Front. Earth Sci. 2018, 12(1): 237–251
https://doi.org/10.1007/s11707-017-0669-5

RESEARCH ARTICLE

Foraminiferal biostratigraphy of the Miocene Qom Formation, northwest of the Qom, Central Iran

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Abstract Near Dochah, in the type area of the Qom Formation, Central Iran, the Miocene is partly developed in pelagic facies. From the 894.1 meter thick, 'a to e' members of this section, 152 samples were collected. Abundant planktonic foraminifera let us correlate the study section with the global planktonic foraminifera biozonations. High diversity of foraminifera in the study section allow us to adapt the study succession to global biozonations. Twenty-seven genera and thirty-four species are reported for the first time from the Dochah section. First reports of *Praeorbulina sicana* and *Praeorbulina transitoria* in the upper part of this section led to recognition of the *Praeorbulina sicana* lower occurrence subzone (M5a) biozone with a late Late Burdigalian age.

Keywords biostratigraphy, foraminifera, Miocene, Central Iran

1 Introduction

Miocene outcrops in Central Iran trend northwest to southeast. The deposits extend to the northwest of northern Mako and Khoi and from there to the series of saline carbonate and clastic sediments of Nakhchivan in Azerbaijan and similar marine sediments in northeast Anatolia, Turkey (Rahimzadeh, 1994; Aghanabati, 2004). Because of the lateral facies changes and tectonic complexity of the Qom Formation, no type section has yet been defined. A type area was designated in the southern Qom plain around Dochah, where outcrops are most extensive and least lateral changes (Stocklin and Setudehnia, 1991; Hadavi et al., 2010; Mohammadi et al., 2011).

The unique character of the Qom formation and the oil reservoir it hosts have prompted a variety of studies (Furrer and Soder, 1955; Daneshian and Ramezani Dana, 2007).

As a part of the Tethyan Seaway, Central Iran was a link between eastern Tethys (the proto-Indian Ocean) and western Tethys (the proto-Mediterranean Sea) (Schuster and Wielandt, 1999; Reuter et al., 2009). The Qom Formation was deposited during the final marine transgression in Central Iran during the Oligo-Miocene (Daneshian and Ramezani Dana, 2007; Reuter et al., 2009; Mohammadi et al., 2011, 2013, 2015). However, uncertainties remain about the precise age and biostratigraphic evidence for correlation. Several studies have been carried out on different aspects of this formation such as biostratigraphy (benthic and planktic foraminifera, nannofossils, ostracods, gastropoda, corals), sequence stratigraphy, microfacies, tectonic, paleogeography, paleoecology, etc. More recently, studies were done by Seyrafian and Torabi (2005); Daneshian and Ramezani Dana (2007); Khaksar and Maghfouri Moghadam (2007); Berning et al. (2009); Morley et al. (2009); Hadavi et al. (2010); Behforouzi and Safari (2011); Hasani and Vaziri Moghadam (2011); Yazdi et al. (2012); Yazdi-Moghadam (2012); Mohammadi et al. (2011, 2013, 2015); Anjomshoa and Amirshahkarami (2014); Amirshahkarami and Karavan (2015); Daneshian and Ramezani Dana (2007); Mohammadi and Ameri (2015); and Daneshian et al. (2017). Some of these investigations specifically considered foraminiferal biostratigraphy of the Qom Formation with references to Daneshian and Ramezani Dana (2007); Behforouzi and Safari (2011); Yazdi Moghadam (2011); Mohammadi et al. (2015); and Mohammadi and Ameri (2015).

Daneshian and Ramezani Dana (2007), after studying the biostratigraphy of the Qom Formation in the northern part of the Central Iran Basin (north of Garmsar), proposed that the biozonation of Adams and Bourgeois (1967) is applicable to the Qom Formation based on the benthic foraminifera present in Oligocene–Miocene sediments of the Asmari Formation in Zagros. They estimated an Aquitanian to Burdigalian age for the studied section (Deh

Received June 23, 2016; accepted May 10, 2017

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Namak). Behforouzi and Safari (2011) by investigating larger benthic foraminifera of the Qom Formation in the Urumieh-Dokhtar magmatic arc (intra-arc basin) in northwestern Kashan, recognized the *Lepidocyclina- Operculina- Ditrupa* assemblage zone of Wynd (1965) in their studied section and assigned the Oligocene age. Yazdi Moghadam (2011) considered larger benthic foraminifera of the Qom Formation south of Uromieh (Baranduz). He correlated the foraminiferal assemblage of this section with SBZ 21, the European standard shallow benthic zonation, and proposed this biozone extends to northwestern Iran. He suggested an Early–Middle Rupelian age for the studied section. Mohammadi et al. (2013) mentioned this age is in contrast to the results of previous studies. They studied the biostratigraphy of two stratigraphic sections (Ghohroud and Vidoja) of the Qom Formation to the south and southwest of Kashan and revised the results of previous works. They concluded that the Qom Formation is Rupelian–Burdigalian in age. They also mentioned the transgression of the Tethyan Seaway on the Iranian Plate started in the southeast and continued to the northwest gradually. This transgression indicates that due to the compressive tectonic regime in the Central Iran back-arc basin, the gates to the open ocean gradually became restricted in the Early Miocene. They suggested that the evaporitic ‘d’ Member in the Qom Formation was deposited in the small area of the Central Iran back-arc basin and was deposited totally within the early Miocene (Aquitanian–Burdigalian). Mohammadi and Ameri (2015) and Mohammadi et al. (2015) studied deposits of this formation in the Sanandaj–Sirjan zone (fore-arc basin in northern Abadeh) and analyzed biotic components, especially foraminiferal assemblages, and documented a Rupelian-Chattian age for deposits in the Abadeh area. They suggested obtained results are compatible with the common trend of the transgression of the Tethyan Seaway onto the Iranian Plate. Mohammadi et al. (2015) studied the larger benthic foraminifera of the Qom Formation, mainly Lepidocyclinidae, Nummulitidae, and *Neoalveolina* biostratigraphically in the Sanandaj–Sirjan fore-arc and Central Iran back-arc basins and dated the deposits to the Rupelian (SW Kashan, Varkan section), Rupelian-Chattian (E Sirjan, Bujan section) and Rupelian-Burdigalian (Qom, Khurabad section). Moreover, they suggested the *Nummulites intermedius-Nummulites vascus* assemblage zone of Wynd (1965) and the *Eulepidina-Nephrolepidina-Nummulites* assemblage zone of Adams and Bourgeois (1967), with Oligocene ages (Rupelian-Chattian), should all be ascribed to the Rupelian.

There are few studies on the foraminiferal biostratigraphy of the Qom Formation of the Dochah area to the northwest of the type area, especially based on planktic foraminifera. Therefore, the foraminiferal components of this formation, particularly planktic forms, are given a detailed study in this paper with respect to foraminiferal assemblages and recognized biozones for correlation.

2 Geological setting

The mountains in the Central Iran zone formed during the Late Eocene to Early Oligocene by the Pyrennian orogenic phase. Shallow depositional environments formed and continental sediments were deposited through the Oligocene; Gansser (1955) named these evaporites and terrestrial deposits the Lower Red Formation. Evaporitic and terrestrial deposition continued up to the Early Oligocene when sea levels rose during the Savian event (Emami, 1991; Rahimzadeh, 1994), causing a transgression from southeast to northwest in Iran (Emami, 1991; Rahimzadeh, 1994; Heydari et al., 2003; Daneshian and Ramezani Dana, 2007; Mohammadi et al., 2013, 2015). The marine sediments of the Qom Formation mainly consist of limestone and marl. These sediments show high variation in thickness, age, and lithology in different parts of Iran (Rahimzadeh, 1994; Heydari et al., 2003; Daneshian and Ramezani Dana, 2007; Mohammadi et al., 2013). Nogol-Sadat (1973) believed that the facies changes in the Qom basin are related to water depth differences due to vertical motion of the basement. Increasing the depth led to limestone deposition, decreasing depth led to marl.

A marine regression led to the thick red clastic-evaporitic deposition of the Upper Red Formation at the end of Burdigalian (Rahimzadeh, 1994; Aghanabati, 2004; Daneshian and Ramezani Dana, 2007; Mohammadi et al., 2011, 2013). Amini (2001) attributed the widespread and thick deposition of this rock unit to faulting that provided accommodation space in the Qom basin. Berberian (1983) believed formation of the Qom basin in Central Iran was related to the subduction of a high Zagros (neo-Tethyan) oceanic plate beneath the active continental margin of the southwestern edge of the Central Iran plate during the Oligocene- Miocene. This subduction led to the opening of a back-arc basin in the center and north of the Central Iran Zone, in which the Qom marine sediments were deposited (Rahimzadeh, 1994; Aghanabati, 2004; Mohammadi et al., 2011, 2013). In fact, this subduction, leading to the collision between the Arabian-African plate and the Iranian plate in the Mesozoic, was the closure of the Tethyan Seaway during the Miocene, known as the so-called Terminal Tethyan Event (TTE) (Schuster and Wielandt, 1999; Harzhauser et al., 2007; Reuter et al., 2009; Mohammadi et al., 2011, 2013).

