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Systematic paleontology of Bartonian larger benthic foraminifera from Shahrekord region in High Zagros, Iran

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Abstract

The Jahrum Formation is characterized by abundant benthic foraminifera in carbonate beds, partly marly and dolomitic limestones at the Kuh-e-Soukhteh (Shahrekord region). This formation covers a huge stretch of the Zagros Zone which is a part of the central Tethyian realm during the Paleogene time. Biostratigraphic analysis of the larger benthic foraminifera is deduced to distinguish one assemblage zone assigned to the late Middle Eocene (Bartonian). This new biostratigraphic range is represented by the index fossil of *Rhabdorites malatyaensis* (Sirel) and correlated with calcareous rocks in the Shiraz area (south Iran), Dhofar section (Oman), and Socotra Island (Yemen). The Jahrum Formation is dominated by rich miliolids-agglutinated foraminifera with rare small rotaliids and without *Nummulites* Lamarck and *Alveolina* d'Orbigny indicating that the formation was deposited in a shallow water environment (nearshore lagoonal zone) with low energy.

Keywords: Bartonian, Iran, Jahrum Formation, Larger benthic foraminifera, Shahrekord, Systematics

Introduction

The separate continental blocks of the Iranian platform are jointed by ophiolitic units. The geological zonation of this platform represents various sedimentary basins such as Alborz, Kopet Dagh, Central Iran, Zagros, Sanandaj-Sirjan, Urumieh-Dokhtar, Lut Block, eastern Zone, and Makran (Figure 1A). Because of different oil formations, various facies analysis and stratigraphical studies have been carried out on the Zagros sedimentary basin, especially Jahrum Formation (James and Wynd, 1965; Rahaghi, 1978, 1980, 1983; Kalantari, 1980; Stocklin and Setudehnia, 1991; Vaziri-Moghaddam *et al.,* 2010). The Jahrum Formation consists of a succession of thick layers to massive calcareous sedimentary rocks, thin and medium marls, and dolomites with intercalation of yellow medium bedded limestones. The lower contact of this formation with the Pabdeh Formation is faulted and the upper contact with the Asmari Formation is unconformable. This work provides new biostratigraphic data on a Bartonian stratigraphic interval of the Jahrum Formation in the study area. The foraminiferal assemblage allows comparing with another biostratigraphic scheme for the adjacent areas (Fars area). The aim of this paper is to examine in detail the microbiostratigraphy of the Jahrum Formation and to introduce the systematic descriptions of larger foraminifera.

Geological setting

The geology of Shahrekord is controlled by numerous faults and consisted of three zones: Northeast (Zayandehrud), Southwest (Karun), and Central Zones (Zahedi and Rahmati Ilakhchi, 2006). The Central Zone (Z2) is a part of the high Zagros and located between the thrust faults (Saman - Fereidoon Shahr) (F1) and (Bazoft Fault) (F3) and divided into two smaller subzones (Z2a) and (Z2b) by the main Zagros thrust fault (Figure 1B). These two sub-zones are located in the Shahrekord region and consist of Cretaceous to Paleogene red clastic rocks, gray to cream limestone, and marl correlating to the Jahrum, Pabdeh, and Asmari formations. The Z2b sub-zone encompasses the high Zagros and is located between the main Zagros thrust fault (F2) and the Bazoft thrust fault (F3) (Zahedi and Rahmati Ilakhchi, 2006). The stratigraphic section is exposed on the roadside and located in Kuh-e-Soukhteh with geographical coordination of 32 ° 00' 00" N to 32 ° 01 ' 21" N and 50° 55' 51" E to 50° 56' 80" E (Figure 1C).

Material and methods

The study is carried out based on thin sections of cemented carbonate rock. The stratigraphic thickness with 157 m, were measured from the sedimentary rocks in the Kuh-e-Soukhteh. A total of 80 rock samples were collected for the systematic study and precise identification of foraminiferal species. The microscopic analysis of samples was carried out in the Geological Lab of Payame Noor University. The stratigraphic column and foraminiferal plate are done with Adobe Illustrator software. All samples are housed in Payame Noor University Laboratory.

Biostratigraphy

Based on the larger benthic foraminifera, the Eocene foraminiferal assemblage zones of Jahrum Formation are established by James and Wynd (1965), Adams and Bourgeois (1967), and Hottinger (2007) in the Zagros zone. In the current study, 18 species of benthic foraminifera have been identified for the first time. The major taxa are found in the Jahrum Formation while some taxa such as *Coskinolina* Stache, *Haymanella* Sirel, and *Austrotrillina* Parr have been reported in other parts of Iran, such as the Alborz Mountains and eastern Iran (Babazadeh, 2003). The benthic foraminiferal association is the same as the foraminiferal fauna of central Neo-Tethys such as Shiraz area (south Iran) (Hottinger, 2007), Dhofar (Oman), and Socotra Island (Yemen) (Serra-Kiel *et al.*, 2016). The Jahrum Formation is attributed to Bartonian based on the concurrent range zone of the benthic foraminiferal association while in some previous works, this formation was considered Ypresian and Lutetian (Early-Middle Eocene) in the study area (Zahedi and Rahmati Ilakhchi, 2006; Babazadeh *et al.,* 2015). This association is collected from the gray to cream-colored thin to thick-bedded limestones and argillaceous limestones and occurred in one columnar section (Kuh-e-Soukhteh section). The distribution of selected benthic foraminifera is shown in the stratigraphic section in Figure 2.

Systematic descriptions

Class Tubothalamea Pawlowski *et al.,* 2013

Order Miliolida Delage and Herouard, 1896

Family Hauerinidae Schwager, 1876

Genus ***Nurdanella*** Özgen, 2000

Nurdanella boluensis Özgen, 2000

Figure 3A

Type species. — *Nurdanella boluensis* Özgen, 2000

Description. — In the record species, the axial and equatorial diameters of the test are 1.2 – 1.7 mm and 1.0 – 1.3 mm, respectively. The early chambers are arranged in a quinquelocoline pattern and the later adult chambers are coiled in a planispiral mode.

