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Diagenetic Evolution of the Middle Eocene Carbonates (Mokattam Formation), Eastern Cairo-Suez District, Egypt

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Abstract. The exposed carbonate rocks of the Mokattam Formation in Gebels Shabrawet, Geneifa and Abu Treifiya are made up of dolosparite, pelbiosparite and dolobiomicrite. Their original compositional and textural characteristics are greatly modified by cementation, neomorphism, dissolution, compaction, dolomitization, dedolomitization and silicification.

Both aggrading and degrading neomorphism were occasionally recorded. Dissolution and leaching of the primary aragonitic and calcitic components of allochems and matrix resulted in the development of fabric- and non fabric-selective porosity. The intensity of selective and pervasive dolomitization varies throughout each of the measured sections in the studied areas.

Evidently, the diagenetic history of the studied Mokattam carbonates commenced with the eogenetic phase which witnessed an initial stage of cementation with calcite, degrading neomorphism and development of fabric-selective porosity in the marine phreatic environment. The early cementation inhibited the effect of burial compaction during mesogenesis. The telogenetic phase, on the other hand, involved the processes of cementation with calcite and silica, aggrading neomorphism and dedolomitization under phreatic meteoric condition. The meteoric vadose zone, on the other hand, was the site of dissolution and leaching. Also, the telogenetic phase involved extensive dolomitization especially in the northern part of the studied area. It occurred in mixed marine-meteoric environments characterized by frequent intermittent intrusion of freshwater lenses during subaerial exposure, either by tectonism or drop of sea level. Also, it is likely that dolomitization was controlled by fracturing which played an important role in flow of the dolomitizing fluid. Generally, the relative abundance of the various diagenetic features in the studied Mokattam carbonates indicated that the diagenetic processes that occurred during telogenesis were much more effective than those occurred during mesogenesis and eogenesis.

Keywords: Diagenesis; Carbonate; Middle Eocene; Mokattam Formation; Cairo-Suez Disrict; Egypt.

Introduction

The studied area is located in the eastern section of the Cairo-Suez district between longitudes 32° 08′ 23″ and 32° 23′ 37″ E and latitudes 29° 57′ 52″ and 30° 16′ 19″ N. The Middle Eocene carbonates form prominent mountains in this district; among which are Gebels Shabrawet, Geneifa and Abu Treifiya (Fig. 1). Gebel Shabrawet lies west of the Great Bitter Lake at the midway between Suez and Ismailia. Gebel Geneifa is one of the main topographic features in the extreme eastern sector of the Cairo-Suez district (~100 km east of Cairo). Gebel Abu Treifiya is located ~ 75 km east of Cairo and forms, with other Gebels (*e.g.* Nasuri, Anqabiya, Ataqa *etc*..), an elongated ridge running parallel to the Cairo-Suez highway depression.

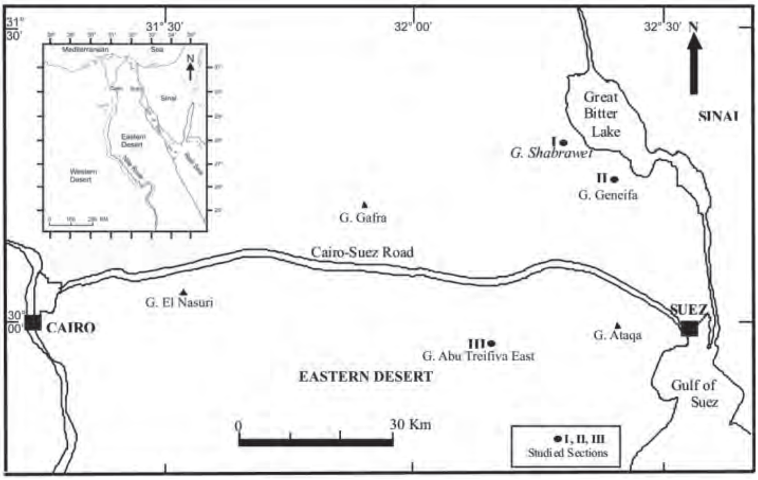

Fig. 1. Location map of the studied areas showing location of the measured sections.

The geology of these localities has been studied by several workers (*e.g*., Barron, 1907; Shukri and Ayouti, 1956; Faris and Abbass, 1961;

Said, 1962; Barakat *et al.,* 1970; Barakat and Abou Khadra, 1971; Barakat and Aboul Ela, 1971; Al Ahwani, 1982; Aboul Ela and Al Ahwani, 1986; Mohammad and Omran, 1991; Shamah and Helal, 1994; Shamah *et al.,* 1995; Ismail, 2001; Abdelghany, 2002 and many others). Despite the availability of the stratigraphic and petrographic studies on the studied area, it is rather difficult to follow the diagenetic evolution of the Middle Eocene carbonates in this area.

The present study is an attempt to shed more light on the diagenetic history of the Middle Eocene Mokattam Formation exposed in the Cairo-Suez district. A special emphasis is put on the dolomitization processes which represent the most dominant diagenetic effect.

Geologic Setting

Gebel Shabrawet is a prominent structure consisting mainly of steeply dipping Cretaceous rocks forming an inlier surrounded by gently-sloping Eocene, Oligocene and Miocene beds. The Eocene rocks are represented by different units of various conditions of sedimentation and separated from the Cretaceous beds by a thick conglomeratic bed (Faris and Abbas, 1961, and Abdelghany, 2002).

Shamah and Helal (1994) reported that the Middle and Upper Eocene rocks constitute the bulk of Gebel El- Goza El Hamra and the escarpments to the south of Darbet El Houtiy in Shabrawet area. Al Ahwani (1982) and Aboul Ela and Al Ahwani (1986) designated the "Mokattam Formation" to the Middle Eocene rocks in Gebel Shabrawet. However, Mohammad and Omran (1991) used the term "El- Goza El Hamra Formation" for this rock unit. Structurally, Gebel Shabrawet was affected by the Syrian arc movements; which resulted in the development of two anticlines separated by a shallow syncline. The region is highly faulted; being affected by both NE-SW and NW-SE faults.

Gebel Geneifa represents one of the conspicuous remnants of the original plateau that extends over the northern part of the Eastern Desert. The stratigraphic succession of Gebel Geneifa ranges in age from Middle Eocene to Quaternary (Barakat and Aboul Ela, 1971). The Middle-Upper Eocene rocks constitute the main bulk of the Geneifa scarp together with most of the structural highs in the Cairo-Suez district. The Middle Eocene rocks dip gently to the west and southwest and are overlain, with a slight angular unconformity in the topmost part of Gebel Geneifa, by the Upper Eocene units. Structurally, Gebel Geneifa is highly affected by normal faults whereas folding and unconformities are less significant (Barakat and Aboul Ela, 1971).

Barron (1907) described Gebel Abu Treifiya as a major block of Middle Eocene limestone surrounded by doleritic intrusions. Shukri and Ayouti (1956) reported that this Gebel is made up of basaltic flow along the sides of an elongated semicircular graben surrounded by Middle Eocene limestone from all sides except for its northern side. Barakat *et al*. (1970) reported that the stratigraphic succession of Gebel Abu Treifiya ranges in age from Middle Eocene (Lower Lutetian) to Quaternary. The Middle Eocene rocks are the most widespread and form the bulk of three main highs; Abu Treifiya, Abu Treifiya North, Abu Treifiya East. Barakat *et al.* (1970) reported that faulting is the most effective structural feature in the Cairo-Suez district in general and in Gebel Abu Treifiya in particular. This Gebel was affected by two main sets of faults related to the Clysmic and Mediterranean trends.

