

FASCICULATE KLEOPATRINID CORALS FROM THE BASHKIRIAN (LATE CARBONIFEROUS) OF SARDAR FORMATION (OZBAK-KUH MOUNTAINS, EAST-CENTRAL IRAN)

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ABSTRACT – In the East-Central Iran, the Sardar Formation (upper Viséan–Moscovian) consists of shallow-water limestone with intercalations of shale containing rugose corals, tabulate corals and brachiopods. Ten sections were sampled in the Ozbak-kuh Mountains, from north to south. Among the rugose corals, an assemblage of fasciculate Kleopatriniidae has been collected. The latter contains the species: *Paraheritschioides antoni antoni*, *P. antoni minor*, *P. gracilis* and two new species for the genera *Fomichevella* and *Heintzella*. *Heintzella* is described from Iran for the first time. However, its age, as determined by conodonts and foraminifers, is early to middle Bashkirian (early late Carboniferous). The most similar, time-equivalent faunal associations are that of the Ellesmere Island, Sverdrup Basin in Arctic Canada, Alexander terrane and Brooks Range in southeastern Alaska and eastern Klamath terrane in northern California, where similar tropical warm water conditions have been identified during the Bashkirian in the northern hemisphere. During these times central Iran block and Northern provinces, characterized by a dominant carbonate facies and more diversified colonial coral faunas.

Key words: Iran, Ozbak-kuh, Sardar, Bashkirian, rugose corals.

RESUMO – A Formação Sardar (Viséano superior–Moscoviano) no Irã Central-Leste é caracterizada por calcários de ambientes pouco profundos com intercalações de folhelhos que contêm corais rugosos, tabulados e braquiópodes. Foram estudadas dez amostras das montanhas Ozbak-kuh, de norte a sul. Entre os corais rugosos foi amostrada uma associação de Kleopatriniidae fasciculados, que contêm as espécies *Paraheritschioides antoni antoni*, *P. antoni minor*, *P. gracilis* e duas novas espécies para os gêneros *Fomichevella* e *Heintzella*. O gênero *Heintzella* é descrito pela primeira vez para o Irã. Contudo, a sua idade, determinada por conodontes e foraminíferos, é Bashkiriano inicial–médio (Neocarbonífero). As associações faunísticas contemporâneas mais semelhantes são as da Ilha de Ellesmere, bacia Sverdrup no Canadá Ártico, Terreno Alexander e Cordilheira Brooks no sudeste de Alasca, e o Terreno Klamath mais a leste na Califórnia setentrional, onde condições de águas quentes tropicais foram identificadas durante o Bashkiriano no hemisfério norte. O bloco central iraniano e as províncias setentrionais, durante este tempo, foram caracterizadas por facies calcárias dominantes e faunas coralinas coloniais diversificadas.

Palavras-chave: Iran, Ozbak-kuh, Sardar, Bashkiriano, corais rugosos.

INTRODUCTION

The rugose corals suffered an important extinction at the Viséan-Serpukhovian boundary (Dubatolov & Vassiljuk, 1980; Fedorowski, 1981). Most families of the Viséan, however, are represented in the Serpukhovian by several long-ranging genera. The end of the Mississippian (end of Serpukhovian) is characterized by a progressive impoverishment of the marine fauna, particularly coral faunas (Fedorowski, 1981; Kossovaya, 1996, 2002), and leading to the extinction of many groups. The Bashkirian recorded the recovery of the rugose corals with the first re-diversification of corals, mainly from solitary species that survived the Serpukhovian extinctions (Fedorowski, 1981; Kossovaya, 1996). The genera are well documented in the Ural Mts and Moscow Basin (Ogar, 1985, 1990; Kossovaya, 1996, 2002), Donets Basin (Fedorowski, 2009a,b, Fedorowski & Vassiljuk 2011, Fedorowski & Ogar, 2013), North America (Armstrong, 1972; Sando, 1985; Stevens, 2012; Fedorowski *et al.*, 2014a,b) and China (Wu & Zhao, 1989; Zhang *et al.*, 2009, 2010). However, they are poorly known in time-equivalent assemblages from the southern Tethys from northern Africa (Semenoff-Tian-Chansky, 1974; Rodriguez *et al.*, 2013) and

East central Iran (Flügel, 1974, 1975, 1994). The present study aims to document the Bashkirian fasciculate kleopatrined rugose corals from east-central Iran.

The oldest report about the Bashkirian coral from Iran is that of Flügel (1974, 1975, 1994), who described some solitary and colonial forms in the Ozbakh Kuh Mountains. Badpa *et al.* (2014) conducted preliminary studies in the same area in order to revise Flügel's fauna and they collected complementary material. The purpose of this paper is the description and illustration of the Bashkirian fasciculate kleopatrined rugose corals and also comparison of these faunas to those from America and Eurasia.

LOCATION OF THE KEY SECTIONS

The Ozbakh-kuh Mountains are located approximately 140 km north of Tabas city (east-central of Iran) (Figure 1). There are several complete Carboniferous outcrops in the central and southern parts of these mountains (Figures 2,3). The Zaladu Section (locality 1) is situated in the Eastern limb of the Zaladu syncline with 10 km length, located on the northern side of the Zaladu Valley at coordinates of N34°39'42" and E57°08'48". This succession is the most complete Carboniferous exposure

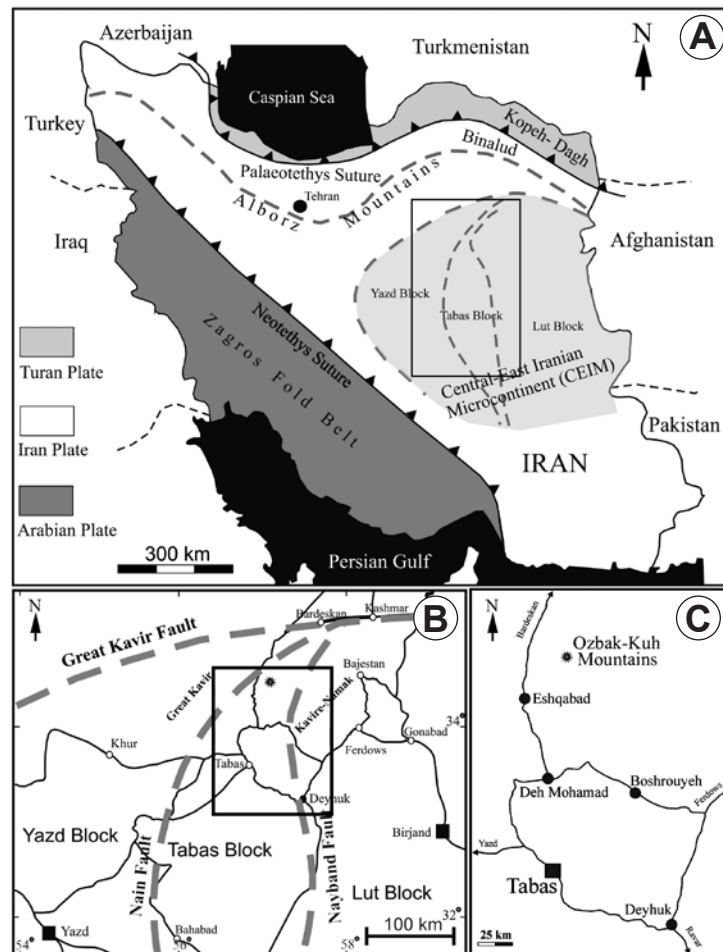


Figure 1. Location map of the study area and measured stratigraphic section in East Central Iran. **A**, map of present-day of Iran showing the geographical domains as well as the main sutures and tectonic structures of the Iran Plate. **B**, close-up view of white square, East-Central Iran (modified from Wilmsen *et al.*, 2010). **C**, close-up view of rectangular area in B, with the location of study area in north Tabas.

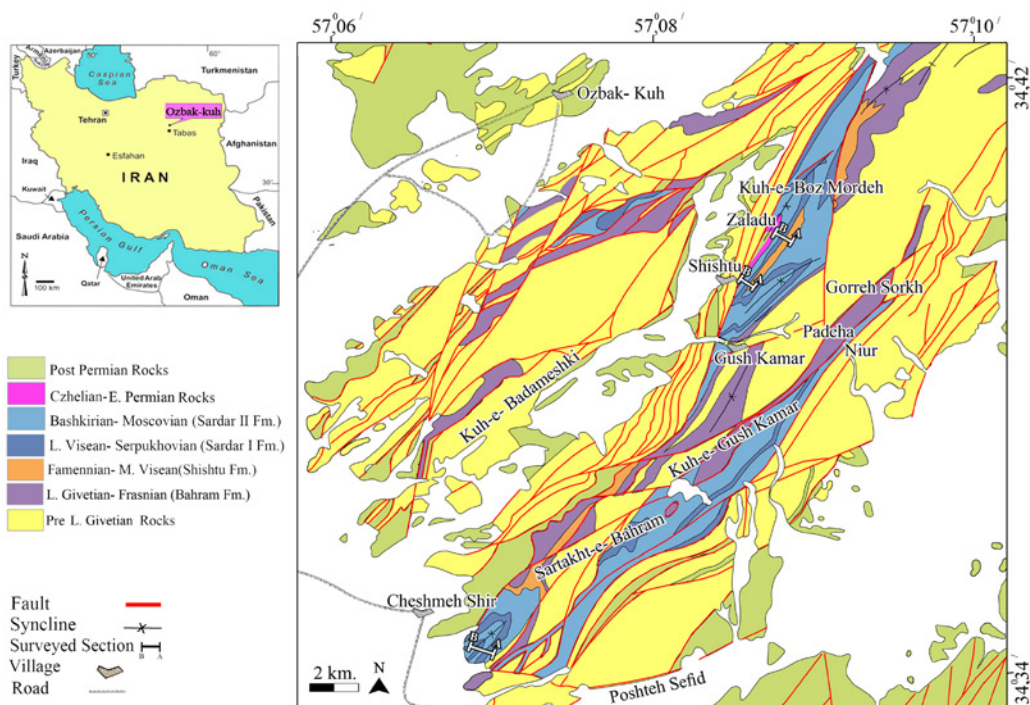


Figure 2. Geological location of studied area in the Ozbak-kuh Mountains (modified from Ruttner *et al.*, 1970).

