POST-DEPOSITIONAL CHANGES OF THE LOWER-MIDDLE EOCENE LIMESTONES OF THE AREA BETWEEN ASSIUT AND MINIA, WEST OF THE NILE VALLEY, EGYPT

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ABSTRACT

The diagenetic changes of the Lower-Middle Eocene limestones in the area to the west of Assiut- Minia Stretch include the following processes: compaction, cementation, neomorphism, silicification, glauconitization and ferrugination. The compaction is represented by mechanical and chemical types. Cementation is either shallow submarine (represented by micrite, fibrous calcite and isopachous calcite cement) or meteoric water (represented by granular spar, and syntaxial overgrowth rim). The recrystallization processes include the aggrading neomorphism of both micrite and skeletal particles (to yield microspar, pseudospar and blocky calcite). The degrading recrystallization (micritization process) of the skeletal particles is exhibited due to their replacing by the micrite produced by the disintegration of the algal components. Silicification process involves the formation of cherts and the selective replacement of the carbonate constituents. The study of the glauconitization and ferrugination processes include their occurrence and origin.

INTRODUCTION

The area under study skirts the Nile Valley from the west in the vicinity of Assiut between south of Abu-Tig till the latitude of Mallawi in the north (Fig.1). It lies between the following co-ordinates: latitudes 26º 27´ & 27º 42´ N. and longitudes 30º 41´ & 31º-15´ E. The exposed limestone rocks in this area belong to the Lower and the Middle Eocene. The main goal of this work is to throw more light on the most dominant diagenetic features that are recorded in the studied carbonate rocks. Lithostratigraphically, the carbonate succession of the present area is subdivided into Drunka, Minia and Samalut formations. The possible depositional environments of the studied rock units are suggested by Hussein (2005) as restricted shelf lagoon (Drunka Formation), Alveolina-orbitolites-dasycladacean algae bank environment (Minia Formation) and nummulitic bank environment (Samalut Formation) (Table 1).

Material and Methods of Study

Our study is based on samples collected from four measured stratigraphic columnar sections from the area under consideration. These samples were used for petrographic and geochemical investigations. About 350 thin sections representing the different limestone facies were prepared and examined under the petrographic microscope. Alizarine Red S, Potassium ferricyanide, XRD and Scanning electron microscopy (SEM) techniques were used to investigate the diagenetic features of the studied rocks.

DIAGENETIC PROCESSES

The most striking post-depositional processes acting on the Lower and Middle Eocene limestones in the area under study include compaction, cementation, recrystallization, silicification, glauconitization and ferrugination.

Compaction

Compaction is defined as irreversible diagenetic process that results in reduction in the bulk volume, thickness or porosity of the sediment in response to the increasing in weight of overlying material or to the pressure resulting from earth movement within the crust (Flugel, 1982 and Mclane, 1995).

In the present work, the petrographic studies indicate that the sediments of the Samalut Formation are subjected to significant compaction with less effect in the facies of the Drunka and Minia formations.

Types of compaction:

A. Mechanical (early) compaction: Is this type of compaction that results from mechanical stress of sufficient magnitude to cause brittle failure of the rock components. It may be originated by the overburden stress or by the crustal deformation (tectonism). The mechanical compaction of the carbonate sediments causes closer packing of the grains, squashing of the soft grains, reorientation of the grains to closer parallism to the bedding, collapsed micrite envelopes, fractures in the delicate shells and expulsion of intergranular fluids. In the present study, the rocks of the Samalut Formation show more liability to the mechanical compaction than that of the Drunka and Minia formations. In the Samalut Formation, the mechanical compaction is represented mainly in the packstones and grainstones microfacies and to less extent in the wackestones microfacies. The rocks of the Samalut Formation show mechanical compaction in forms of: closer packing of

nummulites grains, fracturing of nummulites and fragmentation of the nummulites into smaller grains (Pl.1A). In the Minia Formation, the following mechanical compaction features are observed in some packstones and grainstones textures: closer packing of the allochemical grains, fracturing and breakage of some alveolines, orbitolites, algal and molluscan shells. In the Drunka Formation, the mechanical compaction features are recorded mainly in the packstone texture and rarely observed in the wackestones and grainstones microfacies. These features include: closer packing of particles, breakage of the soft shells (algae, orbitolites or bryozoa), preferred orientation of allochems parallel to the bedding planes and overpacking of the allochemical constitutents.

