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Upper Triassic (Norian-Rhaetian) Foraminifera from the Nayband Formation of the Lut Block (Garm Ab section, Northeast Iran)

Fatemeh AMIRHASSANKHANI [1]
Baba SENOWBARI-DARYAN [(†)]
Koorosh RASHIDI [2]

Abstract: Studies of Nayband Formation from the Garm Ab section in Lut Block in Central Iran led to the identification of 26 foraminiferal taxa. Nine species are reported from Iran for the first time: *Involutina* ex gr. *liassica* (JONES), *Involutina* sp., *Lamelliconus permodiscoides* (OBERHAUSER), *Palaeolituonella* cf. *meridionalis* (LUPERTO), *Palaeolituonella* cf. *angulata* SENOWBARI-DARYAN & CACCIATORE, *Gaudryinella* cf. *kotlensis* TRIFONOVA, *Ammobaculites eumorphos* KRISTAN-TOLLMANN, *Frondicularia rhaetica* KRISTAN-TOLLMANN, *Frondicularia* cf. *xiphoidea* KRISTAN-TOLLMANN, and *Orthotrinacria* ? *expansa* (ZANINETTI *et al.*). The taxa restrict the Upper Triassic interval to probably just the Rhaetian. Based on the foraminifera and their abundance, three different association-types could be distinguished, *i.e.*, the *Decapoalina schaeferae-Miliolipora cuvillieri*, *Trocholina turris-Agathammina iranica* and *Involutina* ex gr. *liassica-Trocholina umbo* associations. *Comparisons of foraminiferal associations* in different parts of central Iran, such as 1) Hassan Abad section, SW of Ferdows in Lut Block, 2) the type locality of the Nayband Formation in Tabas Block, NE of Esfahan in the eastern part of Central Domain Block, and 3) the Garm Ab section in Lut Block, *indicate that the hyaline foraminifers* are most abundant in the Garm Ab. Besides, in the Lut Block, the reef environments in the Garm Ab section are deeper water than those of the Hassan Abad section. The association of *Trocholina umbo* with *Miliolipora cuvillieri* is similar to the foraminiferal association from the NE of Esfahan and shows similar conditions in Lut Block and Central Domain Block. The two assemblages of hyaline foraminifers, especially the new report of *Involutina and Trocholina*, prove to be Rhaetian in age.

Keywords:

- Late Triassic;
- Norian-Rhaetian;
- foraminiferal assemblages;
- Ferdows;
- reef;
- Central Iran

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Résumé : *Foraminifères du Trias supérieur (Norien-Rhétien) de la Formation Nayband du Bloc de Lut (section Garm Ab, Nord-Est de l'Iran).-* L'étude de la Formation Nayband de la coupe de Garm Ab dans le Bloc de Lut dans le centre de l'Iran a conduit à l'identification de 26 taxons de foraminifères. Neuf espèces sont signalées pour la première fois en Iran : *Involutina* ex gr. *liassica* (JONES), *Involutina* sp., *Lamelliconus permodiscoides* (OBERHAUSER), *Palaeolituonella* cf. *meridionalis* (LUPERTO), *Palaeolituonella* cf. *angulata* SENOWBARI-DARYAN & CACCIATORE, *Gaudryinella* cf. *kotlensis* TRIFONOVA, *Ammobaculites eumorphos* KRISTAN-TOLLMANN, *Frondicularia rhaetica* KRISTAN-TOLLMANN, *Frondicularia* cf. *xiphoidea* KRISTAN-TOLLMANN et *Orthotrinacria* ? *expansa* (ZANINETTI *et al.*). Ces taxons permettent de restreindre l'intervalle du Trias supérieur considéré probablement au seul Rhétien. Sur la base

[1] *Educational organisation, No. 4, Abkooh Street, Mashhad (Iran)*
amirhasankhani@gmail.com

[(†)] *deceased*

[2] *Department of Geology, Yazd University, PO Box 89195-741 Yazd (Iran)*
kooroshrashidi@yazd.ac.ir

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des foraminifères et de leur abondance, trois types d'associations différentes ont pu être distinguées, à savoir les associations à *Decapoalina schaeferae-Miliolipora cuvillieri*, *à Trocholina turris-Agathammina iranica* et à *Involutina* ex gr. *liassica-Trocholina umbo*. Les comparaisons des associations de foraminifères recueillies dans différentes parties du centre de l'Iran, telles 1) la coupe de Hassan Abad, au sud-ouest de Ferdows dans le Bloc de Lut, 2) la localité type de la Formation Nayband dans le bloc de Tabas, au nord-est d'Ispahan dans la partie orientale du bloc du domaine central, et 3) la coupe de Garm Ab dans le Bloc de Lut, indiquent que les foraminifères hyalins sont les plus abondants dans le Garm Ab. Par ailleurs, dans le Bloc de Lut, les milieux récifaux de la coupe de Garm Ab sont plus profonds que ceux de la coupe de Hassan Abad. L'association de *Trocholina umbo* avec *Miliolipora cuvillieri* est similaire à l'association de foraminifères du NE d'Esfahan et présente des conditions similaires dans le Bloc de Lut et le bloc du domaine central. Les deux associations de foraminifères hyalins, en particulier le nouveau signalement d'*Involutina* et de *Trocholina*, s'avèrent d'âge rhétien.

Mots-clefs :

- Trias supérieur ;
- Norien-Rhétien ;
- associations de foraminifères ;
- Ferdows ;
- récif ;
- Iran central

1. Introduction

The reef limestones of the Bidestan and Howz-e Khan members of the Nayband Formation are rich in both macro- and microfossils. Whereas the macrofossils of the Nayband Formation are relatively well-known, *e.g.*, corals (Kristan-Tollmann *et al.*, 1980; Shepherd *et al.*, 2012), sponges (Senowbari-Daryan, 1996, 2003, 2005a, 2005b; Senowbari-Daryan & Amirhassankhani, 2012; Amirhassankhani *et al.*, 2014), the hydrozoan *Heterastridium* (Senowbari-Daryan & Link, 2019), gastropods and bivalves (Nützel & Senowbari-Daryan, 1999), there are few investigations dealing with the microproblematica (Senowbari-Daryan & Majidifard, 2003; Amirhassankhani *et al.*, 2010), foraminifers (Brönnimann *et al.*, 1971, 1974; Senowbari-Daryan *et al.*, 2010; Saberzadeh *et al.*, 2016) or algae (Senowbari-Daryan *et al.*, 2008, 2011; Senowbari-Daryan, 2018).

