Early Miocene larger benthic foraminifera from the northwestern Tethyan Seaway (NW Iran): new findings on Shallow Benthic Zone 25

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Abstract

The lower Miocene marine units of NW Iran (Hamedan–Miandoab area) were studied to establish a high-resolution biostratigraphy framework in the context of European standard biozonation (SBZ zonal scheme). The units are dominated by larger and small benthic foraminifera together with coralline algae and corals. Due to its position in the Tethyan Seaway between the Mediterranean and Indo-Pacific, the investigated area has high significance in palaeobiogeography. Seven species of benthic foraminifera were described, including *Miogypsina globulina*, *Amphistegina bohdanowiczi*, *Elphidium crispum*, *Elphidium* sp. 1, *Borelis curdica*, *Austrotrillina asmariensis*, and *Peneroplis thomasi*. The occurrence of *Miogypsina globulina* in the shallow-marine carbonates of the studied sections documents the Burdigalian SBZ 25 Zone. *Austrotrillina asmariensis* and *Peneroplis thomasi* occur with *M. globulina*. Simultaneously, their stratigraphical range is extended to the Burdigalian in the Middle East. Based on the discovery of lower Miocene deposits in the Hamedan–Miandoab area (previously mapped as Oligocene–Miocene units), the stratigraphy of northwest Central Iran is revised. The biostratigraphic results also present a more precise chronology for the marine transgression in the study area, initiating in the late early Miocene. The coralline algal assemblages and the abundance and diversity of larger benthic foraminifera indicate that shallow-marine Qom Formation got deposited in tropical to subtropical warm waters.

Keywords Benthic foraminifera · Burdigalian · Qom Formation · Biostratigraphy

Introduction

Northwestern Iran is characterized by well-exposed Mesozoic and Cenozoic marine strata (e.g., Sarfi and Yazdi-Moghadam 2016; Yazdi-Moghadam et al. 2017; Omidvar et al. 2018; Yazdi-Moghadam et al. 2018a, b). Oligo-Miocene shallow-marine carbonates often contain diverse assemblages of larger benthic foraminifera (LBF) that have been extensively used for biostratigraphic dating, palaeoenvironmental interpretation, and palaeobiogeography of

shallow-marine sequences of the Western Tethys, the Middle East, and the Indo-Pacific region (e.g., Cushman 1939; Henson 1948; Drooger 1952; Bozorgnia 1966; Hansen and Lykke-Andersen 1976; Schaub 1981; Less 1991; Cahuzac and Poignant 1997; Vaziri-Moghaddam et al. 2006; Hottinger 2007; Özcan and Less 2009; Boukhary et al. 2010; Özcan et al. 2010; Sirel et al. 2013; Hakyemez et al. 2016; Saraswati et al. 2018). Associated with the other shallow-marine biota (e.g., echinoderms, pelecypods, gastropods, coralline algae), LBF characterize widespread platform carbonates of the Oligo-Miocene age which are known under different formational names from central and southern Iran, e.g., Asmari, Mishan, and Gachsaran formations (Zagros Mountains), or Qom Formation (Central Iran). Attempts for detailed stratigraphy, and palaeoenvironmental studies of these platform carbonates in Iran, have been made by several authors and are still in progress (e.g., Ehrenberg et al. 2007; Van Buchem et al. 2010; Shabafrooz et al. 2015; Allahkarampour Dill et al. 2018; Yazdi-Moghadam et al. 2018a, b; Basso et al. 2019; Akbar-Baskalayeh et al. 2020). The present study makes an important contribution to

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this study process and reports the occurrence of hyaline and porcelaneous LBF recovered from three outcrop sections in the Hamedan–Miandoab area, NW Iran. The stratigraphic and taxonomic implications of the studied associations are of importance for (1) establishment of a biostratigraphic framework within the context of European standard biozonal scheme (SBZ) and (2) dating the initiation of shallow-marine conditions in the study area.

