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Age, microfacies and sedimentary environments of the Sirenia-bearing deposits of the Qom Formation in Central Iran

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Abstract

Sea cows are exceptional fossil vertebrates recently discovered in the deposits of the Qom Formation. Yet, the Sirenia-bearing limestones are still poorly understood in terms of detail paleoenvironmental and micropaleontological investigations. In order to distinguish the temporal and paleoenvironmental context of the Sirenia (sea cow) bearing deposits of the Qom Formation in central Iran, three stratigraphic sections were studied in Hamedan (Ivak and Shirinsu) and Isfahan (Chahriseh) provinces. A total number of 47 thin sections were studied for micropaleontology, biozonation and carbonate microfacies analysis, as well as sedimentary environment recounstruction. Biostratigraphical investigations suggest that the Sirenia-bearing deposits are Aquitanian/Burdigalian in age, which implies restriction of sea cows remains to the Lower Miocene. We recognized nine microfacies (n=8 correspond to carbonate; n=1 correspond to siliciclastic) in the study areas. They are systematically grouped into two microfacies settings, representing inner and middle ramp environments. This is based on the facies associations and the distribution of skeletal components and rock textures. The Sirenia-bearing limestone consists of peloid/algae bearing wackstone/packstone/floatstone. A carbonate (inner) ramp system under shallow water conditions is interpreted as the habitats of the Sirenian mammals during the Aquitanian/Burdigalian in Central Iran. This paleoenvironmental setting could be utilized for further exploration of Qom Formation deposits for discovering sea cows.

Keywords: *Miocene, Qom Formation, Carbonate ramp, Sirenia, Microfacies.*

1. Introduction

Fossil vertebrates are generally rare worldwide; hence, they are of great importance for reconstructing the evolution of life on Earth and global demonstration of distribution patterns. The herbivorous marine mammals (Sirenia/sea cows) are among the most recent fossil vertebrate discoveries in Iran (Mirzaie Ataabadi et al. 2014; Abbassi et al. 2016). Sirenian fossils were pointed out for the first time in the deposits of the Qom Formation in Central Iran by Reuter et al. (2009). However, they provided no detail of this record. More recently, such fossils have been found in several Oligocene-Miocene strata from different localities in the country, mostly consisting of postcranial (skeletal) material. Geologically, sirenian fossils of Iran have been found in two basins: Zagros (Asmari and Mishan Formations) and Central Iran (Mirzaie Ataabadi et al. 2014). In Central Iran, these fossil materials are hosted within Oligocene-Miocene strata of the Qom Formation. These fossils are so far recorded from areas in the northeast of Isfahan and to the south and northeast of Hamedan (Mirzaie Ataabadi et al. 2014; Abbassi et al. 2016; Poorbehzadi et al. 2019). Even though the exposures of the Oligocene-Miocene Qom Formation are dispersed in Iran (Rahimzadeh 1994), most of its paleontological and paleoenvironmental studies are focused in central parts of the country, where this formation was originally described and studied (e.g. Mohammadi et al. 2011, 2013, 2015 and references therein). On the contrary, in the northwestern and western parts of Iran (compared to the more central parts), the Qom Formation has been less studied (Daneshian et al. 2010; Daneshian and Akhlaghi 2010; Yazdi-Moghadam 2011; Babazadeh et al. 2014; Yazdi-Moghadam et al. 2018; Rabbani et al. 2020). Further research has been conducted on this formation around the city of Isfahan, where the first Sirenia fossils were recorded (Reuter et al. 2009; Yazdi et al. 2012; GhasemShirazi et al. 2014; Nouradini et al. 2014, 2015; Yazdi et al. 2019). Nevertheless, regarding the regions where there are sea cows, only the Shirinsu area was studied by Abbassi et al. (2016). Though, the latter work lacks a detailed paleoenvironmental and micropaleontological study.

Here, the Sirenia-bearing sections of the Qom Formation are studied in order to reconstruct the paleoenvironmental and micropaleontological characteristics of this formation and their fossil horizons. We also define the similarities and differences in the historical record of the sea cows in Central Iran for the first time. These are crucial information for further discovery of such fossils.

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2. Geological and Geographical settings

Deposition of the Qom Formation occurred after the development of a thick terrestrial succession known as the Lower Red Formation. The Qom Formation consists of marine sediments, which had been deposited after a major sea transgression during the Oligocene (Aghanabati 2004). The Qom Formation is widely distributed along a northwest-to-southeast belt in Iran (Fig 1a). It is mostly exposed around the central parts of the country (Central Iran back-arc basin). They are also exposed in the Urmieh-Dokhtar (Intra-arc) and Sanandaj-Sirjan (fore-arc) basins (Mohammadi et al., 2013, 2014, 2015; Baratian et al. 2020). The Qom Formation is mainly composed of carbonates, but siliciclastic and evaporites are also present. The age, thickness and other aspects of these deposits might vary regionally due to different levels of vertical basin movements and tectonics during the Oligocene - Miocene (Aghanabati 2004).

2.1. Isfahan

The main studied region in Isfahan province, the stratigraphic section 2 (33° 0' 14.4" N; 52° 2' 8.2" E), is located near the Chahriseh village, northeast of Isfahan town (Fig 1a-b). This section is accessible through the Isfahan-Ardestan road.

Another section (Zefreh A (32° 56' 35.4" N; 52° 08' 23.4" E), where the first indication of fossil Sirenia is recorded, is also located northeast of Isfahan in geographic proximity (ca. 20km) of Chahriseh. This section is accessible via Isfahan-Nain highway (section1 in Fig 1a-b). Since we were unable to locate or find the exact position of the fossil Sirenia bed in this section, it was not sampled and revisited, thus the present study relies on the results of the previous work (Reuter et al. 2009).

The Isfahan area mostly belongs to the Central Iranian domain. The southern and southwestern parts of this province belong to the metamorphic Sanandaj-Sirjan, and Zagros zones. The main sedimentary outcrops of the studied area in northeast Isfahan are Paleozoic and Mesozoic rocks (Zahedi and Amidi 1978). The Qom Formation in this region is part of the Isfahan–Sirjan fore-arc basin (Reuter et al. 2009). The Qom Formation in Chahriseh area shares angular unconformity with different underlying units such as Permian and Triassic strata. It is up to 120 meters thick (Nouradini et al. 2014). However, in a nearby section in Zefreh, the Qom Formation rests on the deposits of the Lower Red Formation (Reuter et al. 2009). In Chahriseh section where we studied the Qom Formation, it lies unconformably over the Triassic dolomites and is covered by Quaternary deposits.

2.2. Hamedan

The studied sections in Hamedan are situated to the south and north of this province. The stratigraphic section 3 (34° 46' 43.8" N and 48° 40' 50.1" E) is located south of Hamedan city, close to the Ivak village (Fig 1a, c).

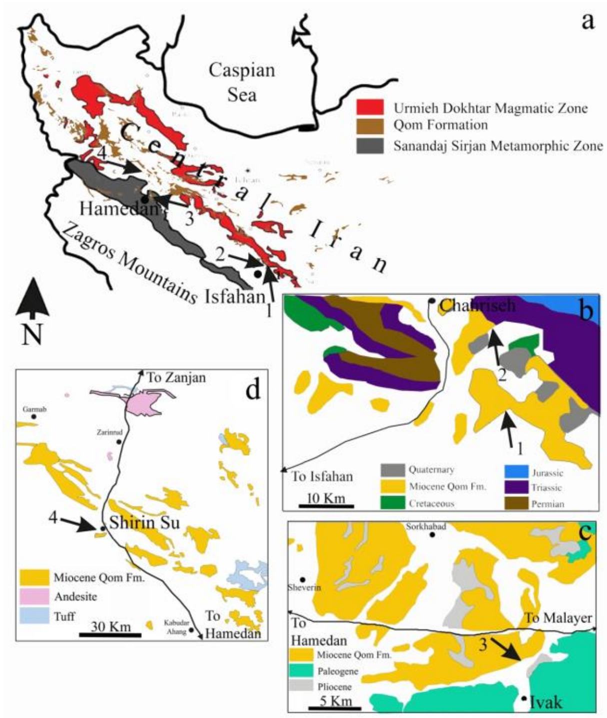

Fig 1. Geographic and geological settings of the Qom Formation in the studied areas. (a) General distribution of Qom Formation in the central and northwestern parts of Iran around the Sanandaj-Sirjan Metamorphic belt and Urmieh-Dokhtar Magmatic zone (modified after Abbassi et al. 2016) and the position of study areas, (b) Geological map of the Zefreh-Chahriseh area to the northeast of Isfahan (modified after Zahedi and Amidi 1978), (c) Geological map of the Hamedan area (modified after Eghlimi 1999) and (d) Geological map of Kabudar Ahang-Shirinsu areas (modified after Bolourchi and Hadjian 1979) ; Zefreh section (1), Chahriseh section (2), Ivak Section (3), Shirinsu section (4).

It can be accessed through Hamedan-Malayer highway. Section 4 (35° 29' 19.4" N and 48° 26' 32.9" E) is located near Shirinsu town (Fig 1a, d) and can be reached through Hamedan-Zanjan road.

Hamedan province is divided into different parts, each of which belonging to a specific geological domain. It is mainly located in Sanandaj-Sirjan metamorphic zone (fore-arc basin). Parts of this province (southwest) belong to the Zagros zone, and the spots toward north and northeast apparently belong to the Urmieh-Dokhtar volcanic belt (intra-arc basin). Therefore, metamorphic and volcanic rocks are the main units of this area. In addition, some Cretaceous and Oligocene-Miocene carbonates also occur. The areas with outcrops of the Qom Formation in this region confine to the east and northeast of Hamedan. In other words, the most important outcrops of the Qom Formation are located in the Ab-e garm, Avaj, Razan and Kabudar Ahang areas of this province. Here, the Qom Formation is deposited in a fault-controlled basin. Hence, its thickness varies significantly (Bolourchi and Hadjian 1979).

Therefore, the outcrops with sirenian remains are short, having 70 meters maximum thickness (Mirzaie Ataabadi et al. 2014; Abbassi et al. 2016). In the studied sections, Qom Formation overlies the Lower Red Formation and is covered unconformably by Quaternary deposits.