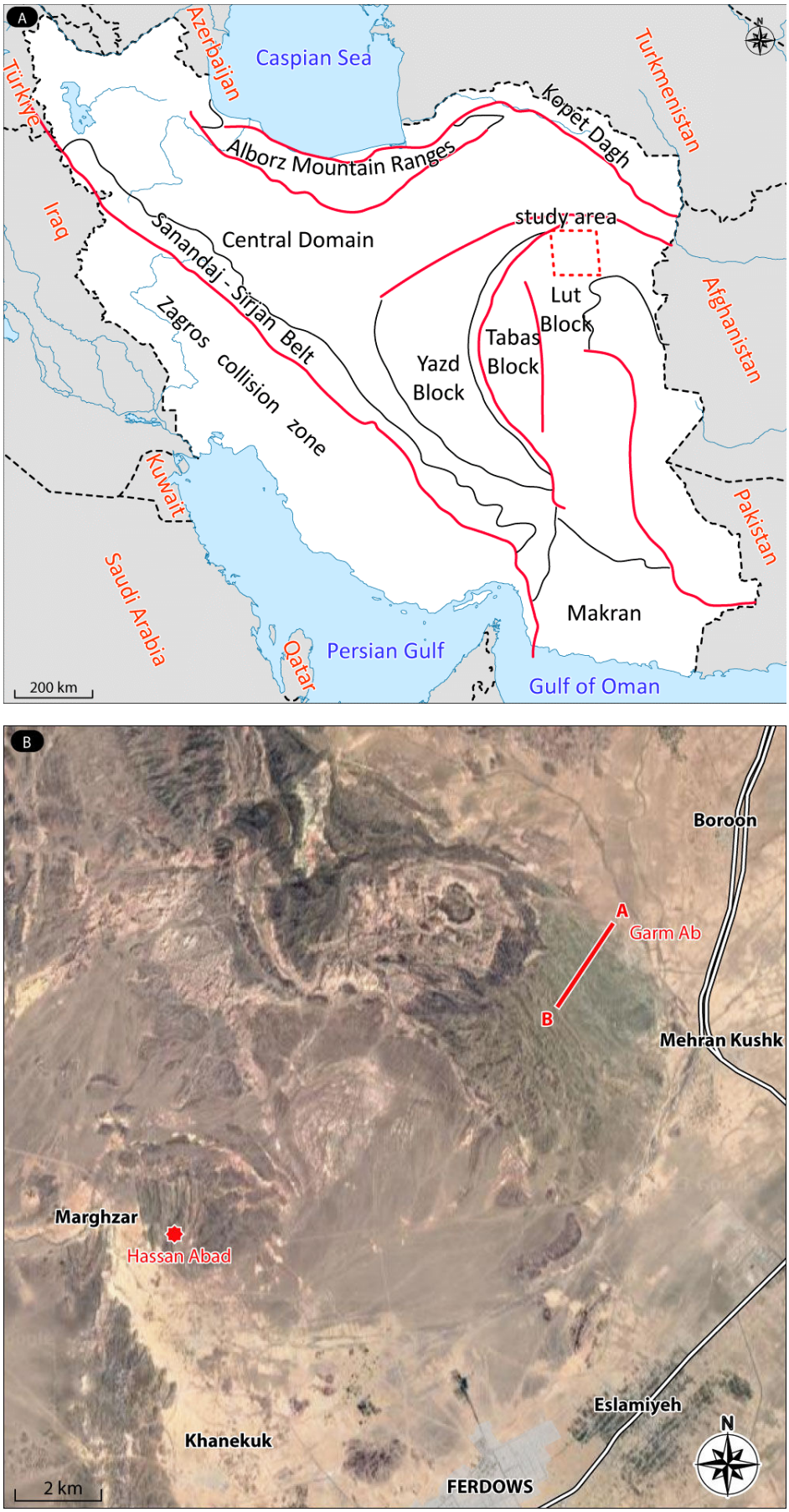
Upper Triassic benthic foraminifers are useful paleoenvironmental indicators. Their wide geographic distribution, abundance and relatively high evolutionary rate give them significant stratigraphic value (*e.g.*, Gaździcki, 1983). Foraminifers are generally rare within the Nayband Formation, but they can be relatively abundant in some intervals of reef carbonates. A relatively rich assemblage of foraminifers was discovered in the Garm Ab section of the Nayband Formation, spanning the Bidestan and Howz-e Khan members. There, foraminifers are linked to eight sponge levels. Among them, nine species are reported for the first time from Iran. Since presence or absence of species from a specific area can be used for paleobiogeographic attribution of the region (*e.g.*, Chablais *et al.*, 2010; Gale *et al.*, 2020), this paper brings important and new data from Upper Triassic of Iran. Taxonomic descriptions of the newly reported taxa are given. Three foraminiferal associations are described, based on the occurrence of foraminifers or their abundance. Finally, some comparisons to other regions where the Nayband Formation crops out are given.

2. The Nayband Formation

The Upper Triassic deposits of the Nayband Formation in Iran are exposed in different parts of central Iran. Paleogeographically, the Nayband Formation was deposited in the northern margin of the Neotethys (Schäfer *et al.*, 2003). At its type locality, along the southern flank of the Nayband Mountain, near the town of Naybandan (Stöcklin & Setudehnia, 1991; Aghanabati, 2010), the Nayband Formation reaches a thickness of almost 2,200 m (Fürsich *et al.*, 2005). There it overlies the Shotori Formation dolomites (Middle Triassic) with slight disconformity and underlies the siliciclastic sediments of the Ab-e Haji Formation (Lower Jurassic). Due to sedimentary similarities of the deposits, the contact between the Nayband Formation and the overlying Ab-e Haji Formation may be difficult to identify (Aghanabati, 2004).

The type section of the Nayband Formation comprises five members with, from bottom to top, the Gelkan, Bidestan, Howz-e Sheikh, Howz-e Khan, and Qadir members. The Gelkan and the Howz-e Sheikh members are composed of grey to green silt- and sandstones whereas the Bidestan and the Howz-e Khan members are made of grey to cream-colored limestones, mainly biostromal and subordinately biohermal corals and sponge patch reefs, usually smaller than 50 m in diameter and less than 20 m high (Senowbari-Daryan, 1996). The Qadir Member is characterized by the abundance of coal layers and carbonaceous clays; it is generally a relatively fine-grained unit and was identified only in Tabas Block (Fürsich *et al.*, 2005).

The sponges are generally the first reef-building organisms in the bioconstructions of the Bidestan Member and the spherical hydrozoan *Heterastridium* seems to be limited to this member. This last fossil indicates a late Alaunian-late Sevatian age: it became extinct in the Rhaetian *Amoenum* Zone of North America, which represents an equivalent to the European *Sagenites reticulatus*



◀ **Figure 1: A)** Simplified structural map of Iran showing the main tectonic subdivisions (with Central Iran including Lut Block, Tabas Block, Yazd Block and Central Domain). Garm Ab and Hassan Abad are located in the Lut Block in central part of Iran (modified after TADAYON *et al.*, 2017). **B)** Satellite image showing the position of the Garm Ab and Hassan Abad sections. Garm Ab section is located NW of Mehran kushk and NE of Ferdows. Hassan Abad is located NW of Ferdows and about 25 km in the distance from the Garm Ab.

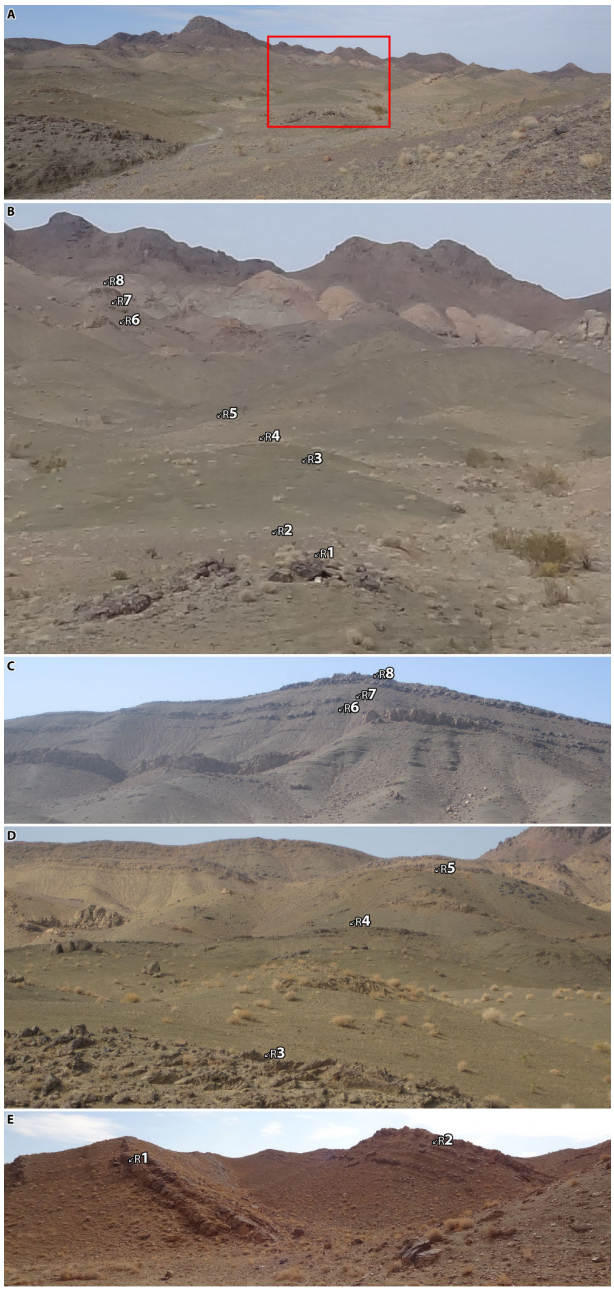


Figure 2: View of the Garm Ab section showing the Upper Triassic Nayband Formation, with the sequence of eight reef carbonates and grey to green shale overlain by siliciclastic sediments of the Lower Jurassic Ab-e Haji Formation. The abundant porcelaneous and hyaline foraminifers are present from the middle part of the Garm Ab section upwards (R3). The two reef levels at the bottom of the section (R1 and R2) show abundance of porcelaneous foraminifera.

ammonoid Zone (SHEPHERD *et al.*, 2012; also see SENOWBARI-DARYAN & LINK, 2019). In contrast, in the Howz-e Khan Member, the corals are the dominating organisms in the reef structures at the type locality (FÜRSICH *et al.*, 2005).

