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Miocene coral reefs of the northern Red Sea coast, Egypt: Facies development and diagenesis

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ABSTRACT. *Late Early to Middle Miocene coral reefs were formed during a transgressive-regressive episode (gradual sea level fall) in Gebel Abu Shaar El Qibli and Quseir area, Northern Red Sea coast, Egypt. They rest directly on Precambrian crystalline basement rocks and/or basal Miocene clastics and underlain Late Miocene evaporites. These reefs could be subdivided into three successive depositional facies: fore-reef, reef-core, and back-reef. The fore-reef consists of massive marly algal coralline limestone, contains abundant pebble to cobble corals, the sediments are moderately sorted wackestones, packstones, rudstones and rarely boundstones. The reef-core framework consists mainly of columnar and massive faviid and poritid corals in life position, forming a dense framework; the sediments are moderately sorted boundstone and minor wackestones in the protected spaces of the growth framework. The back-reef is made up of sandy, bioturbated, coarse, bioclastic calcarenites and stromatolites, with few scattered coral colonies. It consists of wackestones, grainstones and greywacke, rich in remains of coralline algae and corals. Skeletons are generally dissolved and/or replaced by dolosparite and dolomicrosparite, this making most coral determinations impossible at species or even generic level. Coral elements were subjected to intensive flushing by meteoric waters, leading to leaching and destruction of the original aragonitic microstructure. This is indicated by the higher depletion in strontium and calcite, and the increasing in dolomites, especially in poritid corals of Gebel Abu Shaar El Qibli.*

INTRODUCTION

During Miocene times, the Tethys was a tropical sea, and reefs flourished in its shallow water, especially at locations sheltered from the siliciclastic supply. Antunes & Chevalier (1971) and Chevalier (1977), have indicated that coral fauna flourished and were most prosperous during Early Miocene time (Aquitanian and Burdigalian), then gradually became impoverished toward the end of the Miocene. Many authors have described Miocene reefal limestones from the Middle East and Mediterranean area (Buchbinder 1977, 1979, Dabrio et al. 1981, Coniglio et al. 1988, Mankiewicz 1988, Purser et al. 1993, El-Sorogy & Ziko 1999).

During the Middle Miocene, the region of the Gulf of Suez and northern Red Sea was connected to the main basin of the Mediterranean through a wide, open-marine seaway in the Suez area, while to the south, it was probably separated from the Indian Ocean by land barriers (Adams et al. 1983). During Serravalian time, evaporite sediments were formed as a result of increasing restriction of marine conditions, which related to the gradual isolation of the Gulf of Suez-Red Sea from the Mediterranean basin. This caused extinction of coral fauna in this region much earlier than in the Mediterranean generally, where similar coral reefs occurred in the uppermost Miocene (Messinian) of Almeria province, southeastern Spain (Dabrio et al. 1981, Riding et al. 1991).

The studied reef complexes are located in Gebel Abu Shaar El Qibli, near the southern entrance to the Gulf of Suez and in Quseir area to the south, Red Sea coast, Egypt (Fig. 1). They are mostly located on the crests of structural blocks, where fault-blocks formed the substrates for reef growth and also acted as morpho-structural barriers protecting reefs from successive terrigenous supply. The location, geometry, development and facies pattern of these reefs appear to be controlled mainly by the pre-and syn-rift tectonic movements as well as it closely related to the morphology of the underlying structural blocks.

The purpose of this paper is to define and classify subfacies in the coral reefs of northern Red Sea coast, Egypt, to deduce their environmental significance. In addition, it aims also to study the encountered diagenetic features.

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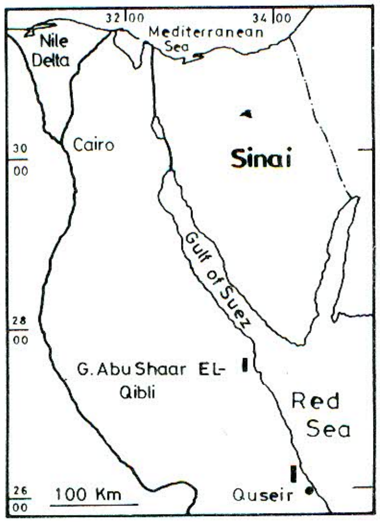

Figure 1. Location map

MATERIAL AND METHODS

Four stratigraphic sections were measured and sampled, two from Gebel Abu Shaar El Qibli and two from Quseir area. More than one hundred samples were sampled from the different studied facies. Forty thin sections were prepared for microfacies analysis.

The very porous samples, especially coral ones, have been impregnated with resin under vacuum for producing thin sections. Ten faviid and poritid coral samples were chemically analyzed for major and trace elements using X-ray fluorescence (XRF) and Atomic Absorption (AAS) and Spectrophotometer (in laboratories of Building Materials Research Institute and Nuclear Materials Authority, Cairo). Selected samples were investigated for diagenetic study, using the scanning electron microscope (SEM).

STRATIGRAPHIC SETTING

Neogene rocks are of wide geographic distribution in northern Egypt, the Gulf of Suez region, and the Red Sea coastal plain (Said 1990, Tawadros 2001). The geology of the studied sections have been discussed within numerous works (Cofer et al. 1984, Youssef & Abu Khadrah 1984, El-Haddad et al. 1984, Halim et al. 1986, Hamza 1992, Darwish & El-Azabi 1993, Purser & Philobbos 1993, Purser et al. 1993, Ahmed & El-Aaser 1994, El-Azabi 1997, Perrin et al. 1998). Based on lithologic characteristics and stratigraphic position the studied carbonates of Abu Shaar El Qibli are related to the Gharamul Formation, while those of Quseir area are related to the Gebel El Rusas Formation (Fig. 2, 3).