3. Material and methods

The sirenian fossil materials from Qom Formation were discovered in four sections in Isfahan and Hamedan provinces (Fig 1). Three sections were systematically measured and sampled for micropaleontological and microfacies studies. The outcrops were analysed bed-by-bed with sampling in 2-4 meter intervals to conduct the analysis of microfacies. Total numbers of 47 thin sections are studied (10 in Chahriseh, 15 in Ivak and 22 in Shirinsu). Loeblich and Tappan (1987) is used for the generic classification of foraminifera. The larger foraminiferal biozonal scheme for the Zagros Mountains by Wynd (1965) and, Adams and Bourgeois (1967) is applied to the studied sections and the zonations have been compared with them. Classification of the microfacies is on the base of the abundance percentage of skeletal and non-skeletal elements, matrix and texture characteristics, and their final compilation with field data. To describe the texture of the sediments, the classification of Dunham (1962) with the modification by Embry and Klovan (1971) was employed. Microfacies belts and sedimentary models of Flügel (2010) are used for interpretation of the depositional environment.

4. Results

4.1. Stratigraphy, Micropaleontology and Biostratigraphy

4.1.1. Stratigraphy

4.1.1.1. Isfahan region

The thickness of the Chahriseh section (Fig 2a) is measured in approximately 37 meters and it consists of limestone and marly units (Fig 3b). The Sirenia-bearing beds in this section are located at the basal parts. They have reddish/pinkish weathered colors, consisting of cream limestone and marly limestone beds with frequent occurrence of coral and red algae remains (Fig 3b, Fig 4a). The total thickness of Qom Formation in the Zefreh section (sections A+B of Reuter et al. 2009) is about 250 meters. In section A, where the presence of sirenian remains is reported, the thickness is 150 meters. It consists of siliciclastic (siltstone, sandstone and conglomerates), marl and limestone units.

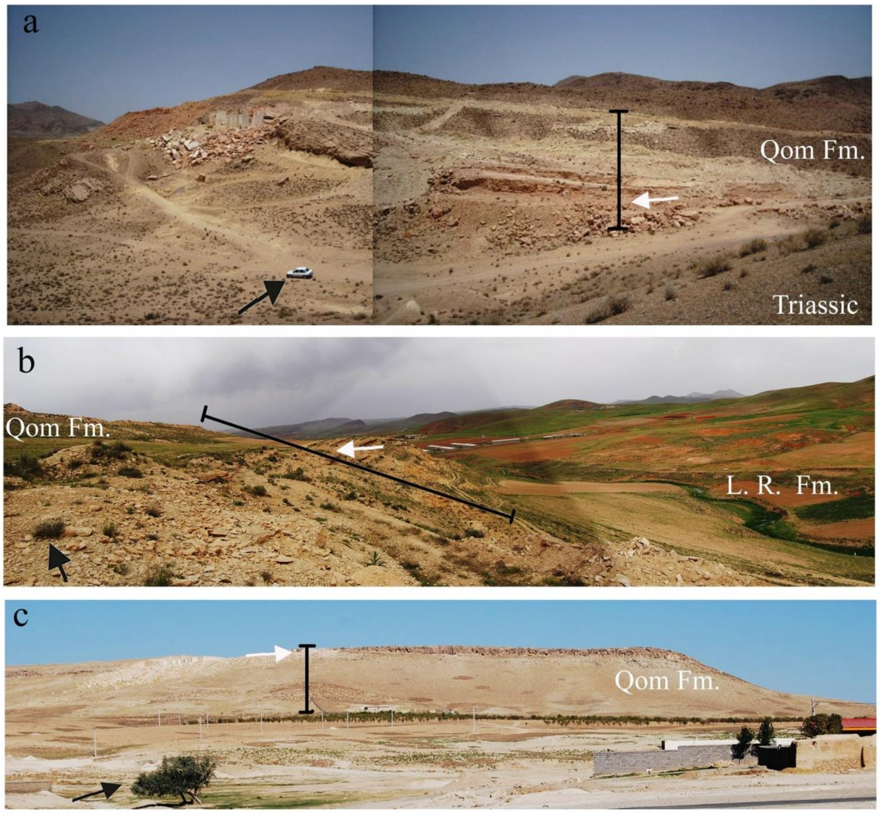

Fig 2. Panoramic view of the studied stratigraphic sections. (a) Chahriseh, Isfahan Province. (b) Ivak and (c) Shirinsu, Hamedan Province. L. R. Fm (Lower Red Formation). White arrows indicate the position of Sirenia-bearing horizons. Black arrows point to the scaling objects (a: white car, b: small bushes, c: tree). Position of sections is indicated by (├──┤)

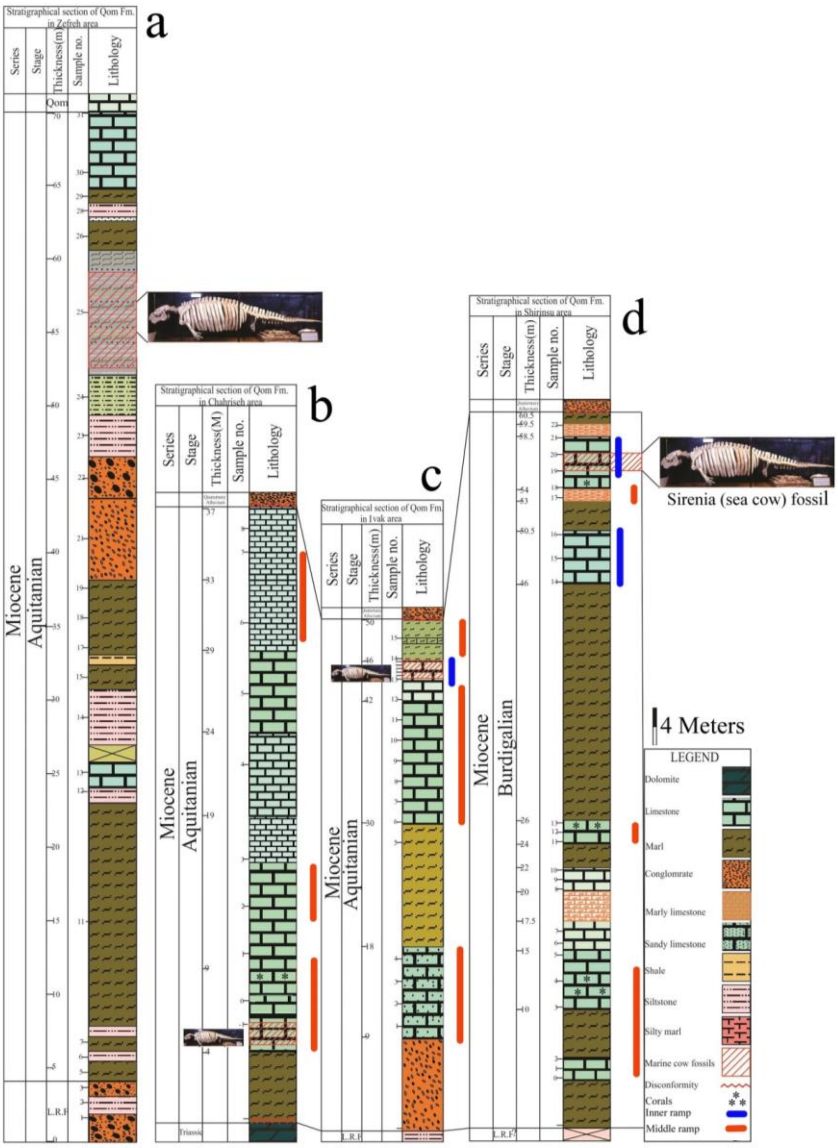

Fig 3. Lithostratigraphic columns of the Qom Formation in the studied sections with indication of the Sirenia-bearing horizons and the recognized paleoenvironments. (a) Zefreh section and (b) Chahriseh section in Isfahan Province, (c) Ivak and (d) Shirinsu sections in Hamedan Province.

The Sirenia-bearing beds here are located at the lower parts of the section at approximately 50-60 meters from the base (Fig 3a). They include a succession of siliciclastics and marls with thin intercalation of volcanic ash layers. The marls are also intercalated with beds of sandstone and siltstone at their top. A coral build-up, constructed mainly by branching and platy colonies, follows these beds (Reuter et al. 2009).

4.1.1.2. Hamedan region

The thickness of the Ivak section (Fig 2b) is approximately 50 meters and consists of 5 lithostratigraphic units namely limestone, marl, marly limestone, sandy limestone and microconglomerate (Fig 3c). In a nearby section (Zia-Aldin), the thickness of this formation is 70 meters with similar lithology (Amanpour 2018). The Sirenia-bearing beds in Ivak section are located near the top at about 45 meters from the base (Fig 2b). They consist of soft white marly limestone beds with red algae remains (Fig 4b).

In Shirinsu section (Fig 2c), on the contrary to previous studies, the outcrop is about 60 meters and consists of three lithostratigraphic units namely limestone, marl, and marly limestone (Fig 3d). The lower boundary of this section is not well exposed (covered), but compared with some nearby sections it seems that the Qom Formation in this area is also resting on the Lower Red Formation (Rafiee and Baghbani 2008). The Sirenia-bearing beds here are also located near the top at about 55 meters from the base. These layers consist of thick, cream colored limestone beds with occasional occurrence of corals (Fig 4c).

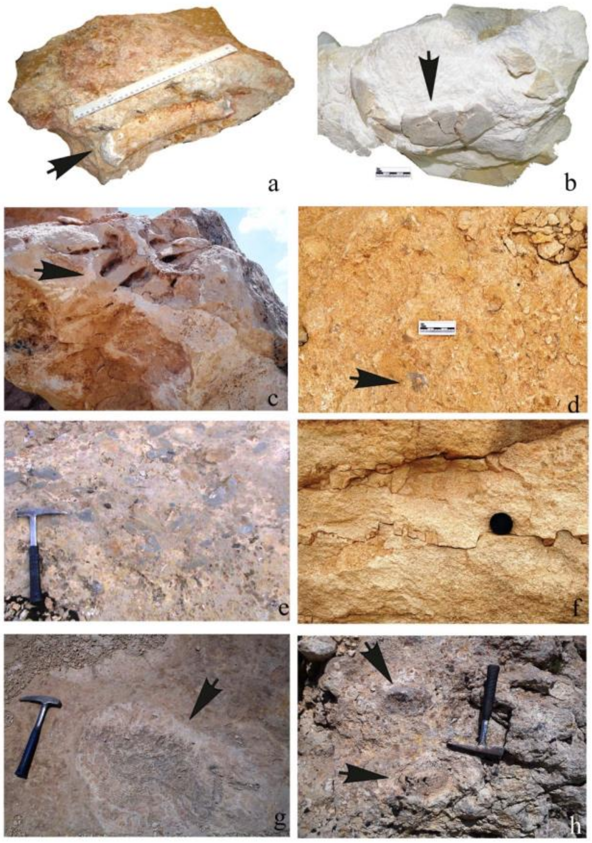

Fig 4. Close view of the Sirenia-bearing beds and some of the macroscopic features of the sedimentary strata in the studied sections. (a) a block of limestone with a sea cow rib (arrow) from Chahriseh section (scale: 30 cm), (b) a chunk of fossiliferous marly limestone with bone fragments (arrow) from Ivak section (scale: 5 cm), (c) a large block (ca. 1m) of fossil bearing horizon with traces of fossils (arrow) from Shirinsu section, (d) the calcareous microconglomerate bed from Ivak section with some shell (arrow) fragments (scale: 5cm), (e) field view from the basal conglomerates of the Ivak section, (f) close up of the sandy limestone beds of the Ivak section (scale: 5cm), (g,h) examples of large coral occurrences (arrows) from the lower (h) and upper (g) horizons of Shirinsu section.