Palynological data (CIRILLI *et al.*, 2005) allow assignment of an early Norian age for the Gelkan Member and most of the Bidestan Member. The upper part of the Bidestan Member is dated as middle to late Norian, and the lower part of the Howz-e Sheikh Member as Rhaetian. Therefore, the Triassic/Jurassic boundary should lie in the middle to the upper part of the Howz-e Khan Member. On the other hand, assemblages of bivalves in the upper part of the Howz-e Khan Member point to a Rhaetian age (HAUTMANN, 2001).

The mass extinction event at the Triassic/Jurassic boundary, which was preceded by ecological changes, began in the late Norian (CIARAPICA, 2007). It was observed in the Lut Block (Garm Ab section in central Iran) with the disappearance of reef carbonate beds and increasing siliciclastic rocks.

3. Geological setting

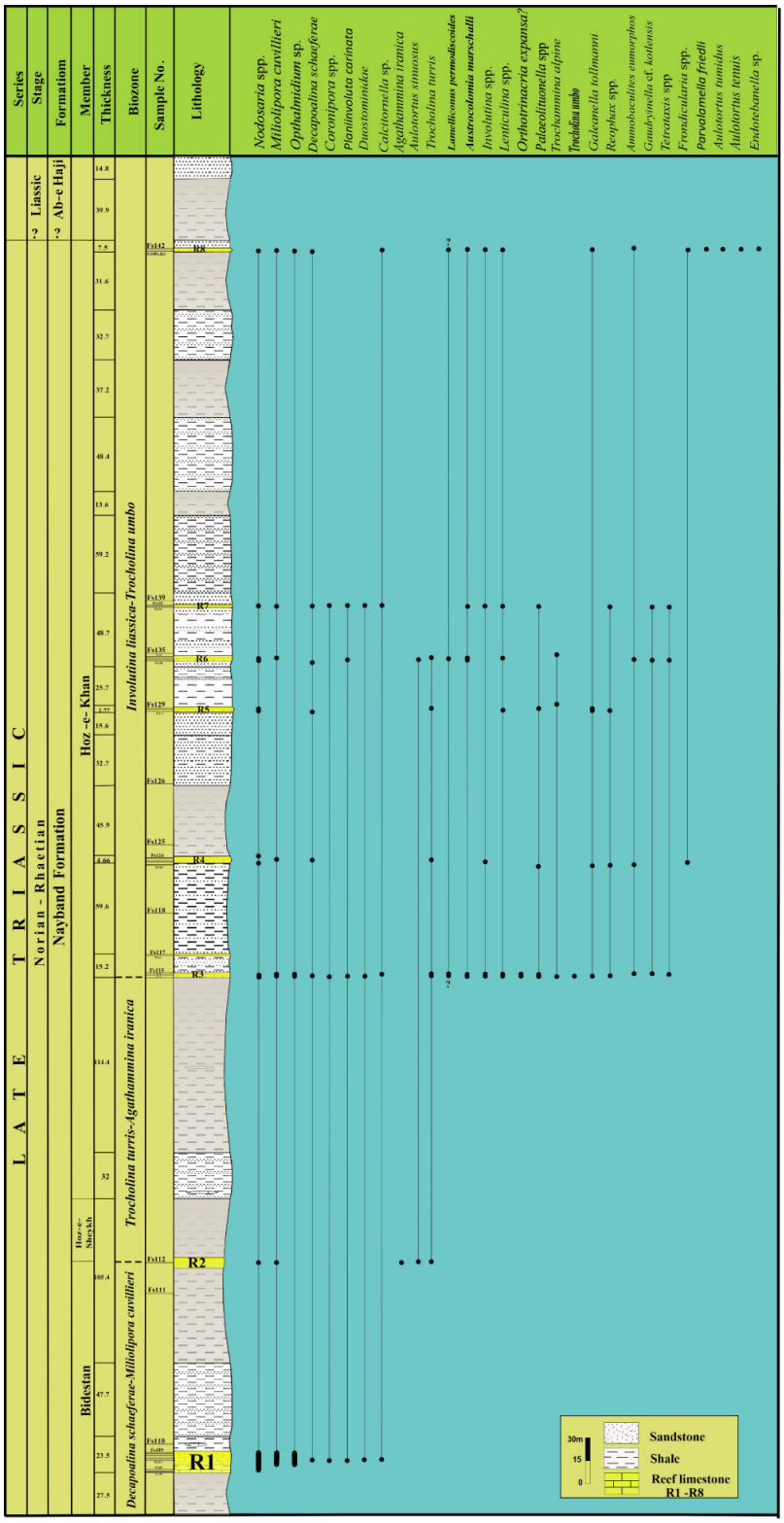
The Garm Ab section is located in the Lut Block, about 20 km North-East of the town Ferdows (GPS coordinates: 34°07'59.4"N 58°12' 08.4"E), near the village of Mehran kushk in the North-East of central Iran (Fig. 1). The location of the Garm Ab section is about 1500 meters above sea-level. It consists of a sequence of reef carbonates and grey to green shales (Figs. 1-2). The abundant macrofauna is composed of sponges (including chaetetids), crinoids, gastropods, and bivalves; the microfauna consists mostly of foraminifera. The lower contact of the Nayband Formation in the Garm Ab section exhibits grey to green siltstones and dark grey sandstones with ripple marks.

The Norian-Rhaetian rocks in the Garm Ab section are about 870 meters thick and include eight sponge horizons of grey reef carbonates (Figs. 1-2) with micritic matrix. They consist of boundstones, floatstones and packstones. The most abundant reef builders are sponges, including inozoan sponges, sphinctozoan sponges, chaetetid corals and some chambered hexactinellid sponges (AMIRHASSANKHANI *et al.*, 2014). The occurrence of scleractinian corals in this area is rare.

The thickness of each part of the reef carbonate horizons is about 50 m. They are separated by thin beds of dark grey sandstones and grey to green shales (Fig. 2). The thickness of the siliciclastic rocks increases to the upper part of the section whereas conversely the thickness of the reef carbonate decreases (Figs. 2-3).

4. Material and methods

The Garm Ab section included eight Upper Triassic reef limestones. It is located near the Hassan Abad section, a part of the Nayband Formation (about 25 kilometers in the distance to the Garm Ab; Fig. 1) chose for studying foraminifers taxa and their associations. The paleontological study was carried out on 42 thin sections of Triassic massive carbonates. For determination of foraminifera, large-sized thin sections in 10 x 15 cm, 7.5 x 10 cm, and 7.5 x 7.5 cm formats were used. The thin sections are deposited at the Mashhad Earth Sciences Park Museum, Geological Survey of Iran North-East Territory (Department for Paleontology and Stratigraphy), Mashhad, Iran.



◀ **Figure 3:** The stratigraphical distribution of foraminifers in the Garm Ab section. It shows three foraminiferal assemblages: *Decapoalina schaeferae-Miliolipora cuvillieri*, *Trocholina turris-Agathammina iranica*, and *Involutina* ex gr. *liassica-Trocholina umbo* in the eight reef carbonate beds (R1 to R8) (modified after AMIRHASSANKHANI *et al.*, 2014).

5. Systematic palaeontology

Studies of thin sections from the Garm Ab section led to the identification of 26 foraminiferal taxa. The complete list is given after taxonomic descriptions of nine selected species. The latter are reported from Iran for the first time. The foraminiferal associations indicate reef depositional environments (SENOWBARI-DARYAN *et al.*, 2010). This systematic classification is based on LOEBLICH and TAPPAN (1987).

Subphylum Foraminifera Orbigny, 1826
Suborder Involutinina
Hohenegger & Piller, 1977
Superfamily Involutinoidea Bütschli, 1880
Family Involutinidae Bütschli, 1880
Subfamily Involutininae Bütschli, 1880
Genus *Involutina* Terquem, 1862
***Involutina* ex gr. *liassica* (Jones, 1853)**
(Pl. 1, fig. 6)

1853 *Nummulites* ? *liassicus* n.sp. – Jones *in* Brodie, p. 275.
1976 *Involutina liassica* (Jones) - Zaninetti, p. 162, Pl. 9, fig. 5; Pl. 15, fig. 23 (with synonymy).
1978 *Involutina liassica* (Jones) - Piller, p. 65, Pl. 2, figs. 1-9.
1983 *Involutina liassica* (Jones) - Gaździcki, p. 150, Pl. 29, fig. 1; Pl. 38, figs. 1-12, 15.
1987 *Involutina liassica* (Jones) - Blau, p. 6, Pl. 1, figs. 1, 4, 6.
1992 *Involutina liassica* (Jones) - Kristan-Tollmann & Colwell, p. 306, Pl. 2, figs. 8-10.
2015 *Involutina liassica* (Jones) - Rigaud *et al.*, p. 5, Fig. 2 A-G.