In Gebel Abu Shaar El Qibli, southern part of Esh El Mellaha block, the reefs overlay the Precambrian basement rocks and/or the early Miocene Abu Gerfan Formation (conglomerate beds alternating with arkosic sandstone) and underlay the Late Miocene Gemsa Formation (gypsum and dolomitic limestone interbeds). In the North of Quseir area the reefs are developed on the north-eastern side of the clysmically oriented basement fault blocks, while to the south, the reefs underlay Abu Dabbab evaporites and rest on the early Miocene non-marine alluvial fans, marine conglomeratic fans, and algal laminites. These sediments form the lower unit of Gebel El Rusas Formation.

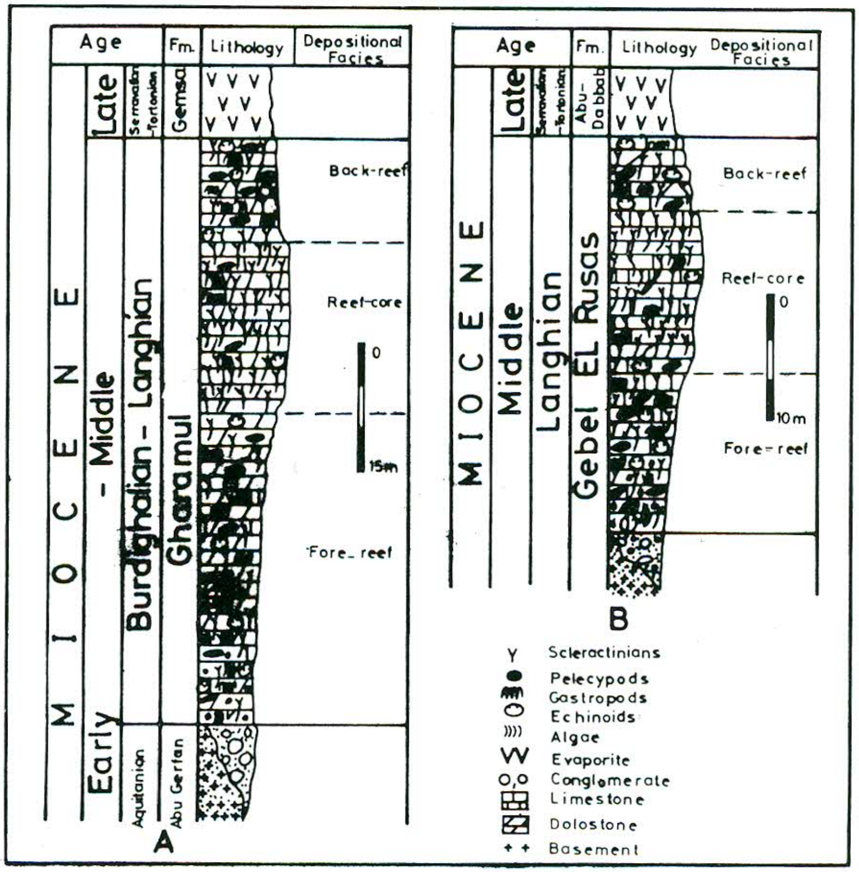

Figure 2. Stratigraphic setting and depositional facies of the reef complexes. A = Gebel Abu Shaar El Qibli, B = Quseir area.

The reefs were formed during the Miocene transgression, that took place due to rift subsidence, and/or global see level rise. The Late Miocene evaporate sediments of Gemsa and Abu Dabbab formations followed coral reefs in Gebel Abu Shaar El Qibli and Quseir respectively may represent the terminal evaporation (salinity crises) in the study area.

Owing to the following factors, the precise age of the studied coral reefs is not resolved: planktonic foraminifera are poorly developed, the large forams provide less precise ages, the megafossils are of long ranging type, and the scarcity of calcareous nannoplankton in the examined samples. Beadnell (1924), assigned these beds to the Middle Miocene on the basis of lithologic and stratigraphic similarities to the *Chlamys submalvinae* coral reef beds, which immediately underlie the gypsum beds further north at Gebel Zeit. Cofer et al. (1984), stated that these carbonates are probably of latest early Miocene (Rudeis Formation) based on calcareous nannoplankton ages recorded from basinal carbonates in subsurface sections in the Zeit Bay area.

However the studied coral reefs are equivalent to the upper calcareous member of the National Stratigraphic Subcommittee (1974). They can be correlated with the *Nullipora* limestone of the Belayim Formation (Hammam Faraun member) in the Gulf of Suez (Moon & Sadek 1923), and to the early to Middle Miocene carbonate succession of Gebel El Safra, Southern Sinai (Abu El-Enain & El-Sorogy 1994). Also they can be correlated to the Middle

Miocene (Langhian) reefal limestone of the Sadat Formation at Gebel Gharra, Northwest Gulf of Suez (El-Safori & El-Sorogy 1999), and at Wadi Hagul, Cairo-Suez district (El-Sorogy & Ziko 1999).