Materials and Methods

Three stratigraphic sections in Gebels Shabrawet, Geneifa and Abu Treifiya representing the Mokattam Formation in Cairo-Suez district were measured and forty representative carbonate samples were collected. These samples were investigated megascopically and their thin sections were examined microscopically before and after staining with Alizarin Red-S. X-ray diffraction analysis was conducted on 28 bulk samples using a Philips diffractometer (model PW/1840, installed in United Arab Emirates University) with Ni filter, Cu–Kα radiation (λ=1.542 Å). Instrument settings were 40 Kv and 30 mA potential, scanning speed of 0.02°/second and the 2θ ranged between 2° and 60°. Mineral identification was interpreted using the ASTM cards. The relative proportions of the identified mineral species were semi-quantitatively determined based on the intensities of their strongest diffraction peaks. Samples were examined using the Scanning Electron Microscope (model JSM-5600 Jeol ,installed in United Arab Emirates University) attached with EDAX in order to obtain more information about the petrographic characteristics of the studied carbonates with a special emphasis on those related to diagenesis.

Lithostratigraphy

The Mokattam Formation, ~ 44.7 m thick, of Gebel Shabrawet is composed of siliciclastics overlain by carbonates (Fig. 2). The siliciclastics are made up of olive gray shale containing small iron oxide lenses grading upward into yellowish brown, hard, calcareous and ferruginous sandstone with a conglomerate band at the base. The carbonate succession is composed mainly of several dolostone beds overlain by thick limestone beds. The dolostone is brown to yellowish brown, hard, sandy and highly ferruginous. Its basal part is argillaceous containing gypsum veins and clay pockets whereas the uppermost part is cavernous, banded, fractured in certain stratigraphic intervals, bioturbated and contains geods. The limestone at the top of the Gebel Shabrawet section is brownish yellow, very hard, dolomitic, fossiliferous and ferruginous with marl interbeds.

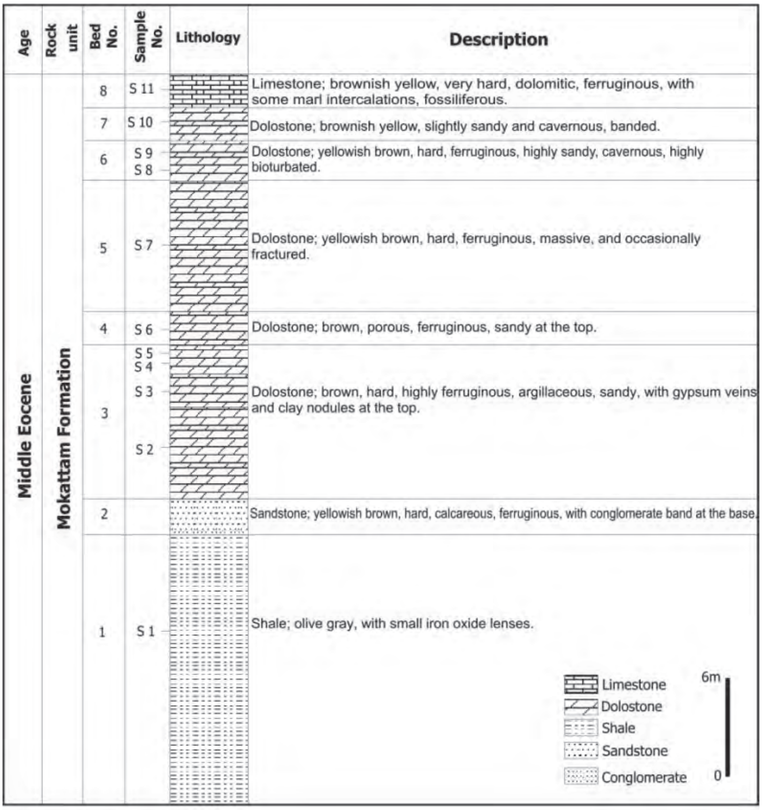

Fig. 2. Stratigraphic section of the Mokattam Formation in Gebel Shabrawet.

The carbonate rocks of Gebel Geneifa, ~ 89.5 m thick, is made up of dolostone intercalated with limestone and sandstone (Fig. 3). The dolostone is yellowish brown, brownish yellow, pale grey, hard, cavernous, sandy, and occasionally bioturbated. The limestone is white to pale yellow, brownish yellow at the top, hard, dolomitic, ferruginous, chalky at certain levels, and bioturbated. The sandstone is brownish to pale yellow, occasionally hard, calcareous, dolomitic, argillaceous in certain stratigraphic horizons and bioturbated.

The carbonate rocks of Gebel Abu Treifiya, ~ 51.3 m thick, consists of limestones intercalated at the base with a thin bed of pale yellow, hard, calcareous and bioturbated sandstone (Fig. 4). The limestone is yellow, white, pink, hard, dolomitic, chalky or sandy at certain stratigraphic levels, fossiliferous, ferruginous and is siliceous at the top of the section.

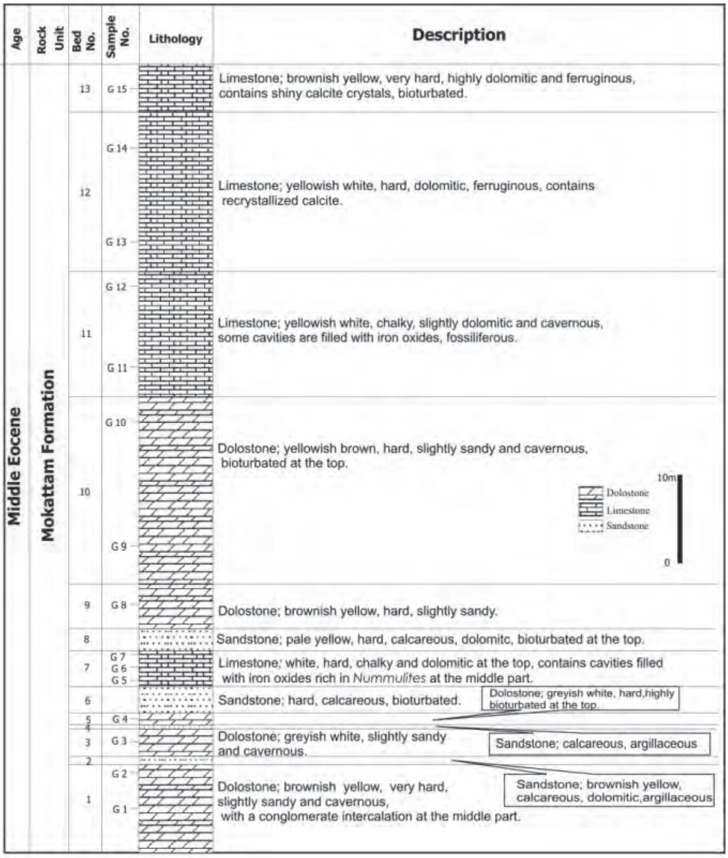

Fig. 3. Stratigraphic section of the Mokattam Formation in Gebel Geneifa.

