Paleoecology of Lower Miocene coralline red algae-rich grainstone facies in the Qom Formation (Vartun section, central Iran)

Amir Hossein Rahiminejad1, Mehdi Yazdi2, Amit Kumar Ghosh3

ABSTRACT

In this paleoecological study we focused on coralline red algae-rich shoal grainstone facies in the Lower Miocene (Aquitanian) carbonates of the Qom Formation in the Vartun section in central Iran. The identified coralline red algae are mainly non-geniculate, although very rare geniculate forms of corallines were also recognized in thin section analysis. The identified algae are represented by Melobesioidae (Lithothamnion cf. valens, Lithothamnion cf. viaeae, Lithothamnion cf. peleense, and Lithothamnion spp.), Mastophoroideae (Neogoniolithon sp., Spongites spp., and Spongites cf. fruticulosus), Sponolithon spp. (Sponolithon spp. and Sponolithon cf. airoldii), and geniculate coralline (Corallina). The algal taxa mainly display fruticose and lumpy growth forms. The dominance of the former is consistent with high water energy in the identified shoal environment. The presence of Lower Miocene algae indicates that deposition of carbonates took place in warm tropical to subtropical waters in a euphotic marine environment during the Aquitanian. Likewise, high water energy and sediment agitation resulted in taphonomic features such as fragmentation, abrasion, and disarticulation.

Keywords: red algae, rhodophyta, carbonate producers, facies, Miocene, Aquitanian.

RESUMEN

En este estudio paleoecológico se enfocó en las facies grainstone rica en algas rojas coralinas en los carbonatos del Mioceno Inferior (Aquitaniense) de la Formación Qom en la sección Vartun del centro de Irán. Las algas rojas coralinas identificadas en las facies son principalmente no geniculadas, aunque también se caracterizaron formas geniculadas mediante análisis de láminas delgadas. Las algas identificadas están representadas por Melobesioidae (Lithothamnion cf. valens, Lithothamnion cf. viaeae, Lithothamnion cf. peleense, y Lithothamnion spp.), Mastophoroideae (Neogoniolithon sp., Spongites spp., y Spongites cf. fruticulosus), Sponolithon spp. (Sponolithon spp. y Sponolithon cf. airoldii), y por corallinas geniculadas (Corallina). Las taxones de algas muestran principalmente formas grandes y grumosas de fruticose. Donde predomina consistentemente con alta energía del agua en el ambiente arrecifal identificado. La presencia de algas del Mioceno Inferior indica que la exposición de carbonatos tuvo lugar en aguas cálidas tropicales a subtropicales en la zona eufótica marina durante el Aquitaniense. Asimismo, tanto la alta energía del agua como la agitación de los sedimentos, dieron lugar a características tafonómicas tales como fragmentación, abrasión, y desarticulación.

Palabras clave: algas rojas, rhodophyta, productoras de carbonato, facies, Mioceno, Aquitaniense.

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1. Introduction

Coralline red algae were one of the major components of calcareous benthic communities, reef builders, and carbonate producers in the Miocene shallow marine paleoenvironments (Halfar and Mutti, 2005; Braga et al., 2010; Sarkar and Ghosh, 2015; Sarkar et al., 2016). Several of the reported genera of coralline red algae in Miocene deposits encompass still living species and constitute a useful tool for paleoenvironmental interpretations (Braga et al., 2010), since they are good indicators of water depth, temperature, light intensity, and hydrodynamic energy of carbonate paleoenvironments (Bosence, 1991; Aguirre et al., 2000; Brando et al., 2005; Braga et al., 2010).

Generally, the Oligocene–Miocene carbonate paleoenvironments represent the highest diversity of coralline red algae in the geologic record (Aguirre et al., 2000; Braga et al., 2010), with its maximum levels of diversity recorded in the Lower Miocene (Aquitanian) and represented by 245 species (Aguirre et al., 2000; Braga et al., 2010). Mainly, non-geniculate coralline red algae were dominant in the Miocene paleoenvironments, whereas, geniculate corallines were subordinate (e.g. Ghosh, 2002; Rösler et al., 2015; Coletti et al., 2018; Roozpeykar et al., 2019a).

The carbonate facies of the Qom and Asmari formations in central Iran and the Zagros Basin are the principal deposits of Miocene coralline red algae in Iran (Zabihi Zoeram et al., 2014;...
Roozpeykar et al., 2019a). This paper focuses on the paleoecological aspects of Lower Miocene coralline red algae from the Qom Formation and contributes data from the algal-rich Cenozoic carbonates of Iran.