Material: Three specimens.

Description: The lenticular test consists of a globular proloculus followed by a planispirally enrolled and undivided tubular deuteroloculus. Wall partly thickened, forming papillae at the test surface. The papillae are uneven. Wall is calcitic, usually a drusy sparite cement. The dimorphism is marked (Piller, 1978; Gaździcki, 1983; Blau, 1987). A large proloculus characterizes the illustrates specimen (Pl. 1, fig. 6) with four whorls, a test diameter of 520 µm, and a thickness of 240 µm.

Remarks: Due to the emendation of Piller (1978), *Involutina turgida* Kristan-Tollmann differs from *I. liassica* (Jones) in having a deuteroloculus tube whereas *I. liassica* builds a semitube. Only in this characteristic are the two types to differentiate. For this reason, sparitic enclosures are not clearly the one or the other type to be assigned and become therefore described in this work as *I.* gr. *liassica* (Blau, 1987). The papillae are one of the essential elements in the evolution of Involutinidae, such as *I. liassica.* It is probable that the appearance of pillars was related to the adaptation to new environmental conditions connected with a change in the sedimentary basin in the early Liassic (Gaździcki *et al.*, 1979). The identification of *Involutina* specimens can be helpful in the Nayband Formation of central Iran because sedimentary similarities of the deposits cause difficulties in identifying the boundary between the Nayband Formation (Upper Triassic) and the overlying Ab-e Haji Formation (Lower Jurassic).

Occurrences: The genus occurs from the Late Triassic to the latest Liassic and perhaps even early Dogger to ? Late Cretaceous (Blau & Haas, 1991). This foraminifer was found in the last reef part of rock units in the investigated section, between thick-bedded grey limestones with macrofossils (including sponges). This horizon of the upper part of the Howz-e Khan Member is ascribed to the Rhaetian.

? *Involutina* sp.
(Pl. 2, fig. 4)

Material: Two specimens.

Description: Large proloculus followed by a single tubular second chamber planispirally coiled. Calcitic wall, a drusy sparite cement. The cross-section of the tubular chamber is ovoid and composed of numerous papillae. The test measures 526 µm in length and 190 µm in width and includes more than three whorls (Pl. 2, fig. 4).

Remarks: The discoidal and evolute test composed of numerous papillae supports as uncertain *Involutina*, could belong to this genus. A similar section is illustrated in Fig. 2 by Rigaud *et al.* (2015). Rigaud's specimen exhibits a pore in the chamber wall, whereas specimens from the Garm Ab section are calcitic, *i.e.*, a drusy sparite cement.

Occurrences: From Rhaetian-lower Middle Jurassic of Austria (Rigaud *et al.*, 2015), this uncertain *Involutina* is in association with *I.* ex gr. *liassica indicating latest* Triassic to Liassic age in the studied section.

Genus *Lamelliconus* Piller, 1978
Lamelliconus permodiscoides
(Oberhauser, 1964)
(Pl. 1, fig. 12)

1964 *Trocholina permodiscoides* n.sp.- Oberhauser, p. 207, Pl. 2, figs. 13-15, 18, 20, 22; Pl. 3, fig. 1.
1976 *Trocholina permodiscoides* Oberhauser – Zaninetti, p. 178, Pl. 12, figs. 9-11.
1978 *Auloconus permodiscoides* (Oberhauser) - Piller, p. 74, Pl. 20, figs. 1-8 (with synonymy).
1983 *Auloconus permodiscoides* (Oberhauser) – Gaździcki, p. 153, Pl. 30, fig. 2; Pl. 35, figs. 1-6.
2012 *Auloconus permodiscoides* (Oberhauser) - Gale, p. 27, Pl. 2, fig. 16.
2013 *Lamelliconus permodiscoides* (Oberhauser) – Rigaud *et al.*, p. 321, Fig. 3; p. 324, Fig. 5.

Material: Three specimens.

Description: As defined by Oberhauser (1964) and Piller (1978), the test of this species (Pl. 1, fig. 12) is low conical with rounded apical part, 600 µm in diameter, and 300 µm in thickness with more than three whorls. A globular proloculus is followed by a trochospirally enrolled undivided tubular deuteroloculus. Half of the whorl is followed by the formation of a laminated sheet over the convex umbilicus. The thick umbilicus is unclear.

Occurrences: *Lamelliconus permodiscoides* is known from the Norian-Rhaetian of the Northern Calcareous Alps (Oberhauser, 1964; Zaninetti, 1969; Piller, 1978; Schäfer, 1979), Greece (Brönnimann *et al.*, 1970; Zaninetti & Thiébault, 1975), Burma (Brönnimann *et al.*, 1975), and China (Ho & Hu, 1977; He, 1980). Brönnimann *et al.* (1971) were the first to report this foraminifer (without systematic description) from Upper

Triassic of Iran. In the Garm Ab section, this foraminifer was found in the last reef horizon, between thick-bedded grey limestone with macrofossils (including sponges) and *Involutina* spp. The reef horizon with *Lamelliconus permodiscoides* from the upper portion of the Howz-e Khan Member is Rhaetian in age.

Suborder Miliolina Delage & Hérouard, 1896
Superfamily Milioliporoidea Ehrenberg, 1839
Family Orthotrinacriniidae
Zaninetti *et al.*, 1985
Genus *Orthotrinacria* Zaninetti *et al.*, 1985
Orthotrinacria* ? *expansa
(Zaninetti *et al.*, 1982)
(Pl. 2, fig. 15)

1982 *Galeanella expansa* - Zaninetti *et al.*, p. 111, Pl. 4, fig. 1.
1985 *Orthotrinacria expansa* (Zaninetti *et al.*) – Zaninetti *et al.*, p. 297, Figs. 1, 2/1-7.
1990 *Orthotrinacria expansa* (Zaninetti *et al.*) - Di Stefano *et al.*, Pl. 3, fig. 8.
1993 *Orthotrinacria expansa* (Zaninetti *et al.*) – Zaninetti & Martini, p. 190, Figs. 1A, 2A.
1996 *Orthotrinacria* ? *expansa* (Zaninetti *et al.*) – Senowbari-Daryan & Flügel, p. 253, Pl. 3, fig. 4A.

Material: One specimen.

Description: The test is ovate to elliptical, with a relatively large proloculus. The coiling is involute, and in the final stage tends to uncoil. The unrolled part is shorter than in *O. gracilis.* The wall is calcareous, porcelaneous, but commonly recrystallized. The surface of the final chamber transversely wrinkled; aperture terminal.

Occurrences: It was reported from the Norian of Turkey (Altiner *et al.*, 1992) and Italy (Senowbari-Daryan *et al.*, 1982), as well as from the Norian to Rhaetian of Italy (Di Stefano *et al.*, 1990) and Austria (Senowbari-Daryan & Flügel, 1996). In the Garm Ab section, this foraminifer was found in reef limestones in the middle part of the section, with macrofossils (including sponges), most probably in the Rhaetian part of the Howz-e Khan Member.

Order Textulariida Mikhalevich, 1980
Superfamily Ataxophragmioidea
Schwager, 1877
Family Ataxophragmiidae Schwager, 1877
Genus *Palaeolituonella* Bérczi-Makk, 1981
Palaeolituonella* cf. *meridionalis
Luperto, 1965
(Pl. 2, fig. 5)

2017 *Palaeolituonella meridionalis* (Luperto) – Senowbari-Daryan & Link, p. 314, Fig. 3e-f (with synonymy).

Material: Four specimens.

Description: The test is conical, about 400 µm in length and 300 µm in width with four chambers (Pl. 2, fig. 5). Early trochospiral whorls are followed by a uniserial stage of broad and low chambers. Wall is thick and agglutinated.