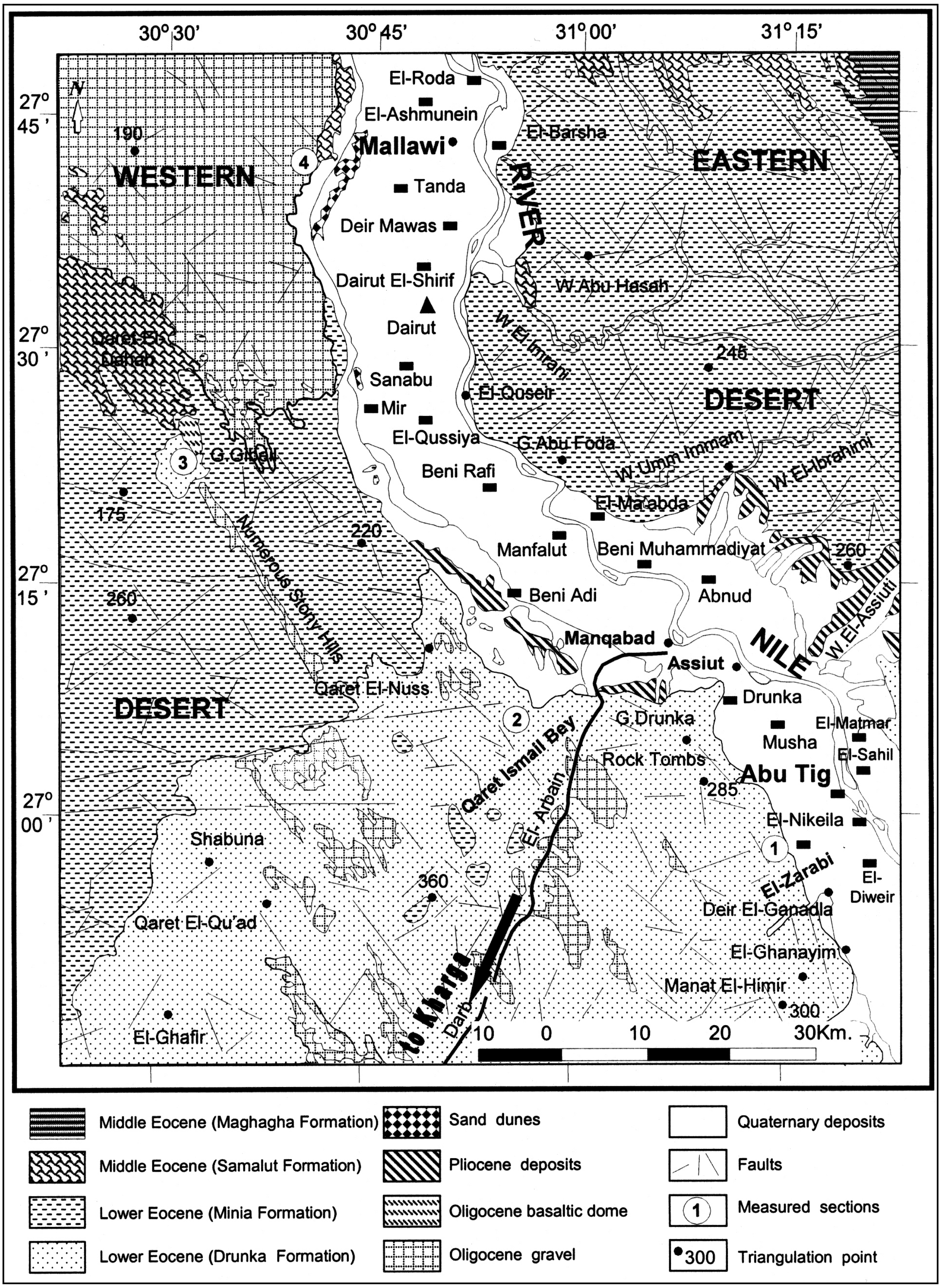

Fig.(1) Geological map of the study area (modified after EGPS and Conoco, 1987)

Table (1) The main characteristics of the studied rock units and their depositional environments

Rock units	Lithology	Sedimentary structures	Fossil Abundance	Fossil diversity	Major Taxa	Depositional textures	Depositional environment
Drunka Formation	Porous,algal limestone with chert bands and concretions	- Burrowing - Ripple marks - Thin lamination - Wavy bedding - Lenticular bedding - Massive to thick -bedded	Medium	Low	Green algae Echinoids Nummulites Miliolids	Lime mudstone Wackestone Packstone Grainstone	Shelf lagoon
Minia Formation	Snow white alveolinid onoitolinid limestone	Massive to thick - bedded and burrowed	High	Medium	Alveolina Orbitolites Dasycladacean algae	Wackestone Packstone Grainstone	Alveolina-Orbitolites-Green algae bank
Samalut Formation	Nummulitic limestone	Unbedded massive of mound shape	Very High	Medium	Nummulites Bryozoa Discocyclines Red algae	Wackestone Packstone Grainstone	Nummulitic bank

B. Chemical (Late) compaction: Pressure solution, as used here, is defined as the process whereby the grains or crystals undergo dissolution at their contact surfaces with each other, where the external pressure exceeds the hydraulic pressure of the interstatial fluid (Bathrust, 1975; Wanless, 1979 and Prothero and Schwab, 1996). Buxton and Sibley (1981) documented three fundamental styles of pressure solution in the Alpena limestone: stylolites, solution seams and fitted fabric texture. Evidence of chemical compaction in the studied rocks includes grain or crystal closely packed (grain-to-grain contacts or crystal-to-crystal contacts), stylolites and solution seams. The grain or crystal-contacts are equivalent to the fitted fabric of Buxton and Sibley (1981). This style of chemical compaction is resulted due to the localization of the strain at the grain contacts and hence preferential solution of upper and lower surfaces of grains in a solution film leads to creation of planar, concavo-convex and sutured contacts. This grain contact dissolution must occur before cement. The grain-to-grain contacts are commonly recorded in the packstones microfacies of the Samalut and Minia formations, while they are completely absent in the microfacies of the Drunka Formation.

The crystal-to-crystal contacts are observed in the calcite crystals of the recrystallized lime mudstone of the upper unit of the Drunka Formation (Pl.1B). Stylolites are indicative of the intrastratal pressure solution phenomena. They consist of serrated seams marked by a thin layer of dark clayey material and/or ferruginous substones (Bathrust, 1975; Buxton and Sibley, 1981 and Flugel, 1982). The occurrence of stylolites at the grain boundaries suggests that they were formed early post consolidation in response to pressure solution. Here, the microstylolitic surfaces are observed particularly in the packstones microfacies of the Samalut Formation, while they are scarcely found in Drunka and Minia formations (Pl.1C). Solution seams (as studied by Buxton and Sibley, 1981) are smooth, undulating boundaries, lacking the sutured form of stylolites. This type of pressure solution is the most common type recorded throughout the studied microfacies. They also have an accumulation of clay minerals and iron oxides (Pl.1D). This type of chemical compaction is commonly observed in the microfacies of the Drunka Formation.

Cementation

Cementation is the fundamental diagenetic process by which the loose sediments become lithified or consolidated (transformation of sediments into solid rocks) through precipitation of a material matter carried by water seeping through the pore space between the grains (Bathrust, 1975; Flugel, 1982; McLane, 1995 and Prothero and Schwab, 1996). The cements in the carbonate rocks may be intergranular or intragranular. Harris *et al.* (1997) interpreted the post-depositional diagenetic changes to have occurred in marine and freshwater phreatic environments. In the shallow marine environments, the cements are represented by aragonite and high Mg-calcite (PettiJohn, 1975; Longman, 1980; Tucker, 1981 and McLane, 1995). The aragonite can be identified by its acicular, fibrous and needle shape (Shinn, 1969; Milliman, 1974; Land and Moore, 1979 and McLane, 1995). On the other hand, the high Mg-calcite is microcrystalline and cryptocrystalline of semi-opaque appearance (Flugel, 1982). The subaerial (meteoric) cements are represented by the low Mg-calcite (Tucker, 1981; Blatt, 1992 and Mclane, 1995), which appears as coarse to very coarse sparry calcite crystals characterized by blocky, massive and drusy shape (Folk, 1974a; Folk and Land, 1975 and Al-Hashimi, 1977).