Remarks. — *Nurdanella boluensis* Özgen differs from *Nurdanella paleocenica* Sirel in its larger size with high chambers. There are two chambers in the last whorl of the holotype of *Nurdanella* Özgen (2000). Whereas, the *N. boluensis* has 5 to 6 chambers in the last whorl of the microspheric form. The record species is close to *N. boluensis* due to its size. The measurement of embryonic apparatus is not possible consequently the term of *confer* is used for this specimen. The *N. boluensis* occurs in the Thanetian and Lutetian limestones of Turkey (Özgen, 2000; Sirel, 2013) but the biostratigraphic range of this species reaches to Bartonian stages in the study area.

Family Hauerinidae Schwager, 1876 or Family Austrotrilinidae Loeblich and Tappan, 1987

Genus ***Austrotrillina*** Parr, 1942

Austrotrillina eocaenica Hottinger, 2007

Figure 3B

Type species. —*Trillina howchini* Schlumberger, 1893

Description. — The *Austrotrillina eocaenica* Hottinger is a true miliolid with an alveolar exoskeleton and thickened basal layer recorded from the Early ?- Lutetian−Priabonian of Shiraz in Iran (Hottinger, 2007), of Lampione Island near Sicily (southern Italy) (Di Carlo and Pignatti, 2009) of western Dhofar in Oman and Socotra Island in Yemen (Serra-Kiel *et al.,* 2016). The megalospheric forms of the *Austrotrillina eocaenica* Hottinger show a subtriangular outline with a rounded margin in the axial section. The outline in the longitudinal section is ovate. The basal layer is thick. The maximum length in the axial sections for megalospheric forms is between 1.0 to 1.3 mm in the record species.

Remarks. — The morphology of Eocene austrotilinas is different from the Oligocene taxon. The *Austrotrillina eocaenica* Hottinger differs from *Austrotrillina paucialveolata* Grimsdale and *Austrotrillina brunni* Marie (Oligocene forms) in a larger size, increased diameter of the proloculus, axial length in megalospheric forms, and the thicker basal layer. The *A. eocaenica* has the same kind of alveoli as *A. paucialveolata*. This species differs from *Austrotrillina asmariensis* Adams (Oligocene form) in deduced diameter of axial length in megalospheric forms. In Oman and Iran, the *A. eocaenica* occurs in association with most of the conical agglutinated species as *Coskinolina perpera* (Hottinger, 2007). According to Adams (1968), the *Austrotrilina* Parr ranges from Lower Oligocene to Lower Miocene (Loeblich and Tappan, 1987). Hottinger (2007) extended the biostratigraphic range of the *A. eocaenica* from Lutetian to Priabonian (SBZ 17-18). The recorded specimen of the *A. eocaenica* in the studied area is associated with *Neorhipidionina spiralis* Hottinger, *Nurdanella boluensis* Özgen, *Quinqueloculina* sp. and other small miliolids. Its biostratigraphic range can be assigned to Bartonian based on faunal association in the studied area.

Family Soritidae Ehrenberg, 1839

Genus ***Macetadiscus*** Hottinger, Serra- Kiel and Gallardo-Garcia, *in:* Serra- Kiel *et al*., 2016, page 35 of 95

Macetadiscus* cf. *incolumnatus Hottinger, Serra-Kiel and Gallardo-Garcia, *in:* Serra- Kiel *et al*., 2016, page 36 of 95, figure 27 (1-27)

Figures 3C1 and 4G2

Type Species. — *Macetadiscus incolumnatus* Hottinger, Serra- Kiel and Gallardo-Garcia

Description. — In megalospheric forms of record species, the equatorial diameter is 2.6 mm and the equatorial thickness is 0.3 mm. The microspheric forms are not observed in this study. There are not endoskeletal structures such as pillars or partitions in the *Macetadiscus* Hottinger.

Remarks. — The *Macetadiscus incolumnatus* Hottinger, Serra- Kiel and Gallardo-Garcia is presented and figured as a new genus and new species in Serra- Kiel *et al*. (2016) for the first time. The Late Paleocene Turkish specimen such as *Mardinella* Meric and Çoruh (type species: *Orbitolites shirazensis* Rahaghi) was presented by Meric and Çoruh (1991) is very similar to *Macetadiscus* Hottinger, Serra- Kiel and Gallardo-Garcia based on its morphostructure. On the other hand, the figured specimen (pl. 18, figs. 10-12) of *Orbitolites* sp. in the Late Paleocene of Shiraz area (Rahaghi, 1983) looks like *Macetadiscus* Hottinger, Serra- Kiel and Gallardo-Garcia Certainly. The *Mardinella* Meric and Çoruh could not be placed *O. shirazensis*. However, it seems more likely that the two genera (*Mardinella* and *Macetadiscus*) are synonymous. The biostratigraphic range of the *Macetadiscus* cf. *incolumnatus* Hottinger, Serra- Kiel and Gallardo-Garcia extends from the late Lutetian to the Priabonian (SBZ 16–20) according to Serra-Kiel *et al.* (2016) and Nafarieh *et al.* (2019). In this work, the biostratigraphic range of recorded species can be attributed to the Bartonian stage.

Family Soritidae Ehrenberg, 1839

Genus ***Rhabdorites*** Fleury, 1996

Rhabdorites malatyaensis (Sirel, 1976)

Figures 3C2, 3D and 3E2

Type species. — *Rhapydionina malatyaensis* (Sirel), 1976

Description. — There are 12-13 chambers in a uniserial arrangement with a diameter of 1.25 mm in the record species. The longitudinal and transversal diameters of the test are reached to 3.6 and 0.9 mm, respectively.

