasnian to Early Permian age occur in a conglomerate unit near the base of the Jamal Formation and indicate deep erosion and reworking in the basin.

Key words: Ammonoidea, Carboniferous, Permian, Iran, biostratigraphy.

1. Introduction

The area around Tabas (east-central Iran) is remarkable for its excellent exposures of a long stratigraphic sequence, ranging from the younger Proterozoic to the Neogene (Stöcklin et al. 1965; Ruttner et al. 1968). Despite this long sedimentary succession, fossil cephalopods have been reported in this area from only a few strata, (1) from the Middle Ordovician Shirgesht Formation of the Derenjal Mountains (Evans et al. 2013), (2) from the Late Devonian Shishtu Formation of the Shotori Range (Stöcklin et al. 1965; Wallıser 1966; Becker et al. 2004; Ashouri & Yamini 2006; Hairapetian & Korn 2011; Korn et al. 2019), (3) from the Early Carboniferous lower part of the Sardar Formation of the Ozbak-Kuh range (Wallıser 1966), (4) the Late Carboniferous upper part of the Sardar Formation of the Shotori Range (Wallıser 1966), (5) the Late Carboniferous Sardar Formation at Kuh-e-Shesh Angosht (Hairapetian et al. 2006; Balini et al. 2015) and (6) the Early Permian part of the Jamal Formation at Kuh-e-Bagh-e-Vang (taxa list provided by Wallıser in Ruttner et al. 1968).

The section at Kuh-e-Bagh-e-Vang was measured and sampled by the authors during a field visit in 2015. A small suite of ammonoids was recovered, complementing earlier collections by Jobst Wendt (Tübingen). Wallıser already provided a list published by Ruttner et al. (1968) with eight ammonoid families from the lower range of the Bagh-e-Vang Member and regarded this assemblage as Sakmarian in age. In the following we describe a small assemblage of ammonoids from the Carboniferous-Permian boundary. Although the material cannot be clearly stratigraphically assigned because it is either a surface collection or is from components from the conglomerate, it can contribute to the understanding of the distribution of ammonoids from this time interval.

2. The section at Kuh-e-Bagh-e-Vang

Kuh-e-Bagh-e-Vang is located 45 km north-northwest of Tabas and forms a solid ridge that emerges from the plain over an extension of about 1.5 kilometres (Fig. 1).

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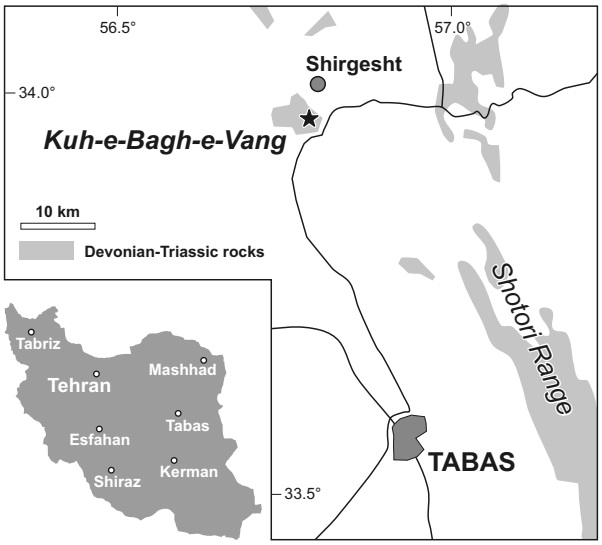

Fig. 1. The geographic position of the Kuh-e-Bagh-e-Vang section in the region of Tabas.

The section first described by Ruttner et al. (1968) is exposed on the north-western flank of the steep ridge; it comprises the uppermost part of the Carboniferous Sardar Formation, the entire Permian Jamal Formation and the lower part of the Triassic Sorkh Shale.

Ruttner et al. (1968) measured a thickness of 293 metres for the Jamal Formation at Kuh-e-Bagh-e-Vang; they separated a lower part (58 m thick), which consists mainly of shales and grey bioclastic limestones, with a conglomerate at its base, and an upper part, which is built up almost exclusively by bedded micritic limestones and dolomites. In their section logs, hey drew the boundary between the Sardar Formation and the Jamal Formation at the lithological change from silty shales to carbonates, following an earlier definition at the type locality of the Jamal Formation in the Shotori Range (Stöcklin et al. 1965).

