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RESEARCH PAPER

Coralline Red Algae and Microfacies studies as environmental indicators: A case study from the Gharamul formation, Gulf of Suez Region, Egypt

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Abstract
The systematic studies and taxonomic investigations carried out on the Early Miocene Gharamul Formation exposed in Gebel Abu Shaar El Qabili plateau, western side of the Gulf of Suez region, led to the recognition of twelve coralline algal species belonging mainly to five genera of three subfamilies (Mastrophoroideae, Lithophylloideae, and Melobesioideae) of Rhodophyta (Corallinaceae). The geniculate coralline algae are relatively scarce and represented by a single genus *Corallina* sp. The Mastophoroids (*Neogonilithon* and *Spongites*) and Lithophylloids (*Lithophyllum*) are more dominant coralline algal species and dominate the shallower coralline algal assemblages. On the other hand, Melobesioids (*Mesophyllum* and *Lithothamnion*) and sporolithales (*Sporolithon*) are the most abundant components and diverse in the deeper-water assemblages. The Gharamul Formation (Burdigalian) consists of a thick carbonate□clastics succession. The lower part consists of a cyclic sequence of laminated, fossiliferous and argillaceous limestone intercalated with mudstone, and sandstones. It is documented that the clastic microfacies have good reservoir quality in the region due to the impacts of dissolution and fracturing diagenetic processes. The carbonate microfacies are impervious due to the effects of cementation, and micritization. The dominance of coralline algae and larger benthic foraminifera indicate deposition in the photic zone. Frequent oscillation of lower-energy (foraminiferal wackestones) with higher-energy (grain-supported grainstones, packstones and rudstone) suggest the likely incidence of cyclones/storms during the depositional time.

Keywords: Coralline Algae, Gharamul Formation, Miocene, Gebel Abu Shaar El Qabili, Gulf of Suez, Egypt.

Introduction

There are little studies pertaining to the coralline red algae, benthic foraminifera, the biofacies and paleoenvironmental analyses of the Early Miocene in the Gharamul Formation outcropping in Gebel Abu Shaar El Qabili, western side of the Gulf of Suez, Egypt (Fig. 1). The Early Miocene was relatively neglected even though it represents a significant part of the stratigraphic sequence dealing with an await discovery of petroleum resources of the western side of the Gulf of Suez region and evaluates oil exploration in the Gulf of Suez region.

The Gulf of Suez, considered as the most important prolific area in Egypt, produces more than 75% of Egyptian oil production (EGPC, 1996). The reservoir quality and microfacies of the Lower Miocene in the Gulf of Suez has been studied in detail for many decades (Barakat et al., 2015; El□Khadragy et al., 2017; Nabawy and Barakat, 2017; Nabawy et al., 2018 and

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Sallam et al., 2019).

Recently, Nabawy et al. (2019) documented that the clastic microfacies of Aquitanian□Burdigalian Rudeis Formation in the Gulf of Suez (equivalent to Abu Gerfan and Gharamul formations of the present work) have good reservoir quality in the October Field and poor quality in Wadi Wasit. This is due to the impacts of dissolution and fracturing diagenetic processes. The carbonate microfacies are impervious due to the effects of cementation, mechanical compaction, and micritization. it is important to study the sedimentary rocks in the area utilizing petrographic and paleontological data from field and laboratory observations.

The corallines have a thallus that calcifies early which allows them to be readily preserved as fossils. They grow as crustose or arborescent forms. The crustose forms can form rhodoliths, free-living, unattached
nodules consisting predominantly of superimposed thalli of calcareous red algae (Bosence 1983; Foster et al. 1997; Marrack 1999).

Coralline algae are among the main producers of sediment in photic carbonate factories. They are important contributors to Cretaceous, Paleocene and Eocene platform deposits, and become dominant especially on Oligo-Miocene carbonate ramps (Carannante et al. 1995; Pedley 1998; Aguirre et al. 2000; Halfar and Mutti 2005; Aguirre et al. 2007).

The fundamental aim of this study is; 1) to describe the microfacies types of the studied section about the Gharamul Formation, 2) to present brief systematic description on the distribution and abundance of the major coralline red algae and benthic foraminifera and 3) to decipher the main depositional paleoenvironments prevailed during of the deposition of Gharamul Formation.

Materials and Methods

Four outcrop sections were examined in detail in the field and one major composite section was compiled and presented (Fig. 2).

Figure 1. Google Earth image showing the location of the studied Gebel Abu Shaar El Qiblie

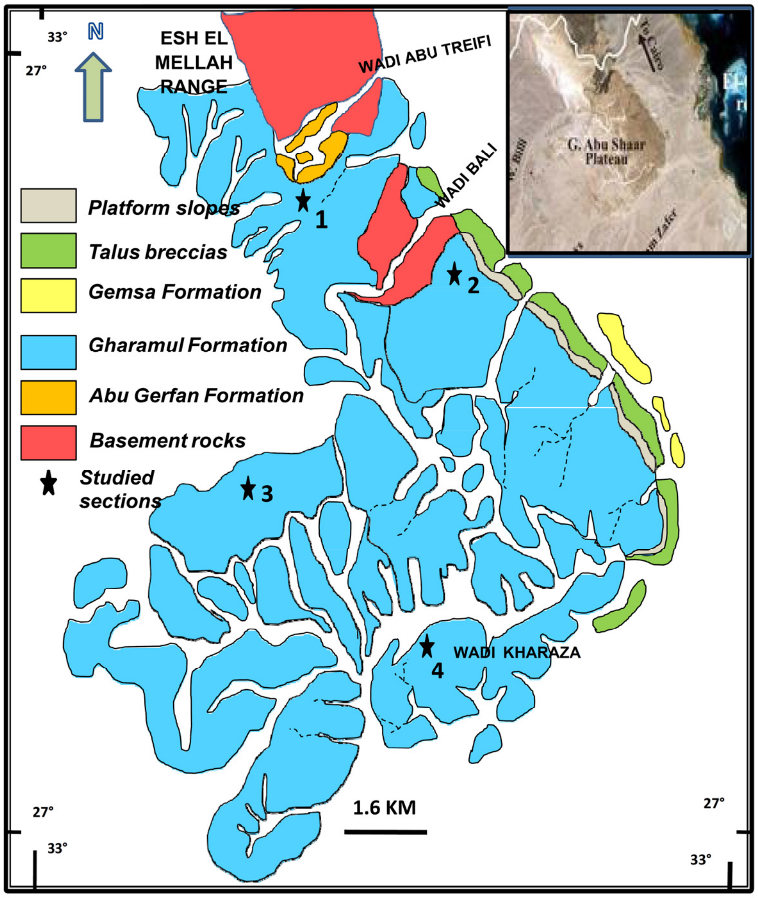

Figure 2. Simplified Geological Map Showing the Different Miocene formations and the Studied Sections in Gebel Abu Shaar El Qibli Plateau, Westrn Side of the Gulf of Suez, Egypt (Modified After Ahmed & El-Aaser, 1994)

About 80 samples of mostly carbonate rocks (notably, limestone) and a few mixed siliciclastic-carbonates (marly limestone and sandy limestone were collected from four outcrops throughout the Early Miocene (Burdigalian) coralline algal limestones of the Gharamul Formation, Gebel Abu Shaar El Qabili, Western side of the Gulf of Suez region, Egypt. (Fig. 2). All samples were collected at a maximum interval of 2m; within lithologic facies changes the samples were more closely spaced. The majority of the hard samples collected were subsequently processed for thin-section preparations, with several lithologies being documented. The microfacies characteristics were described from thin sections in 40 samples. The reorganization of carbonates microfacies is the basis of the nomenclature of Folk (1959); Dunham (1962); Wilson (1975) and Flügel (2010). Analyses have allowed the interpretation of carbonate marine environments, depositional system tracts, sea-level changes and stratigraphic architectures of Gharamul Formation in the study

For algal identification, the cell and conceptacle dimensions were measured according to the latest method proposed by Woelkerling et al. (1993), Aguirre and Braga (1998), Rasser and Piller (1999), Nebelsick and Bassi (2000), Maneveldt et al. (2008), Basso et al. (2008, 2015) and Kundal (2011) have been applied in the present study. Measurements were made by a microscope at the magnification of 500x to the nearest 1μm. The terms of the diagnostic anatomical and taxonomic features of Woelkerling (1988) and the growth forms Woelkerling et al. (1993) are adopted in the present work.