According to the stratigraphic position, field observations and the correlation with the last mentioned formations, a late early to middle Miocene age can be assigned to the studied coral reefs.

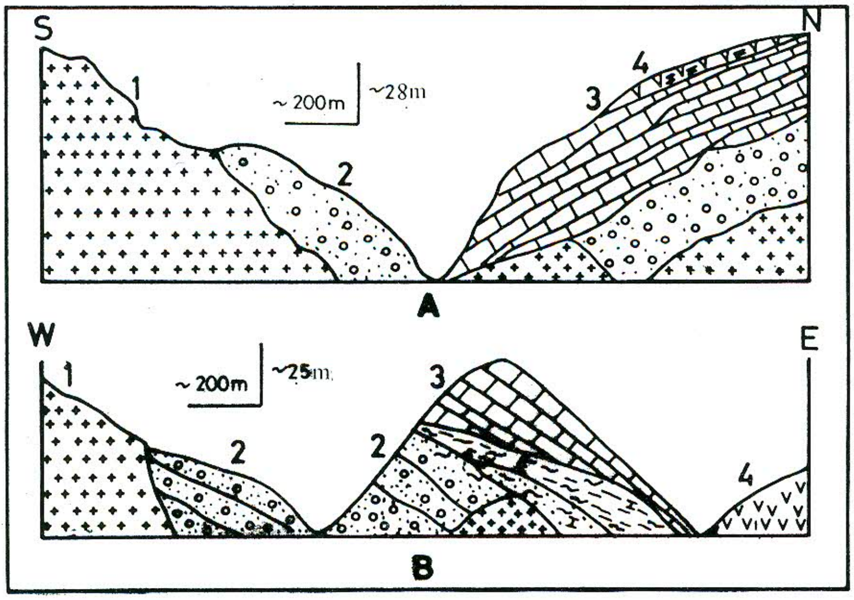

Figure 3. Simplified cross-section showing the stratigraphic relatioship between the reef complexes and other rock units.
A = Gebel Abu Shaar El Qibli: 1 = Basement, 2 = Abu Gerfan conglomerates, 3 = Gharamul reef complex, 4 = Gemsa gypsum and dolomitic limestone interbeds.
B = Quseir area: 1 = Basement, 2 = Gebel El Rusas conglomerates, and marls, 3 = Gebel El Rusas reef complex, 4 = Abu Dabbab evaporites.

FACIES DEVELOPMENT

On the basis of field observations, microfacies analysis and associated megafossils, three successive facies belts were distinguished within the reef complexes, these are from base to top:

The fore-reef slope facies

In Gebel Abu Shaar El-Qibli (Fig. 2/A, 3/A) the fore-reef sediments vary in thickness from 15 to 40 m and rest on Abu Gerfan conglomerates and in parts rest on the Precambrian crystalline basement rocks (granitoids, volcanics and metasediments). In Quseir area (Fig. 2/B, 3/B) the fore reef sediments vary in thickness from 4 to 15 m, and rest on Precambrian basement rocks and or the conglomerates of the lower member of Gebel El Rusas Formation.

This facies consists of massive, marly algal coralline limestone, dolomitic, especially at Gebel Abu Shaar El Qibli, pebbly in the lower part. The pebbles range in size from 0.5 to 7 cm and decrease upwards. It contains abundant pebbles to cobble, moderate to badly preserved corals, e.g. *Tarbellastraea reussiana*, *Porites collegniana*, *Montastraea mellahica*, *Cycloseris* sp., *Favites neglecta*, *Goniastrea* sp., *Cyphastrea* sp., badly preserved molluscs,

e.g. *Lithodomus aturensis*, *Chama benoisti*, *Meretrix erycinoid*, *Dosinia exoleta* and echinoid molds. Sediments of the fore-reef facies are represented mainly by reef-talus slope and proximal slope in local parts. There is no evidence of distal slope elements. This is supported by the absence of planktonic foraminifera in these sediments.

Green algal bed (*Halimeda* sp.) is recorded in Gebel Abu Shaar El Qibli, typically massive, and is 50 to 75 cm thick. *Halimeda* segments are randomly oriented, unbroken, and contain no terrigenous mud and typically make up over 80 to 90 % of the biotic constitutes (Fig. 4/3, 4). The non fragmented nature of the *Halimeda* points out the low energy conditions, and suggest growth in a protected shoal. The *Halimeda* rich bed, is texturally most similar to those reported by Roberts et al. (1987) in modern shelf bioherms in Indonesia. Lagoonal and reefal settings of *Halimeda* limestones have been described from the Paleocene and Miocene of the Mediterranean area, as well as from the Miocene carbonate platforms of the South China Sea, Enewetak Atoll and the Philippines (Wray 1977, Hillis-Calnvaux 1986, Wiedicke 1987, Flügel 1988).

The coralline algae in the fore reef sediments do exist in the form of free-rolling, or partly attached rhodoliths (Fig. 4/6), and as algal debris (*Mesophyllum* sp., *Lithothamnium* sp.). The free growth of coralline algae reflects low water energy (Studencki 1988). The algal beds represent a deposition in deeper fore reef, with low wave and current energy. The close association of the algal deposits with marly sediments supports this assumption.

