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Petrography and depositional environment of the Paleocene-Eocene sequence in Hammam Faraun, southern Sinai, Egypt.

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Abstract: The Paleocene- Eocene succession in the Hammam Faraun area consists of eight conformable formations; namely (from older to younger): the Esna Shale, Thebes, Darat, Samalut, Khaboba, Mokattam, Tanka and Tayiba. Generally, carbonates constitute the major part of the studied sequence which contains also chert and shale interbeds. Petrographically, these rocks are represented by the microfacies associations: micrite, foraminiferal biomicrite, pel-foraminiferal biomicrite, pel-algal foraminiferal biomicrite, sparry micrite, microsparite, foraminiferal pel-biomicrosparite, dolomicrosparite, pel-foraminiferal biosparite, pel-algal-foraminiferal biosparite and microcrystalline quartz (chert). Calcite dominates in the limestones, while quartz and dolomite are the most abundant constituents in the chert and dolomitic limestone interbeds; respectively. Hematite, halite and gypsum exist in varying proportion in the studied rocks. Shale intervals are occasional and consist mainly of montmorillonite, kaolinite and illite. The studied Paleocene- Eocene sequence accumulated in shallow to deep neritic marine environments during a regressive phase of the sea characterized by pronounced sea-level oscillations. The original textural and compositional characteristics of the studied carbonates were modified by several diagenetic possesses represented by recrystallization (neomorphism), cementation, glauconitization, dolomitization and silicification.

Key words: Sinai, Hammam Faraun, Eocene, Paleocene, carbonates, marine environments, diagenesis.

INTRODUCTION

The Hammam Faraun area lies in the northeastern part of the Suez rift between the narrow coastal plain of the Gulf of Suez and the topographically high area extending from El Tih plateau, (1100 a.s.l) southward to Gebel Nukhul in southern Sinai. This area has a fairly high relief and is bounded at the south by El-Markha plain and at the north by Wadi Gharandal. Several topographic highs exist in the study area and are represented by questas and isolated mountains. The area may be divided roughly into three northwest-oriented longitudinal subareas. The northwest and southwestern subareas are topographically higher than the central province which contains abundant Quaternary terraces. Several wadis drain the area westward into the Gulf of Suez.

The study area is highly dissected by faults. These are mainly normal and, in a few cases, diagonal- slip. A thrust fault was identified affecting the Eocene succession in the northeastern part of the area. Also, several folds and monoclines also exist in the study area (Abdeen 1988).

The present study is devoted to the investigation of the detail microfacies associations, mineral composition, depositional environments and diagenesis of the Paleocene- Eocene sequence in three selected sections; namely: Hammam Faraun, North El- Markha, and Wadi Feiran sections (Fig.1).

MATERIALS AND METHODS

The selected three stratigraphic sections were carefully measured and sampled. A total of 54 thin sections of the limestone samples and 8 thin sections of the chert samples were carefully examined using a polarizing microscope. X-ray diffraction analysis was conducted on twenty-seven selected samples to identify the mineral composition of the rocks. Ten bulk samples were used to identify the carbonate and non-carbonate minerals. The clay (<2 μm) fractions of selected seventeen samples were separated from their acid-insoluble residues after treating with HCl(10%). These fractions were used to prepare three mounts: oriented-particles, untreated,

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saturated with ethylene glycol, and heated at 550 °C for two hours. These mounts were subjected to X-ray diffractomety using a BRUKER - D8 advanced diffractometer with Cu Ka target and secondary monochromater available at the Central Metallurgical Research and Development Institute, Egypt. The diffraction runs were made at 40KV and 40 mA. The scanning speed was 2θ/min in the range 2° to 40° 2θ for the oriented-mount samples, and 2° to 60° 2θ for the bulk samples (2θ =2°/min). The identification of the clay minerals was carried out using the schemes adopted by Carroll (1970) and Hard and Tucker (1988). Semi-quantitative determination of the detected clay minerals was achieved by applying the method proposed by Siegel *et al*. (1981)

Fig. 1: Satellite image of the study area showing the location of the studied sections.

which is based on the use of the peak heights of the strongest reflections of the individual clay minerals as a direct measure of their relative proportions in the mixture.

RESULT AND DISCUSSION

Lithostratigraphy:

The Hammam Faraun Section:

This section lies at 46km to the north of Abu Rudeis town and is about 410m thick. It consists of the formations (from older to younger): the Esna Shale (~20m), the Thebes (~167m), the Darat (~85m), the Khaboba (~93m), the Tanka (~21m) , the Tayiba (~23m) and the Early Miocene Nukhul Formation (Fig. 2). Except for the latter, the boundaries between all the rock units are conformable.

The North El- Markha Section:

This section lies at 12km to the north of Abu Rudeis town and measures ~283m (Fig. 3). It is made up of (from older to younger): the Esna Shale (~41m), the Thebes Formation (~161m), the Darat Formation (~50m) and the Khaboba Formation (~30.5m). All these rock unites have conformable relationships.

The Wadi Feiran Section:

This section lies at 42km to the south of Abu Rudeis town and is about 226m thick (Fig. 4). The sucession consists of the formations (from older to younger): the Esna Shale (~31m), the Thebes (~110m), the Samalut (~77m), the Mokattam (~7m) and the Miocene Nukhul Formation. Except for the latter, all the rock units have conformable relationships.

In conclusion, the exposed Paleocene- Eocene sedimentary sequence in the study area consists of eight rock units. Six of these units are encountered in the Hammam Faraun and North El- Markha sections these are (from oldest to youngest): the Esna Shale, Thebes, Darat, Khaboba, Tanka and Tayiba formations. Two rock units; namely the Samalut (equivalent to Darat) and the Mokattam (equivalent to Khaboba) formations are encountered in the Wadi Feiran section. The following is a detailed description of each of these rock units.

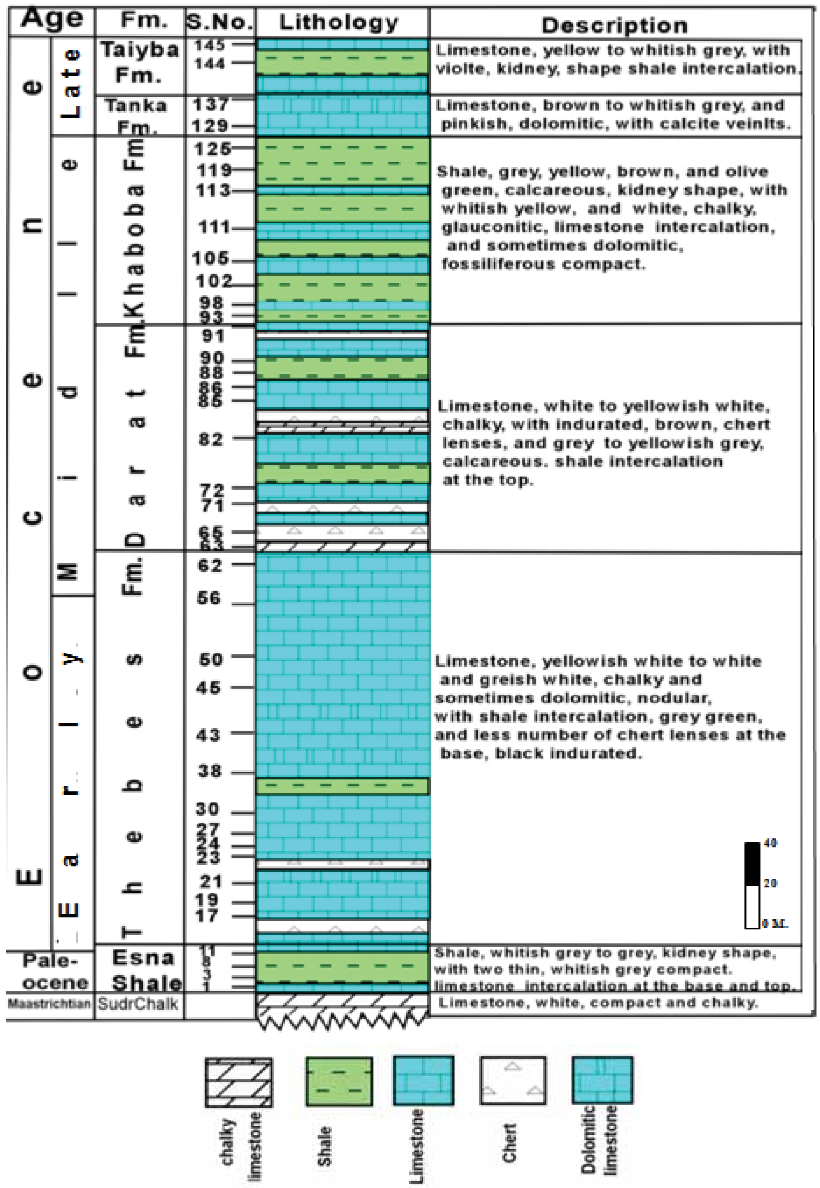


Fig. 2: Lithological columnar section of the Paleocene-Eocene sequence in Gebel Hamman Faraun section, Southern Sinal, Egypt.

The Esna Shale (Paleocene to Early Eocene):

In the Hammam Faraun section, the Esna Shale is relatively thin (~ 20m thick) and displays conformable relationship and gradational contacts with the underlying Sudr Chalk and the overlying Thebes Formation (Fig. 5). The Esna Shale consists of grey to green, semi-compact shale interbedded with two light grey, argillaceous limestone beds (3m thick).

The Esna Shale attains a maximum thickness (41.3m) in the North El Markha section. It consists of yellowish white, greyish brown, highly fractured shale containing gypsum veinlets and interbedded with light yellow, hard limestone and yellowish brown disconnected chert bands (Fig. 6). In the Wadi Feiran section, the Esna Shale measures ~31.5m and consists of green to brown, grey to reddish brown, highly fractured shale containing gypsum veinlets and iron oxides and pyrite concretions (Figs 7&8).

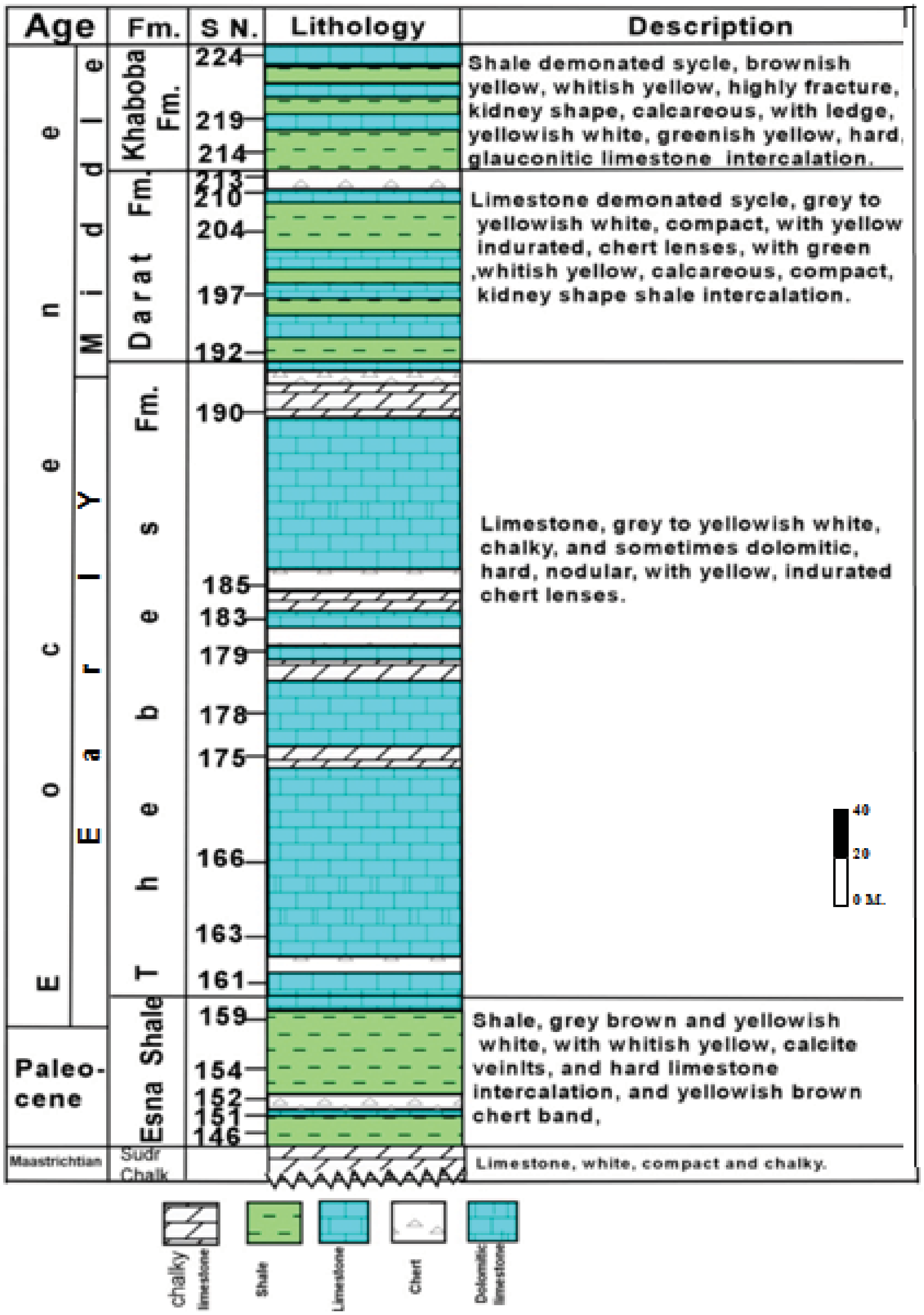


Fig. 3: Lithological columnar section of the Paleocene-Eocene sequence in North El-Markha section, Southern Sinal, Egypt.