4.1.2. Micropaleontology and Biostratigraphy

Studying the fossil assemblages in the mentioned sections (Ivak, Shirinsu and Chahriseh), resulted in the recognition of thirty-five (35) genera and fourty-eight (48) species of benthic foraminifera, and three (3) species of plankthic foraminifera. According to the age and stratigraphic range of the benthic foraminifera, and the defined biozonation for the Oligocene/Miocene of Iran by Wynd (1965) and Adams and Bourgeios (1967), the following two (2) biozones are represented for the studied sections.

4.1.2.1. Ivak (Hamedan) and Chahriseh (Isfahan) sections

The *Miogypsinoides* – *Archaias* – valvulinid Assemblage Zone (Adams and Bourgeios 1967) is recognized for the deposits of the Qom Formation in these stratigraphic sections (Fig 6-7). This biozone is distinguished with the presence of *Miogypsinoides* sp. (Fig 5a) and *Miogypsinoides complanatus* (Fig 5b) , in addition to the following fossils:

Glomospira sp., *Haplophragmium* sp., *Pseudolituonella reicheli*, *Bigenerina* sp., *Textularia* sp., *Valvulina* sp., *Spiroloculina* sp., *Massilina* sp., *Quinqueloculina* sp., *Triloculina trigonula*, *Bolivina* sp., *Pyrgo* sp., *Denderitina rangi*, *Reussella* sp., *Victoriella* sp., *Sphaerogypsina globulus*, *Amphistegina* sp., *Spiroclypeus vermicularia*, *Spiroclypeus orbitoides*, *Spiroclypeus* sp. (Fig 5g), *Nephrolepidina marginata*, *Nephrolepidina tournoueri*, *Nephrolepidina chaperi*, *Nephrolepidina parva*, *Nephrolepidina* sp., *Lepidocyclina* sp. (Fig 5h), *Eulepidina* sp., *Heterolepa* sp., *Neorotalia viennotti*, *Neorotalia* sp., *Rotalia* sp.,

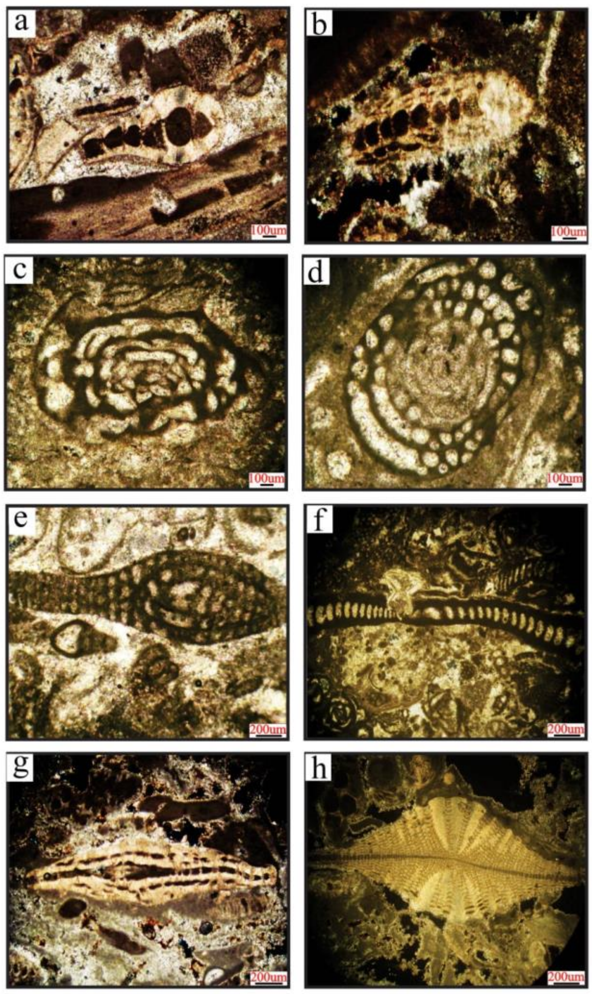

Fig 5. Some of the main foraminifera from the studied sections. (a) *Miogypsinoides* sp., (Chahriseh section). (b) *Miogypsinoides complanatus*, (Ivak section). (c) *Borelis* sp., (Shirinsu section). (d) *Borelis melo curdica*, (Shirinsu section). (e) *Archaias* sp., (Shirinsu section). (f) *Meandropsina iranica*, (Shirinsu section). (g) *Spiroclypeus* sp., (Chahriseh section). (h) *Lepidocyclina* sp., (Ivak section). Scale bars (a-d) 100 microns, (e-h) 200 microns.

Ammonia beccari, *Ammonia* sp., *Elphidium* sp., *Miogypsina irregularis*, *Miogypsina globulina*, *Miogypsina* sp., and *Operculina complanata*,. Hence, an early Miocene (Aquitanian) age is proposed for these sections. In Zefreh section (Fig 3a) the lower parts of the succession include a fauna characterized by gastropods, bivalves and bryozoans. Foraminifers are also represented by *Lepidocyclina (Eulepidina) dilatata*, *L. (E.)* aff. *favosa*, *L. (Nephrolepidina) morgani*, *Operculina complanata*, heterosteginids, and a few Miogypsinids. The fauna reveals an early Miocene (Aquitanian) age for this section (Reuter et al. 2009).

4.1.2.2. Shirinsu section (Hamedan)

The *Borelis melo* group–*Meandropsina iranica* Assemblage Zone (Adams and Bourgeios 1967), which is equivalent to *Borelis melo curdica* Assemblage Zone (zone 61, 62 of Wynd 1965), is recognized in this section (Fig 8). This zone includes the following fossils: *Glomospira* sp., *Haplophragmium* sp., *Bigenerina* sp., *Textularia* sp., *Spiroloculina* sp., *Massilina* sp., *Quinqueloculina* sp., *Bolivina* sp., *Pyrgo* sp., *Borelis* sp. (Fig 5c), *Borelis melo curdica* (Fig 5d) *Denderitina rangi*, *Archaias* sp. (Fig 5e), *Discorbis* sp., *Planorbulina* sp., *Meandropsina iranica* (Fig 5f), *Halkyardia* sp., *Victoriella* sp., *Sphaerogypsina globulus*, *Amphistegina* sp., *Rotalia* sp., *Ammonia* sp., *Elphidium* sp.

An early Miocene (Burdigalian) age is also proposed for this section.

4.2. Microfacies analysis

By the examinations of fourty-seven (47) thin sections from the outcrops of the Qom Formation in Ivak, Shirinsu and Chahriseh sections, a total of nine (9) microfacies were recognized. Eight (8) correspond to carbonate microfacies and one (1) to siliciclastic microfacies (Table 1). Among these recognized microfacies, three (3) belongs to Ivak and Shirinsu, and four (4) belongs to Chahriseh. A coral microfacies is common among Shirinsu and Chahriseh sections (Table1). The recognized microfacies, according to the environment depth, are as follow:

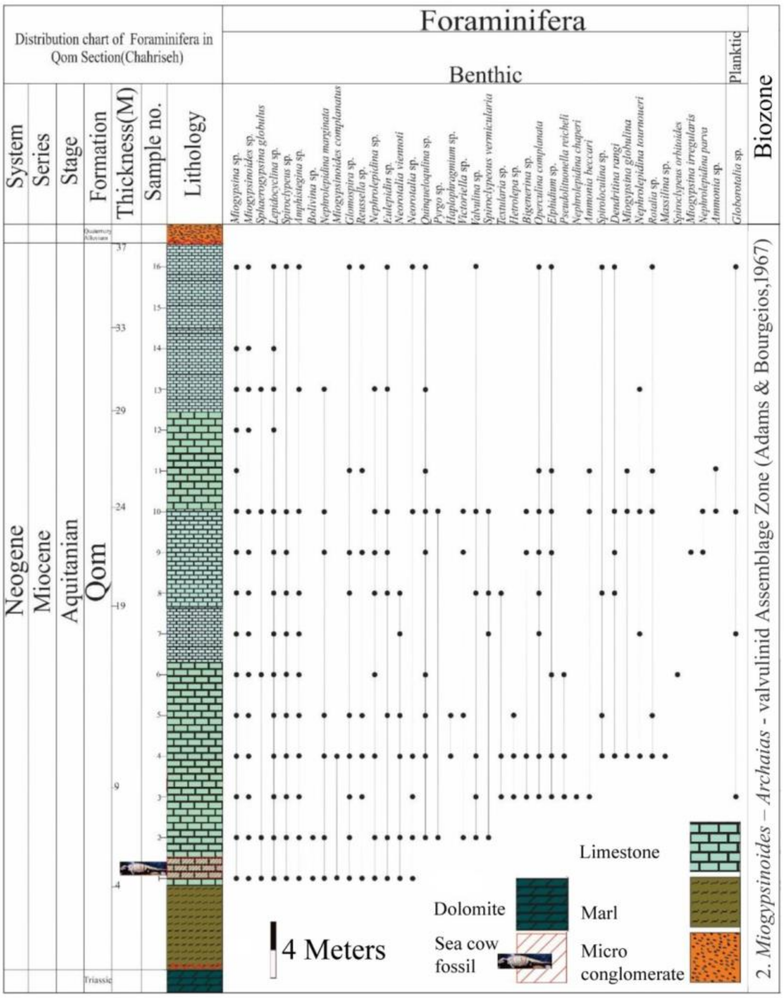

Fig 6. Distribution of foraminifera in the Chahriseh section and the inferred biozonation