Fore-reef-slope sediments are of moderately to well sorted wackestones, packstones, rudstones and rarely boundstones. In thin sections these sediments gave *Halimeda* rudstone, peloidal wackestone, and coralline framestone (Fig. 4/3-7). Most of these sediments are derived from the reef-core framework. Many sheltered cavities within the coral framework are partly infilled with peloidal mud. Pore filling fibrous cement (isopachous fringes) occurs in primary and secondary pores of the coral skeletons and between *Halimeda* segments (Fig. 4/4).

The reef-core framework facies

The thickness of the reef-core sediments in Gebel Abu Shaar El-Qibli varies from 5-20m. The underlain fore reef sediments offered the substrate needed for coral growth (Fig. 2/A). In some parts, the reef-core sediments rest directly on the Precambrian basement rocks. In Quseir area the reef-core sediments are 1-4m thick, directly rested on the fore-reef sediments

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Figure 4

1 Close up view of *Goniastrea* mass. The reef-core sediments, Gebel El Rusas Formation, Quseir area.
2 Close up view of *Echinopora* mass. The reef-core sediments, Gharamul Formation, Gebel Abu Shaar El Qibli.
3 *Halimeda* rudstone, the *Halimeda* plates are mostly well preserved and the utricles are dolomitized. The fore-reef sediments, Gharamul Formation, Gebel Abu Shaar El Qibli.
4 Pore filling fibrous cement, as isopachous fringes (f), occurs between *Halimeda* segments. The fore-reef sediments, Gharamul Formation, Gebel Abu Shaar El Qibli.
5 Pelloidal wackestone, pellets are embedded in dolomicrites. The fore-reef sediments, Gebel El Rusas Formation, Quseir area.
6 Dolomitized algae (rhodolith) around a nuclei of lime mud. The fore-reef sediments, Gebel El Rusas Formation, Quseir area.
7 Coralline framestone, septa and synapticulae (s) of *Favites neglecta* are completely leached and replaced by dolomicrites, which act as substrate to dolosparite cements (c). The fore-reef sediments, Gebel El Rusas Formation, Quseir area.
8 Coralline framestone. The poritid coral (p) incrusted by laminar coralline algae (a) in the lower left corner. The primary aragonitic microstructure has already been replaced by dolomite. The reef-core sediments, Gharamul Formation, Gebel Abu Shaar El Qibli.