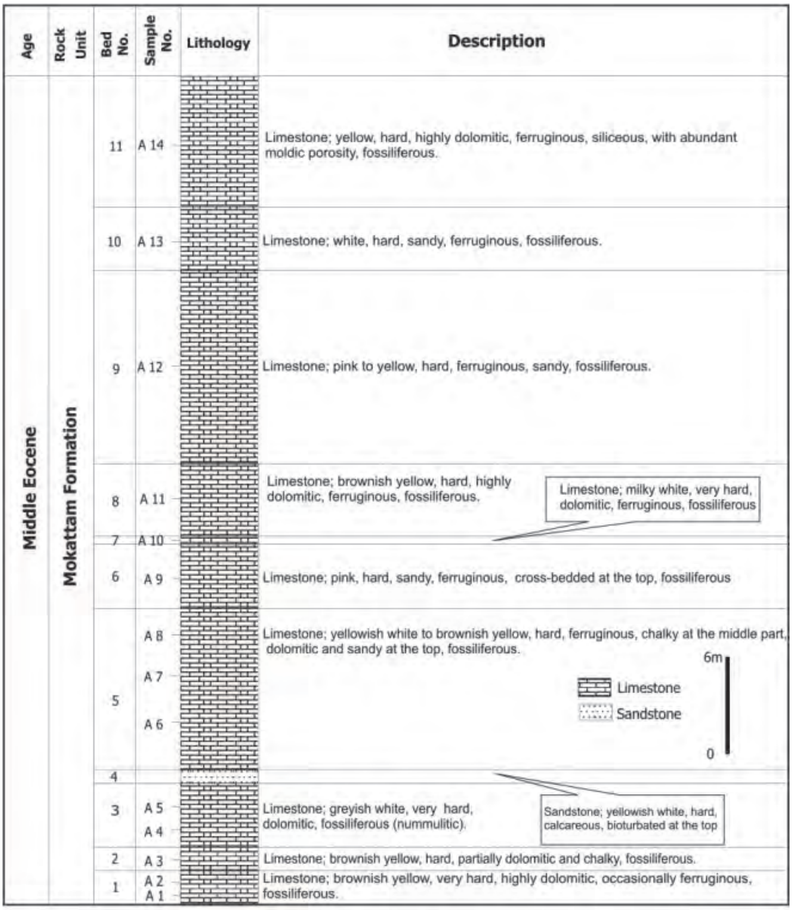

Fig. 4. Stratigraphic section of the Mokattam Formation in Gebel Abu Treifiya.

Petrography

The microscopic examination of thin sections is mineralogically confirmed by X-ray diffraction analysis. The studied carbonates of the Mokattam Formation are composed of calcite and dolomite (Fig. 5). Dolomite percentages vary vertically in the studied stratigraphic sections as well as laterally throughout the study areas (Fig. 6-8). Generally, all these sections display an upward decrease in dolomite percentage. Also, the dolomite percentage increases from Gebel Abu Treifiya at the south (10-46%; average 32%) to Gebel Geneifa (10-100%; average 69%) to Gebel Shabrawet at the north (34-100%; average 87%).

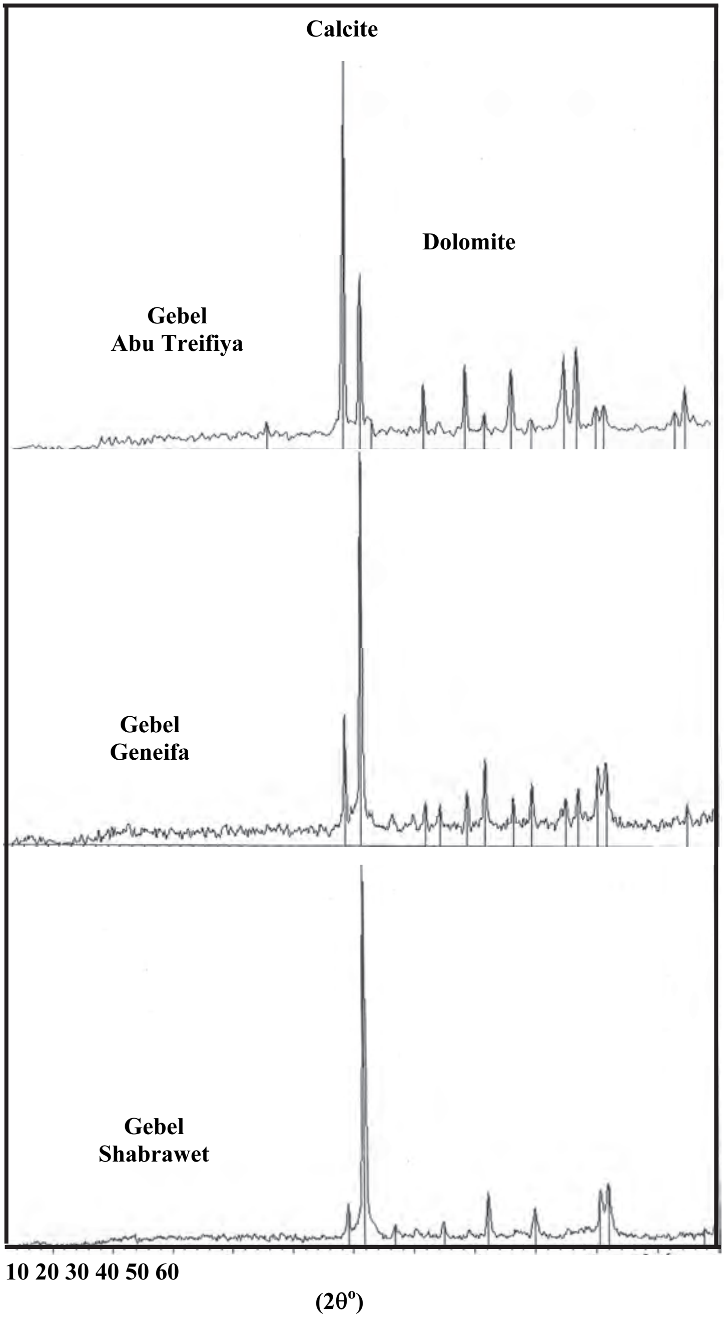

Fig. 5. Selected X-ray diffractograms of some carbonate samples from the studied areas.

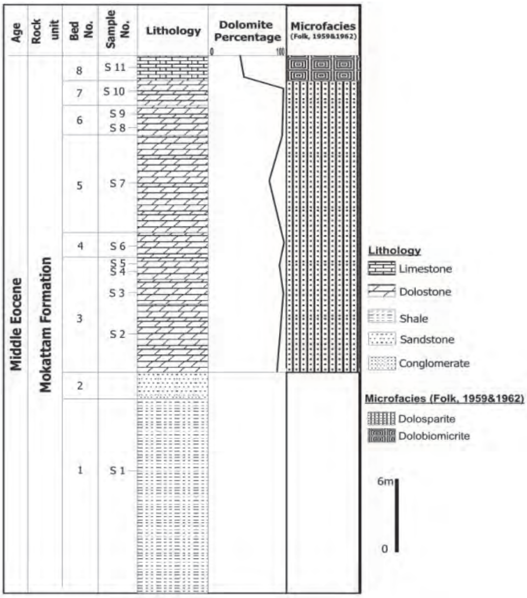

Fig. 6. Vertical variation in the compositional characteristics of the Mokattam carbonates throughout the Gebel Shabrawet section.

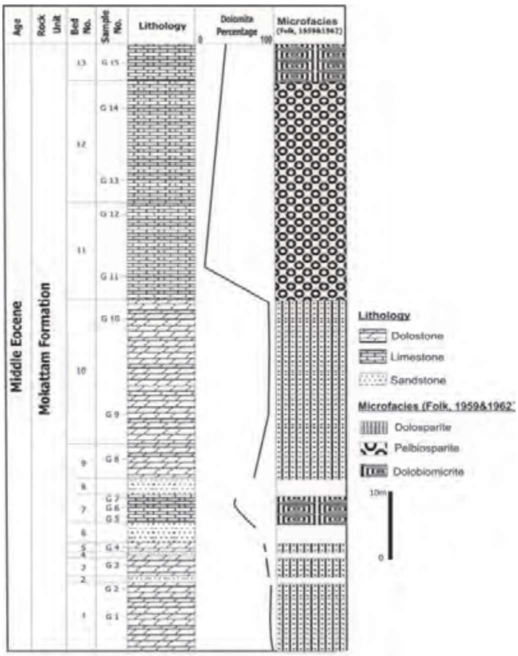

Fig. 7. Vertical variation in the compositional characteristics of the Mokattam carbonates throughout the Gebel Geneifa section.