Geological and stratigraphic setting

The Cenozoic geology of Iran is characterized by an array of structural units including Zagros fold and thrust belt (ZFTB), Sanandaj–Sirjan Zone (SSZ), Uromia–Dokhtar Magmatic Arc (UDMA), Central Iran, Alborz, Koppehdagh, and eastern Iran (e.g., Stöcklin 1968; Stöcklin and Nabavi 1973; Berberian 1974; Berberian and King 1981) (Fig. 1a). The Lower Red, the Qom and the Upper Red Formations are superbly exposed and usually very thick in Central Iran. In contrast, the strata of the Qom Formation have locally deposited, with less thickness, in UDMA

and SSZ, and the Lower Red and Upper Red Formations are absent in many areas of these two structural units. As a part of the Alpine–Himalayan orogenic belt, Central Iran, UDMA, and SSZ exhibit complex structural features that are the result of long structural history from Palaeozoic time up to the present (Letouzey and Rudkiewicz 2005; Morley et al. 2009). Before Permian rifting, Central Iran and Zagros formed a single structural unit. During the Permian–Triassic time boundary, Central Iran was separated from the Zagros Mountains in the south, by an oceanic basin (Neo-Tethys). Following the Late Cretaceous closure of the Neo-Tethys, the northward migration of the Arabian plate continued until the continental collision with the Eurasian/Iranian plate at the Oligocene–Miocene boundary. The occurrence of the Oligo-Miocene marine deposits in Central Iran, UDMA, and SSZ is the result of the subduction of Neo-Tethys oceanic crust below the southern margin of Central Iran, which led to opening a back-arc basin (Central Iran) and a fore-arc basin (SSZ) separated by a magmatic arc (UDMA). In fact, the Qom Formation can be considered as part of a large depositional system of shallow-marine platform carbonates and deep-marine marlstones that characterized large parts of the

Fig. 1 Geological and geographical setting. **a** Simplified structural map of Iran showing the main tectonic subdivisions (modified from Agard et al. 2011). The white stars indicate the location of the sections studied. **a** Goli section, **b** Qaraie section, **c** Qabakh Tappeh section. **b–d** Road maps showing the position of the studied sections. (MZF Main Zagros Thrust, SSZ Sanandaj–Sirjan Zone, ZFTB Zagros Fold Thrust Belt, CEIM Central East Iran Microplate, UDMA Uromia–Dokhtar Magmatic Arc)

present-day Iran during the Oligo-Miocene times (e.g., Qom, Asmari, Pabdeh, and Mishan formations). The Oligo-Miocene marine strata of Central Iran, UDMA, SSZ, and ZFTB form important components of the late Paleogene–early Neogene Tethyan warm to temperate marine depositional belts. From the aforementioned data, it becomes clear that the Oligo-Miocene sedimentary sequences of central and southern Iran bear important information for the geodynamic history of Iran and the Middle East.

Furrer and Soder (1955) divided the Qom Formation into six members, including: basal limestones (a-Member), sandy marlstones (b-Member), alternating marlstones and limestones (c-Member), evaporites (d-Member), green marlstones (e-Member), and top limestones (f-Member). Inter-areal tracing of the Qom Fm. members, mostly developed at the type locality, is complicated by rapid lateral facies changes and strongly varying thicknesses. In other words, except for the f-Member, the other members can hardly be traced in places far from the type area (e.g., NW Iran). One of the key areas for stratigraphical studies in the SSZ and UDMA is NW Iran (including the Hamedan–Miandoab area), where the deposits of the Qom Formation are well exposed and widespread. Early mapping surveys of NW Iran have only been supplemented with gross stratigraphy in this area. Only recently, some modern micropaleontological studies have been published (Yazdi-Moghadam 2011; Daneshian and Ghanbari 2017; Yazdi-Moghadam et al. 2018a, b). During the Miocene, carbonate-dominated strata (Qom Formation) of variable shallow to moderately deep-marine environments have been deposited in the Hamedan–Miandoab area which are the subject of this study for micropaleontology and biostratigraphy. Therefore, this study is intended to describe LBF of northwest of Iran and to build the global SB system of biochronozones as proposed by Pignatti and Papazzoni (2017).

Materials and methods

This study is based on three outcrop sections: Goli (36° 59' 21.8" N, 46° 51' 59" E), Qabakh Tappeh (35° 27' 1.98" N, 48° 33' 46.33" E), and Qaraie (36° 32' 19.7" N, 47° 59' 13.0" E), all located in the northwest Iran in an area extending from Hamedan to Miandoab (Fig. 1). A total of 104 samples (including 165 thin sections) were studied from the three sections, covering the whole marine strata of the Qom Formation. Larger benthic foraminifera occurred in cemented hard rocks, and matrix-free specimens were not available. Therefore, multiple thin sections were prepared from the limestone samples to obtain oriented sections of the specimens. The generic classification of foraminifera follows Loeblich and Tappan (1987). All the samples and thin sections presented in this paper are deposited in the collection

of the National Iranian Oil Company Exploration Directorate (NIOCEXP), Tehran, Iran, under the acronyms of RCH (Goli section), ASK (Qaraie), and ANM (Qabakh Tappeh).