In subsequent articles, the lower part was referred to as the Bagh-e-Vang Formation (Partoazar 1995) or Bagh-e-Vang Member (e.g., Leven & Vaziri Moghaddam 2004). Different interpretations have been expressed regarding the contact between the Sardar Formation and the Jamal Formation. Whereas some workers (Ruttner et al. 1968) did not recognise any angular unconformity, others assumed a transgressive overlay (Vuolo 2015) or a clear disconformity (Arefifard & Isaacson 2011; Partoazar et al. 2014). The general facies, carbonate microfacies and palaeoenvironmental setting has been outlined in the last years (Sotouhain & Ranjbaran 2014; Aghajani & Aleali 2019; Yegane et al. 2021).

The biostratigraphic attribution and subdivision of the Bagh-e-Vang section is based almost exclusively on the study of foraminifera (Leven & Vaziri Moghaddam 2004; Davydov & Arefifard 2007; Leven & Gorgij 2011; Partoazar et al. 2014, Partoazar et al. 2017; Sharahi et al. 2020). Most of these studies postulated a Late Early Permian (Bolorian = early Kungurian) age for the entire Bagh-e-Vang Member, but Partoazar et al. (2014, 2017) suggested a Middle Permian (Murgabian = Roadian) age. After a comparison of the stratigraphic successions of foraminifera and conodonts, Leven et al. (2007) concluded that the lowest sample of the Bagh-e-Vang Member belongs to the Yakhtashian (= Artinskian) and those following above to the Bolorian. According to their study, the Kubergandinian (late Kungurian) begins in the uppermost part of the Bagh-e-Vang Member. However, it must be said that in some samples only fragments were found that were identified in open nomenclature.

By studying conodonts more intensively, Vuolo (2015) arrived at results that deviated from the foraminifera stratigraphy. According to conodonts, the basal seven metres of the Bagh-e-Vang Member has a Sakmarian age.

The section at Bagh-e-Vang has been known for its fossil richness since its first description. Among the fossil groups described, illustrated and discussed are the corals (Flügel 1972; Niko et al. 2018; Ataei et al. 2019), brachiopods (Vuolo 2015), bryozoans (Ernst et al. 2006), sponges (Senowbari-Daryan et al. 2005), algae (Senowbari-Daryan & Rashidi 2010; Partoazar et al. 2017), and problematica (Senowbari-Daryan & Rashidi 2011).

We investigated four parallel sections of the boundary between the Sardar Formation and the Jamal Formation on the northwest flank of Kuh-e-Bagh-e-Vang (Fig. 2). They start with silty shales of the upper Sardar Formation (unit 1 in Fig. 2), from which the paratype specimen of *Agathiceras iranicum* Korn & Ghaderi n. sp. was surface-collected. Ruttner et al. (1968: 59) stated that "the uppermost beds of the Sardar Formation are Early Permian age, as proved by brachiopods collected in the Sardar Formation on both sides of Kuh-e-Shesh Angosht". However, this age determination requires confirmation.

This unit is overlain by the Jamal Formation beginning with a conspicuous unit up to 1.50 m thick, consisting of several beds of a herringbone-laminated calcarenite (unit 2). This is followed by a unit up to