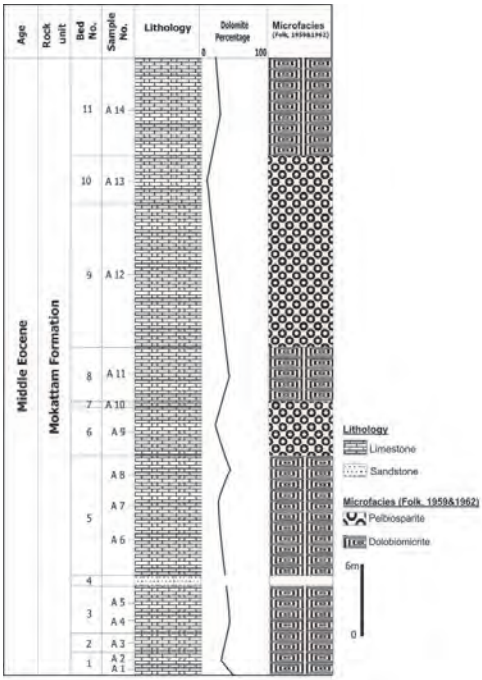

Fig. 8. Vertical variation in the compositional characteristics of the Mokattam carbonates throughout the Gebel Abu Treifiya section.

The results of petrographic study revealed the presence of three distinguishable microfacies types (based on the classification of Folk 1959, 1962).

1. *Dolosparite*

This microfacies represents ~ 38.2% of the studied Middle Eocene carbonates. It dominates most of the Shabrawet (53.7%) and the lower half of the Geneifa (45.6%) sections.

The major part of the dolosparite microfacies consists of a mosaic built up of fine- to coarse-crystalline dolomite crystals (Fig. 9 A-D). In the rocks of Gebel Shabrawet, dolomite crystals appear floating in an argillaceous micritic matrix (Fig. 9 C); the abundance of the argillaceous material decreases upward in the succession. It is most likely that their presence had prohibited the enlargement of dolomite crystals (Salem, 1977). The dolomite crystals are subhedral to euhedral; the latter shows idiotopic texture consisting of fine to medium rhombs some of which are cloudy, zoned and have iron nuclei. A number of the dolomite crystals had undergone varying degrees of dissolution that commenced in their cores and, in some cases, proceeded outward to form dolomolds. Few dolomite crystals display evidence of dedolomitization expressed by the replacement of their cores by calcite. The coarse-crystalline dolomite crystals form xenotopic and, rarely, idiotopic textures. Relics of micritic and sparitic calcite are scattered throughout the rocks. Quartz and other rock fragments are relatively more abundant in the samples collected from the Shabrawet section. Quartz grains are fine to coarse sand-sized, angular to subrounded, mono-and polycrystalline, and display unit to undulose extinction. The majority of the coarse quartz grains are polycrystalline and display semiundulose to undulose extinction. The rock fragments are sand- to gravel-sized and made up of micritic calcite. Also, very rare glauconite grains were recorded.

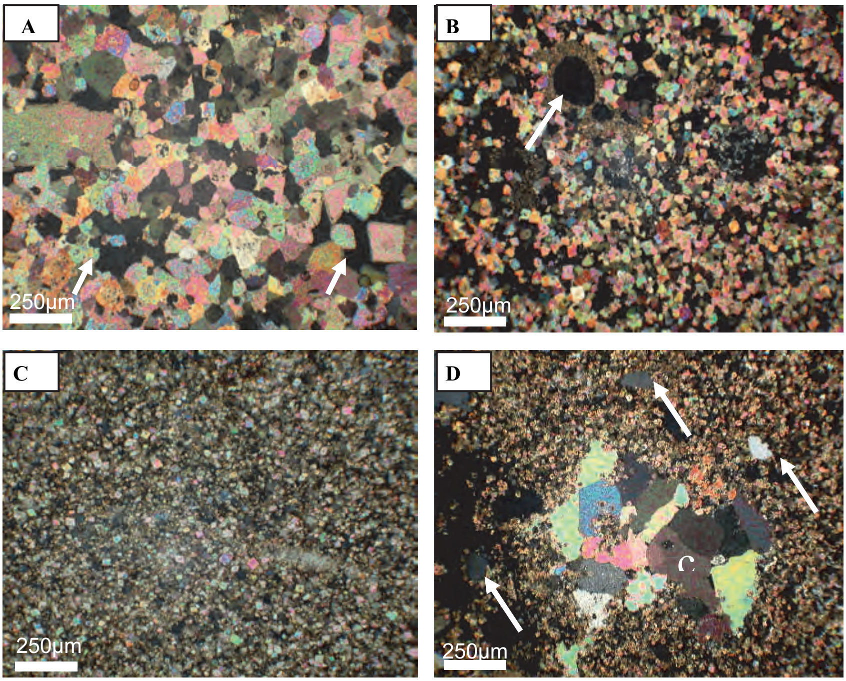

Fig. 9. Photomicrographs of dolosparite microfacies (all photos under Crossed Nicols):
This microfacies consists of fine to coarse, subhedral to euhedral, predominantly rhombohedral crystals some of which are cloudy, zoned and have iron oxide nuclei.
(A) Intercrystalline porosity (arrows) (Sample No. G 2).
(B) Moldic porosity (arrow) (Sample No. G 9).
(C) Dolomite crystals floating in a highly ferruginous, dolomitic and argillaceous micrite (Sample No. S 3).
(D) Quartz grains (arrows) and coarse crystalline xenotopic dolomite crystals (c) in a groundmass made up of fine-crystalline ferroan dolomite (Sample No. S 10).

Silicification was recorded in the upper part of the dolosparite bed in the Shabrawet section. Chalcedony is more abundant than the micro-quartz. The rock porosity is intercrystal, moldic and less commonly fractured. Patches and pigments of iron oxides are abundant and related to the late diagenetic stage.

2. *Pelbiosparite*

This microfacies constitutes ~ 31% of the studied carbonates. It is encountered in the upper halves of Abu Treifiya and Geneifa sections where it represents ~ 38.6% and ~ 35.9%; respectively.

Skeletal allochems of this microfacies consist of foraminiferal tests and, much less commonly, echinoid fragments (Fig. 10 A-D). The forams are represented by (in a decreasing order of abundance) miliolids, planktonic, biserial benthonic and Nummulites sp. Other skeletal grains are rare and include those of algal fragments, bryozoa, corals and ostracods. Peloids are abundant in the Abu Treifiya carbonates (Fig. 10 A & B). Quartz grains are rare and some display undulose extinction. Micro- to meso-crystalline circumgranular and drusy calcite cements are more abundant in Gebel Genifa than those recorded in Gebel Abu Treifiya carbonates. The majority of the echinoid fragments encountered in Abu Treifiya carbonates have syntaxial calcite overgrowths (Fig. 10 B). Some silicified echinoid fragments exist in the Abu Treifiya rocks. Pigments and patches of iron oxides are recorded in this microfacies. Structures of most of the tests were obliterated by the effects of micritization (Fig. 10 C) and/or dissolution; the latter process led to the development of moldic porosity (Fig. 10 A & C).

3. Dolobiomicrite

Dolobiomicrite microfacies represents ~ 30.8% of the studied Mokattam carbonates. It constitutes most (59.4%) of the lower part of the Abu Treifiya section. In Geneifa and Shabrawet sections, the dolobiomicrite represents ~ 10.6% and ~ 4.7% of the two succession; respectively.