2. Geological Setting

In the present study, samples yielding fossil coralline red algae were collected from the Lower Miocene Qom Formation in the Vartun section (Figures 1 and 2). This section is located about 50 km northeast of the city of Esfahan (32° 56′ 13.79″ N and 52° 08′ 45.32″ E; Figure 1) and is situated in the north of the Esfahan–Sirjan fore-arc basin in central Iran (Figure 1A). The most exposed strata in the studied area comprise Quaternary terraces in addition to Triassic (massive dolomite, dolomitic limestone, limestone, shale), Jurassic (sandy shale, sandstone, conglomerate), and Oligocene–Miocene deposits (Figure 1C). Strata of the Qom Formation were deposited on the northeastern edge of the Tethyan Seaway in the Sanandaj–Sirjan fore-arc basin, and/or Esfahan–Sirjan fore-arc basin, and the Urumieh–Dokhtar magmatic arc basin in central Iran during the last marine transgression in the Oligo–Miocene (Daneshian and Ramezani Dana, 2007; Reuter et al., 2009; Zágoršek et al., 2017).

Generally, the Oligocene and Miocene deposits of the Qom Formation in central Iran consist mainly of limestone, marl, gypsum, and subordinate siliciclastic sediments containing diverse fossil invertebrates represented by corals, gastropods, echinoids, bivalves (particularly pectinids), and coralline red algae (Seyrafian and Toraby, 2005; Reuter et al., 2009; Zágoršek et al., 2017). The age of the Qom Formation in the Vartun section (Figures 1 and 2) is based on previous studies carried out by Rahiminejad et al. (2020) (Figure 3).

3. Materials and Methods

The investigation of fossil coralline red algae and their associated facies or sedimentary texture was based on microscopic analyses of thin-section slides from thirty rock samples of algal limestone that were examined with a Stereo binocular Microscope model Yaxun YX AK21 and photographed using a CCD digital camera model KECam. The classification of carbonate facies followed that of Dunham (1962) and Flügel (2010), which is based on the types and abundance of grains and the matrix in the deposits. Taxonomic analysis of the identified coralline red algae was based on Braga (2003), Brandano and Piller (2010), and Sarkar (2017). Coralline red algal growth forms were described according to Woelkerling et al. (1993), and Nebelsick and Bassi (2000).

Since the collected algal specimens in the studied section are present as bioclasts and partially preserved fossils, confirmation of taxa at the species level cannot be accurately established. However, detailed statistical analyses on well-preserved algal samples may improve paleoecological interpretation in future studies.

The age of the Qom Formation in the Vartun section (Figures 1 and 2) is based on previous studies carried out by Rahiminejad et al. (2020) (Figure 3).

4. Results

4.1. STRATIGRAPHY AND FACIES ANALYSIS OF THE STUDIED ALGAE-RICH LIMESTONE

We focused our paleoecological studies on a 1 m thick interval of Lower Miocene (Aquitanian)
RESULTS

Figure 2: Measured stratigraphic column of the Qom Formation in the Vartun section. Age of the Qom Formation in the section is based on Rahiminejad et al., 2020. Our studies focused on a 1 m-thick interval algal limestone comprising coralline red algae-rich grainstone. The symbols illustrating the growth forms of the identified algae are redrawn and modified from Woelkerling et al., (1993), and Nebelsick and Bassi (2000). The percentage or relative abundance of different algal growth forms in the studied grainstone facies is as follows: fruticose: 70 %, lumpy: 20%, foliose, encrusting, and arborescent: 10%.
RESULTS

Figure 3 Some of the identified large benthic foraminifera used for age determination of the Qom Formation in the Vartun section (Rahimnejad et al., 2020). (A) Lepidocyclus sp., (B) Nephrolepidina sp., (C) Eulepidina sp., (D) Operculina spp., (E) Miogypsina sp., (F) Amphistegina sp. Note that these microfossil specimens were not collected from the algal grainstone facies in this study.
massive and lithified coralline red algae-rich limestone in the Qom Formation (Figures 2 and 4). The stratigraphic details of the Qom Formation in the studied section are shown in Figure 2. In the field, the limestone interval (Figures 2 and 4) is laterally exposed up to ca 70 m, is discontinuous, and untraceable in a wide area. Cylindrical *Skolithos* burrows are common and fossils of bivalves (*pectinids*), gastropods (*Conus, Natica, and Pleurotomaria*), and echinoids (*Clypeasteroids*) are abundant in the interval (Figure 2). Likewise, the limestone interval is composed of coralline algae-rich grainstone facies dominated by skeletal grains embedded in a sparitic matrix or sparry cement (Figures 5A and 5B). The latter (65%) include coarse-grained bioclasts and partially preserved specimens of abundant coralline red algae. Coarse-grained bioclasts of corals, echinoids, gastropods, and bivalves (22%) as well as scarce (13%) larger benthic foraminifera (*Nephrolepidina* sp., *Amphistegina* sp., and miliolids) comprise the subordinate skeletal grains.