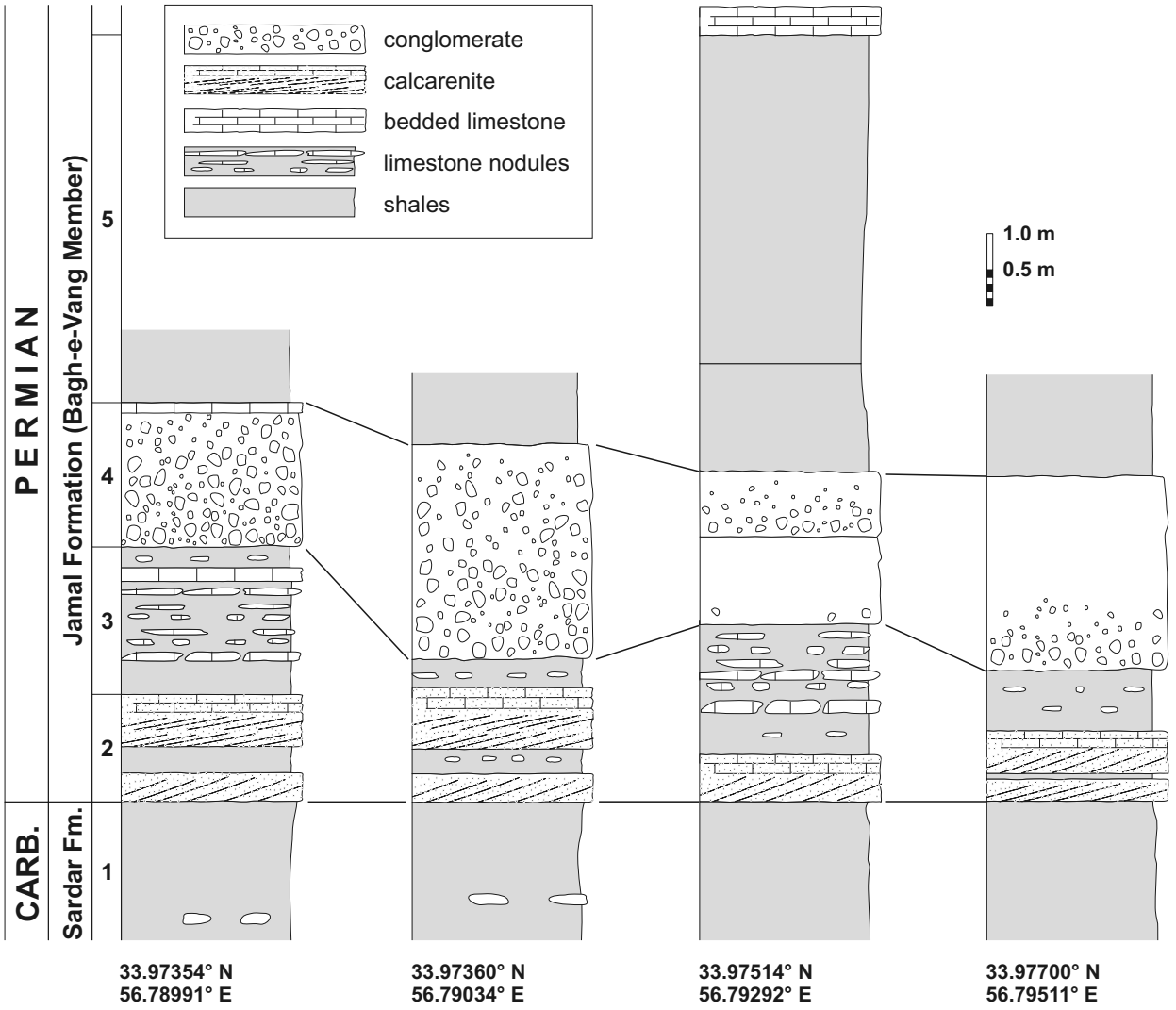

Fig. 2. Four parallel sections of the contact between the Sardar Formation and the Jamal Formation at Kuh-e-Bagh-e-Vang.

2.10 m thick of greenish to reddish shales with up to ten nodular micritic limestone layers (unit 3). According to the lithology, this is probably the horizon from where the specimens of *Eoasianites baghevangensis* Korn & Ghaderi n. sp. originate.

The striking lateral differences in thickness and composition of this unit is probably caused by an erosive contact of the following conglomerate bed (unit 4). This compact conglomerate bed, which was regarded by Partoazar et al. (2014) as the base of the Jamal Formation, reaches a thickness of four metres and has a carbonatic matrix. It contains preferably carbonate components with a wide range of lithologies; many of these yielded fossils (corals, brachiopods, bryozoans, echinoderms, bivalves, gastropods, ammonoids). Most of the ammonoid specimens seem to have the same stratigraphic age (Early Permian). However, considerably older fragments were also collected, such as a phragmocone chamber of a gephuroceratid (Frasnian) and a possible Carboniferous prolecanitid. Above the conglomerate, 5.50 metres of grey and reddish shales follow (unit 5).

3. Systematic palaeontology (DK, AG)

The descriptive part follows the key for the description of Palaeozoic ammonoid species (Fig. 3), published by Korn (2010) and Klug et al. (2015). Sutural ter-