The dolobiomicrite (Fig. 11 A-D) consists of micritic matrix in which skeletal allochems and rare quartz grains are embedded. The former are dominated by foraminiferal tests (miliolids, planktonic and Nummulites sp.) and echinoid fragments. Other skeletal grains include corals, ostracods, bryozoa, algae and unidentifiable bioclasts. Non-skeletal allochems (coarse peloids and lithoclasts) were rarely recorded in the Abu Treifiya section. The lithoclasts are sand-sized, rounded and consist of micrite which may encompass fine quartz grains. Most of these lithoclasts are highly ferruginous, siliceous and, rarely, dolomitized. In a few cases, the micritic matrix is partially recrystallized into pseudospar which occurs as circumgranular or drusy calcite cement filling the moldic cavities (Fig. 11 A). Some lithoclasts show two stages of drusy calcite cementation. Syntaxial calcite overgrowths of echinoid fragments were recorded in Gebel Geneifa carbonates. Dolomitization of the micrite matrix (Fig. 11 B) and allochems (Fig. 11 D) is more abundant than silicification. Dolomite occurs in the form of fine to medium rhombohedra, some of which are zoned forming idiotopic texture and display evidence of dedolomitization. Coarse-crystalline xenotopic dolomite crystals are uncommon.

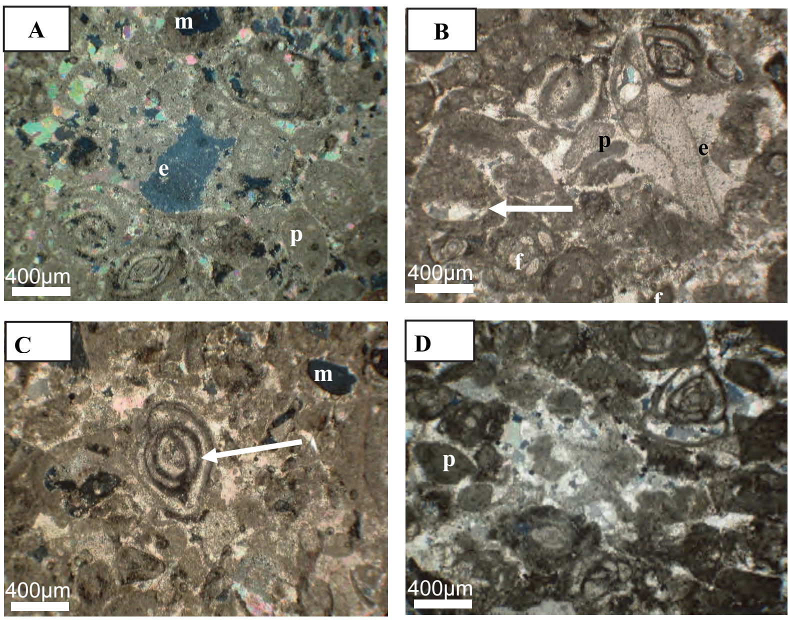

Fig. 10. Photomicrographs of pelbiosparite microfacies (all photos under Crossed Nicols): The pelbiosparite microfacies made up of foraminiferal tests (f), echinoid fragments (e) and peloids (p) cemented with sparite.

(A) Circumgranular calcitic cement in the formerly open frameworks of the rocks and moldic porosity (m) (Sample No. A 9).

(B) Obliteration of a skeletal allochem as a result of partial dissolution followed by filling with sparitic calcite (arrow) and syntaxial calcite around echinoid fragment (e) (Sample No. A 12).

(C) Closely packed skeletal allochems, moldic porosity (m) and micritic envelope (arrow) (Sample No. G 11).

(D) Circumgranular calcitic cement. (Sample No. G 13).

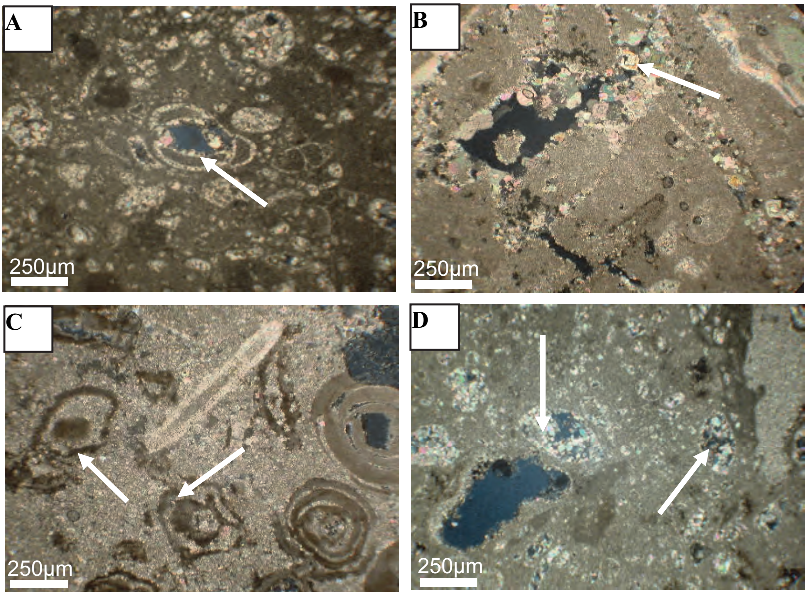

Fig. 11. Photomicrographs of dolobiomicrite microfacies (all photos under Crossed Nicols): This microfacies consists of several skeletal allochems embedded in a dolomitized micritic matrix.
(A) Drusy calcite cement (arrow) lining a moldic pore which resulted from the partial leaching of a foraminiferal test (Sample No. G 15).
(B) Zoned dolomite rhombs (arrow) scattered in micrite (Sample No. A 11).
(C) Micritization of skeletal allochems (arrows) (Sample No. S 11).
(D) Complete filling of skeletal cavities (arrows) with dolomite crystals (Sample No. A 7).

Micritic envelopes (Fig. 11 C) for some miliolids are common in the carbonates of the Shabrawet and Abu Treifiya sections. Pigments and patches of iron oxides stain allochems as well as the micritic constituents. Dissolution was responsible for the abundant development of vuggy, moldic and intercrystalline pores which are usually lined with iron oxides. Intraparticles and fracture porosity types are rare.

Diagenesis

The petrographic investigation of the studied Mokattam carbonates revealed that they were subjected to several diagenetic processes which largely modified their original and compositional characteristics. These processes are cementation, neomorphism, dissolution, compaction, dolomitization, dedolomitization and silicification (Table 1).

Table 1. Diagenetic sequence in the studied carbonates.

Processes of Diagenesis	Stages of Diagenesis		
	Eodiagenesis	**Mesodiagenesis**	**Telodiagenesis**
Cementation	X		X
Neomorphism	X		X
Dissolution	X		X
Compaction		X	
Dolomitization			X
Dedolomitization			X
Silicification			X

1. Cementation

Circumgranular, drusy and syntaxial calcite cements are common in the pelbiosparite and dolobiomicrite microfaciess of the studied Mokattam Formation. The inversion of aragonite to calcite was responsible for the development of circumgranular cement (Oldershaw and Scoffin 1967) filling the open spaces in the framework of the Geneifa pelbiosparites. Drusy calcite is often recorded in the cavities of the skeletal allochems which constitute a part of the pelbiosparite and dolobiomicrite rocks. Seemingly, it was developed as several generations which display an increase in crystal size toward the center of the cavity (Fig. 12 A). Most of the echinoid fragments were enlarged by syntaxial calcite rims (Fig. 12 B). Cementation with dolomite and, rarely, silica was recorded in the dolosparite and dolobiomicrite microfacies of the studied carbonates. It is believed that the meteoric phreatic environment was the site of cementation with calcite and silica, whereas the mixed marine phreatic environment witnessed the development of replacement dolomite.