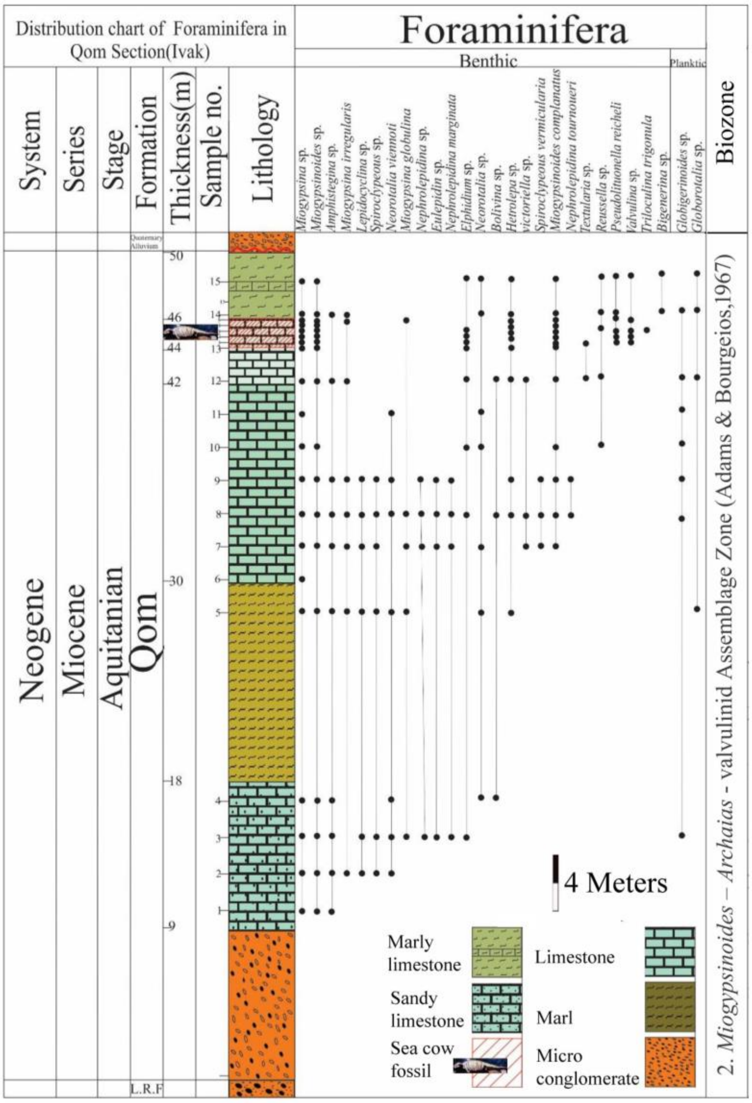

Fig 7. Distribution of foraminifera in the Ivak section and the inferred biozonation.

Table 1. Summary of the microfacies characteristics of the Qom Formation in the studied areas

Microfacies Name	Stratigraphic location	Sample No.	Main Lithology	Main Allochems	Minor Allochems	Sedimentary Environment
Peloid red algae packstone to floatstone	44 to 46 m in the Ivak section	13, 14	medium-bedded limestone	red algae	peloids	inner ramp
Peloid wackestone to packstone	46 to 50.5 m and 55 to 58.5 of the Shirinsu section	14, 15, 16,19, 20, 21	limestone	peloids	benthic foraminifera such as *Borelis* and *Meandropsina*	inner ramp
Calcareous microconglomerate	9 to 18 m in the Ivak section	1, 2, 3, 4	calcareous microconglomerate	clastic grains such as angular, coarse grain quartz	benthic foraminifera, as well as red algae, bryozoans and bivalves	middle ramp
Coral floatstone	11 to 13 m, 25 to 26 m and 53 to 54 m of the Shirinsu section, and base of the Chahriseh section	4, 12, 13, 17, 18 (Shirinsu),1(Chahriseh)	limestone and marly limestone	large coral fragments	benthic foraminifera, bryozoans, and echinoid	middle ramp
Echinoid red algae packstone to grainstone	4 to 11 m of the Shirinsu section	0, 1, 2, 3	limestone	red algae and echinoid fragments	bryozoan and bivalve fragments	middle ramp
Bryozoan red algae packstone to floatstone	4 to 6 m interval of the Chahriseh section	1	limestone	large red algae fragments and bryozoans	echinoid and benthic foraminifera	middle ramp
Bryozoan echinoid benthic foraminifera packstone to grainstone	6 to 7 m and 30 to 35 m intervals of the Chahriseh section	2, 13, 14, 15	limestone	bryozoans, echinoid and benthic foraminifera	quartz grains and red algae fragments	middle ramp
Red algae benthic foraminifera packstone to rudstone	12 to 15 m interval of the Chahriseh section	5, 6	limestone	red algae fragments and benthic foraminifera	bryozoans	middle ramp
Bryozoan benthic foraminifera packstone to rudstone	30 to 42 m, 42 to 44 m, and 46 to 50 m interval of the Ivak section	6, 7, 8, 9, 10, 11, 12, 15	limestone and marly limestone	bryozoan fragments along with benthic foraminifera	quartz grains and red algae	middle ramp

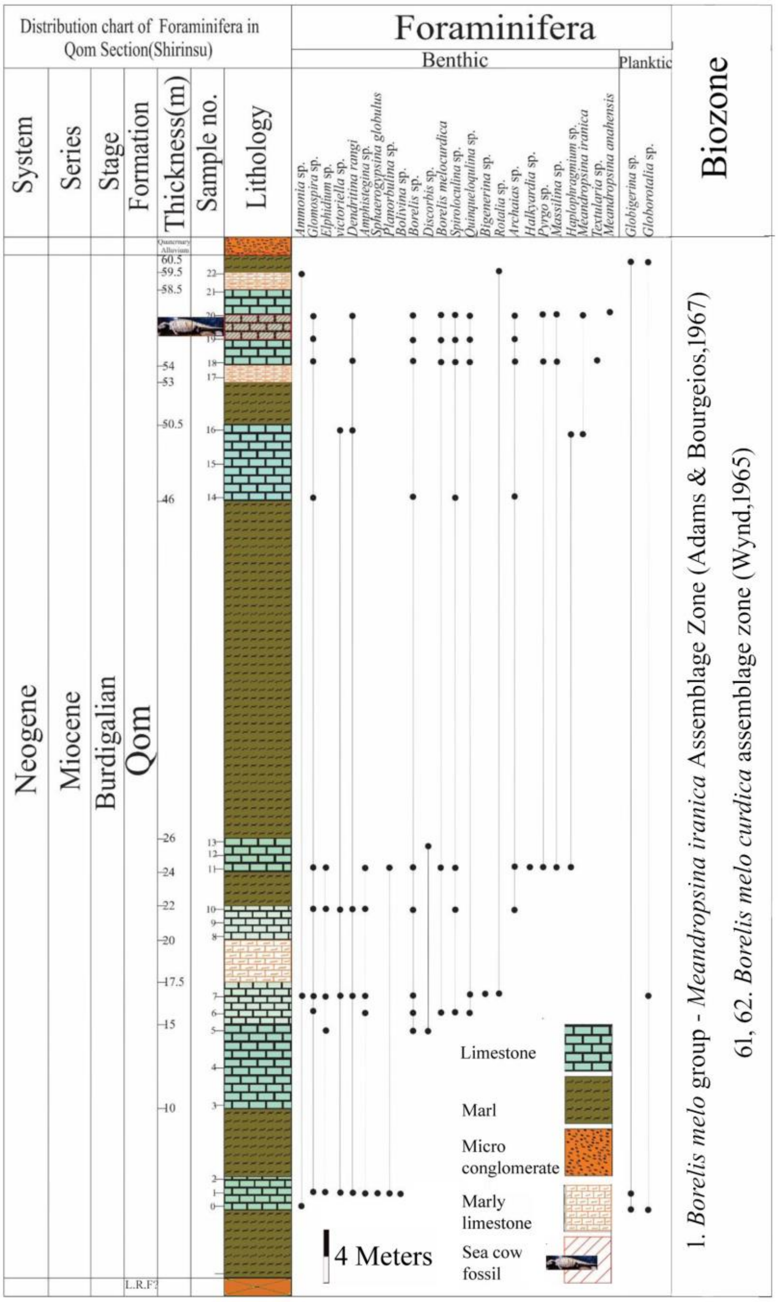

Fig 8. Distribution of foraminifera in the Shirinsu section and the inferred biozonation.

4.2.1. Inner ramp microfacies association+

This microfacies association is mainly characterised by medium-bedded limestone with cream to light cream colour. Two microfacies are associated in this environment and are composed mainly of peloids, red algae and imperforate foraminifera such as *Borelis* and *Meandropsina*. The groundmasses of these microfacies are only micrite with mainly wackestone to packstone textures. The contact of these two microfacies is transitional and marked by an increase in peloid and benthic foraminifera through the studied sections.

4.2.1.1. Peloid red algae packstone to floatstone

The interval from 44 to 46 m in the Ivak section (Fig 3c) is recognized as a medium thickness, cream to light cream limestone, which mainly contains this sedimentary microfacies. The Sirenia-bearing horizon in this section is also present in this interval. More than 50% of the allochem in this microfacies consist of red algae (coralline red algae with radial ornamentation and almost reticulate 1 to 1.5 mm cells) and small peloids, which mostly are rather angular to poorly round. In this microfacies, size of the red algae grains reaches up to several centimeters, as they are easily visible by naked eye in the field investigation (fig 4b). Coralline algae have been cut by boring organisms and the bores are filled with internal sediments and calcite cements. The abundance of the grains in some thin sections is so high that the remained spaces between grains are filled with carbonate mud. Depositional textures are represented by packstone to rudstone. It should be noted that the peloids are mostly the result of micritization of algae grains. The groundmass of this microfacies only shows micrite and no carbonate cement observed between the allochems. Lamination and rare porosity (moldic) are also visible in this microfacies. According to the facies belts and sedimentary models of Flügel (2010), this microfacies is similar to RMF20 (Fig 9a).