One of consequences of this event was the creation of the volcanic arc of the Urumieh–Dokhtar belt during the Eocene which led to compartmentalization of the region and creating the Esfahan–Sirjan fore-arc and the Qom back-arc basins at the northern margin of the Tethyan Seaway (Berning et al., 2009; Reuter et al., 2009; Mohammadi et al., 2013; Mohammadi and Ameri, 2015). In both basins, the deposition of Qom marine deposits started in the Oligocene and continued up to the Early Miocene (Reuter et al., 2009; Mohammadi et al., 2011, 2013; Seddighi et al., 2012). There has been a lot of debate pertaining the precise timing of the Tethyan Seaway closing. For instance Adams et al. (1983) assigned it to the Aquitanain and Rogl and Steininger (1984) attributed it to the Burdigalian. Schuster and Wielandt (1999) mentioned that the marine sedimentation began during the Early Oligocene and continued until the end of the Early Miocene.

Deposition of the Qom Formation (Rupelian–Burdigalian) took place in three NW–SE-trending basins including: the Sanandaj–Sirjan (fore-arc basin), the Urumieh–Dokhtar magmatic arc (intra-arc basin), and the Central Iran (back-arc basin). Marine conditions in the low latitudes of these three basins started in the Rupelian. But in the back-arc basin, Rupelian sediments were deposited only in a few places in close proximity to the magmatic arc (Mohammadi et al., 2013).

The study area is located in the north-central Iran zone, near Qom city. The study section (Dochah) is located in the northwest of the Type area (Fig. 1), where shallow marine carbonates of the Qom Formation unconformably overlie the Lower Red Formation and underlie the shale and siltstone of the Upper Red Formation (Fig. 2). Generally, the Qom Formation was deposited in a shallow marine environment and consists mainly of limestone and marl layers. This rock unit was divided into members by researchers such as Dozy (1944), Furrer and Soder (1955), Abaie et al. (1964), and Bozorgnia (1966). Stocklin and Setudehnia (1991) based on Bozorgnia (1966), in the Stratigraphic Lexicon of Iran, defined nine members (a, b, c-1, c-2, c-3, c-4, d, e, and f) for the Qom Formation and described lithological features of these members in the Type area. The Qom Formation in the Dochah section is 894.1 meters thick, including 'a to e' members and lithologically consists of limestone, sandy limestone, argillaceous limestone, shale, sandstone, gypsum, marl, sandy marl, and siltstone (Fig. 2).

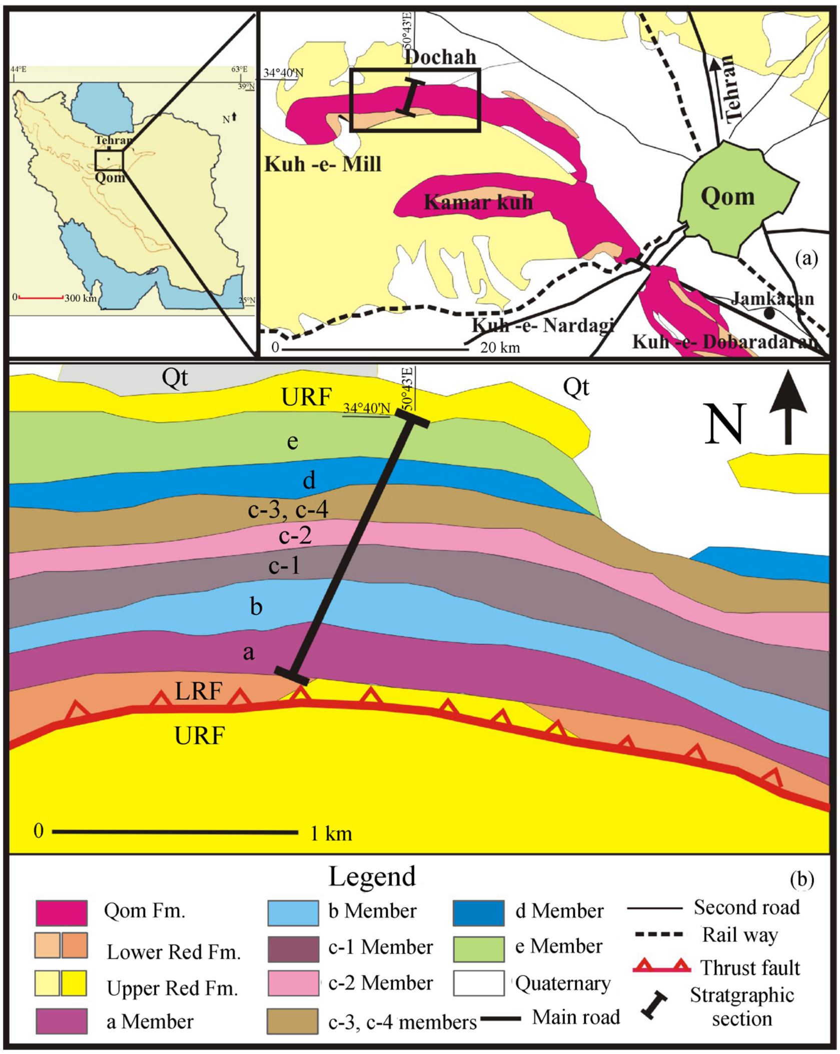

Fig. 1 Geological maps of study area (a) 1:250,000 (after Emami, 1991); and (b) 1:100,000 (after Zamani, 2002).

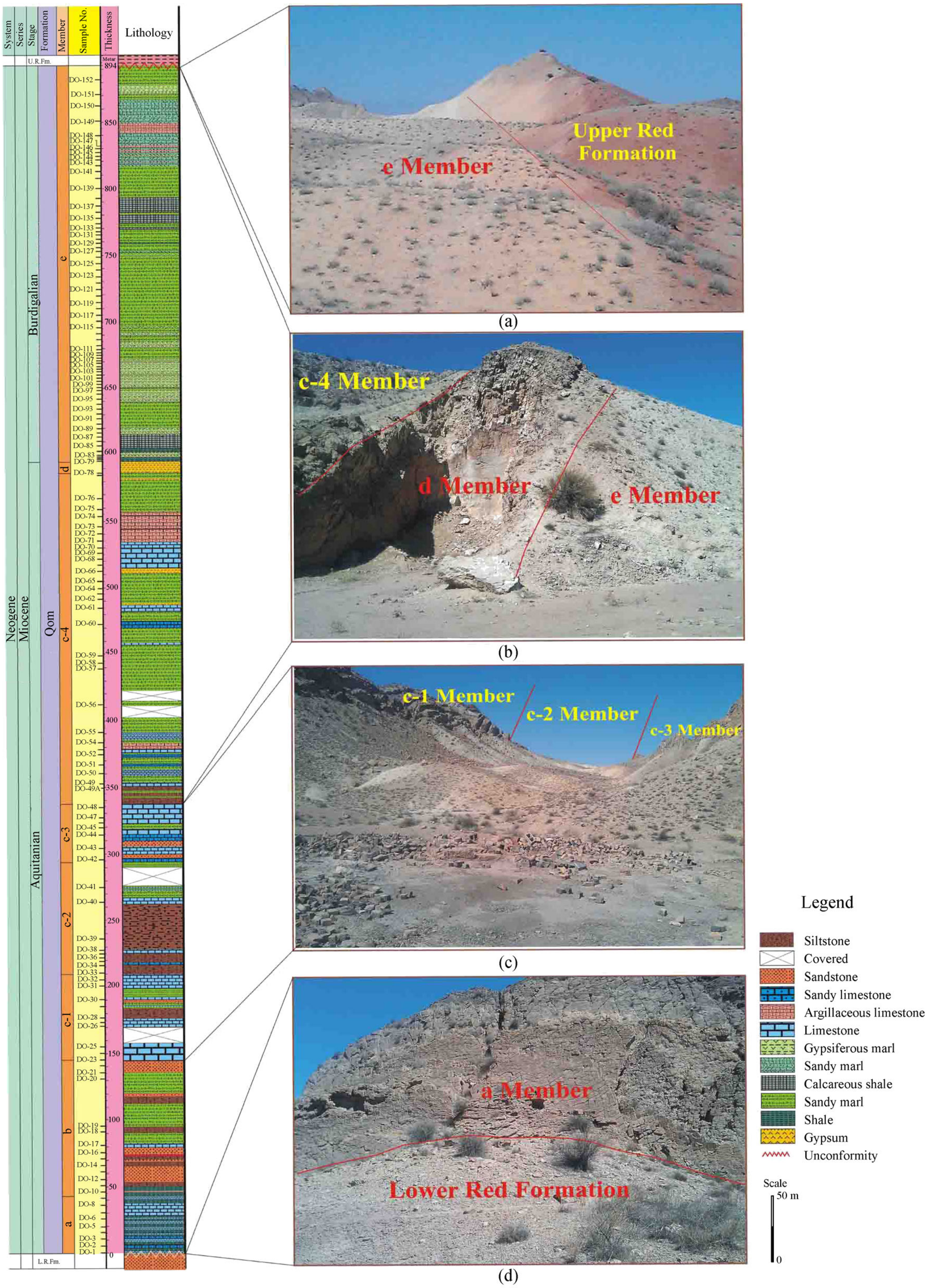

Fig. 2 Lithologic column of the Dochah section; (a) Contact between Upper Red Formation and Qom Formation (Member e), view toward northwest; (b) Contact between e, d, and c-4 members, view toward southeast; (c) c-1 to c-3 members, view toward west-southwest; (d) contact between Lower Red and Qom Formations (Member a), view toward north.