SYSTEM SUBSYS. SERIES	STAGE	ZAGROS	SANANDAJ-SIRJAN ZONE RAMSHEH	YAZD-BLOCK ANARAK	KALMARD BLOCK	TABAS-BLOCK OZBAK-KUH	EAST-ALBORZ		C-ALBORZ CHALUS
							ALI-ABAD	RAMIYAN	
CARBONIFEROUS PENNSYLVANIAN	GZHELIAN			ZALADU Fm.		ZALADU Fm.	Toyeh Fm.		
	KASIMOVIAN								
	MOSCOVIAN								
	BASHKIRIAN			SARDAR Fm.		SARDAR Fm.	GHESEL-GHALEH FM.	BAGHER ABAD FM.	
	SERPUKHOVIAN								DOZD-BAND Fm.
	VISEAN			Shishtu II Fm.	Shishtu II Fm.	Gachal Fm.	Shishtu II Fm.	Mobarak Fm.	Mobarak Fm.
TOURNAISIAN									

Figure 3. Synoptic chart of the Carboniferous formations of Iran. Ramsheh (Boncheva *et al.*, 2007); Anarak (Leven & Gorgij, 2006, 2011); Kalmard Block (Wendt *et al.*, 2002, 2005; Aghabanati, 1977, 2009); Ozbak-kuh Mountains (Leven & Gorgij, 2006, Sohrabi, 2005); East Alborz (Jenny *et al.*, 1978, Jenny & Stampfli, 1978; Brunet *et al.*, 2009); central Alborz (Aghabanati, 2004, 2009; Brunet *et al.*, 2009).

in the Ozbak-kuh Mountains. The other studied sections are the Zaladu Valley sections (localities 2, 3), Zaladu II (locality 4), Shishtu (locality 5), and Tangal-e-zireh sections (locality 6), situated in the middle parts of these mountains N34°38'40" and E57°08'38". The Cheshmeh-Shir sections (localities A-D), are located on the southern part of the Ozbak-kuh, situated in a syncline between coordination of N34°33'30", E57°06'04" and N34°33'15", E57°06'04".

GEOLOGIC SETTING

The Ozbak-kuh Mountains are located in the northern part of the Tabas Block (Figure 1), (Stöcklin *et al.*, 1965; Wendt *et al.*, 2002, 2005; Brunet *et al.*, 2009), which once was a

failed rift basin related to the southern part of Paleotethys margin (Bagheri & Stampfli, 2008; Lasemi, 2001; Scotese & Langford, 1995; Stampfli & Pillevuit, 1993; Sengor, 1984). The Carboniferous strata are represented by a thick succession consisting of the Shishtu (Famennian-middle Visean), Sardar (late Visean-late Moscovian), and Zaladu formations (early Gzhelian-middle Asselian), (Figure 2). The stratigraphic and sedimentological settings of the Ozbak-kuh area (Figures 2,3) were studied by Weddige (1984); Flügel (1994), Leven *et al.* (2006), Sohrabi (2005), Badpa *et al.* (2011, 2014), and Khanehbad (2012). The latter concluded that the carbonate rocks were deposited along a shallow-water homoclinal ramp.

The Sardar Formation is about 280 m thick (Figure 4). The formation covers the shales and limestones of the Shishtu

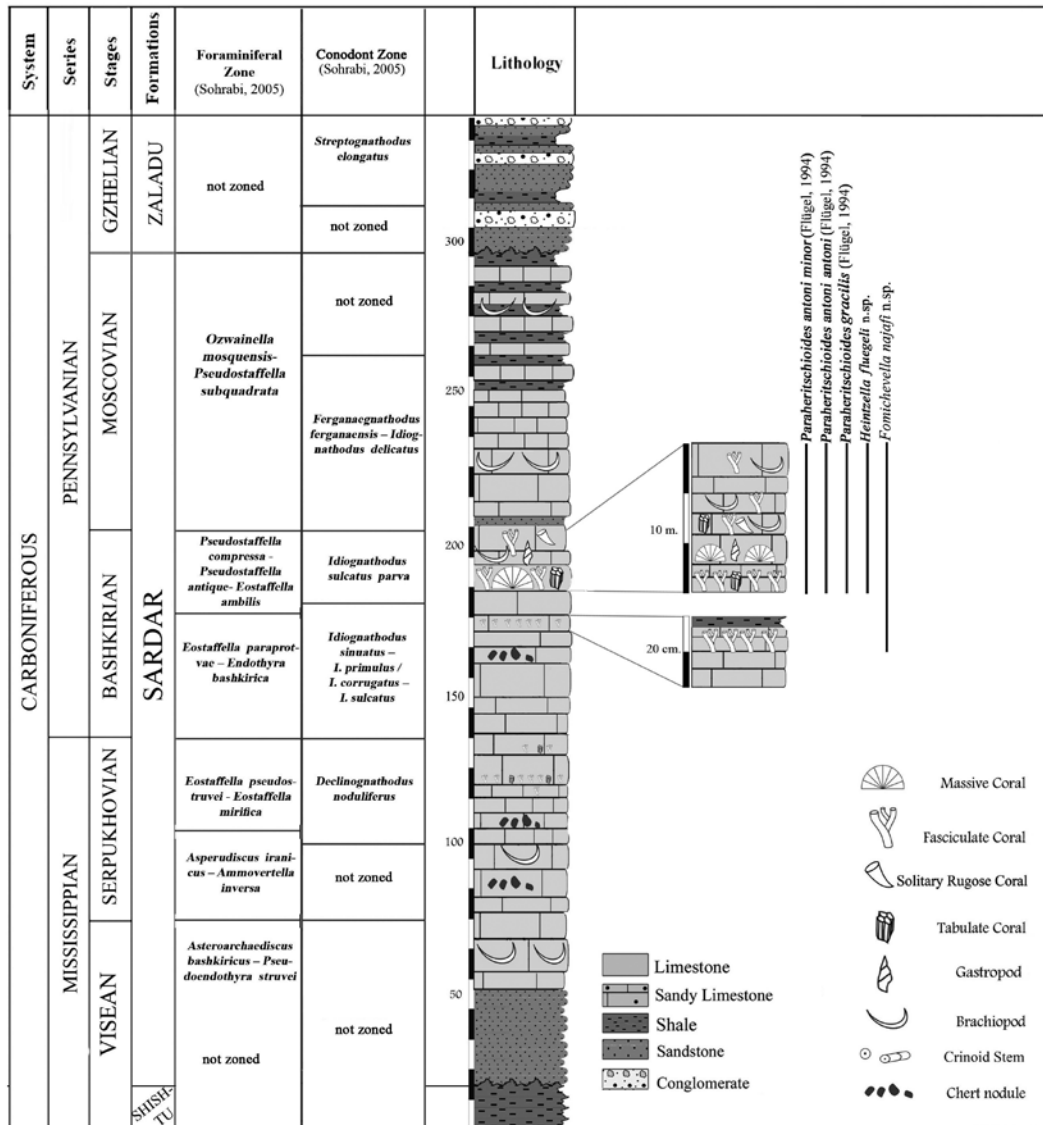


Figure 4. Generalized stratigraphical log of the Carboniferous succession in the Zaladu outcrop with the approximate position of the fossiliferous horizons and stratigraphic distribution of the rugose coral species.

Formation and is overlaid by the Zaladu Formation (Figures 2,4). Lithologically, the Sardar Formation can be divided into three parts. The lower part consists of about 30 m of sandstone (late Visean), the middle part consists of limestone with intercalations of shale (late Visean-Bashkirian) and the upper part consists of intercalations of limestone, shale, and sandstone (Moscovian).

CORAL HORIZONS

The studied corals were collected from two horizons in the middle part of the Sardar Formation (Figure 4). The lower horizon (~10 cm thick) is situated 167 m from the base of the formation. It yields only one genus of fasciculate rugose coral (*Fomichevella*). The matrix, embracing colonies is bioclastic wackestone. Study of the microfacies shows that they were formed in a lagoon of a shallow marine environment (Khanehbad, 2012).

Sohrabi (2005) studied the conodonts and foraminiferal assemblages in the Zaladu stratigraphic section and she indicated the early Bashkirian age for the mentioned horizon. It spans *Eostaffella paraprotvae-Endothyra bashkirica* foraminiferal zone and *Idiognathoides sinuatus, Idiognathoides primulus-Idiognathoides corrugatus-Idiognathoides sulcatus* conodont zone.

The upper horizon contains bundle of several fossiliferous limestone layers across an unit 5-10 m thick (173 m above the base of the formation). It yielded assemblages of fasciculate (*Fomichevella, Heintzella, Paraheritschioides, Heritschioides, Opiphyllum*), cerioid rugose (*Minatoa, Klepatrina*) and tabulate corals (*Multithecopora, Michelinia*). The matrix is a dominantly bioclastic wackestone-packstone. The limestones of this horizon contain brachiopods, gastropods, crinoids, and bryozoan remains. Study of the microfacies has shown that they were precipitated in a lagoon

to open marine of a shallow marine carbonate ramp platform environment (Khanehbad, 2012).