Remarks: The test dimensions of the specimens from the investigated area are smaller than those reported by Senowbari-Daryan and Cacciatore (2009). The latter are 500-800 µm in length, and 400-600 µm in width. *Palaeolituonella majzoni* Bérczi-Makk (1981) represents a junior synonym of *P. meridionalis* (Luperto, 1965) according to Zaninetti *et al.* (1986).

Occurrences: *Palaeolituonella meridionalis* was reported from the Anisian of Italy (Emmerich *et al.*, 2005), former Yugoslavia and Austria (Rüffer & Zamparelli, 1997), the Ladinian of Italy (Ciarapica *et al.*, 1990) and Germany (Rüffer & Zamparelli, 1997), the Carnian (Kanmera, 1964) and also the Norian-Rhaetian of Japan (Chablais *et al.*, 2010), the Norian of Oman (Bernecker, 1996), and the Upper Triassic of China (Payne *et al.*, 2011) and Turkey (Senowbari-Daryan & Link, 2017).

In the Garm Ab, this foraminifer was found in four reef horizons in the middle part of the section, associated with macrofossils (including sponges). This level is most probably Rhaetian in age.

Palaeolituonella* cf. *angulata
Senowbari-Daryan & Cacciatore, 2009
(Pl. 2, fig. 10)

2009 *Palaeolituonella angulata* n.sp. - Senowbari-Daryan & Cacciatore, p. 51-57, Figs. 1-10.

Material: Three specimens.

Description: Dimensions of this conical and thick-walled agglutinated test is 543 µm in height and 600 µm in width with at least three chambers in the uniserial stage (in Pl. 2, fig. 10). The aperture is not visible. The edge of some chambers shows the zigzag pattern as in the first description of *Palaeolituonella angulata.*

Remarks: The zigzag pattern which is typical for determining *P. angulata* is not visible in the wall of all chambers; therefore, the exact determination of the species is uncertain.

Occurrences: *Palaeolituonella angulata* was reported from the Norian-Rhaetian of Austria, Greece and Sicily (Senowbari-Daryan & Cacciatore, 2009).

In the investigated section, this foraminifer was found in the four reef horizons with *P. cf. meridionalis* and macrofossils (including sponges). The middle part of the Howz-e Khan Member, probably Rhaetian in age.

Genus *Gaudryinella* Plummer, 1931
***Gaudryinella* cf. *kotlensis* Trifonova, 1967**
(Pl. 2, fig. 18)

1967 *Gaudryinella kotlensis* n.sp. - Trifonova, p. 60, Pl. 1, figs. 1-8.
1978 *Gaudryinella* aff*. kotlensis* Trifonova- Gaździcki et al, p. 370, Pl. 43, fig. 7.

Material: Two specimens.

Description: The test is small, elongated (500 µm, Pl. 2, fig. 18), and the chambers show a rec-

tilinear arrangement. The proloculus is followed by a triserial part (222 µm in length, Pl. 2, fig. 18), becoming biserial and finally uniserial. At the end of the triserial part, the test width rapidly increases (267 µm, Pl. 2, fig. 18). The triserial part is followed by a biserial part and finally by a short uniserial part (one chamber length). Chambers are rounded, sutures lightly depressed. The test wall is agglutinated.

Remarks: These specimens have a short uniserial part, like in *Gaudryinella kotlensis* TRIFONOVA. However, the more pronounced development of the triserial part, the test width, and the rapid increase in width resemble *G. clavuliniformis (*TRIFONOVA).

Occurrences: *Gaudryinella kotlensis* was reported from the Lower Carnian of the Western Carpathians (GAŹDZICKI *et al.*, 1978) and from Rhaetian of Ukraine (KORCHAGIN *et al.*, 2003). In the Garm Ab section, it was found in three reef parts with macrofossils (including sponges), in the Rhaetian part of the Howz-e Khan Member.

Ammobaculites eumorphos
KRISTAN-TOLLMANN, 1964
(Pl. 2, fig. 3)

1964 *Ammobaculites eumorphos* n.sp. - KRISTAN-TOLLMANN, p. 38, Pl. 5, figs. 3-4:, Pl. 6, figs. 1-5.
1976 *Ammobaculites eumorphos* KRISTAN-TOLLMANN - ZANINETTI, p. 250, Pl. 21, fig. 18a-b.

Material: Two specimens.

Description**:** After the early coiled portion follows the straight, elongate and uniserial low chamber stage of 633 µm height. The total test height is about 830 µm (Pl. 2, fig. 3). Chamber wall is coarsely agglutinated.

Occurrences: *Ammobaculites eumorphos* was reported from the Rhaetian-Liassic (KRISTAN-TOLLMANN, 1964) from the upper Norian to Rhaetian of Austria (ZANINETTI, 1976). In the investigated section, this foraminifer was found in reef parts of rock units associated with macrofossils (including sponges). The level is most likely Rhaetian in age.

Frondicularia rhaetica
KRISTAN-TOLLMANN, 1964
(Pl. 1, fig. 14)

1964 *Frondicularia rhaetica* n.sp. - KRISTAN-TOLLMANN, p. 248, Pl. 32, figs. 1-8.
1990 *Frondicularia rhaetica* KRISTAN-TOLLMANN - KRISTAN-TOLLMANN, p. 230, Pl. 10, figs. 9-10.
1992 *Frondicularia rhaetica* KRISTAN-TOLLMANN - KRISTAN-TOLLMANN & GRAMANN, p. 472, Pl. 2, fig. 1.

Material: One specimen.

Description: Only about half of an incomplete specimen is available. Proloculus is destroyed. Approximately leaf-shaped with a sharp, scalloped edge. Chambers low, swinging down more on edge. Aperture terminal.

Occurrences: This species was reported from the Rhaetian-Liassic of Austria (KRISTAN-TOLLMANN, 1964; KRISTAN-TOLLMANN & GRAMANN, 1992) and from the Rhaetian of Indonesia (KRISTAN-TOLLMANN, 1990). In the study area, this foraminifer was found in reef part in the middle of rock units, associated with macrofossils (including sponges). The level is mostly Rhaetian in age.

Frondicularia* cf. *xiphoidea
KRISTAN-TOLLMANN, 1964
(Pl. 1, fig. 15)

1964 *Frondicularia rhaetica* n.sp. - KRISTAN-TOLLMANN, p. 245, Pl. 31, figs. 1-6.

Material: Two specimens.

Description: The length of the test is 615µm and composed of several uniserial hemispherical chambers of a sharp edge (Pl. 1, fig. 15). Wall is sparry, bead-like thickened central longitudinal strips. Aperture is terminal.

Remark: The test dimensions of our specimens are smaller than those of the type specimens (KRISTAN-TOLLMANN, 1964).

Occurrences: This species was reported from the Rhaetian-Liassic of Austria (KRISTAN-TOLLMANN, 1964) and the lower-middle Anisian of the southeastern Pamirs (KORCHAGIN, 2007). In the investigated section, this foraminifer was found in two reef horizons in the middle of the section (Howz-e-Khan Member) with *Frondicularia rhaetica* and different macrofossils (including sponges). The reef beds are dated as Rhaetian.

6. Foraminiferal associations

The naming of different association-types is based on the occurrence of foraminifers or their abundance in the 870 m thick sequence of eight reef carbonates.

The most stratigraphically significant foraminifers in the Garm Ab section are *Decapoalina schaeferae* (ZANINETTI *et al.*, 1982), *Trocholina turris* FRENTZEN, and *Involutina* ex gr. *liassica. Trocholina turris* and *Involutina* are useful markers for the Rhaetian age (RAMOVS & KRISTAN-TOLLMANN, 1967; BRÖNNIMANN *et al.*, 1970; BLAU 1987; BLAU & HAAS, 1991; RIGAUD *et al.*, 2015).

A) *Decapoalina schaeferae-Miliolipora cuvillieri* association

In the lower part of the Garm Ab section, foraminifers are rare (Fig. 3). In this part, the index macrofossil of the Upper Triassic (Norian) strata is *Heterastridium* REUSS, which is also common in the type locality of the Nayband Formation in the Bidestan Member (SENOWBARI-DARYAN, 1996). The lower part of the Garm Ab section contains one horizon of reef carbonate. Named foraminifers for this part are *Decapoalina schaeferae* and *Miliolipora cuvillieri* (Fig. 3). Accompanying taxa are *Coronipora etrusca*, *C. serraforma, Planiinvoluta carinata*, *Ophthalmidium* sp., *Diplotremina* sp., *Calcitornella* sp., and *Nodosaria* sp. (Fig. 3).