Seventeen samples of soft lithologies were crushed and disaggregated by the hydrogen peroxide solution and washed through a 63-µm sieve. Particular attention was given to the foraminiferal specimens, as they are the main group in the study material. Only a few dozen small and large benthic foraminifera per sample showing good preservation were picked, identified and stored in cardboard slides. The thin sections are stored in the Cairo University, Faculty of Science, Geology Department, Egypt. The relative abundance of calcareous algae and benthic foraminifera were estimated in thin-section by image analysis and measuring the proportional area occupied by each taxon relative to the total biogenic population (Perrin et al. 1995).

Geological setting

The Miocene rocks are exposed in the study area as small outcrops at Gebel Abu Shaar El Qabili, as low-lying hills scattered in the Quaternary deposits. The Miocene rocks in the study area are mainly represented by the elevated rectangular plateau of Gebel Abu Shaar El-Qibli (100 km2) at the southern limit of the Precambrian horst block of the Esh El Mellaha range (Fig. 2).

The Gebel Abu Shaar El Qiblie is located to the south of the Pre-Cambrian volcanic of the Esh El Mellaha Range that borders the southwestern part of the Gulf of Suez. The Esh El Mellaha Range is a part of horsts and grabens paralleling the principal downthrown block of the Gulf (Cofer et al. 1984). This range is tilted in the Early Miocene toward the southwest to produce half-graben in the front of the northern Red Sea hills (Burchette 1986). The volcanic rocks of Esh El Mellaha Range are bordered by Cretaceous and Eocene rocks on the western side, while the eastern and southern sides are bordered by Miocene rocks. The Pre-Cambrian Basement rocks are exposed beneath the Miocene sedimentary cover, especially in the northern part of the Gebel Abu Shaar El Qiblie plateau, after cross-cutting the Miocene rocks by a series of W-E drainage wadies.

El-Haddad et al. (1984) studied the Miocene rocks of Gebel Abu Shaar and identified three principal facies, they are arranged as follow: 1) platform interior facies located on the plateau and consists of chalky dolomites, carbonates, silicates, algal domes, green sandy marls and sandstones, 2) platform edge facies along the eastern periphery and consists of dolomitized mudstones, wackestones, packstones and boundstones, and 3) talus facies, spectacular, steeply inclined beds along the eastern margin, and composed of two distinct units; the lower one is purely carbonated rich in mollusks, coral, stromatolitic domes and the upper is essentially dolomitic with subordinate sandy green marls and sandstones and its bedding is very irregular and locally slumped.

The Egyptian General Petroleum Corporation "EGPC" (1964) divided the non-marine Miocene and coastal facies of Ghorab and Marzouk (1967) into four main formations from base to top as follows; Abu Gerfan, Gharamul, Gemsa and Sarbut El-Gamal formations, respectively. Also, they added that Abu Gerfan and Gharamul formations are the coastal equivalents of Gharandal Group, while Gemsa and Sarbut El-Gamal formations are the marginal equivalents of the Ras Malaab Group (Table 1). According to the classification of "NSSC" (1974), the Miocene rocks exposed at Gebel Abu Shaar El Qabili area are represented by three distinct formations from base to top; Abu Gerfan, Gharamul and Gemsa (Fig. 3). These formations were adopted and described in details in Gebel Abu Shaar by Ahmed and El-Aaser (1994), so in the present study, the present authors focused their work on Gharamul Formation only.

Stratigraphy

The Miocene rocks at Gebel Abu Shaar and along the Gulf of Suez are subjected to many authors (e.g., Cofer et al., 1984; El Haddad et al., 1984; Aissaoui et al., 1986; Hosny et al., 1986; Burchette, 1986; Coniglio et al., 1988, 1996; James et al., 1988; Purser et al., 1990; Purser and Philobbos 1993; Ahmed and El Aaser, 1994; Coniglio et al., 1996; El Azabi, 1996; Shaaban, 1997; Clig et al., 1998; Cross et al., 1998; El Haddad, 2003). The study of the vertical variation in the sedimentary facies of the Early Miocene Gharamul Formation is necessary, where no satisfactory classification of these sediments exists. (Darwish and EL-Azabi, 1993; Ahmed and El-Aaser 1994; Mansourand and Abd-Ellatif, 2013) reported the Miocene rocks exposed at Gebel Abu Shaar area, which represented by three distinct formations from base to top; Abu Gerfan, Gharamul and Gemsa. These formations were adopted and described in detail in Gebel Abu Shaar El Qibli to a thorough knowledge of various aspects of the Miocene geology and understanding the structural evolution of the western side of the Gulf of Suez region.

Based on coral faunas, the Miocene age was given for Gebel Abu Shaar by Gregory (1906) and Hume (1916). Rouchy et al. (1983) noted that two main types of sediments comprising Gebel Abu Shaar area; the carbonate sediments building up the rocky plateau and evaporites deposited around the plateau foot slopes.

The Gharamul Formation of Ghorab and Marzouk (1967) is represented by reefal coralline alga limestones that overlain Abu Gerfan Formation and underlain Gemsa Formation (Fig. 3). Gharamul Formation varies in thickness from 50 to 110m at Gebel Abu Shaar and shows lateral variations. It is mainly composed of algal dolostone with few clastic beds. Ahmed and El-Aaser (1994) subdivided the carbonate facies of Gharamul Formation into two main facies; platform edge and platform interior, where these two facies are equivalent to the facies described by El-Haddad et al. (1984). Platform edge facies: the horizontal and inclined carbonate beds of the platform edge facies are located along the eastern and southeastern edges of Gebel Abu Shaar and composed of coralline reef lenses and shallow platform slope deposits. The entrance of Wadi Kharaza and the eastern margin of Wadi Billi (Fig. 2) is the most perfect occurrences of the exposed coral reef bodies in the study area.