Conodonts and foraminiferal assemblages (Sohrabi, 2005) indicated a middle Bashkirian age for this horizon. It spans *Pseudostaffella compressa*, *P. antique*, *Eostaffella ambilis* foraminiferal zone and *Idiognathoides sulcatus parva* conodont zone (Figure 4).

SYSTEMATIC PALEONTOLOGY

The newly collected material is housed in the museum of the Ferdowsi University of Mashhad, Iran. The terminology used in this paper follows Hill (1981) with some additions by Fedorowski *et al.* (2007).

Subclass RUGOSA Milne-Edwards & Haime, 1850
Order STAUROIDA Verrill, 1865
Family KLEOPATRINIDAE Fedorowski,
Bamber & Stevens, 2007

Fomichevella Fedorowski, 1975

Type species. *Campophyllum hoeli* Høltedahl, 1913, Upper Carboniferous, base of *Fusulina* Limestone, west of Green Harbour, Vestspitsbergen.

Diagnosis. Fasciculate Kleopatriniidae with axial structure weakly developed in immature growth stages or entirely absent; cardinal septum shortened, in open cardinal fossula; lonsdaleoid dissepiments rare; tabularium biform where minor septa cross dissepimentarium (Fedorowski *et al.*, 2007).

Fomichevella najafi n. sp.

(Figures 5A₁₋₆, B₁₋₂)

1994 *Fomichevella uralica* (Dobrolyubova, 1936), Flügel, p. 607, pl. 3, figs. 1, 2.

Etymology. This species is named in honor of Dr. Mehdi Najafi, who encouraged the first author to study this fauna.

Holotype. Specimen 90 BZ 5-13.

Type locality. East central Iran, Zaladu Section.

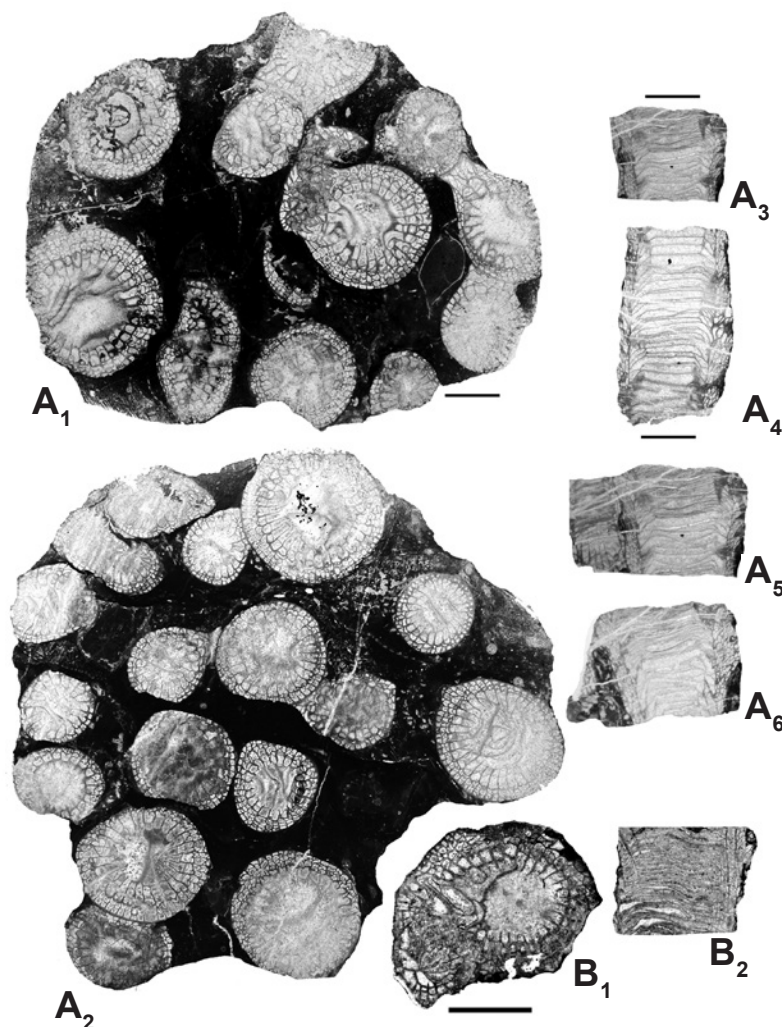


Figure 5. A-B, *Fomichevella najafi* n. sp. from the Zaladu Section: specimen 90BZ 5-13 (holotype), A_{1,2}, successive transverse sections; A₃₋₆, longitudinal sections; B, specimen 90BZ 42, B₁, transverse sections, B₂, longitudinal sections through specimen. Scale bars = 5 mm.

Type horizon. Early-middle Bashkirian, Sardar Formation.

Material. Five colonies including the holotype (52 corallites in 15 transverse serial sections, 13 longitudinal sections, 90 BZ 5-13, Sdo8, BZ 16, BZ 53, BZ 42). Specimens 90 BZ 5-13, BZ 42, BZ 16 and, BZ 53 were collected in the Zaladu Section, Sdo 8 comes from the Shishtu Section, and the Tangal-e-zireh Section.

Occurrence. Early-middle Bashkirian, East central Iran, Ozbak-kuh Mountains.

Diagnosis. *Fomichevella* with n:d values 26-27:13-14 mm, 30-34:15 mm, 32-35:15.5-16 mm; dissepimentarium composed of up to eight rows of dissepiments; minor septa very different in length; cardinal septum maybe shortened but commonly indistinct; short cardinal fossula not always well developed.

Description. Corallum is phaceloid. Corallites are sub-cylindrical, closely spaced, with lateral increase. In transverse section, the outer wall is about 0.1-0.2 mm thick. Corallite are 10-16 mm in diameter. n: d values (number of septa to corallite diameter value) of corallites 20-24:8-8.5 mm, 21:9.5 mm, 20-23:10 mm, 21-26:11-11.5 mm, 26-27:13-13.5 mm, 26:14 mm, 30-34:15 mm, 32-35:15.5-16 mm (Figure 6). The major septa are commonly 2-5 mm in length, straight or slightly sinuous, thin in dissepimentarium and dilated in tabularium, except near the axis. The cardinal septum may be shortened (Figure 5A₁) but commonly indistinct or as long as its neighboring major septa (Figures 5A_{1,2}). The cardinal fossula is commonly indistinct. The minor septa are differentiated in length, 0.2 to 1.0 mm and about 1/3 of the length of the major septa (Figures 5A_{1,2}, B₁) and commonly penetrating into tabularium. The dissepimentarium is 2-4 mm wide and is composed of 1-8 rows of small, globose dissepiments at the periphery and elongated ones near the tabularium boundary, with inner walls of the innermost row thickened by sclerenchyma (Figures 5A-B). The tabularium is 7-11 mm wide, tabulae are complete and incomplete, mostly trapezoid, some slightly convex or sagging axially, with 1-3 long axial tabellae, attached to a given tabula; peripheral tabellae are rare, short, elevated less distinctly than peripheral parts of tabulae. There are about 12-17 tabulae per centimeter (Figures 5A_{3,5}, B₂).

Remarks. This species differs from the type species, *Fomichevella hoeli* Holstedahl, 1913 from the Upper

Carboniferous of west of Green Harbour, Vestspitsbergen, by smaller diameter and more septa or Iranian species in similar diameters has higher number of septa. n:d values of Vestspitsbergen species is 24-31:16-20 mm, whereas *Fomichevella najafi* n. sp. n:d has values of 26-27:13-14 mm, 30-34:15 mm, 32-35:15.5-16 mm. The cardinal septum in the type species is slightly shortened but in the Iranian species is commonly indistinct. Tabulae of *F. najafi* n. sp. are complete and incomplete, mostly trapezoid, with 1-3 axial tabellae; peripheral tabellae are rare; but tabularium in the type species, *F. hoeli* is wide, with complete tabulae usually flat, less commonly slightly convex or concave. *F. najafi* n. sp. differs from the Ural species *F. uralica* (Dobrolyubova, 1936) by smaller diameter and less septa. Flügel (1994) reported *F. uralica* from the Bashkirian of the Ozbak-Kuh Mountains, but he did not notice to different n:d values of two species, so that Flügel's species n: d values of corallites 23-27:11-17 mm, and in maximum in the mature corallites it has 30-31 septa. But *F. uralica* has n:d values of 41: 24-33mm, 38: 23-30 mm, 36:12-20mm, 26:15-18 mm. The revision of topotypes of corals attributed to *F. uralica* by Flügel (1994) allow the re-attribution of this material to the new species *F. najafi* n. sp.

The new species is similar in size to *Fomichevella longiseptata* Zhu & Zhao, 1992 but has shorter septa. Moreover, *F. longiseptata* has major septa thick in tabularium and thin in dissepimentarium (particularly in the cardinal quadrants), whereas the thickness of the septa is constant in *F. najafi* n. sp. *F. sotoi* Rodríguez, 1984 from the Bashkirian of the Cantabrian Mountains has a similar diameter but have more septa and more regular dissepiments. *Fomichevella najafi* n. sp. is different from *F. smithi* Fontaine, Ibrahim & Vachard, 2003 in diameter of corallites; Malaysian species has more septa (with n: d values 24-36:10-13 mm), in similar diameters in comparison with *F. najafi* n. sp. (with n: d values 20-27:10-13 mm), but Iranian species is longer than in size of corallites at maturity stage up to 27-35 septa in 13-16 mm.; *F. smithi* have typical thick septa (Fontaine *et al.*, 2003). Moreover, the minor septa of *F. smithi* are also longer (up to 3/4 of the length of major septa whereas in *F. najafi* n. sp., they are about 1/3 of the length of the major septa). The cardinal fossula of *F. najafi* n. sp. is commonly present but it is not well marked in *F. smithi*, moreover the Iranian species has more tabulae per centimeter.