2.Neomorphism

Degrading neomorphism is more common in the studied carbonates than the aggrading type. The former was recognized in the pelbiosparite and dolobiomicrite microfacies of the Abu Treifiya and Shabrawet sections; respectively. It is represented by the development of micrite envelopes (Fig. 12 C) and coarse peloids. It is most likely that the marine phreatic environment was the site of this diagenetic process (Friedman *et al*., 1971).

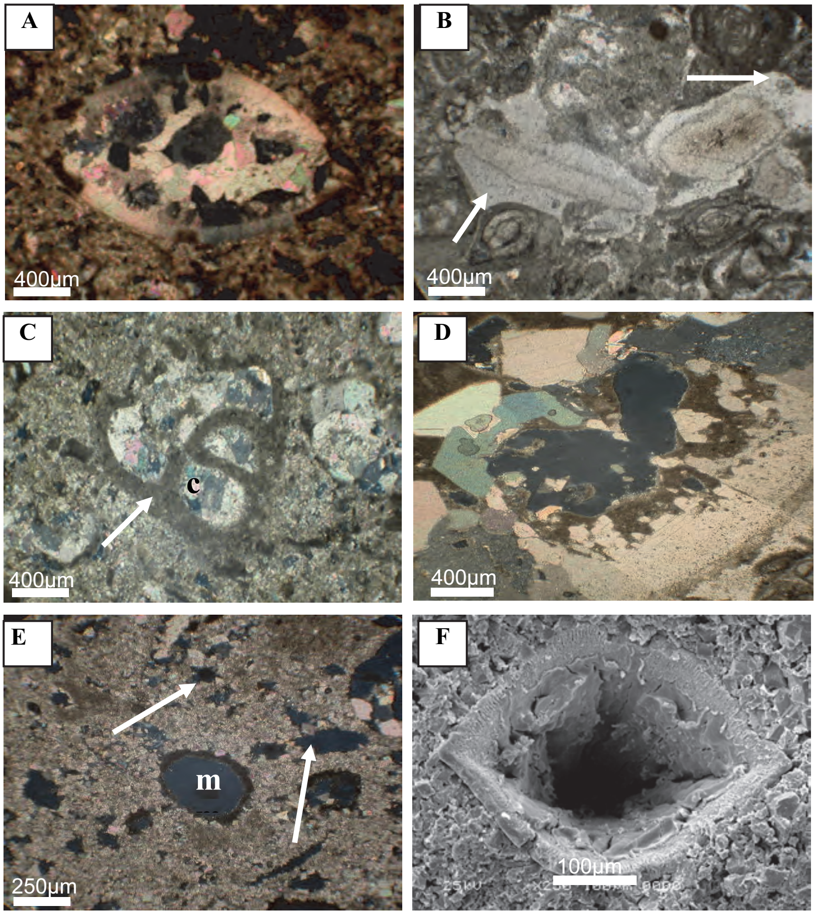

Fig. 12. Microscopic and SEM photomicrographs showing some diagenetic features displayed by the studied microfacies (all microscopic photos under Crossed Nicols):

(A) A Nummulites test showing more than one stage of cementation with drusy calcite crystals; the sizes of which increase towards the central part of the test (Sample No. G 12).

(B) A photomicrograph showing the development of syntaxial calcite cements (arrows) around echinoid fragments (Sample No. A 13).

(C) Development of micrite envelope (arrow) around a skeletal grain. Note the complete filling of a skeletal grain by calcite (c). (Sample No. G 12).

(D) Aggrading neomorphism of an originally micritic rock groundmass into sparite (Sample No. A 13).

(E) A rock groundmass containing moldic (m) and intercrystalline (arrows) pores (Sample No. A 14).

(F) SEM photomicrograph showing a well developed moldic pore which resulted from the dissolution and leaching of a skeletal grain (Sample No. S 7).

Aggrading neomorphism was commonly observed in the dolobiomicrite microfacies of the studied carbonates. It is represented by the partial or complete recrystallization of the micritic groundmass into micro-and/or pseudosparite (Fig. 12 D). Also, microcrystalline aragonitic and calcitic skeletal grains are commonly, to varying extent, recrystallized into sparitic, low-magnesian calcite which, in many cases, resulted in the obliteration of their original structures. It is most probable that this type of neomorphism occurred in the meteoric phreatic environment where mineral equilibrium was achieved.

3. Dissolution

The effect of dissolution on the studied carbonates is evidenced by the occurrence of various types of secondary porosity including vuggy, some intercrystalline and moldic pores (Fig. 12 E & F). These porosity types are especially common in the dolosparite and dolobiomicrite microfacies. It is believed that the transition from mixed marine phreatic to freshwater phreatic conditions favoured dissolution of aragonite and calcite. Moore (1989) reported that dissolution events take place in response to significant changes in physical and/or chemical properties of pore fluids such as temperature, partial pressure of CO2 and salinity. Most of these changes occurred in the studied Mokattam carbonates during the eogenetic and telogenetic phases of diagenesis. The former phase witnessed the replacement of marine pore waters with fresh meteoric water which led to their dilution and the generation of excess CO_2 (Abu Zeid *et al.*, 2001). The originally aragonitic and high-magnesian calcitic components of the rocks were unstable under these conditions and their dissolution and leaching resulted in the development of moldic porosity. This porosity was controlled by the mineral composition of the rock constituents (fabric selective). Other porosity types (vuggy and intercrystalline) are non-fabric selective which are usually formed in the vadose or phreatic meteoric environment during the telogenetic phase of diagenesis (James and Choquette, 1984).

4. Compaction

Compaction played a minor role in the diagenesis of the studied carbonates as evidenced by the rarity of compaction features and the presence of floating textures. This may be attributed to the prohibiting effect of the early phase of cementation during the shallow burial stage (Mesogenesis).

5. Dolomitization

Both selective and pervasive dolomitization are the main diagenetic processes which affected the studied carbonates. Selective dolomitization is represented mainly by the partial replacement of the originally aragonitic or calcitic materials of allochems and/or groundmass. This process was relatively more active in the carbonates of the lower part of Abu Treifiya section. Pervasive dolomitization , on the other hand, was recorded mainly in the rocks which constitute the upper half of Gebel Shabrawet and the lower half of Gebel Geneifa. It is most likely that both types of dolomitization were the product of mixed marine and freshwater diagenesis (Hanshaw *et al.,* 1971; Land, 1973; Badiozamani, 1973; Folk and Land 1975; Longman, 1982; Purser *et al.,* 1994; Abu-Zeid and Baghdady, 2002; Baghdady *et al.,* 2007 and others). The mixed-water model explains early diagenetic dolomitization during shallow burial without the precipitation of evaporites (Dunham and Olson, 1980). The development of freshwater/saltwater interface necessitated subaerial exposure either by tectonism or drop in eustatic sea level (Baum *et al.,* 1985).

The replacement origin of the studied dolomite is supported by: (i) the absence of evaporites and supratidal sedimentary structures; (ii) the occurrence of micritic calcite relics in the rock groundmass; (iii) the presence of skeletal grains which demonstrate shallow water depositional environments of normal salinity; and (vi) the presence of cloudy dolomite rhombs which are known to originate by transformation from low-Mg calcite during prolonged diagenesis (Carozzi, 1993).