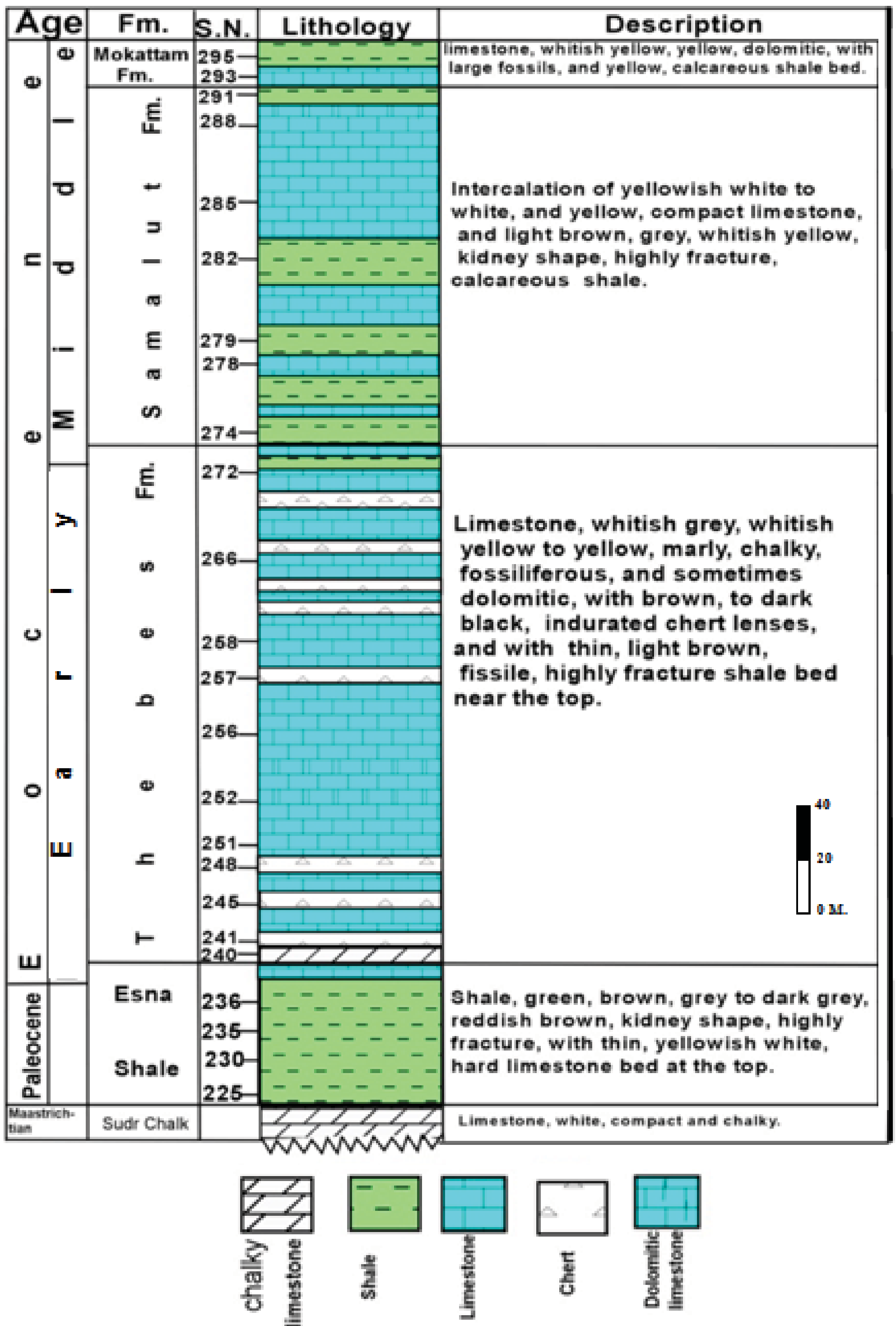


Fig. 4: Lithological columnar section of the Paleocene-Eocene sequence in Wadi Feiran section, Southern Sinai, Egypt.

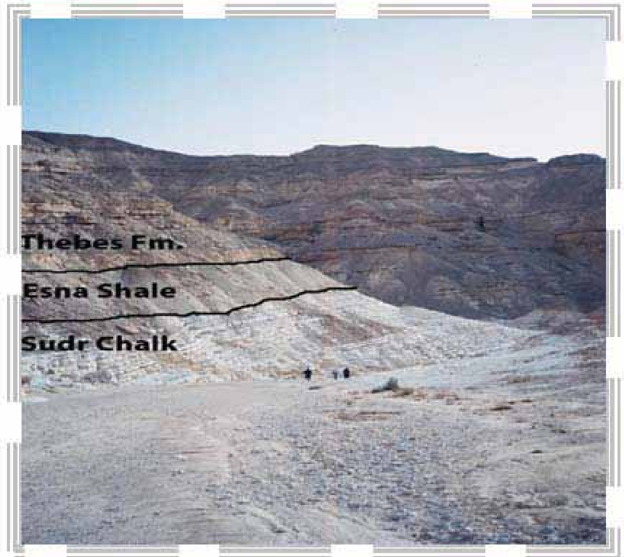


Fig. 5: The contacts between the Sudr Chalk, Esna Shale and Thebes Formation in the Hammam Faraun section.

Fig. 6: The disconnected chert bands in the Esna Shale bed no. (2), in the North El- Markha section.

The Thebes Formation (Early to Early Middle Eocene):

In the Hammam Faraun section, the Thebes Formation (~167 m thick) is composed of limestone, pale grey to grey, yellowish white, bedded, chalky, argillaceous at the base, moderately compact, with black disconnected chert bands and lenses (Fig. 5). It changes upwards to limestone buff, compact, dolomitic and fossiliferous (large forams). In this section, the limestone is intruded by a Tertiary basic dyke (Fig. 9)The contact between the Thebes Formation and the overlying Darat Formation is characterized by the presence of yellowish white semi-compact limestone.

In the North El Markha section, the Thebes Formation (~161 m thick) consists of dolomitic limestone, grey to yellowish white, more chalky at the top and contain disconnected chert lenses of varying diameters.

In the Wadi Feiran section, the Thebes Formation (~110 m. thick) is composed of limestone, pale grey to yellow, compact, chalky, argillaceous, fossiliferous, with disconnected bands, lenses and concretions of chert (Fig. 10). A ledge of yellowish grey dolomitic limestone is present in the middle part of the rock unit. Intercalations, light brown, highly fractured, gypsiferous shaleare present in the upper part of the formation.

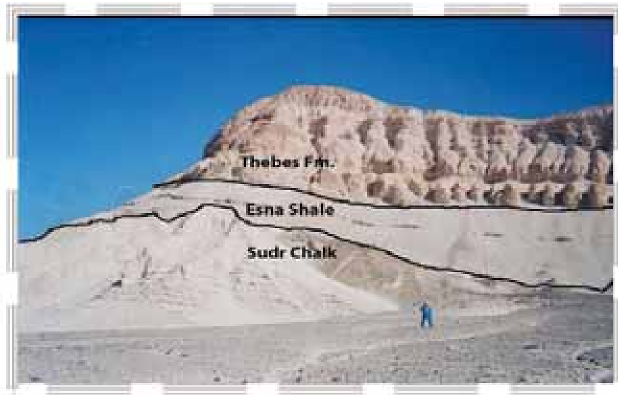


Fig. 7: The contacts between Sudr Chalk, Esna Shale and Thebes Formation in Wadi Feiran section.

Fig. 8: The iron oxide concretions in the Esna Shale in Wadi Feiran section.

Fig. 9: The effect of Tertiary basic dyke (arrow) on the rock of the Thebes Formation in the Hammam Faraun section.

Fig. 10: The disconnected chert bands parallel to the bedding planes of the Thebes limestone running in Wadi Feiran section.

The Darat Formation (Middle Eocene):

In the Hammam Faraun section, the Darat Formation (~85m thick) consists of limestone, white, yellowish white, and pink, chalky, fractured, with brown chert lenses and grey and yellowish grey shale intercalations. In the North El Markha section, the Darat Formation (~50 m thick) consists of three thick beds. The lowest (~30 m. thick) is made up of limestone, grey, chalky, compact and contains shale and marl lenses. This bed is followed upward by a bed (~15m) of shale, yellow, calcareous, compact to semi- compact (Fig.11). The upper bed (~5m thick) is made up of limestone yellowish white, compact and contains chert lenses and concretions.

Fig. 11: The contacts between the Darat, Khaboba and the lower part of the Miocene Nukhul Formation. A thick shale bed (white arrow) near the top of the Darat Formation is topped by limestone in North El- Markha section.

The Samalut Formation (Middle Eocene):

In the Wadi Feiran section, the Samalut Formation (~ 87m thick) consists of intercalations of yellowish white, white, yellow, compact limestone and light brown, grey and light yellow, highly fractured calcareous shale (Fig. 12). In the Hammam Faraun and the North El Markha sections, the Samalut Formation is equivalent to Darat Formation. It is amounts to 77.5m thick and consists of shale, pale yellow to yellow and light brown to brownish yellow, highly fractured, with gypsum veinlets, alternating with limestone, yellowish white to yellow, compact and contains calcite veinlets. This succession is followed upward by limestone, yellowish white, dolomitic, compact with thin intercalations of shale.

The Khaboba Formation (Late Middle Eocene):

In the Hammam Faraun section, the Khaboba Formation measures about 90m and consists mainly of intercalations of limestone and shale beds (Fig. 13). The limestone is yellowish white to pale yellow, chalky. highly fractured and becomes glauconitic upward. The shale beds are whitish grey to grey and yellow

Fig. 12: The contacts between the Thebes, Samalut and Mokattam formations in Wadi Feiran section

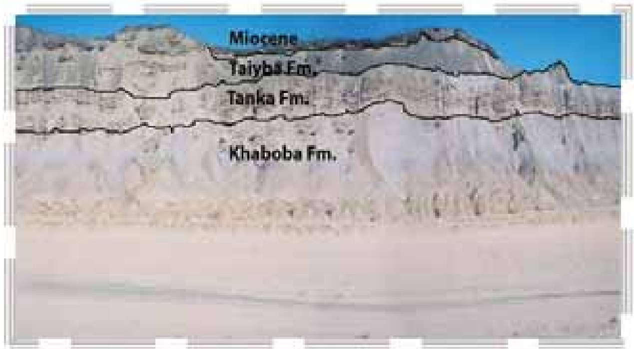


Fig. 13: The contacts between the Khaboba, Tanka, Tayiba and the lower part of the Miocene Nukhul formations in the Hammam Faraun section.

calcareous with gypsum veinlets. In the North El Markha section, the Khaboba Formation is thinner (~30 m. thick) than that in the Hammam Faraun section. Lithologically, the formation is dominated by shale (~24m. thick) which is pale to brownish yellow, highly fractured, with gypsum veinlets, and thin intercalations of limestone, yellowish white, compact, occasionally glauconitic (6.5m. thick) with rare shark teeth (Fig. 11).

The Mokattam Formation (Late Middle Eocene):

The Mokattam Formation was encountered only in Wadi Feiran section where it is 7m thick and unconformably overlain by the Quaternary deposits. The lower part of the formation is made up of limestone, light yellow to yellow, compact, dolomitic, marly, with large fossils. While its upper part consists of yellow, moderately fractured shale. In the Hammam Faraun and North El Markha sections, the Mokattam Formation is equivalent to the Khaboba Formation and consists of a limestone bed (3m thick) which is light yellow to yellow, dolomitic and fossiliferous. It is followed upward by 4m of shale, yellow, calcareous and compact.

