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Microfacies, depositional environments and geochemistry of the Miocene carbonate succession of Gabal El Safra, southern Sinai, Egypt

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ABSTRACT. *The Miocene sequence in Gabal El-Safra is lithologically divided into a clastic succession at the base, followed upwards by the carbonate Safra Formation. The Safra Formation is subdivided into four informal units, from base to top: dolomitic limestone, dolostone, argillaceous limestone and dolomitic reefal limestone. Microscopic and SEM examinations and chemical analysis reveal the presence of the microfacies types: algal wackestone, dolomitic molluscan grainstone, foraminiferal grainstone/packstone, foraminiferal bindstone and scleractinian framestone. Dolomitization was the most effective diagenetic process in the studied limestones. It played a significant role in decreasing the Sr content, while does not appear to have had an influence on the Mn content. Field observations, microfacies analysis and faunal content, combined with trace element composition revealed that the carbonates of the Safra Formation were deposited in shallow shelf lagoon, winnowed platform edge and organic reef build up environments.*

INTRODUCTION

The southern tip of Sinai is located at the triple junction between the African plate, the Arabian plate and the Sinai subplate. Gabal El-Safra (Fig. 1) is a faulted block tilted towards the southwest being a part of the southern dip province of the Gulf of Suez (Mostafa 1976, Steckler et al. 1988). It consists of a Miocene succession that is divided into a clastic unit at the base, followed by the carbonate Safra Formation at the top. Abdelwahab (1991) studied the sedimentology of the Lower Miocene clastic succession (125 m thick). It consists of alternating conglomerates and red pebbly and coarse sandstone beds merging upwards into fine sands and silt then marls. The present study focuses on the carbonate Safra Formation. It is composed of dolomitic limestone, dolostone, argillaceous limestone and reefal limestone. The purpose of this work is to determine their microfacies analysis, depositional environment and geochemical characteristics.

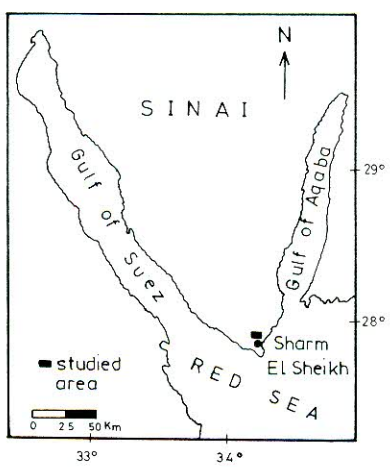


Figure 1. Location map of the studied area.

MATERIAL AND METHODS

Seventy two samples were collected from the Safra Formation. Thin sections of forty selected samples were microscopically studied. Selected samples were examined by the SEM (in the Research Center for Marine Geosciences, GEOMAR at Kiel University, Germany). Twenty four samples were chemically analyzed using complexometric, gravimetric, colorimetric, flame photometric and atomic absorption spectrophotometric techniques (Laboratories of Nuclear Materials Authority).

LITHOSTRATIGRAPHY

The Safra Formation was proposed by Hume (1906, 1916) who reported that these carbonates are of a Miocene age and are related to those of Mediterranean and Sind areas. The Miocene sequence in the study area was previously studied by different authors such as Omara (1959), Garfunkel et al. (1974), Garfunkel & Bartov (1977), Sellwood & Netherwood (1984) and Abdelwahab (1991). The studied Safra Formation measures 102 m thick. It is dipping 30°-40° to the southwest and conformably overlies the lower clastic succession in Gabal El-Safra where the contact is marked by the presence of a marl bed. In wadis El-Kharita and Hidamiya in the same area the Safra Formation was deposited directly on an irregular basement topography in discontinuous patches. A complete stratigraphic section (Fig. 2) was prepared based on detailed field and laboratory works. It reveals that the succession can be subdivided lithologically into four informal units, described from base to top.