The abundance of the replacement dolomite in the studied carbonates suggests a very long-lived marine-freshwater diagenetic stage; especially towards the northern part of the study area. The occurrence of zoned ferroan dolomite crystals in these rocks may be related to changes in the Fe^{++}/Mg^{++} ratio as a result of salinity change. The latter is controlled by the multiple periods of phreatic conditions (El Sayed, 2001). Dolomites are recrystallized via multiple steps (Land, 1992) which may be evidenced by the inter-tonguing relationship between these crystals.

The extent of dolomitization varies vertically throughout each of the measured sections and laterally in the studied area. The carbonates in the southern Abu Treifiya section are slightly affected by dolomitization when compared with those in the northern Shabrawet and Geneifa sections. Dunham and Olson (1980) reported that the intrusion of freshwater into submarine deposited carbonate sediments took place in the shallow subsurface as a result of the lateral extension of freshwater lenses developed beneath the subaerially exposed tracts. Also, they mentioned that one of the reasons responsible for the rarity of dolomitization is the difference in paleogeographic setting of the studied sections. According to these findings, the highly dolomitized rocks of the northern Shabrawet and Geneifa sections seem to have been more exposed to freshwater recharge than those of the southern Abu Treifiya section. The proximity of the northern sections to the land which was directly affected by the freshwater lenses is manifested by the abundance of siliciclastics relative to the southern section. It is most likely that the dolomitization process operated repeatedly by the effect of frequent intrusions of fresh water lenses and/or development of a mixing zone.

Dolomitization diminishes upwards throughout all the studied sections, due to the depletion of magnesium sources and/or sealing of pathways of Mg-rich solutions. Mountjoy *et al.* (1999) reported that dolomitization may be controlled by faulting which seems to have played a much more prominent role in paleo-fluid flow.

On the other side, dolomitization (Fig. 13 A & B) of the studied carbonate rocks was accompanied and/or followed by dissolution which led to the generation of considerable moldic and vuggy porosity (Machel and Mountjoy, 1987 and Drivet and Mountjoy 1997). Careful investigation of dolomite crystals in the studied rocks suggests the presence of three stages of dissolution which represented by: (i) the incipient development of dissolution pits (Fig. 13 C); (ii) the partial dissolution of the relatively less stable crystal cores (Fig. 13 D); and (iii) the complete dissolution of these cores which resulted in the development of hollow dolomite crystals (Fig. 13 E). These stages are similar to those suggested by Randazzo and Cook (1987) and El Sayed (2001). Folk and Siedlecka (1974) reported that more intensive dissolution as a result of salinity reduction produces dissolution-centered crystals (Fig.13 F).

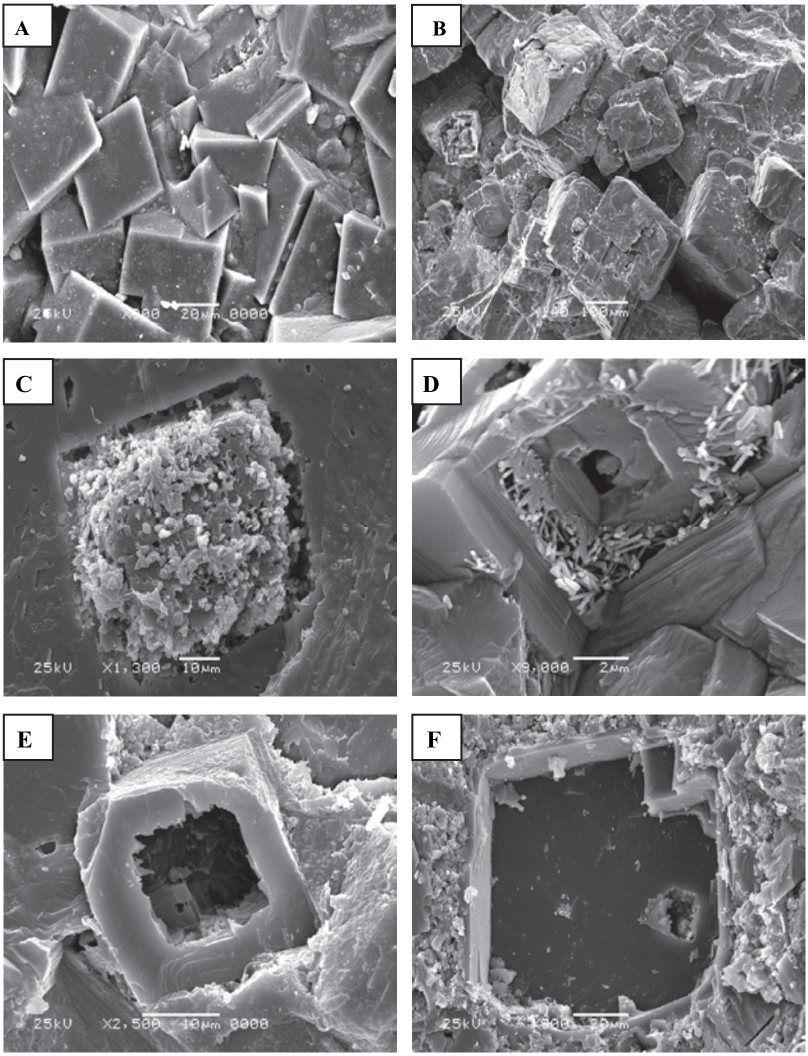

Fig. 13. SEM photomicrographs of the dolomite crystals and the successive stages of their dissolution:

(A) Unzoned idiotopic dolomite rhombs (Sample No. G 8).

(B) Zoned idiotopic dolomite rhombs (Sample No. S 9).

(C) Initial development of dissolution pits on the surface of the crystal (Sample No. G 10).

(D) Partial dissolution of its relatively less stable core (Sample No. G 1).

(E) Complete dissolution and leaching leaving behind a hollowed dolomite crystal (Sample No. S 8).

(F) Extensive dissolution and leaching of a dolomite crystal and the consequent development of a distinct moldic pore (Sample No. G 8).

6. Dedolomitization

Dedolomitization was recorded in the dolosparite and dolobiomicrite microfacies and seems to be the product of meteoric diagenesis. The effect of dedolomitization in the studied rocks is manifested by the presence of calcite pseudomorphic crystals having the form of rhombohedral dolomite precursor (Fig. 14 A). Growth of these calcite crystals started in the relatively less stable crystal cores and proceeded toward their peripheries.

Dolomite crystals rich in iron oxides are more susceptible to dedolomitization than those poor in iron oxides (Frank, 1981). Upon dedolomitization, iron in the dolomite crystal lattice is oxidized and precipitated as ferric hydroxide (Evamy, 1963 and Katz, 1971). In the studied carbonates, the presence of pore-filling iron aggregates (Fig.14 B) manifests the breakdown of ferroan dolomite under subaerial conditions by the action of circulating sea water along the permeable zones (Al-Hashimi and Hemingway, 1973).

7. Silicification

Chalcedony and, less commonly, microquartz were recorded in the upper parts of the dolosparite beds in the Shabrawet section (Fig. 14 C & D). The pelbiosparite microfacies contains silicified echinoid fragments in the Abu Treifiya section and its groundmass is rarely silicified in the Geneifa rocks. Most of the lithoclasts in the dolobiomicrite microfacies of the Abu Treifiya section are highly siliceous whereas their groundmass is rarely silicified. It is most likely that this type of silicification occurred in the meteoric phreatic zone in which the pores were supersaturated with respect to silica and undersaturated with dissolved carbonate minerals (Hesse, 1989).