3 Material and methods

In all, 152 samples were collected, including 78 hard samples and 74 soft samples. The lithology of the top 'e' member of the section consisted of significant thicknesses of marl and sandy marl. Abundant planktic foraminiferal components led to sampling in the lower reaches of the member. From the hard samples, 161 thin sections were examined. The 74 soft samples were washed according to the usual procedures. Then one gram of the 35 micron and 120 micron sieve fractions was weighed out and picked for identification of foraminifera. Foraminifera were photographed and SEM images were prepared for free specimens. An ultrasonic treatment was used to remove particles from the best free specimens prior to imaging by TEScan-VagaII at the Razi Metallurgical Research Center.

For identifying genera and species of foraminifera, references such as Papp and Schmid (1985), Petrová (2004), Sharaf et al. (2005), Iaccarino and Premoli-Silva (2005), Popescu and Crihan (2005), Wilson (2005), Kender et al. (2009), Finger (2013), and Sirel (2015) were applied and the systematics follow Loeblich and Tappan (1988). For biozonation and correlation, the main purposes of this research, bioevents of index foraminifera were extracted. First and last occurrences of planktic foraminifera were used as limits on biozonation. Planktic foraminifera are less affected by diachroneity of provincialism than benthic foraminifera. Biozonation of planktic foraminifera follows Wade et al. (2011), the most recent biozonation for planktic foraminifera. Previous biozonations such as Banner and Blow (1965), Kennett and Srinivasan (1983), Bolli and Saunders (1985), and Berggren et al. (1995) were compared for this section with biostratigraphy criteria schematically shown in Fig. 3. Biozonation of benthic foraminifera was considered according to the biozonation of Adams and Bourgeois (1967) which was proposed for the Asmari Formation and were applied where planktic foraminifera were inadequate.

4 Results

Investigation of hard and soft samples led to the identification of 12 genera and 27 species of planktic foraminifera and 68 genera and 155 species of benthic foraminifera (Figs. 4–6). Figure 7 presents the ranges of index foraminifera and the taxa reported for the first time in this section. Table 1 lists all identified foraminifera; highlighted species are reported for the first time.

Benthic and planktic foraminifera, ostracods, bivalves,

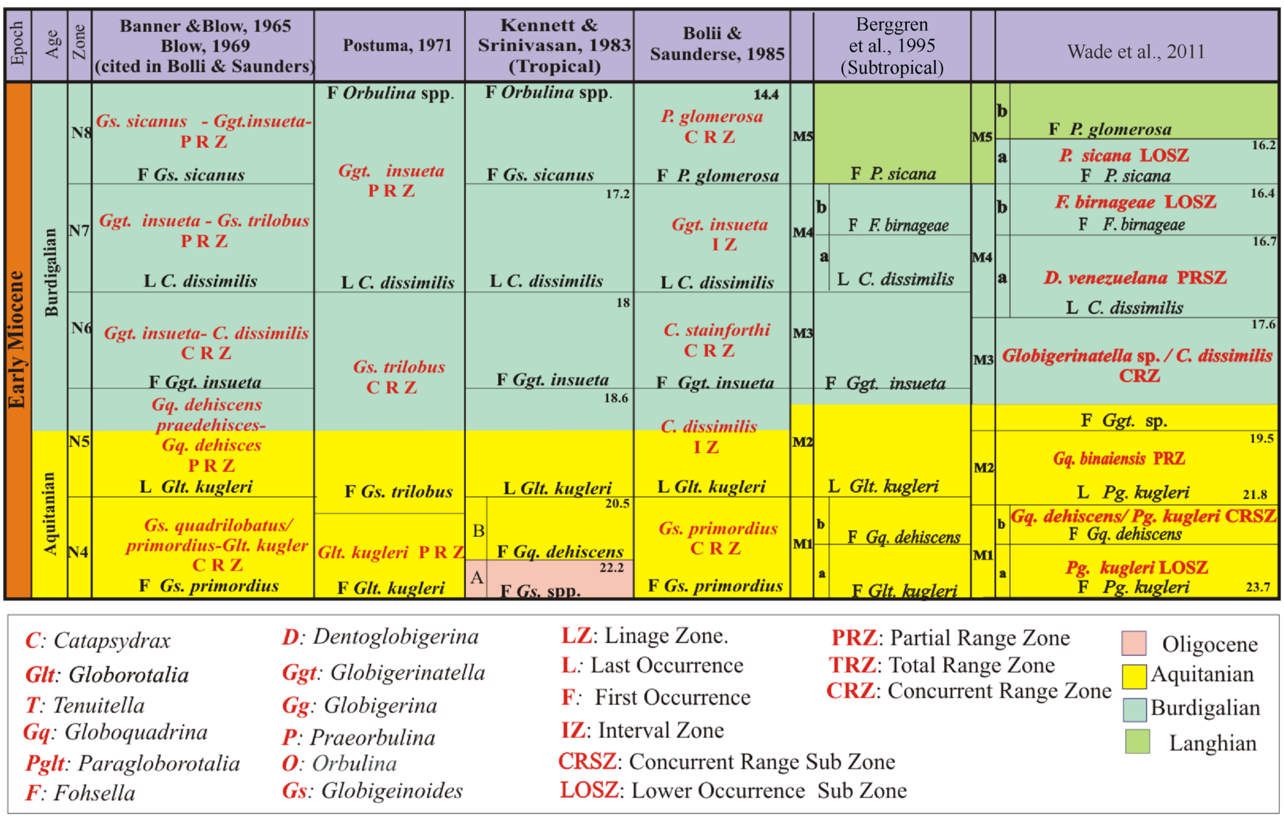

Fig. 3 Biozonal schemes of the early Miocene deposits proposed by different researchers.

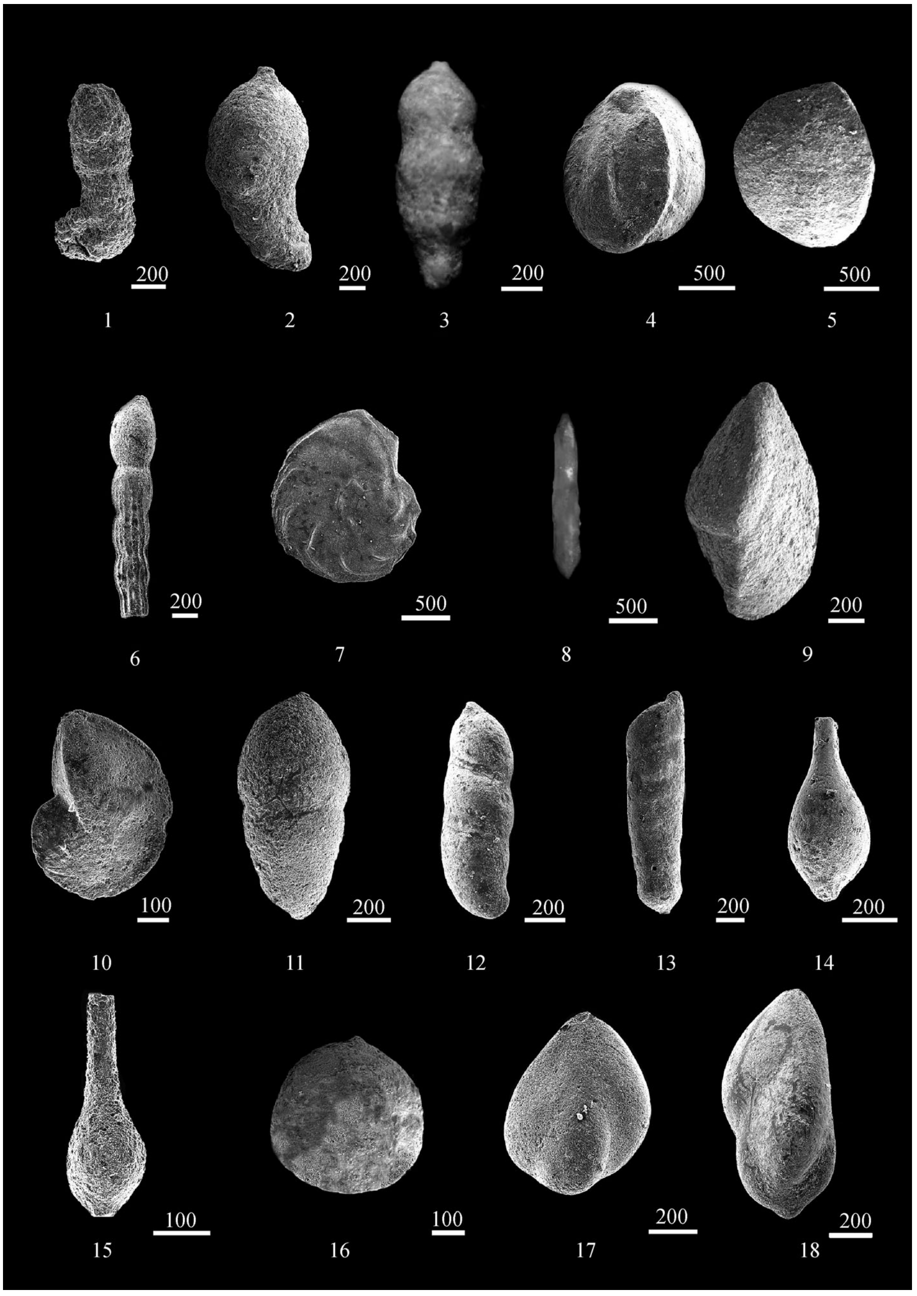

Fig. 4 1: *Ammobaculites agglutinans*(d' Orbigny) Sample No. DO- 104; 2, 3: *Liebusella* spp. 2: Sample No. DO- 108, 3: Sample No. DO- 151; 4, 5: *Quinqueloculina buchiana* d' Orbigny, 1846, Sample No. DO-87; 6: *Dentalina acuta* d' Orbigny, 1846, Sample No. DO-146; 7, 8 *Lenticulina americana grandis* (Cushman), Sample No. DO- 114; 9: *Lenticulina arcuata* (d' Orbigny); Sample No. DO- 130; 10: *Lenticulina gibba*(d' Orbigny), Sample No. DO- 127; 11: *Marginulina nodosaria* (d' Orbigny),Sample No. DO- 105; 12: *Marginulina oblique* (d' Orbigny), Sample No. DO- 139; 13: *Vaginulina legumen* (Linne), Sample No. DO- 148; 14, 15: *Lagena* spp., Sample No. DO-141; 16: *Globulina gibba* d' Orbigny, 1846, Sample No. DO-79; 17: *Guttulina problema* d' Orbigny, 1846, Sample No. DO- 123; 18: *Guttulina austriaca* d' Orbigny, 1846, Sample No. DO- 128.