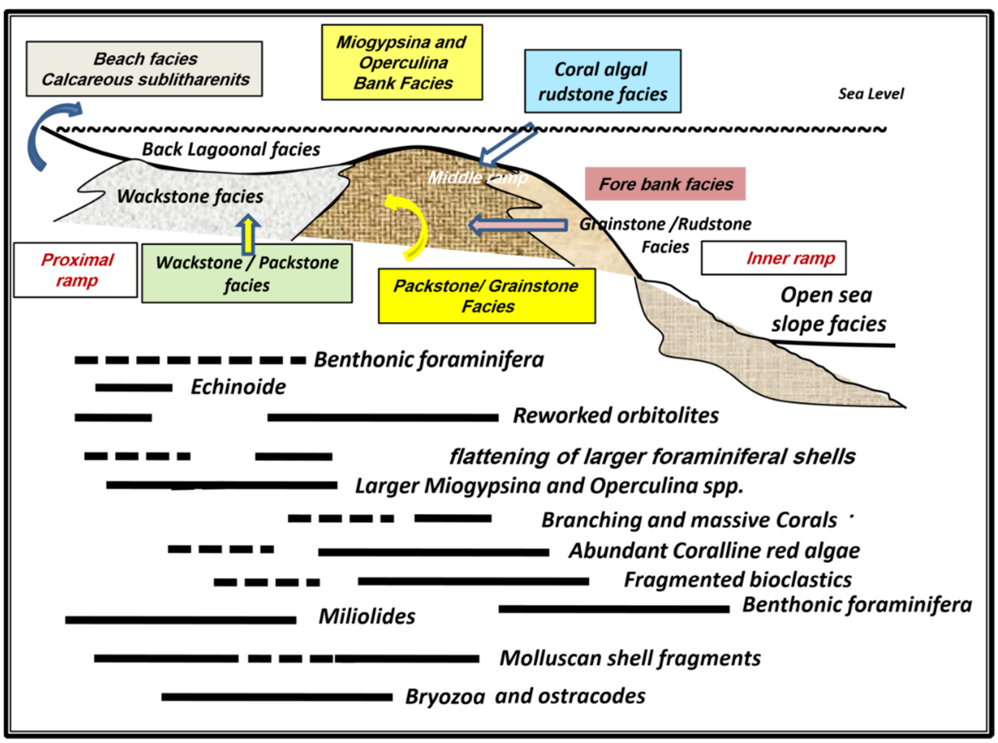

Figure 3. Schematic reconstruction of the Early Miocene Facies Pattern of the Gharamul Formation, in Gebel Abu Shaar El Qibli Plateau, Western Side of the Gulf of Suez, Region (Not to Scale)

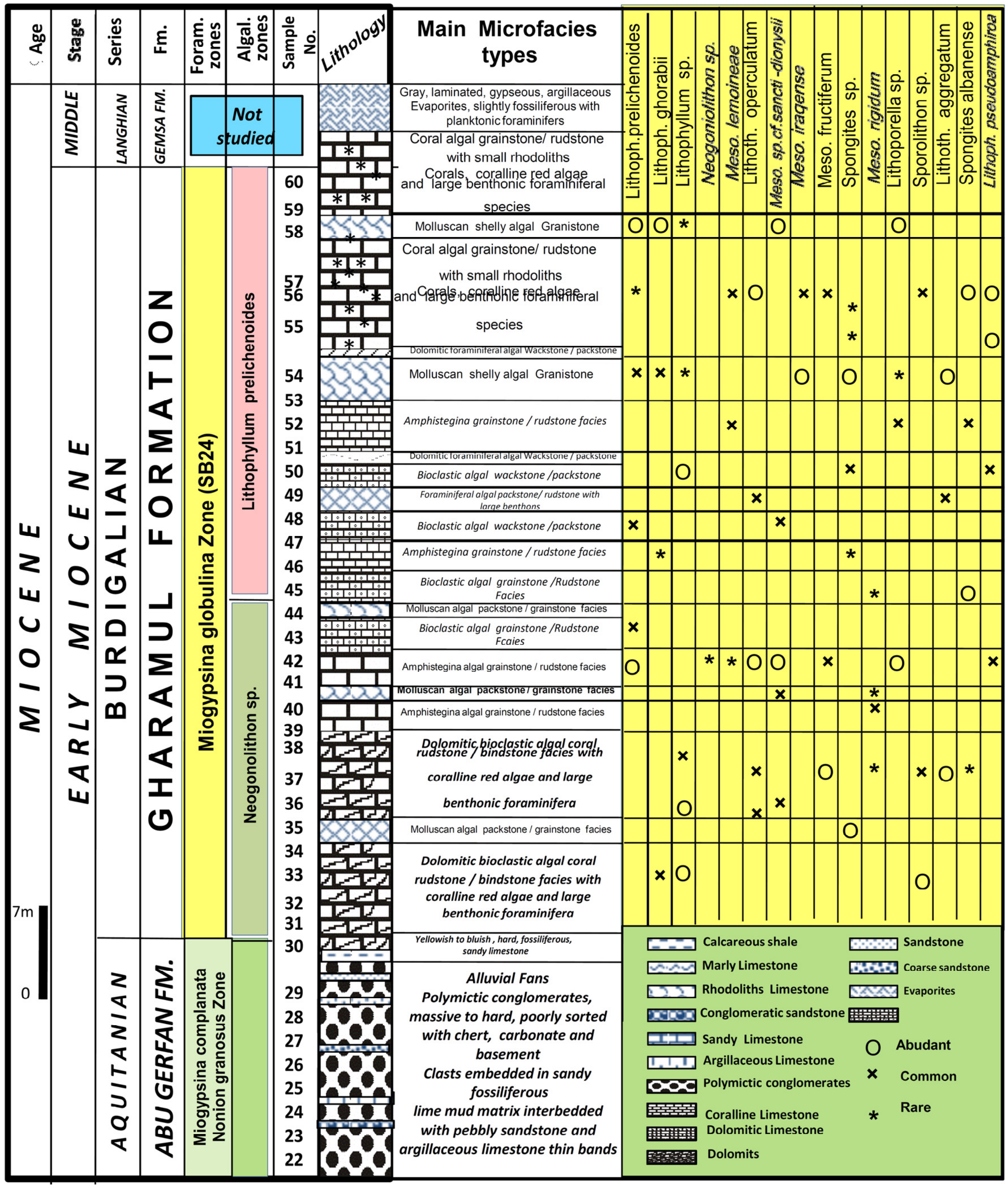

Figure 4. Stratigraphic section of the Early Miocene Gharamul Formation showing distribution of the Coralline Red Algae at Gebel Abu Shaar El Qibili, eastern side of the Gulf of Suez, Egypt

The coral reef beds reach up to 6m thick approaching laterally the form of broad lenses embedded in bioclastic dolostones (Ahmed & El-Aaser, 1994). Platform interior facies: volumetrically this microfacies is the most important one. It comprises sequences up to 100m thick made up of bedded fossiliferous and/or nonfossiliferous dolostones, sandstones and green shales. The platform interior facies, especially along both sides of Wadi Billi and W. Kharaza is rich in burrowing pelecypods such as Pectinids and Lucinids (Ahmed & El-Aaser, 1994).

Systematic paleontology of the main coralline algal taxa

In the following paragraphs, the main characteristic coralline algal species that characterize every morphological type will be discussed from their arrangement and characters of the core filaments and peripheral filaments (shape of cells and their arrangement), the shape of the reproductive organs (conceptacles and sporangia) and different growth forms for algal thalli.
The terminology according to the revision of Woelkerling, 1988 using "core filaments "instead of "hypothallus" and "peripheral filaments" instead of "perithallus" is adopted. Moreover, the taxonomic features of Braga et al. 1993 and the different growth forms of Woelkerling et al, 1993 and Kumar et al. 2014 are adopted in the taxonomy and identification of the present fossil material.

Division: Rhodophyta Wettstein, 1901
Class: Rhodophyceae Rabenhorst, 1863
Order: Corallinales Silva & Johansen, 1986
Family: Corallinaceae Lamouroux, 1816
Subfamily: Lithophylloideae (Setchell, 1943)

Diagnosis: Cells of contiguous filaments are normally joined only by secondary pit connections. Cell fusions are rare or absent. All types of conceptacles are uniporate (Woelkerling, 1988; Braga and Aguirre, 1995, 2001 and Rosler et al., 2015).