4.2. THE IDENTIFIED CORALLINE RED ALGAE AND THEIR GROWTH FORMS

The micropaleontological studies revealed the presence of five genera of coralline red algae in the studied grainstone facies (Table 1 and Figures 5 to 8). Non-geniculate forms of the identified algae predominate (Table 1), whereas algae representative of geniculate forms (genus *Corallina*) are scarce. Several of the non-geniculate algae are highly fragmented and abraded, while geniculate forms are disarticulated and fragmented. The
percentage or relative abundance of the algae is indicated in Table 1. The non-geniculate algae include melobesioids, mastophoroids, and sporolithaceans (Table 1). Melobesioids comprise the taxa *Lithothamnion cf. valens*, *Lithothamnion cf. roveiroi*, *Lithothamnion cf. peleense*, and *Lithothamnion* spp. Mastophoroids are represented by the taxa *Neogoniolithon* sp., *Spongites cf. fruticulosus*, and *Spongites* spp. Sporolithaceans include the taxa *Sporolithon* spp., and *Sporolithon cf. airoldii*.

In the studied grainstone facies, the identified coralline red algae mainly display fruticose (70%) and lumpy (20%) growth forms (Table 1). Algae with foliose, encrusting, and arborescent growth forms are also present (Table 1), although subordinately (10%).

5. Discussion and interpretation

5.1. PALEOECOLOGY OF THE IDENTIFIED CORALLINE RED ALGAE

The dominance of a sparitic matrix or sparry cement in the identified algal grainstone facies and the abundance of bioclasts and skeletal grains

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Figure 5  (A, B) Algal grainstone facies. (C–F) Identified coralline red algae in grainstone facies; (C) Fruticose thallus of *Spongites* sp.; (D) Lumpy thallus of *Spongites cf. fruticulosus*; (E, F) Lumpy thalli of *Sporolithon cf. airoldii*.
point to a shoal environment (in an inner ramp) in a high-energy water zone above the fair-weather wave base during the Aquitanian (Flügel, 2010; Sadeghi et al., 2011; Vescogni et al., 2014; Roozpeykar et al., 2019b).

The presence of Skolithos burrows in the algal grainstone-bearing limestone indicates high hydrodynamic (water) energy (Vinn and Wilson, 2013; Sedorko et al., 2018). Further details on the depositional environment of the Lower Miocene deposits of the Qom Formation in the Vartun section have been provided by Rahiminejad et al. (2020), whose results confirm our environmental interpretation.

The co-occurrence of melobesioids (Lithothamnion), mastophoroids (Neogoniolithon, Spongites), and Sporolithon may be representative of the basinward part of the shoal environment, although a number of these algae could have been reworked and transported in the shoal environment.

Usually, the occurrence of coralline red algae in a grainstone facies is related to nutrient influx due to encroachment of siliciclastic (Erlich et al., 1990, 1993; Roozpeykar et al., 2019a). For instance, Ghosh and Sarkar (2013) have reported a grainstone facies comprising an algal association of Corallina, Lithothamnion, and Spongites from Pliocene reef and back-reef shelf environments as well as a melobesioid coralline algal assemblage of Phymatolithon, Mesophyllum, and Lithothamnion from a coralline algal boundstone in a Pliocene fore-reef environment. Roozpeykar et al. (2019a, 2019b) have studied a coralline red algae-rich grainstone in a Miocene shoal environment in the Zagros Basin and have reported non-geniculate (dominant Spongites and reworked melobesioids) and geniculate algae (Corallina).

Generally, coralline red algae were one of the major and most abundant biotic components of photozoan and heterozoan communities of Oligocene–Miocene cool waters (non-tropic) and tropical carbonates (Bassi and Nebelsick, 2010; Braga et al., 2010). Mastophoroids (specifically Spongites) are common in shallow tropical carbonates (Adey et al., 1982; Braga and Aguirre, 2001, 2004), but are also present in subtropical and temperate environments. Some genera (e.g. Lithothamnion and Mesophyllum) of the subfamily Melobesioidae