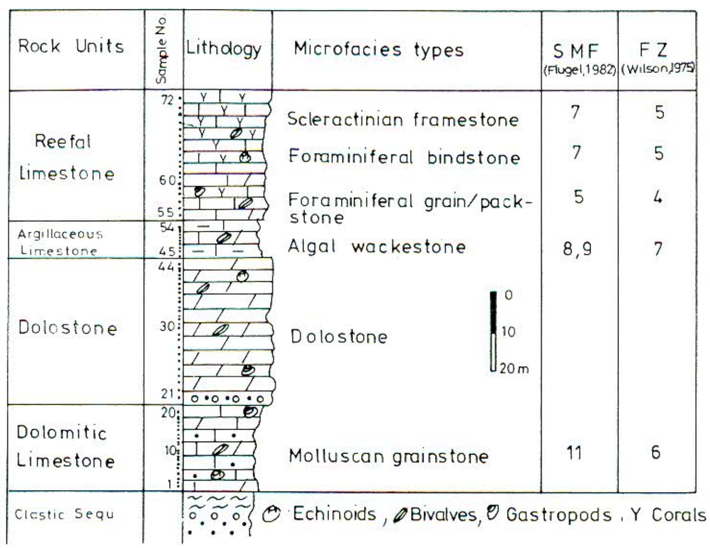


Figure 2. Stratigraphic columnar section and microfacies distribution of the Safra Formation.

Unit I (Dolomitic limestone). This unit overlies the Lower Miocene clastic succession. It attains a thickness of 22.5 m, light yellowish, massive, sandy, hard, fossiliferous with bivalves *Ostrea virleti, Dosinia exoleta, Chama gryphoides,*

Lithodomus cf. *aturensis, Meretrix erycinoides* and badly preserved molds of pectinids and echinoids.

Unit II (Dolostone). This unit rests on a 2.5 m thick conglomeratic bed. Clasts are granule to boulder in size, but are mainly in the pebble-cobble range. The matrix is a composed of reddish ferruginous argillaceous sand. The dolostone unit attains 33.5 m thick, grey, very hard, massive, highly fractured and poorly fossiliferous with badly preserved molds of *Tellina* sp., *Pecten* sp., *Lithophaga* sp. and some spines and plates of echinoids and a few gastropod molds.

Unit III (Argillaceous limestone). This unit attains 10 m thick, grey, bioturbated, slightly compact, fossiliferous with fragmented red algae.

Unit IV (Reefal limestone). The reefal limestone unit (33 m thick) represents the uppermost part of the studied section (Fig. 3). The rocks are yellowish white, cavernous, dolomitized and closely resemble the recent patch reef in the form of asymmetric mound, isolated build ups paralleling to the paleoshore line. The unit is of rigid and massive wave resistant framework build up, mainly of corals (50-80% by volume of reef), represented by massive, irregular, branching and incrusting forms of *Porites* sp., *Stylophora* sp., *Acanthastrea* sp., *Caulastrea* sp. and *Montastrea* sp. The coralline algae are of subsidiary importance with molluscs, bryozoa, echinoids, worms, all are found in their life positions and are mostly dissolved, leaving only their molds. Abdelwahab (1991) assigned Lower Miocene age for the lower clastic succession, based on the calcareous nannoplanktons *Helicosphaera ampliaperta* and *Sphenodilus conicus*. The studied carbonates are fossiliferous with bivalves *Dosinia exoleta, Chama gryphoides, Lithodomus* cf. *aturensis* and *Meretrix erycinoides*, indicating lower and Middle Miocene age. Such species are known in the Lower and Middle Miocene deposits of southern France (in Al-Rifaiy & Cherif 1989). So, on their faunal content and stratigraphic position the studied carbonates of the Safra Formation can be assigned an Early to Middle Miocene age.