4.2.1.2. Peloid wackestone to packstone

The stratigraphic location of this microfacies is the interval from 46 to 50.5 m and 55 to 58.5 m of Shirinsu section (Fig 3d). It is the most dominant microfacies at the top of Shirinsu section, where Sirenia-bearing horizon occurs. This microfacies consists of medium to thick-bedded, light cream and gray limestones (Fig 4c). Other fossils are rare here and relatively low diversity is present. There is no sedimentary structure. It is composed of 40-45% by volume of peloids as the major framework grains.

Peloid grains are not usually in contact with each other and they can be considered as floated components within the micritic groundmass. Benthic foraminifera such as *Borelis* and *Meandropsina* (Fig 5c-d, f) constitute 10% to 15% of this microfacies. In general, this microfacies is poor in large skeletal grains and mainly contains diminutive fauna. Due to their texture and size, it seems that peloids are the result of the breakage and micritization of red algae grains. The groundmass of this microfacies is mainly composed of micrite (mud-rich texture) with a little carbonate cement (Fig 9b). This microfacies is comparable with RMF20 of Flügel (2010).

4.2.2. Middle ramp microfacies association

This microfacies association is mainly characterised by limestone along with some marly limestone and calcareous microconglomerate. According to type and frequency of allochems and matrix, this microfacies association includes seven microfacies that have high frequency in the studied sections. This microfacies association contains a wide range of skeletal grains. These mainly include: bryozoans, echinoid, perforate benthic foraminifera and coral. The groundmasses of these microfacies are mainly micrite with mionor sparry calcite cements. These microfacies grade transitionally into each other through the studied sections.

4.2.2.1. Calcareous microconglomerate

The stratigraphic location of this microfacies is at the base of the Ivak section at the interval from 9 to 18 m (Fig 3c). The main lithology in this microfacies is yellowish-gray, calcareous microconglomerate (Fig 4d). This microfacies is mainly characterized by massive to crudely stratified, coarse sand-sized to microconglomerate, terrigenous particles. Terrigenous clasts are subangular to moderately round. About 30% of the main allochems in this microfacies is constructed with clastic grains such as: angular, coarse grain quartz with wavy extinction. Benthic foraminifera such as *Miogypsina* and *Lepidocyclina* (Fig 5h), as well as red algae, bryozoans and bivalves (Fig 4d) make the minor elements of this microfacies. The components are mostly fragmented and abraded, though well-preserved ones are also present. This microconglomerate is grain-supported and the groundmass only shows the micrite (Fig 9c-d). According to Flügel (2010) data, this microfacies is similar to RMF10.

4.2.2.2. Coral floatstone

The stratigraphic location of this microfacies is at the interval of 11 to 13 m, 25 to 26 m and 53 to 54 m of the Shirinsu section (Fig 3d). The main lithology in this microfacies is limestone and marly limestone (Fig 4g-h). This microfacies is also recognized at the Chahriseh section from 7 to 9 m interval (Fig 3b), with limestone lithology.

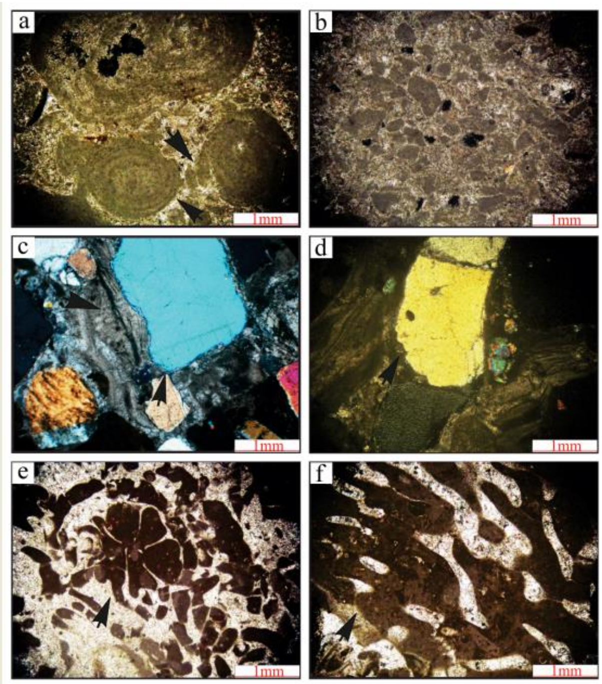

Fig 9. Microfacies of the Qom Formation deposits in the Ivak, Shirinsu and Chahriseh sections. (a) Peloid red algae packstone to rudstone: radial formed Coralline red algae with central core are observed next to the Peloids (Shirinsu section). (b) Peloid wackestone to packstone: some Peloid grains have inner structures formed by breakage and micritization of the red algae (Shirinsu section). (c-d) Calcareous microconglomerate: large quartz grains are found next to the benthic foraminifera with hyaline crust such as *Spiroclypeous* (Ivak section). (e-f) Coral floatstone: coral cross section with septa traces (Shirinsu and Chahriseh sections). Main skeletal components mentioned in the captions are also marked with arrows in the figures. All figures are PPL except c-d which are XPL, scales are 1mm.

This massive, medium to thick-bedded, cream to light gray boundstone microfacies is largely comprised of pebble to coarse-grain sized coral remains. The texture is floatstone. In this microfacies, the main allochems are large coral fragments, which are abundant in the matrix (Fig 4g-h). The corals are so abundant that they occasionally construct the bulk of limestones. Some small coral colonies are also locally present in this microfacies. Spaces between framework components are filled by medium to fine-grained bioclastic matrix. In these sections, corals are meandered and multi-directed in cross section, and chambers are filled with calcite cement. The minor associated fauna include foraminifera, bryozoans, and fragments of echinoids. Some diagenetic cement is also present into the groundmass of this microfacies (Fig 9e-f). Consistent with the facies belts and sedimentary models of Flügel (2010), this microfacies resembles RMF12.

4.2.2.3. Echinoid red algae packstone to grainstone

This microfacies occurs at an interval from 4 to 11 m of the Shirinsu section (Fig 3d). It is distinguished by medium- to coarse-grained bioclastic packstone. Subordinate grainstone containing poor to moderately sorted echinoid and red algae, embedded in a matrix of carbonate mud and microspar. Approximately, 40% to 45% of allochems in this microfacies consist of red algae remains, which are mainly seen as peloid due to micritization process. Additionally, echinoid fragments of about 10% are clearly visible in this microfacies. The minor fossil components such as bryozoan and bivalve fragments are also recognizable. Grains are coarse sand to granule size and are in a finer grained carbonate matrix and cement. All of these components are well preserved. Into the groundmass, some pores have been filled with calcic cement (Fig 10a). This microfacies resembles RMF7 of Flügel (2010).

4.2.2.4. Bryozoan red algae packstone to floatstone

This microfacies is most prominent in lower parts of the Qom Formation at the 4 to 6 m interval of the Chahriseh section (Fig 3b). This microfacies comprises medium- to thick-bedded, cream to light cream (weathered color reddish/pinkish) limestones (Fig 4a). The Sirenia-bearing beds in this section occur at this interval. This microfacies was characterized by coarse-grained bioclasts dominated by unbroken bryozoan and red algae. More than 40% of its main elements consist of large red algae fragments (Coralline red algae with reticulate appearance with almost rectangular and small cells, pores in algae skeleton are filled by sparite calcite) and bryozoans. Other fossil elements like echinoid and benthic foraminifera such as *Miogypsina*, *Lepidocyclina*, and *Spiroclypeous* (Fig 5g-h) are found in the matrix as minor allochems. The spaces between grains are filled with micritic mud (Fig 10b). Based on the information available in Flügel (2010), this microfacies is similar to RMF9.

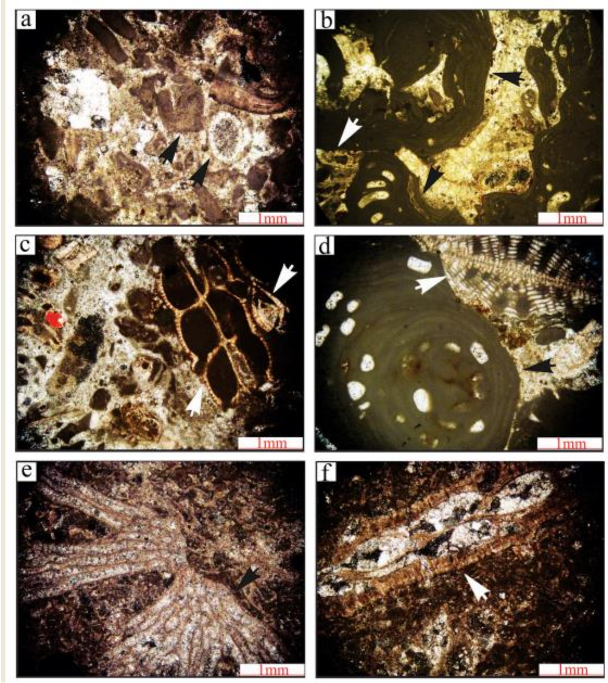

Fig 10. Microfacies of the Qom Formation deposits in the Ivak, Shirinsu and Chahriseh sections. (a) Echinoid red algae packstone to grainstone: Red algae and the cross section of echinoid spine next to each other (Shirinsu section). (b) Bryozoan red algae packstone to floatstone: Red algae next to the benthic foraminifera with hyaline crust and bryozoan (Chahriseh section). (c) Bryozoan echinoid benthic foraminifera packstone to grainstone: Linear section of Tubucellaria bryozoan is observed next to the *Amphistegina* and echinoid spine (Chahriseh section). (d) Red algae benthic foraminifera packstone to rudstone: Red algae is seen along with *Lepidocyclina* (Chahriseh section). (e-f) Bryozoan benthic foraminifera packstone to rudstone: Bryozoan along with bentic foraminifera segments and bryozoan with linear section (Ivak section). Main skeletal components mentioned in the captions are also marked with arrows in the figures. All figures are PPL, scales are 1mm.

4.2.2.5. Bryozoan echinoid benthic foraminifera packstone to grainstone

This microfacies is located 6 to 7 m and 30 to 35 m intervals of the Chahriseh section (Fig 3b). This microfacies contains massive, medium- to thick-bedded, light cream to light gray limestone. It is characterized by coarse-grained packstone, rich in perforate foraminifera, echinoid, and bryozoans, preserved in a carbonate mud matrix. Grains are poorly sorted, medium to coarse sand to granule. The microfacies organisms include wide range of components. Main allochems in this microfacies consist of 40% bryozoans (Bryozoans have hard calcite skeleton and laminated structure of septa are well-preserved), and 15% echinoid and benthic foraminifera such as: *Lepidocyclina*, *Miogypsina* and *Amphistegina* (Fig 5h). Red algae fragments also exist as minor elements in this microfacies. Perforate foraminifera are elongated/large and mainly well preserved. Bryozoans are *in situ*, and sporadically fragmented. Small monocrystalline quartz grains which are low to moderately sorted and rounded are also ocasionally present. This microfacies is related to sandy limestone lithology (Fig 4f), which has been described earlier in this text. The majority of groundmass in this microfacies consists of micrite along with some calcite cement between the grains (Fig 10c). Original void spaces are mostly filled by coarse crystalline calcite. This microfacies resemble RMF8 of Flügel (2010).