Heintzella Fedorowski, 1967

Type species. *Heintzella multiseptata* Fedorowski, 1967, lower Permian, Treskelodden, Vestspitsbergen.

Diagnosis. Fasciculate Kleopatriniidae with axial structure interrupted, irregular, commonly lacking median lamella, open cardinal fossula generally present; cardinal septum variably shortened, lonsdaleoid dissepiments rarely present; microstructure finely trabecular (Fedorowski *et al.*, 2007).

Heintzella fluegeli n. sp.
(Figures 7A₁₋₁₂)

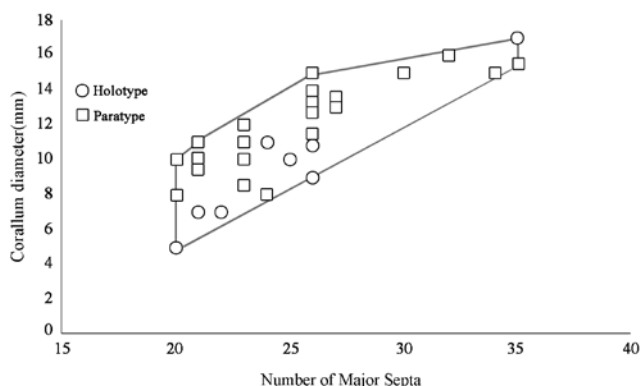


Figure 6. Scatter diagram showing the number of septa plotted against corallum diameter for *Fomichevella najafi* n. sp.

Etymology. This species is named in honor of Dr. Helmut W. Flügel, who has contributed significantly to the study of Paleozoic corals of Iran.

Holotype. Specimen 90 BZ 5-14.

Type locality. East central Iran, Zaladu Section.

Type horizon. Middle Bashkirian, Sardar Formation.

Material. Four colonies including the holotype (17 Transverse sections, 3 longitudinal sections, 90 BZ 5-14, Sah 23, Sah 35, Sdo 27). Specimens 90 BZ 5-14, Sah 23, Sah 35 were collected in the Zaladu Section, Sdo 27 comes from the Tangal-e-zireh Section.

Occurrence. Middle Bashkirian, East central Iran, Ozbak kuh Mountains.

Diagnosis. *Heintzella* with n:d values of corallites 27-30:13 mm, 31:16 mm. Septa thin in dissepimentarium, taper axially. 3-6 rows of herringbone, pseudoherringbone dissepiments, regular dissepiments and few lonsdaleoid dissepiments interrupting minor septa.

Description. Corallum is phaceloid. Corallite walls are approximately 0.1 mm thick. Corallites are cylindrical, 12-16 mm in diameter. There are 26-31 septa of each order in mature corallites. n:d values of corallites 27: 12-14 mm, 27-30:13 mm, 31:16 mm (Figure 8). Septa are straight to sinuous. The major septa are generally 3-4.5 mm-long (~1/2 corallite radius), except for cardinal septum, which is commonly

shortened; 1-1.5 mm in length (Figures 7A_{3,6,8-11}) or may be as long as neighboring major septa. The major septa are thin in the dissepimentarium and dilated in the tabularium, tapering axially. The minor septa have different length; they are 0.5-2 mm long, generally confined to dissepimentarium (Figure 7A₃), some may penetrate tabularium (Figure 7A₈), some of them interrupted by small lonsdaleoid dissepiments (Figure 7A_{6,8-10}). The cardinal fossula is distinct (Figures 7A_{3,4,6,9,10}) but not always well developed (Figure 7A_{1,5,7}). The axial structure is very simple, composed of a weak median plate sometimes attached to the axial ends of one major septa. There are occasional axial tabellae. The dissepimentarium is 2.5-4 mm wide with 3-6 rows of mostly herringbone and pseudo-herringbone dissepiments (Figures 7A_{4,6}). Regular interseptal dissepiments are common (Figures 7A_{1,4,11}). There are few lonsdaleoid dissepiments (Figures 7A_{6,9-11}). Tabulae are complete and incomplete, locally steeply elevated toward median lamella (Figure 7A₁₂), mostly trapezoid, some slightly convex or sagging, long axial tabellae are attached to a simple median plate. They are short, elevated less distinctly than peripheral parts of tabulae. There are about 12 tabulae per cm (Figure 7A₁₂).

Remarks. *Heintzella fluegeli* n. sp. is distinguished from the type species, *H. multiseptata* Fedorowski, 1967 from the Lower Permian of Vestspitsbergen, by its smaller diameter

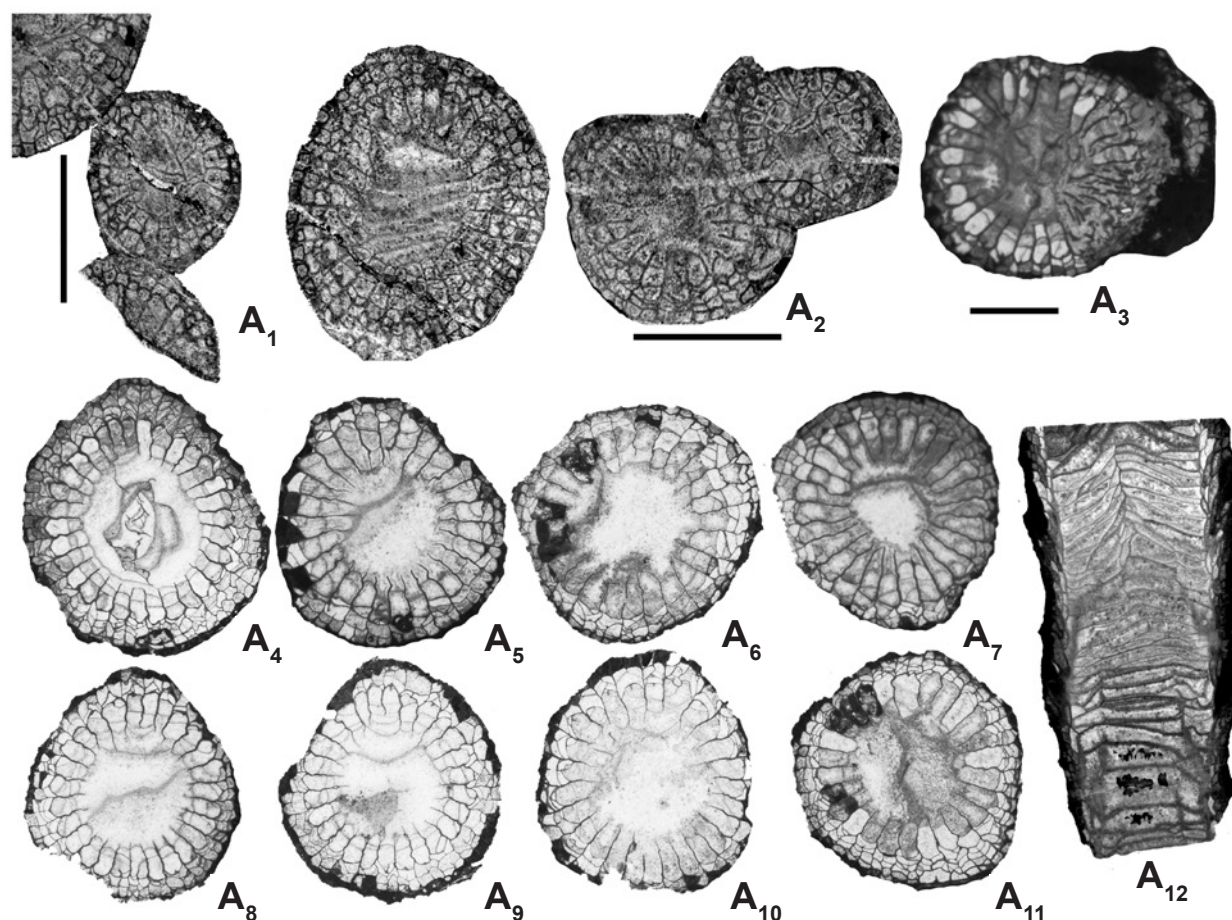


Figure 7. A, *Heintzella fluegeli* n. sp. from Zaladu Section: A, specimen 90BZ5-14, holotype, A₁₋₁₁, successive transverse sections, A₁₂, longitudinal section. Scale bars = 5 mm.

and fewer septa. Vestspitsbergen species with n:d values of 30-38:18-22 mm is different from the Iranian species with values of 27-31:12-16mm. *H. multiseptata* has longer major septa than the Iranian specimens ($3/4$ radius in Vestspitsbergen coral, whereas about $1/2$ corallite radius in the Iranian species). The minor septa of *H. multiseptata* are longer than minor septa of Iranian species. Minor septa reach to $1/3$ of corallite radius and are more penetrated into tabularium in *H. multiseptata* but they are different in length, less than $1/2$ to $1/3$ length of the major septa and generally confined to dissepimentarium in *H. fluegeli* n. sp. Dissepimentarium is narrow in *H. fluegeli* n. sp. (less than $1/4$ of corallite radius, whereas this value is $1/3$ in *H. multiseptata*). *Heintzella fluegeli* n. sp. has weak, vertically interrupted median lamellae, simpler axial structure and better developed dissepiments than *Heintzella borealis* Fedorowski, Bamber & Stevens, 2007) from early (?) Sakmarian of Spitsbergen and Canada. *H. fluegeli* n. sp. has 3-6 rows of herringbone, pseudo-herringbone dissepiments, concentric dissepiments, and fewer lonsdaleoid dissepiments, whereas *H. borealis* has 2-3 rows of irregular interseptal dissepiments. Moreover, *H. borealis* differs from the new species by longer minor septa and weaker sinuosity characteristic of the major septa. The minor septa of *H. borealis* are mostly penetrated into tabulae but in *Heintzella fluegeli* n. sp., they are much different in length and generally confined to dissepimentarium. Dissepimentarium width in *H. fluegeli* n. sp. is less than of $1/4$ radius, whereas it is measured $1/3$ in *H. borealis*). *Heintzella radiata* (Fedorowski, 1965) has a thicker axial plate. *H. densiseptata* (Fedorowski, 1964) has a denser axial structure.