According to SENOWBARI-DARYAN *et al.* (2010) and GALE (2012), *Coronipora etrusca* (PIRINI) more properly supports a Rhaetian age. On the other

hand, the common occurrence of the spherical hydrozoan *Heterastridium* in this part, as well as in the Bidestan Member of the type locality of the Nayband Formation, suggests a Norian age (SENOWBARI-DARYAN, 1996; SENOWBARI-DARYAN & LINK, 2019). Therefore, the foraminiferal association with *Heterastridium in* this part is considered as late Norian-Rhaetian in age.

B) *Trocholina turris-Agathammina iranica* association

The most important species in this assemblage are *Trocholina turris* and *Agathammina iranica*. Accessory species include *Aulotortus sinuosus*. In this part of the section, foraminifers are rare (Fig. 3). According to various authors (KRISTAN-TOLLMANN, 1986, 1990; KRISTAN-TOLLMANN & GRAMANN, 1992; ZANINETTI *et al.*, 1992; SENOWBARI-DARYAN *et al.*, 2010; GALE *et al.*, 2012, 2020), *Trocholina turris* is an index foraminifer for the Rhaetian to the Lower Jurassic (RAMOVŠ & KRISTAN-TOLLMANN, 1967; BRÖNNIMANN *et al.*, 1970; BLAU, 1987; BLAU & HAAS, 1991).

The middle part of the section comprises thick layers of grey to green shale and siltstone. The microfacies types are sponge framestone, sponge bafflestone, boundstone, packstone to rudstone, and grainstone. Therefore, lithostratigraphy and the general community of macrofossils are more similar to Howz-e Sheikh Member, supporting the Rhaetian age.

C) *Involutina* ex gr. *liassica-Trocholina umbo* association

The upper part of the section contains many more foraminifers than the lower parts. Foraminifers were found in six reef horizons (Fig. 3). The following foraminifers were determined: *Lamelliconus permodiscoides*, *Involutina* ex gr. *liassica*, *Involutina* ? sp., *Lenticulina* spp., *Miliolipora cuvillieri, Ophthalmidium* sp., *Orthotrinacria* ? *expansa*, *Palaeolituonella* cf. *angulata*, *P.* cf. *meridionalis*, *Trochammina alpina*, *Trocholina umbo, Galeanella tollmanni, Reophax* sp., *Gaudryinella* cf. *kotlensis*, *Ammobaculites eumorphos*, *Frondicularia rhaetica*, *F.* cf. *xiphoidea*, *Tetrataxis* spp., *Parvalamella friedli*, *Aulotortus tenuis*, *A. tumidus*, *Austrocolomia marschalli*, and *Endotebanella* sp. (Fig. 3). The most important species in this assemblage are *Involutina* ex gr. *liassica* and *Trocholina umbo*.

The association of *Trocholina umbo* with *Miliolipora cuvillieri* is similar to the foraminiferal association described by SENOWBARI-DARYAN *et al.* (2010), from the area NE of Esfahan, which was considered to be Rhaetian in age. Because some foraminifera, such as *Aulotortus* spp. and *Orthotrinacria* ? *expansa*, are limited to the Triassic, this part of the section is considered to be Rhaetian in age.

The microfacies types of the upper part reef horizons are diverse: sponge boundstones (framestone and bafflestone), packstone to rudstone, wackestone to floatstone and grainstone.

7. Discussion and conclusion

The Nayband Formation, which covers a vast area of central Iran, in the Garm Ab area (NE Iran), yielded new micropaleontological data. The foraminifers are more diversified and less abundant in reef limestone, absent in shale and sandstone or sandy shale in the studied section.

Three groups of foraminifers (porcelaneous, agglutinated, and hyaline) are distributed in the Nayband Formation, in different parts of central Iran, such as: Hassan Abad section in SW of Ferdows in Lut Block (AMIRHASSANKHANI *et al.*, 2015); the type locality of the Nayband Formation in Tabas Block (BRÖNNIMANN *et al.*, 1971, 1974; ZANINETTI, 1976; SABERZADEH *et al.* 2016), North-East of Esfahan in East part of Central Domain Block (SENOWBARI-DARYAN *et al.*, 2010), and the Garm Ab section in Lut Block in this study (Fig. 1). Comparison of the foraminifers in these four areas shows similarity but with fewer microgranular and agglutinated foraminifers. *Parvalamella* is a common foraminifer in all these areas whereas the *Duotaxis* has not been observed in the Garm Ab section in this group.

The porcelaneous foraminifers especially Miliolidae are most abundant in all localities of Nayband Formation except in the Garm Ab, whether the *Involutina* and *Trocholina* (hyaline foraminifera) are abundant there. The *Miliolechina*, *Cucurbita*, and *Altinerina* are rare and were not found in the Nayband Formation, just in the Hassan Abad section (Table 1).

The frequency of hyaline foraminifers in the Trocholinidae group in the Garm Ab in Lut Block and Central Domain Block (North-East of Esfahan; SENOWBARI-DARYAN *et al.*, 2010) is similar (Table 1; Fig. 4). The *Involutina* usually occurs in deeper environments than *Aulotortus* (PILLER, 1978). Papillae probable reinforce the test structure related to higher hydrostatic pressure (RIGAUD *et al.*, 2015). It shows the effect of temperate and acidification during the Late Triassic (GALE *et al.*, 2020).

Based on the foraminifera, three different association types could be distinguished: 1) *Decapoalina schaeferae-Miliolipora cuvillieri*, 2) *Trocholina turris-Agathammina iranica*, and 3) *Involutina* ex gr. *liassica-Trocholina umbo* (Fig. 3). The *Decapoalina schaeferae-Miliolipora cuvillieri* association is similar to the foraminiferal association from the other parts of central Iran in Nayband Formation such as Hassan Abad and the type locality of the Nayband Formation.

The two assemblages of hyaline test foraminifera, especially the reporting of *Involutina* and *Trocholina*, in this part of Nayband Formation, prove the Rhaetian age in a deeper part of the reef environment for Garm Ab section than the Hassan Abad section (about 25 kilometers in the distance to the Garm Ab) in Lut Block.

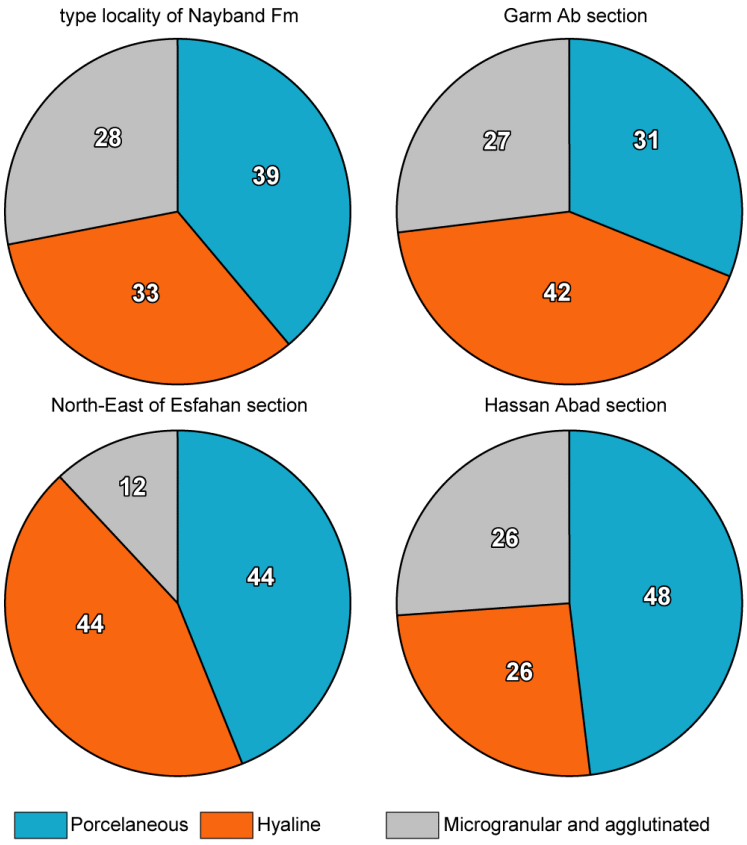
Table 1: Comparison of the foraminifers from the Nayband Formation including; Garm Ab section in Lut Block (in this study); the type locality of Nayband Formation in Tabas Block (BRÖNNIMANN *et al.*, 1971, 1974; ZANINETTI, 1976; SABERZADEH *et al.*, 2016); North-East of Esfahan in Central Domain (SENOWBARI-DARYAN *et al.*, 2010) and Hassan Abad section, South-West of Ferdows in Lut Block (AMIRHASSANKHANI *et al.*, 2015).