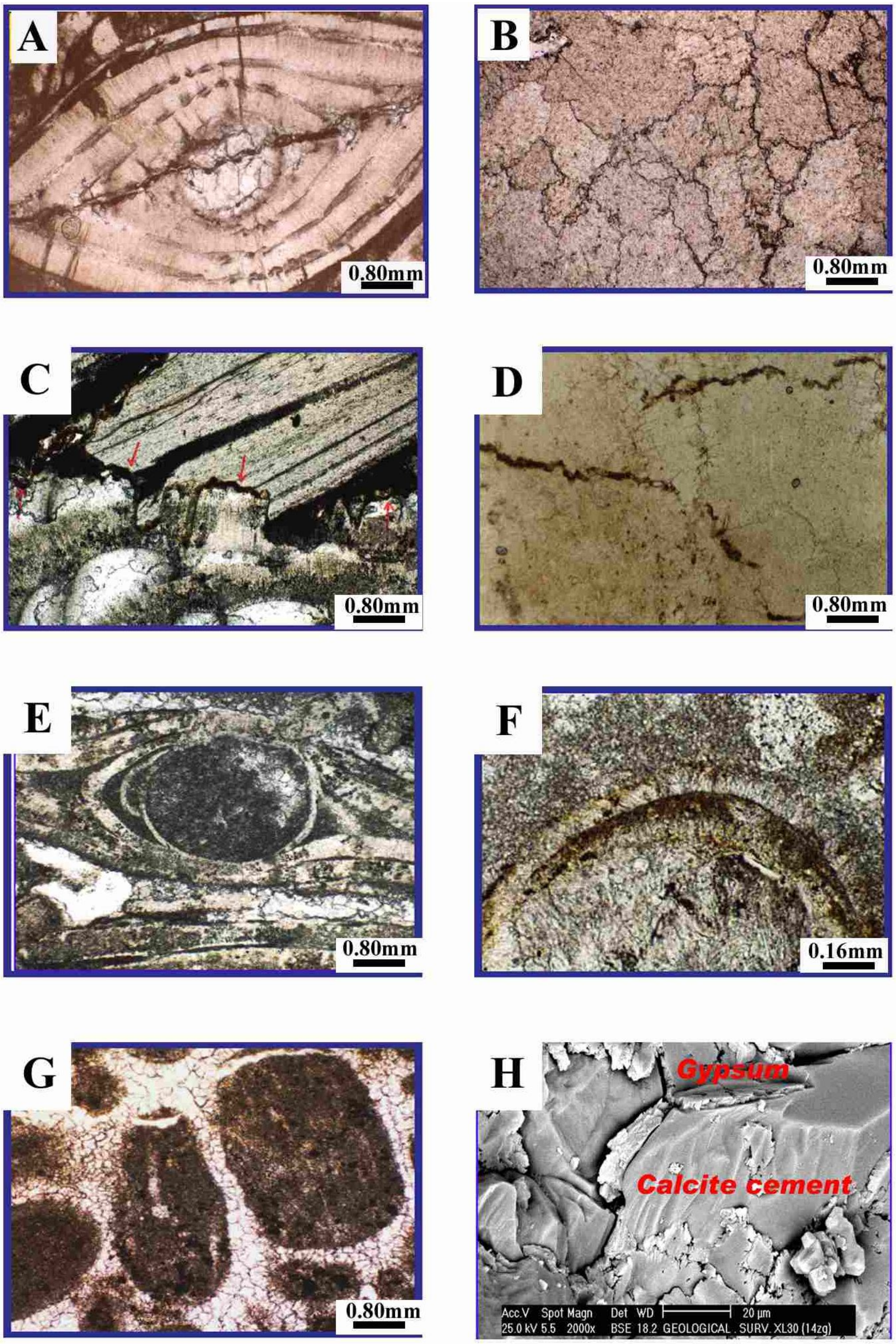

Plate (1)

(A) photomicrograph showing the nummulitic packstone illustrating the fracture in nummulites due to compaction. Note that the fracture zone was filled with iron oxide. Samalut Formation, Mallawi Section. (B) Irregular, serrate to sutured contacts between the neomorphic calcite crystals. Note: the micrite fills the boundaries between these crystals. Recrystallized lime mudstone. Upper Unit, Drunka Formation, Ismail Bey Section. (C) Microstylolitic surface fihhs with reddish brown materials, probably composed of iron oxide. This surface is formed by the interpenetration between the bivalvia (upper part) and nummulites grains (left and lower parts). Nummulitic packstone microfacies. Samalut Formation, Mallawi Section. (D) Photomicrograph showing solution seam filled with brownish material. Note: the lack in the sutured form of stylolites. Echinoidal wackestone microfacies. Upper unit, Drunka Formation, Ismail Bey Section. (E) Photomicrograph showing intraparticle micrite is observed within some skeletal chambers and hollows especially in the nummulite grains. (F) Photomicrograph showing the fibrous calcite cement is made up of tightly-packed fibrous to bladed circumgranular crystals, coating the outer surface of the bivalvian particles. (G) Photomicrograph showing isophacous calcite cement appears as rim cement around fecal peloid grains. (H) SEM image showing the presence of gypsum between the interstices of the granular calcite cement as an evidence about their freshwater origin. Fecal peloid grainstone microfacies. Lower unit of the Drunka Formation, El-Zarabi section

A. Shallow submarine cementation

The shallow marine diagenetic environment is represented here by the marine phreatic zone where most of the carbonate sediments begin their diagenetic history (Longman, 1980). In the present study, the following types of the marine phreatic cements are recorded:

a. Micrite cement: The micrite cement is usually deposited in the marine environment (Folk, 1974a; Bathrust, 1975; Land and Moore, 1979 Longman, 1980; Tucker, 1981; Blatt, 1992, McLane, 1995; Prothero and Schwab, 1996; Adams and Mackenzie, 1998; Nelson and James, 2000 and Melim *et al.,* 2002). The micrite cement is the most predominant interparticle binding material in the wackestones and packstones microfacies of the studied rock units. Intraparticle micrite is also observed within some skeletal chambers and hollows especially in the algal, foraminiferal and molluscan grains (Pl.1E). The micrite cement in the present work is composed of a dense dark cryptocrystalline to microcrystalline calcite with cloudy appearance. It is composed of randomly oriented calcite crystals in which the individual crystal has average size of about 4 μ. In the studied rocks, the authors suggest that the micrite cement in the examined microfacies of both the Drunka and Minia formations resulted from the disaggregation of the calcareous algae while that of the microfacies of the Samalut Formation seems to be formed by the mechanical disintegration or bioerosion of the large particles (e.g. *Nummulites gizehensis* (Forskal)).