Bar scale = 0.6mm, except 1, 2 = 1cm

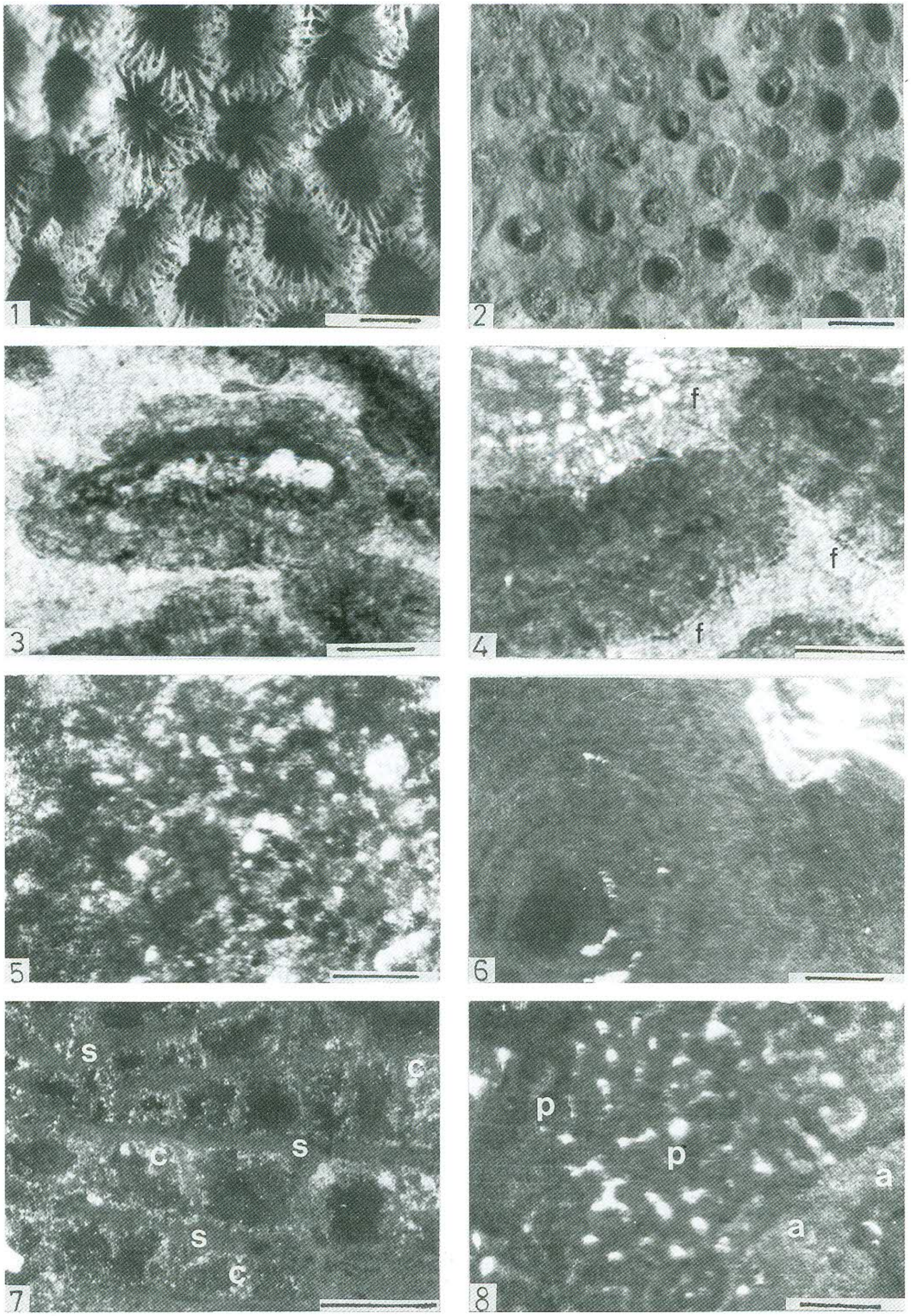


Figure 4. *(Legend on page 188).*

(Fig. 2/B). The corals are preserved in life position and show massive and columnar growth forms of poritids such as *Porites collegniana*, and massive and hemispherical faviids, with masses range from 0.5 to more than 1.5 m in diameter. The corals are mostly of the same genera found in the fore-reef slope e.g., *Tarbellastraea reussiana*, *Favites* sp., *Goniastrea* sp., *Cyphastrea* sp., and *Echinopora* sp. (Fig. 4/1, 2)

This facies is mainly made up of dense-rigid framework of faviid and poritid corals, associated with coralline algal crusts. Coralline algae play a significant role in the construction of the reef-core facies. They form crusts, which bind and cement coral colonies and other skeletal constituents into a coherent mass. Growth of the coralline algae probably took place after the death of the coral colonies, since in many cases the algal crusts totally surround coral masses.

A frequent part of the reef-core framework is formed by laminated micrite coatings, which constitute as much as 15-25% of the reef core sediments, while the coral framework itself may represent up to 75%. These micrite coatings have poorly defined pelloidal texture, represented now by equant secondary vuggy dolomite cement in primary inter- and intraparticle pores, and also in moldic pores. Skeletal and cement dolomites are characterized by smooth surfaces, and show evidence of intercrystalline leaching, particularly in the central or core region (Fig. 6/3-7). The original mineralogy of the micrite cement may have been either Mg calcite or aragonite. Similar Middle Miocene micrite coatings have also been observed by El-Sorogy & Ziko (1999) from Cairo-Suez District, Egypt, and from the Uppermost Miocene (Messinian) coral reefs from southeastern Spain (Dabrio et al. 1981).

Sediments of the reef-core consist of moderately sorted boundstone and minor wackestones in the protected spaces of the growth framework. Fragments of echinoids, molluscs and foraminifers are present. In thin sections these sediments are represented by coralline framestone, algal framestone, algal coralline bindstone, algal bryozoan bindstone, coralline bafflestone and bioclastic wackestone (Fig. 4/8, Fig. 5/1-5). Corals show evidence of intense organic boring by *Lithodomus*, clionid sponges and worms (Fig. 5/2). Matrix fillers include also many gastropods, pelecypods (especially pectinids), echinoids and sandy in parts. The sand grains are rare, fine to medium size, subangular to subrounded and moderately sorted.

Figure 5

1 Coralline bafflestone. A sediment rich in bioclasts (s) occurs between the dolomitic baffling coral skeleton (c). The reef-core sediments, Gebel El Rusas Formation, Quseir area.

2 Boring *Lithodomus*, clionid sponges and worms (b) in the coral skeleton (c), the pores are filled with quartz grains and lime mud. The reef-core sediments, Gharamul Formation, Gebel Abu Shaar El Qibli.

3 Sandy algal coralline bindstone. *Porites* sp. (p) encrusted by micritized coralline algae *Lithoporella* (l). Algal segments trap micrite crusts, bioclasts and quartz grains. The reef-core sediments, Gebel El Rusas Formation, Quseir area.

4 Algal bryozoan bindstone, the membraniporiform chambers (B) are filled by fine quartz grains and micrite. The reef-core sediments, Gebel El Rusas Formation, Quseir area.