Genus *Lithophyllum* Philippi, 1837

Diagnosis: Thallus is a dimerous or dimerous and secondary monomerous in one plant. Primigenous cells are predominantly non-palisade (Braga and Aguirre, 1995). Thallus margin is multistratose (Chamberlain, 1991). The Thallus is a dimerous and secondary monomerous in one plant. Primigenous cells are predominantly non-palisade (Braga and Aguirre, 1995). Thallus margin is multistratose (Chamberlain, 1991). This type of arrangement is easy to distinguish from those subfamilies Mastrophoroideae and Melobesioideae both in the thin sections and in the SEM techniques (Bassi, 1995, 1998). In these later subfamilies, cell fusions interconnecting adjacent filaments can be observed and the tissue has a spongy appearance with irregularly shaped and sized cells. In the following is the main *Lithophyllum* recorded in the studied materials:

Lithophyllum ghorabi Souaya, 1963.
(Fig 6, No. 8)

See Hamad (2008c, 2009) and Hamad et al. (2015) for synonyms
Description: Branching form varying in thickness from 590–770 µm, the core filaments are thick (180–320 µm thick) composed of regular coaxial rectangular cells measuring 11- 29 µm in diameter and 20–44 µm in length where the cells become smaller toward the peripheries. The peripheral filaments (300- 430µm in thickness) composed also of rectangular cells measuring 25–34 µm in length and 10-19µm in diameter. The specimen under consideration resembles some extent the thalli of Souaya (1963a) and Hamad (2008a, b) but differs in that it has not reproductive organs (Conceptacles).

Lithophyllum pseudoamphiroa Johnson, 1964
(Fig. 5, No.3 and Fig. 6, No. 1)

See Hamad (2008c, 2009) Hamad et al. (2015) for synonyms

Description: Dimerous thalli show encrusting and commonly encrusts the other bioclastic constituents, unconsolidated growth-forms. The primigenous filaments are formed by squarish to rectangular cells which measure10-16 µm in length and 12-20 µm in diameter. Postigenous filaments are well developed and formed by quadrangular cells. The cells are 9-15 µm in length and 8-17 µm in diameter. Cell fusions are absent. Tetra/bisporangial conceptacles are uniporate and measure 90-180 µm in height and 250-410 µm in diameter. Cells in the conceptacle roof measure 17-23 µm in length and 9-13 µm in diameter. Epithallial cells are not observed.

Lithophyllum prelichenioides Lemoine, 1917
(Fig. 5, No.1)

See Hamad (2008c, 2009) for synonyms
Description: crustose to long branched forms composed of uniform core filaments and variably thick peripheral filaments. The core filaments composed of regular coaxial cell rows. These cells are 10–13 µm in length and 15–19 µm in diameter. The peripheral filaments consist of rectangular cells. Cells are 15–23 µm in length and 13–17 µm in diameter. Conceptacles are not observed in the studied materials.

Lithophyllum simplex Johnson, 1964
(Fig. 5, No .8)

See Hamad (2008c, 2009) for synonyms
Description: Thallus is layered and reaches 450µm in thickness. Core thickness is between120 and 240µm. Cores are coaxial with the good lateral alignment of filaments in parts of the plant. Cells are of thick-walled, measuring 19–23 µm in length and 10–13 µm in diameter, arranged in regular rows of fan–like appearance. Cell fusions are common. Lateral alignment in the perithallus is poor due to the highly variable cell height. Conceptacles commonly occur in groups of three or more in lateral alignment. Bi-/tetrasporangial conceptacles are small, oval in shape and conceptacle roofs are several cells and usually concave. Conceptacle walls that are raised above the thallus surface in many cases are not thicker than the roof.

Subfamily Mastrophoroideae Setchell, 1943
Genus *Lithoporella* (Foslie) Foslie, 1909

Woelkerling, 1988; Rasser and Piller, 1999 stated that this genus was characterized by non-endophytic dimerous thallus that lacks haustoria, primigenous filaments composed of palisade cells, thallus 2–3 (5) cells thick, tetra / bisporangial conceptacles lack columella, conceptacles roof formed by filaments interspersed between sporangia, pstigenous filaments are restricted to branching zones and conceptacles. Braga et al. (1993) characterized *Lithoporella* by a thin thallus and multiple overgrows of large primigenous cells. This genus is well recorded in the studied materials commonly overgrows the fragmented corals, bryozoa and other shell fragments. It is easily identified by it its unistratose thallus with large cells.

Lithoporella melobesioides (Foslie) Foslie, 1909
(Fig. 5, No. 6, 7)

See Hamad (2008c, 2009) and Hamad et al. (2015) for synonyms
Description: Thick unistratose thallus of multilayered (multiple overgrowths), representing the basal primigenous filaments. The crusts are superimposed on each other, every single layer consisting of large rectangular palisade cells except around the conceptacles where the thalli

are thick. Cells are 42 - 58 µm in length and 14–23 µm in diameter. The conceptacles are circular measuring 80–120 µm in height and 70–130 µm in diameter.