b. Fibrous calcite cement: The fibrous calcite cement is precipitated in the shallow marine diagenetic environment by the following authors: Folk (1974a), Al-Hashimi (1977), Longman (1980), Tucker (1981), McLane (1995), Prothero and Schwab (1996), Nelson and James (2000), Moore (2001) and Melim *et al.* (2002). The fibrous calcite cement can be considered as the first generation of calcite cement in this study. It is recorded as encrusting crystals on the bivalvian grains of the orbitolites alveolinid dasycladacean green algae grainstone microfacies of the Minia Formation. This cement is made up of tightly-packed fibrous to bladed circumgranular crystals, coating the outer surface of the bivalvian particles (Pl.1F). In some cases, the fibrous calcite crystals line the fractures within the shell fragments. The fibrous calcite crystals are oriented with their long axes normal or nearly normal to the surface of the substrate on which they develop. Such crystals have an average length to width ratio of about 3:1. The boundaries between these crystals are mainly planar. In the present study, the fibrous to bladed calcite cement in the orbitolites alveolinid dasycladacean green algae grainstone is followed by coarser sparry calcite which can be indication about that the origin of this cement is with or just after the deposition of the particles in the early stages of diagenesis. From the petrographic observations, it is suggested that this type of cement is of high Mg-calcite not aragonite due to its crusty, bladed or fibrous habit rather than the acicular appearance, which characterizes the aragonite crystals. The absence of microdolomite inclusion in these fibrous calcite crystals indicates that these crystals are formed by the cementation process in a marine diagenetic environment not by the neomorphic process (Longman, 1980).

c. Isopachous calcite rim cement: The isopachous bladed calcite rim cement is precipitated in the marine phreatic diagenetic environment (Folk, 1974a; Lahann and Seibert, 1982; Given and Wilkinson, 1985, Moore, 1989 and Nelson and James, 2000). This type of cement crusts on the grains consisting of micrite crystals. It is composed of calcite crystals or fringes of equal thickness arranged normal or nearly normal to the allochemical grains and are often surrounded by coarser sparry calcite crystals and show sharp contact with them. The isophacous calcite cement in the studied rocks is common in oolitic and fecal peloid grainstone microfacies of the Drunka Formation and to less extent in the Minia Formation where it appears as rim cement around some algal plates (Pl.1G).

B. Meteoric water cementation

The meteoric water diagenetic environment is one of the most important diagenetic settings where most shallow marine carbonate sediments were subjected to post-depositional changes. Longman (1980) subdivided the freshwater diagenetic environment into the following zones: freshwater phreatic zone where the main diagenetic products are the equant calcite cement and syntaxial rim cement on the echinoderms and the freshwater vadose zone where the main diagenetic products are the meniscus and pendant cements. In the present study, the authors believe that the meteoric cementation is represented by the cementation in the freshwater phreatic zone with complete absence of either the meniscus or pendant cements that indicate the vadose zone.

a. Equant spar cement (granular cement): In the present work, the term granular cement refers to the equigranular, anhedral to subhedral patches and mosaics of sparry calcite with planar to slightly curved intercrystalline boundaries. The crystal size ranges from 108 to 198 μm. This type of cement often fills the void space as a second generation following the fibrous calcite or the isopachous spar cement in the grainstones microfacies of the Drunka, Minia and Samalut formations. This cement is inferred to have been precipitated as low Mg-calcite from meteoric pore water as indicated by:-1. This cement contains iron oxides, which may be derived from subaerially exposed continental facies. 2. SEM images show that the interstices between the grains of this cement are occupied by gypsum (Pl.1H). In the Drunka Formation, the equant spar cement is recorded in the bivalvian, algal, foraminiferal, pelletal and oolitic grainstones. The granular cement in the pelletal, oolitic algal grainstones surrounds the isopachous spar cement. In the Minia Formation, the equant spar cement is observed in algal and / or foraminiferal grainstones as the binding material between the algal and foraminiferal allochemical grains. In the Samalut Formation, this type of cement is only recorded in the bioclastic grainstone microfacies.

b. Syntaxial rim cement: This type of cement is obvious in the echinoderm-rich rock. It is a feature of which the monocrystalline echinodermal fragments exhibit a well-developed outer syntaxial rim of calcite cement that is precipitated in the same optical orientation around the borders of the echnidermal fragments. This type of cement can be considered as one of the most predominant cement types in the Drunka and Minia formations, while it is rarely observed in the rocks of the Samalut Formation. It is found that most of the echinoid particles in the bioclastic, echinoidal, algal and foraminiferal wackestones, packstones and grainstones microfacies exhibit a well developed syntaxial rim cement around their broders where the calcite cement surrounds the echinoidal grains from all sides and extends beyond them to show a sharp contact with the adjacent particles. On the basis of textural evidence, the authors suggest that the syntaxial overgrowths on the echinodermal grains were precipitated during freshwater diagenesis in a subaerial environment. This is because, the syntaxial rim cements in the wackestones and packstones microfacies are associated with matrix that is recrystallized to sparry calcite to show effect of meteoric water (Pl.2A). This can also be indicated in the grainstone microfacies where the cement is entirely of granular calcite mosaics that are precipitated under subaerial diagenesis. The persistence of the calcite cement around the echinodermal particles in the studied rocks indicates that this type of cement is precipitated under freshwater phreatic zone not freshwater vadose zone (Badiozamani *et al.* 1977). This is in harmony with Al-Hashimi (1977), Longman (1980), McLane (1995) and others, who suggested the freshwater phreatic origin of the syntaxial rim cement on the echinoid particles.

Recrystallization (Neomorphism)

Recrystallization (neomophism) is the most striking diagenetic feature in the diagenetic history of the studied rocks where it affects both the allochems and the groundmass of these rocks. Recrystallization is term used when a remarkable change in size and / or morphology of calcite crystals is recorded (Land and Moore, 1979). In such process, the mineral is the same after as before the reaction. Folk (1965) introduced the term “neomorphism” to describe all transformations between one mineral and itself or a polymorph where the new mineral has the same composition but may show difference in the crystal size, shape or orientation differing from the original.

A. Aggrading neomorphism:

The aggrading neomorphism is volumetrically the most important form of recrystallization in the carbonate rocks of the present area as it is affecting both the matrix and particles.

a. Aggrading neomorphism of matrix: It is found that the great majority of the microcrystalline calcite in the studied samples has been found to be recrystallized to sparry calcite mosaics with a wide range of crystal size. The aggrading neomorphism of the matrix has produced different forms of calcite such as microspars, pseudospars, blocky and massive calcite.