The Safra Formation is most probably equivalent to the group B of the first syn-rift transgressive marine sediments (Montenat, et al. 1988, Purser & Hotzl 1988), in the western side of the Red Sea, which is dated as uppermost Burdigalian. Also it is comparable to the Gharamoul Formation in the Gulf of Suez region which was studied previously by Ghorab & Marzouk (1967), Hamza et al. (1990), Darwish & El- Azabi (1993) and others.

MICROFACIES AND DEPOSITIONAL ENVIRONMENTS

Nomenclature of limestones in the present study follows that systems introduced by Dunham (1962) and Embry & Klovan (1972) as well as the energy index classification of Plumley et al. (1972).

Limestone facies

The following microfacies types are recognized in the studied limestones:

Algal wackestone (Fig. 4). This microfacies type is common in Unit III (Fig. 2). Micritic matrix is partially neomorphozed into microspar. Skeletal grains are mainly of monomictic bioclasts, coarse to fine red algae (*Lithothamnium* sp.,

Lithophyllum sp.), most of them are fragmented and represent about 20% of the whole rock.
Such microfacies characteristics are comparable with the standard microfacies types SMF 8, 9 of Flügel (1982), namely wackestone with whole organisms which are rooted in micrite, only few bioclasts may be micritized. Such carbonate body was deposited most probably in a shallow shelf lagoon with open circulation, just below the wave base (facies belt 7 of Wilson 1975).

Dolomitic molluscan grainstone (Fig. 5-6). This microfacies is represented by Unit I (Fig. 2). The cement is mostly of dolosparite. Skeletal grains are in the form of coarse polymictic bioclasts of bivalves, echinoids, most of them are stained by iron oxides and dolomitized. Coarse grained intraclasts are composed of lime mud, and represent about 2% of the studied sections.

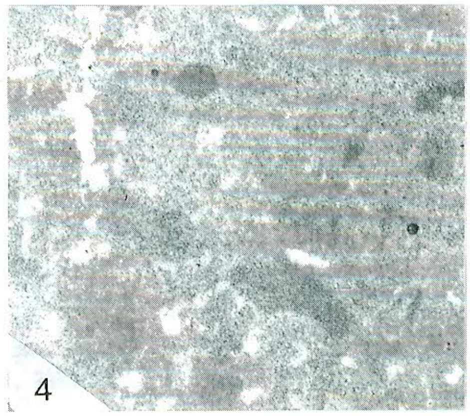
Non-carbonate particles are mainly angular to subrounded, poorly sorted, coarse to fine quartz grains (5-15%) and fresh and altered feldspars. Most of quartz grains are polycrystalline, some are cracked and the borders are replaced by carbonates.

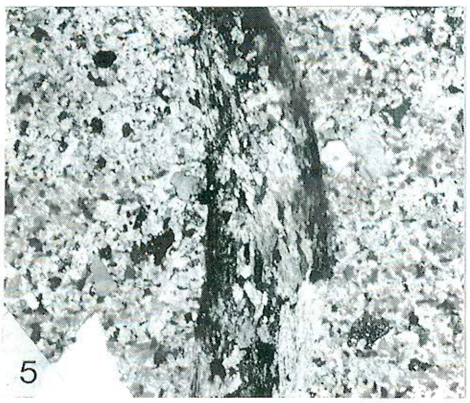
This microfacies type can be compared with SMF 11 of Flügel (1982) namely grainstone with coated bioclasts in sparry cement. It suggests deposition in winnowed platform edge with constant wave action at/or above the wave base (facies belt 6 of Wilson 1975).