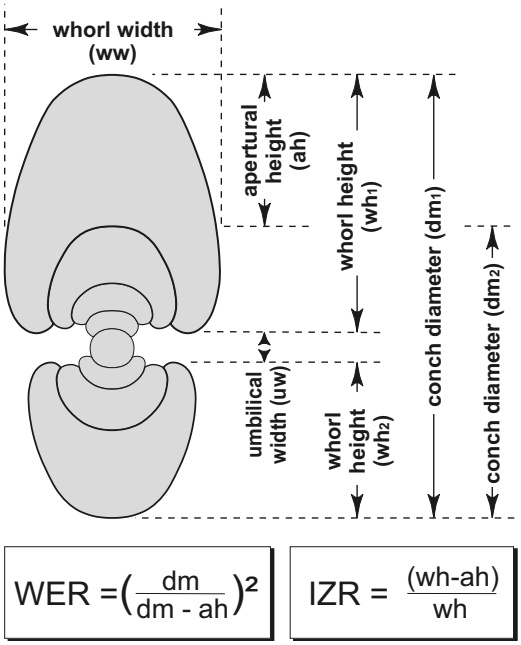

Fig. 3. Dimensions obtained from an ammonoid conch and explanation of whorl expansion rate and imprint zone rate as used in the systematic descriptions.

minology follows Korn et al. (2003). The specimens are reposited in the Museum für Naturkunde, Berlin (MB.C. prefix) and the Ferdowsi University of Mashhad (FUM prefix).

Order Goniatitida Hyatt, 1884
Suborder Goniatitina Hyatt, 1884
Superfamily Goniatitoidea de Haan, 1825
Family Agathiceratidae v. Arthaber, 1911

Genus *Agathiceras* Gemmellaro, 1887

Agathiceras iranicum Korn & Ghaderi, n. sp.
Figs. 4, 5

Etymology: After the type locality in Iran.

Holotype: Specimen MB.C.8198 (Wendt 1998 Coll.), illustrated in Fig. 4A.

Type locality and horizon: Kuh-e-Bagh-e-Vang (45 km NNW of Tabas, east-central Iran n); probably top of the Sardar Formation (latest Carboniferous).

Material: Two specimens, the holotype and paratype MB.C.30290.

Diagnosis: Species of the genus *Agathiceras* with thinly pachyconic, almost completely involute conch (ww/dm = 0.60–0.70; uw/dm = 0.05); coiling rate moderate (WER = 1.85). Shell with linear internal thickenings. Suture line with prongs of the external lobe and branches of the adventive lobe similarly shaped, being strongly pouched and subacute at the base. The median saddle attains three quarters of the external lobe depth.

Description: Holotype MB.C.8198 is a rather well-preserved, limonitic specimen with 19 mm conch diameter; it is fully septate and does not show traces of the shell (Fig. 4A). The conch is thinly pachyconic (ww/dm = 0.70) with an almost closed umbilicus; the whorl profile is horseshoe-shaped and depressed ventrally (ww/wh = 1.26). The coiling rate is moderately high (WER = 1.85). The specimen possesses four constrictions of the internal mould on the last whorl; they are arranged in angles slightly less or more than 90 degrees. These constrictions extend almost linearly across flanks and venter.

The suture line of the holotype shows four similarly shaped lobes (E_1 prong, trifid A lobe), all of which are strongly pouched and have a pointed base (Fig. 5). Only the E_1 prong is slightly blunt and weakly asymmetric, while the three branches of the adventive lobe are almost symmetric. The median saddle reaches 80 % the height in the E lobe.

Paratype MB.C.30290 has 27.5 mm diameter and is slenderer (ww/dm = 0.62) than the holotype. It also shows linear steinkern constrictions (Fig. 4B).

Discussion: There are two morphological trends in the evolution of the genus *Agathiceras*; (1) the elevation of the median saddle in the external lobe and (2) the rounding of the three prongs of the adventitious lobe. Most Permian species, for example, show a median saddle that rises almost as high as the depth of the external lobe; in some species it even protrudes from the external lobe (e.g., *A. mediterraneum* Toumansky, 1949). The prongs of the adventitious lobe are drop-shaped with a broadly rounded base in almost all Permian species such as *A. suessi* Gemmellaro, 1887 and *A. uralicum* (Karpinsky, 1874). The new species differs from most of these species in the pointed external and prongs of the adventive lobes.

Table 1. Conch dimensions (in mm) and ratios of selected specimens of *Agathiceras iranicum* Korn & Ghaderi n. sp.

	dm	ww	wh	uw	ah	ww/dm	ww/wh	uw/dm	WER	IZW
MB.C.8198	19.3	13.6	10.8	0.9	5.1	0.70	1.26	0.05	1.85	0.53
MB.C.30290	27.4	16.9	14.8	1.0	7.3	0.62	1.14	0.04	1.86	0.51

Fig. 4. *Agathiceras iranicum* Korn & Ghaderi n. sp. from Kuh-e-Bagh-e-Vang. **A** – Holotype MB.C.8198 (Wendt 1998 Coll.). **B** – Paratype MB.C.30290. Scale bar units = 1 mm.