Results

Goli section

The sedimentary succession of the Qom Formation at Goli is 214-m-thick and starts with conglomerates covering the palaeo-relief of Eocene igneous rocks. It characterizes the unconformable contact between the overlying Qom strata and the underlying Eocene volcanics. The onlap of the Qom Formation onto the Eocene igneous paleo-relief continued with the deposition of shallow-marine strata composed of very thick to thick bedded limestones and sandy limestones together with thin beds of marlstones. Detailed lithostratigraphic description of the Qom Formation in the Goli section is shown in Fig. 2. The shallow-marine strata are characterized by the presence of LBF, including *Miogypsina globulina*, *Amphistegina bohdanowiczii*, *Borelis curdica*, and *Peneroplis thomasi* (Fig. 3). Significant occurrences of smaller benthic foraminifera include *Elphidium crispum*, *Elphidium* sp. 1, miliolids, and textulariids. Coralline algae are mainly represented by lithophylloids [e.g., *Titanoderma pustulatum* (Lamouroux)], mastophoroids (*Lithoporella melobesioides* Foslie), Sporolithales (*Sporolithon* sp.), and neogoniolithoids (*Spongites* sp.). Lithophylloids and neogoniolithoids are common. Bryozoans, corals (*Porites*-Faviidae assemblage and solitary corals), and *Kuphus*-tubes are subordinate. The Qom Formation at Goli is unconformably overlain by continental deposits of the Upper Red Formation.

Qabakh Tappeh section

The Qom Formation at Qabakh Tappeh is a competent-weathering, cliff-forming unit. The lower contact between the Qom Fm. and the underlying strata is not exposed due to alluvial cover (Fig. 4). The marine succession of the Qom Formation, 169.5-m-thick, is a carbonate sequence consisting of very thick, thick, and medium bedded shallow-marine limestones. As shown in Fig. 5, limestones contain LBF, including *Miogypsina globulina*, *Amphistegina bohdanowiczii*, and *Borelis curdica*. Acervulinids are common encrusting foraminifers. Miliolids and textulariids chiefly represent the association of small benthic foraminifera. Coralline algae include lithophylloids, neogoniolithoids (*Spongites* sp.), melobesioids, and Sporolithales (*Sporolithon* sp.). Lithophylloids and neogoniolithoids are more abundant. Bryozoans, bivalves, echinoids, and corals (*Porites*-Faviidae assemblage) are associated. The upper contact of the Qom

Fig. 2 Lithostratigraphic log of the Goli section. (URF Upper Red Formation)

Fig. 3 Log of the Goli section showing the distribution of benthic foraminifera and non-foraminiferal skeletal elements

Fig. 4 Lithostratigraphic log of the Qabakh Tappeh section

Formation is erosional, and the Upper Red Formation is not present here.

Qaraie section

The Qaraie section is characterized by a disconformable contact between the red polymictic conglomerates, marlstones, and siltstones of the underlying Lower Red Formation and the overlying carbonates of the Qom Formation

Fig. 5 Log of the Qabakh Tappeh section showing the distribution of benthic foraminifera and non-foraminiferal skeletal elements

(Fig. 6). The Qom Fm. is composed of two lithotypes in this area, i.e., the shallow-marine carbonates and deep-marine marlstones and argillaceous limestones. It permits a further subdivision into two lithostratigraphic units. Unit I, with a thickness of 32 m, is composed mainly of very thick bedded to thick bedded shallow-marine limestones. Compared to the type locality, this unit can be correlated with the f-Member. The assemblage of LBF shown in Fig. 7, includes *Miogypsina globulina*, *Amphistegina bohdanowiczii*, and *Austrotrillina asmariensis*. An associated assemblage of small benthic foraminifera is mainly represented by *Lobatula* sp., *Textularia* spp., and Miliolidae. Coralline algae are chiefly represented by mastophoroids (*Lithoporella melobesioides*), Sporolithales (*Sporolithon* sp.), and a few occurrences of sterile melobesioids. Corals (branching *Porites*) dominate most of the unit, while bryozoans rarely occur. The first marine marlstones appear 32 m above the base of the Qom Formation, marking the base of Unit II. This unit is characterized by the occurrence of planktonic foraminifera, including *Globigerinoides altiaperturus*, *Streptochilus pristinum*, and *Globigerina praebulloides*, documenting the platform drowning. Finally, the marine strata of the Qom Fm. are unconformably overlain by the continental conglomerates of the Upper Red Formation.