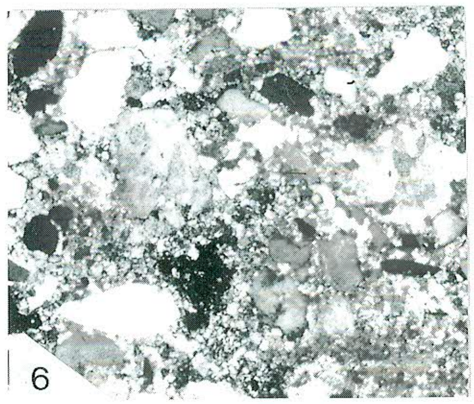
Foraminiferal grainstone/packstone (Fig. 7). This microfacies type represented by the lower part of Unit IV. In this microfacies the cement is mainly fibrous rim in the form of isopachous cement, most probably aragonite and high magnesian calcite and locally equigranular calcite cement, which increases in size towards the pore center. Skeletal grains are in the form of polymictic, coarse to fine, biomorpha and bioclasts of miliolids, *Acervulina inhaerens*, bivalves and echinoid fragments. Most of the skeletal grains show dark micritic envelopes related to the activity of endolithic algae (Bathurst 1966). The miliolid tests were locally leached producing moldic porosity. Most of these molds were later infilled by sparry calcite cement. Intraclasts in the form of poorly sorted, coarse to medium grains are fairly abundant, mostly formed of lime mud. Non carbonate grains are represented by fine to medium, rounded to subangular quartz grains.

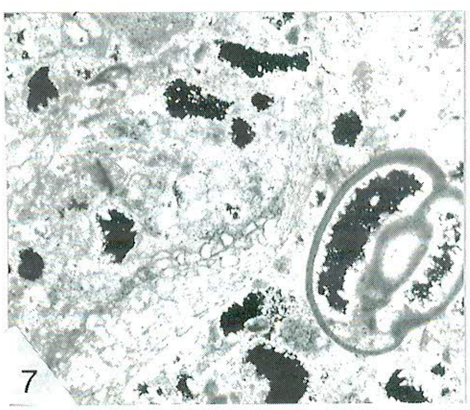
This microfacies type is similar to SMF 5 of Flügel (1982) namely foraminiferal grainstone/packstone with bioclasts derived from reef dwellers and reef builders, related to facies belt 4 of Wilson (1975), typical reef flank facies, commonly in high energy zone.

Foraminiferal bindstone (Fig. 8). This microfacies is reported in the middle part of Unit IV (Fig. 2). Sparite cement exhibits two generations of calcite crystals. The first is formed of fibrous (needle or palisade) sparite, generally found just around the particles, increases in size away from the particle surface to form the second generation of blocky sparite cement. Skeletal grains are formed of poorly sorted, coarse to fine miliolid and sessile incrusting foraminifers (*Acervulina inhaerens*). They act as sediment binder for other constituents of molluscs, corals, echinoids and bryozoans. Terrigenous grains are found in the form of a few angular, medium to fine quartz grains.









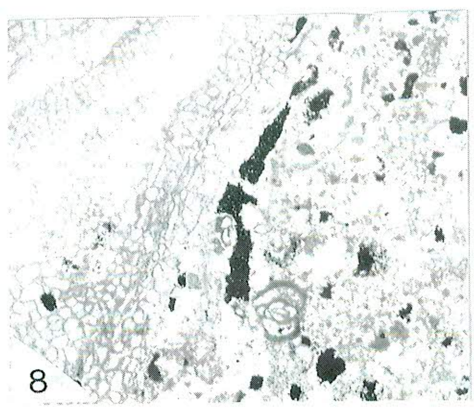
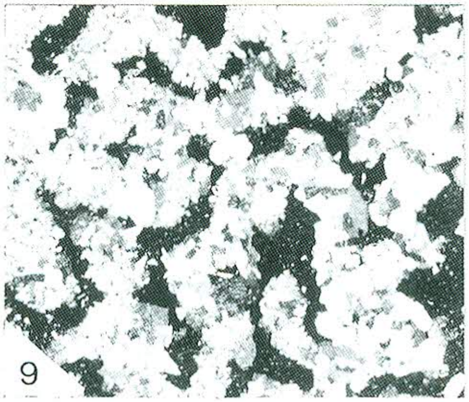
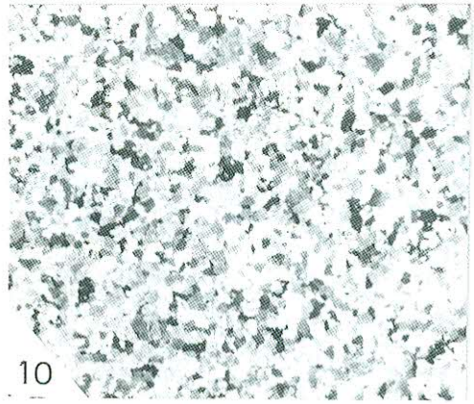
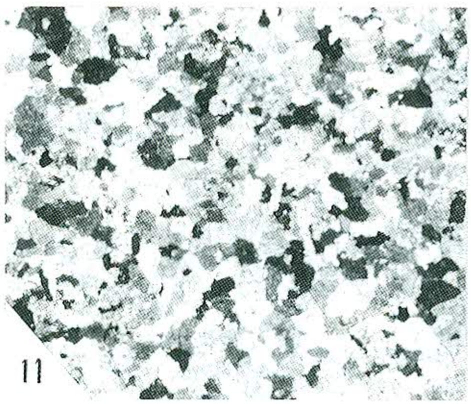