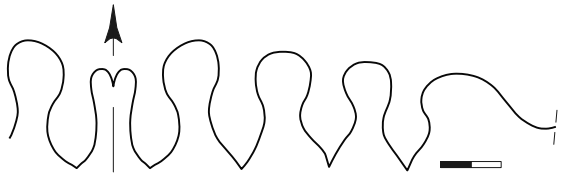

Fig. 5. *Agathiceras iranicum* Korn & Ghaderi n. sp. from Kuh-e-Bagh-e-Vang, suture line of holotype MB.C.8198, at 19.0 mm dm, 13.5 mm ww, 10.5 mm wh. Scale bar units = 1 mm.

Agathiceras iranicum is therefore more similar to the Carboniferous or earliest Permian species of *Agathiceras*. Of these species from near the Carboniferous-Permian boundary, *A. vulgatum* Ruzhencev, 1978 has a similar suture line, but the lobes are narrower and much less pouched. *A. frechi* Böse, 1917 also has a similar suture line and conch proportions resembling the new species, but it differs in the much wider external lobe, whose prongs are much wider than the three branches of the adventive lobe. These are of equal length in *A. iranicum*.

The paratype of the new species was found as a surface collection in the upper Sardar Formation. Even if a displacement from younger, carbonate strata cannot be completely excluded, an origin of the specimen in limonitic preservation from the shales of the Sardar Formation is considerably more probable. The stratigraphic age of this section is latest Carboniferous or earliest Permian (Ruttner et al. 1968).

Superfamily Neoicoceratoidea Hyatt, 1900
Family Neoicoceratidae Hyatt, 1900

Genus *Eoasianites* Ruzhencev, 1933

Eoasianites baghevangensis Korn & Ghaderi n. sp.
Figs. 6, 7

Etymology: After the type locality.

Holotype: Specimen MB.C.8197 (Wendt 1998 Coll.), illustrated in Fig. 6.

Type locality and horizon: Kuh-e-Bagh-e-Vang (45 km NNW of Tabas, east-central Iran); Jamal Formation, probably base of the Bagh-e-Vang Member (probably Asselian or Sakmarian).

Material: Two specimens, the holotype and paratype FUM#BV.A4 (with nearly 100 mm conch diameter).

Diagnosis: Species of the genus *Eoasianites* with thickly discoidal, subevolute conch (ww/dm ~ 0.50; uw/dm ~ 0.35); coiling rate moderate (WER ~ 1.65). Whorl profile crescent-shaped with subangular umbilical margin. Shell with spiral lines around the umbilicus. Suture line with strongly pouched prongs of the external lobe and strongly pouched adventive lobe.

Description: Holotype MB.C.8197 is a well-preserved, largely exfoliated specimen with 67 mm conch diameter (Fig. 6); three quarters of the last preserved whorl belong to the body chamber. The conch is thickly discoidal and subevolute (ww/dm = 0.50; uw/dm = 0.37) with a depressed whorl profile (ww/wh = 1.37) and a low coiling rate (WER = 1.64). The whorl profile is crescent-shaped with a convex umbilical wall, a rounded umbilical margin and broadly rounded flanks, which continue into the broadly rounded venter. Shell remains are present at some places, they show lamellar growth lines on the flank. Five coarse spiral lines are visible on the umbilical margin, of which the middle ones are more pronounced than the outer ones.

The suture line of the holotype is characterised by strongly curved flanks of saddles and lobes (Fig. 7). The external lobe has a width/depth ratio of 0.80; it possesses rather strongly pouched prongs and a median saddle that is raised to nearly 0.65 of the lobe depth. The external lobe has 1.5 times the width of the slightly asymmetric, strongly pouched adventive lobe. The ventrolateral saddle, which is constricted in the middle part and inflated in the upper part, has a narrowly rounded top; the saddle has the same with like the adventive lobe.