Foraminifera	Geographical distribution						
	Eastern Southern Alps	South-East Asia	Turkey	Nayband Fm (type locality)	NE of Esfahan section	Garm Ab section	Hassan Abad section
Palaeolituonella spp.	●	●		●	●	●	
Aulotortus spp.	●	●	●	●	●	●	●
Agathamina iranica	●				●		
Ammobaculites eumorphos	●					●	
Calcitornella sp.	●					●	
Ophthalmidium sp.	●	●	●	●	●	●	●
Gaudryinella cf. *kotlensis*	●					●	
Tetrataxis spp.	●	●		●		●	●
Trochammina alpina	●	●		●		●	●
Planiinvoluta carinata	●	●	●			●	●
Decapoalina schaeferae	●	●	●	●	●	●	●
Frondicularia spp.	●	●				●	
Austrocolomia spp.	●				●	●	
Galeanella panticae	●	●	●	●	●	●	●
Orthotrinacria ? *expansa*	●					●	●
Miliolipora cuvillieri	●	●	●	●	●	●	●
Trocholina spp.	●	●	●	●		●	●
Coronipora spp.		●		●	●	●	
Reophax spp.	●	●	●			●	
Trocholina turris		●		●	●		
Trocholina umbo	●				●	●	
Involutina spp.	●					●	
Auloconus permodiscoides	●	●		●		●	
Lenticulina spp.	●	●				●	
Endothybanella sp.	●	●				●	●
Nodosaria sp.	●	●	●	●	●	●	●
Diplotremina sp.	●	●				●	

The lower boundary of Nayband Formation in Garm Ab section is covered by recent sediment and could not be studied. This part is composed of grey to green siltstones and dark grey sandstones with ripple marks whereas the amount of sandy shale and sandstone increases. Because of the similarities of the sedimentation, it is difficult to identify the contact between the Nayband Formation (Upper Triassic) and the Ab-e Haji Formation (Lower Jurassic) even with paleontologic data.

The genus *Heterastridium* is represented in the lower part of the Garm Ab section (Fig. 3). Therefore, this part could be considered as the Bidestan Member and Norian in age (SENOWBARI-DARYAN, 1996; SENOWBARI-DARYAN & LINK, 2019). Similarly, the association of *Decapoalina schaeferae-Miliolipora cuvillieri* with accompanied taxa such as *Coronipora etrusca* (PIRINI). According to SENOWBARI-DARYAN *et al.* (2010) and GALE (2012), more appropriately supports a Rhaetian age.

The boundaries between Bidestan and Howz-e Sheikh in Garm Ab are characterized by the disappearance of *Heterastridium* and the appearance of *Trocholina turris* that is an index foraminifer of the Rhaetian (SENOWBARI-DARYAN *et al.*, 2010; GALE *et al.*, 2012, 2020).



◀ **Figure 4:** Pie charts of the biodiversity of three groups of foraminifers (porcelaneous, agglutinating, and hyaline) of the Upper Triassic foraminifers of Nayband Formation indicate the most abundant hyaline foraminifers in Garm Ab and North-East of Esfahan. The difference in diversity of porcelaneous and hyaline foraminifers between Garm Ab and Hassan Abad in Lut Block (located about 25 kilometers from the Garm Ab) is considerable.

From the lithologic data, the Howz-e Khan Member is more accurately defined by its increasing amount of reef carbonates. The association of foraminifers for this part is the *Involutina* ex gr. *liassica-Trocholina umbo* as the index of the upper part of Triassic. *Trocholina umbo* was described from the North-East of Esfahan (Senowbari-Daryan *et al.*, 2010) as Rhaetian in age.

The paleontological value of some taxa (*e.g.*, *Involutina*, *Trocholina*, and *Coronipora*) in the Garm Ab indicates their most probable Rhaetian age.

The similarity of foraminiferal data between Garm Ab in Lut Block and North-East of Esfahan in eastern part of Central Domain Block (Senowbari-Daryan *et al.*, 2010) permits some perspectives about the similar depositional conditions in eastern and western blocks of central Iran during the upper Triassic.

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Plates

Plate 1: Foraminifera from the Nayband Formation. Scale bar in all figures is 100 µm, except in fig. 16, for which it is 200 µm. **1:** *Coronipora serraforma* SENOWBARI-DARYAN *et al.* The illustration clearly shows the saw-like ornamentation on the wall of the youngest chamber. Some perforations on the last chamber wall are visible, thin section FA-F-140; **2:** *Coronipora etrusca* (PIRINI). Test straight on one side and concave on the other side. The latter contains hair-like elements, thin section FA-F-140; **3:** *Coronipora* ? sp. The species is strongly sparitic, thin section FA-F-140; **4:** *Miliolipora cuvillieri* BRÖNNIMANN & ZANINETTI. The last chambers are almost twice the size of the first chambers, thin section FA-F-115; **5:** *Trocholina umbo* FRENTZEN; the specimen shows the umbilical mass and pillar-like elements extending from the umbilicus, thin section FA-F-207; **6:** *Involutina ex gr. liassica* (JONES). The lenticular test is characterized by a large proloculus followed by more than three whorls of deuteroloculus, thin section FA-F-217; **7-8:** *Involutina* sp., some pillars in the wall are well visible. The test is lenticular with low preservation and small size. The small proloculus is surrounded by 4-7 whorls. The test is 250 µm in diameter, and 150 µm in thickness. Wall hyaline and perforate. Perforations occur mostly at the tubular-chamber periphery. The proloculus is not visible because of the low preservation. The last whorls show a low trochospiral coiling. It is indicative of the Upper Triassic to Liassic in association with *Involutina* ex gr. *liassica, thin* sections FA-F-303 (7) and FA-F-305 (8); **9-10:** *Trocholina turris* FRENTZEN; both specimens show the umbilical masses, thin section FA-F-404; **11:** *Planiinvoluta carinata* LEISCHNER; the specimen is attached to the lower surface of a sponge fragment, thin section FA-F-140; **12:** *Lamelliconus permodiscoides* (OBERHAUSER); the specimen is partly sparitic. The last chamber is filled with micritic sediment, thin section FA-F-122; **13:** *Aulotortus sinuosus* WEYNSCHENK. It is characterized by a large proloculus followed by three whorls of deuteroloculus, thin section FA-F-210; **14:** *Frondicularia rhaetica* KRISTAN-TOLLMANN. The half of an incomplete specimen with approximately leaf-shaped test, thin section FA-F-303; **15:** *Frondicularia* cf. *xiphoidea* KRISTAN-TOLLMANN, thin section FA-F-201; **16:** *Reophax tauricus* (KRISTAN-TOLLMANN), thin section FA-F-113; **17:** *Austrocolomia marschalli* OBERHAUSER. The first whorls partly fragmented, thin section FA-F-141.