4.2.2.6. Red algae benthic foraminifera packstone to rudstone

The lithology of this microfacies is recognized as limestone. Through the stratigraphic section of Chahriseh, this microfacies occur in the 12 to 15 m interval (Fig 3b). In some layers of this microfacies, skeletal components are large and can be observed easily on the rocks. More than 50% of main elements in this microfacies are red algae (Coralline) fragments, in addition to some benthic foraminifera such as: *Lepidocyclina*, *Miogypsina*, *Miogypsinoides* and *Spiroclypeous* (Fig 5a-b, g-h). *Lepidocyclina* are visible on the rock surfaces. Near 5% of bryozoans are also present into the matrix. Rare calcite cement filled the pore space of the rocks (Fig 10d). The mentioned microfacies correspond to RMF9 of Flügel (2010).

4.2.2.7. Bryozoan benthic foraminifera packstone to rudstone

The lithology of this microfacies is limestone and marly limestone. Through the stratigraphic log, this microfacies occurred in the 30 to 42 m, 42 to 44 m, and 46 to 50 m interval of the Ivak section (Fig 3c). The framework grains forming this microfacies are bryozoan fragments with 35% frequency, along with 15% of benthic foraminifera such as *Miogypsina*, *Lepidocyclina* and *Spiroclypeous* (Fig 5g-h). Fragmentation of larger benthic foraminifera is common in this microfacies and they are distributed irregularly among the bioclast. Around 5% of sparse quartz grains and red algae are also discovered in this microfacies. The non-skeletal components consist of rare peloids. The allochems are present in a fine micritic matrix. Some bioclasts have dark micritic envelopes. This microfacies has a mainly packstone texture, but includes a range from packstone to rudstone. No sedimentary characteristic which shows shallow water or high energy sedimentation were detectd. Some calcite cement is filling fossil cavities (Fig 10e-f). Consistent with the facies belts and sedimentary models of Flügel (2010), this microfacies is similar to RMF 9.

4.2.3. Microfacies of the Sirenia-bearing beds

The Sirenia-bearing horizons in the studied sections indicate three microfacies (Fig 11). In the Ivak section the fossil horizon sedimentary microfacies is defined as peloid red algae packstone to floatstone, while in Shirinsu section the fossil bed demonstrates peloid wackestone to packstone microfacies. Both microfaceis are indicative of inner ramp settings. They consist mainly of red algae and peloid allochems. Most large peloids are also result of red algae micritization. In Chahriseh section the fossil intervals show bryozoan red algae packstone to floatstone microfacies of the middle ramp setting. This microfacies is dominated by bryozoan and red algae bioclasts, as well as some echinoid and benthic foraminifera.

Ramp	Microfacies	Shirinsu	Ivak	Chahriseh
Inner ramp	Peloid and red algae bearing packstone to floastone		●★	
	Peloid bearing wackstone to packstone	●★		
Middle ramp	Calcareous micro-conglomerate		●	
	Coral bearing floastone	●		●★
	Echinoid and red algae packstone to grainstone	●		
	Bryozoan and red algae bearing packstone to floastone			●
	Bryozoan, Echinoid and benthic foraminifera bearing packstone to grainstone			●
	Red algae and benthic foraminifera bearing packstone to rudstone			●
	Bryozoan and benthic foraminifera bearing packstone to rudstone		●	
	Sea cow fossils ★			

Fig 11. Distribution of microfacies and sedimentary environments in the three studied sections and the characteristics of the Sirenia-bearing horizons in these sections.

4.2.4. Sedimentary model

Using depositional models by Wilson (1975) and Flügel (2010), the sediments of the studied sections were analyzed and interpreted on the basis of sedimentological and paleontological data, and a depositional model was proposed for the Qom Formation in the studied areas. The sedimentary environment of the Qom Formation in the Ivak, Shirinsu and Chahriseh sections is thus reconstructed as a carbonate ramp with a gentle slope. This kind of carbonate platform (ramp-type) is distinguished based on evidence such as: gradual changes of the microfacies from deep to shallow water carbonate environments and the significant amount of components (e.g., benthic foraminifera and echinoid) which were not bound together during deposition (Fig 12). Distally steepened ramp features are absent in the studied sections. Therefore, a homoclinal ramp depositional setting is proposed.

Comparison of the textures and faunal assemblages of the Qom Formation with recent settings indicate that this Formation ramp is comparable to the current homoclinal ramp of the Persian Gulf (Jones and Desrochers 1992). Larger benthic foraminifera, coralline red algae, and corals are dominated at this proposed carbonate ramp setting. These biotic communities have been used as environmental and paleoenvironmental indicators (Stephenson et al. 2015, Robbins et al. 2016). Both large benthic foraminifera (*Lepidocyclina*) and bryozoans are primarily heterotrophic and indicate warm, moderate-energy waters and oligotrophic environments in the Qom carbonate ramp. According to Romero et al. (2002), the oligotrophic zone is dominated by large, flat, perforate foraminifera (like lepidocyclinids) in association with symbiont-bearing diatoms.

As mentioned, based on the distribution of the biotic components and vertical microfacies relationships, the Qom carbonate ramp in the studied areas consists of two main depositional environments. These include inner and middle ramp settings (Fig 12). Inner ramp is characterized by little diversity of benthic foraminiferal assemblages. Imperforated foraminifera are frequent in these settings (Sadeghi et al. 2009). The presence of some allochems such as small micritized red algae, lots of peloids, small imperforate benthic foraminifera like Miliolids, and *Meandropsina*, in addition to some corals proves an inner to proximal middle ramp environment (Avarjani et al. 2015). Along with these mentioned bioclasts, the presence of peloids are indicators of low energy, warm and over-saturated calcium carbonate waters with semi-limited circulation in this inner ramp setting (Adabi et al. 2015; Abyat et al. 2019). This is the paleoenvironment suitable for thriving sea cows.

According to Hallock (2015), a biogenic reef is preferably a major, rigid skeletal structure, which is topographically higher than surrounding sediments. Meanwhile, because of the occurrences of middle ramp bioclasts along with the inner ramp elements, it seems that there were no reefal and continuous barriers present (huge coral reef) in the studied areas (e.g. Shirinsu sections). The inner ramp environment was therefore connected to the middle ramp with some channels (grain-supported microfacies with calcite cements) within this patch reef microfacies. In addition, the presence of microconglomerate microfacies, which contains monocrystalline quartz grains and small benthic foraminifera (Fig 9c), reveals that this microfacies is likely deposited in a relatively high-energy shallow water environment close to the carbonate microfacies. This environment could be observed in the Ivak and Shirinsu sections at a few intervals (Fig 3 c-d).

On the other hand, the microfacies consisting of coralline red algae and other middle ramp bioclasts such as bryozoans, echinoids and benthic foraminifera with hyaline tests prove a higher probability of middle ramp situation during the deposition of the Qom Formation in the studied sections. In more details, poorly sorted bioclast microfacies (e.g., bryozoan red algae packstone to floatstone) with fragments of algae, bryozoans, echinoids, and lepidocyclinids was deposited in fairly shallowparts of the photic zone (mesophotic) in the proximal middle ramp. In such settings, a sea cow rib fragment from Chahriseh section has been recovered. The presence of bryozoans along with benthic foraminifera with hyaline tests, which needs light for surviving, represents the sedimentation in proximal parts of the middle ramp (Mohammadi et al. 2014).

Heterotrophes like bryozoans, are independent of light and depth of waters, so they are able to live in deep and low energy waters (Pomar 2001). Presence of bryozoans along with hyaline foraminifera, which are depended to light for surviving, shows the precipitation of this microfacies in relatively deep parts of photic zone, at the proximal parts of the middle ramp. On the other hand, the presence of elongated, symbiosis-bearing, larger benthic foraminifera like *Lepidocyclina* point to the increase in depth and seaward decrease of hydrodynamic energy (Romero et al. 2002). Accordingly, abundance of these bioclasts with echinoids is possibly related to the shallow part of the middle ramp or more distal part of the inner ramp setting (Jalali et al. 2017). This environment is present in the Ivak, Shirinsu and Chahriseh sections at various intervals (Fig 3b-d).

The outer ramp deposits, characterized by presence of light-independent heterotroph organisms and plankthic foraminifera, and absence of symbiont-bearing benthic foraminifera, are not discovered in the study areas. In the proposed palaeoenvironment model, the distribution and abundance of recognized microfacies are clearly confined to distal inner ramp and proximal part of the middle ramp carbonate platform of the Qom Formation during the early Miocene (Fig 12). In this model, the presence of the red algae and abundance of hyaline benthic foraminifera relative to the porcelaneous and agglutinated foraminifera is a proof of normal salinity of water with euphotic to oligophotic conditions.

The paleoenvironment of the Sirenia-bearing strata in Zefreh section are also distinguished as a carbonate ramp platform (Reuter et al. 2009), similar to other three sections discussed above (Ivak, Shirinsu and Chahriseh). In this section, the Qom Formation strata start with sandstones and coarse-grained calcareous conglomerates, indicative of a relative sea-level lowstand. With continuation of deepening, the coarse siliciclastic content decreases as the lithology shifts into an alternation of silt, silty marl and clay. The bivalve fauna and sirenian bones here imply a shallow water environment. The coral microfacies of the neighboring beds also reflect a shallow water environment. An inner ramp environment could be inferred for this part, including the Sirenia-bearing beds. With relative sea-level rise through the sequence, the siliciclastic input decreases and skeletal limestones rich in corallinaceans, bryozoan and larger benthic foraminifers are formed. These are typical for the middle ramp environment which covers upper parts of the succession.