Remarks. — The genus *Rhabdorites* Fleury differs from *Praerhapydionina* Van Wessem in the presence of multiple apertures. It differs from *Neotaberina* Hottinger in the absence of pillars in the endoskeleton and more cylindrical morphology. The species of *Rhabdorites malatyaensis* (Sirel) was described from Lutetian of Oman and Yemen under the taxon of *Rhabdorites minimus* Henson (Serra-Kiel *et al.,* 2016). The biostratigraphic range of the *R. malatyaensis* extends from Bartonian to Priabonian (Papazzoni and Sirotti, 1995; Serra-Kiel *et al.,* 2016;

Nafarieh *et al.,* 2019). This species is associated with the last large *Orbitolites* spp. and *Malatyna vicensis* Sirel (Sirel and Acar, 2008). According to Sirel (2003), *R. malatyaensis* is associated with *Nummulites fabianii* (Perver) and *Nummulites biedai* Schaub in Arabil and Devely sections, respectively. Therefore, the range of *R. malatyaensis* is shown to overlap that of *N. fabianii.* The co-occurrence of *R. malatyaensis* with *Orbitolites minimus* Henson seems to draw the position of the boundary between Middle Eocene and Upper Eocene (Hottinger, 2007). According to Romero *et al.* (1999), the *R. malatyaensis* occurs in association with *Malatyna vicensis* Sirel and Acar, in Igualada basin of northern Spain during the Bartonian. After Hottinger (2007), the *R. malatyaensis* occurs in association with *Globoreticulina iranica* Rahaghi in the Shiraz area (west Iran) and indicates the Bartonian age. In this work, the *Rhabdorites malatyaensis* (Sirel) is observed in the Bartonian age. The biostratigraphical range of *R. malatyaensis* is particularly important because most researchers proposed the Bartonian age based on the foraminiferal associations.

Family Soritidae Ehrenberg, 1839

Genus ***Praerhapydionina*** Van Wessem, 1943

Praerhapydionina delicata Henson, 1950

Figure 3E1

Remarks. — The *Praerhapydionina delicata* Henson differs from *Praerhapydionina huberi* Henson by its small size (less than 2 mm). According to Sirel (2003), *P. delicata* and *P. huberi* have the same biostratigraphic range. For the first time, the *P. delicata* was represented in Oligocene from Iran and Iraq (Henson, 1950). After Fleury (1997), the biostratigraphic range of *P. delicata* extends from the Middle to Late Eocene. This species is reported from Paleocene in Iran (Rahaghi, 1983). It is also assigned to Bartonian-Rupelian by Hottinger (2007) and Serra-Kiel *et al.* (2016). Based on foraminiferal association, the recorded species is occurred in the Bartonian stage.

Family Soritidae Ehrenberg, 1839

Genus ***Haymanella*** Sirel, 1998

Haymanella huberi (Henson, 1950)

Figure 3F

Type species. — *Haymanella paleocaenica* Sirel, 1998

Description. — The *Haymanella* Sirel differs from the other praerhapydioninid genera by the presence of agglutinated grains in its porcelaneous wall (Sirel, 1998; Hottinger, 2007; Nafarieh *et al.,* 2019).

Remarks. — The *Haymanella huberi* (Henson) differs from the *Haymanella paleocaenica* Sirel in its shorter nepionic spiral stage in the megalospheric generation and its more complex foramina in the adult. The outline of the foramen is stellar with at least six branches of petaloid extensions. The *H. huberi* is about twice the size of *H. paleocaenica.* The *H. huberi* is known from Eocene deposits of Jahrum Formation (Iran) and Eocene deposits of Iraq, Turkey, and

Oman (Henson, 1950; Sirel, 1998; Hottinger, 2007). According to Hottinger (2007) and Serra-Kiel *et al.* (2016), the biostratigraphic range of *H. huberi* is assigned to Bartonian–Priabonian (SBZ 17−20). This species is associated with *R. malatyaensis* and indicating the Bartonian age.

Family Soritidae Ehrenberg, 1839

Genus ***Neorhipidionina*** Hottinger, 2007

Neorhipidionina spiralis Hottinger, 2007

Figure 3G

Type species. — *Rhipidionina williamsoni* Henson, 1948

Description. — In the record species, the maximum diameter reaches 4.75 mm with a thickness of 0.6 mm.

Remarks. — The taxon found in this work is attributed to *Neorhipidionina spiralis* Hottinger due to its more flattened in respect to *Neorhipidionina urensis* (Henson). The latter species is showing an oval outline in cross section and its coils are more inflated and narrow. The megalospheric form of *Neorhipidionina williamsoni* (Henson) is twice as large as the *N. spiralis*. The recorded species is characterized by comparatively small size and long spiral early stage of growth followed by rapidly flaring adult stage. According to Serra-Kiel *et al.* (2016), this species ranges Lutetian in age. After Hottinger (2007), its biostratigraphic range extends from Bartonian to Priabonian. Based on faunal assemblage, the recorded species is assigned to the Bartonian stage.

Family Soritidae Ehrenberg, 1839

Genus ***Archaias*** de Montfort, 1808

Archaias operculiniformis Henson, 1950

Figures 3H1 and 3I

Type species. — *Nautilus angulatus* Fichtel and Moll, 1798

Description. — The equatorial diameter in megalospheric form reaches 3.2 mm in the record sample.

Remarks. — The *Archaias operculiniformis* Henson differs from *Archaias diyarbakirensis* (Sirel) in its smaller size of test shell and proloculus. This species is characterized by fewer pillars in respect of the *A. diyarbakirensis*. The basal layer ridges in the genus of *Penarchaias* Hottinger could not be formed the pillars. According to Sirel (1998), Hottinger (2007), and Bassi *et al*. (2007), the genus *Praearchaias* Sirel has the same structural elements as the *Archaias* De Montfort. Hottinger (2007) mentioned the *Archaias operculiniformis* Henson from Bartonian-Priabonian, but Serra-Kiel *et al.* (2016) extended this species to Rupelian in Oman. In this work, the biostratigraphic range of recorded species can be attributed to the Bartonian stage.