1. Microspars: Are the coarser mosaics that are formed as an aggrading recrystallization product of the lime mud matrix in the early diagenetic stages. The recrystallization of the lime mud into microspars is a common feature in the most of the studied lime mudstones, wackestones and packstones of the Drunka, Minia and Samalut formations. The microspars are very well represented in the recrystallized lime mudstones where micrite is converted to neomorphic blocky calcite passing through the microspar and pseduospar stages. Folk (1965 and 1974a) used the term “microspar” to describe the neomorphic fabric that formed by the recrystallization of micrite with average range size between 4 to 30 μm. In the present study, the neomorphic microspars are recorded as mosaics of equant calcite crystals with average size of 15 μm. The neomorphic microspars here are formed of rounded calcite crystals with uniformal size and wavy, curved or irregular intercrystalline boundaries. They show cloudy appearance and exhibit dark borders due to the effect of impurities that have been pushed aside by the driving force during recrystallization. Some micritic relics can be observed within the uniform equant microspars to show indication about the incompletence of the recrystalliztion process (Pl.2B).

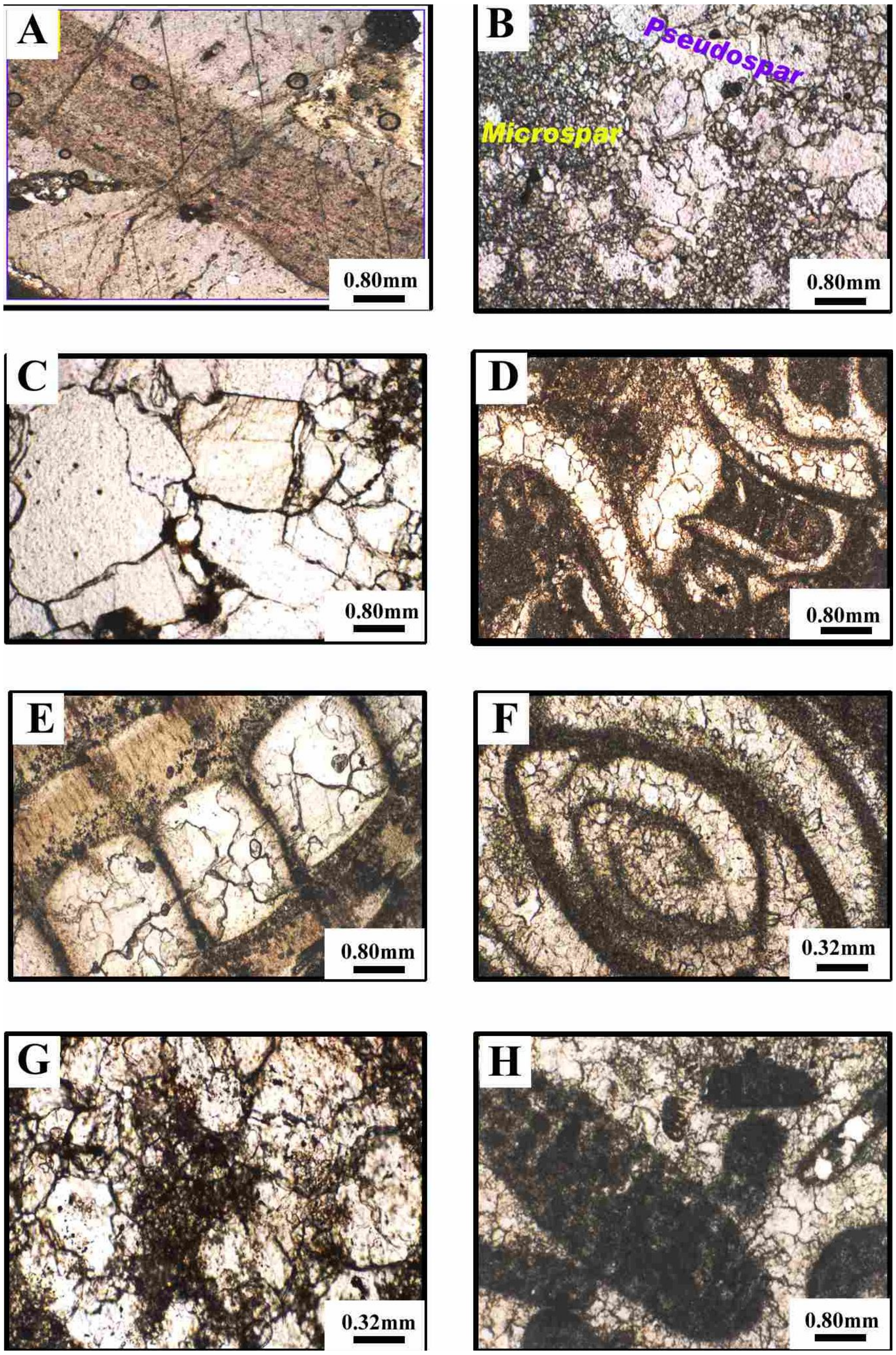

Plate (2)

(A} Photomicrograph showing an echinoid particle embedded in packstone showing complete syntaxial overgrowth. Nummulitic packstone microfacies. Samalut Formation. C.N. (B) Photomicrograph showing the recrystallized microspar and the inequigranular pseudospar with irregular and curved boundaries. Recrystallized lime mudstone microfacies. Upper unit, Drunka Formation, Gebel Gibeil section. O.L. (C) Photomicrograph of lime mudstone showing the three varieties of neomorphic spar, from right to left: microspar, pseudospars and blocky calcite. Recrystallized lime mudstone. Upper unit, Drunka Formation, Gebel Gibeil section. O.L. (D) Photomicrograph showing pelecypod debris shows the aggrading neomorphism from center. Notice: The micrite envelope surrounds borders of the grains due to the effect of the leaching process. Coadiacean algae packstone microfacies. Upper unit, Drunka Formation, El-Zarabi section. O.L. (E) Photomicrograph showing a nummulitess particle exhibit a partial aggrading neomorphism. Note: The chambers of nummulitess replaced by pseudospars. Nummulitic packstone microfacies. Samalut Formation. O.L. (F) Photomicrograph showing aggrading neomorphism of a foraminifer particle (miliolid) from the canter toward the borders. Foraminiferal bioclastic packstone microfacies. Upper unit, Drunka Formation, Ismail Bey section. O.L. (G) Photomicrograph showing complete recrystallization of an algal particle by pseudospars. Notice: The particle is converted to a ghost of pseudospar. Dasycladacean algae wackestone microfacies. Minia Formation. O.L. (H) Photomicrograph showing the micritization of Dasycladacean algal grains. Orbitolites alveolinid dasycladacean algae grainstone microfacies. Minia Formation. O.L.