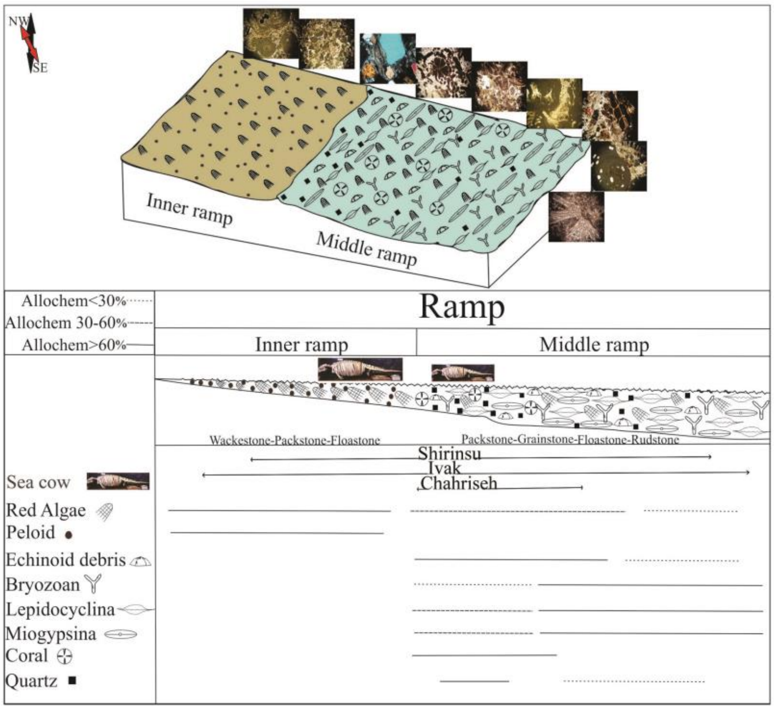

Fig 12. Sedimentary model of the Qom Formation deposits in the Shirinsu, Ivak and Chahriseh sections. Ivak and Shirinsu sections constitute of inner ramp and middle ramp settings. In these sections, the presence of the peloid and red algae along with abundant imperforate benthic foraminifera indicate an inner ramp environment. Open marine bioclasts also show its connection with middle ramp settings. The beginning of the middle ramp is marked here by the existence of more clastic microfacies with angular quartz, echinoid, coral, and accompaniment of few perforate foraminifera. Simultaneous abundance of bryozoans with benthic foraminifera (*Miogypsina* and *Lepidocyclina*) are indicators of deeper zone of the middle ramp. Chahriseh section includes open marine bioclasts and is allocated only to the beginning of middle ramp.

5. Discussion

5.1. Age

The comparison of the Qom Formation and its Sirenia-bearing horizons in the studied sections (Shirinsu, Ivak, Chahriseh and Zefreh), indicates a time transgressive trend toward north. In other words, from southeast to northwest (from Isfahan to Hamedan), the age of the Sirenia-bearing deposits of the Qom Formation changes from Aquitanian to Burdigalian and become younger. Even though the Burdigalian age deposits of the Qom Formation also exist in Isfahan area near the studied section (Reuter et al. 2009; Nouradini et al. 2014, 2015), it is evident that a clear northward transgression took place during the deposition of the Qom Formation. This means that deposits of the Qom Formation with an older (Oligocene) age are more frequent in the southern parts of the greater Qom Formation basin (Mohammadi et al. 2011, 2013, 2015). It is also apparent in the age of the Qom Formation in western and northwestern parts of Iran (Hamedan, Zanjan, and Azarbaijan region), which is early Miocene, majorly Burdigalian, (Bolourchi and Hadjian 1979; Daneshian et al. 2010; Daneshian and Akhlaghi 2010; Rafiee and Baghbani 2008; Babazadeh et al. 2014; Yazdi Moghadam et al. 2018). However, the occurrence of early Oligocene age deposits in Urmieh region is not in accordance with this point of view (Yazdi Moghadam 2011). Interestingly, the recent work by Yazdi Moghadam (2018) from the eastern and western Azarbaijan presents contrary evidence (Burdigalian age) for the strata of the Qom Formation in the northenmost parts of Iran. If the Oligocene age of the Qom Formation deposits in Azarbaijan is valid, this might indicate that the opening of the Tethyan sea way might have taken place from both southeast and northwest (Harzhauser et al. 2007; Popov et al. 2004), and hence the Oligocene age deposits of the Qom Formation are not present in the areas in Hamedan and Zanjan.

The temporal distribution of sirenian fossil horizons implies that the occurrence of sea cows in the Qom Formation is so far restricted to early Miocene. Nevertheless, moving toward west and northwest, younger fossils could be found (Burdigalian vs Aquitanian). The early Miocene record of sea cows in the Tethyan realm is quite abundant and widespread. They are specially reported from the early Miocene of India (Bajpai and Domning 1997; Thewissen and Bajpai 2009; Bajpai et al. 2010), Pakistan (Reza et al. 1984), Turkey (Inan et al. 2008), and Miocene of Europe

(Kordos 1985; Sorbi 2008; Domning and Pervesler 2013; Bianucci et al. 2003).

5.2. Paleoenvironment

The ramp-type carbonate platform identified in the studied sections is considered as the typical paleoenvironment of the Qom Formation. In a recent analysis, Rabani et al. (2020) review and report two general types of sedimentary environment for the strata of the Qom Formation in the central and northwestern parts of Iran. Based on this research, carbonate shelf environment is more widespread in the Qom Formation. Meanwhile, the carbonate ramp model is also quite abundant and is specially recorded from areas around the city of Qom and central Kavir.

The paleoenvironment of the studied sections indicates slight regional differences. Although open marine (Shelf) conditions exist in Isfahan (Reuter et al. 2009; Nouradini et al. 2015), the situation in more western and northwestern parts (Hamedan) is shallower and shows inner ramp-middle ramp conditions (Fig 12). Similar conditions have been reported for another area in Hamedan near the Ivak section, where homoclinal ramp conditions are reported (Amanpour 2018). In Isfahan, around the studied section, a similar paleoenvironmental condition is observed in Zefreh area (Reuter et al. 2009). Among the previous studies, apparently due to longer stratigraphical sections, the paleoenvironment of the Qom Formation is generally more diverse in depositional settings and more facies associations are present (Daneshian et al. 2010; Mohammadi et al. 2011; Seddighi et al. 2011; Safari et al. 2013; Mohammadi et al. 2014; Karevan et al. 2015; Amir-Shah-Karami and Naeimi 2016; Jalali et al. 2017; Rabbani et al. 2020).

The paleoenvironment of the Sirenia-bearing strata studied here demonstrates that only the conditions in Isfahan (Chahriseh) are different from other localities (Figs 11-12; inner ramp versus middle ramp). The fragmentary nature of the sea cow fossil in this section (Fig 4a), which includes a single rib (Mirzaie Ataabadi et al. 2014), actually indicate its possible transportation from its original position in account of more energetic depositional environment. This position, with similar conditions to other sections, should be the inner ramp environment, where a shallow warm sea supports the life of sea cows (Berta et al. 2006). Therefore, the more complete preservation of fossils in Hamedan indicates their *in situ* nature and less transportation.

6. Conclusions

The Qom Formation in the studied sections (Shirinsu and Ivak in Hamedan province and Chahriseh in Isfahan province), which contain Sirenia remains, consists of a total number of nine (9) microfacies (a siliciclastic and eight (8) carbonate microfacies). They were deposited in a carbonate-ramp platform with two sub-environments: inner ramp and middle ramp.

The age of the fossil bearing strata is Aquitanian (Chahriseh and Ivak sections) and Burdigalian (Shirinsu section), respectively. This supports a possible transgression of sea from south to north during the deposition of the Qom Formation. The differences in the age indicate that sea cows were present in early Miocene, as long as their favorable environmental conditions (the shallow warm inner ramp environment) were present. These inner ramp environments were rich in red algae and peloids. Our research calls for further investigations in other areas with similar paleoenvironmental conditions for future discovery of sea cow remains.

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References

Abbassi N, Domning DP, Navidi Izad N, Shakeri S (2016) Sirenia fossils from Qom Formation (Burdigalian) of the Kabudar Ahang area, Northwest Iran, *Rivista Italiana Paleontologia et Stratigrafia* 122: 13-24.

Abyat Y, Abyat A, Abyat A (2019) Microfacies and depositional environment of Asmari formation in the Zeloi oil field, Zagros basin, south-west Iran, *Carbonates and Evaporites* 34: 1583-1593.

Adabi MH, Kakemem U, Sadeghi A (2015) Sedimentary facies, depositional environment, and sequence stratigraphy of Oligocene–Miocene shallow water carbonate from the Rig Mountain, Zagros basin (SW Iran), *Carbonates and Evaporites* 31: 69-85.

Adams TD, Bourgeois F (1967) Asmari biostratigraphy of Iran. Oil Operation Co., Geological Exploration Division, Report: 1074, 37p.

Aghanabati A (2004) Geology of Iran, Geological Survey of Iran, Tehran, 586 p. (in Persian).

Amanpour M (2018) Vertebrates paleontology, biostratigraphy and microfacies of Qom Formation at Sorkh Abad region, south-east of Hamedan. Master thesis of Zanjan university (in Persian).

Amir-Shah-Karami M, Naimi M (2016) Biostratigraphy of large benthic foraminifera in Oligocene-Miocene deposits of Qom Formation at Kahak region in Urmieh-Dokhtar, *Stratigraphy and sedimentary researches* 36:91-108 (in Persian).

Avarjani S, Mahboubi A, Moussavi-Harami R, Amiri-Bakhtiar H, Brenner RL (2015) Facies, depositional sequences, and biostratigraphy of the Oligo-Miocene Asmari Formation in Marun oilfield, North Dezful Embayment, Zagros Basin, SW Iran, *Palaeoworld* 24: 336-358.

Babazadeh SA, Ghasemiyan S, Mosadegh H, Shakeri A (2014) Biostratigraphy and Lithostratigraphy Qom Formation from Shahanjarin Section in Garmab City, Zanjan, *Stratigraphy and paleontology researches quarterly* 1:31-39 (in Persian).

Bajpai S, Domning DP (1997) A new dugongine Sirenian from the early Miocene of India, *Journal of Vertebrate Paleontology* 17: 219-228.

Bajpai S, Domning DP, Das DP, Vélez-Juarbe J, Mishra VP (2010) A new fossil Sirenian (Mammalia, Dugonginae) from the Miocene of India. *Neues Jahrbuch Geologie Palentologie* 258: 39-50.