The Tanka Formation (Late Eocene):

The Tanka Formation (~21m. thick) was encountered only in the Hammam Faraun section (Fig. 13). It is composed of limestone, pale grey and pinkish grey, chalky, dolomitic in parts, and contains calcite veinlets.

G. The Tayiba Formation (Late Eocene):

This formation was encountered only in the Hammam Faraun section where it measures ~23m and consists of two limestone beds (Fig. 13). The lower bed (13.5m thick) is light grey to yellow, hard, marly and interbedded with shale. The upper bed (10m thick) is creamy to violet and highly fractured shale.

Stratigraphic Correlation:

The correlation between the studied three stratigraphic sections (Fig. 14) reveals that the Tayiba and Tanka formations are exposed only in the Hammam Faraun section which may indicate that these two rock units could have been deposited in the whole area but were later eroded in the other topographically high two localities. The correlation chart shows also a southward decrease in thicknesses of the Thebes, Darat and Khaboba formations. This may be attributed to the paleotopography of the area or variation in the environment of deposition. As for the Esna Shale, the correlation chart shows irregular variations in its thickness from one locality to the other which suggests deposition in an area of varying topography.

Microfacies Analysis:

The classifications of Dunham (1962) and Folk (1974) were used to describe and nomenclate the studied limestones. Also, the recognized microfacies types were correlated with the standard types of Wilson (1975) (plates 1 and 2). The obtained results led to the delineation of 11 microfacies associations comprising 40 submicrofacies types (Table 1 and Figs 15-17). The following is a detailed description of these microfacies associations (arranged based on the decrease in abundance).

Foraminiferal Biomicrite (Wackestone-packstone) (Plate 1A-1E):

This microfacies is the most dominant type. It is encountered in all the studied sections and most of the rock units except for the Tanka and Mokattam formations. It comprises three subfacies; namely: ferruginous, glauconitic and sandy foraminiferal biomicrite which represented by packstone and less common by wackestone.

Generally, the foraminiferal biomicrite microfacies associations consist mainly of abundant foraminiferal tests (20-70% in packstone, and 12-15% in wackestone) and shell fragments. The former tests are mainly planktonic. Their chambers together with the shell fragments are filled with sparite. Quartz grains, green glauconitic pellets and dolomite rhombs are occasionally present. All these allochemical components are embedded in a micritic matrix. A few sparitic calcite patches and veinlets are present in the rock fragments. Iron oxide are occasionally present mainly staining foraminiferal tests and the rock matrix.

In the ferruginous foraminiferal biomicrite variety, reddish brown iron oxides (~10%) stain a large part of the rock components. The glauconitic variety contains green glauconitic grains which are fine to coarse sand sized and subrounded to rounded. Some of the foraminiferal tests are stained or filled with glauconite. In the sandy foraminiferal biomicrite variety the sand grains are very fine to fine and angular to subrounded.

Table 1: The identified microfacies associations in the three studied sections

Age	Rock units	Hammam Faraun section		North El- Markha section		Wadi Feiran section	
		Folk (1959)	Dunham (1962)	Folk (1959)	Dunham (1962)	Folk (1959)	Dunham (1962)
Paleocene to Early Eocene	Esna Shale	Foraminiferal biomicrite	Packstone	Foraminiferal biomicrite	Packstone	-	-
				Ferruginous foraminiferal biomicrite	Packstone		
		Foraminiferal biomicrite	Wackestone	Foraminiferal biomicrite	Wackestone		
				Microcrystalline quartz chert		-	
Early to Middle Eocene	Thebes Formation	Foraminiferal biomicrite	Wackestone	Foraminiferal biomicrite	Packstone	Foraminiferal biomicrite	Packstone
		Pel-algal foraminiferal biomicrite	Packstone	Ferruginous foraminiferal biomicrite	Wackestone	Dolomicrosparite-sparite	Crystalline carbonate
		Pel- foraminiferal biosparite	Grainstone				
		Pel- foraminiferal biomicrite	Packstone			Foraminiferal biomicrite	Wackestone
		Foraminiferal biomicrite	Packstone	Microcrystalline quartz chert	-		
		Foraminiferal-pel biomicrosparite	Grainstone			Microcrystalline quartz chert	-
		Pel-algal foraminiferal biosparite	Grainstone				
Middle Eocene	Darat (Samalut) Formation	Foraminiferal biomicrite	Wackestone	Foraminiferal biosparite	Grainstone	Ferruginous foraminiferal biomicrite	Wackestone
				Foraminiferal biomicrite	Packstone	Sparry micrite	Crystalline carbonate
		Microcrystalline quartz chert	-	Microcrystalline quartz chert	-	Micrite	Mudstone
Middle Eocene	Khaboba (Mokattam) Formation	Foraminiferal biomicrite	Wackestone	Foraminiferal biomicrite	Packstone	Dolomicrosparite	Crystalline carbonate
		Microsparite	Crystalline carbonate				
		Foraminiferal biomicrite	Packstone				
		Ferruginous foraminiferal biomicrite	Packstone				
		Glauconitic foraminiferal biomicrite	Packstone				
		Sandy micrite	Mudstone				
Late Eocene	Tanka Formation	Sandy sparry micrite	Crystalline carbonate	-	-	-	-
Late Eocene	Tayiba Formation	Sandy foraminiferal biomicrite	Wackestone	-	-	-	-
		Sandy micrite	Mudstone				

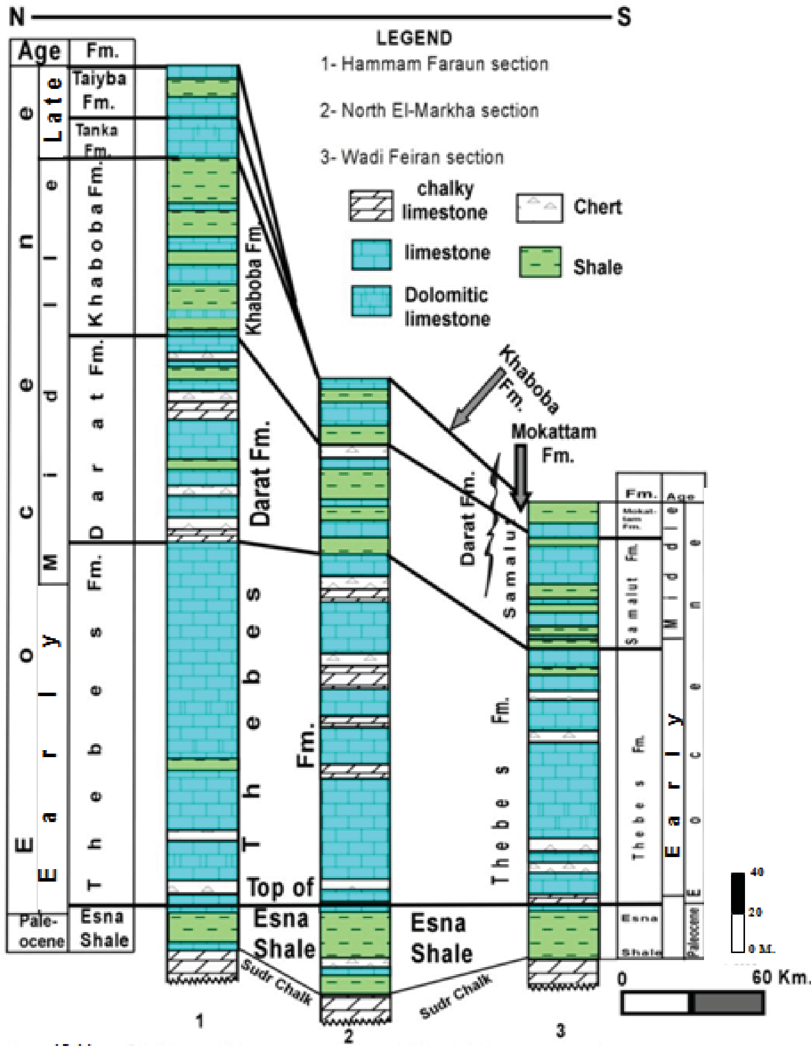


Fig. 14: Strtiigraphic correlation of the Paleocene-Eocene rock units in hammam Faraun area, southern Sinai, Egypt.

Microcrystalline Quartz Chert:

This microfacies is encountered in the middle part of the Esna Shale in the North El-Markha section, in the middle part and near to the top of the Thebes Formation in North El-Markha and Wadi Feiran sections; respectively, and in the lower part and the lower and upper parts of Darat Formation in the Hammam Faraun and North El-Markha sections, respectively. This lithofacies consists of microcrystalline quartz and minor dolomite rhombs, subhedral quartz crystals and iron oxide, sparite and numerous micrite patches (plate-1F). The microcrystalline quartz exists as a fine mosaic of quartz crystals with even to uneven extinction and sutured contacts.

Micrite (Lime mudstone):

This microfacies is encountered in the upper part of the Samalut Formation in Wadi Feiran section. A sandy variety exists at the top of the middle part of the Khaboba Formation and the upper part of the Tayiba Formation in the Hammam Faraun section. It consists of rare foraminiferal tests, iron oxide, and light green, fine, rounded glauconitic pellets, all are embedded in a micritic matrix (75-88%). Sparry calcite patches and veinlets are occasionally present in the sandy micrite variety. Very fine, suhedral to euhedral quartz grains (10-20%) are present.

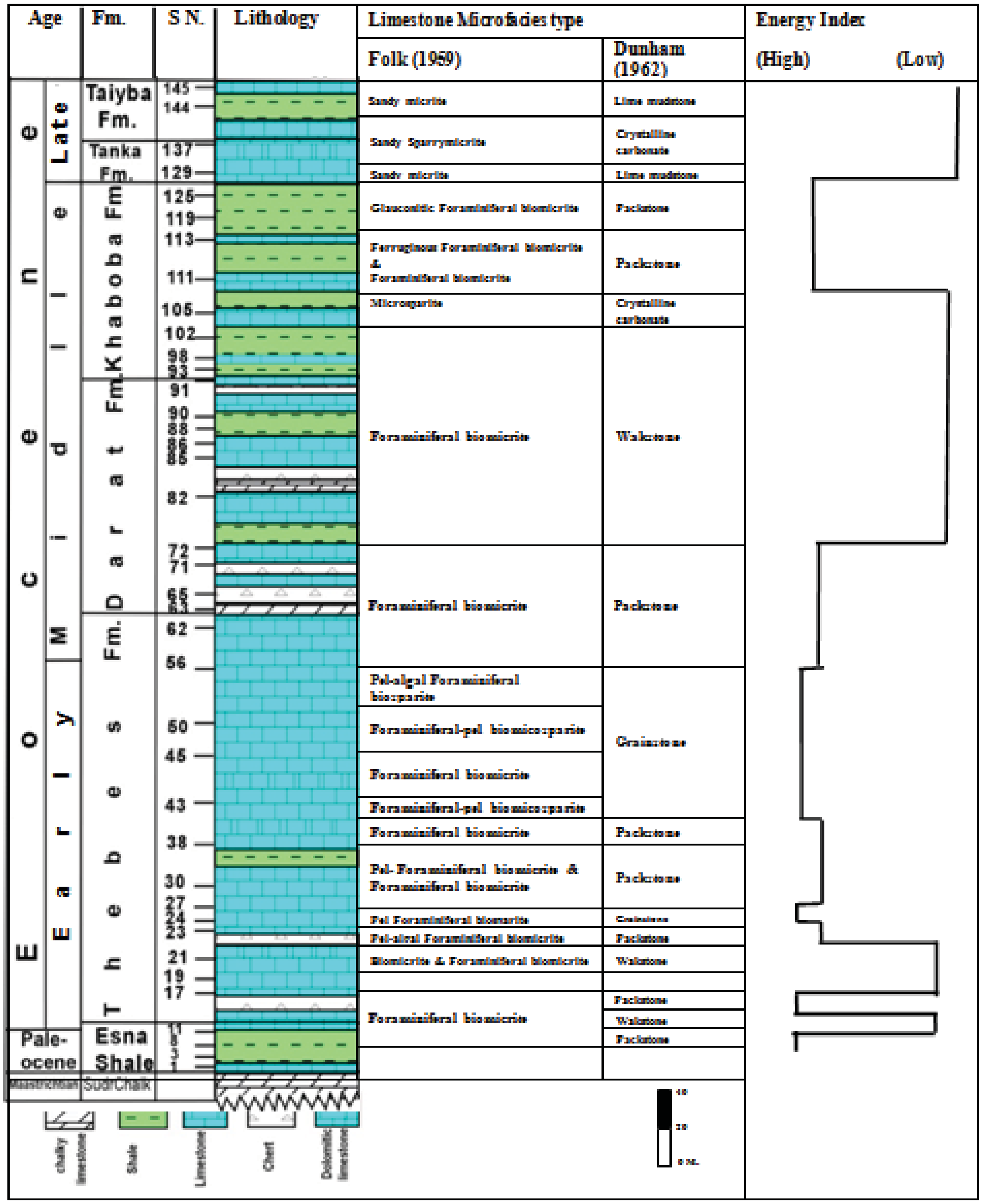


Fig. 15: The vertical variation in the microfacies associations and depositional energy in the Hammam Faraun section.