2. Pseudospars: Pseudospars are the coarser neomorphosed calcite crystals (Folk, 1965). These crystals are formed in the more advanced stages of the aggrading recrystallization process. The pseudospars are recorded in few, most and all of the wackestones and packstones of the Drunka, Minia and Samalut formations respectively. The neomorphic pseudospars fabric are well-developed in the recrystallized lime mudstone of the upper unit of the Drunka Formation as the second product of the aggrading neomorphism of the micrite after the finer microspar mosaics (Pl.2B). In the studied rocks, the pseudospars are represented, as coarse inequigranular calcite crystals with irregular, curved and rarely straight comprise boundaries. They range in size from 40 to 160 μm. The outer margins of the pseudospars are of dark colour due to the presence of minute particles of lime mud. In more advanced stages of the recrystallization, the microspars are completely consumed and converted into pseudospars. Khalifa and Zaghloul (1990b) revealed that the pseudospars could be produced by the coalescive recrystallization of the microspars of which the microspar crystals coalesce with one another to form a single coarse pseudospar crystal.

3. Neomorphic blocky calcite: In the present study, the neomorphic blocky calcite crystals are recorded mainly in the recrystallized lime mudstones of the upper unit of the Drunka Formation. Also they are recorded in the miliolidae packstone of the same unit. The neomorphic blocky calcite crystals can be considered as the product of the third stage of the aggrading neomorphism process after the microspars and pseudospar. They are represented as very coarse calcite crystals with size ranges from 350 to 600 μm and with slightly curved to curved irregular and sometimes planar boundaries (Pl.2C). The The presence of the microspars and pseudospars in the studied rocks abreast with the blocky calcite crystals supports the neomorphic origin of these blocky crystals.

b. Aggrading neomorphism of skeletal particles: The aggrading neomorphism of the skeletal particles is common in most of the identified microfacies associations where these particles go through many stages from partial to complete aggrading recrystallization. This process depends on the conversion of metastable aragonite and / or high Mg-calcite that probably builds up the shells of the most skeletal particles to the stable phase (mostly low Mg-calcite) under the impact of meteoric conditions. In the present study, the skeletal particles that are influenced by the aggrading recrystallization show alteration from the originally aragnoite, microcrystalline and / or crypotocrystalline calcite into coarsely crystalline calcite (granular microspars and pseudospars). This alteration mostly begins from the center towards the periphery of the particles then form opaque rinds of micrite surrounding the grains (micrite envelopes) with diameter ranges from 2 to 6 μm. The great majority of the molluscan shells in the wackestones, packstones and grainstones textures of the recognized microfacies are preserved as calcite casts marked by a dark calcareous thin micritic envelope (Pl.2D). Sometimes the foraminiferal and algal grains are coated by these micrite envelopes. Khalifa (1981) proposed that the development of the micrite envelopes is in command of the aggrading neomorphism of both matrix and particles during the subaerial diagenesis. Freidman (1964) found by the experiment that the high Mg-calcite is more soluble than the low Mg-calcite in the distilled water but not in seawater.

The generation of the micrite envelopes in the present work is based on the results of the previous experiment. Thus the present writers reveal that when the present sediments are exposed to the subaerial diagenesis, their components are affected by the meteoric water and hence the carbonate particles that are composed of high Mg-calcite or aragonite (i.e. molluscan, algal and foraminiferal shells), matrix and the lime mud secreting from the disintegration of the calcareous algae are dissolved out leading to formation of low Mg-calcite. That is to say; in the wackestones and packstones, the less stable high Mg-calcite or aragonite that form the skeletal particles and matrix is converted to more stable low Mg-calcite throughout the aggrading neomorphism process. This conversion results in releasing of Mg, Fe ions and clay minerals. In grainstones microfacies the formation of micrite envelopes is related to the aggrading neomorphism of the allochemical constituents that are composed of high Mg-Calcite or aragonite by which the Mg and Fe ions are leached by the influence of the meteoric water. The Mg, Fe ions and mud that liberated from the skeletal particles and / or from the matrix during the aggrading neomorphism are concentrating towards the borders of the particles initiating the micrite envelopes (Table 2). By the incipient recrystallization, this alteration advanced to such a degree that the internal structure of the particles have been converted to ghosts of coarse sparry calcite with only a thin layer of microcrystalline calcite picturing the original outlines of the particles.

Molluscan shells are the most extensively recrystallized particles in the studied microfacies. The molluscan shells (bivalves and gastropods) are composed originally of aragonite (Taylor *et al.,* 1969). The molluscan shells are replaced by interlocking, semi-equigranular mosaics of microspar and pseudospar under the effect of the aggrading neomorphism. In most of the recrystallized molluscan shells, it is noticed that the coarser pseudospar occurs in the center of the shell, while the finer mosaics are found towards their margins

(Pl.2D). This indicates that the replacement process begins from the center of the skeletal particle and progressively proceeds towards its wall. The recrystallized large foraminifera in the present microfacies are represented by the alveolines, miliolids, nummulites and assilines. The recrystallization processes of these particles show partial recrystallization affects some chambers of the nummulites tests of the Samalut Formation making slight alteration of these particles (Pl.2E). The more extensive partial recrystallization acts upon the alveolinid and miliolid shells of the Minia and Drunka formations. This more extensive partial recrystallization causes the replacement of the alveolinid and miliolid shells by the sparry calcite crystals but still showing a recognizable particle texture (Pl.2F).The complete recrystallization is the most advanced stage in this aggrading recrystallization of the large foraminiferal tests. This process results in destroying the internal structure of the alveolines of the Minia Formation and hence its original morphology is hardly recognizable.

Table (2). Showing the EDX analyses of two pelecypod grains and the micrite between them. Notice the increasing of the wt% of the Mg and Fe ions from the center to the periphery of the examined grains.

Cations	Grain No. (1)			Grain No. (2)				Micrite
	Center → Periphery			Center → Periphery				
	wt %			wt %				wt %
	Spot (1)	Spot (2)	Spot (3)	Spot (1)	Spot (2)	Spot (3)	Spot (4)	
Mg K	0.78	1.06	1.22	3.57	4.86	5.89	7.93	9.45
Fe K	0.57	0.88	1.59	0.38	1.3	2.07	2.72	6.24
Na K	1.25	1.41	1.48	0.84	1.34	2.73	0.68	1.67
Al K	0.65	0.94	0.97	0.65	1.06	0.97	0.85	3.51
Si K	5.65	5.86	6.03	1.25	5.89	4.26	5.05	5.33
Sr L	0.6	0.65	0.34	0.46	0.43	0	0	0
P K	0.59	0.57	0.56	0.53	0.57	0.56	0.52	0.8
S K	1.43	1.54	1.39	0.28	0.54	1.15	1.28	0.48
Cl k	0.77	0.87	0.78	0.76	0.87	2.96	3.33	2.55
K K	0.57	0.58	0.71	0.81	0.76	1.2	0.62	2.31
Ca K	87.15	85.64	84.93	90.47		78.22	77.02	67.66

Most of the algal components of the present rocks are influenced by the aggrading recrystallization. It is noticed that the green algae (codiaceans and dasycladaceans) are most susceptible to this process than the red ones. The green algal components of both the Drunka (mainly coadiaceans) and Minia (mainly dasycladaceans) formations are subjected either to partial or complete recrystallizatin. The partial aggrading neomorphism of the dasycladacean algae of the Minia Formation results in obliterating the central stem of the thallus of the algal segments and conversion of it into equant sparry calcite with preservation of the branches that outline the algal segments. The complete recrystallization of the green algae causes the obliteration of the whole algal segments and hence the remaining ghosts are composed of clear equigranular sparry calcite crystals (Pl.2G).