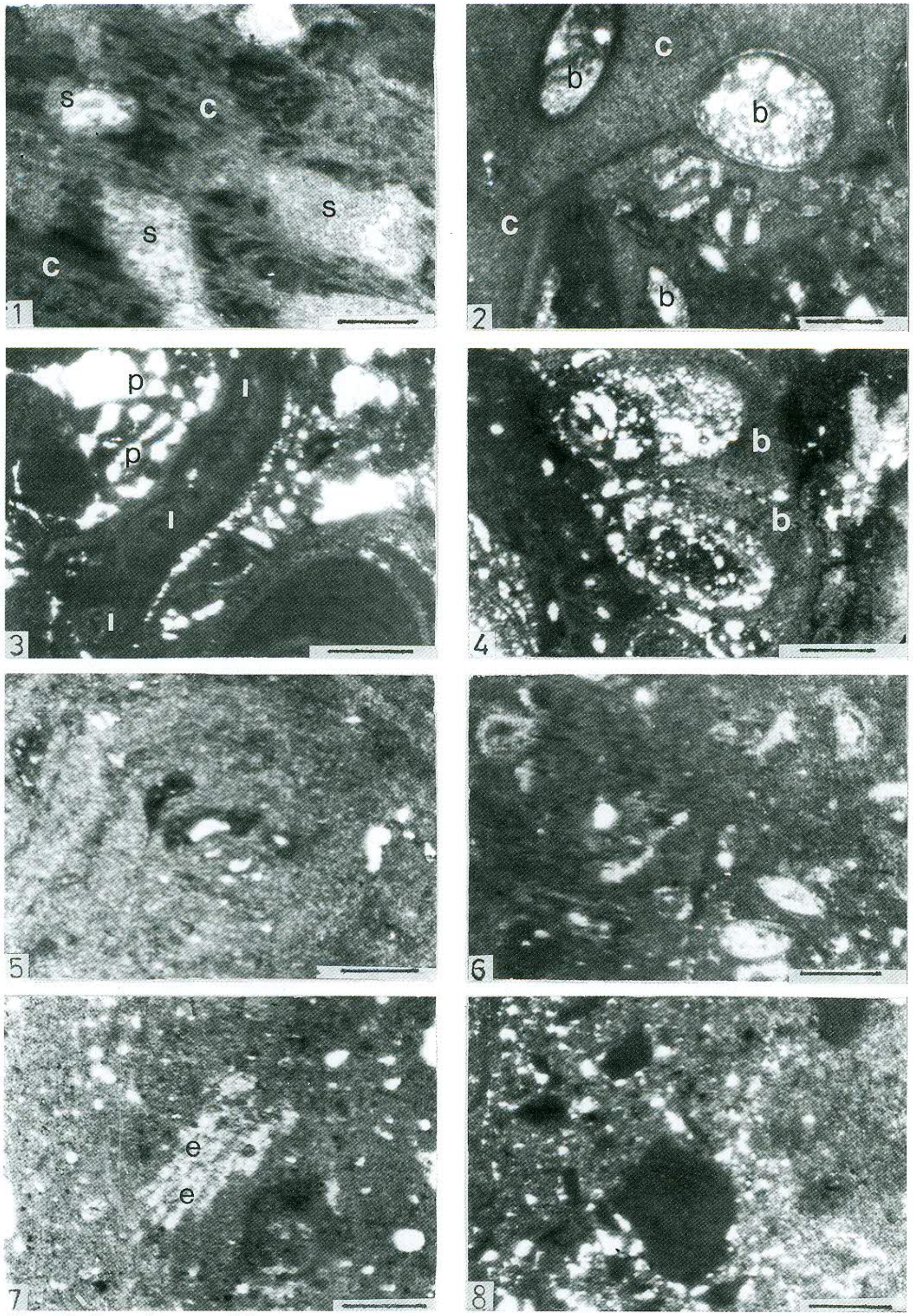
5 Algal framestone, the micritized *Lithothamnium* sp. acts as concentrically laminated cortex. The fore-reef slope sediments, Gebel El Rusas Formation, Quseir area.

6 Foraminiferal wackestone with benthonic foraminifers (amphisteginids). late blocky calcite cement infilled the benthos and other fossil particles. The back-reef sediments, Gebel El Rusas Formation, Quseir area.

7 Sandy bioclastic wackestone with micritized algal fragments, oblique section of echinoid spine (e) and silt sized quartz grains. The back-reef sediments, Gebel El Rusas Formation, Quseir area.

8 Sandy algal wackestone (algal dolo-micrite) with micritized algal fragments, rare iron pockets and silt sized quartz grains. The back-reef sediments, Gharamul Formation, Gebel Abu Shaar El Qibli.