Sparry Micrite (Crystalline Carbonate):

This microfacies is encountered in the middle part of Samalut Formation in Wadi Feiran section. It consists of a micro- to macrocrystalline calcite groundmass (75-95 %) containing a few glauconitic pellets, very fine quartz grains and iron oxides. Veinlets of sparry calcite are occasional. It contains 5-15% quartz grains (plate-2A). Sandy sparry micrite variety was recorded in the lower and upper parts of the Tanka Formation in Hammam Faraun section.

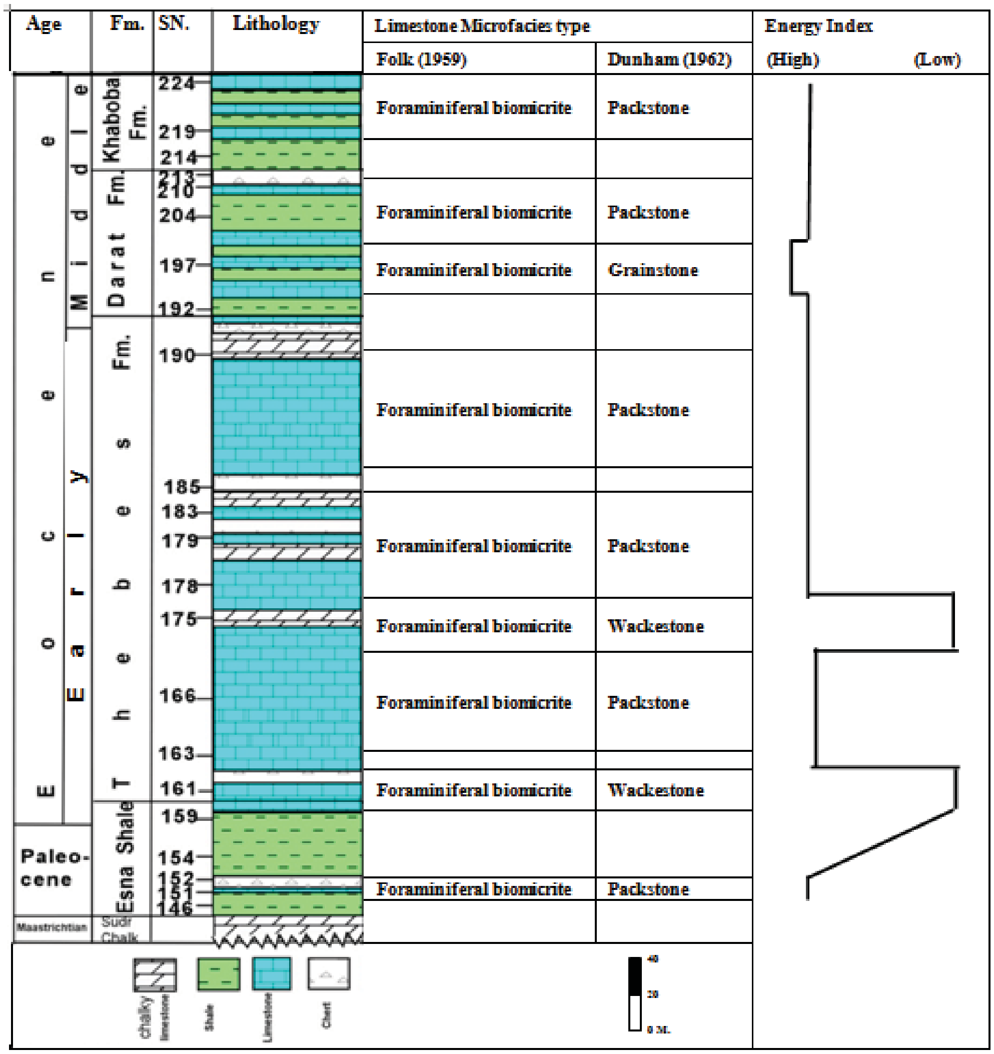


Fig. 16: The vertical variation in the microfacies associations and depositional energy in the North El Markha section.

Plate-1

A: Photomicrograph showing ferruginous foraminiferal biomicrite (packstone) microfacies composed of dark brown ferruginous micrite groundmass contains skeletal grains represented by foraminiferal planktonic tests filled with sparite and iron oxide (North El Markha section, Esna Shale, sample 151, plane polarized light, X. 20).

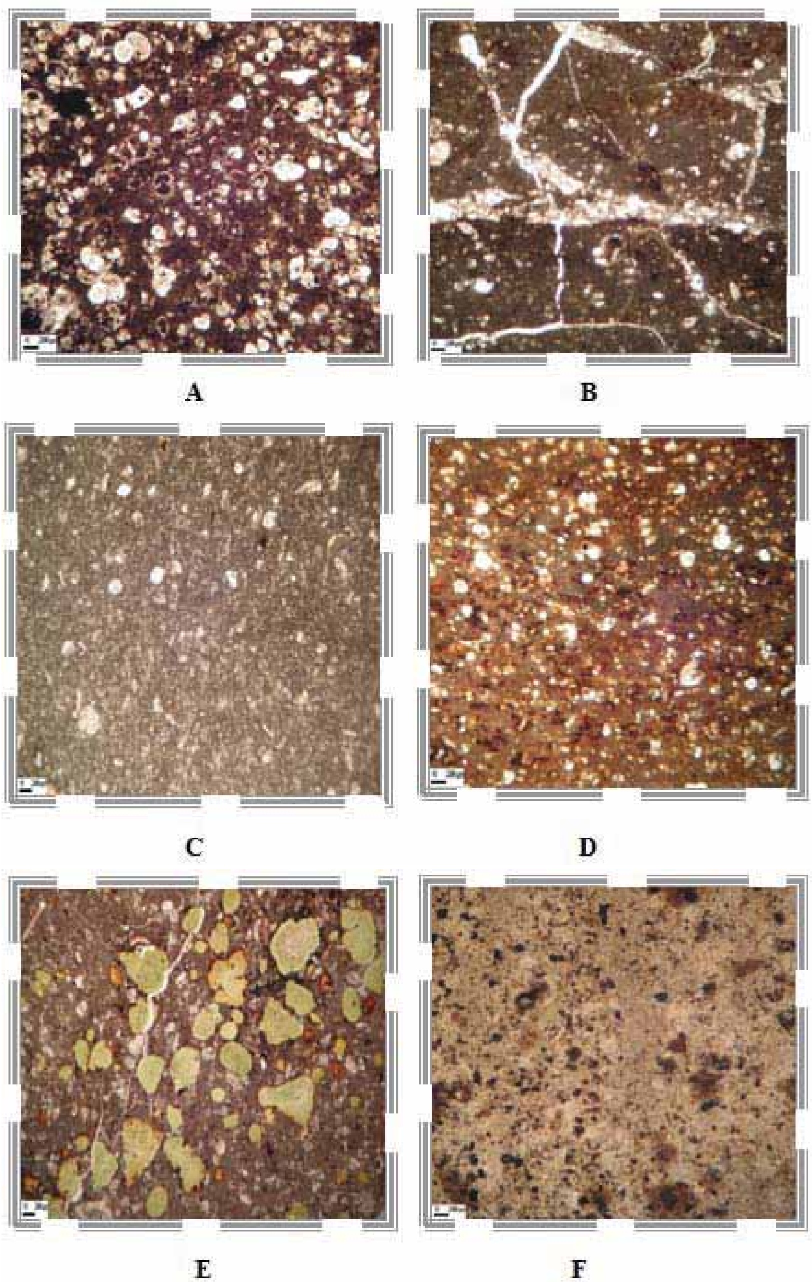
B: Photomicrograph showing foraminiferal biomicrite (packstone) composed of brown micritic matrix containing skeletal grains of foraminiferal planktonic tests filled with sparite. Calcite veinlets are present, North El Markha section (Thebes Formation, sample 166, plane polarized light, X. 20).

C: Photomicrograph showing foraminiferal biomicrite (wackestone) consisting of planktonic foraminiferal tests and a few iron oxide patches embedded in a micritic matrix. The chambers of the foraminiferal tests are filled with sparite (Hammam Faraun section, Khaboba Formation, sample 98, plane polarized light, X. 20).

D: Photomicrograph showing ferruginous foraminiferal biomicrite (packstone) the rock is composed of reddish brown ferruginous micrite groundmass with skeletal grains of foraminiferal planktonic tests filled with sparite and iron oxide (Hammam Faraun section, sample 111, the Khaboba Formation, plane polarized light, X. 20).

E: Photomicrograph showing glauconitic foraminiferal biomicrite (packstone) consists of skeletal grains of foraminiferal planktonic tests filled with sparite embedded in micritic matrix. Pale green glauconitic grains coated with iron oxides, and sparite veinlets are present (Hammam Faraun section, Khaboba Formation, sample 113, plane polarized light, X. 20).

F: Photomicrograph showing microcrystalline chert with rare iron oxides patches, rare sparite patches, and numerous micritic patches (North El Markha, Esna Shale, sample 152, plane polarized light, X. 20).



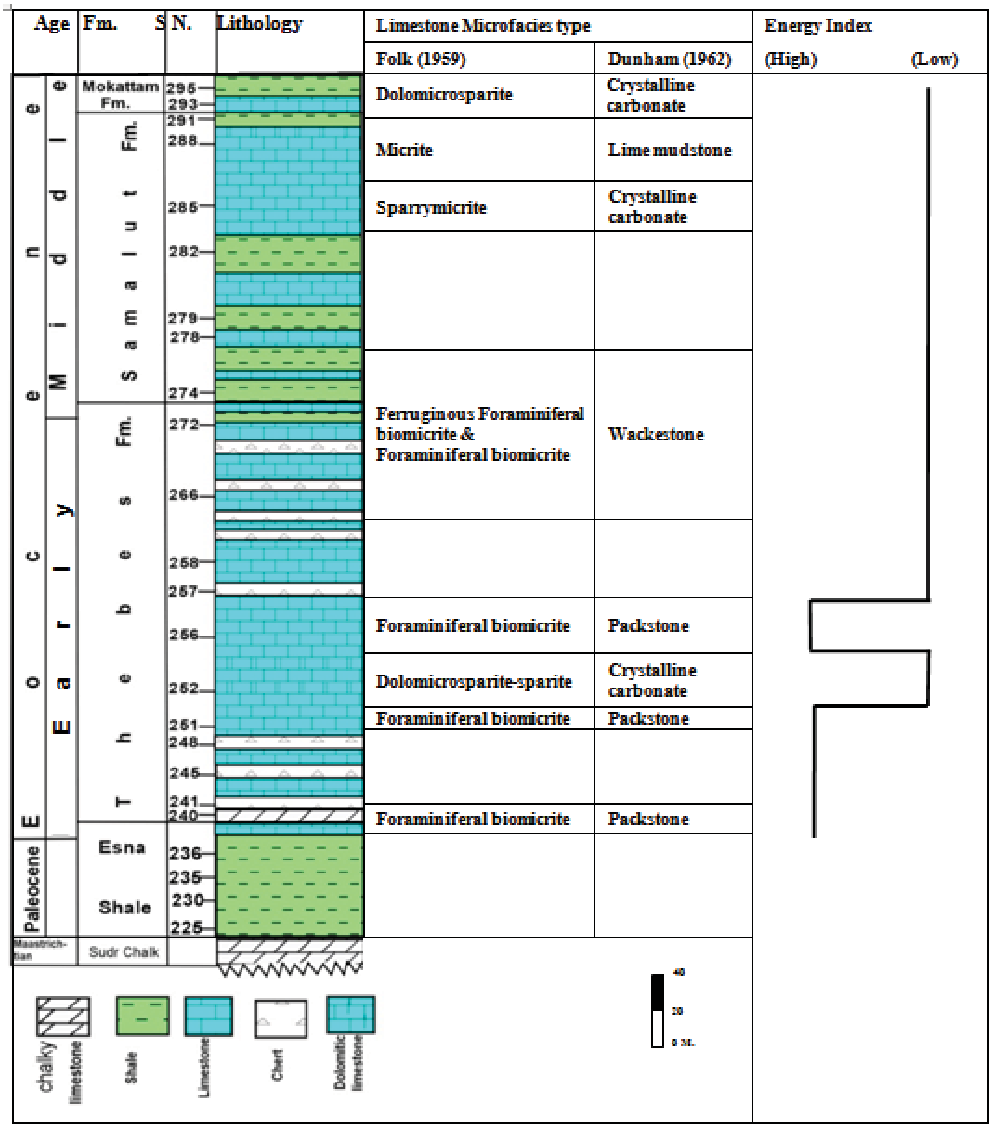


Fig. 17: The vertical variation in the microfacies associations and depositional energy in the Wadi Feiran section.