The mechanism of the aggrading neomorphism is depending upon the transformation of the unstable minerals (high Mg-calcite and aragnoite) that originally form the micrite matrix and skeletal particles into more stable minerals (low Mg-calcite) that are represented by the pseudospars and blocky calcite crystals passing through the microspar stage. The aragonite and high Mg-calcite of the skeletal particles are stable under marine conditions but under the effect of the subaerial conditions and mixing with meteoric water, they became unstable and tend to change into a stable mineral (low Mg-calcite). Folk (1974a) revealed that the coarsening of calcite crystals might be caused by the leaching of Mg ions from the lime mud, since their presence prevents the enlargement of calcite.

The factors controlling the progress of aggrading neomorphism are the presence of fresh meteoric water, Mg ions and the clay minerals. Freshwater is capable of leaching Mg ions from the micrite as indicated by the presence of the coarser calcite near the fissures and cracks; away from fractures, grain size gradually decreases. The presence of Mg ions leads to minimize the size of the calcite crystals due to forming a cage around the calcite grains (Longman, 1977). So, the removal of these Mg ions is the key to the enlargement process of the micrite. Longman (op.cit) revealed that the most important method for removing Mg ions from the micrites is the role of clay minerals (mainly cholorite and Montimorillonite) by which the clays pick up the Mg ions expelled from the micrite during diagenesis. The absorption of these Mg ions on the clay surface leads gradually to removing the cage around the calcite crystals and then allowed them to be grown in size. By this method, the micrite present adjacent to clay particles can be converted into coarser low Mg-calcite crystals. The microspars are formed by the later method of which their formation requires the presence of clay particles distributed randomly through the micrite. By the coalescence of two microspar crystals a pseudospar crystal is formed, which may coalesce with another pseudospar crystal to form the neomorphic blocky calcite. The formation of pseudospars or blocky calcites directly from the micrite (without passing through the microspars) requires greater amount and wider surface area of clays to facilitate the removal of Mg ions from the calcite crystals in the micrite.

The diagenetic history of the aggrading neomorphism of the skeletal particles in the studied samples can be divided into three stages:- 1. Removal of Mg ions from the particle without significant change in the texture of the particle. 2. Recrystallization of the original fibrous aragonite and / or laths of high Mg-calcite into more tightly welded mosaics of larger equant calcite crystals. In this stage, the biogenic textures are still well preserved. 3. The third stage results in production of coarser mosaics of microspars and pseudospars that tend to destroy the biogenic textures and structures.

B. Degrading recrystallization (micritization)

Bathrust (1966) defined the micritization process as the process by which the skeletal particles are replaced by micrite. Following Alexanderson (1972) used the term "micritization" to refer to shallow water diagenetic process that causes the loss of the internal structure of the skeletal particles by the gradual alteration to cryptocrystalline carbonate. Micritization of skeletal particles is considered as an important diagenetic process in the shallow marine environment by different authors: Ginsburg (1957), Bathrust (1966 & 1975), Alexanderson (1972), Dixon and Wright (1983), Reid *et al.* (1992), Reid and Macintyre (1998 & 2000).

The most susceptible grains to the micritization process in the studied rocks are the algae, foraminifera and echinoids. Most of the algal particles in the present formations show partial or complete micritization (Pl.2H). The partial micritization results in changing the original cellular structure of the thallus of the algal segment but the algal particle may be still recognizable. In case of complete micritization, the original structure of the algal particles is converted into dark, nearly opaque cryptocrystalline calcium carbonate and then it is so difficult to be defined. In the present work, it is observed that the degree of micritization of the algal grains of the Minia Formation is heavier than that of those of both the Drunka and Samalut formations.

The micritization of the foraminifera is recorded mostly in the wackestones and packstones of the Drunka, Minia and Samalut formations. However, the more extensive micritization occurs in the microfacies of the Minia Formation. Alveolines, miliolids, orbitolites and nummulites are liable to micritization process (Pl.3A). It is noticed from the studied microfacies that the miliolids and orbitolites grains are more susceptible to micritization than those of alveolines and nummulites. The latter types were partially affected by the aggrading neomorphism. The micritization of the foraminiferal shells displays all gradations from partial to complete micritization.

Most of the echinoidal particles in the studied microfacies of the Drunka and Minia formations suffered from the micritization process. The micritization process results in giving the echinoidal fragments their speckled or dusty appearance due to the infilling of their finer pores with micrite. Three forms of micritization of the echinoidal particles are observed in the present facies. The first form starts from the margins and continues towards the center of the grain resulting in exhibition of irregular outlines of the particles (Pl.3B). The second form represents minute dark spots, which are randomly distributed within the uniform single calcite crystal of the echinoid particle. The third form is achieved in the advanced stage of micritization at which the former spots increase in size and then weld together to form dark patches of cryptocrystalline micrite (Pl.3C).

More than one mechanism was proposed by the previous workers to explain the stages of the micritization process. Bathrust (1966 & 1975) suggested that the micritization of the skeletal particles is achieved by passing through the following stages:- (1). Boring and colonization of the borders of the skeletal particles by algae. (2). Death of these boring algae leads to formation of vacated tubes. (3) These tubes are apt to be filled with micrite. (4). By repeating boring and infilling of the micoborings with microcrystalline precipitates, the particle may be transformed into masses of micrite (peloids).