bryozoa, coralline red algae, corals, echinoids, and gastropods are biogenic components of the Qom Formation in the Dochah section, of which the main faunal components are foraminifera. Due to the availability of both benthic and planktic foraminifera in the Dochah section, biozonation was carried out in two separate parts. Although Adams and Bourgeois (1967) built their biozonation for the Zagros basin in Iran, it can be applied to the Central Iran and the Qom Formation deposits. This biozonation is applicable to Central Iran sediments because a connection between the Qom and Zagros basins in Late Aquitanian time has been suggested (Bozorgnia, 1966;

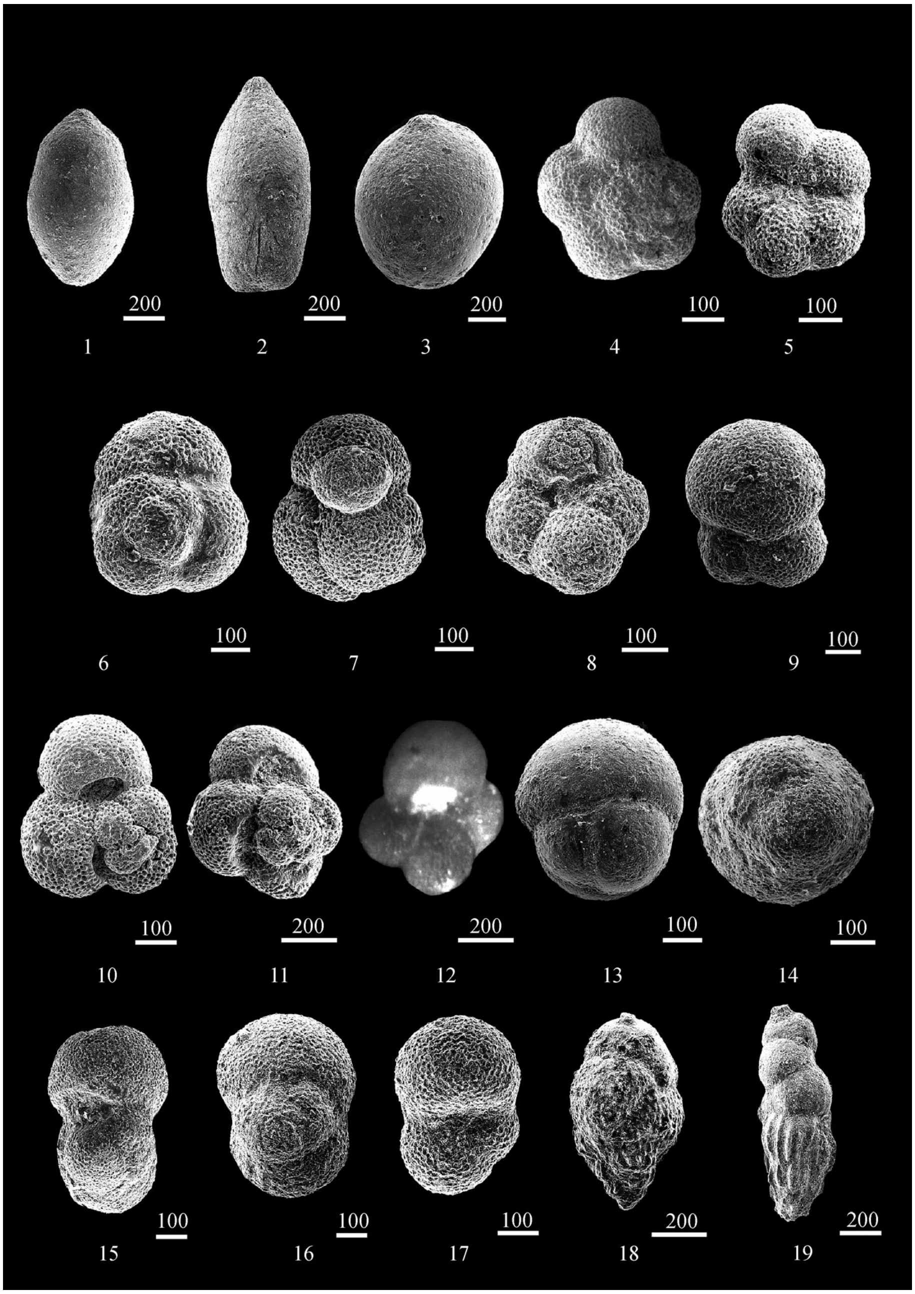

Fig. 5 1–3: *Glandulina* spp.,1, 2: Sample No. DO-107, 3: Sample No. DO-136 ; 4,5: *Paragloborotalia bella* (Jenkins), Sample No. DO-142; 6,7: *Catapsydrax parvula* (Bolli, Loeblich & Tappan), Sample No. D0-135; 8: *Globigerina woodi* Jenkins, 1960, Sample No. DO-71; 9: *Globigerinoides bisphericus* Todd, 1954, Sample No. DO-96; 10–12: *Globigerinoides* spp. 10: Sample No. DO-148, 11, 12: Sample No. DO-152; 13, 14: *Praeorbulina sicana* (De Stefani), 13: Sample No. DO-120 14: Sample No. DO-138; 15–17: *Praeorbulinatransitoria* (Blow), 15: Sample No. DO-130, 16, 17: Sample No. DO- 137; 18: *Uvigerina* sp. cf. *U. grilli* d' Orbigny, 1846, Sample No. DO-125; 19: *Uvigerina* sp. 1, Sample No. DO-122.

Adams and Bourgeois, 1967; Kashfi, 1988). However, Mohammadi et al. (2013) believe that there is no connection between the Oligo-Miocene deposits of Qom and the Asmari Formation. This idea was proved using faunal similarities, especially foraminifera, between the Qom and Asmari formations. New data and more investigations indicate that there are some differences in the fauna and stratigraphic distribution of species between these two basins. Besides the Adams and Bourgeois (1967) biozonations, which were applied by some authors (Bozorgnia, 1966; Daneshian and Ramezani Dana, 2007; Mohammadi et al., 2015) for the Qom Formation biostratigraphy, there are other biozonations for the Oligo- Miocene deposits of the Zagros basin such as Wynd (1965); Ehrenberg et al. (2007) and Laursen et al. (2009). Considering Adams and Bourgeois (1967), their