Bar scale = 0.6mm



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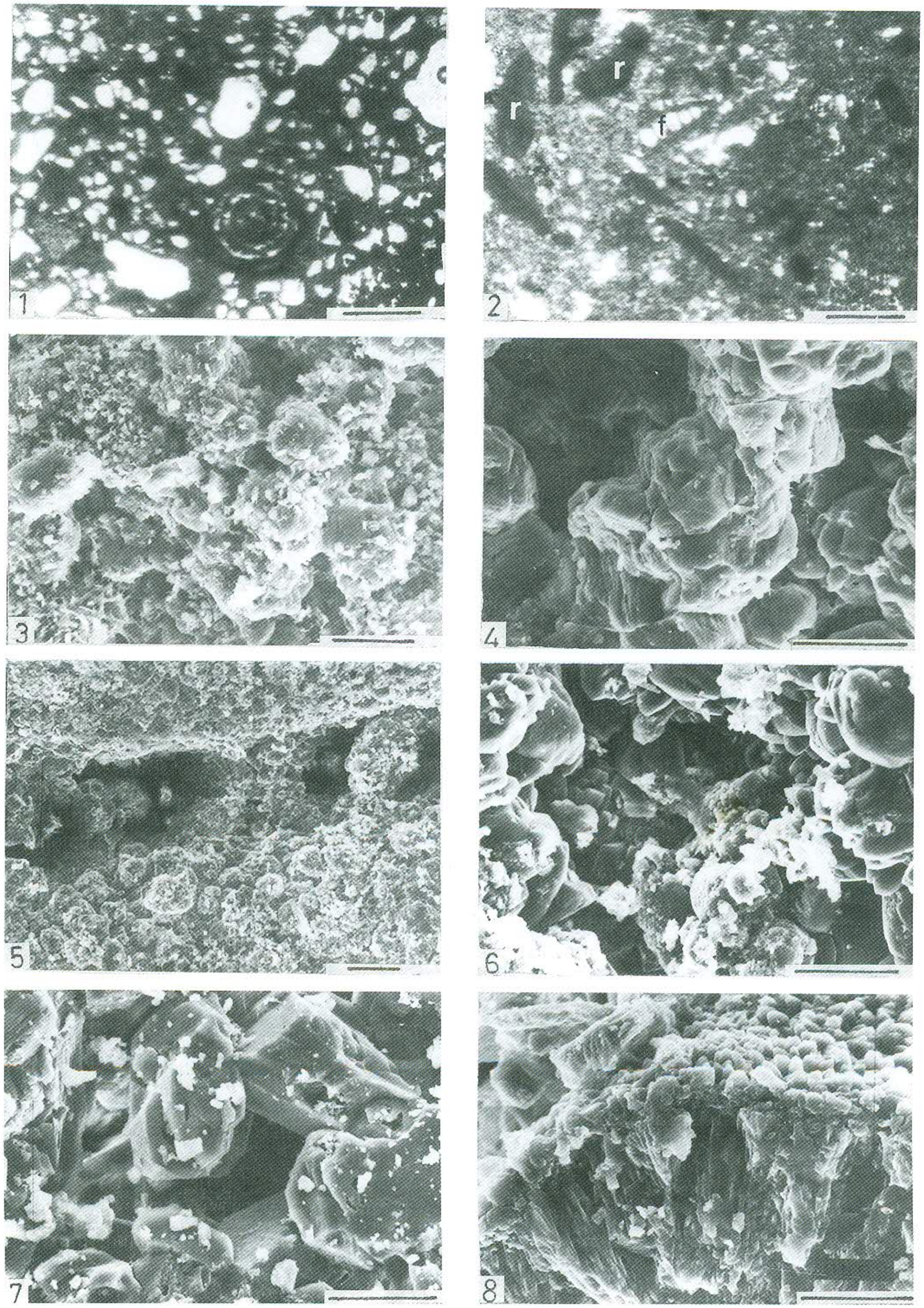

Figure 6. (Legend on page 193).

The back-reef facies

This facies is characterized by the presence of few scattered coral colonies in life position such as *Porites* sp., *Tarbellastraea* sp. and *Goniastrea* sp.. These corals are embedded in sandy, bioturbated, coarse, bioclastic grit with spectacular stromatolitic ridges in the uppermost part and show evidences of boring activity by bivalves. This facies varies in thickness from 4.5 to 10 m in Gebel Abu Shaar El Qibli (Fig. 2/A) and from 0.5 to 2.5 m in Quseir area (Fig. 2/B).

The back reef facies is marked by rich molluscan fauna, especially burrowing pelecypods such as cardiids, lucinids, and arcids, which live in soft substrates (Stanley 1970, Buchbinder 1979). The echinoids such as clypeasterids are frequent. They are also soft substrate inhabitants. The abundant algal grains in these sediments are assumed to have been derived from the coralline algal flora, which lived on these soft calcarenite substrates. Sediment of the back reef facies is dominated by reef-derived bioclastic debris. Framework builders seem to have played only a minor role. The few isolated coral colonies do not form true reef structures. The transition from coral-coralline algal reefs to stromatolite-dominated sediments probably reflects the initial phases of the salinity crises, which culminated in evaporites deposition.

The microfacies consists of wackestone, grainstone and greywacke rich in remnants of coralline algae and corals. Molluscs, echinoid plates and spines, besides abundant foraminifera (*Borelis melo*). The molluscan shells were dissolved, forming molds, which were later, filled with sparry mosaic of low-magnesian calcite. In thin sections these sediments gave foraminiferal wackestone, bioclastic wackestone, algal wackestone, and foraminiferal greywacke (Fig. 5/6-8, Fig. 6/1-2). Fine-grained carbonate mud, indistinct faecal pellets and minute fossil debris fill the interstices between fossil fragments. Thin isopachous fringes of fibrous cement rim many grains, while some micrite matrix is present throughout. Sand grains of silt to medium size, subangular to subrounded and poorly to moderately sorted are abundant. They derived from the crystalline basement rocks exposed in nearby terrestrial settings.

Figure 6

1 Sandy foraminiferal greywacke with isopacheous micrite submarine cement coats the benthonic foraminifera (*Borelis melo*), other fossil particles and silt to medium quartz grains. The back-reef sediments, Gebel El Rusas Formation, Quseir area.

2 Sandy bioclastic wackestone, with red algal fragments (r) and uniserial foraminiferal test (f), embedded in micrite matrix. The back-reef sediments, Gebel El Rusas Formation, Quseir area.

3 Dolomite cement and skeletal dolomite in the Reef-core facies, Gharamul Formation, Gebel Abu Shaar El Qibli.

4 Porous mosaic of anhedral dolomite crystals of *Porites* skeleton, Reef-core facies, Gharamul Formation, Gebel Abu Shaar El Qibli.

5 Transverse section of *Favites neglecta* wall, the microstructure is replaced by dolomite, Reef-core facies, Gharamul Formation, Gebel Abu Shaar El Qibli.

6 Porous mosaic of anhedral dolomite with smooth crystal surfaces. Reef-core facies, Gharamul Formation, Gebel Abu Shaar El Qibli.