Family Soritidae Ehrenberg, 1839

Genus ***Penarchaias*** Hottinger, 2007

Penarchaias glynnjonesi (Henson, 1950)

Figure 3H2

Type species. — *Peneroplis glynnjonesi* Henson, 1950

Description. — In the present species, the equatorial diameter of the test is 1.9-2.2 mm with a thickness of 0.9 mm.

Remarks. — The genus of *Penarchaias* (Henson) differs from *Archaias* De Montfort in the absence of pillars. But in the point of view of morphological chambers and distribution of the foramina, this genus is close to *Archaias* De Montfort. The *Penarchaias glynnjonesi* (Henson), is recorded in the Bartonian stages in the studied area but its biostratigraphic range extends to Oligocene (Hottinger, 2007; Serra-Kiel *et al.,* 2016).

Class Globothalamea Pawlowski *et al.,* 2013

Order Loftusiida Kaminski and Mikhalevich, 2004, *in:* Kaminski, 2004

Family Coskinolinidae Moullade, 1965

Genus ***Coskinolina*** Stache, 1875

Coskinolina perpera Hottinger and Drobne, 1980

Figures 4B and 4C

Type species. — Coskinolina liburnica Stache, 1875

Description. — In the record species, the axial length and basal diameter are 1.9- 2.0 mm and 1.7 -1.9 mm, respectively. The endoskeleton is only represented by irregular pillars and showing a looser aspect. The pillars are discontinuous from one chamber to the next.

Remarks. — Conical agglutinated shell shows pseudokeriothecal wall without beams and intercalary beams. The endoskeleton is only represented by pillars and showing a looser aspect. The wall is thicker than in all other species of the same genus. *Coskinolina perpera* Hottinger and Drobne is ranged from Late Cuisian to Early Lutetian (Hottinger and Drobne, 1980). Hottinger (2007) reported this species from Lutetian to Bartonian of Iran. According to Serra-Kiel *et al.* (2016), the age of this species can be reached to Priabonian in Oman and Yemen. The recorded species is assigned to the Bartonian (SBZ 17−18) in the studied area.

Family Coskinolinidae Moullade, 1985

Genus ***Coskinolina*** Stache, 1875

Coskinolina liburnica Stache, 1875

Figure 4A

Type species. — *Coskinolina liburnica* Stache, 1875

Description. — The axial length and basal diameter of the record sample are 2.1 mm and 1.9 mm, respectively. The pillars are densely arranged from one chamber to the next. There are not exoskeletal elements (beams and rafters) in the marginal chamber.

Remarks. — The identification of generic forms is distinguished by the lack of exoskeletal structures in trochspiral nepionts. The *Coskinolina liburnica* Stache shows an acute cone angle. The uniserial chambers are low and the pillars show a dense internal structure compared to all other species of the same genus. According to Hottinger and Drobne (1980), *C. liburnica* is assigned to the late Early Eocene (Cuisian) in the Island of Molat (Melada, *Croatian* Island in the Adriatic Sea). Serra-Kiel *et al.* (1998) considered its biostratigraphic range from middle Cuisian to Late Cuisian. Serra-Kiel *et al.* (2016) stated that the co-occurrence of *C. liburnica* Stache with *Nummulites fabianii* (Prever) (SBZ 19) in the western Dhofar (Oman), indicates the Periabonian age. As a result, the species of *C. liburnica* Stache can be extended from the late Ypresian to the Priabonian. In east Iran, the *C. liburnica* Stache is reported from the Early Eocene (Babazadeh, 2003; Schlagintweit and Hadi, 2018). In this work, this species is found in late Middle Eocene (Bartonian) sedimentary rocks.

Family Orbitolinidae Martin 1890

Genus ***Barattolites*** Vecchio and Hottinger, 2007

Barattolites trentinarensis Vecchio and Hottinger, 2007

Figures 4D and 4E

Type species. — *Barattolites trentinarensis* Vecchio and Hottinger, 2007, figs. 12 a-b, 13 a-b, 14 a-b, 15 a-m, 16 a-m, 17 a-r, 18 a-j

Remarks. — The genus *Barattolites* Vecchio and Hottinger differs from the genus *Daviesiconus* Hottinger and Drobne in having a long trochospiral early growth stage, the constant occurrence of intercalary beams, and in the absence of marginal apertures. This genus differs from the genus *Dictyoconus* Blanckenhorn and *Fallotella* Mangin due to the absence of horizontal partitions (rafters) and to presence of a simple exoskeleton. It differs from *Coskinolina* Stache in having simple radial partitions (beams and intercalary beams). The stratigraphic range of *Barattolites trentinarensis* Vecchio and Hottinger covers the Ypresian to the Early Lutetian (Vecchio and Hottinger, 2007). Based on foraminiferal association, the recorded species is assigned to Bartonian in the studied area.

Order Rotaliida Delage and Herouard, 1896

Family Rotaliidae Ehrenberg 1839

Genus ***Medocia*** Parvati, 1971

***Medocia blayensis* Parvati, 1971**

Figures 4F and 4G1

Type species. — Medocia blayensis Parvati, 1971

Description. — The diameter of the record sample is larger than 1 mm (ratio of equatorial to an axial diameter about 2).