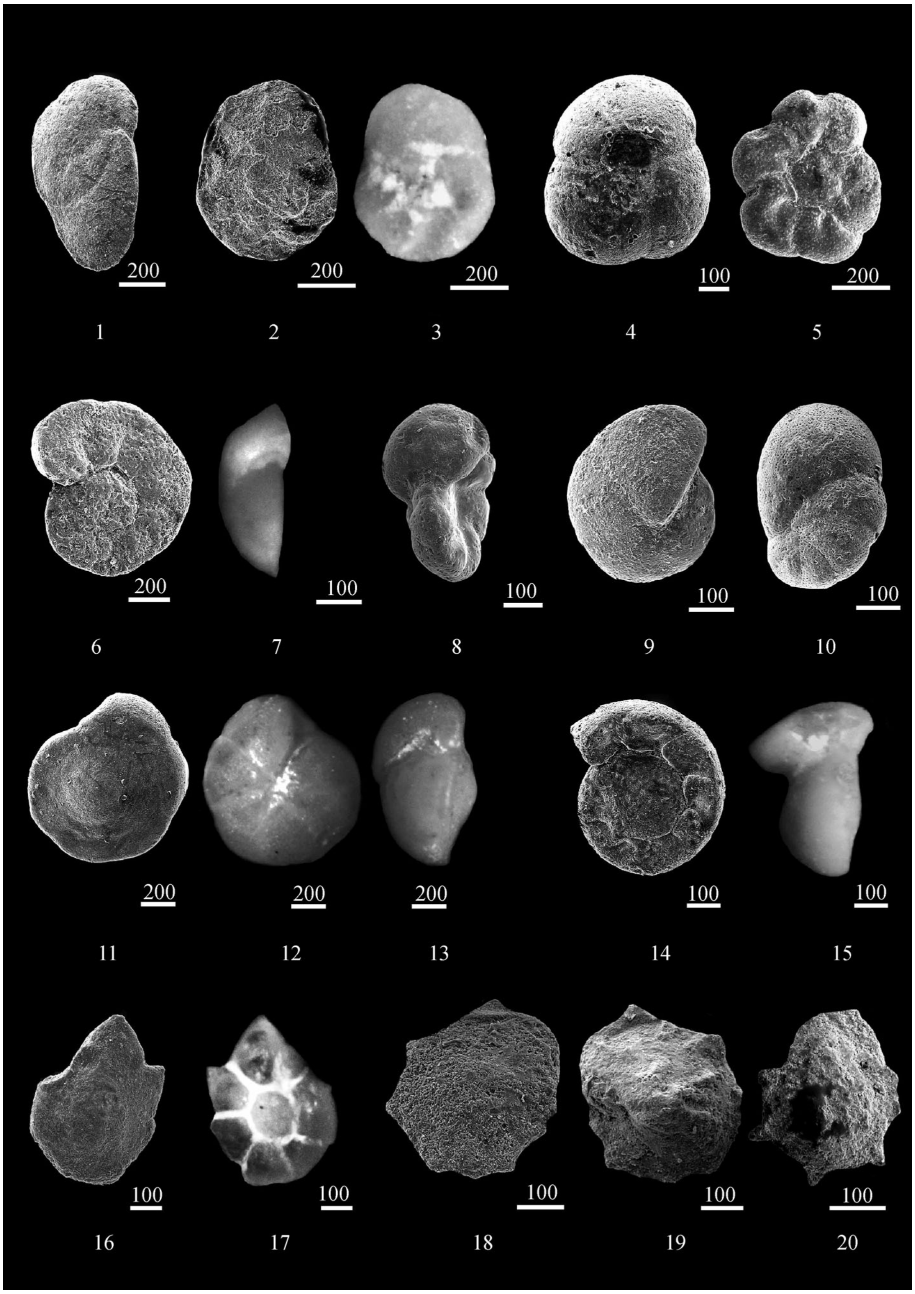

Fig. 6 1: *Cancris oblongus* (Fichtel & Moll), Sample No. DO-121; 2,3: *Discorbis subaraucana* Cushman, 1922, Sample No. DO-136; 4: *Sphaeroidina bulloides* d' Orbigny, 1826, Sample No. DO-120; 5: *Planulina austrica* (d' Orbigny), Sample No. DO-87; 6, 7: *Cibicides boueanus* (d' Orbigny), Sample No. DO-93; 8: *Anomalina* sp., Sample No. DO-151; 9: *Nonion pauper* Egger, Sample No. DO-122; 10: *Nonionella* sp. cf. *N. extens* Brotzen 1936, Sample No. DO-87; 11–13: *Gyroidinoides* sp., Sample No. DO-131; 14,15: *Gyroidina girardana* (Reuss), Sample No. DO-110; 16,17: *Rotalia byramensis* Cushman, 1923, Sample No. DO-110, 18–20: *Rotalia parva* Cushman, 1922, Sample No. DO-93.

biozonation, although it has some difficulties is more accurate than other biozonations in respect to benthic foraminiferal content of the studied section. The dissimilarity between foraminiferal assemblages and their stratigraphic distribution in both Qom and Zagros basins make it necessary to develop a more comprehensive biozonation specifically for the Qom Formation (Daneshian and Ramezani Dana, 2007). In the Dochah section, the best data for biozonation based on planktic foraminifera occur at top of the section. Herein, we apply the biozonation of Wade et al. (2011) together with consideration of schemes proposed earlier by Banner and Blow (1965), Kennett and Srinivasan (1983), Bolli and Saunders (1985), and Berggren et al. (1995) (Fig. 3).

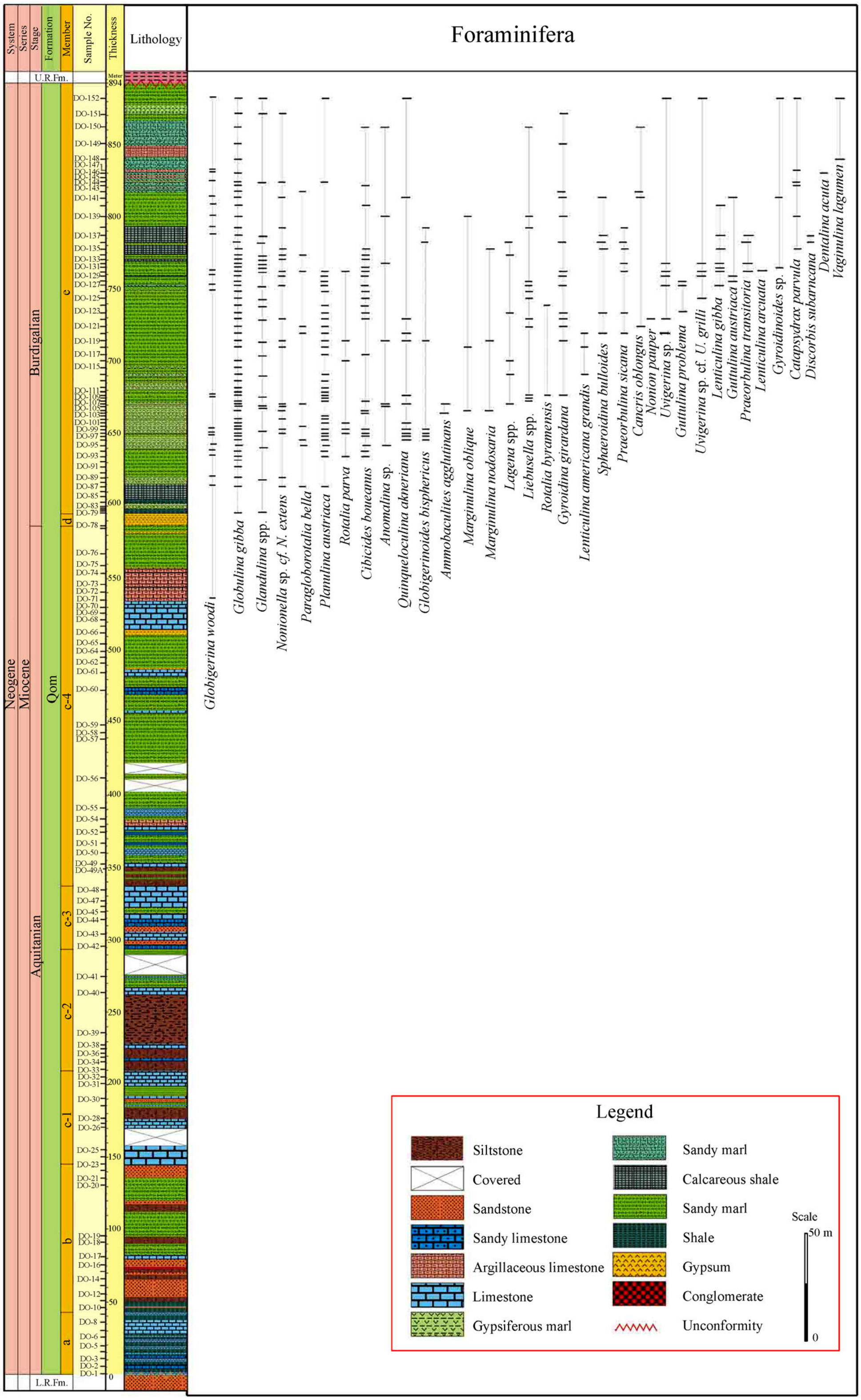

Fig. 7 Distribution chart of planktic foraminifera and benthic forms reported for the first time from the Qom Formation at Dochah.

5 Discussion

Planktic foraminifera from the Qom Basin at Dochah are considerably more abundant and diverse that at localities in central Iran (Daneshian and RamezaniDana, 2007; Daneshian and Aftabi, 2010; Daneshian and Naderi, 2014;

Table 1 Foraminifera genera and species in the Dochah section. The bold-face names are taxa reported for the first time from the Qom Formation