Conclusions

The Middle Eocene Mokattam Formation exposed in the eastern part of the Cairo-Suez district at Gebels Shabrawet, Geneifa and Abu Treifiya (from north to south) consists of carbonates and subordinate siliciclastics. The carbonates are made up of dolosparite, pelbiosparite and dolobiomicrite. Dolosparite dominates the upper half of the northern Shabrawet and the lower half of the Geneifa sections. Pelbiosparite forms the upper halves of the Geneifa and the southern Abu Treifiya sections.

Dolobiomicrite constitutes the tops of the Shabrawet and Geneifa sections in addition to several thick intervals in the Abu Treifiya successions.

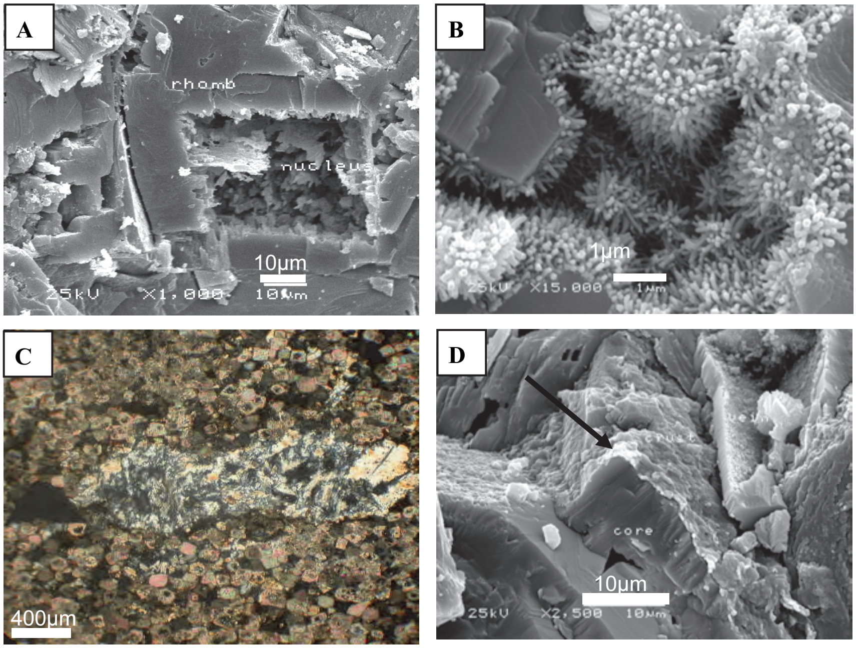

Fig. 14. SEM and microscopic photomicrographs showing dedolomitized crystal, pore filling iron and silica in the studied microfacies (microscopic photo under Crossed Nicols):

(A) A pseudomorphic calcite crystal has been developed from a rhombohedral dolomite precursor. (Sample No. S 2).

(B) Iron aggregates coating dolomite rhombohedra and filling intercrystal pores (Sample No. G 1).

(C) Partial silicification of a dolostone represented by the development of a chalcedonic veinlet (Sample No. S 8).

(D) Thin silica crusts on dolomite crystals (arrow). (Sample No. S 10).

The original compositional and textural characteristics of the studied Mokattam carbonates were greatly altered by cementation, neomorphism, dissolution, compaction, dolomitization, dedolomitization, and silicification. Cementation was mainly by calcite, dolomite and, rarely, silica. Calcite cements occur in the form of open filling, syntaxial rims or replacing dolomite by the effect of dedolomitization. Neomorphism is of both the aggrading and degrading types. Dissolution of the originally aragonitic and/or calcitic components resulted in the development of fabric and non-fabric selective porosity. The intensity of selective and pervasive dolomitization varies throughout the measured sections as well as the study area.

An initial stage of cementation with calcite, degrading neomorphism and development of fabric-selective porosity occurred during the eogenetic phase of diagenesis in the phreatic marine environment. The early phase of cementation inhibited the effect of burial compaction during mesogenesis. Cementation with calcite and silica and aggrading neomorphism were favoured by the phreatic meteoric conditions during telogenesis. Evidently, dolomitization of the studied carbonates occurred mainly during the telogenetic phase of diagenesis in mixed marine-meteoric phreatic environments characterized by frequent intermittent intrusions of freshwater lenses especially in the northern part of the study area. This necessitated subaerial exposure either by tectonism or drop in eustatic sea level. It is most probable that the dolomitization process was controlled by faulting which played an important role in flow of the dolomitizing fluid. On the other hand, dedolomitization and dissolution occurred during telogenesis in the meteoric environment under phreatic and vadose conditions; respectively. Generally, the relative dominance of the various diagenetic effects displayed by the studied carbonates indicates that telogenesis was much more effective than mesogenesis and eogenesis.

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تطور عمليات النشأة المتأخرة لصخور الأيوسين الأوسط الجيرية (متكون المقطم)، الجزء الشرقي من طريق القاهرة – السويس، مصر.

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المستخلص. تتشكل الأحجار الجيرية المنتمية لمتكون المقطم والمنكشفة في جبال شبراويت وجينيفة وأبو طريفية من سحنات السباريت الدولووميتي، السباريت الحيوي العقدي والميكريت الحيوي الدولوميتي. وتسببت العمليات اللاحقة للترسيب في إحداث تغيرات كبيرة في صفاتها التركيبية والنسيجية وذلك بفعل الالتحام والاستحداث الشكلي ووالإذابة والانضغاط والدلمتة وإزالة الدلمتة والتسلكن. ولقد تأثرت بعض الأحجار بعملية الإستحداث الشكلي سواء البناء أو الهدام كما أدت عمليات إذابة المكونات الأراجونيتية والكلسية الأصلية إلى نشأة المسامية التفاضلية. وقد تبين التفاوت الواضح في مدى شدة الدلمتة الاختيارية والشاملة رأسيًا في كل من القطاعات الإستراتجرافية بمنطقة الدراسة.

وتدل نتائج الدراسة على أن تاريخ النشأة المتأخرة للأحجار الجيرية قد بدأ في مرحلة مبكرة (Eogenesis) والتي شهدت تأثير المرحلة الأولى من الإلتحام بالكالسيت وعمليات الإستحداث الشكلي الهدام والإذابة التفاضلية وذلك في بيئة بحرية مغمورة . وقد تسببت عملية الالتحام المبكر في تقليل تأثير الانضغاط خلال المرحلة الوسطى (Mesogenesis). وشهدت المرحلة الأخيرة من تاريخ النشأة

المتــأخرة (Telogenesis) عمليــات الالتحــام بالكالســيت والســيليكا والاستحداث الشكلي البناء وإزالة التدلمت تحت ظروف قارية مغمورة. وعلى الجانب الآخر فإن نطاق القارية غير مشبعة كان موقعًا ملائمًا لعمليات الإذابة. وأيضًا شـهدت المرحلـة الأخيرة من تـاريخ النشـأة المتأخرة تأثيرًا كبيرًا لعملية الدلمتة وخاصة في الأجزاء الشمالية من منطقة الدراسة وذلك في بيئة الخلط بين المياه البحرية والقارية والتي تميزت بحدوث اقتحامات متقطعة لعدسات المياه العذبة وذلك نتيجة لسيادة ظروف قارية سواء بفعل الحركات التكتونية أو نتيجة لهبوط منسوب سطح البحر. ويعتقد أن عملية الدلمتة قد تـأثرت بوجود الكسـور التـي لعبـت دورًا هامًـا فـي حركـة السـوائل المسـؤولة عـن التـدلمت. وبصـورة عامـة فـإن السـيادة النسـبية للظـواهر المختلفـة الخاصة بالنشأة المتأخرة في الأحجار الجيرية التابعة لمتكون "المقطم" تدل على أن المرحلـة الأخيرة من تاريخ النشأة المتأخرة كانت أكثر فاعلية من المرحلتين المبكرة والوسطى.