Remarks. — The typical forms of *Medocia blayensis* Parvati are described from the Middle Eocene (Lutetian - Bartonian) of France and Iran by Parvati (1971) and Hottinger (2007) respectively. The small forms (d < 1mm) of *Medocia blayensis* Parvati are reported by Vecchio (2003) and Benedetti *et al*. (2011) from Ypresian of central and southern Italy. According to Le Calvez and Blondeau (1978), *Medocia blayensis* Parvati together with *Alveolina elongate* d'Orbigny, *Alveolina fusiformis* Stache and *Orbitolites cotentinensis* Lehmann found in Late Lutetian sediments of the Atlantic Coast (Europe). Whereas, in the Trentinara Formation (Southern Italy), this species is occurred in Late Early Eocene sediments. After Serra-Kiel *et al.* (2016), the biostratigraphic range of *Medocia blayensis* Parvati is Early?-Middle Lutetian to Priabonian (SBZ 13?–SBZ 20). The biostratigraphic range of the recorded species is assigned to Bartonian in the studied area.

Family Rotaliidae Ehrenberg, 1839

Genus ***Rotaliconus*** Hottinger, 2007

Rotaliconus persicus Hottinger, 2007

Figure 4H

Type species. — *Rotaliconus persicus* Hottinger, 2007

Remarks. Rotaliconus Hottinger differs from all other calcarinids in its single interiomarginal aperture and the presence of an enveloping canal system. It differs from rotaliids with umbilici covered by funnel orifices, such as *Kathina* Smout and related forms, in having dorsal orifices of the canal system and in the absence of continuity in the funnels of successive whorls (Hottinger, 2007). In recoded specimens, the axial diameter of the test is larger than 1 mm (ratio of horizontal to an axial diameter about 1.4). The diameter of the base of the cone in the final whorl measured 1.25 mm. According to Rahaghi (1980), its biostratigraphic range is Lutetian, but Hottinger (2007) extended its biostratigraphic range to Bartonian (SBZ 17-18). Serra-Kiel *et al.* (2016) reported that the biostratigraphic range of this species could be extended from early?-middle Lutetian to Priabonian (SBZ 13?–SBZ 20). The biostratigraphic range of the recorded species is considered to Bartonian in the studied area.

Discussion and Conclusion

The present work focused on the benthic foraminiferal biostratigraphy of the Jahrum Formation in the Shahrekord region of southern Iran. According to Rahaghi (1978), the nummulite facies with the *Assilina exponens* group and other nummulitids appear at the lower part of Jahrum Formation during Early Eocene (Ypresian) to early Middle Eocene (Lutetian) in the type locality of this formation in the Shiraz area. But the upper part of the Jahrum Formation consists of porcelaneous foraminifera (miliolids), conical agglutinated foraminifera (coskinolinids), and rare small rotalids. The miliolids along with small rotaliids represent an oligotypic community of epifaunal benthos and indicate a low energy depositional setting (Zamagni et al., 2008). This association occurs in near-shore lagoonal environments with muddy substrates and nutrient-enriched conditions. The presence of *Macetadiscus* Hottinger, Serra- Kiel and Gallardo-Garcia suggests relatively shallower water than *Alveolina* d'Orbigny. The *Macetadiscus* bearing facies has a lateral paleoenvironmental relationship with the *Alveolina* facies. Apparently, the upper part of the Jahrum Formation as the same as the Igualada basin (Northeastern Spain), is formed in a shallowing upward trend which represents a regressive cycle at the end of the late Middle Eocene (Bartonian). The absence of larger benthic foraminifera such as *Nummulites* Lamarck and *Alveolina* d'Orbigny in the study area can be matched with the different environments because both taxa adapted to a reduced light condition in the open platform and occurred in deeper water or offshore carbonate platform.

In the point of view of paleontology, the *R. malatyaensis* is an index fossil for Bartonian because it has a wide geographic distribution from western to central Neotethys (Hottinger, 2007). The co-occurrence of *R. malatyaensis* with *N. fabianii* (Perver) and *N. biedai* Schaub in Arabil and Devely sections (Turkey) represents that the *Rhabdorites malatyaensis* (Sirel) is ranged from Bartonian to Priabonian in age (Sirel, 2003). Afterward, some researchers, such as Serra-Kiel *et al.* (2016) and Nafarieh *et al.* (2019), proposed that the biostratigraphic range of the *R. malatyaensis* extends from Bartonian to Priabonian age. On the other hand, the occurrence of *R. malatyaensis* seems to mark the level of *G. iranica* in the Shiraz area (west Iran). The range of *R. malatyaensis* is shown to overlap that of *N. fabianii* (SBZ 19) (Serra-Kiel *et al.,* 1998). According to Hottinger (2007), the type level of *G. iranica* is older than the range of *N. fabianii* and maybe younger than the range of the *Assilina exponens* group (SBZ 13-17), which is younger than SBZ 17. Also, the *R. malatyaensis* occurs in association with *M. vicensis*, in the Bartonian sediments of the Igualada Basin of northern Spain (Romero *et al.,* 1999). Therefore, the age of the *R. malatyaensis* is attributed to the Bartonian and this species can be considered as an index fossil for Bartonian age. Thus, among the large benthic foraminifera in the study area, only *R. malatyaensis* is known as a well-dated taxon. In the study area, the foraminiferal association represents one concurrent range zone (Figure 5) which is compatible with the biozone introduced by Hottinger (2007). Therefore the similar association of Bartonian benthic foraminifera has been compared with the established assemblage for the Shiraz area (south Iran), Dhofar section (Oman), and Socotra Island (Yemen) (Hottinger, 2007; Serra-Kiel *et al.,* 2016; Nafarieh *et al.,* 2019).

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Figure captions

Figure 1. (A) Iran map showing the several sedimentary basin zones; (B) Location of the study area (Kuh-e-Soukhteh) in the High Zagros Zone on the Chaharmahal Bakhtiari Province (Zahedi and Rahmati Ilkhechi, 2006); (C) Location of the study area in Ardal geological map (1: 250 000).

Figure 2. Distribution of selected benthic foraminifera on stratigraphic section.