Figure 3. Cavernous, reefal limestone forming the upper most part of the Safra Formation.
Figure 4. Algal wackestone in Unit III, Safra Formation (Pl. X22).
Figure 5. Dolomitic molluscan grainstone in the upper part of Unit I, Safra Formation (CN, X22).
Figure 6. Sandy dolomitic grainstone in the lower part of Unit I, Safra Formation (CN X44).
Figure 7. Foraminiferal grainstone/packstone in the lower part of Unit IV, Safra Formation (CN X22).
Figure 8. Foraminiferal bindstone (*Acervulina inhaerens*) in middle part of Unit IV, Safra Formation (CN X44).







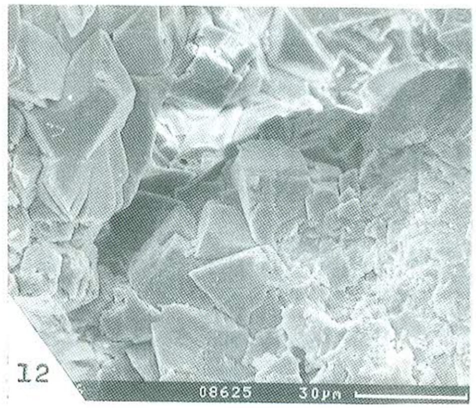


Figure 9. Scleractinian framestone (*Porites* sp.) in the upper part of Unit IV, Safra Formation (CN X44).
Figure 10. Fine grained dolostones in the lower part of Unit II, Safra Formation (CN X44).
Figure 11. Coarse grained dolostone in the upper part of Unit 11, Safra Formation (CN X44).
Figure 12. SEM microphotograph showing equiranular, idiotopic dolomite rhombs, Unit II, Safra Formation.

Scleractinian framestone (Fig. 9). This microfacies is represented by the upper part of Unit IV (Fig. 2). The scleractinian corals *Porites* sp., *Stylophora* sp., *Caulastrea* sp., *Montastrea* sp. and *Acanthastrea* sp. act as framebuilders. All the aragonitic trabecular microstructure of corals are leached and replaced by neomorphic calcite. Coral skeletons are partially to completely dolomitized or dissolved leaving only molds or vugs.

The foraminiferal bindstone and scleractinian framestone (boundstone facies) are similar to SMF 7 of Flügel (1982) and Facies belt 5 of Wilson (1975). Sessile organism in situ, represent an organic build up. Such an environment would be shallow, warm and agitated enough to produce an organic build up or reef structure.

The growth of scleractinian reef was favoured relative as a result of a rise of sea level and accommodation space was created (transgressive deposits). During the mid-clysmic event the Gulf of Suez changed to half a graben (Garfunkel & Bartov 1977). Lyberis (1988) stated that pelagic sedimentation took place in the deeper part of the basin, while on border slopes and structural highs, reefal build-

ups were developed. Moreover, scleractinian associations in the studied reefal facies show growth in upper reef slope environment.