Dolomicrosparite (Dolomitic Crystalline Carbonate):

This lithofacies is encountered at the top of the lower part of the Thebes Formation and in the lower part of the Mokattam Formation in Wadi Feiran section . It consists of abundant (~75%) euhedral to subhedral, clear, unzoned dolomite crystals embedded in a micro- to macrocrystalline calcitic groundmass (plate-2B). Euhedral to subhedral quartz grains and iron oxides are rare.

Microsparite (Crystalline Carbonate):

This facies type is encountered only in the upper interval of the lower part of the Khaboba Formation in Hammam Faraun section. It is made up of microsparitic subhedral crystals and, less commonly, micritic groundmass (92 %) containing a few planktonic foraminiferal tests. The latter have chambers filled with sparite. Rare iron oxides stain some of the foraminiferal tests and the rock matrix.

Pel-algal Foraminiferal Biomicrite (Packstone):

This microfacies association is encountered only in the upper interval of the lower part of the Thebes Formation in the Hammam Faraun section. It consists of abundant planktonic and benthonic (*Nummulites*) foraminiferal tests, shell fragments, light to deep brownish green peloids (15- 20 %) and medium sand-sized pellets (5 %). Algal and bryozoans fragments (5 %), quartz and green, fine, subrounded glauconite grains, and subhedral clear dolomite rhombs are present. The chambers of the foraminiferal tests and bryozoan fragments are mainly filled with sparite or, rarely, micrite. Some of these tests have sharp ragged micritic walls. All allochemical components are embedded in micritic matrix (20- 35 %). Iron oxide patches are rather rare present (plate-2C).

Pel-foraminiferal Biomicrite (Packstone):

This microfacies is encountered only in the upper interval of the lower part and the middle part of the Thebes Formation in the Hammam Faraun section. It consists of abundant foraminiferal tests (45- 50 %), light to deep brownish green, fine peloids (15- 20 %), rare quartz grains and subhedral clear dolomite rhombs, all are embedded in a micritic matrix (20- 35%). The foraminiferal tests are mainly planktonic and their chambers are filled with sparite. Iron oxides stain large parts of the allochems and rock fragments.

Pel-algal Foraminiferal Biosparite (Grainstone):

This micorfacies is encountered only in the upper part of the Thebes Formation in the Hammam Faraun section. It is made up of abundant foraminiferal tests (55 %), echinid and algal fragments (5- 10 %), brownish green, medium sand-sized pellets (5 %) and rare green, fine, subrounded glauconite gains, all are cemented with sparite (10- 20 %). The foraminiferal tests are planktonic and have chambers filled with sparite and, rarely, micrite. Veinlets of sparitic calcite are present (plate-2D).

Pel-foraminiferal Biosparite (Grainstone):

This microfacies is encountered only in the upper interval of the lower part of the Thebes Formation in the Hammam Faraun section. It consists mainly of foraminiferal tests (30- 45 %), light brown, medium sand-size pellets(10- 25 %) and echinid, algal, bryozoan and gastropod fragments together with quartz grains. These components are cemented with sparry calcite cement (10- 20 %). The foraminiferal tests are mainly benthonic (*Nummulites, Alveolina*) having chambers filled with sparite and, rarely, micrite (plate-2E).

Foraminiferal-pel Biomicrosparite (Grainstone):

This microdacies is encountered only in the middle and upper parts of the Thebes Formation in the Hammam Faraun section. It is made up of planktonic foraminiferal tests and shell fragments (10- 30 %), dark brownish green pellets (10- 40 %) and euhedral quartz grains (4 %), all are cemented with a microsparitic calcite (10- 20 %). Chambers of the foraminiferal tests and the molluskan shell fragments are filled with sparite (plate-2F).

The foregoing discussion on the distribution of the recorded microfacies types reveals that the foraminiferal biomicrite (wackestone-backstone) microfacies is present in all the studied rock units in the three section except for the Tanka Formation in the Hammam Faraun section and the Mokattam Formation in Wadi Feiran section (Table 2). Limestones in Hammam Faraun section are characterized by the presence of the largest number of microfacies types as compared with those of the other two studied sections. Comparison between the studied rock units reveals that the Thebes Formation in the Hammam Faraun section is thickets and characterized by the presence of largest number of microfacies types (Tables 2&3). Since each of the Esna, Thebes and Darat (and its equivalent Samalut) formations in the three studied sections have conformable relationships with the overlaying and underlying units, their present-day thicknesses (Table 3) can be considered original i.e., were not reduced by erosion. Hence, it can be concluded that the sedimentation rate of the carbonate deposits in the Hammam Faraun area was higher than in North Markha area; the smallest rate was in Wadi Feiran area

Plate-2

A: Photomicrograph showing sandy micrite (mudstone) the rock is composed of euhedral to subhedral quartz crystals, and iron oxide patches embedded in micritic matrix (Hammam Faraun section, Tayiba Formation, sample 145, plane polarized light, X. 20).

B: Photomicrograph showing dolomicrosparite to sparite microfacies, it consists of dolomite rhombs scattered in a micro- to macrocrystalline calcite ground mass (Wadi Feiran section, Thebes Formation, sample 252, plane polarized light, X. 20).

C: Photomicrograph showing pel- algal foraminiferal biomicrite (packstone) microfacies consists of dark color micritic ground mass containing foraminiferal tests of *Nummulites*, and a few algae and peloids and iron oxide patches (Hammam Faraun section, Thebes Formation, sample 21, plane polarized light, X. 20).
D: Photomicrograph showing pel- algal-foraminiferal biosparite (grainstone) the rock is composed of sparite groundmass containing benthonic foraminiferal tests filled with micrite, algae and echinoid fragments are present (Hammam Faraun section, Thebes Formation, sample 56, plane polarized light, X. 20).
E: Photomicrograph showing pel- foraminiferal biosparite (grainstone) microfacies, composed of sparite groudmass and foraminiferal tests represented mainly by *Alveolina* filled with micrite, and a few algae, peloids, echinoid and bryozoan (Hammam Faraun section, Thebes Formation, sample 23, plane polarized light, X. 20).
F: Photomicrograph showing foraminiferal -Pel biomicrosparite (grainstone) it is composed mainly of well sorted peloids, foraminiferal tests represented mainly by *Alveolina*, algae and gastropod shell fragments embedded in microsparite groundmass, some of the gastropod shell fragments filled completely with sparite (center) (Hammam Faraun section, Thebes Formation, sample 43, plane polarized light, X. 20).

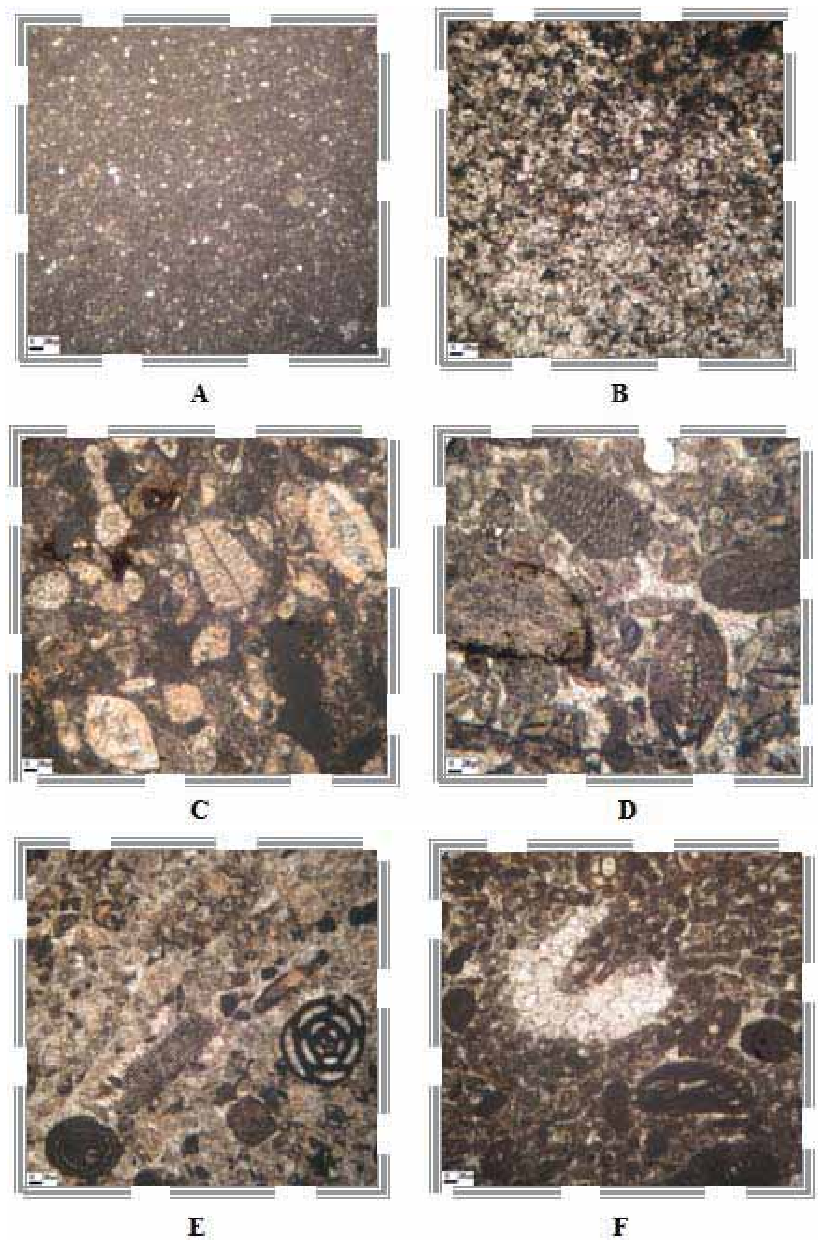


Table 2: Summary of the identified microfacies association in the three studied sections

Section	Formation	1	2	3	4	5	6	7	8	9	10	11
Hammam Faraun	Esna Shale	X										
	Thebes	X						X	X	X	X	X
	Darat	X	X									
	Khaboba	X		X			X					
	Tanka				X							
	Tayiba	X		X								
North El-Markha	Esna Shale	X	X									
	Thebes	X	X									
	Darat	X	X									
	Khaboba	X										
Wadi Feiran	Thebes	X	X			X						
	Samalut	X		X	X							
	Mokattam					X						

1= Foraminiferal biomicrite 2= Microcrystalline quartz chert 3= Micrite 4= Sparry micrite 5= Dolomicrosparite 6= Microsparite 7= Pell-algal foraminiferal biomicrite 8= Pell-foraminiferal biomicrite 9= Pell-algal foraminiferal biosparite 10= Pell-foraminiferal biosparite 11= Foraminiferal-Pell biomicrosparite.

Table 3: Variations in the limestone and shale thicknesses in the studied sections.

Section	Hammam Faraun Thickness (m)		North Markha Thickness (m)		Wadi Feiran Thickness (m)	
Rock Unite	limestone	Shale	limestone	Shale	limestone	Shale
Esna	9	11	2.3	38	3	28.5
Thebes	166.15	1	161		109.5	1
Darat/Samalut	84.9	0.75	35	15	52	25.5
Total	260.05	12.75	198.3	53	164.5	55
	272.8		251.3		219.5	
Khaboba/Mokattam	26	47	21.5	9	3	4
Tanka	21	-----	-----	-----	-----	-----
Tayiba	13.4	10	-----	-----	-----	-----

An opposite situation characterizes the argillaceous deposits.This implies that the basin of deposition was deeper in the northern Hammam Faraun area than in the southern Wadi Feiran area.It may be confirmed by the presence of different concentrations of various planktonic and benthonic Foraminifera together with algael,echini and molluscan fragments in the limestones of the Hammam Faraun section.