Systematic paleontology

Miogypsina globulina (Michelotti, 1841) Figs. 8 and 9

1841 *Nummulites globulina* Michelotti, p. 297, pl. 3, Fig. 6.

1952 *Miogypsina irregularis* (Michelotti), Drooger, p. 54, pl. 2, Figs. 25, 26, 27, 28 and 29.

1959 *Miogypsina globulina* (Michelotti), Drooger and Socin, pl. 1, Fig. 5.

1974 *Miogypsina globulina* (Michelotti), Raju, pp. 82–83, pl. 2, Figs. 1, 2, 3 and 4; pl. 5, Figs. 6, 7; pl. 6, Fig. 1.

1979 *Miogypsina globulina* (Michelotti), Schiavinotto, pp. 267–268, pl. 3, Figs. 3, 4.

2009 *Miogypsina globulina* (Michelotti), Özcan and Less, p. 33, pl. 1, Figs. 24, 25; pl. 2, Fig. 6, text-Fig. 8.

2009 *Miogypsina globulina* (Michelotti), Özcan et al., pp. 568–569, pl. 2, Figs. 20, 21, 22, 23, 24, 25, 26, 27, 28 and 29, text-Fig. 11.

For measurements, see Table 1.

Remarks: According to Drooger (1993), representatives of *Miogypsina globulina* are defined by having the mean *V* values between 0 and 45. Our specimens exhibit *V* values ranging from 29.47 to 39.69 (Table 1), falling within the range of *M. globulina*.

Fig. 6 Lithostratigraphic log of the Qaraie section. (LRF Lower Red Formation, URF Upper Red Formation)

Amphistegina bohdanowiczi (Bieda 1936) Fig. 10

1936 *Amphistegina bohdanowiczi*, Bieda, p. 266, pl. 8, Fig. 4a–c.

1993 *Amphistegina bohdanowiczi*, Bieda, Rögl and Brandstätter, pl. 3, Figs. 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33 and 34; pl. 4, Figs. 1, 2, 3, 4, 5 and 6; pl. 6, Figs. 5, 6.

2017 *Amphistegina bohdanowiczi*, Bieda, Ferrández-Cañadell and Bover-Arnal, p. 103, Figs. 3E, 15A–J, P. (cum syn.).

Like many parts of the western and central Tethys, this species is widespread in the Oligocene and early Miocene of central and southern Iran. In our studied material, it is characterized by having a small and asymmetrical test reaching to 1 mm in diameter and 0.6 mm in thickness. The triangular test is more or less plano-convex to unequally biconvex with a more inflated ventral side. The tangential section of the test represents a large triangular postulate area in front of the foramen.

Elphidium sp. 1. (Adams and Bourgeois 1967) Fig. 11a–d

1967 *Elphidium* sp. 1. Adams and Bourgeois, p. 709, pl. 19, Fig. 1d.

This species is characterized by having a planispiral, lenticular, and biumbonate test. The umbilical plug is generally large, identical to that in *Elphidium craticulatum*. Periphery is subacute. The axial section of the test represents the retral process and spiral canal.

Remarks: This species is not adequately described by Adams and Bourgeois (1967). These authors did not point to any features of the internal structure, such as the retral process and spiral canal. According to Adams and Bourgeois (1967), *Elphidium* sp. 1 has an overall range from the base of Rupelian to Burdigalian. More investigations based on well-preserved material are to be conducted to determine whether or not the Oligocene representatives assigned to this species are true.

Fig. 7 Log of the Qaraie section showing the distribution of benthic foraminifera and non-foraminiferal skeletal elements

Fig. 8 *Miogypsina globulina* (Michelotti). **a–i** and **j–k** are equatorial and axial sections of the A-forms, respectively. (**a** ANM 4594; **b** RCH 1326; **c** ASK 3132; **d**, **f** RCH 1279; **e** ASK 3129; **g**, **i**: RCH 1313; **h** RCH 1279; **j** ANM 4596; **k** ANM 4592)

Fig. 9 **a** Measurement system for a bispiralled *Miogypsina* with two principal auxiliary chambers (PAC). The other parameters are explained in the header of Table 1. **b–j** are embryonic–neponic drawings of **a–i** in Fig. 8. (PAC principal auxiliary chamber, cch closing chamber)

Elphidium crispum (Linnaeus 1758) Fig. 11e, f

1758 *Nautilus crispus* Linnaeus, p. 709, pl. 19, Fig. 1d.