7 Moldic porosity in anhedral dolomite crystals, as a result of selective intracrystalline dissolution, Reef-core sediments, Gebel El Rusas Formation, Quseir area.

8 Ghost microstructure in *Tarbellastraea reussiana*. The aragonite is replaced by calcite in situ, without the formation of visible cavities. Reef-core sediments, Gebel El Rusas Formation, Quseir area.

Bar scale = 15ųm, except 1, 2 = 0.6mm

Strontium is mostly accommodated within the calcite lattice (Fig. 9), and it is seriously lowered as a result of dolomitization. The depletion in Sr, as a result of dolomitization, is accompanied with relative enrichment in the content of Mn, which occupies Mg^{2+} sites in dolomite.

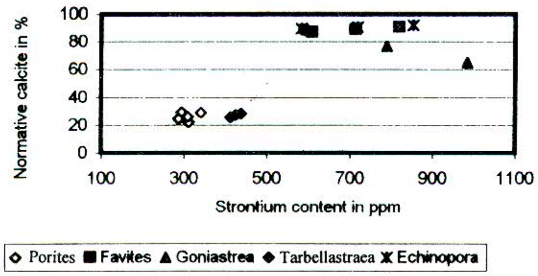

Figure 9. Relationship between normative calcite and strontium in coral genera.

The difference between the diagenetic fabrics of the faviids and poritids can be described as related to the difference in their original porosity and permeability. The poritids exhibit much higher porosities than the faviids. Thus the coral elements were subjected to intensive flushing by meteoric waters that caused the complete leaching and the destruction of the original aragonitic microstructure. In the faviids, the flushing was less intensive, because of the relatively low porosity and permeability. Hence the dissolution process was slower and the subsequent calcite precipitation kept with the dissolution, consequently, some of the original microstructure were preserved, indicated by slightly decrease in Ca, Sr and Mg.

Dullo (1986) and El-Sorogy (1997) attributed the difference in the rate of diagenetic alteration between poritid and faviid species from the Pleistocene coral reefs, Red Sea coast of Saudi Arabia and Egypt to their microstructure and microarchitecture and their relation to the reactive surface area.

Stylophorid corals

Based on field and petrographic examination there is no evidence that stylophorid branching corals (*Stylophora, Pocillopora, Acropora*) occur in the studied carbonates. The absence of these corals may be attributed to complete destruction of their skeletal elements during leaching process, and boring organisms or by others environmental parameters.

The small corallites of the modern stylophorids are embedded in solid coenosteum, these corallites have no point of immediate contact with each other (Wells 1956) and therefore they are not as closely packed as the corallites of the faviids and the poritids. Thus, during the leaching phase the framework of the micritic envelopes, which outline the original pore system of the stylophorids, may have formed a loose unsupported structure, which was mechanically unstable. This structure probably collapsed, resulting in the complete destruction of the coral elements, especially in these highly diagenetic carbonates.

Fishelson (1973) studied the damage of the living coral population of the Eilat reef, Red Sea by a catastrophic low tide. According to his observation the dead population of the branching genera (*Stylophora*, *Pocillopora* and *Acropora*) had been subjected to intensive boring activity (the insides of the coral branches were left eroded, leaving almost hollow structures). Whereas the faviids, were more resistant to the destructive processes. Correlating with the Recent corals of Eilat, it is possible to assume that the branching stylophorids from the studied Miocene sections were more susceptible to boring activity, compared to the faviid and the poritid corals.

CONCLUSIONS

During the late early to middle Miocene age coral reefs were formed in the northern Red Sea coast, Egypt. They form isolated build ups, parallel to the paleoshore line. The geometry of these reefs are closely related to the morphology of the underlying structural blocks of crystalline basement rocks and/or early Miocene clastics. The vertical sequence of the studied reefs shows transgressive-regressive episode (gradual sea fall), perhaps caused by increasing restriction and evaporation in the basin. It begins with marly algal coralline sediments, which probably represent deep fore-reef facies, and changes upward regressively to reefal limestone of reef core framework, which represent initial shallow water sediments. Skeletal limestones and stromatolites of back-reef facies overlie the reef-core sediments. Finally they are overlain by laminated dolomicrites with scattered gypsum indicating increasing salinities prior to onset of regional evaporites sedimentation (Serravalian-Tortonian), which was initiated by the partial isolation of the Red Sea basin from its parental Mediterranean due to structural uplift.

The studied coral reefs are characterized by low diversity of coral fauna, of entirely Miocene Mediterranean affinity. However the low diversity of Miocene coral fauna is not a feature of the Egyptian Miocene alone, but may however apply to the contemporaneous Mediterranean scleractinians as a whole.

Poritid corals were completely leached and refilled with dolomite. Higher depletion in strontium and calcite and increasing in dolomite contents, especially in Gebel Abu Shaar El Qibli, indicate such assumption. Faviid corals underwent dissolution and reprecipitation of low-Mg calcite by a concomitant process, with preservation of few dark centers of sclero-dermites. The absence of branching corals (stylophorids) in the studied carbonates may be related to the complete destruction of their skeletal elements during leaching process (diagenesis), and boring organisms or others environmental parameters.

The difference between the diagenetic fabrics of the poritids and the faviids can be attributed to the difference in their original porosity and permeability, which control the flow of under saturated groundwater and to the coral microstructure and microarchitecture as well as their relation to the reactive surface area.

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