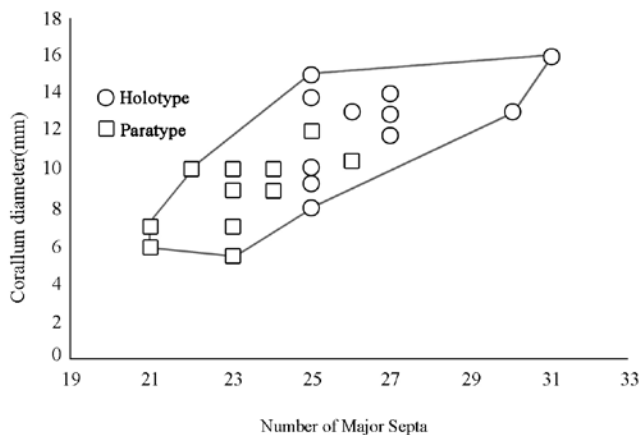


Figure 8. Scatter diagram showing the number of septa plotted against corallum diameter for *Heintzella fluegeli* n. sp.

Paraheiritschioides Sando, 1985

Type species. *Paraheiritschioides grandis* Sando, 1985, Upper Pennsylvanian Oquirrh Formation of the Western Interior Region (Idaho, USA).

Diagnosis. Fasciculate Kleopatrinidae with axial structure that may disappeared over short intervals of growth; discontinuous axial column within axial structure variably developed,

complex in some species; median lamella closely connected to counter septum; cardinal septum variable, not shortened in some corallites; dissepiments locally lonsdaleoid; tabularium indistinctly biform (Fedorowski *et al.*, 2007; Fedorowski & Stevens, 2014).

Paraheiritschioides antoni Flügel, 1994

1994 *Paraheiritschioides antoni* Flügel, p. 604, pl. 3, fig. 5,6; pl. 2, figs. 2-4.

Emended diagnosis. *Paraheiritschioides* with 10-20 mm in diameter and 23-35; major septa slightly withdrawn from axial structure consisting of a variable median plate and rare, short septal lamellae; major septa thin in dissepimentarium, dilated in tabularium; cardinal septum varies in length, equal to adjacent major septa in some corallites; cardinal fossula indistinct; minor septa half as long as major septa, locally entering tabularium; dissepiments herringbone, pseudo-herringbone, concentric and lonsdaleoid.

Paraheiritschioides antoni antoni Flügel, 1994 (Figures 9A₁₋₅, B₁₋₂, C₁₋₇)

1994 *Paraheiritschioides antoni antoni* Flügel, p. 604, pl. 3, figs. 5, 6.

Material. Fragments of three colonies (Vch 14, Vch 19, Vch 150). (25 transverse sections, five longitudinal sections). Colonies fragments of Vch 14, Vch 19 and Vch 150 were collected in the Cheshmeh-Shir Section.

Age and occurrence. Middle Bashkirian, East central Iran, Ozbak kuh Mountains.

Emended diagnosis. Subspecies characterized with n:d values 30:10-13 mm, 31:14mm, 32-35:15-20 mm. Dissepimentarium more complex with small lonsdaleoid dissepiments; cardinal septum shortened.

Description. Corallites are sub-cylindrical. There are 30-35 septa of each order at a diameter of 14-19 mm (Figures 9A₁₋₅, B_{1,2}, C₁₋₇) in mature corallites. n:d values 21: 6 mm, 25-27:8-10 mm, 30:10-13 mm, 31:14mm, 32-35:15-20 mm (Figure 10). The major septa are about $2/3$ of the corallite radius, commonly 5-7 mm long and 0.2-0.3 mm-thick, generally withdrawn from the axial structure, straight to slightly sinuous, dilated in tabularium and tapered axially. The cardinal septum is shortened (Figures 9A₁₋₅, B_{1,2}) or may be as long as neighboring major septa (Figures 9C_{1,2,6}). The counter septum is commonly elongated (Figures 9A_{1,2}). The minor septa are half as long as the major septa (1.5-2.5 mm-long) and restricted to the peripheral part of the dissepimentarium.

The axial structure is variable in width in mature corallites. They are connected to some or most major septa (Figures 9A_{1,2}, C₁₋₇), consisting of thin median lamella, more septal lamellae and/or inner margins of major septa, and several very steeply inclined axial tabellae (Figures 9C₁₋₇) to form distinct axial column. Axial structure in general trend from weakest in early ontogeny with few lamellae, to fairly

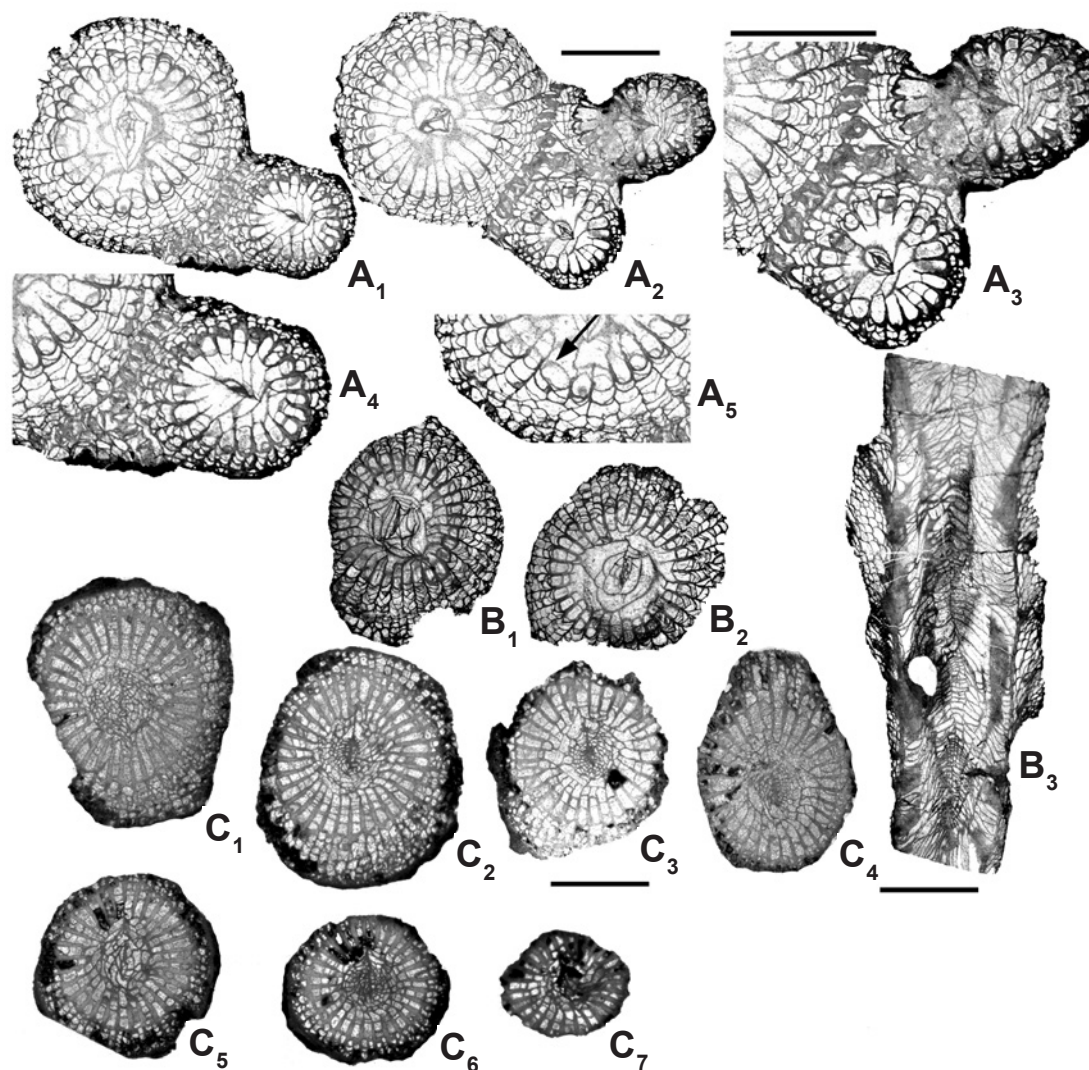


Figure 9. *Paraheritschioides antoni antoni* (Flügel, 1994) from Cheshmeh-Shir Section: **A**, specimen Vch19, **A**_{1,2}, successive transverse sections, **A**₃, enlarged from **A**₂, young corallite with simple axial structure connected to counter septum, **A**₄, enlarged from **A**₁, young corallite with simple axial structure connected to counter septum, **A**₅, enlarged from **A**₁ to document biform morphology; **B**, specimen Vch14, **B**_{1,2}, transverse sections, **B**₃, longitudinal section; **C**, specimen Vch150, **C**₁₋₇, successive transverse sections. Scale bars = 5 mm.

complex at maturity (Figures 9A_{1,2}, C₁₋₇). Several exceptions to general trend occur: axial structure may be comparatively complex in early ontogeny (Figure 9C₁) or weak at maturity (Figures 9A_{1,2}); median lamella elongated, thin curved and commonly attached to counter septum (Figures 9A_{1,2}), thus indicating its derivation from that septum; in weak axial structure axial tabellae are strongly reduced in number. The dissepimentarium is 4-8 mm-wide and composed of 5-7 rows of mostly herringbone, pseudo-herringbone, and few lonsdaleoid dissepiments (Figures 9A_{1,2}). The tabularium is 5-12 mm-wide, with biform morphology (Figures 9A_{1,5}). It consists of mostly complete tabulae and several very steeply inclined axial tabellae (Figures 9C₁₋₇) to form distinct axial column. There are 14-16 tabulae per centimeter (Figures 9B_{1,2}).