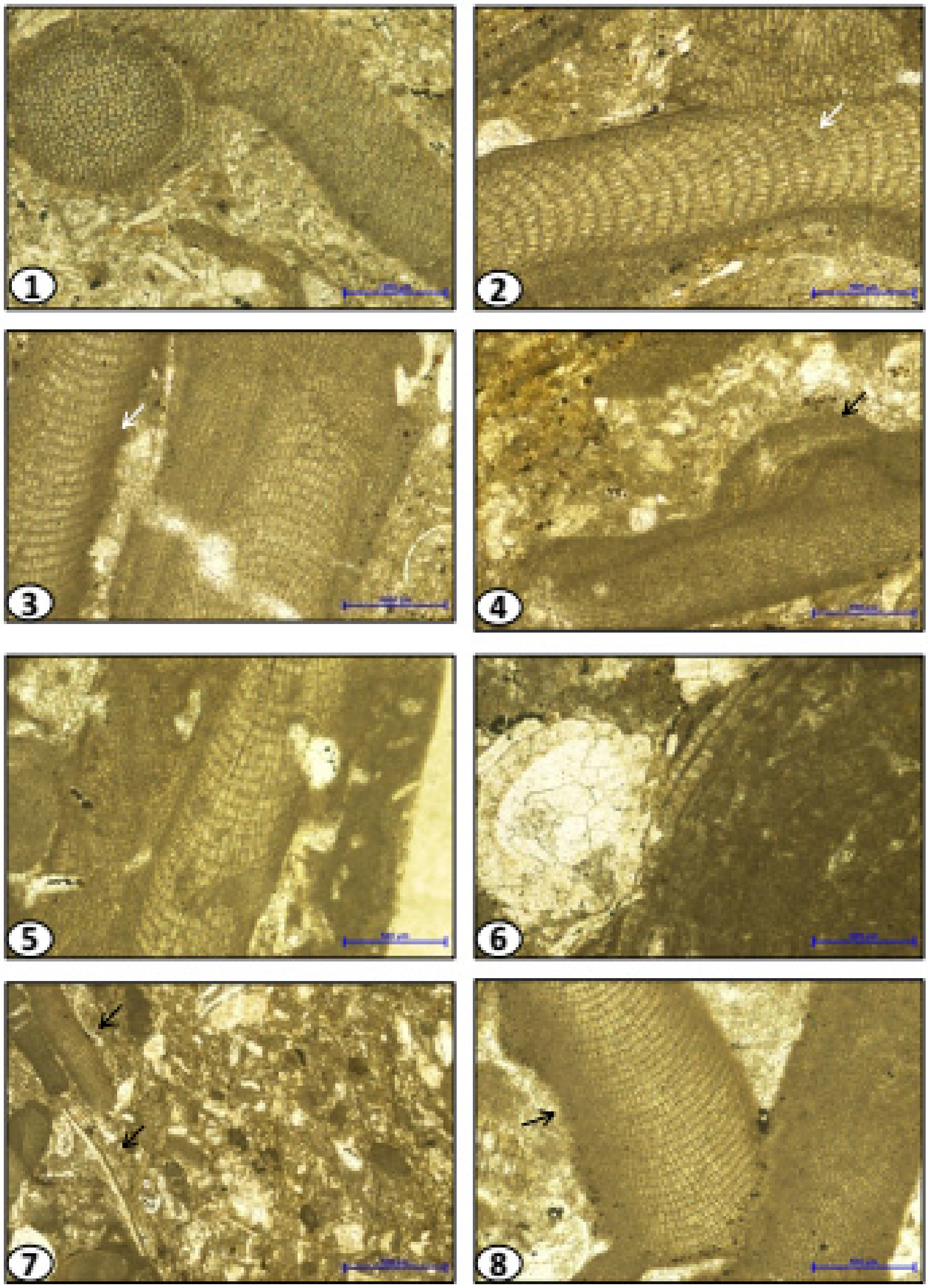

Figure 5. 1. *Lithophyllum prelichenoides* Lemoine, branche of coaxial core filaments, sample 47. 2. *Mesophyllum iraqense* Johnson, warty protuberance of coaxial core filaments and outer peripheral filaments, sample 54. 3. *Lithophyllum pseudoamphiora* Johnson, coaxial core filaments, sample 59. 4. *Lithothamnion* sp., Warty protuberance of poorly developed core filaments at base with peripheral filaments, sample 55. 5. *Mesophyllum rigidum* Mastrorilli, peripheral filaments showing oval - shaped uniporate cenceptacle chamber conceptacles in irregular grid peripheral thalli, sample 58. 6, 7. *Lithoporella melabesioideae (Foslie) Foslie,* single layers of palisade cells with cell fusions; note the small epithallial cells, sample 46. 8. *Lithophyllum simplex* Johnson, single branch showing coaxial core filaments embedded in micrite matrix, sample 47.

Genus *Spongites* Kützing, 1841

This genus is characterized by non- endophytic thallus that commonly occurred as monomerous or rarely dimerous; the dimerous thallus usually lacks the palisade cells; filaments around the conceptacle pore canals subparallel to the roof surface (Penrose and Woelkerling, 1992). Braga and Martini (1988) and Renema et al. (2015) additionally showed that the presence of non-coaxial core filaments to separate *Spongites* from *Neogoniolithon*.

Spongites albanense Lemoine, 1924
(Fig. 6, No. 3)

See Hamad (2008c, 2009) and Hamad et al. (2015) for synonyms
Description: Irregular crustose thalli (0.5–1.9mm thick). Thallus composed of irregular peripheral filaments with rectangular cells measuring 10 –19µm in length and 9-12 µm in diameter and indistinct basal core filaments with cells measuring 13–25µm in length and 12-17µm in diameter. Conceptacles are observed measuring 290–430 µm in diameter and 160–180 µm in height with a single short thick opening. This species ascribed before to *Lithophyllum albanense*, but the tissue of this taxon shows clear and abundant cell fusions and therefore belongs to subfamily Mastrophoroideae and not to the Lithophylloideae.

Subfamily Melobesioideae Bizzorzero, 1897
Genus *Lithothamnion* Heydrich, 1897
(Former name: Lithothamnium Rhilippi, 1837)

Diagnosis: Plants are monomerous (Woelkerling, 1988). Cores are plumose (Braga et al., 1993). Subepithallial initials are as long or longer than their immediate inward derivates (Rasser and Piller, 2000). Tetra/bisporangial conceptacles are multiporate; cell fusions are common (Woelkerling, 1988).

Lithothamnion aggregatum Lemoine, 1939
(Fig. 6, No. 6)

See Hamad (2008c, 2009) and Hamad et al. (2015) for synonyms
Description: Thallus is usually lumpy to fruticose. Cores are plumose and filaments curve upward sheaf-like. Upward curving filaments. Cells have slightly arched, rectangular shape and measure 7–14 µm in diameter and 9-22 µm in length. The peripheral filaments are well developed in the form of zonation, consist of irregular lenticular growth zones. Cells are 7–10 µm in diameter and 9-12 µm in length. Epithallial cells are flattened and subepithallial initials are longer than their immediate inward derivates. Cell fusions are common but multiple fusions are rare. Conceptacles occur in intervals within protuberances. Bi-/tetrasporangial conceptacles are 125–280 µm in height and 270–700 µm in diameter. They are rectangular with rounded edges.

Lithothamnion saxorum Capeder, 1900
(Fig. 6, No. 5)

See Hamad (2008c, 2009) for synonyms
Description: lumpy to fruticose. Cores reach a thickness of 250- 300µm.hickness is little variable in the growth direction. Cores are plumose and filaments curve upwards heaf-like. Upward curving filaments. Core cells are large (8-17µm in length and 3-7µm in diameter)

compared to peripheral cells that are 5-18μm in length and 1-5μm in diameter. Cell fusions are common but multiple fusions are rare. Protuberances are >3mm in width and in many cases branched. They have a banded appearance due to layers of shorter. Lateral alignment in the perithallus is usually good. Conceptacles are rare and measure 260–320 μm in diameter and 110-140 μ in height.