Dolostone facies (Fig. 10-12).

This microfacies is reported from Unit II (Fig. 2). It consists of 80-90% dolomite, exhibiting different crystal sizes and shapes, probably due to several dolomitization events. Two dolostone textures have been observed. The first is the fine grained dolostone, 30-40 μm in diameter, nearly equigranular, hypidiotypic to idiotypic and mainly found in the lower part of the facies. The second is the coarser grained dolostone, 40-100 μm in diameter, mainly equigranular, idiotopic, found mostly in the upper part of the facies. Most of the studied dolomite crystals show sharp extinction. The widespread distribution of dolostones in the studied Safra Formation (about 40% of whole section) suggest the availability of considerable Mg-rich solution. Groundwater source alone was not enough for producing such widespread dolomitization.

It is believed that the presence of marine fauna (echinoids and bivalves) and the lack of evaporites suggest that dolomitization mostly took place in the zone of mixing of marine and fresh waters (Hanshaw et al. 1971, Land 1973, Badiozamani, 1973, Folk & Land 1975). The main evidence come from the cement textures observed such as sparry calcite cement within moldic voids of foraminifers and the syntaxial overgrowth of echinoids, which indicate a change from marine phreatic to fresh water phreatic conditions. The relation of dolomite crystals to other diagenetic textures indicates that dolomitization took place after dissolution of aragonite, the latter process is promoted by meteoric solution, thus the dolomitization post date the beginning of meteoric infiltration. Also dolomitization post dated the cementation phase.

GEOCHEMICAL INVESTIGATIONS

The chemical analysis data is given in Table 1 and illustrated in Figure 13. These data show that:

On basis of the calculated Ca/Mg ratio the Safra Formation can be subdivided into three geochemical units (Fig. 13). Slightly dolomitic limestone (Unit III) highly dolomitic limestone (Units I and IV) and dolostone (Unit II).

The average Sr content is 85 ppm and is very low in comparison with the world carbonates (610 ppm) reported by Turekian and Wedepohl (1961). The relatively low strontium values may indicate that the studied carbonates have been subjected to meteoric diagenesis leading to Sr depletion (Kitano & Kawasaki 1958, Kinsman 1969, Land 1973). Figure 13 shows that Sr values decrease with increasing dolomitization nature. This is in agreement with the observation of Land (1991) who suggested that dolomitic rocks have low much strontium content than pure limestone. Moreover, Qing & Mountjoy (1989) stated that neomorphism after dolomitization could be partly responsible for the lower Sr content.

The Mn values (average 809 ppm) are close to those reported in the world limestones (1100 ppm). The Ti contents is relatively higher in comparison with that given by Turekian & Wedepohl (1961). This can be attributed to the amount and nature of terrigenous materials brought to the site of deposition. Keith & Degens (1959) considered that titanium contents decrease from shallow to deep

marine environments. The nickel and iron contents are higher in the Safra Formation in comparison with the world carbonates.

The contents of Mn, Ti, Ni and Fe in the Safra formation suggest deposition in a near-shore environment.

Table 1. Distribution of some major and trace elements in the Safra Formation.