Remarks. The present specimens have lonsdaleoid dissepiments, the feature that is not present in the holotype of *Paraheritschioides antoni antoni*. *Heritschioides vepres*

Flügel, 1994 from the Bashkirian of central Iran, has an axial plate elongated towards the cardinal septum, more extra septal lamellae in the axial structure, which is isolated from the tabularium by vertically arranged lateral tabellae. Unlike *H. vepres*, *P. antoni antoni* possesses a continuous to discontinuous axial structure with a discontinuous axial column and its median lamella is connected to counter septum. *Protodurhamina strelzovkensis* Kozyreva, 1978 unlike *Paraheritschioides* do not clearly show the shortened cardinal septum or the linked axial tabellae. In addition, *P. antoni antoni* differs from latter Russian species by the median lamella of axial structure connected to counter septum in young corallite and lonsdaleoid dissepiments. Fedorowski (2004) emended the diagnosis of *Corwenia* and stated that the median lamella of *Corwenia* stronger connected with cardinal septum and there are open cardinal fossula. *P. antoni antoni* differs from *Heintzella stuckenbergi* (Dobrolyubova, 1936), from the Ural; Iranian species with similar diameters has higher number of

septa; moreover has a stronger median lamella and complex axial structure and lonsdaleoid dissepiments.

Paraheritschioides antoni antoni differs from *P. jagoensis* (Armstrong, 1972) from the early Atokan (Bashkirian) of Alaska and NW California by more septa and a simpler axial structure. *P. antoni antoni* has n:d values 30:10-13 mm, 31:14mm, 32-35:15-20 mm but these values are measured 29-32:16-18mm in *P. jagoensis*. *Paraheritschioides compositus* Fedorowski & Stevens, 2014 from the early Atokan (Bashkirian) and *P. katvalae* Fedorowski & Stevens, 2014 from the Moscovian of Alaska and NW California differs from *P. antoni antoni* by a smaller diameter, less septa, major septa approaching to the axial structure and a narrow dissepimentarium.

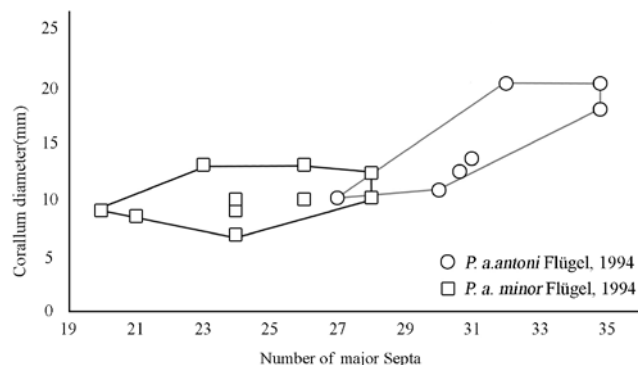


Figure 10. Scatter diagram showing the number of septa plotted against corallum diameter for *Paraheritschioides antoni antoni* (Flügel, 1994) and *P. antoni minor* (Flügel, 1994).

Paraheritschioides antoni minor Flügel, 1994
(Figures 11A₁₋₆, B₁₋₃, C₁₋₄, D₁₋₅)

1994 *Paraheritschioides antoni minor* Flügel, p. 605, pl. 2, figs. 2-4.

Material. Fragments of six colonies (Sdo 7, Sdo 22, Sdo 24, Sdo 121, Sdo 123, Sdo 130, Sz 5, Sz 6, Sz 8) (17 transverse sections and 8 longitudinal sections). Colony fragments Sdo 7, Sdo 22, Sdo 24, Sdo 121, Sdo 123 and Sdo 130 were collected in the E-Shishtu Village, in the Tangal-e-zireh Section. Colonies of Sz 5, Sz 6 and Sz 8 collected in the Zaladu Section.

Age and occurrence. Middle Bashkirian, East central Iran, Ozbak kuh Mountains.

Emended diagnosis. Subspecies characterized with n:d values 23-28:10-14mm. cardinal septums slightly shortened, counter septum elongated.

Description. The corallites are sub-cylindrical, 6.5-14 mm in diameter. There are 19-28 septa of each order (Figure 11), n:d values 19:6.5 mm, 22-24:7 mm, 21: 8.5-9.5 mm, 20-24:9 mm, 23-26:10 mm, 28:10.5 mm, 23-28:11-13 mm (Figure 10). The major septa are commonly 2-4 mm-long and 0.25 mm-thick. They are straight, more than 2/3 of the corallite radius in length, mostly withdrawn from the axial structure. The cardinal septum is slightly shortened and 1.5-3.5 mm-long (Figures 11A_{1,2,4,5}, D₁₋₄). The axial ends of some major septa

are connected to the margin of the axial structure. The minor septa are 1-2 mm long, and extend into the tabularium. The axial structure consists of a thin elongated median lamella 2-4 mm long (Figures 11A_{1,2,4}, C₁₋₃, D₁₋₄), commonly attached to counter septum (Figures 11A_{1,2,4,5,6}, C₃, D₁₋₄) and a few septal lamellae (Figures 10A_{4,5}, B₃, C_{1,2}, D₁₋₄). Morphology of the axial structure varies at the mature growth stage from comparatively simple to complex with several septal lamellae incorporated (Figures 11A₅, B_{1,2}). The dissepimentarium is 2-4 mm wide, consists of 1-7 rows of concentric dissepiments. The tabularium is 5-8.5 mm-wide, composed of generally concave, complete tabulae and several steeply inclined axial tabellae (Figures 11C₄, D₅) to form interrupted axial column. There are 16 tabulae per centimeter (Figures 11C₄, D₅).

Remarks. This subspecies does not appear to be a durhaminid, as suggested by Fedorowski *et al.* (2007, p. 96), because the smallest specimen shows major septa, except for the counter septum, withdrawn from the axial region, the cardinal septum is shortened, and the axial structure is continuous, however this species is assigned to the Kleopatrinidae.

Paraheritschioides antoni minor differs from *P. jagoensis* (Armstrong, 1972) from the early Atokan (Bashkirian) of Alaska and NW California by a smaller diameter, less septa (*P. antoni minor* with n:d values 23-26:10 mm, 28:10.5 mm, 23-28:11-13 mm but *P. jagoensis* with n:d values 29-32:16-18mm); simpler axial structure and narrow dissepimentarium. *Paraheritschioides compositus* Fedorowski & Stevens, 2014 from the early Atokan (Bashkirian) of Alaska and NW California is distinguished from *P. antoni minor* by more developed axial structure, narrow dissepimentarium and major septa approaching the axial structure; n:d values of *P. compositus* are 23:8 mm to 25:9.5 mm; but *P. antoni minor* has a larger diameter and more septa with values of 23-26:10 mm, 28:10.5 mm, 23-28:11-13 mm. *Paraheritschioides katvalae* Fedorowski & Stevens, 2014 from the Moscovian of Alaska and NW California differs from *P. antoni minor* by a smaller diameter, less septa number (most common n:d value 20:7.0mm.), more developed axial structure and narrow dissepimentarium.

In comparison with the type species of the genus, *Paraheritschioides grandis* (Sando, 1985) from the upper Pennsylvanian (Missourian or Virgilian) of Idaho, *P. antoni minor* has a wider range of dimensions, shorter major septa and more rows of dissepiments. However, *P. grandis* has some large lonsdaleoid dissepiments whereas *P. antoni minor* has none.

Paraheritschioides gracilis Flügel, 1994
(Figures 12A_{1,9}, B, C₁₋₅)

1994 *Paraheritschioides gracilis* Flügel, p. 605, pl. 3, figs. 8-10.

Material. Four colonies (C4, BZ 87, Sdo6, Sdo 21). (five transverse sections, two longitudinal section). Colonies specimens BZ 87 and C4 collected in the Zaladu Section, specimens Sdo6, and Sdo 21 were collected in the the Tangal-e-zireh Section.

Occurrence. Middle Bashkirian, East central Iran, Ozbak kuh Mountains.

Emended diagnosis. *Paraheritchioides* with n:d values 26:10 mm to 20:7.5-8 mm; major septa mainly withdrawn from corallite axis; most minor septa intersect narrow dissepimentarium; axial structure consists of thin median lamella alone, with a few septal lamellae in some corallites.