Discussion: The strongly pouched external and adventive lobes of the new species allow a clear separation from all

Table 2. Conch dimensions (in mm) and ratios of selected specimens of *Eoasianites baghevangensis* Korn & Ghaderi n. sp.

	dm	ww	wh	uw	ah	ww/dm	ww/wh	uw/dm	WER	IZW
MB.C.8197	67.2	33.4	24.3	24.6	14.8	0.50	1.37	0.37	1.64	0.39
	53.5	28.7	19.8	19.6	-	0.54	1.45	0.37	–	–

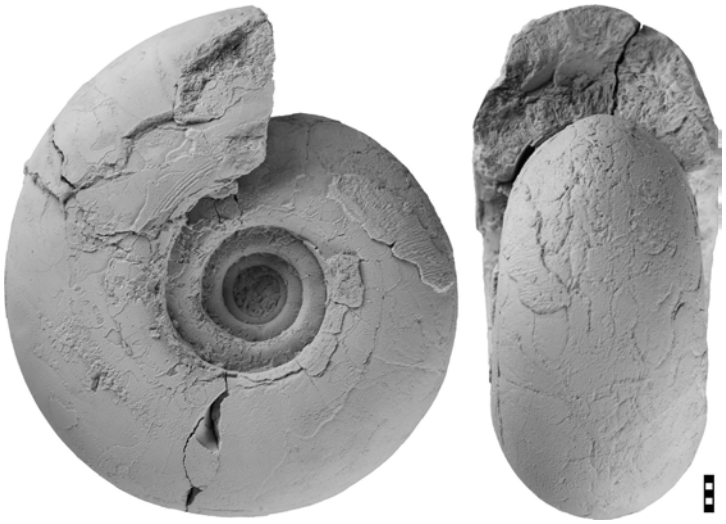

Fig. 6. *Eoasianites baghevangensis* Korn & Ghaderi n. sp. from Kuh-e-Bagh-e-Vang. Holotype MB.C.8197 (Wendt 1998 Coll.). Scale bar units = 1 mm.

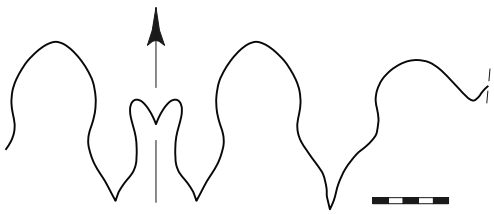

Fig. 7. *Eoasianites baghevangensis* Korn & Ghaderi n. sp. from Kuh-e-Bagh-e-Vang, suture line of holotype MB.C.8197, at 27.5 mm ww, 18.0 mm wh. Scale bar units = 1 mm.

of the other, stratigraphically older (Carboniferous) species of the genus, which possess subparallel flanks (e.g., Ruzhencev 1950). Among those with a similar suture line, i.e. stratigraphically younger (Permian) species, *E. grandis* Ruzhencev, 1978 shows some similarity, but that species has, at a conch diameter of 67 mm, a wider conch (ww/dm = 0.60 in contrast to 0.50 in *E. baghevangensis*) and a wider umbilicus (uw/dm = 0.50 in contrast to 0.37).

E. stenus Ruzhencev, 1978 has a similar conch width, but a wider umbilicus (uw/dm = 0.44 at 77 mm dm) and a more pronounced, subangular umbilical margin. Constrictions of the internal mould are present in *E. stenus* but absent in *E. baghevangensis*.

Order Prolecanitida Miller & Furnish, 1954
Suborder Prolecanitina Miller & Furnish, 1954
Superfamily Medlicottioidea Karpinsky, 1889
Family Medlicottiidae Karpinsky, 1889

Genus *Synartinskia* Ruzhencev, 1939

Synartinskia sp.
Figs. 8, 9

Material: Eleven specimens from limestone pebbles in the conglomerate (unit 4).

Description: The most complete individual is the fully septate, corroded specimen MB.C.30290, 48 mm in diameter (Fig. 8A). It is thinly discoidal with flattened flanks and an almost closed umbilicus. The venter is strongly corroded

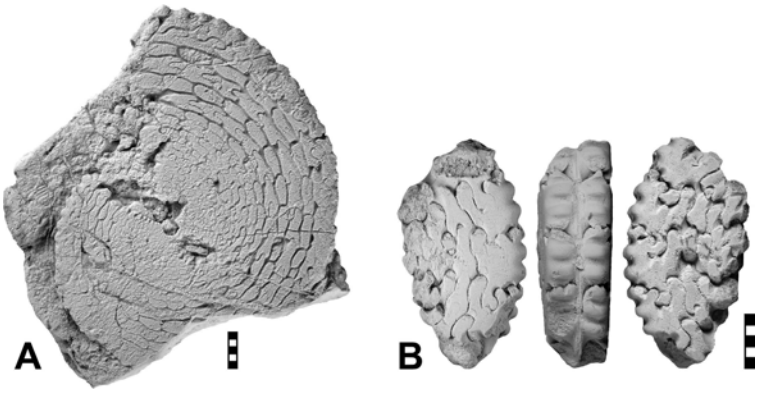

Fig. 8. *Synartinskia* sp. from the basal conglomerate of the Jamal Formation at Kuh-e-Bagh-e-Vang. **A** – Specimen MB.C.30290. **B** – Specimen FUM#BV.A5. Scale bar units = 1 mm.