	Foraminifera genera and species			
Benthic foraminifera	*Ammonia* spp.	*Anomalinoides* sp.	*Nephrolepidina* spp.	*Miogypsina* spp.
	***Anomalina* sp.**	*Lenticulina cultrate*	***Lagena* spp.**	*Cibicides ungerianus*
	Bolivina spp.	*Bozorgniella qumiensis*	***Liebusella*** spp.	*Cibicides* spp.
	Cibicides lobatolus	*Bolivina scalprata miocenica*	*Bolivina Mexicana*	*Spiroplectamina* spp.
	Dentalina elegans	***Gyroidinoides*spp**.	*Sphaerogypsina globulus*	*Nodosaria badenesis*
	Dentalina acuta	***Vaginulina lagumen***	*Operculina complanata*	*Dentalina inornata*
	Dentalina brevis	*Bullimina costata*	*Heterostegina* spp.	*Spieroclypeus blakenhorni*
	Discorbis sp.	*Lepidocyclina* spp.	*Bozorgniella* sp.	*Cycloforina* spp.
	Discorbis subarncana	*Eponides boueanus*	*Lagena simplex*	*Discorbis subglobosa*
	Elphidium spp.	*Borelis* sp.	*Spieroclypeus* spp.	*Textularia mariae*
	Eponides alabamensis	*Cibicides planoconvexus*	*Cancris auriculus*	*Latibolivina* spp.
	Eponides karsteni	*Gaudryina* spp.	*Quinqueloculina boueana*	*Uvigerina molticostata*
	Glandulina ovula	*Melonis pomplioides*	*Eponides parantillanum*	*Pseudolituonella reicheli*
	Lagena striata	*Operculina* sp.	*Heterolepa dutemplei*	***Glandulina* spp**.
	Lagena substriata	*Nonion decoratum*	*Cornuspira byramensis*	*Nonionella hantkeni*
	Lenticulina vortex	*Nodosaria* spp.	*Nodosaria affinis*	*Gudryina mayeriana*
	Marginulina nodosaria	*Miogypsinoides* spp.	***Nonionella* sp. cf. *N. extensa***	*Pseudolituonella* sp.
	Martinottiella communis	*Amphistegina* spp.	*Glomospira* spp.	***Lenticulina arcuata***
	Massilina sp.	*Elphidium granosum*	*Heterolepa* spp.	*Amphistegina lessoni*
	Nodosaria raphanistrum	*Bulimina elongate*	*Lagena laevis*	*Bolivina suteri*
	Noion danvillense	*Liebusella soldani*	***Lenticulina gibba***	***Globulina gibba***
	Siphotextularia rolshauseni	*Nonionella paciloba*	***Quinqueloculina akneriana***	*Lenticulina inornata*
	Spiroloculina sp.	*Nonion scapha*	***Ammobaculites agglutinanus***	*Bigenerina* sp.
	Spiroplectinella carinata	*Bolivina antique*	*Uvigerina semiornata*	*Pyrgo inornata*
	Textularia departita	*Cancris* sp.	*Textularia laevigata*	*Nonion castifer*
	Triloculina gibba	*Asterigerina* spp.	*Textularia gramen*	*Nonion boueanum*
	Triloculina spp.	*Dentalina antennule*	*Textularia adalta*	*Pyrgo simplex*
	Rotalia byramensis	***Gyroidina girardana***	*Gyroidina soldani*	*Pyrgo* spp.
	Ammonia beccarii	*Lenticulina* spp.	***Lenticulina americana grandis***	***Uvigerina* sp.1**
	Planulina austriaca	*Pullenia bulloides*	*Miolepidocyclina* sp.	*Uvigerina* spp.
	Bulimina pyrula	***Uvigerina* sp. cf. *U. grilli***	*Quinqueloculina buchiana*	*Uvigerina pygmoides*
	Elphidium flexuosum	***Cancris oblongus***	*Hanzawaia boueana*	*Quinqueloculina* spp.
	Pyrgo lunula	*Quinqueloculina peregrine*	***Marginulina oblique***	*Quinqueloculina triangularis*
	Nephrolepidina tournoueri	*Textularia* spp.	*Lenticulina calcar*	*Asterigerina rotula*
	Schlumbergerina spp.	*Reussella* spp.	*Bolivina plicatella*	*Triloculina tricarinata*
	Cibicides boueanus	*Rotalia parva*	*Nonion commune*	*Neoeponides schreibersi*
	Guttulina problema	*Rotalia viennotti*	*Nonion* spp.	*Elphidum* sp. 14
	Guttulina commonis	*Rotalia* spp.	*Nonionella* spp.	*Valvulina* spp.
	Guttulinan austriaca	*Fursenkoina acuta*	***Nonion pauper***	*Vaginulinopsis* spp.
Planktic foraminifera	*Catapsydrax dissimilis*	*Globigerinoides immaturus*	*Neogloboquadrina continusa*	*Paragloborotalia celemenica*
	Catapsydrax parvula	*Globigerinoides quadralobatus*	*Globoquadrina venezuelana*	*Paragloborotalia mayeri*
	Dentoglobigerina altispira	*Globigerinoides subquadratus*	*Globoquadrina* sp.	*Paragloborotalia siakensis*
	Globigerina praebulloides	*Globigerinoides triloba*	*Globorotalia archeomenardi*	*Praeorbulina sicana*
	Globigerina woodi	*Globigerinoides obliqus*	*Globorotalia* sp.	*Praeorbulina transitoria*
	Globigerinella obesa	*Globigerinoides* spp.	*Globorotaloides suteri*	***Sphaeroidina bulloides***
	Globigerinoides bisphericus	*Globoquadrina dehiscence*	***Paragloborotalia bella***	

Daneshian and Ramezani Dana, 2015; Daneshian et al., 2017). From formation Members 'a' to 'd' the presence of benthic *genera Miogypsinoides* and *Valvulina* prove an Aquitanian age, equivalent to biozone 2 of Adams and Bourgeois (1967). The lack of Borelis species at top of the section in Member 'e' prohibited using the Adams and Bourgeois biozonation. The diagnostic species *Borelis melo curdica* is not present here due to different environmental conditions. However, based on planktic foraminifera, the age of upper part (Member 'e') of the section is Burdigalian.

The occurrences of planktic foraminifera such as *Globigerinoides triloba* and *Globigerinoides immaturus* which appear from 45 meters above the section base and the presence of Globorotalia sp. and Ammonia sp. from 5 meters in Member 'a', confirms an Early Miocene (Aquitanian) age. Also, the presence of *Paragloborotalia* and *Globigerinoides* with their abundance and diversity indicate Aquitanian age for Members 'a', 'b' and 'c-1' to 'd'. The presence of *Catapsydrax parvula* , *Globorotalia archeomenardi*, *Globigerinoides bisphericus*, *Praeorbulina sicana*, *Praeorbulina transitoria* confirm a Late Burdigalian age for the beginning of Member 'e' at Dochah. In this, we follow the biozonation of Wade et al. (2011) as compared with other biozonations in Fig. 8.

The biozonations of Banner and Blow (1965) and Blow (1969) use the first appearance of *Globigerinoides primordius* to define the lower boundary of biozone N4, *Paragloborotalia kugleri* for N5, and *Globigerinatell insueta* for N6 biozone (Fig. 3). Because these three species are missing at Dochah, separate recognition of N4, N5, and N6 is impossible, but this does not rule out the possibility that the section extends through the top of biozone N6.

From Member 'a' up to middle part of Member 'e' (DO-120) the section likely spans biozones N4-N7. The first appearance of *Praeorbulina sicana* (at 719 m) represents the lower boundary of N7. Also, foraminiferal contents show a Late Burdigalian age (Fig. 8).

Definitive bioevents for the Kennett and Srinivasan (1983) zone boundaries are lacking in Dochah. Based on the presence of species such as *Globigerinoides triloba* (slightly higher than biozone (N4B), *Globigerinoides subquadratus* (N4B), *Globigerinoides immaturus* (N5), and also *Globigerinoides quadrilobatus* (N6), and the lack of any Oligocene taxa at the base of the section, we place the bottom part of the Dochah section in the Miocene (Aquitanain) and equivalent to biozone N4. There is no index indicator for determining the upper boundary of this zone. Only the first occurrence of *Globigerinoides quadrilobatus* can be used for placing biozone N5 – a species not defined as an event for this biozone, but helpful for separation of biozones. Thus the base of the section is determined to be equivalent to the N4-N5 biozones. Above that, strata from the beginning of Member 'e' (sample DO-79) up to the first appearance of *Praeorbulina sicana* (DO-120 at 590 m) are equivalent to biozones N6-N7. According to Kennett and Srinivasan (1983), the first appearance of this species defines the lower boundary of N8 biozone (Fig. 3). There is an event for separating biozones N6 and N7 in the tropics but no event for the lower boundary of biozone N9, such as *Orbulina* species. Therefore, we attribute the top of the section to biozone N8 (Fig. 8).

In Bolli and Saunders' (1985) biozones, an Early Miocene age is assigned to biozone N4. Its lower boundary corresponds with the last appearance of *Globigerinoides primordius* and the upper boundary is determined by the last appearance of *Paragloborotalia kugleri*. This event is not present at Dochah. Thus, the base of the section could not be placed into the biozonation of Bolli and Saunders (1985). Similarly, there is no event for recognizing their N5 and N6 biozones. The single occurrence of *Catapsydrax dissimilis* creates a disparity in age and we decided to ignore the presence of this species. The first appearance of *Globigerinoides bisphericus* helps identify the lower boundary of biozone N7. In fact, the beginning of Member 'e' (DO-96 at 645 m) can be considered as an equivalent to the N7 biozone . The lower boundary of biozone N8 was defined by the presence of *Praeorbulina glomerosa*, a species absent from Dochah. Therefore, the presence of *Praeorbulina transitoria*, *Praeorbulina sicana*, and *Catapsydrax parvula*, was used to recognize this biozone based on Bolli and Saunders (1985). From the first appearance of *Globigerinoides bisphericus* up to the end of the section is considered equivalent to the N7-N8 biozones and indicates a Late Burdigalian age (Fig. 8).

In subtropical regions, the first and last appearances of *Paragloborotalia kugleri* define the M1 biozone, and the last occurrence of *Globigerinatella insueta* defines the upper boundary of M2 and the lower boundary of M3, of Burdigalian age (Berggren et al., 1995). The last appearance of *Catapsydrax dissimilis* defines the lower boundary of M4, also Burdigalian (Fig. 3). None of these events can be used for separating biozones in the Dochah section. Only the first appearance of *Globoquadrina dehiscens* can be applied; it places biozone M1b at the base of the 'e' Member, but it is not definitive for the biozone. The absence of this species at the base of the section can be caused by different factors and in any case, the local first appearance contradicts other information and was not used. In summary, the lack of definitive events at Dochah prevents separation of biozones M1, M2, M3, and M4. As a consequence, the base of the section (Member 'a') is assigned to the Early Miocene (Aquitanian) age up to sample DO-120 and the first appearance of *Praeorbulina sicana*. This Member 'a' can be considered the equivalent to the M1-M4 biozones of Berggren et al. (1995).