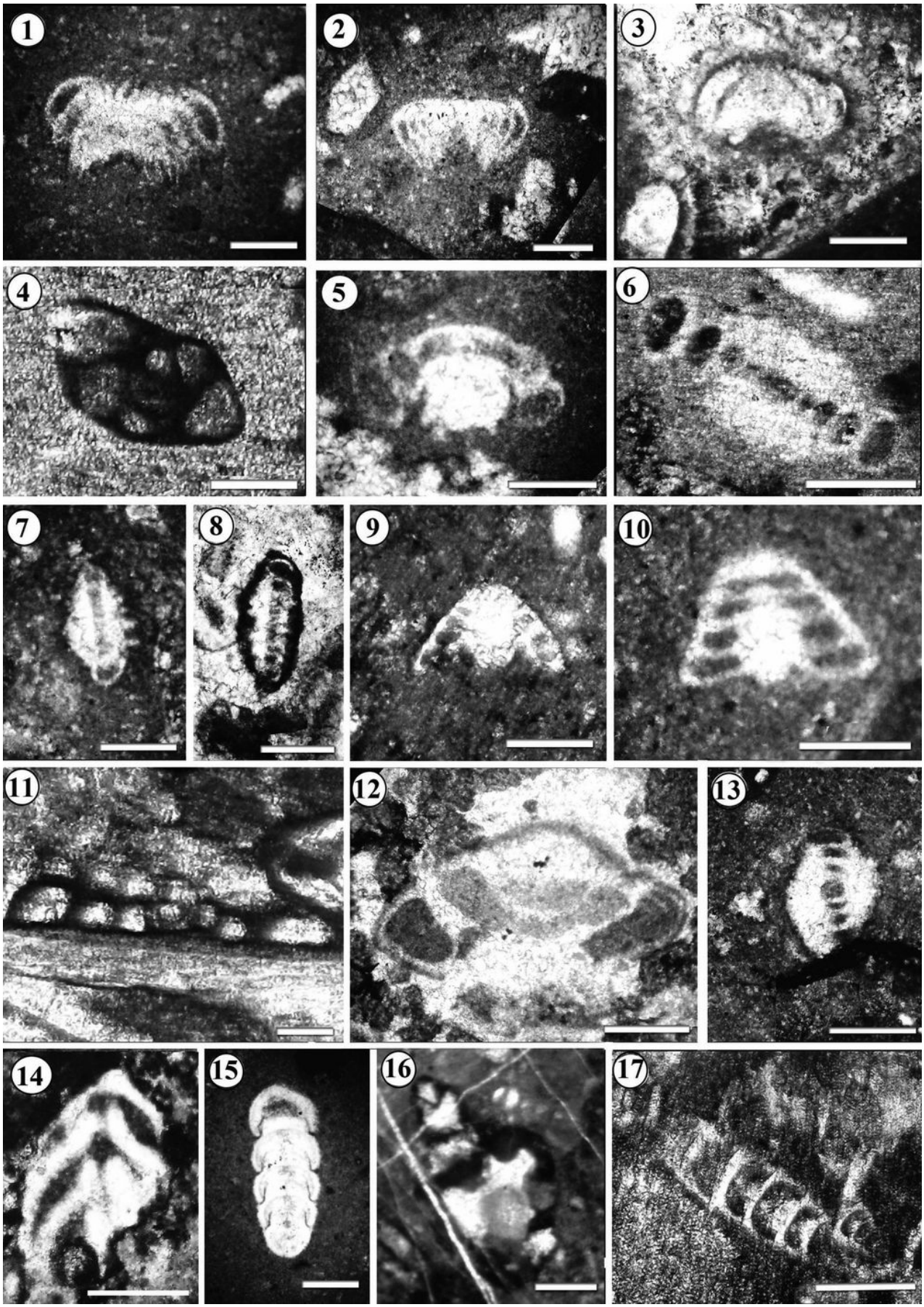
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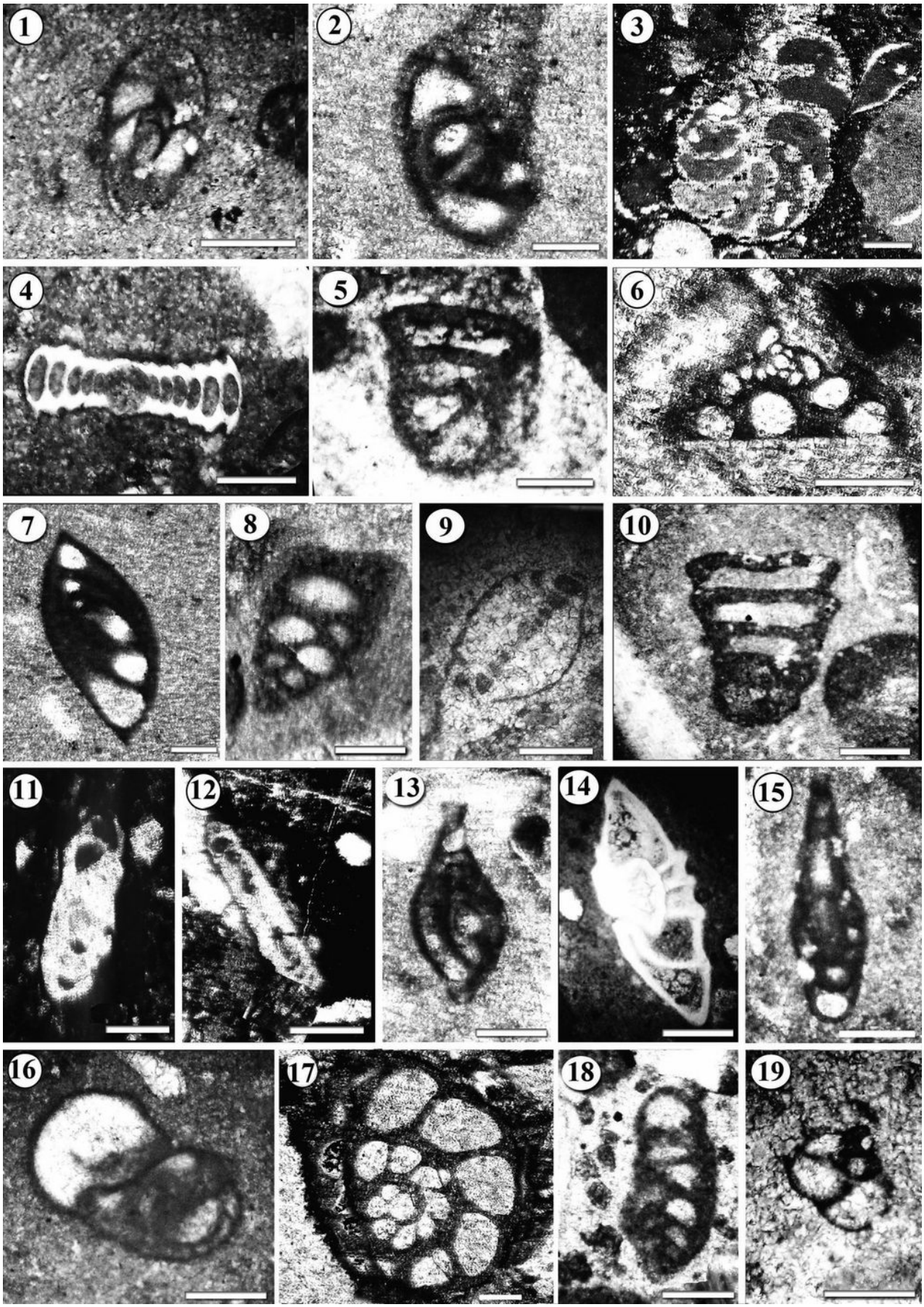
Plate 2: Foraminifera from the Nayband Formation. Scale bar in all figures is 100 µm, except in figs. 4-5, and 10 = 200 µm. **1-2:** *Agathammina iranica* ZANINETTI *et al.*, thin sections FA-F-207 (1) and FA-F-217 (2); **3:** *Ammobaculites eumorphos* KRISTAN-TOLLMANN. The chamber walls of the specimen are strongly sparitic, thin section FA-F-202; **4:** ? *Involutina* sp. (n.sp.?). Axial section. The specimen shows a large proloculus followed by several chambers. The wall is well preserved. Due to the extended wall of the last chamber, a spine-like element seems to be characteristic. This foraminifer is similar to specimen, illustrated in fig. 2 in RIGAUD *et al.* (2015) Thin section FA-F-136; **5:** *Palaeolituonella* cf. *meridionalis* (LUPERTO), thin section FA-F-305; **6:** *Calcitornella* sp., thin section FA-F-140; **7:** *Decapoalina schaeferae* (ZANINETTI *et al.*), thin section FA-F-132; **8:** "*Tetrataxis*" *inflata* KRISTAN, thin section FA-F-137; **9:** *Aulotortus sinuosus* WEYNSCHENK, thin section FA-F-207; **10:** *Palaeolituonella* cf*. angulata* SENOWBARI-DARYAN & CACCIATORE, thin section FA-F-401; **11-12:** *Aulotortus tenuis* (KRISTIAN), thin sections FA-F-140a (11) and FA-F-140b (12); **13:** *Ophthalmidium* sp, thin section FA-F-140a; **14:** *Lenticulina* sp., thin section FA-F-207; **15:** *Orthotrinacria* ? *expansa* (ZANINETTI *et al.*), thin section FA-F-201*;* **16:** *Galeanella tollmanni* (ZANINETTI & BRÖNNIMANN), thin section FA-F-206*;* **17:** Duostominidae, thin section FA-F-201; **18:** *Gaudryinella* cf. *kotlensis* TRIFONOVA, thin section FA-F-503*;* **19:** "*Trochammina*" *alpina* KRISTAN-TOLLMANN, thin section FA-F-207.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