Description. The corallites are sub-cylindrical with lateral increase and thin walls. They are 6-10 mm in diameter and have 19-26 septa of each order; n:d values of mature corallites 19:6 mm, 20:7.5-8, 21:8 mm, 26:10 mm (Figure 13). The major septa are commonly 1-4 mm-long (1/2-2/3 of the

corallite radius) and less than 0.1 mm-thick, straight to slightly sinuous, tapering axially. The cardinal septum is shortened; the counter septum is occasionally elongated (Figures 12A_{1,4,5}, B, C₂). The minor septa vary in length between corallites and at different growth levels of individual corallites, they mostly 0.5-1.5 mm long, and 1/2- 1/3 of the major septa, inner margins of longest minor septa thin, penetrate tabularium (Figures 12A_{7,8}, B, C_{3,4}). The axial structure is discontinuous and simple. It consists of the thin median lamella accompanied by a few, short septal lamellae, the inner margins of major septa in some corallites, and some very steeply inclined axial tabellae (Figures 12A_{2,3,4,5}, B, C_{1,5}). The median lamella may

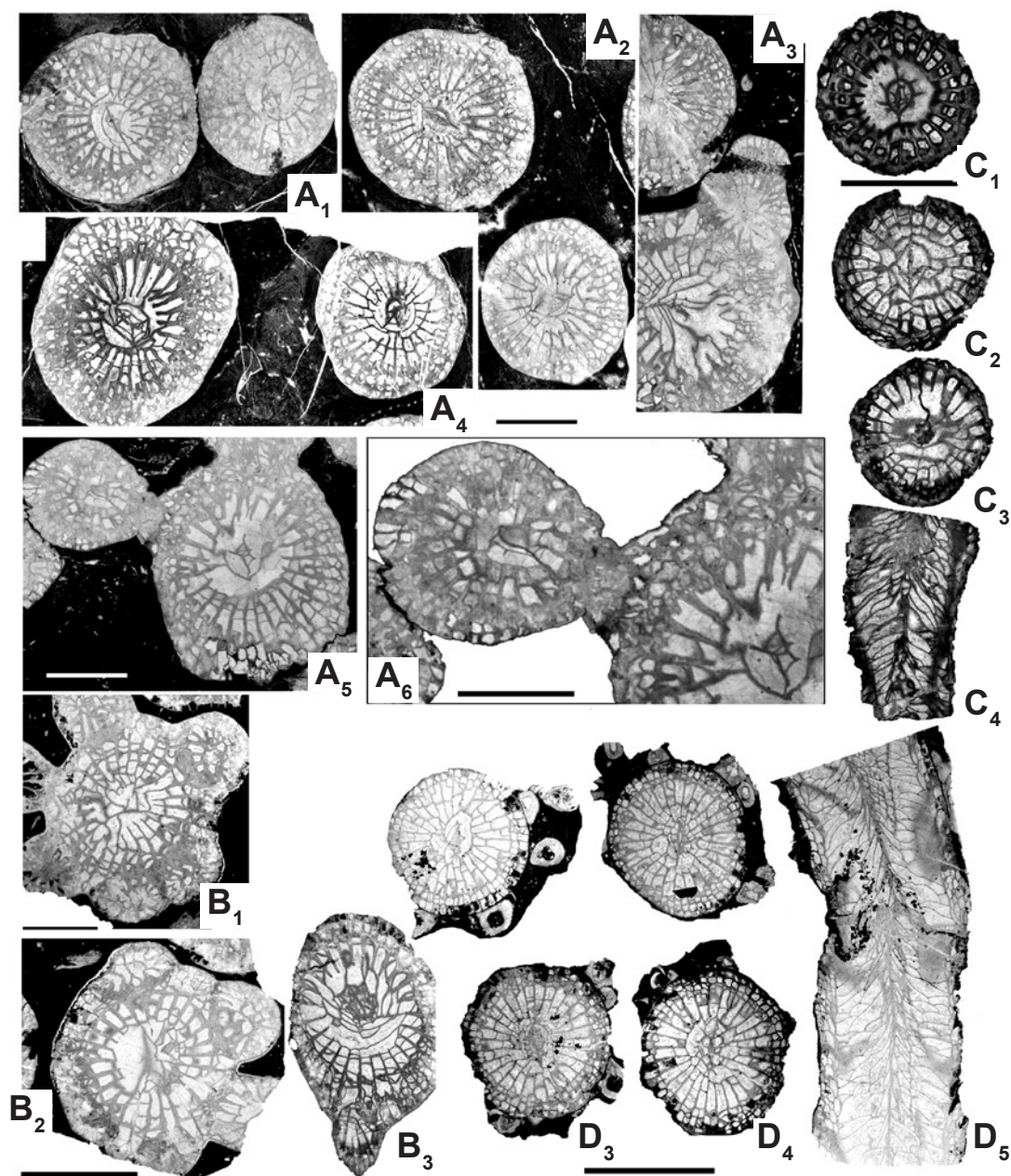


Figure 11. *Paraheritchioides antoni minor* (Flügel, 1994) from Zaladu and E-Shishtu village, Tangal-e-zireh: A, specimen Sz5, A₁₋₆, successive transverse sections, A₇, enlarged from A₅, young corallite with simple axial structure connected to counter septum; B, specimen Sz6, B₁₋₃, successive transverse sections; C, specimen Sz8, C₁₋₃, successive transverse sections, C₄, longitudinal section; D, specimen Sdo24, D₁₋₄, successive transverse sections, D₅, longitudinal section. Scale bars = 5 mm.

be absent from a weak axial structure (Figures 12A₁, B, C₂₋₄); when present, median lamella elongated, thin, irregularly curved and commonly attached to counter septum (Figures 12A_{1,4-6}, B); in weak axial structure axial tabellae strongly reduced in number or absent. The dissepimentarium is narrow, 0.5-3.5 mm wide, which mostly composed of 2-3 rows of regular and concentric dissepiments. The tabularium is 1-5 mm wide; it consists of mostly complete tabulae, gently elevated towards the axial structure and some steeply inclined

axial tabellae (Figures 12A_{2,3}, C₅). There are about 12 tabulae per centimeter (Figures 12A_{2,3}, C₅).

Remarks. *Paraheritschioides gracilis* bears all the main characteristics of the genus, although none is fully developed. This species is readily distinguishable by this simple feature from another species of the genus. *P. gracilis* differs from the type species *P. grandis* (Sando, 1985) from the late Pennsylvanian (Missourian or Virgilian) of Idaho by a smaller diameter, a less complex axial structure with lesser tabellae

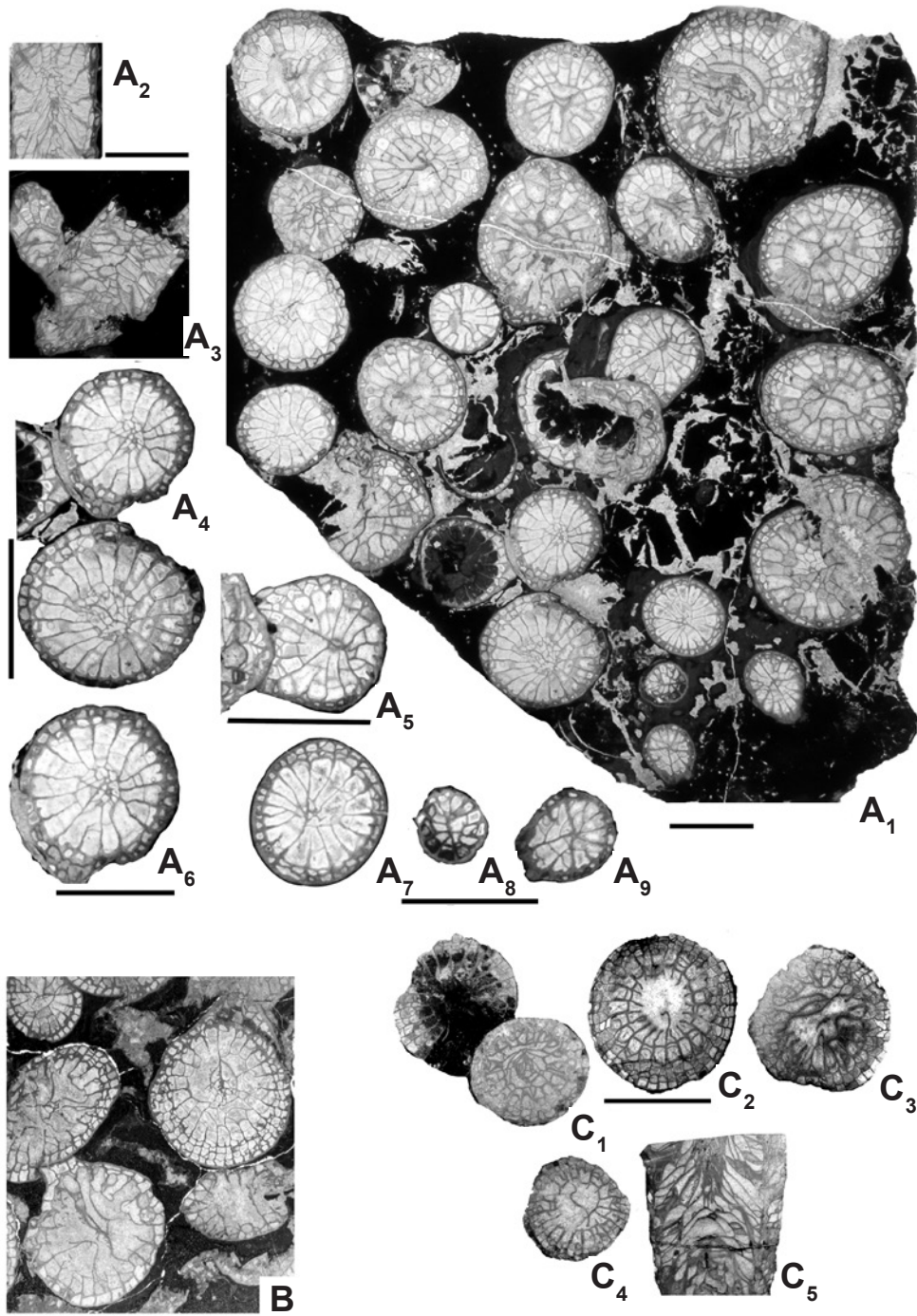


Figure 12. *Paraheritschioides gracilis* (Flügel, 1994): **A**, specimen Sdo6, A₁, transverse section, A₂₋₃, longitudinal sections, A₄₋₉, transverse sections, enlarged from A₁, corallites with simple axial structure connected to counter septum; **B**, specimen C4, transverse section; **C**, specimen Bz87, C₁₋₄, successive transverse sections, C₅, longitudinal section. Scale bars = 5mm.