Mineral Composition:

The obtained X-ray diffraction data for the study samples are given in Table (4) and Figures (18-22). Bulk sample X-ray diffraction patterns of the bulk limestone and dolomitic limestone samples revealed that they are composed almost entirely of calcite and, much less commonly, dolomite. Petrographically, calcite is present either as micrite matrixor as sparite formed by recrystallization from micrite, the main constituent of many carbonate allochems. Dolomite is found mainly associating calcite in the dolomitic limestones. The dolomite rhombs, as revealed by the microscopic examination, are present scattered throughout the micrite matrix and or sparite groundmass. X-ray diffraction study revealed the presence of ferroan- dolomite. Wilson (1978) noticed that the dolomite mineral which has a strong rhombic crystal habit always has some Fe^{+2} sub-situating for Mg^{+2} in the lattice. Awad (1982) noted ferroan- dolomite is present in the dolostone and high dolomitized lithofacies. The presence of ferroan- dolomite associated with sparry calcite (mainly recrystallized from micrite) may be attributed to a highly dolomitized phase. Accordingly, iron solution which may accompany this process penetrates along the crystal boundaries and the cleavage planes of sparite.

The noncarbonate minerals recorded in the bulk samples are (in order of decreasing abundance) quartz, hematite, clay minerals (kaolinite and illite) and halite. The microscopic investigation revealed the presence of fine to very fine, angular to subangular quartz grains scattered throughout the micrite matrix and sometimes the sparite cement. Hematite is present mainly as cementing materials and/or filling-material in some of the studied limestones. Halite is recorded as a trace mineral at the middle horizon of the lower part of the Samalut Formation in Wadi Feiran section.

On the other hand, the obtained X-ray diffraction data for the study chert samples revealed that quartz is the major mineral which may be associated with minor proportions of calcite. Crypto- or microcrystalline quartz is the major constituent of chert Carozzi, 1960 and Blatt *et al*., 1979.

Table 4: Semi-quantitative clay mineral composition of the shale beds in the three studied sections

Formation	Hammam Faraun				North El-Markha				Wadi Feiran			
	Sample No.	Clay minerals %			Sample No.	Clay minerals %			Sample No.	Clay minerals %		
		Mont.	Kao.	Illi.		Mont.	Kao.	Illi.		Mont.	Kao	Illi.
Esna	3	40	51	9	146	27	64	9	225	24	69	7
									230	46	40	14
	11	66	14	20	154	84	--	16	236	46	--	54
Thebes	--	--	--	--	--	--	--	--	272	53	47	--
Darat (Samalut)	88	76	24	--	--	--	--	--	274	21	28	51
									279	34	66	--
									282	42	58	Trace
									291	83	17	Trace
Khaboba (Mokattam)	119	64	36	--	214	54	37	9	295	39	47	14
Tayiba	144	58	--	42	--	--	--	--	--	--	--	--

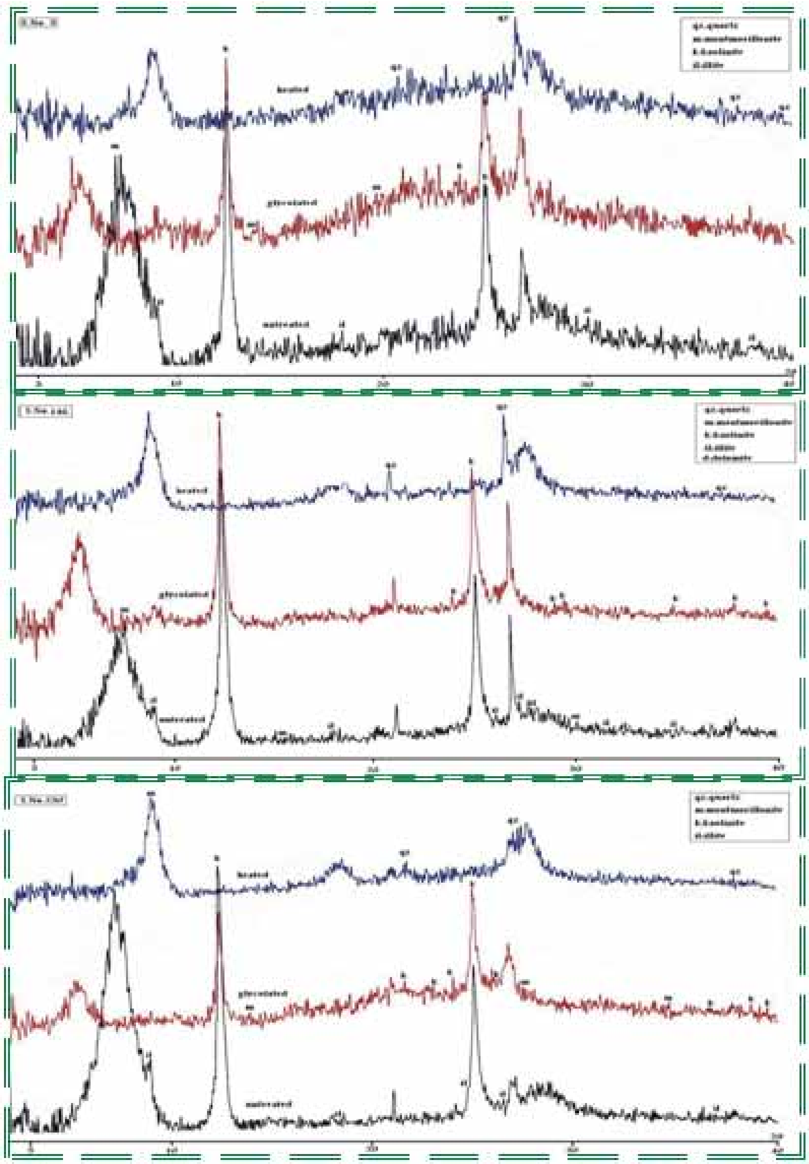


Fig. 18: X-ray diffraction patterns of the clay fractions of three selected Esna Shale samples from the Hammam Faraun, North El-Markha and Wadi Feiran sections, respectively.

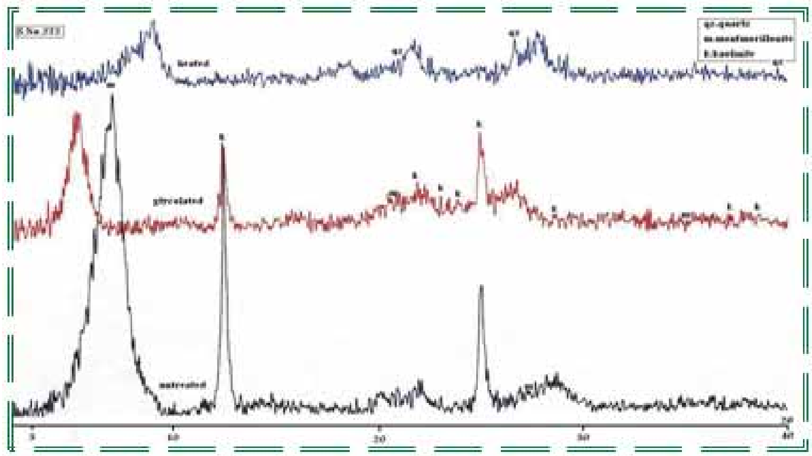


Fig. 19: X-ray diffraction pattern of the clay fraction of a selected shale sample from the Thebes Formation, Wadi Feiran section.

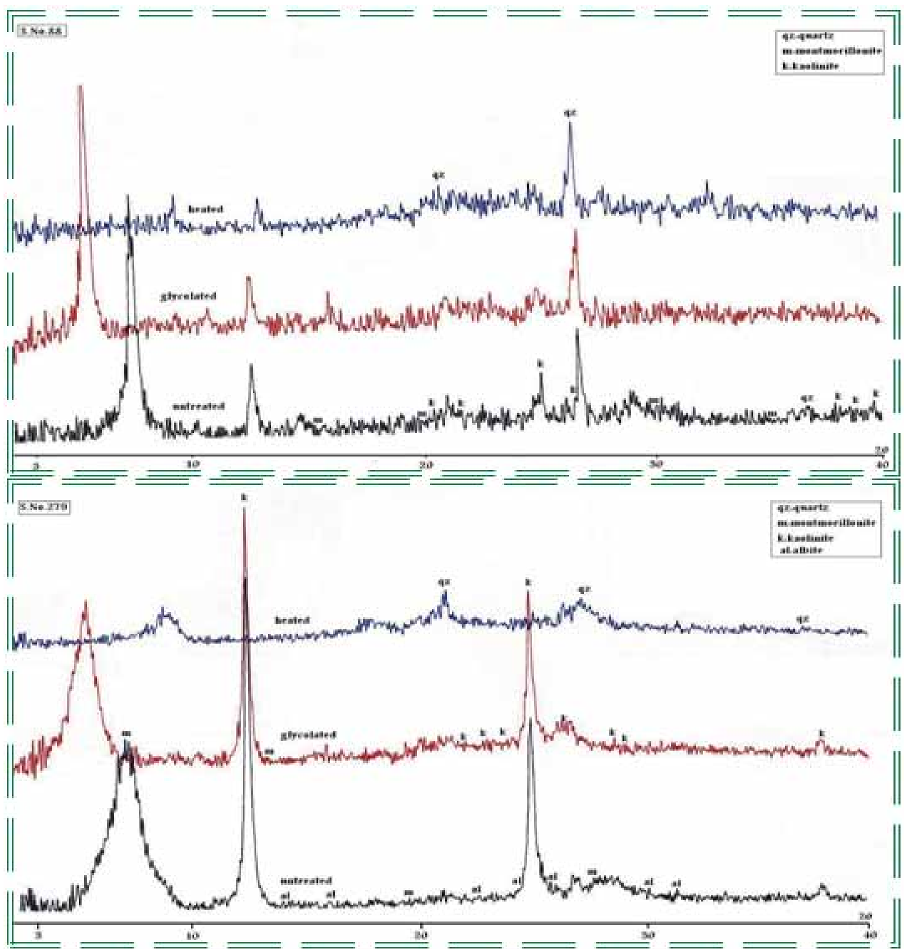


Fig. 20: X-ray diffraction patterns of the clay fractions of selected shale samples of the Darat Formation and its equivalent Samalut Formations from the Hammam Faraun and Wadi Feiran sections, respectively.

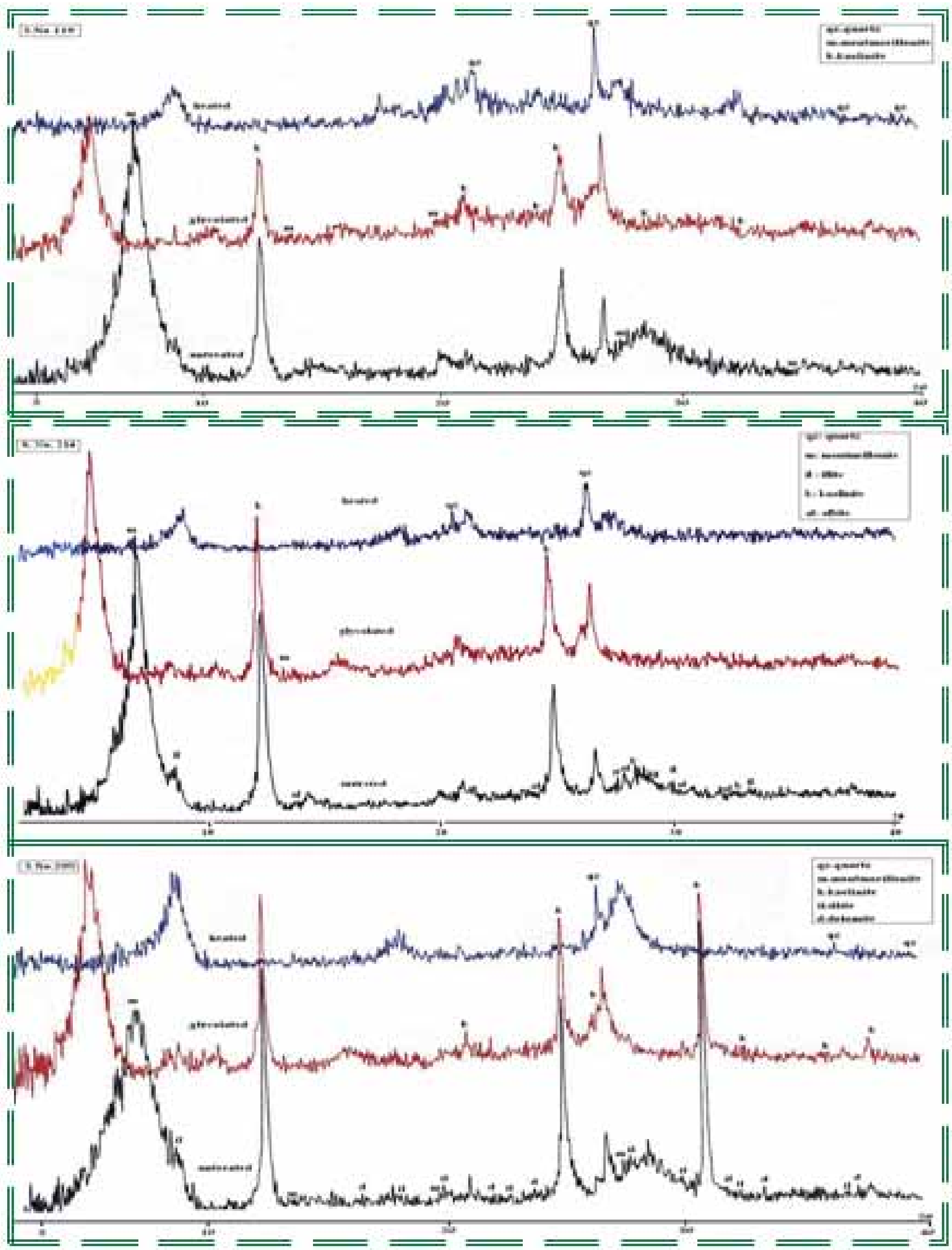


Fig. 21: X-ray diffraction patterns of the clay fractions of three selected Shale samples from the Khaboba Formation in the Hammam Faraun and North El-Markha sections, and its equivalent Mokattam Formation from Wadi Feiran section, respectively.