From the first appearance of *Praeorbulina sicana* up to the top of the Dochah section is considered to be an equivalent to biozone M5, which represents beginning of

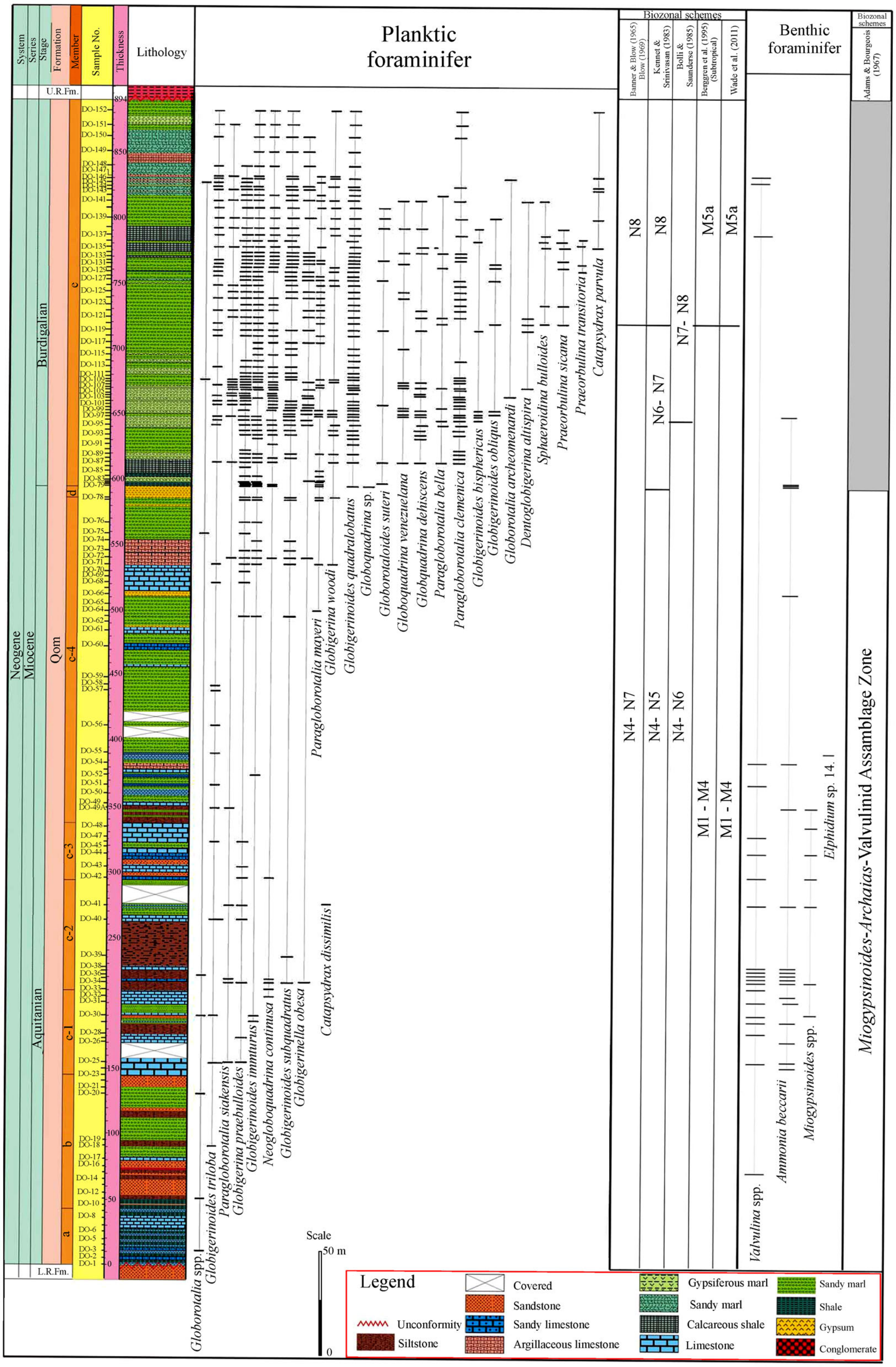

Fig. 8 Range chart and biozonation of planktic and index benthic foraminifera in the Dochah section.

the Langhian. There is no evidence for the start of the next biozone (Fig. 8). The biozonation of Wade et al. (2011) confirms that the age of succession is Aquitanian. In this way, due to absence of distinctive events, strata from the base (Member 'a') up to the first appearance of *Praeorbulina sicana* are equivalent to biozones M1-M4 and include Members 'a', 'b', 'c1-4' and 'd' with the basal part of Member 'e' indicating Aquitanian- Burdigalian age. The first appearance of *Praeorbulina sicana* is beginning of biozone M5a of late Late Burdigalian age. The upper boundary of this zone corresponds to the first occurrence of *Praeorbulina glomerosa* which is not present at Dochah. Thus, the age of the section according to Wade et al. (2011), ranges from Aquitanian up to late Late Burdigalian (Fig. 8).

6 Conclusions

Study of the Qom Formation in its type area yielded 33 taxa of Miocene foraminifera not previously reported. Among the identified species, *Praeorbulina sicana*, *Praeorbulina transitoria,* and *Globigerinoides bisphericus* have particular importance because of their role in age determination and biozonation. Among these species, *Praeorbulina sicana* indicates biozone subzone (M5a), proving a younger age than previously recognized. Therefore, the Tethyan seaway occupied this area up to the end of Burdigalian time and must have closed later than previously estimated.

Acknowledgements We are grateful to the NIOC Exploration Directorate and Kharazmi University for providing the facilities for this study. We would also like to show our immensely gratitude to Dr. Peter M. Sadler from the University of California for his comments on an earlier version of this manuscript that greatly improved it . In addition, we thank all referees for their comments which were helpful for improving the quality of this manuscript.

References

Abaie I, Ansari H J, Badakhshan A, Jaafari A (1964). History and development of the Alborz and Sarajeh fields of Central Iran. Buellton of Iranian Petroleum Institute, 15: 561–574

Adams C G, Gentry A W, Whybrow P J (1983). Dating the terminal Tethyan event. Utrecht Micropaleontol Bulletin, 30: 273–298

Adams T D, Bourgeois F (1967). Asmari biostratigraphy Iran, Oil Operation Company, Geological Exploration. Report No. 1074, 1–37

Aghanabati A (2004). Geology of Iran. Geological Survey of Iran (in Persian)

Amini A (2001). Sandstone petrofacies expression of source and tectonic controls on sedimentation in a back–arc basin, central zone, Iran. Iranian International Journal of Science, 3(1): 43–67

Amirshahkarami M, Karavan M (2015). Microfacies models and sequence stratigraphic architecture of the Oligocene-Miocene Qom Formation, south of Qom City, Iran. Geoscience Frontiers, 6: 593–604

Anjomshoa A, Amirshahkarami M (2014). Biostratigraphy and paleoenvironmental model of the Late Oligocene depositions of the Tanbour section (SW Kerman, Central Iran). Sedimentary Facies, 6: 130–149 (in Persian)

Banner F T, Blow W H (1965). Progress in the planktonic foraminiferal biostratigraphy of the Neogene. Nature, 208(5016): 1164–1166

Behforouzi E, Safari A (2011). Biostratigraphy and paleoecology of the Qom Formation in Chenar area (northwestern Kashan), Iran. Rev Mex Cienc Geol, 28(3): 555–565

Berberian M (1983). The southern Caspian: a compressional depression floored by a trapped, modified oceanic crust. Can J Earth Sci, 20(2): 163–183

Berggren W A, Kent D V, Swisher C C, Aubry M P (1995). A revised Cenozoic geochronology and chronostratigraphy. Society for Sedimentary Geology Special Publication, 54: 129–212

Berning B, Reuter M, Piller W E, Harzhauser M, Kroh A (2009). Larger foraminifera as a substratum for encrusting bryozoans (Late Oligocene, Tethyan Seaway, Iran). Facies, 55(2): 227–241

Blow W H (1969). Late Middle Eocene to recent planktonic foraminiferal biostratigraphy. In: Bronnimann P, Renz H H, eds. Proceedings of the First International Conference on Planktonic Microfossils. Leiden: E. J. Brill, 199–421

Bolli H M, Saunders J B (1985). Oligocene to Holocene low latitude planktic foraminifera. In: Bolli H M, Saunders J B, Perch-Nielson K, eds. Plankton Stratigraphy. Cambridge University Press, 155–262

Bozorgnia F (1966). Qum Formation stratigraphy of the Central Basin of Iran and its intercontinental position. Bull Iran Pet Inst, 24: 69–75

Daneshian J, Aftabi A (2010). Foraminiferal biostratigraphy of the Qom Formation on the basis of new investigations at Navab anticline, in southeast Kashan. Journal of Science University of Tehran, 35: 137–154 (in Persian)

Daneshian J, Naderi E (2014). Lithostratigraphy, Biostratigraphy and identify several new genera and species of Qom Formation in Khafr section, northeast Natanz. Researches in Earth Sciences, 4: 40–55 (in Persian)

Daneshian J, Ramezani Dana L (2007). Early Miocene benthic foraminifera and biostratigraphy of Qom Formation, Deh Namak, Central Iran. J Earth Sci, 29(5): 844–858