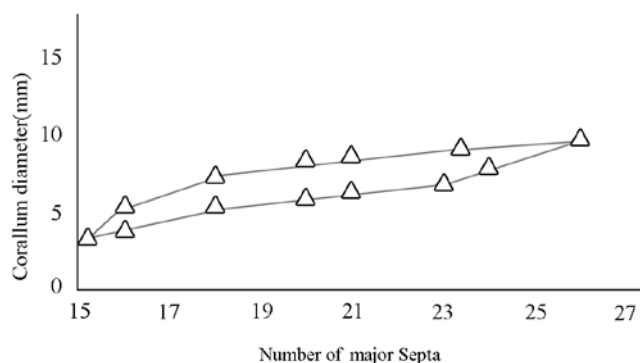


Figure 13. Scatter diagram showing the number of septa plotted against corallum diameter for *Paraheritschioides gracilis* (Flügel, 1994).

and axial lamellae. *Paraheritschioides* sp. (Fedorowski *et al.*, 2012) from the late? Bashkirian of the Sverdrup Basin with n:d values of mature corallites 16:5.9 mm, 16:6.5 mm, 17:7.0 mm. is smaller and has less septa than *P. gracilis* with n:d values 20:7.5-8 mm, 26:10 mm. *Paraheritschioides* sp. has a more complex axial structure, more tabellae and more axial lamellae (Fedorowski *et al.*, 2012). *P. compositus* Fedorowski & Stevens, 2014 from the early Atokan (Bashkirian) of Alaska and NW California is distinguished from *P. gracilis* by more developed axial structure with more septal lamellae and axial tabellae, longer major septa approaching to the axial structure. *P. katvalae* Fedorowski & Stevens, 2014 from the Moscovian of Alaska and NW California differs from *P. gracilis*. Maximum corallite diameter of *P. katvalae* is 7.5mm. In this species n:d values are 18:6.5mm, 19:6.3mm, 20:6.0, 6.5, 7.0, 7.5mm, 21:6.0, 7.0mm. with most common n:d value of 20:7.0mm, but the Iranian species has a larger diameter and more septa with values of 19:6 mm, 20:7.5-8, 21:8 mm, 26:10 mm. *P. katvalae* has longer major septa, more developed axial structure with more tabellae and more axial lamellae and thickened median lamella.

DISCUSSION

There are few studies about the Late Carboniferous coral faunas in the Central and the other localities in Iran. Therefore, conducting a study to find out the similarities within these areas can be troublesome. In addition, the information on the Late Carboniferous coral faunas of the Ozbak-kuh Mountains in the East Central Iran is confined to a few works (*e.g.* Flügel, 1974, 1975, 1994). Nonetheless, the studies carried out by Flügel (1974, 1975, 1994) provide little information on morphological variability of the region; hence, making a thorough comparison can be problematic. Moreover, there are still unanswered questions with regard to the coral faunas of the above-mentioned areas, especially the colonial forms which were taxonomically revised and summarized by Fedorowski *et al.* (2007, 2012, 2014a,b), and Fedorowski & Stevens (2014).

Flügel (1994) reported the genus *Paraheritschioides* in the Ozbak-kuh Mountains and suggested that it belongs to Bashkirian age. His suggestion was based on the studies of

brachiopods carried out by Stepanov (1971) and conodonts conducted by Weddige (1984). In addition, the findings of the studies on foraminiferal (Sohrabi, 2005; Leven *et al.*, 2006) and conodonts data (Sohrabi, 2005) corroborate Flügel's suggestion. However, we found a new composition of corals in these studied areas that indicated the late Serpukhovian/early Bashkirian foraminifers and conodonts (Sohrabi, 2005) and allowed a new approach to the genus *Paraheritschioides* by Badpa *et al.* (2011).

Fedorowski *et al.* (2007, p. 96) mentioned that "Generic affinities are difficult to determine for the Bashkirian species described by Flügel (1994, p. 604-606) and assigned to *Paraheritschioides*." They excluded these species from the genus "because they appear to have durhaminid or clisiophyllid morphology in their axial structures" (Fedorowski *et al.*, 2007, p. 96). Unfortunately, we did not have access to the holotype and paratypes of Flügel's species; however, in this study, we collected many topotype materials from the type localities that had been studied by Flügel (1994). The *Paraheritschioides* that we found belong to the family Kleopatriniidae. The *Paraheritschioides* that we studied are similar in n:d values to Flügel's species. In addition, because they have the median lamella derived from the counter septum in offsets they belong to the family Kleopatriniidae. Thus, contrary to Fedorowski *et al.* (2007) opinion, Flügel's and our samples have the main characters of genus *Paraheritschioides*.

The revision of topotypes of corals attributed to *Fomichevella uralica* by Flügel (1994) allowed the re-attribution of this material to a new species called *F. najafi* n. sp. that differs from the Russian species by smaller diameter and less septa number. Flügel (1994) reported *F. uralica* from the Bashkirian of the Ozbak-Kuh Mountains, but he did not reported the n:d values of two species.

Palaeobiogeography

The Ozbak-Kuh Mountains (in East Central Iran) were the north-west margin of Gondwana (Figure 14) and edged northward by a carbonate platform during the late Carboniferous. Contrary to the other parts of Iran in the Ozbakkuh Mnts. (In East Central Iran) marine conditions did not change considerably and the shallow water carbonate ramp of Visean continued to Moscovian.

Based on their species level, these fauna are local to Central Iran; therefore, there is no faunistic connection or relation between coral faunas of the Central Iran and the neighbouring blocks.

Based on their generic level, *Fomichevella*, *Heintzella* and *Paraheritschioides* are confined to the study areas and have not been reported from other parts of Iran. *Fomichevella* and *Heintzella* are present around cratonic margin of Laurasia, the Chinese microcontinent, and northernmost Gondwana and in North America during the Carboniferous (García-Bellido & Rodríguez, 2005) (Figure 14). The presence of *Paraheritschioides* among the Central Iran coral composition is remarkably similar to the fauna reported from C.A.U realm (Fedorowski *et al.*, 2007) such as the Arctic Canada, the northwestern margin of the Sverdrup Basin (Fedorowski *et al.*,



Figure 14. Distribution of Kleopatriniid coral faunas in bioprovinces of the Late Carboniferous (320Ma). **Abbreviations:** KZ, Khazakhstan; U, Urals; Sp, Spitsbergen; CA, Canadian Arctic (Sverdrup Basin); EA, eastern Alaska; S, Stikine terrane (western British Columbia); EK, Eastern Klamath terrane (northern California); Mo, Morocco; NC, North China; SC, South China; TM, Tarim; Tr, Taurides, Turkey; SS, Sanandaj-Sirjan; Alb, Alborz; T, Tabas; cA, Central Afghanistan; Tib, Tibet; Sibumasu, Siam-Burma-Malaya-Sumatra, Aus, Australia.

2012), Klamath mountains, in NW California, the Alexander terrane and Brooks Range in southeastern Alaska (Armstrong, 1972, Fedorowski & Stevens, 2014). Furthermore, based on their generic level, composition of the Central Iran colonial corals including *Heritschioides*, *Minatoa* and *Kleopatrina* (*porfirievella*) *bashkirica* mentioned by Flügel (1974, 1994) and Badpa *et al.* (2011, 2014), show a close affinity between Iranian fauna and those of the Northern provinces of Urals, Novaya Zemlja (Gorsky, 1938, 1951, Fedorowski & Stevens, 2014), the Kuiu Island area and Brooks Range, Alaska (Armstrong, 1972, Fedorowski & Stevens, 2014, Fedorowski *et al.*, 2014) (Figure 14).

The faunal similarities between the South West of Paleotethys's corals association with coeval biota in the Arctic could be due to continuity of tropical warm water conditions in the northern hemisphere and connection with south western of Paleotethys ocean during the Bashkirian. The studies carried out on fossil groups other than corals, such as brachiopods by Angiolini *et al.* (2007), foraminifera (Leven & Gorgij, 2006), crinoids (Webster *et al.*, 2003) and palynomorphs (Angiolini & Stephenson, 2007), indicate that the late Carboniferous-early Permian Iranian fauna is similar to coeval biota from the warm Boreal Realm (Shi, 1998; Fedorowski *et al.*, 2007) of the Arctic and Urals (Figure 14). The findings of the present study gives an idea for late Carboniferous corals' evolution and larval migration that lived in the northern margin of the Gondwana.

CONCLUSION

There are an assemblage of Fasciculate Kleopatriniid rugose corals in the Bashkirian of East Central Iran (Ozbak-Kuh Mnts.); belonging to the genera *Fomichevella* including a new species *F. najafi* sp. nov., *Heintzella* comprising of a new species *H. fluegeli* sp. nov. and *Paraheritschioides*. It is the first time that *Heintzella* is reported from Iran. Based on their generic level, the composition of the Central Iran colonial corals show a close affinity between Iranian fauna and those of the Northern provinces of Urals, Novaya Zemlja, the Kuiu Island area and Brooks Range, Alaska. The Iranian species of *Paraheritschioides* in the present study represents the oldest known occurrence of that genus in the world.

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