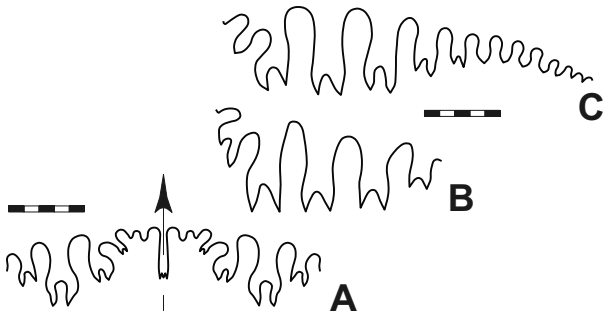

Fig. 9. *Synartinskia* sp. from Kuh-e-Bagh-e-Vang, suture lines. **A** – Specimen FUM#BV.A5, at 6.4 mm ww. **B** – Specimen MB.C.30291, at 7.2 mm ww, 20.0 mm wh. **C** – Specimen MB.C.30290, at 41.5 mm dm, 22.5 mm wh. Scale bar units = 1 mm.

and does not allow a detailed study; the suture line is only visible on the flanks. Only a small part of the ventrolateral saddle can be studied; it shows an obviously simple first lateral secondary notch. The asymmetric, bifid adventive lobe has a strongly convex ventral side; is not as deep as the lateral lobe. All in all, there are five bifid lobes and at least six simple lobes (Fig. 9C).

The fragmentary specimen MB.C.30291 shows a bifid first lateral secondary lobe on the ventrolateral saddle; its adventive lobe is as deep as the lateral lobe (Fig. 9B). Another fragment (FUM#BV.A5) allows the study of the ventral suture line (Fig. 9A). It shows the very narrow external lobe without secondary lobes and a ventrolateral saddle with only three secondary lobes, of which the first lateral one is bifid. The lateral lobe is wider and much deeper that the adventive lobe and the first umbilical lobe.

Discussion: The specimens show some variation in terms of conch morphology and suture line. Since they are all either fragmented, corroded or both, a clear assignment to a specific species is not possible. It is not even clear whether they belong to only one species.

Ruzhencev (1949, 1950, 1956) had shown that the morphological evolution of the medlicottiid ammonoids is characterised by several trends, (1) the increasing number of umbilical lobes, (2) the increasing number of bifid lobes (concerning the adventive lobe, lateral lobe and outer umbilical lobes) and (3) the elevation and increasing number of notches of the ventrolateral saddle. Attribution to the genus *Synartinskia* is proposed here because of the shape of the ventrolateral saddle (which is rather low and indented by only few secondary lobes), the number of bifid lobes (five) and the number of umbilical lobes (at least ten).

4. Additional ammonoids from the conglomerate

In the basal conglomerate of the Jamal Formation, ammonoids from various stratigraphic levels can be found. They are discussed only briefly here:

Cardiella sp.: Specimen FUM#BV.A1 (Fig. 10A) is a septate fragment with a whorl height of about 25 mm. It shows lobes with regularly four notches on the flank and thus differs from most known material, which usually has trifid lobes. However, Leonova (in Leonova & Dmitriev 1989) figured asymmetric suture lines of *Cardiella shyndensis*, which sometimes have lobes with four notches.

Agathiceras sp.: Specimens FUM#BV.A2 (14.5 mm dm; Fig. 10B) and FUM#BV.A3 (9.5 mm dm; Fig. 10C) represent the inner whorls of larger specimens lacking the body chamber and parts of the phrag-