Sample No.	Rock Unit	Fe_2O_3 %	Na_2O %	K_2O %	CaO %	MgO %	SiO_2 %	L.O.I %	Sr. ppm	Ni ppm	Mn ppm	Ti ppm
72	Reefal limestone	1.66	0.31	0.26	44.29	6.13	2.10	41.66	95	60	920	830
69		1.20	0.29	0.23	42.13	8.50	2.90	41.90	100	70	760	780
66		1.10	0.31	0.19	41.80	9.10	2.15	44.12	105	75	730	790
64		0.40	0.26	0.16	42.15	7.14	1.90	43.89	90	50	780	840
61		1.20	0.24	0.23	45.00	5.13	3.10	42.13	105	80	930	870
59		1.95	0.38	0.30	42.60	6.40	2.55	40.90	110	90	800	870
55		1.40	0.14	0.10	43.13	7.80	2.13	41.50	100	85	800	870
53	Argillaceous limestone	1.46	0.80	0.10	40.90	2.15	2.60	42.50	130	85	960	1450
51		1.30	1.10	0.30	42.60	2.70	4.20	43.10	150	60	930	1600
48		1.27	0.70	0.20	39.30	2.07	4.29	43.20	130	75	890	1400
45		1.46	0.90	0.10	41.90	2.10	3.60	43.50	150	75	850	1180
44	Dolostone	1.90	0.17	0.27	27.15	23.90	0.85	46.85	50	83	900	800
41		1.30	0.13	0.20	24.10	22.40	0.75	44.13	54	75	780	830
39		1.90	0.11	0.10	27.29	23.20	2.20	45.15	50	60	800	960
34		1.90	0.24	0.19	21.17	18.15	1.80	35.18	53	75	890	830
31		1.30	0.24	0.19	28.27	24.91	0.90	47.33	51	80	800	830
28		1.30	0.19	0.10	27.13	25.16	1.30	46.11	50	83	890	1118
24		1.83	0.13	0.10	29.17	22.14	1.90	40.20	53	81	830	840
21		1.40	0.24	0.23	26.80	22.12	1.20	44.50	50	80	830	940
18	Dolomitic limestone	1.12	0.91	1.80	39.60	6.11	10.50	40.50	80	43	900	790
13		0.96	0.85	1.90	39.50	6.14	11.15	41.68	75	60	850	900
9		1.13	0.81	2.13	35.40	5.23	10.13	43.60	60	55	800	950
6		0.75	0.96	1.90	33.14	4.57	11.13	40.00	75	43	900	980
2		0.70	0.81	2.16	38.18	5.23	12.14	34.20	80	70	800	890
Average world carbonates*		0.54	0.05	0.33	42.6	7.90	5.19	-	610	20	1100	400

* Turekian and Wedepohl (1961)

CONCLUSIONS

From the obtained data, the following main points could be summarized.

(1) The Miocene sequence exposed at Gabal El-Safra consists of a clastic succession at the base conformably overlain by carbonate sequence (102 m thick). Based on the faunal content and stratigraphic position, the studied carbonates of the Safra Formation can be assigned an Early to Middle Miocene age. Lithologically it is subdivided into four informal units from base to top: dolomitic limestone, dolostone, argillaceous limestone and reefal limestone.

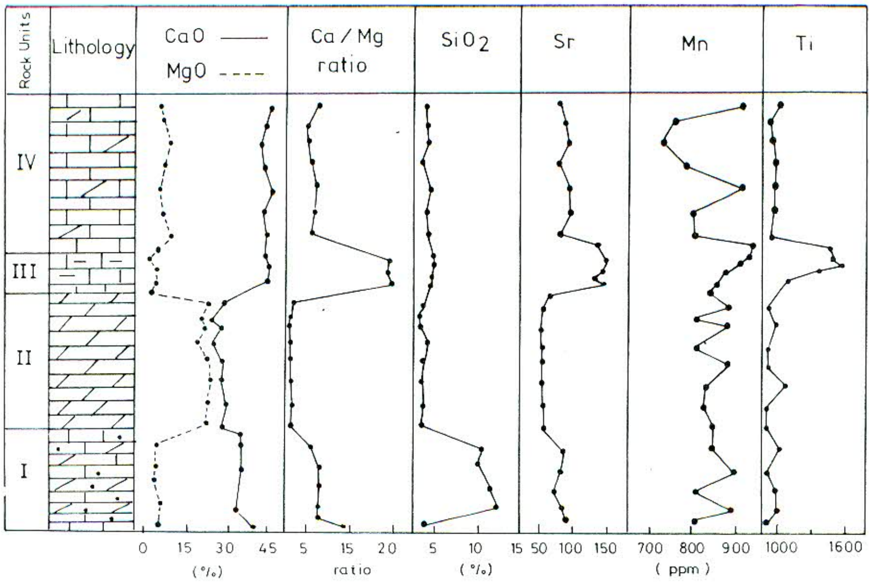


Figure 13. Vertical distribution of some chemical components in the Safra Formation.