Table (4) presents the clay mineral composition of the examined shale samples. The recorded clay minerals are (in order of decreasing abundance); montmorillonite, illite and kaolinite. Montmorillonite is the most common mineral in the shales of all rock units in the study area as it was recorded in all samples. Its proportions are 24% to 84% in the Esna shale, 53% in the Thebes Formation, 76% in the Darat Formation, 21% to 83% in the Samalut Formation, 54% to 64% in the Khaboba Formation. 39.3% in the Mokattam Formation and 58% in the Tayiba Formation. Kaolinite comes next in abundance in the shales of all rock units

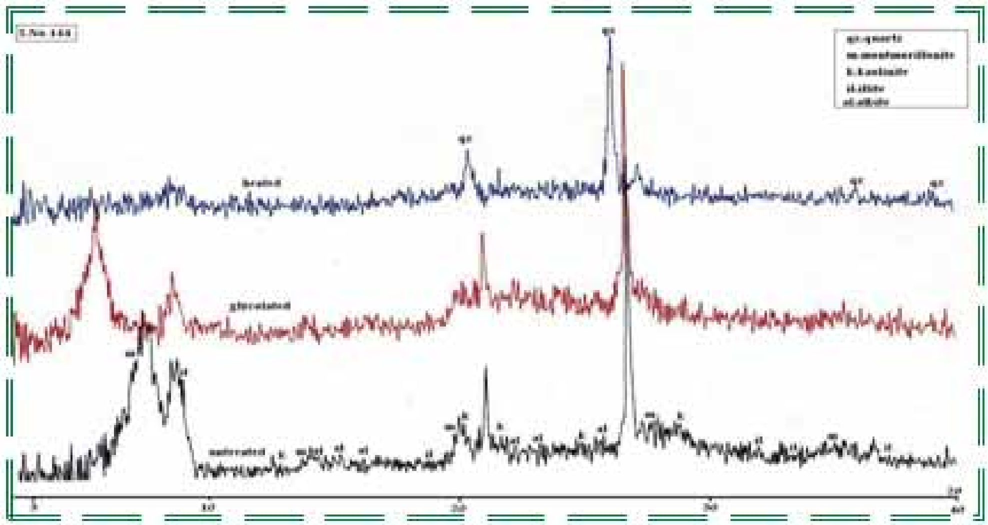


Fig. 22: X-ray diffraction patterns of the clay fraction of a selected shale sample from the Taiyba Formation in the Hammam Faraun section.

in the study area. Its proportions are 14% to 69% in the Esna Shale, 46.6% in the Thebes Formation, 24% in the Darat Formation, 17% to 66% in the Samalut Formation, 36% to 37% in the Khaboba Formation and 47% in the Mokattam Formation. Kaolinite was not detected in Tayiba Formation. Illite was recorded in most of the shale samples of Esna Shale (7% to 54%), Samalut Formation (traces to 51%), Khaboba Formation (9%), Mokattam Formation (14%) and Tayiba Formation (42%), while it is absent in the Thebes and Darat formations.

The non- clay minerals occur mostly as minor constituents. They are represented by (in order of decreasing abundance) quartz, albite, calcite and dolomite together with traces of halite and gypsum.

Depositional Environments:

The studied Paleocene- Eocene sequence consists generally of bedded or massive limestones intercalated with vari-colored, kidney-shape shale and chert bands and lenses. The succession is made up of the formations (from older to younger): Esna Shale, Thebes, Darat, Samalut, Khaboba, Mokattam, Tanka and Tayiba. It is represented by many microfacies associations. The limestone is medium- to thick-bedded or massive, the shale is semi- papery and thinly-laminated and the chert occurs as concretions and disconnected lenses or bands. The faunal contents are represented by planktonic and benthonic Foraminifera and subordinate proportions of, echinid and bryozoan fragments. The following is a discussion on the probable depositional environments of each rock unit:

The Esna Shale:

Khalil and El- Gammal (1997) emphasized that the lower part of the Esna Shale in southwest Sinai was deposited in quiet mud- free water whereas its upper part accumulated under calm deep marine conditions of normal salinity. El-Deeb *et al*. (2000) reported that the same Esna Shale sequence was deposited in outer-neritic to bathyal environments. Based on the microfacies associations, Hassan (2005) concluded that the Esna Shale in Sinai was deposited in outer-neritic to deep inner neritic environments characterized by quiet water and normal salinity.

The microfacies characteristics of the limestone intervals in the Esna Shale in the studied area indicate that this rock unit was deposited in a neritic marine environment characterized by intermittent oscillations of the sea level which resulted in the deposition of the carbonate intercalations within the shale sequence.

The clay minerals identified in the Esna Shale are montmorillonite, kaolinite and illite. The formation of montmorillonite requires the retention of Mg^{+2}, Ca^{+2}, Fe^{+2} and Na^{+} in effective leaching alkalinity and retention of silica (Keller 1970). Under such conditions, which are characteristic of sedimentary basins of alkaline chemical affinity, the montmorillonite may be deposited as well as carbonate and phosphate. However, the presence of halite and gypsum in the middle part of the Esna Shale in Wadi Feiran section favors deposition in an outer-neritic environment which confirms with the conclusion reached by Awad (1982). The marked dominance of micrite and the preservation of the whole foraminiferal tests indicate that the deposition occurred under relatively quiet conditions and normal salinity suitable for living organisms including Foraminifera (Twenhofel 1950, Tanner 1953, Henson 1959, Tampson 1970, Tilman 1971, and Bowman 1979). On the other hand, the chert bands recorded in the middle part of the Esna Shale in the North El- Markha section seem to have originated from high concentrations of diatoms and radiolaria, on one hand and, the prevalence of pH values around 7.8. At such values, silica is weakly soluble which resulted in the deposition of banded chert (Awad 1982).

The Thebes Formation:

Khalil and El- Gammal (1997) reported that the Thebes Formation in southwest Sinai was deposited in deep water of shelf environments whereas El-Deeb *et al*. (2000) suggested deposition under outer neritic conditions. Abu-Zeid *et al*. (2001) concluded that the Lower Eocene Thebes Formation in westcentral Sinai accumulated during a regressive phase of the Eocene sea in environments ranging between low-energy, pelagic to high-energy intertidal. Hassan (2005) suggested shallow outer-neritic to deep inner-neritic and basinal margin environments characterized by quiet water and normal salinity for the Thebes Formation in Sinai.

In the present study, the recognized microfacies associations in Thebes Formation in southern Sinai reflect deposition in a deeper part of the neritic zone (cf. Weeks 1952, Folk 1962) characterized by quiet, clear water and normal salinity. This is confirmed by the relative abundance of mud-supported fabrics and the preservation of foraminiferal tests in micrite matrix. The occasional presence of primary sparite and algae suggests intermittent accumulation in comparatively shallower parts of the neritic zone (Folk 1962) characterized by active waves (Pettijohn 1975). The presence of nodular limestone in the middle part of the Thebes Formation in the Hammam Faraun section is indicative of shallowing of the marine environment during the deposition of this part of the rock unit (Awad 1979 and Snavely *et al*. 1979). The microsparite intervals in the rock unit may reflect accumulation in shallower part of the neritic zone of marine environment (Folk 1962 & Bowman 1979). The abundance of shell fragments in the micritic matrix of some limestones indicates the action of turbidity currents within the environment (Robertson 1976). Similar to the middle part of the Esna Shale in North El- Markha section, chert bands recorded in Thebes Formation at various levels seem to have originated from high concentrations of diatoms and radiolarian. At pH values around 7.8, silica is weakly soluble and the banded chert was deposited (Awad 1982). The presence of dolosparite microfacies reflects deposition in shallow restricted warm water of a marine environment (Pilky and Hower 1960). In conclusion, the Thebes Formation indicates deposition under deep part of a neritic zone in an open marine environment.

The Darat Formation:

Abu-Zeid *et al*. (2001) concluded that the Darat Formation in westcentral Sinai was deposited in a relatively deep marine (outer- neritic) environment. Hassan (2005) suggested accumulation in an inner-neritic environment with quiet water and normal salinity for the Darat Formation in Sinai.

In the present study, the recognized microfacies associations in the Darat Formation reflect deposition in a deep part of the neritic zone (Weeks 1952, Folk 1962) characterized by quiet, clear water and normal salinity. This is confirmed by the dominance of mud-supported fabrics and the preservation of foraminiferal tests and echinid fragments in the micrite matrix. The chert nodules in the upper part of the Darat Formation were probably deposited pencontemporaneously due to changes in the environment caused by death of organisms rich in silica. The presence of sparite, algae and abundant allochems suggests accumulation in a comparatively shallower part of the neritic zone (Folk 1962) with active waves responsible for the formation of sparry calcite (Pettijohn 1975). Also, the presence of montmorillonite and, less commonly, kaolinite in the intercalated shale beds reflects the influence of a continental influx into the depositional basin. In conclusion, the Darat Formation was most probably deposited in shallow to deep neritic environments.

The Samalut Formation:

Abu-Zeid *et al*. (2001) reported that the Middle Eocene Sea was much shallower towards southern Sinai where the Samalut Formation was accumulated. Hassan (2005) suggested its deposition in protected coastal lagoon and inner-neritic environments with quiet water and moderately high salinity.

In the present study, the microfacies characteristics of the Samalut Formation in Wadi Feiran section reflect deposition in a deep part of a neritic zone (Weeks 1952, Folk 1962) characterized by quiet, clear water and normal salinity. This is confirmed by the abundance of mud-supported fabrics and the preservation of foraminiferal tests in micrite matrix. The oscillations in the relative abundances of the clay minerals montmorillonite, kaolinite and illite in the shale intercalations reflects intermittent sea-level oscillation during the deposition of the Samalut Formation. In conclusion, the Samalut Formation seems to have been deposited during a regressive phase of the see in a neritic environment characterized by intermittent oscillations in the sea level.

The Khaboba Formation:

Abu-Zeid *et al*. (2001) reported that the regression of the Middle Eocene Sea continued during the deposition of the Khaboba Formation. Hassan (2005) concluded that the Khaboba Formation was deposited in outer-neritic to shallow inner-neritic environments characterized by quiet water and normal salinity.

In the present study, the recognized microfacies associations in the Khaboba Formation reflect a relatively deeper part of a neritic environment (Weeks 1952, Folk 1962, Leighton and Pendexter 1962, Chilingar *et al*. 1967 and Robertson 1976). The abundance of micrite and the characteristic light color of the sediments indicate that the deposition occurred under relatively quiet conditions, clear water and normal salinity suitable for living organisms as foraminifera (Twenhofel 1950, Tanner 1953, Henson 1959, Tampson 1970, Tilman 1971, and Bowman 1979). The presence of various types of microsparite reflects accumulation in a shallower part of the neritic zone of the marine environment (Folk 1962 and Bowman 1979). The relatively high P_2O_5 content in the rocks of the lower part of the Khaboba Formation in the Hammam Faraun section suggests its deposition in an oxidizing environment, as the reduced conditions are not favorable for the fixation of phosphate ions. This may indicate that the marine environment was not deep (Awad 1982). However, reducing rather than oxidizing conditions, seem to have prevailed during the time of deposition of some shale and limestone intervals. This is indicated by the abundance of pyrite nodules and lenses in the shales, and the presence of glauconite in the sandy limestone beds. The presence of halite and gypsum within the shale intervals in the lower and upper parts of the Khaboba Formation in the Hammam Faraun section favors deposition in a shallow warm environment. On the other hand, the identified clay-mineral association (montmorillonite, kaolinite and illite) in the shale intervals indicates that the Khaboba Formation was deposited in shallow marine environment. In conclusion, the lower part of the Khaboba Formation was deposited in a shallower neritic zone of the marine environment, than that in which its upper part was accumulated.