1939 *Elphidium crispum* (Linnaeus), Cushman p. 50, pl. 13, Figs. 17, 18, 19, 20 and 21.

1958 *Elphidium crispum* (Linnaeus), Reiss and Merling, pl. 5, Fig. 2.

1976 *Elphidium crispum* (Linnaeus), Hansen and Lykke-Andersen, p. 6, pl. 1, Figs. 10, 11 and 12; pl. 2, Figs. 1, 2.

2001 *Elphidium crispum* (Linnaeus), Hottinger, Reiss and Langer, p. 28, pl. 10, Figs. 4, 5, 6 and 7.

Remarks: *Elphidium crispum* is a typical species of *Elphidium*. Vertical canals arising from the spiral canal are present in the umbilical plug. Sutures are curved, especially towards the periphery of the test. It is shallow water, normal marine, symbiotic chloroplast-bearing, epibenthic species (Leutenegger 1984; Jorissen 1988; Langer 1989; Hottinger et al. 2001).

Borelis curdica (Reichel 1937) Fig. 12

1937 *Neoalveolina melo curdica* n. sp. Reichel, p. 108, pl. 10, Figs. 4, 5, 6 and 7.

2019 *Borelis curdica* (Reichel), Bassi et al., pp. 11–14, Figs. 9, 10 and 11. (cum syn.).

Only A-forms are present in our material characterized by subspherical to spherical shape of the test. Chamberlets

become alternately large and small, resulting in the development of intercalary chamberlets separated by Y-shaped septula. This kind of septula occurs throughout the ontogeny. The elongation index is around 1 and the spherical proloculus varies in diameter from 39 to 60 μ m.

Remarks: *Borelis curdica* is a widespread species in the Burdigalian–Tortonian shallow-marine carbonates of the Mediterranean area. So far, the reliable records of this species are only from the Burdigalian of southern and central Iran (e.g., Hottinger 1974; Seyrafian et al. 2011; Yazdi-Moghadam et al. 2018a).

Peneroplis thomasi (Henson 1950) Fig. 13

1950 *Peneroplis thomasi* sp. nov. Henson, pp. 36–37, pl. 5, Figs. 7, 8, 9, 10 and 11.

1981 *Peneroplis thomasi* Henson, Radoičić, pl. 1, Figs. 3, 4.

2011 *Peneroplis thomasi* Henson, Yazdi-Moghadam, pl. 2, Figs. 8.

2013 *Peneroplis thomasi* Henson, Amirshahkarami, pl. 5, Figs. 9, 10 and 11.

2016 *Peneroplis thomasi* Henson, Habibi, pl. 2, Fig. 15.

2014 *Peneroplis thomasi*, Karevan et al., Fig. 5C.

The planispiral, compressed test of *Peneroplis thomasi* is characterized by initial involute stage with 2–2.5 whorls, followed by a flabelliform evolute final stage of growth.

Table 1 Numerical data for *Miogypsina globulina* (Michelotti) from the Hamedan–Miandoab area (After Amato and Drooger 1969)

Sample	P (μm)	D (μm)	α	β	γ ($^\circ$)	V values ($200\alpha/\beta$)
Goli section						
RCH 1279	187	203	42	285	7	29.47
RCH 1279	172	195	41	266	0	30.82
RCH 1279	210	250	42	265	3	33.96
RCH 1313	195	265	47	265	31	35.47
RCH 1326	193	211	42	260	34	32.30
RCH 1338	187	237	50	262	36	38.16
Mean	190.66	226.83	44	267.16	18.50	33.85
Standard deviation	12.43	28.03	3.63	9.02	16.83	3.77
Qabakh Tappeh section						
ANM 4592	188	203	40	268	27	29.85
ANM 4594	177	269	40	270	21	29.62
ANM 4595	175	200	40	263	28	30.41
ANM 4596	180	275	38	247	20	30.77
ANM 4600	200	256	39	255	30	30.59
ANM 4611	202	258	52	262	35	39.69
Mean	186.8	251.6	41.8	259.40	26.80	31.82
Standard deviation	13.10	29.88	5.76	8.73	6.30	3.87
Qaraie section						
ASK 3129	180	230	48	290	35	33.10
ASK 3132	157	195	47	264	22	35.60
ASK 3133	173	212	46	264	14	34.84
ASK 3134	182	234	48	254	36	37.80
Mean	173	217.75	47.25	268	26.75	35.33
Standard deviation	11.34	17.93	0.95	15.40	10.62	1.94