Figure 3. Photographs of foraminiferal species. (**A**) *Nurdanella boluensis* Özgen, equatorial section, As 14; (**B**) *Austrotrilina eocaenica* Hottinger, axial section, As 38; (**C1**) *Macetadiscus* cf. *incolumnatus* Hottinger, subaxial section and (**C2**) *Rhabdorites malatyaensis* (Sirel), equatorial section, As 38; (**D**) *Rhabdorites malatyaensis* (Sirel), axial section, As 43; (**E1**) *Praerhapydionina delicata* Henson, axial section, complete skeleton, As 50 and (**E2**) *Rhabdorites malatyaensis* (Sirel), axial section, As 50; (**F**) *Haymanella huberi* (Henson), axial section, As 55; (**G**) *Neorhipidionina spiralis* Hottinger, subaxial section, As 14; (**H1**) *Archaias operculiniformis* Henson, oblique section, (**H2**) *Penarchaias glynnjonesi* (Henson), axial section, As77; (**I**) *Archaias operculiniformis* Henson, axial section, As 38; Bartonian, Scale bars: 1mm. The arrow shows the foraminiferal species in a thin section.

Figure 4. Photographs of foraminiferal species. (**A**) *Coskinolina liburnica* Stache, axial section, As 46; (**B and C**) *Coskinolina perpera* Hottinger and Drobne, **B**, Axial section, As 40, **C**, equatorial section, As 38; (**D and E**) *Barattolites trentinarensis* Vecchio and Hottinger, **D**, subaxial section, As 69, **E**, equatorial section; (**F**) *Medocia blayensis* Parvati, axial section, As 42; (**G1**) *Medocia blayensis* Parvati, subaxial section, As 41, (**G2**) *Macetadiscus* cf. *incolumnatus* Hottinger, subaxial section, As 41; (**H**) *Rotaliconus persicus* Hottinger, axial

section, As 38, Bartonian, Scale bars: 1mm. The arrow shows the foraminiferal species in the thin section.

Figure 5. Range chart of selected benthic foraminifera based on Romero *et al.* (1999); Sirel (2003); Hottinger (2007); Serra-Kiel *et al.* (2016); Nafarieh *et al.* (2019) and study area. SBZ zonation according to Serra-Kiel *et al.* (1998), the pale grey area shows concurrent range zone.