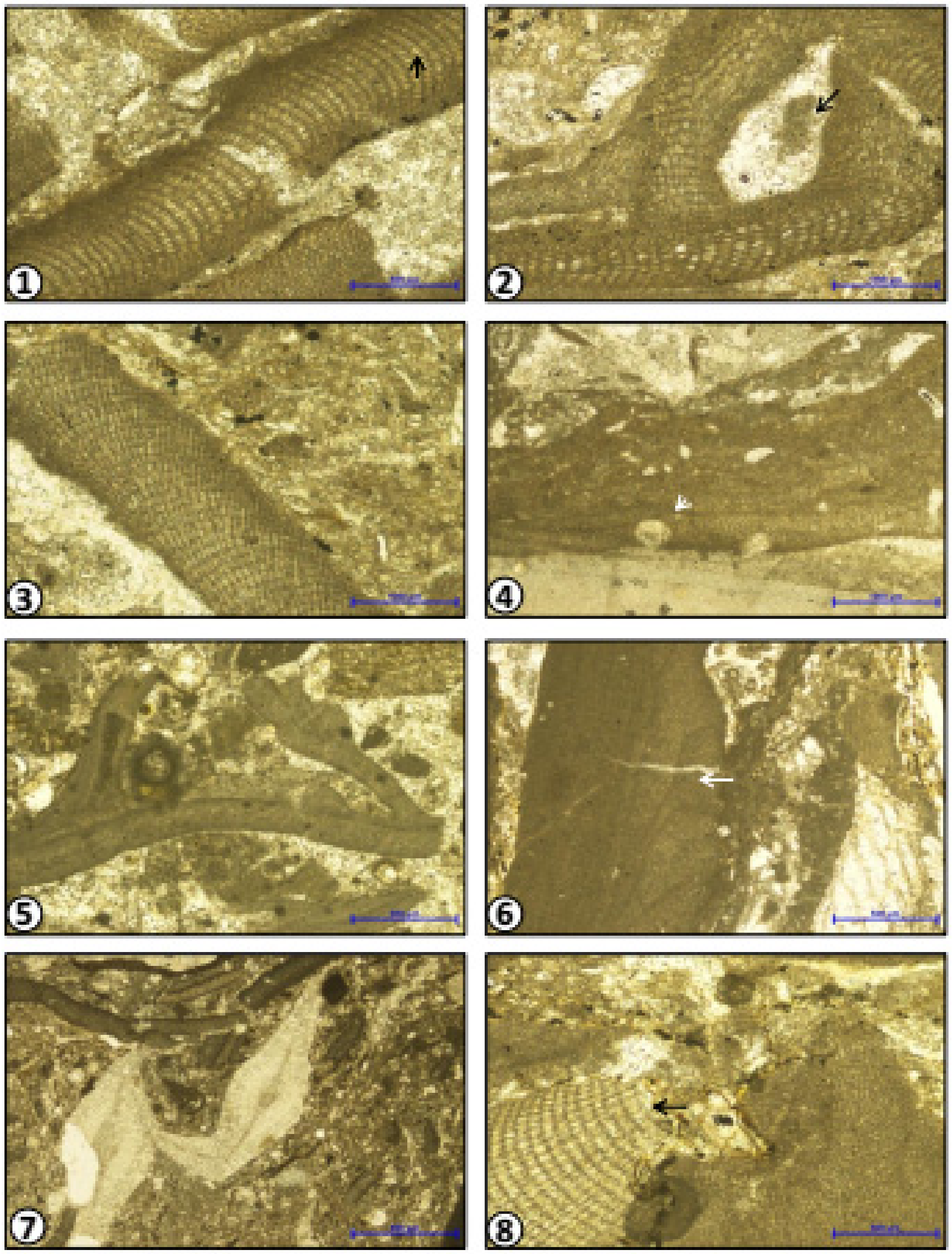

Figure 6. 1. *Lithophyllum pseudoamphiora* Johnson, branch of COAXIAL core filaments, sample 45. 2. *Mesophyllum* cf. *sancti-dionysi* Lemoine, long branch protuberance with large conceptacles, sample 58. 3. *Spongites albanense* (Lemoine), noncoaxial core filaments, sample 51. 4. *Mesophyllum lemoineae* Souaya, long branch protuberance with conceptacles, sample 54. 5. *Lithothamnion saxorum* Capeder, postigenous filaments with conceptacle, sample 56. 6. *Lithothamnium aggregatum* Lemoine, fragment of branch thalli showing protuberance with conceptacle, sample; 7. *Mesophyllum iraqense* Johnson, warty protuberance of coaxial core filaments and outer peripheral filaments, sample 54. 8. *Lithophyllum ghorabi* Souaya, Single branch showing coaxial core filaments embedded in micrite matrix, sample 56.

Genus *Mesophyllum* Lemoine, 1928
Mesophyllum iraqense Johnson, 1964
(Fig. 5, No. 2 and Fig. 6, No. 7)

See Hamad (2008c, 2009) and Hamad et al. (2015) for synonyms
Description: Simple crusts provided with short mamillae or short massive columns, or long slender branches. The core filaments consisting of cells measuring 7–11 µm in diameter and 15-22 µm in length. The marginal peripheral filaments are sometimes worn with rare conceptacles of minute sizes. The cells of the peripheral filaments are 9–13 µm in diameter and 15-20 µm in length. This species is commonly recorded in the studied materials and contributes to the forming of the rhodoliths.

Mesophyllum lemoinaea Souaya, 1963
(Fig. 6, No. 4)

See Hamad (2008c, 2009) for synonyms
Description: Thallus crustose, relatively thin, commonly 300–500 µm thick. The core filaments are poorly developed with cells not arranged in regular rows and gradually passing to the peripheral filaments. Irregularly peripheral filaments often lenticularly owing to the presence of conceptacles. Their cells are 7–11 µm in diameter and 15-22 µm in length. Conceptacles embedded and distributed in the peripheral part of the growth zone in the peripheral filaments They are measuring 240–430 µm in diameter and 130–190 µm in height. This species sometimes grows freely over the other coralline algae with alternative layers of *Lithoporella* and bryozoans.

Mesophyllum cf *sanctidionysii* Lemoine, 1939
(Fig. 6, No. 2)

See Hamad (2008c, 2009) for synonyms
Description: Thallus is encrusting to warty, more rarely foliose. The thickness of a single layer within layered portions of the thallus reaches 700-1000µm. Several mammillae crusts composed of partly developed core filaments and strongly zoned peripheral filaments with numerous conceptacles. The cells of the core filaments are 8 – 10 µm in diameter and 15 - 18 µm in length. The peripheral filaments are composed of strong lenticular growth zones with cells measuring 8–12 µm in diameter and 17-21 µm in length. Conceptacles embedded in the center of each growth zone, measuring 220– 400 µm in diameter and 140–180 µm in height.

Mesophyllum rigidum Mastrorilli, 1967
(Fig. 5, No. 5)

See Hamad (2008c, 2009) for synonyms
Description: Thallus forming mammillate crusts with short stubby branches. The core filaments are basal and zoned with rectangular cells having sizes 23–38 µm in length and 10 - 12 µm in diameter. The peripheral filaments with strong lenticular growth zones composed of subquadrate cells 8–2 µm in length and 10–12 µm in diameter. Conceptacles are large, multipored, commonly oval in section, measuring 340–580 µm in diameter and 160–240 µm in height.

Family Sporolithaceae Verheij, 1993

Rasser and Piller (1999) showed that this family is characterized by monomerous, plumose, non – nucleated, almost entirely calcified thalli, both cell fusion and secondary pit connections occur, Tetra / bisporangia formed between filaments, on one or more stalk cells. Verheij (op. cit) treated the Sporolithaceae as a separate families to be distinguished from the Family Corallinaceae due to the preservation of calcified sori and paraphyses of this family that can be easily identified in the fossil materials.

Microfacies Analysis

The paleoecological conditions that prevailed during the deposition of the Early Miocene deposits of Gharamul Formation exposed in the studied section have been interpreted based on microfossil assemblage (coralline red algal assemblage, planktonic and benthic foraminiferal and other different bioclatic content) as well as the lithologic types included the rock fabric (sorting, grain sizes) and field relationships. Eight distinct carbonate microfacies types were identified using the carbonate classification.

The Gharamul Formation is exposed along a Gebel Abu Shaar El Qibili contains carbonate microfacies types, which can be distinguished from the overlying Abu Gerfan Formation of polymictic conglomerates rocks. Eight major carbonate microfacies types are commonly repeated in the studied section and interpreted based on the dominating biogenic components, texture and depositional fabric as the following:

1- Dolomitic bioclastic algal coral rudstone/bindstone Facies (Fig. 7, No. 6). This microfacies is characterized by colonial corals. Macroscopically, it is a discontinuous massive limestone containing autochthonous Scleractinian colonial corals (Sample No. 84). The occurrence of in-situ organisms such as colonial corals suggests a reef environment (Wilson, 1975; Flügel, 2004). The discontinuous coral boundstone layers interbedded with the other different beds indicate a patch reef depositional environment. Coral reef communities are adapted to oligotrophic environments. The coral reef suffers losses because of high nutrient concentration (Hallock and Schlager, 1986; Flügel, 2004). This microfacies consists also of moderately preserved to partially recrystallized bryozoans usually filled with microspars. Corals are commonly fragmented and the others are formed in situ. Coralline red algae constitute the second majority of these components. They are encrusting the fragmented corals and other bivalve shell fragments. Small sized molluscan fragments, larger foraminifera are represented by *Operculina, Lepidocyclina (Nephrolepidina), Ammonia* and planktonic foraminiferal tests, ostracods, bryozoans that filled with sparry calcite as well as echinoid spines are also identified. The non-skeletal constituents are presented in the form of reworked subrounded micritic carbonate intraclasts and subrounded, terrigenous qartz grains. All these constituents are well preserved in sparry micritic matrix. This microfacies denote near shore shoals (shelf lagoon deposits).

2- Molluscan algal packstone/grainston (Fig. 7, No. 7): This light to dark yellowish to brownish facies is dominated by skeletal components consists largely of medium to small sized molluscan shell fragments, in situ and fragmented coralline red algal (*Lithophyllum* and *Spongites*), reworked fragments of geniculate coralline algae and non-geniculate rhodoliths, rare mastophoroids, corals, smaller miliolid benthic foraminifera are represented by *Amphistegina*, *Operculina* (15-30%) represented by *Amphistegina*, *Operculina, reworked* nummulitids, few forms likely to be *Spiroclypeus* and *Cycloclypeus*, orthophragminids (15-20%) represented by species of *Nephrolepidina* and larger rotaliids (>7%) represented by *Planorbulinella* and *Elphidium*, planktonic foraminiferal tests, bryozoa and ostracods as well as large echinoid spines (sample 63). The non-skeletal constituents are depicted in the form of reworked subrounded carbonate intraclasts of micrite composition and subrounded, poorly sorted, terrigenous quartz grains.