P inner cross-diameter of protoconch, D inner cross-diameter of deuteroconch, α arc length of the circumference of the protoconch underlying the shorter spiral, β arc length of the circumference of the protoconch underlying both protoconchal spirals, γ orientation of the nepion, V symmetry index of the two protoconchal spirals

Specimens of the Goli section show up to 14 chambers in the neanic growth stage. In axial and subaxial sections, the test appears as a “knotted rope”. The epidermis is thick. This species is distinct from the other species of the genus *Peneroplis* by its particular growth morphology and thick epidermis.

Austrotrillina asmariensis (Adams 1968) Fig. 14

1968 *Austrotrillina asmariensis* Adams, pp. 82–85, pl. 1, Figs. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 and 12.

2017 *Austrotrillina asmariensis* Adams, Ferràndez-Cañadell and Bover-Arnal, p. 88, Figs. 4c–g. (cum syn.).

Only A-forms are recorded. This species is characterized by triloculine fashion of growth and exoskeleton as simple, closely spaced, narrow, and deep alveols. Alveols first appear at the initial stages of the growth. The globular to subglobular proloculus of 76–117 μm has a reniform flexostyle that attains a length of half the circumference of the proloculus (Fig. 14i). The specimens of the Qaraie section reach the length of 0.8–0.106 mm which are somewhat shorter

than the original material (1–1.5 mm) described by Adams (1968). The width of the specimens varies between 0.62 and 0.9 mm. Alveoli range in diameter from 13 to 26 μm . The thickness of the wall in the final chambers is between 70 and 82 μm and the number of alveoli per 100 μm in cross-section varies from 3 to 4. Chamber walls are rounded. Our specimens show a few bifurcations in the exoskeleton of the final chambers, a feature that can be observed in B-forms by Adams (1968) and is also reported by Ferràndez-Cañadell and Bover-Arnal (2017).

Discussion

Biostratigraphy

Larger benthic foraminiferal associations of the Goli, Qabakh Tappeh, and Qaraie sections correspond to SBZ 25 based on the occurrence of key taxon *Miogypsina globulina*. This miogypsinid species is well known from the early Burdigalian of the Tethys realm (Drooger and Socin

Fig. 10 a–f *Amphistegina bohdanowiczi* Bieda. (a RCH 1291; b RCH 1321; c–e ASK 1329; f ANM 4610)

1959; Raju 1974; Schiavinotto 1979; Drooger 1993; Cahuzac and Poignant 1997; Özcan and Less 2009; Özcan et al. 2009; Bassi et al. 2019). It marks the SBZ 25 Zone (e.g., Cahuzac and Poignant 1997). *Borelis curdica* has an overall range of Burdigalian–Tortonian (Adams 1970; Cahuzac and Poignant 1997; Jones et al. 2006; Bassi et al. 2019). *Peneroplis thomasi* is common in the lower to upper Oligocene shallow-marine deposits of the Middle East (e.g., Henson 1950; Radoičić 1981; Yazdi-Moghadam 2011; Karevan et al. 2014; Habibi 2016). The occurrence of this species in the upper Oligocene of Europe (Western Tethys) is reported by Ferràndez-Cañadell and Bover-Arnal (2017). A Rupelian–Aquitian stratigraphic range is suggested by Eames et al. (1962), and a Chattian–Aquitian range has also been inferred by Amirshahkarami (2013). The occurrence of this species from the Burdigalian (SBZ 25 Zone) shallow-marine limestones of the Qom Fm. in the Goli section, represents its youngest known record. Therefore, the overall range of *Peneroplis thomasi* has to be considered as Rupelian–Burdigalian (SBZ 21–SBZ 25). *Austrorillina asmariensis* has been mostly reported from the Rupelian to Aquitainian in Europe and the Middle East (e.g., Adams 1968; Accordi et al. 1998; Gallardo et al. 2001; Sirel 2003; Bassi et al. 2007; Gedik 2015; Serra-Kiel et al. 2016; Ferràndez-Cañadell and Bover-Arnal 2017). The only occurrence of this species from the Burdigalian of the Far East (Upper Te, Borneo) is by BouDagher-Fadel et al. (2000). The occurrence of *Austrorillina*