(2) Microscopic investigations of the carbonates of the Safra Formation reveal the presence of the following microfacies associations: algal wackestone, molluscan grainstone, foraminiferal grainstone/packstone, foraminiferal bindstone and scleractinian framestone.

(3) Dolomitization was the main diagenetic feature that affected the studied carbonates. It took place mostly in the zone of mixing of marine and fresh waters. The diagenetic textures indicate that dolomitization postdated the meteoric infiltration and cementation phase.

(4) The calculated Ca/Mg ratios indicate that the studied succession consists of slightly dolomitic limestones, highly dolomitic limestones and dolostones.

(5) The reported average Sr content is very low in comparison with the average world carbonates. This may indicate that the Safra Formation was subjected to meteoric diagenesis.

(6) Field observations combined with microfacies analysis, faunal content and trace elements revealed that the carbonate Safra Formation was deposited in shallow shelf lagoon, winnowed platform and finally organic reef build up environments.

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Eocene biostratigraphy of Wadi Wardan, Sinai, with especial emphasis on calcareous nannofossils

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ABSTRACT. *The studied succession of Wadi Wardan spans the Middle and Late Eocene. The Late Eocene part of the succession starts within the Khaboba Formation. The recognized planktic foraminiferal and calcareous nannofossil zones are discussed in the text.*

INTRODUCTION

Several contributions to the Eocene biostratigraphy of Sinai have been made since the works of Ansary (1955), based on benthic foraminifera, and of Viotti & El Demerdash (1969), based on planktic foraminifera. The upper part of the Eocene succession in Sinai (Khaboba Formation, Tanka Formation and Tayiba Formation) was assigned to the Upper Eocene by some workers (Viotti & El Demerdash 1969, Bassiouni et al. 1980, Barakat et al. 1988, Haggag 1989, 1992) and to the Middle Eocene by others (El Heiny & Morsi 1986). Lately, Abul-Nasr (1993a, b) separated important Middle and Upper Eocene index planktic foraminiferal species from west central Sinai and Wadi Wardan area (Fig. 1), respectively. Abul-Nasr (1993a) recognized the *Orbulinoides beckmanni* Zone in west central Sinai based on the occurrence of the nominate species near the top of the Darat Formation. He also confirmed the occurrence of the Upper Eocene based on the rich occurrence of *Globigerinatheka semiinvoluta* in the upper part of the Khaboba Formation and the Tanka Formation in Wadi Wardan. The calcareous nannofossils are used here to shed more light on the biostratigraphy of the Eocene of Sinai, and are correlated with the results obtained from planktic foraminifera. The succession of Wadi Wardan has been selected for such purpose.

EOCENE SUCCESSION OF WADI WARDAN

The Eocene succession which is exposed near the eastern end of Wadi Wardan does not differ much from that of west central Sinai. They all were described in detail by Abul-Nasr (1990, 1992, 1993a, b). This succession consists, from base to top, of the Darat Formation, the Khaboba Formation, the Tanka Formation and the Tayiba Formation (Fig. 2). The Darat Formation consists of marls with occasional limestone interbeds, turning upward into more massive marl with thin shale interbeds and finally a thick unit of well bedded limestone with thin marl intercalations. The Khaboba Formation consists of interbedded shales and marls in the lower part and massive gypsiferous shale in the upper part.The boundary between these two parts marks the Middle/Upper Eocene boundary as shown by Abul-Nasr (1993a, b). The Tanka Formation consists of in-