Daneshian J, Ramezani Dana L (2015). Lower Miocene uncoiled agglutinated foraminifera from Dobaradar Section, southeast Qom. Journal of Stratigraphy and Sedimentology Researches, 61: 51–68 (in Persian)

Daneshian J, Ramezani Dana L, Sadler P (2017). A composite foraminiferal biostratigraphic sequence for the Lower Miocene deposits in the type area of the Qom Formation, central Iran, developed by constrained optimization (CONOP). J Afr Earth Sci, 125: 214–229

Dozy J J (1944). Comments on geological report No. 1, by Thiebaud (on Qum–Saveh area), Geological report 308

Ehrenberg S N, Pickard N A, Laursen G V, Monibi S, Mossadegh Z K, Svånå T A, Aqrawi A A M, McArthur J M, Thirlwall M F (2007). Strontium isotope stratigraphy of the Asmari Formation (Oligocene-Lower Miocene), SW Iran. J Pet Geol, 30(2): 107–128

Emami M H (1991). Exploratory text of the Qom, Geological Quadrangle No. E6. Geological Survey of Iran, 1–179

Finger K (2013). Miocene foraminifera from the south-central coast of Chile. Micropaleontology, 59(4): 341–492

Furrer M A, Soder P A (1955). The Oligo–Miocene marine Formation in the Qom region (Central Iran). In: Proceedings of 4th World Petrology Congress. Roma, section I/A/5, 267–277

Gansser A (1955). New aspects of the geology in Central Iran. In: Proceedings of 4th World Petrology Congress. Roma, section I/A/5, 279–300

Hadavi F, Notghi Moghaddam M, Mousazadeh H (2010). Burdigalian–Serravalian calcareous nannoplanktons from Qom Formation, North Center Iran. Arab J Geosci, 3(2): 133–139

Harzhauser M, Kroha A, Mandica O, Pillerb W E, Gohlicha U, Reuterb MBerning B (2007). Biogeographic responses to geodynamics: a key study all around the Oligo–Miocene Tethyan Seaway. Zoologischer Anzeiger, 246: 241–256

Hasani M J, Vaziri Moghadam R (2011). Early-Miocene gastropods from Khavich area, south of Sirjan, (Kerman, Iran): biostratigraphy, paleogeography and paleoecology. Journal of Science Islam Republic of Iran, 22: 125–133

Heydari E, Hassanzadeh J, Wade W J, Ghazi A M (2003). Permian–Triassic boundary interval in the Abadeh section of Iran with implications for mass extinction. Part 1—sedimentology. Palaeogeogr Palaeoclimatol Palaeoecol, 193(3–4): 405–423

Iaccarino A, Premoli-Silva M (2005). Practical Manual of Oligocene to Middle Miocene Planktonic Foraminifera, International School on Planktonic Foraminifera, 4th course

Kashfi M S (1988). Evidence for non-collision geology in the Middle East. Petrol Geol, 11(4): 443–460

Kender S, Kaminski M, Jones R W (2009). Early to middle Miocene foraminifera from the deep-sea Congo Fan, offshore Angola. Micropaleontology, 54(6): 477–568

Kennett J M, Srinivasan M S (1983). Neogene Planktonic Foraminifera: A Phylogenetic Atlas. Pennsylvania: Hutchinson Ross publishing Company, 1–263

Khaksar K, Maghfouri Moghadam I (2007). Paleontological study of the echinoderms in the Qom Formation (Central Iran). Earth Sci Res J, 11 (1): 57–79

Laursen G V, Monibi S, Allan T L, Pickard N A, Hosseiney A, Vincent B, Hamon Y, Van Buchem F H, Moallemi A, Driullion G (2009). The Asmari Formation revisited: changed stratigraphic allocation and new biozonation. In: Shiraz First international petroleum conference and exhibition. Iran, 4–6

Loeblich A R, Tappan J H (1988). Foraminiferal genera and their classification. Van Nostrand Reinhold Company, 1–869

Mohammadi E, Ameri A (2015). Biotic components and biostratigraphy of the Qom Formation in northern Abadeh, Sanandaj–Sirjan fore-arc basin, Iran (northeastern margin of the Tethyan Seaway). Arab J Geosci, 8(12): 10789–10802

Mohammadi E, Hasanzadeh-Dastgerdi M, Ghaedi M, Dehghan R, Safari A, Vaziri Moghaddam H, Baizidi C, Vaziri M, Sfidari E (2013). The Tethyan Seaway Iranian Plate Oligo-Miocene deposits (the Qom Formation): distribution of Rupelian (Early Oligocene) and evaporate deposits as evidences for timing and trending of opening and closure of the Tethyan Seaway. Carbonates Evaporites, 28(3): 321–345

Mohammadi E, Safari A, Vaziri Moghadam H, Vaziri M R, Ghaedi M (2011). Microfacies analysis and paleoenviornmental interpretation of the Qom Formation, South of the Kashan, Central Iran. Carbonates and Evaporates, 26(3): 255–271

Mohammadi E, Vaziri M, Dastanpour M (2015). Biostratigraphy of the nummulitids and lepidocyclinids bearing Qom Formation based on larger benthic foraminifera (Sanandaj–Sirjan fore-arc basin and Central Iran back-arc basin, Iran). Arab J Geosci, 8(1): 403–423

Morley C, Kongwung K, Julapour A A, Abdolghafourian M, Hajian M, Waples D J, Warren J, Otterdoom H, Srisuriyon K, Kazemi H (2009). Structural development of a major late Cenozoic basin and transpressional belt in central Iran. The Central Basin in the Qom-Saveh. Geosphere, 5(4): 325–362

Nogol-Sadat M A (1973). Les zone de decrochement et les virgations structurales en Iran, Consequences des resultants de I analyse structrale de la region de Qom. Tresie University Scientifique et Medicate de Grenoble, 1–201

Papp A, Schmid M E (1985). Die fossilen foraminiferen des Tertiaren Beckens von Wien Revision der Monographie von Alcide d'Orbigny (1846), Abhandle. Geology, 37: 1–311

Petrová P (2004). Foraminiferal assemblages as an indicator of foreland basin evolution (Carpathian Foredeep, Czech Republic). Bulletin of Geosciences, 79: 231–242

Popescu G, Crihan I M (2005). Contributions to the knowledge of the Miocene foraminifera from Romania, Superfamily Nodosariac (Family: Nodosariidae and Vaginulinidae). Acta Palaeontologica Romaniae, 200(4): 385–402

Rahimzadeh F (1994). Treatise on the Geology of Iran: Oligocene-Miocene, Pliocene. Report 12, Ministry of Mines and Metals, Geology Survey Iran, 1–311 (in Persian)

Reuter M, Piller W E, Harzhauser M, Mandic O, Berning B, Rogl F, Kroh A, Aubry P, Wielandt-Schuster U, Hamedani A (2009). The Oligo- Miocene Qom Formation (Iran): evidence for an early Burdigalian restriction of the Tethyan seaway and closure of its Iranian gateways. J Earth Sci, 98(3): 627–650

Rogl F, Steininger F F (1984). Neogene Paratethys, Mediterranean and Indo- Pacific Seaway. In: Brenchley P, ed. Fossils and Climate. Chichester: Wiley, 171–200

Schuster F, Wielandt U (1999). Oligocene and Early Miocene coral faunas from Iran: palaeoecology and palaeobiogeography. Int J Earth Sci, 88(3): 571–581

Seddighi M, Vaziri Moghadam H, Taheri A, Ghabeishavi A (2012). Depositional environment and constraining factors on the facies architecture of the Qom Formation, Central Basin, Iran. Hist Biol, 24 (1): 91–100

Sharaf E F, BouDagher-Fadel M K, Simo J A, Carroll A R (2005). Biostratigraphy and strontium isotope dating of Oligocene-Miocene strata, East Java, Indonesia. Stratigraphy, 3(2): 1–19

Sirel E (2015). Reference section and key location of the Paleogen stage and discussion C-T, P-T and E-O boundaries by the very shallow sallow water foraminifera in Turkey, Ankara. University faculty of engineering, Department of Geological engineering, 1–171

Stocklin J, Setudehnia A (1991). Stratigraphic Lexicon of Iran Ministry of Industry and Mine. Geological Survey of Iran, Report No. 18

Wade B S, Pearson P N, Berggren W A, Pälike H (2011). Review and revision of Cenozoic tropical planktonic foraminiferal biostratigraphy and calibration to the geomagnetic polarity and astronomical time scale. Earth Sci Rev, 104(1-3): 111–142

Wilson B (2005). Planktonic foraminiferal biostratigraphy and paleoecology of the Brasso Formation (Middle Miocene) at St. Fabien Quarry, Trinidad, West Indies. Caribb J Sci, 4: 797–803

Wynd J (1965). Biofacies of the Iranian consortium agreement area. Iranian Oil Offshore Company Report No. 1082

Yazdi M, Shirazi M P, Rahiminejad A H, Motavalipoor R (2012). Paleobathymetry and paleoecology of colonial corals from the Oligocene–Early Miocene (?) Qom Formation (Dizlu area, central Iran). Carbonates Evaporites, 27(3): 395–405

Yazdi Moghadam M (2011). Early Oligocene larger foraminiferal biostratigraphy of the Qom Formation, South of Uromieh (NW Iran). Turk J Earth Sci, 20: 847–856