asmariensis from the Burdigalian (SBZ 25) shallow-marine limestones of the Qom Fm. in the Qaraie section represents its youngest record in Iran and the Middle East. Hence, the total range of this species has to be revised to Rupelian–Burdigalian (SBZ 21–SBZ 25). So far, *Elphidium crispum* is known from the Miocene to recent (e.g., Reiss and Merling 1958; Hottinger 2010). Our observations based on previously published data (Yazdi-Moghadam et al. 2018a), together with the results of the current study, suggest that the earliest occurrence of *Elphidium crispum* characterizes the Burdigalian age (SBZ 25) in Central Iran.

Palaeoenvironmental and palaeoclimatic implications

Larger benthic foraminifera and coralline algae occur abundantly in many platform deposits (e.g., Beavington-Penney and Racey 2004; Bassi and Nebelsick 2010; Ghosh and Sarkar 2013; Sarkar 2016; Pomar et al. 2017). The groups are distributed in a wide range of platform environments. Therefore, LBF and coralline algae are excellent palaeoenvironmental indicators which may be used as valuable tools to discern environmental changes in lithologically monotonous platforms (e.g., Nebelsick et al. 2013; Sarkar and Ghosh 2015; Basso et al. 2019). According to Drooger (1993), *Miogypsina* thrives in shallow waters (up to 50–80 m). The high abundance of miogypsinids

Fig. 11 **a–d** *Elphidium* sp. 1. Adams and Bourgeois. **e, f** *Elphidium crispum* (Linnaeus). (**a, d, f** RCH 1314; **b** RCH 1289; **c** RCH 1315; **e** RCH 1299). (*f* foramen, *rp* retrol process, *s* septum, *sp* spiral canal, *up* umbilical plug, *vc* vertical canal)

indicates middle ramp to proximal part of the outer ramp environment. *Amphistegina* is an inhabitant of the tropical-subtropical belt. It is dependent on symbionts and lives in shallow waters down to 70–80 m, occasionally somewhat deeper (Rögl and Branstätter 1993). *Borelis* is said to thrive in shallow, warm, protected zones of reef complexes (Cole 1954, 1957; Chevalier 1973; Ghose 1977). A detailed ecological study in the Gulf of Aqaba revealed that *Borelis* hosts B-3 diatom symbionts and is restricted to depths of 5–65 m (Reiss and Hottinger 1984). For the Miocene, these authors postulate a shallow environment where the alveolinids (e.g., *Borelis*) lived down to a depth between 20 and 40 m. A warm, clear, shallow water up to 33 m deep environment with a temperature around 25 is inferred for *Borelis melo*, an early-middle Miocene marker in the Mediterranean area and the Middle East, by Bandy (1960) and Murray (1991). The genus *Peneroplis*, very common on the reef flat, clearly prefers hardgrounds of the shallowest slope parts down to 30 m (Hohenegger et al. 1999). Schuster and Wielandt (1999) state that the association of LBF, including *Borelis curdica*, *Peneroplis evolutus*, *Archaias* sp., and miliolids occurring within the patch reefs in the Qom Fm., are typical for very shallow

and well-illuminated habitats in sheltered, back-reef environments. According to these authors, the late Oligocene and early Miocene coral faunas of Central Iran, represent a mixture of Indo-Pacific and Mediterranean elements characterizing the normal marine sedimentation. Coralline algae are also common in taxonomic composition of the Qom Formation. The association of coralline algae and corals together with LBF are usually considered to live in the oligophotic zone of the middle ramp environment (e.g., Pomar 2001a; b; Brandano and Corda 2002; Corda and Brandano 2003; Bassi 2005). Similarly, limestones of the Qom Fm. composed of corallinaceans and LBF have been interpreted to be typical for the middle ramp (e.g., Reuter et al. 2009). The abundance of red algae is compatible with a water depth of about 30–50 m for the oligophotic zones (Hallock 1987, 1988; Brandano et al. 2010). Coralline algae are common both in tropical as well as in temperate waters (Braga and Aguirre 2001). According to Aguirre et al. (2000), in modern tropical environments, mastophoroids are the most abundant coralline algae in shallow water, whereas melobesioids become more abundant below 10–20 m, and Sporolithales are abundant at greater depth (40–50 m). Neogoniolithoids are common