<table>
<thead>
<tr>
<th>Algae: percentage (relative abundance)</th>
<th>Genera / species</th>
<th>Growth form</th>
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<tbody>
<tr>
<td>Non-geniculate</td>
<td></td>
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<tr>
<td>Melobesioids: 60%</td>
<td>Lithothamnion cf. valens</td>
<td>Fruticose</td>
</tr>
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<td></td>
<td>Lithothamnion cf. rovereti</td>
<td>Lumpy</td>
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<td></td>
<td>Lithothamnion cf. peleense</td>
<td>Fruticose</td>
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<td></td>
<td>Lithothamnion spp.</td>
<td>1–Encrusting</td>
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<tr>
<td>Mastophoroid: 25%</td>
<td>Neogoniolithon sp.</td>
<td>Foliose</td>
</tr>
<tr>
<td></td>
<td>Spongites spp.</td>
<td>Fruticose</td>
</tr>
<tr>
<td></td>
<td>Spongites cf. fruticulosus</td>
<td>Lumpy</td>
</tr>
<tr>
<td>Sporolithaceans: 10%</td>
<td>Sporolithon spp.</td>
<td>Lumpy</td>
</tr>
<tr>
<td></td>
<td>Sporolithon cf. airolidii</td>
<td>Lumpy</td>
</tr>
<tr>
<td>Geniculate</td>
<td>Corallina: 5%</td>
<td>Arborescent</td>
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<tr>
<td>Corallina</td>
<td>Corallina</td>
<td>Arborescent</td>
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occur in both temperate and warm conditions (Braga and Aguirre, 2001; Halfar and Mutti, 2005; Bassi et al., 2009; Braga et al., 2010; Brandano and Piller, 2010; Rösl er et al., 2015; Roozpeykar et al., 2019a, 2019b). Also, sporolithaceans (*Sporolithon*) are common in tropical deposits (Brandano et al., 2005). Coralline red algae can survive in different trophic conditions ranging from oligotrophic to mesotrophic environments in different latitudes (Braga et al., 2010). The main paleoecological factors controlling their growth and development in benthic marine environments include depth, hydrodynamic energy, chemical composition, light intensity, and temperature of marine waters (Sarkar, 2017). The different growth forms of coralline red algae are useful tools in paleoecological interpretation of marine carbonate facies (Bosence and Pedley, 1982; Braga and Martin, 1988; Braga and Aguirre, 2001; Rasser and Piller, 2004; Brandano et al., 2005; Brandano and Ronca, 2014) and include warty, lumpy, fruticose, foliose, encrusting, layered (non-geniculate), and arborescent (geniculate) (Woelkerling et al., 1993; Nebelsick and Bassi, 2000).

![Image](image-url)

**Figure 6** Identified coralline red algae in the grainstone facies. (A) Fragment of *Sporolithon* sp. showing a lumpy growth form. (B) Fragment of a fruticose thallus of a melobesioid. (C) Foliose thalli of *Neogoniolithon* sp. (D) Fragment (disarticulated) of *Corallina* sp. with an arborescent growth form. (E) Fragment of a fruticose thallus of *Lithothamnion cf. valens*. 
As evidenced in this study, the dominance of coralline red algae with fruticose growth forms (Table 1) in the shoal carbonate environment is consistent with high water energy (Bosence, 1991; Basso, 1998; Nebelsick et al., 2000). Agitation in the shoal environment, resulted different taphonomic features such as high fragmentation, disarticulation, and abrasion of several algae (Nebelsick et al., 2000; Nebelsick and Bassi, 2000; Roozpeykar et al., 2019a, 2019b). The identified algae (Table 1 and Figures 5–8) and the presence of larger benthic foraminifera point to a well-illuminated euphotic marine zone (Vescogni et al., 2014; Roozpeykar et al., 2019a, 2019b). The overall recognition of algae indicates that the Lower Miocene grainstone was deposited in warm tropical to subtropical waters (Bosence, 1983a, 1983b; Braga and Aguirre, 2001; Brandano et al., 2005; Roozpeykar et al., 2019a). Moreover, tropical conditions can be inferred owing to the presence of skeletal grains of corals and larger benthic foraminifera such as miliolids, Amphistegina, and Nephrolepidina in the studied grainstone facies (Pomar et al., 2004; Brandano et al., 2009; Roozpeykar et al., 2019a, 2019b).
6. Conclusions

The Lower Miocene (Aquitanian) algal-rich grainstone facies of the Qom Formation of Esfahan–Sirjan basin in central Iran is characterized by non-geniculate coralline red algae represented by melobesioids, mastophoroids, and sporolithaceans. The distribution of coralline red algae in the grainstone facies is probably linked to nutrient influx and the dominance of the fruticose growth form is indicative of high-energy conditions in a shoal environment. Due to the dominance of algae in well-illuminated waters, it may be concluded that the studied facies was deposited in the euphotic marine zone, and the Lower Miocene algal forms were inhabited in warm tropical to subtropical waters during the Aquitanian, having high-energy conditions, (i.e. increased hydrodynamic activity coupled with sediment agitation) that led to enhanced fragmentation, abrasion, and disarticulation of many algal forms recorded herein.

Contributions of authors

Amir Hossein Rahiminejad: conceptualization, analysis, and data acquisition, methodology, writing of the original manuscript, graphic design, fieldwork, interpretation, financing (applicant). Mehdi Yazdi: conceptualization, fieldwork. Amit Kumar Ghosh: correction and edition of the manuscript, contributed with paleontological interpretation and confirmation of fossil taxa.
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Conflicts of interest

The authors have no conflicts of interest to declare.

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