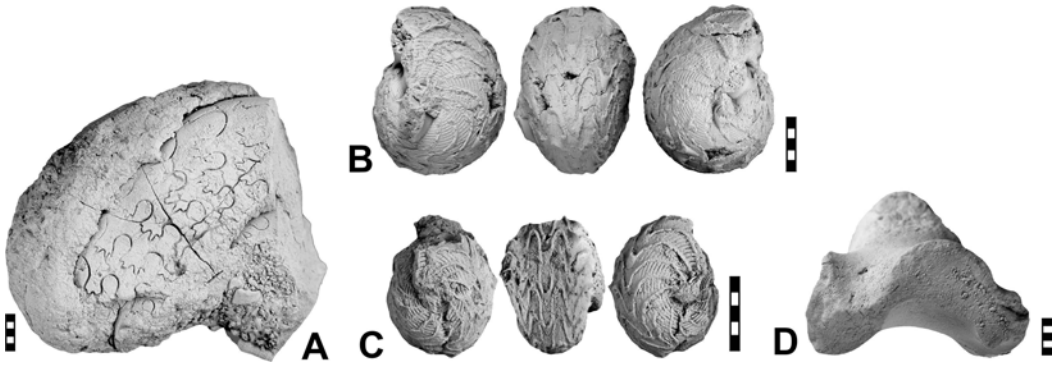

Fig. 10. Ammonoids from the basal conglomerate of the Jamal Formation at Kuh-e-Bagh-e-Vang. **A** – *Cardiella* sp., specimen FUM#BV.A1. **B** – *Agathiceras* sp., specimen FUM#BV.A2. **C** – *Agathiceras* sp., specimen FUM#BV.A3. **D** – *Manticoceras* sp., specimen MB.C.30292. Scale bar units = 1 mm.

mocone. Both are thinly pachyconic conchs, which are ornamented with coarse spiral lines that are more than twice as wide as their interspaces. It cannot be said if these specimens belong to the new species *Agathiceras iranicum*.

Further, but poorly preserved specimens of a probable Early Permian age belong to *Popanoceras* sp. and *Properrinites* sp.

Manticoceras sp.: Specimen MB.C.30292 is a surprising component in the assemblage because it is a fragment of a Frasnian ammonoid (Fig. 10D). This means that significant reworking took place at the Bagh-e-Vang site. The specimen is only the filling of one phragmocone chamber with nearly 30 mm whorl height; it clearly shows the septal surface only characteristic for *Manticoceras* and closely related genera.

5. Biostratigraphic position of the assemblage

A clear stratigraphic determination of the ammonoid assemblage from Kuh-e-Bagh-e-Vang is difficult because of the mostly fragmentary preservation of most of the material, which does not allow a reliable determination on the species level. In addition, there is the difficulty that the stratigraphic schemes presented so far for the section are contradictory: According to foraminifera, the Bagh-e-Vang Member should have a stratigraphically higher position (Kungurian) (Leven & Vaziri Moghaddam 2004; Davydov & Arefifard 2007; Leven & Gorgij 2011; Sharahi et al. 2020) or even Roadian (Partoazar et al. 2014, 2017) than according to conodonts, which suggested an Artinskian age (Leven et al. 2007) or Sakmarian age (Vuolo 2015).

The ammonoids of Kuh-e-Bagh-e-Vang must be subdivided into three groups as far as their stratigraphic assignment is concerned:

(1) The specimens of *Agathiceras iranicum* Korn & Ghaderi n. sp. cannot be clearly assigned, because the genus *Agathiceras* has a long stratigraphic range from the Late Carboniferous to the Early Permian (Ruzhencev 1950, 1956). However, the morphology with a moderately high median saddle and pointed external and adventive lobes suggests a latest Carboniferous age.

(2) The genus *Eoasianites* has its main distribution in Gzhelian to Asselian times. A stratigraphically younger placement is not very likely. *Eoasianites baghevangensis* Korn & Ghaderi n. sp., which belongs to the morphologically advanced species of the genus with strongly pouched lobes, shows the greatest similarity to the species assemblage from Shor-Bulak-say (Tajikistan) described by Bogoslovskaya (1978) and Ruzhencev (1978). This assemblage was assigned to the Asselian by both authors on the basis of the morphological development of the ammonoids.

(3) The specimens from the conglomerate can only help in determining a minimum age. While some components, such as *Agathiceras* sp. do not provide precise information, an age from Sakmarian to Artinskian can be given for *Synartinskia* sp. for the occurrences in the South Urals and Pamirs (Ruzhencev 1951; Leven

et al. 1992) and from Asselian to Kungurian for *Cardiella* for the occurrences in the Pamirs (Leonova & Dmitriev 1989; Leven et al. 1992). The finding of *Manticoceras* can only be explained by deep erosion at some place in the basin. Cephalopod-bearing Frasnian carbonates are known, for instance, from the Shotori Range south-east of Kuh-e-Bagh-e-Vang (Stöcklin et al. 1965; Hairapetian & Korn 2011; Korn et al. 2019).

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