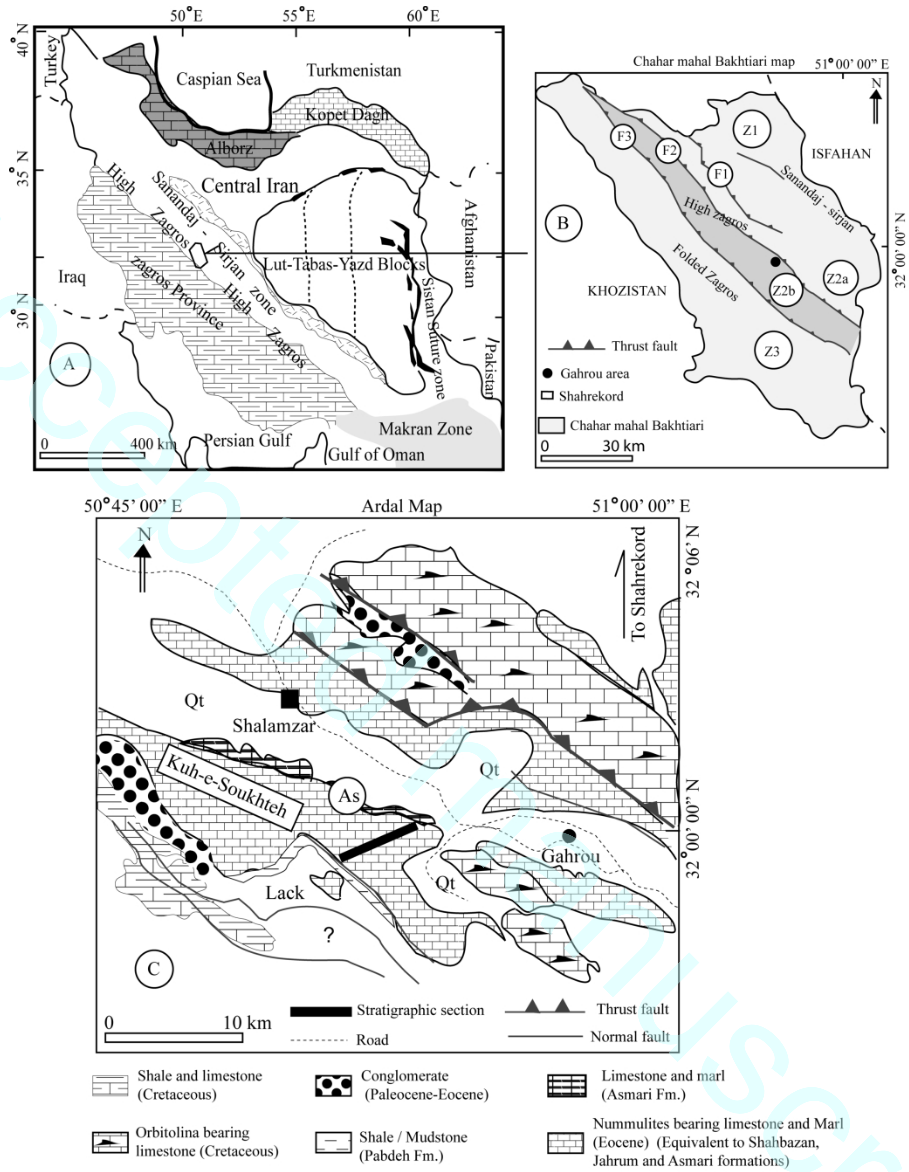

Fig. 1

Figure 1

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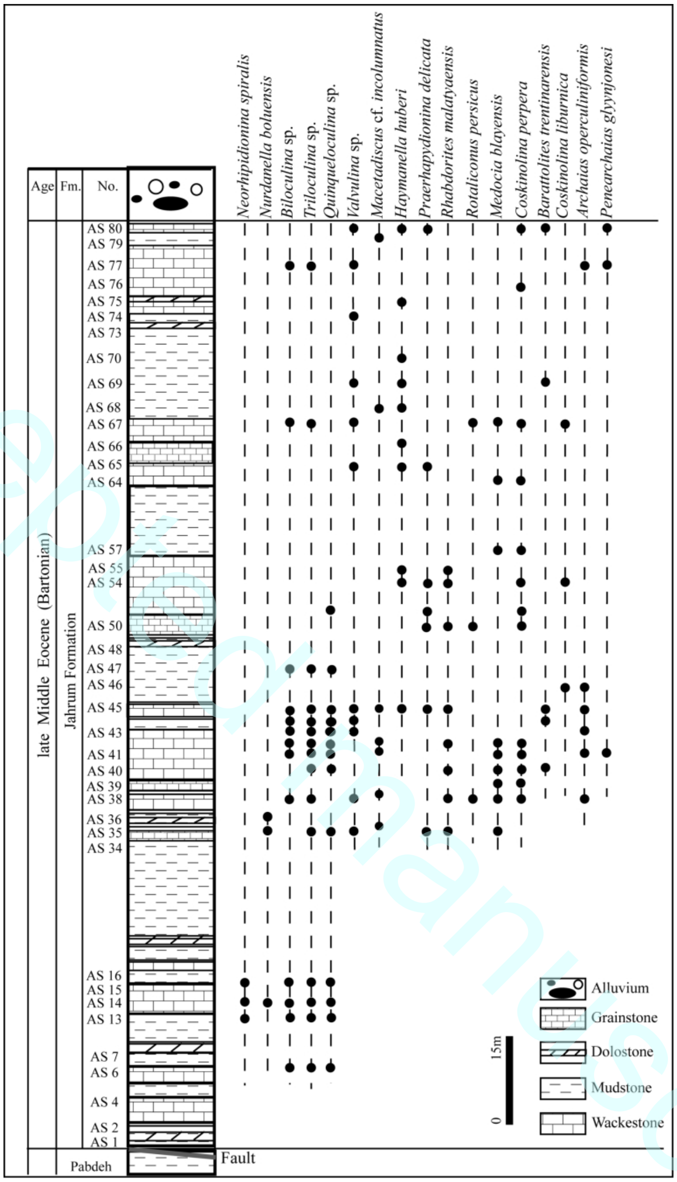

Fig. 2

Figure 2

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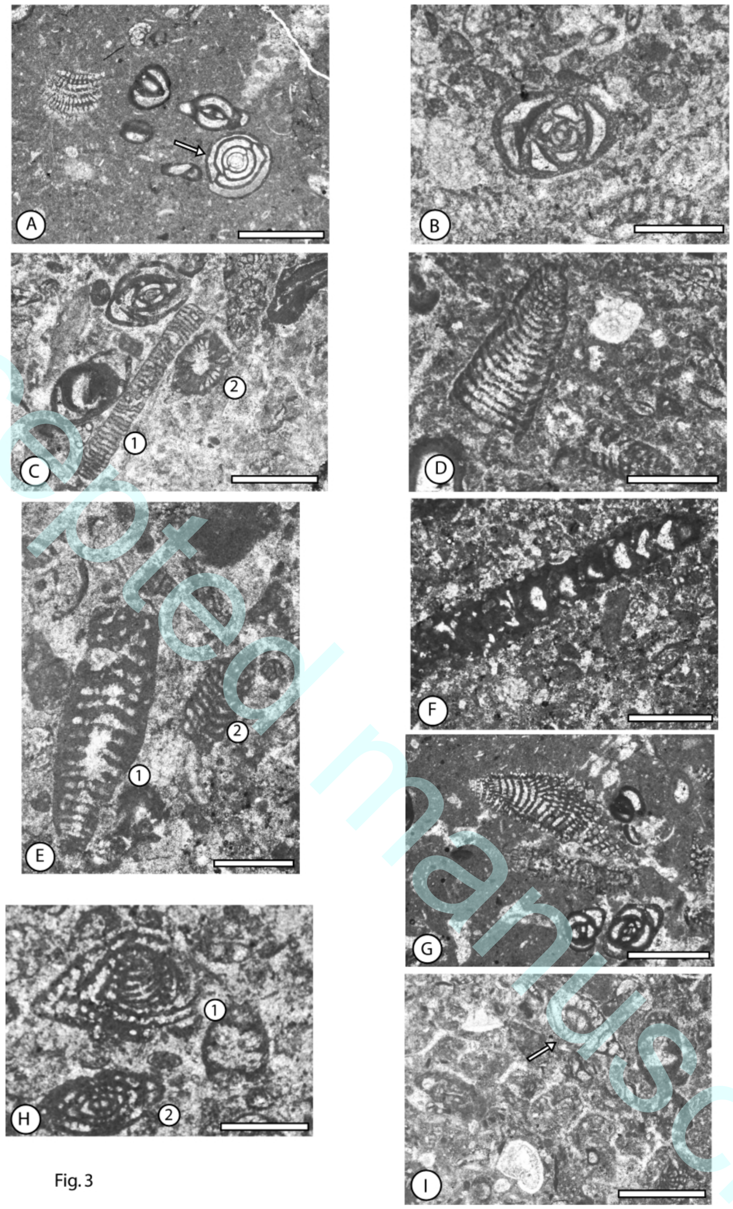