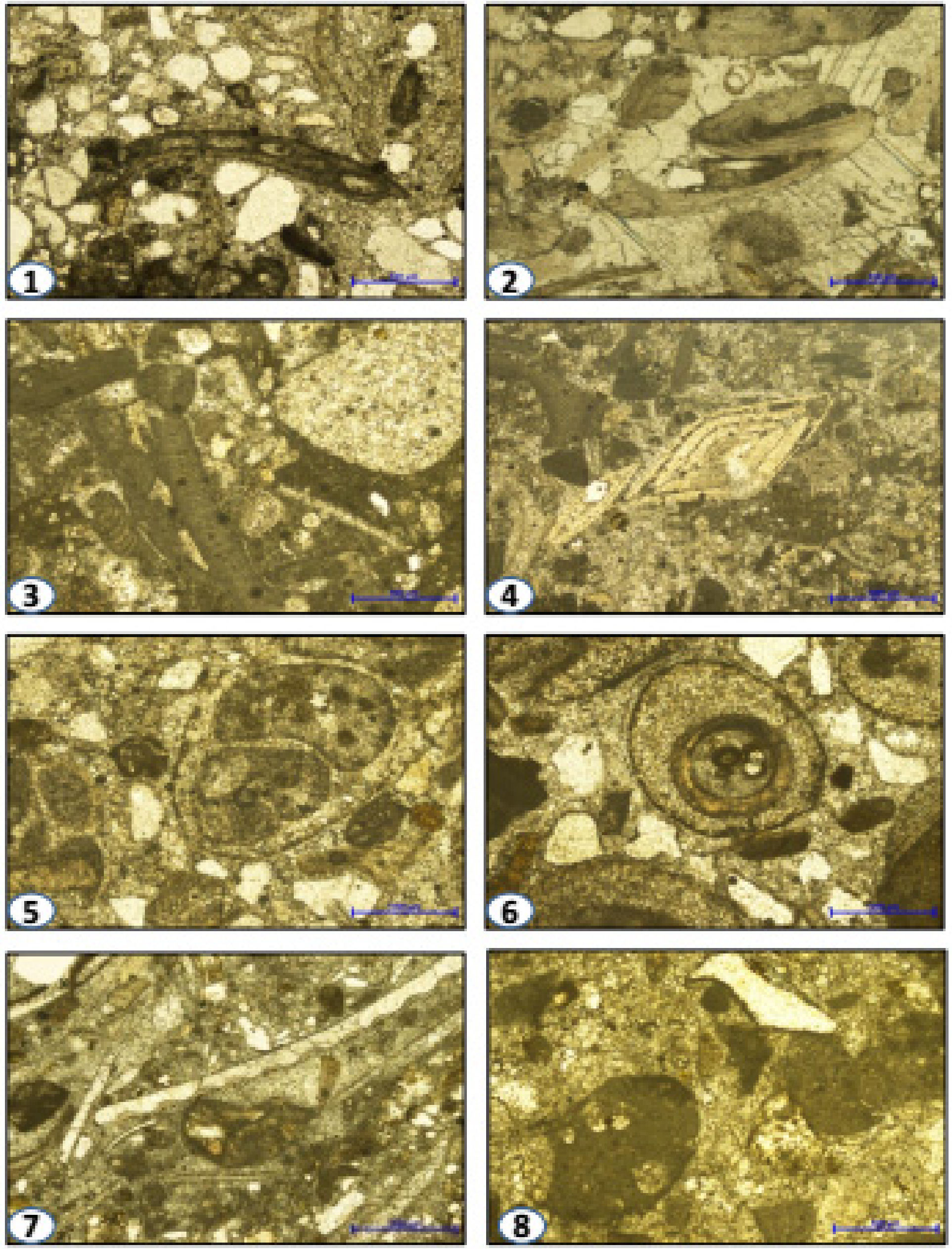

Figure 7. 1. algal foraminiferal packstone/grainstone facies, subrounded dark micritic intraclasts, with subangular detrital quarz grains associated with minute foraminiferal tests in sparry micrite matrix, sample 79. 2. bioclastic algal grainstone/rudstone facies, dark micritic intraclast, angular chert lithoclast and large benthonic foraminifera (*Amphestegina* sp.) associated small tests of foraminifera embedded in sparry micrite matrix, sample 79. 3. Coralline algal wackstone/packstone, large subrounded badly preserved coralline algae with rounded echinoid spine and recyrstallized bivalved shell fragments in sparry calcite cement, sample 78. 4. *Amphistegina* algal grainstone/rudstone, large subrounded dark micritic intraclasts with reworked coralline algae and bryozoans fragement, sample 85. 5. foraminiferal/coralline algal grainstone, large bryozoans with recrysatllized shell fragments and minute subangular quartz grains embedded in sparry micritic matrix, sample 76. 6. bioclastic algal coral rudstone/bindstone facies, large benthonic foraminifera of *Amphestegina* sp. with reworked coralline red algae and milliolid entobded in partialy recrystallized micritic matrix, sample 84. 7. molluscan algal packstone/grainston, large fragmentd coral with subrounded micritic intraclasts embedded in sparry micritic matrix, sample 63. 8. coral algal grainstone/rudstone facies, coral fragment of well-developed interlocked septa and fragments of coralline red algae in sparry calcite cement, sample 81.

These allochems are embedded in calcareous sparry calcite cement. Such type of facies indicates deposition in near shore shoal conditions with high energy, normal salinity, shallow marine environments. Large melobesioids (*Lithothmanion/Mesophyllum*) are also observed (5-18%). Smaller rotaliids (possibly *Pararotalia*, *Neorotalia*, *Cibicides*, *Elphidium*), soritids (possibly *Archaias*, *Peneroplis*, *Sorites*), reworked fragments of geniculate coralline algae and non-geniculate rhodoliths, rare mastophoroids, corals, echinoids, barnacle shells, mollusks and ooids are the components of subordinate facies. Poorly sorted grainstone-packstone facies are characterized by a packstone matrix.

3- Bioclastic algal grainstone/rudstone Facies (Fig. 7, No. 2): Thin section investigation revealed that it consists mainly of moderately to badly preserved to partially recrystallized colonial forms with ill-defined septa that recrystallized in microspars (Sample No. 79). These types of corals are commonly fragmented and the others are formed in situ and showing Indo-Pacific affinity. Coralline red algae constitute the second majority of these components, they are encrusting the corals and other bivalve shell fragments. Large sized molluscan fragments, large benthonic foraminifera are represented by *Amphistegina*, *Ammonia*, and *Borelis*, small planktonic foraminiferal tests, shell fragments, ostracods and bryozoans (Pl. 3, Fig. 4), as well as echinoid spines are also recognized. The non-skeletal constituents are presented in the form of reworked subrounded carbonate intraclasts of micrite composition and subangular to subrounded, poorly sorted, detrital quartz grains. These allochems are preserved in sparry calcite cement (Pl. 3, Fig. 6). Such type of facies indicates deposition in clear normal, high energy shallow marine environments with normal salinity and open circulation conditions. This microfacies represents deposition in reef–flank environments.