Baratian M, Arian MA, Yazdi A (2020) Petrology and Petrogenesis of Siah Kooh Volcanic Rocks in the Eastern Alborz. *Geosaberes* 11: 349-363

Berta A, Sumich J, Kovacs K (2006) Marine Mammals: Evolutionary Biology, Academic Press, 547 p.

Bianucci G, Landini W, Varola A (2003) New records of *Metaxytherium* (Mammalia: Sirenia) from the late Miocene of Cisterna quarry (Apulia, southern Italy). *Boll. Soc. Paleontol. Ital.*, 42(1-2): 59-63.

Bolourchi MH, Hadjian J (1979) Geological map and explanatory text of Kabudar Ahang Quadrangle 1:250000, Geological Survey of Iran.

Daneshian J, Akhlaghi M (2010) Introduction of new genus and species of benthic foraminifera of Qom Formation in Kaltakeh section, south-east of Mahneshan, *Journal of Stratigraphy and Sedimentology Researches* 39:71-104 (in Persian).

Daneshian J, Shahrabi M, Akhlaghi M (2010) Biostartigraphy and paleoenvironment of the Qom Formation deposits at north-east of Mahneshan, *Geosciences* 19: 45-50 (in Persian).

Domning DP, Pervesler P (2013) The Sirenian *Metaxytherium* (Mammalia: Dugongidae) in the Badenian (Middle Miocene) of Central Europe. *Austrian Journal of Earth Sciences* 105: 125-160.

Dunham RJ (1962) Classifcation of carbonate rocks according to depositional texture. In: Ham WE. (Eds.) Classifcation of carbonate rocks, *American Association of Petroleum Geologist Memoir* 1:108-121.

Eghlimi B (1999) Geological map of Hamedan quadrangle 1/100000, Geological Survey of Iran.

Embry AF, Klovan JE (1971) A late Devonian reef tract on northeastern Banks Island Northwest Territories. *Bulletin of Canadian Petroleum Geology* 19:730-781.

Flügel E (2010) Microfacies of carbonate rocks; Analysis, interpretation and application, Springer, 976 p.

GhasemShirazi B, Bakhshandeh L, Yazdi A (2014) Paleoecology of Upper Cretaceous Sediments in Central Iran, Kerman (Bondar- e Bido Section) Based on Ostracods. *Marine Science* 4 (2): 49-57

Hallock P (2015) Changing influences between life and limestones in earth history. *Coral Reefs in the Anthropocene*:17-42.

Harzhauser M, Kroh A, Mandic O, Piller WE, Göhlich U, Reuter M, Berning B (2007) Biogeographic responses to geodynamics: a key study all around the Oligo- Miocene Tethyan Seaway. *Zoologischer Anzeiger* 246: 241-256.

Inan S, Tasli K, Eren M, Inan N, Koç H, Zorlu K, Taga H, Zorlu K, Arslanbaş O, Demircan F (2008) First finding of *Metaxytherium* (sea cow) in the Miocene limestones of the Erdemli (Mersin) area (S Turkey), *Turkish Geology congress Abstracts* 61: 1-7.

Jalali M, Sadeghi A, Adabi MH (2017) Microfacies, sedimentary environment and sequence stratigraphy of Qom Formation at Chah Yorteh Shah 1 and Mureh Kuh section (South of Tehran), *Journal of Stratigraphy and Sedimentology Researches* 33: 25-48 (in Persian).

Jones B, Desrochers A (1992) Shallow platform carbonates. In: Walker RG, James NP, (Eds.), *Facies Models Response to Sea Level Changes*: 277-303.

Karevan M, Mahboubi A, Vaziri-Moghaddam H, Moussavi-Harami R (2015) Sedimentary facies and sequence stratigraphy of the Qom Formation deposits, NE Delijan, NW Central Iran, *Geosciences* 24:237-248 (in Persian).

Kordos L (1985) The evolution of the Cenozoic Sirenian on the basic of Hungarian fossil remains, *Abstracts of the 8th Congress of Regional Committee of Mediterranean Neogene Stratigraphy, Symposium on European Late Cenozoic Mineral Resources:* 314.

Loeblich A, Tappan H (1987) Foraminiferal genera and their classification. Van Nostrand Reinhold, New York.

Mirzaie Ataabadi M, Orak Z, Paknia M, Alizadeh JM, Gholamalian H, Mojib I, Mirzaie J, Yazdi M (2014) First report of marine mammal remains from the Oligo-Miocene deposits of Central Iran and Zagros basins, *Proceedings of the 8th meeting of the Paleontological Society of Iran*: 124-129 (in Persian).

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

Mohammadi E, Safari A, Vaziri-Moghaddam H, Vaziri MR, Ghaedi M (2011) Microfacies analysis and paleoenviornmental interpretation of the Qom Formation, South of Kashan, Central Iran, *Carbonate Evaporite* 26:255-271.

Mohammadi E, Vaziri MR, and 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), *Arabian Journal of Geosciences* 8:403-423.

Mohammadi E. Vaziri MR. and Dastanpour M. (2014) Microfacies evaluation and sedimentary environment recounstruction of the Qom formation in Sirjan area, southwest Kerman. *Journal of Stratigraphy and Sedimentology Researches*, 30: 35- 54 (in Persian).

Nouradini M, Azami SH, Hamad M, Yazdi M, Ashouri A (2015) Foraminiferal paleoecology and paleoenvironmental reconstructions of the lower Miocene deposits of the Qom Formation in Northeastern Isfahan, Central Iran, *Boletín de la Sociedad Geológica Mexicana* 67:59-73.

Nouradini M, Yazdi M, Ashouri A (2014) Systematic notes on Burdigalian Echinoids from the Qom Formation in the Bagher Abad area, Central Iran, *Geopersia* 4:155-167.

Pomar L (2001) Types of carbonate platforms, a genetic approach, *Basin Research* 13:313-334.

Poorbehzadi K, Yazdi A, Sharifi Teshnizi E, Dabiri R (2019) Investigating of Geotechnical Parameters of Alluvial Foundation in Zaram-Rud Dam Site, North Iran. *International Journal of Mining Engineering and Technology* 1(1): 33-34.

Popov SV, Rögl S, Rozanov AY, Steininger FF, Shcherba IG and Kovac M (2004) Lithological-Paleogeographic maps of the Paratethys. *Courier Forschungsinstitüt Senckenberg* 250:1-46.

Rabbani J, Mirzaie Ataabadi M, Shaahsavari E (2020) Microfacies, sedimentary environmental model and relative sea level change of marly strata of the Qom Formation in Zarrin-Abad section, South of Zanjan. *Journal of Stratigraphy and Sedimentology Researches* 36:115-134 (in Persian).

Rafiee P, Baghbani D (2008) Biostratigraphy of the Qom Formation in Shahnajrin region, south-east of Razan. Proceedings of the 2nd meeting of the Paleontological society of Iran, p. 70-73 (in Persian).

Rahimzadeh F (1994) Treatise on the Geology of Iran; Oligocene, Miocene, Pliocene. Geological Survey of Iran, 311 p. (in Persian).

Reuter M, Piller WE, Harzhauser M, Mandic O, Berning B, Rögl F, Kroh A, Aubry MP, 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. *International Journal of Earth Science* 98: 627-650.

Reza SM, Barry JC, Meyer GE, Martin L (1984) Preliminary report on the geology and vertebrate fauna of the Miocene Manchar Formation, Sind, Pakistan, *Journal of Vertebrate Paleontology* 4: 584-599.

Robbins LL, Knorr PO, Wynn JG, Hallock P (2016) Interpreting the role of pH on stable isotopes in large benthic foraminifera, *ICES Journal of Marine Science* 74: 955-964.

Romero J, Caus E, Rossel J (2002) A model for the palaeoenvironmental distribution of larger foraminifera based on Late Middle Eocene deposits on the margin of the south Pyrenean basin (SE Spain), *Palaeogeography, Palaeoclimatology, Palaeoecology* 179: 43-56.

Sadeghi R, Vaziri-Moghaddam H, Taheri A (2009) Biostratigraphy and paleoecology of the Oligo-Miocene succession in Fars and Khuzestan areas (Zagros Basin, SW Iran), *Historical Biology* 21: 17-31.

Safari A, Ameri H, Vaziri MR, Mohammadi E (2013) Micofacies and sedimentary environment of the Qom Formation at Varakan region (South-West of Kerman) fore-arc basin of Sanandaj- Sirjan, *Paleontology* 1: 187-204, (in Persian).

Seddighi M, Vaziri-Moghaddam H, Taheri A, Ghabeishavi A (2011) Depositional environment and constraining factors on the facies architecture of the Qom Formation, Central Basin, Iran, *Historical Biology* 24:91-100.

Sorbi S (2008) New record of *Metaxytherium* (Mammalia, Sirenia) from the lower Miocene of Manosque (Provence, France), *Geodiversitas* 30: 433-444.

Stephenson CM, Hallock P, Kelmo F (2015) Foraminiferal assemblage indices: a comparison of sediment and reef rubble samples from Conch Reef, Florida, USA, *Ecological Indicators* 48: 1-7.

Thewissen JGM, Bajpai S (2009) A new Miocene Sirenian from Kutch, India, *Acta Palaeontologia Polonica* 54: 7-13.

Wilson JL (1975) Carbonate facies in geological history, Springer.

Wynd JG (1965) Biofacies of the Iranian Oil Consortium Agreement area, Report No. 1082.

Yazdi A, Shahhosini E, Dabiri R, Abedzadeh H (2019) Magmatic differentiation evidences and source characteristics using mineral chemistry in the Torud intrusion (Northern Iran). *Revista Geoaraguaia* 9(2): 1-21.

Yazdi M, Shirazi MP, Rahiminejad AH, Motavalipoor R (2012) Paleobathymetry and paleoecology of colonial corals from the Oligocene-Early Miocene Qom Formation (Dizlu area, central Iran), *Carbonate Evaporite* 27:395– 405.

Yazdi-Moghadam M (2011) Early Oligocene Larger Foraminiferal Biostratigraphy of the Qom Formation, South of Urmieh (NW Iran), *Turkish Journal of Earth Science* 20:847- 856.

Yazdi-Moghadam M, Sadeghi A, Adabi MH, Tahmasbi A (2018) Foraminiferal biostratigraphy of the lower Miocene Hamzian and Arashtanab sections (NW Iran), northern margin of the Tethyan Seaway, *Geobios* 5:231-246.

Zahedi M, Amidi M (1978) Geological map of the Isfahan quadrangle 1/250000, Geological Survey of Iran.