Figure 3

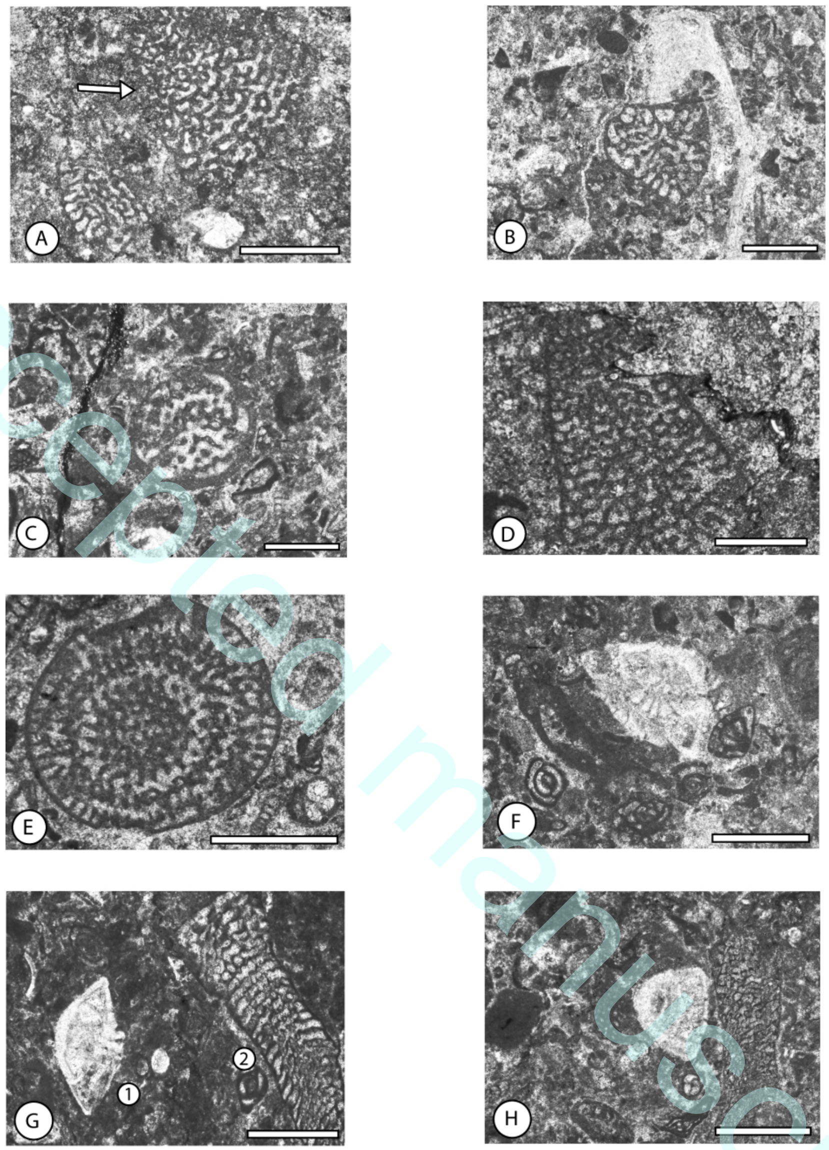

Fig. 4

Figure 4

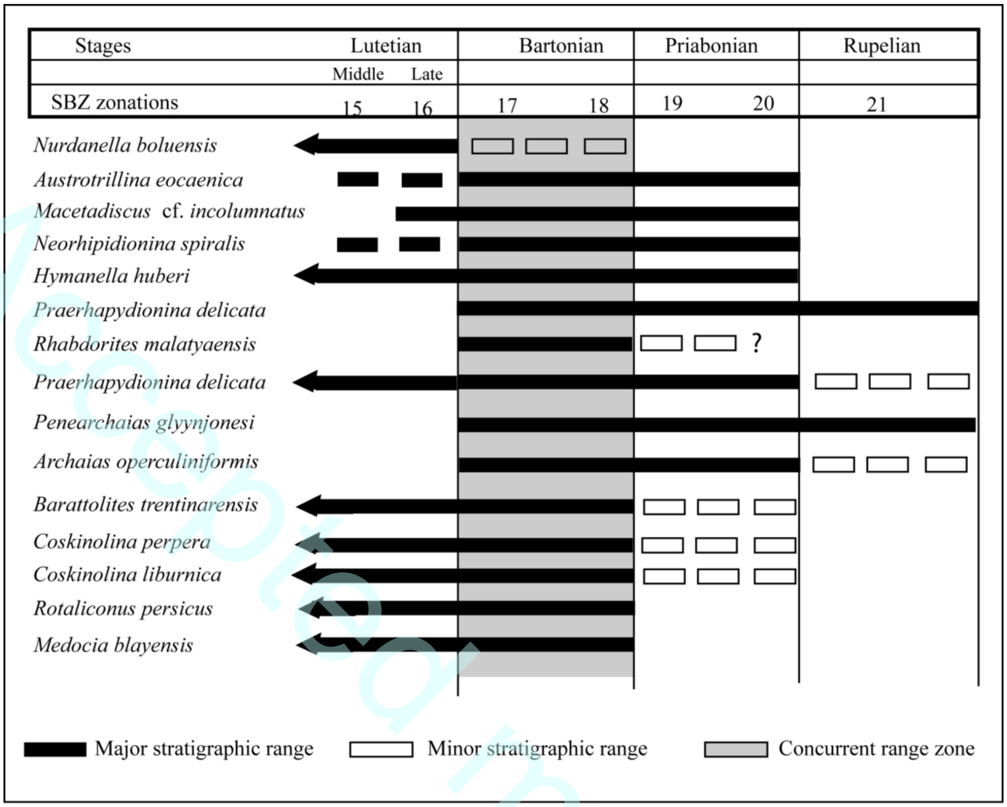

Fig. 5

Figure 5

196x165mm (300 x 300 DPI)