The Mokattam Formation:

Hassan (2005) suggested that the Mokattam Formation in Sinai was deposited in deep subtidal to shallow inner-neritic environments characterized by quiet water and normal salinity. In the present study, the characteristics of the Mokattam Formation in Wadi Feiran section suggest deposition in a shallow restricted marine environment (Wilson 1975). The clay minerals which constitute the shale beds of the Mokattam Formation are kaolinite, montmorillonite and illite. This may indicate that these shale beds were deposited in shallow neritic marine environments.

The Tanka Formation:

Abu- Zeid *et al*. (2001) suggested that the accumulation the of Tanka Formation in west-central Sinai witnessed a short transgressive phase of the sea. Hassan (2005) concluded that the Tanka Formation in Sinai was deposited in shallow subtidal to inner-neritic and coastal lagoonal environments, with slightly agitated water. In the present study, the lithologic microfacies types which constitute the Tanka Formation show the presence of the sandy micrite and lime mudstone microfacies. These reflect deposition in a shallow part of the neritic zone characterized by quiet and clear water with normal salinity (Weeks 1952, Folk 1962).

The Tayiba Formation:

In the present study, the Tayiba Formation is represented by the microfacies associations (from bottom to top): sandy foraminiferal biomicrite (packstone) and sandy micrite (lime mudstone). The presence of the various types of micrite (sandy foraminiferal biomicrite and sandy micrite) reflects deposition in a shallower part of the neritic zone. The abundance of micrite indicates the prevalence of relatively quiet conditions, clear water and normal salinity suitable for living organisms as Foraminifera (Twenhofel 1950, Tanner 1953, Henson 1959, Tampson 1970, Tilman 1971, and Bowman 1979). The presence of quartz sand associating micrites suggests deposition in a shallow neritic environment. On the other hand, the presence of montmorillonite and illite and absence of kaolinite in the shales may indicate a dominantly marine environment. In conclusion, the studied Tayiba Formation was deposited in a shallow inner-neritic zone of a marine environment.

Diagenesis:

The rocks of the Paleocene- Eocene sequence in Hammam Faraun area were subjected to several diagenetic processes. These are represented by recrystallization (Neomorphism), cementation, glauconitization, dolomitization and silicification.

Recrystallization (Neomorphism):

In most of the studied rocks, the lime mud (micrite) shows a partial aggrading recrystallization to microsparite and sparry calcite plate-1D).Also, aggrading neomorphism was observed in the dolomitic rocks being represented by the partial or complete recrystallization of the micrite groundmass into micro-and /or pseudosparite (plate-2B). Recrystalliation is indicated by nongradation in crystal size toward the margins of the affected areas, embayed crystal boundaries, and the abundance of inclusions (relics) in the crystals. Generally, patchy recrystalliation has occurred as indicated by the presence of randomly-scattered patches throughout the matrix. Folk (1974) believed that neomorphism of lime mud to microspar, pseudospar and the formation of sparry calcite is related to loss of MgO either by the seizure of Mg^{+2} ions by clay minerals or these adsorption on clay particles, then micritic calcite is free to grow into microspar. On the other hand, degrading neomorphism is much less common in the studied rocks and is represented by the development of micrite envelopes and pseudofaecal peloids (plate-1D).

Cementation:

El- Albani *et al*. (2001) reported that the early cementation of carbonates prevents dissolution of the preserved original biogenic content, thus, their biogenic content may be regarded as retaining a 'memory' of the prediagenetic sediment. The cement materials in the studied limestones are made up mainly of microcrystalline calcite and, less commonly, microsparite (plates-1C & 2F) and sparite (plate-2D & E). Calcite cements occur as primary or secondary void-fillings. Primary void-filling calcite fills the chambers of the foraminiferal tests and shell fragments (plat-2A &C and plate-2F). Crystal sizes decrease gradually toward the void margins, and the crystals adjoin one another along smooth, straight faces. Secondary void-fillings occur where some fossils were partially or completely dissolved and the resulting voids were filled with sparry calcite. Occasionally, these cements are present in the form of scattered patches and vienlets of sparry calcite (plat-1B &C and plate-2F). Again, the crystal boundaries are smooth and straight and, in many cases, suture lines were formed where crystals grew inward from the walls of the voids. Crystals increase in size abruptly in the void with no gradation in size. Also, iron oxide cements were reported forming dispersed patches. This reflects the intermittent prevalence of oxidation conditions which resulted in the occasional deposition of iron oxides from pore water (plate-1A & D).

Glauconitization:

Glauconite exists in some of the studied rocks in the form of grains or peloids scattered in the groundmass (pate-1E). It might have been formed from pre-existing clay minerals and biotite. Glauconite is known to be formed in warm water (15- 200Cº) having a pH value of 7-8, sometimes at depth ranging from 40 to 500m. The glauconitization process occurs in mildly reducing solution (Eh 0- 200 mv.). The formation of glauconite is facilitated by the presence of decaying organic matter (Wageih 2005).

Dolomitization:

Folk (1965), Fairbridge (1967), Chilinger *et al*. (1967), Friedman and Sanders (1967), Lovering (1969), Pettijohn (1975) and many others discussed the dolomitization phenomenon. Most of these workers related the dolomitization of the carbonate rocks to the replacement during or after the deposition. Friedman and Sander (1967) concluded that most dolomites originated by replacement of calcium carbonate in sediments which was either in the form of calcite or aragonite either within the depositional environment, during diagenesis or later tectonic activity. Fisher and Rodda (1969) considered that the presence of non-dolomitized solid shell in a dolomite sediment is an evidence for the formation of dolomite before lithification. Pettijohn (1975) stated that most dolomites are clearly replaced limestones in the environment of deposition or after burial. The source of magnesium necessary for the dolomitization is most probably the calcareous algae, nummulites, foraminiferal tests and other organisms enriched in $MgCO_3$ where Mg^{2+} evolves during neomorphism of these bioclasts from high magnesium-clacite to calcite (Friedman and Sanders 1967, and Maliva and Dickson, 1994). The same result was obtained by Awad and El Fokha (1991).

Many of the studied limestones contain dolomite rhombs scattered throughout the micritic, microsparitic and sparitic matrices (plate-2B). In these rocks, two phases of dolomitization were recorded. The first phase involved the replacement of the original micritic matrix with dolomite. In this case, the dolomitization event affected the rocks early in their diagenetic history before the recrystallization of the micritic matrix. The second phase witnessed the replacement of the recrystallized microsparite and sparry calcite by dolomite. This implies that dolomitization followed the neomorphic recrystallization of calcite (plate-2B). In some of the examined chert samples, early-formed dolomite rhombs were found to be scattered throughout the rock matrix. This phenomenon is similar to that reported by Awad (1982) for the chert of the Thebes Formation in the Eastern Desert.

Silicification:

The studied Paleocene-Eocene succession was occasionally affected by silicification which resulted in the formation of chert lenses and disconnected bands. In the Hammam Faraun section, chert was recorded in the lower part of the Thebes Formation and the lower and upper parts of the Darat Formation. In the North El-Markha section, it exists in the middle part of the Esna Shale, in the entire succession of the Thebes Formation and in some parts of the Darat Formation. In Wadi Feiran section, the chert lenses and bands are distributed throughout the whole Thebes Formation. They run parallel to the bedding planes which may indicate their formation pencontemporaneously with the deposition of the host limestone, i.e. during an early diagenetic stage prior to the lithification (Awad 1982, 1984 &1992b). Kennedy and Garrison (1975) suggested a replacement origin for the chert nodules of the Cretaceous chalk of Southern England. German and Stathyanarayan (1980) demonstrated a secondary origin after dolomitization for the nodular chert in the carbonate rocks of the Kaladgia Group of India. Based on field evidence, Anwar and El-Tarabili (1960) suggested a pencontemporaneous origin for the chert found in the Cretaceous sediments cropping out in the Quseir-Safaga district. Pettijohn (1975) considered that no single mode of origin is responsible for the source of the silica. It may be partially organic and/or partially a weathering product. Blatt *et al*. (1979) related the origin of chert in the limestone in West Taxas and Southern New Mexico to the dissolution of siliceous organisms. They emphasized that the presence of chert in the form of bands may be attributed to the abundance of the siliceous organisms. In some studies, the source of silica forming the chert has been considered as precipitation concurrent with deposition of the limestone after the siliceous organisms as diatoms and radiolarian (Pettijohn 1975 and Blatt *et al*. 1979). The organic origin of the silica forming the chert was suggested by Carrozi (1960), Anwar and El-Tarabili (1960), Eley and Jull (1982), Meyers (1977) and Knauth (1979). This origin was suggested based on the absence of other possible sources of the silica such as the dissolution of feldspars or ascending hydrothermal siliceous solution. Coniglio and James (1985) and Walker (1962) concluded that a contemporaneous origin for chert with limestone is eliminated because the latter is usually deposited at pH 7.8 at which silica is soluble. The changes in the pH of the environment have opposite effects on the solubilities of calcium carbonate explaining its replacement by silica. Awad and El Fokha (1991) reported that the presence of carbonate remnant materials in chert of Jordan may indicate a partial replacement origin. A similar phenomenon has been observed in the studied chert. Accordingly, pencontemporaneous replacement origin for this chert is most probable.

Conclusions:

The Paleocene- Eocene sequence in Hammam Faraun area is made up of limestone, dolomitic limestone, shale and chert. It consists of eight formations, namely (arranged chronologically): the Esna Shale, Thebes, Darat, Samalut, Khaboba, Mokattam, Tanka and Tayiba. The Samalut and Mokattam formations exist only in the Wadi Feiran section while the presence of the Tanka and Tayiba formations is restricted to the Hammam Faraun section.

The studied Paleocene-Eocene succession is represented by eleven microfacies associations. These are foraminiferal biomicrite (wackestone-packstone), microcrystalline quartz chert, micrite (lime mudstone), sparry micrite (crystalline carbonate), dolomicrosparite (dolomitic crystalline carbonate), microsparite (crystalline carbonate), pel-algal foraminiferal biomicrite (packstone), pel-foraminiferal biomicrite (packstone), pel-algal foraminiferal biosparite (grainstone), pel-foraminiferal biosparite (grainstone), foraminiferal-pel biomicrosparite (grainstone). Generally, the foraminiferal biomicrite (wackestone-backstone) is the most dominant microfacies association.

Calcite is the dominant mineral in the limestone, while quartz and dolomite dominate chert and dolomitic limestone interbeds. Montmorillonite, kaolinite and illite constitute the clay fractions of the shales. Hematite, halite and gypsum exist in the studied rocks occasionally and in varying proportions.

The Esna Shale was deposited during a regressive phase of the sea in a neritic environment characterized by intermittent sea-level oscillations. The Thebes Formation was accumulated in a deeper part of the neritic zone of an open marine environment. The Darat Formation was deposited also in a deep part of a neritic zone characterized by quiet and clear water of normal salinity. The Samalut Formation reflects deposition in the outer-neritic zone of the marine environment under conditions similar to those of the overlying Darat Formation. The lower part of the Khaboba Formation was accumulated in a shallow neritic zone of the marine environment while its upper part was deposited in deeper waters of the same neritic environment. The Mokattam Formation reflects deposition in the shallower part of the neritic zone of the marine environment during a regressive phase of the Middle Eocene Sea. The Tanka Formation was formed in a shallow inner-neritic zone. The Tayiba Formation reflects a shallow inner-neritic environment characterized by quiet and clear water having normal salinity.

Rocks of the studied sequence were diagenetically affected by recrystallization (neomorphism), cementation, glauconitization, dolomitization and silicification. In most of the studied rocks, the lime mud shows a partial aggrading recrystallization to microsparite and sparite while degrading recrystallization is much less common. Cements in the studied limestones are made up of microcrystalline calcite and, less commonly, microsparite and sparite. Two phases of dolomitization were recorded. The first phase involved the replacement of the original micritic matrix with dolomite while the second phase witnessed the replacement of the recrystallized microsparite and sparry calcite by dolomite. The studied succession was occasionally affected by silicification which resulted in the formation of chert lenses and disconnected bands.

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