Fig. 12 a–f *Borelis curdica* (Reichel). (chl chamberlet, ichl intercalary chamberlet, psp preseptal passage, Y-spt Y-shaped septulum). (a RCH 1333; b, e RCH 1299; c, d RCH 1295; f ANM 4592)

in shallow subtidal depths below 40 m (Adey et al. 1982; Perrin et al. 1995; Aguirre et al. 2000). The presence of tropical genera (*Lithoporella* and *Sporolithon*) in the red algal assemblages of the Qom Fm. suggests that carbonate sedimentation took place in warm waters. LBF are generally restricted to warm tropical and subtropical waters, with means of 18–20 °C for the warmest months of the year (Adams et al. 1990). Oligocene and early Miocene LBF, such as miogypsinids are thought to be restricted to tropical to subtropical regions in oligo- to slightly mesotrophic conditions (Betzler et al. 1997). Therefore, also the larger benthic foraminiferal assemblages of the Qom Fm. support deposition in warm waters. The presence of planktonic foraminifera is indicative of open marine environment and their relative abundance increases basinward

(e.g., Geel 2000). Summing up, the biotic assemblages of the shallow-marine part of the Qom Fm. (f-Member) in the study area suggest that the deposition took place in shallow-marine environment (middle ramp) under oligotrophic conditions and in warm waters of the tropical to subtropical zones. The common occurrences of neogoniolithoids and lithophylloids together with the abundance of certain LBF (*Borelis* and *Peneroplis*) in Goli and Qabakh Tappeh sections suggest a water depth less than 40 m (5–40 m). Instead, a greater water depth (30–50 m) can be inferred for the shallow-marine limestones of the Qaraie section due to the dominance of *Sporolithales* and mastophoroids with respect to melobesioids. The presence of planktonic foraminifera in the upper part of this section (Unit II) is indicative of outer ramp deposition with a water depth

Fig. 13 a–f *Peneroplis thomasi* Henson. (a RCH 1337; b–f RCH 1318). (f foramen, fl flexostyle, lw lateral wall, s septum, p protoconch). Scale bars represents 250 μ m

possibly more than 50 m. The absence of deep-marine representatives of coralline algae in this part of the Qaraie section may point to fine-grained sedimentation which severely reduced water transparency.

Conclusions

In the lower Miocene shallow-marine platforms of NW Iran, *Peneroplis thomasi* and *Austrotrillina asmariensis*

Fig. 14 a–i *Austrotrillina asmariensis* Adams. (a–d ASK 3129; e–h ASK 3130; i ASK 3133). (al alveole, fl flexostyle, p protoconch)

Fig. 15 Stratigraphic distribution of selected hyaline and porcelainous benthic foraminifera based on Cahuzac and Poignant (1997) and results of this study

coexist with key Burdigalian species *Miogypsina globulina* (Fig. 15). Therefore, the upper range of these porcelaneous foraminifera has to be extended into the Burdigalian (SBZ 25). The larger foraminiferal and red algal assemblages of the Qom Fm. (Hamedan–Miandoab area) confirm sedimentation in warm waters of the tropical–subtropical zones (middle ramp setting). Deposition in the oligotrophic conditions is also compatible with the composition of red algal assemblages and the abundance and diversity of larger benthic foraminifera. The results of this study together with the previously published data suggest that the LBF composition of Central Iran show faunal elements from both western and eastern sides of the Tethys during the Burdigalian. This demonstrates the persisting connection between the Qom Basin with both Mediterranean and Indo-Pacific Oceans until the early to mid-Burdigalian. However, the presence of porcelaneous larger benthic foraminifera, including *A. asmariensis* and *P. thomasi*, so far completely unknown from the Burdigalian strata in Western Tethys, points to the restriction of the Tethyan Seaway before its final closure. This restriction of seaway connection is in agreement with the idea of Reuter et al. (2009), who stated that the differentiation into an Atlantic–Mediterranean and an Indo-Pacific bioprovince took place before the final paleogeographic disjunction of the Tethys (Terminal Tethyan Event). Our biostratigraphic results suggest that the marine transgression of the Hamedan–Miandoab platform (Qom Fm.) occurred during the early Burdigalian.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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