4- *Amphistegina* algal grainstone/rudstone (Fig. 7. No. 4): It is light yellowish to light grayish yellow facies that is highly fossiliferous with large benthonic foraminifera such as *Amphistegina* and *Operculina*, with little rotaliids such as *Cibicides, Elphidium* and *Nonion* (Sample No. 85). Moderately occurrence of other foraminifera resembling *Heterostegina, Orthophragminid, Nephrolepidina* and fragmented of ooids, echinoids and nongeniculate coralline algal fragments. Melobesioids are also encountered represented by nongeniculate coralline algal nodules (mastophoroids, lithophylloids and additionally melobsioids) and mollusks present are parts of subordinate facies. The non-skeletal constituents are depicted in the form of reworked subrounded carbonate intraclasts of micrite composition and subrounded, poorly sorted, terrigenous quartz grains. These allochems are embedded in dolomitized calcareous sparry calcite cement.

5- Foraminiferal algal wackstone/packstone (Fig. 7, No. 5): This light to dark yellowish facies is dominated by reworked foraminiferal tests in the form of *Nummulites, Assilina*. Other in situ large forams represented by *Operculina* and some poorly preserved forms (probably *Heterostegina*), Miogypsinoids represented by *Miogypsinoides globulina* and some tests with poor preservation (possibly *Miogypsina*), other planktonic foraminifera are represented by *Globigerinoides*, *Globigerina* and *Globorotalia* (sample No. 76). A few mastophoroid forms represented by *Spongites* are also observed. Geniculate coralline algae represented by *Corallina* sp. Zooxanthellate corals, abraded foraminifera, non-geniculate algae debris, echinoids, mollusks and textulariids are the subordinate facies components coralline red algae in the form of *Lithophyllum* and *Neogonilithon* and bioclastic components of bivalve shell fragments and echinoids spines. The lithoclastic (non–skeletal components) are represented by subrounded micritic intraclasts and subrangular detrital quartz grains packed in granular sparry micrite matrix that dolomitized to large extent. The presence of in situ and fragmented corals and coralline red algae denote shallow, clear and warm water marine environments with open circulation (reef flank to back reef facies).

6- Coral algal grainstone/rudstone facies (Fig. 7, No. 8): This microfacies type is represented in the field by coralline reefal deposits located in the uppermost of Gharamul Formation. The geometry of this bedded facies suggests a biohermal development rather than biostromal one that locally developed above the submarine paleohighs. It is located in the whole Gharamul Formation forming 40% of the carbonate facies. This microfacies is represented by fairly high proportion, a thick accumulation of organic organisms commonly contain scattered in situ hermatypic corals (*Porites, Pavona*, *Orbicella*, *Mycetophyllia* and *Stylophora*), molluscan shell fragments, bryozoans, ostracods, large benthonic foraminifers (*Borelis*, *Amphistegina, Operculina* and *Ammonia*) and small sized rhodoliths (up to 1.8 cm in diameter) bounded by highly diversified coralline red algae in the form of *Lithophyllum*, *Neogoniolithon*, and *Lithoporella* (sample No. 81). It is noteworthy to mention that some remains of bivalve shells, echinoids and even corals are bioeroded with *Lithophaga* borings. Petrographic investigation revealed that the groundmass of this microfacies type is composed essentially of coral fragments of well-developed septa filled with sparry calcite cement (30%) coralline red algae in the form of *Lithophyllum* and *Neogonilithon* (40%) and 10% of bioclastic components of bivalve shell fragments, echinoids spines and (10 % of the skeletal components). The lithoclastic (non–skeletal components) are represented by subrounded micritic intraclasts and subrangular detrital quartz grains packed in granular sparry micrite matrix. The presence of in situ and fragmented corals denotes shallow, clear and warm water marine environments with open circulation (reef flank to back reef facies).

7-Coralline algal wackstone/packstone (Fig. 7, No. 3): The petrographic analysis revealed that it consists mainly of moderately to badly preserved to partially recrystallized bryozoans usually filled with microspars (Sample No 78). Corals are commonly fragmented and the others are formed in situ and showing Indo-Pacific affinity. Coralline red algae constitute the majority of these components. They are encrusting the fragmented corals and other bivalve shell fragments. Small sized molluscan fragments, larger benthic foraminifera (*Operculinides* and *Ammonia*), planktonic foraminiferal tests, ostracods and bryozoans that filled with sparry calcite as well as echinoid spines are also identified (Fig. 7, No. 3). The non-skeletal constituents are presented in the form of reworked subrounded micritic carbonate intraclasts and subrounded, terrigenous quartz grains. All these constituents are well preserved in sparry micritic matrix. This Coralline Algal Wackstone/Packstone supported facies have been deposited in near-shore shoals (shelf lagoonal deposits).

8- Algal foraminiferal packstone/grainstone facies (Fig. 7, No. 1): Investigation of this facies revealed that this microfacies consists mainly of algae *(Borelis, Meandropsina, Dendritina* and *miliolids*), planktonic and benthonic foraminifera, with small sized molluscan fragments. Benthic foraminifera are represented by *Ammonia*, *Elphidium*, *Peneroplis,* and *Discorbis*, where the planktonic foraminiferal tests are depicted in the presence of *Globorotalia*., *Globigerina* and *Globigerinoides*. Shell fragments, bryozoa and ostracods as well as echinoid spines have been deducted (Sample No. 79). The non-skeletal constituents are depicted in the form of reworked carbonate intraclasts of micrite composition and subangular to subrounded, poorly sorted, terrigenous quartz grains. These skeletal and non-skeletal allochems are embedded in microspar calcite cement (Pl. 5, Fig. 1). Such type of facies indicates deposition in normal shallow marine environments.

Conclusions

The study of the coralline red algae from the Early Miocene deposits of the Gharamul

Formation in one composite stratigraphic section namely Gebel Abu Shaar El Qabili plateau, Western side of the Gulf of Suez region, Egypt, led to the recognition of twelve coralline algal species belonging mainly to five genera include ten species and three subfamilies (Mastrophoroideae, Lithophylloideae and Melobesioideae) of the Phylum Rhodophyta. The recognized species have been taxonomically studied and their occurrence is also mentioned. The algal association comprises the following genera: *Lithophyllum, Lithothamnion, Mesophyllum* with rare *Spongites* and *Lithoporella.* The investigation showed that the most dominant genera is *Lithophyllum* and represented mainly by *Lithophyllum ghorabi, L. prelichenoides,* and *L. pseudoamphiora*. These species occur encrusting different skeletal fragments such as large foraminifera, coral fragments and other reworked coralline red algae. Concerning the relative abundance of the other genera, *Lithothamnion* and *Mesophyllum* are recorded in more or less frequencies. They represented mainly by *Lithothamnion saxorum, L. aggregatum, Mesophyllum lemoinaea, M. rigidum, M. iraqense* and *M.* cf *sanctidyonesii*. The monostromatic *Lithoporella melobesioides* is commonly recorded.

Petrographically, the microfacies analysis of the studied sequences indicates the presence of eight microfacies types. The study showed that the coral algal rudstone and bioclastic algal packstone /grainstone facies are commonly characterized by coralline red algal assemblages dominated by lithophylloids (*Lithophyllum*) and mastophoroids (*Spongites* and *Neogoniolithon*). The distinction is less marked in the relativelly deep carbonate deposits such as algal foraminiferal packstone, shelly algal grainstone and foraminiferal algal packstone facies where the melobesioids (*Lithothamnion*, *Mesophyllum*) are the major coralline algal species in these facies. *Sporolithon*, the only representative of the family Sporolithaceae, is frequent in reef deposits but very rare in the studied microfacies types.

The Gharamul Formation (Burdigalian) consists of a thick carbonate□clastic succession. The lower part consists of a cyclic sequence of laminated, fossiliferous and argillaceous limestone intercalated with mudstone, and sandstones. It is documented that the clastic microfacies have good reservoir quality in the region due to the impacts of dissolution and fracturing diagenetic processes. The carbonate microfacies are impervious due to the effects of cementation, and micritization.

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