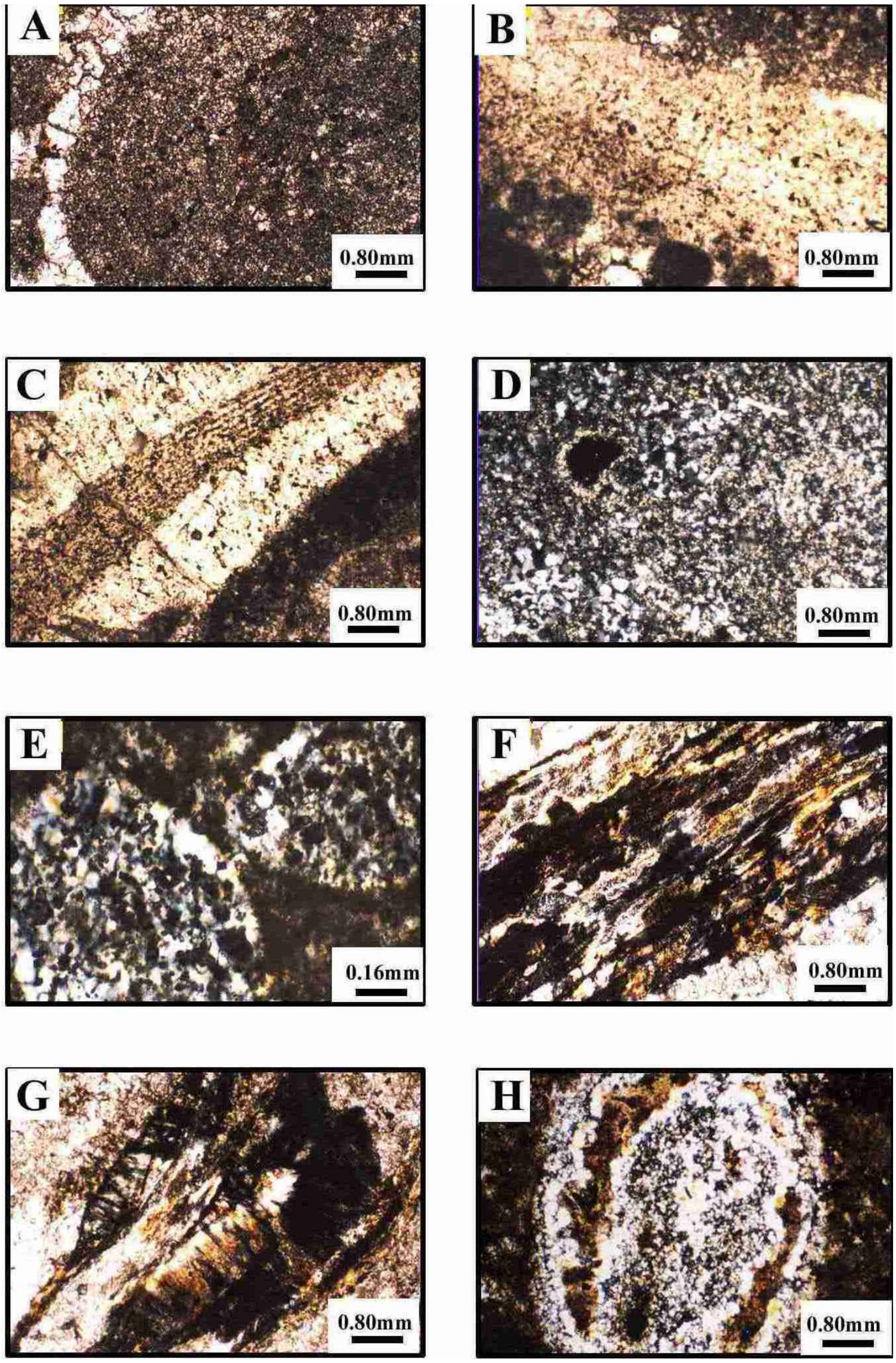

Plate (3)

(A) Photomicrograph showing the micritization of alveolinid shell. Notice: Fe-oxide pigments stain some parts of the alveolinid grain. Micritized grains packstone microfacies. Minia Formation. O.L. (B) Photomicrograph showing the micritization of an echinoidal particle from the margins towards the center. This can be indicated by the irregular outlines of the echinoid particle. Note: The micritization is expressed by tiny darks spots scattered within the particle. Dasycladacean algae orbitolites packstone microfacies. Minia Formation. O.L. (C) Photomicrograph showing more dense micritization of an echinoidal particle. The micritic are welded together to form dark patches (appears as lines) of micrite. Orbitolites alveolinid dasycladacean algae grainstone microfacies. Minia Formation. O.L. (D) Photomicrograph showing microquartz grains replacing the matrix and the internal structure of skeletal particles in chert. Bioclastic wackestone microfacies. Upper unit, Drunka Formation, Ismail Bey section. C.N. (E) Photomicrograph showing algal particles replaced by length-slow spherulitic chalcedony. Bioclastic wackestone microfacies. Upper unit, Drunka Formation, Ismail Bey section. C.N. (F) Photomicrograph showing microstructure-controlled chalcedony replacing a pelecypod shell. Pelecypoda packstone microfacies. Upper unit, Drunka Formation, Gebel Gibeil section. C.N. (G) Photomicrograph showing fibrous spherulitic chalcedony replaces the pelecypod shell. Pelecypoda packstone microfacies. Upper unit, Drunka Formation, Gebel Gibeil section. C.N. (H) Photomicrograph showing a milolid grain is completely replaced by microquartz crystals. Codiacean algae Packstone microfacies. Upper unit, Drunka Formation, El-Zarabi section. C.N.

Several authors concluded that the cryptocrystalline textures of the shallow marine sediments are formed by the degrading recrystallization process on basis of detailed petrographic investigation (Kendall and Skipwith, 1969 and Pusey, 1975) and recently on basis of thin section petrography and SEM work (Reid *et al.* 1992 and Reid and Macintyre, 1998).

In the present work and form the detailed microscopic investigation and SEM images, it was noticed in all the above described micritized grains that there is an apparent lack of microborings in the micritized areas of the skeletal grains. Thus the present authors believe that the micritization in the studied microfacies is mainly the result of degrading recrystallization of skeletal material of which the micrite that is produced by the disintegration of algal components or that of the matrix (in the wackestones and packstones microfacies) replaces the skeletal particles from the borders towards their center. This conclusion is in agreement with Reid and Macintyre (1998).

Three successive stages of micritization are recorded in the studied rocks: In the first stage, the micrite replaces the borders of the skeletal particle. The seconds stage results in partial micritization of the shells at which the micrite invades the internal structure but the details of this structure still be recognizable. The further third stage of micritization gives rise to complete micritization. This high degree of micritization leads to complete obliteration of the particles and converts them into ghosts of micritized grains and hence these particles are too difficult to be identified.

Silicification

Silicification is the diagenetic process by which the carbonate rocks are replaced by silica. The silicification process involves the formation of cherts and the selective replacement of the limestone components.

A. Chert: In some beds of of the Drunka Formation of the studied sections, the entire limestone unit is converted to chert. Chert is a dense crystalline sedimentary rock. It is composed of silica minerals (megaquartz, microquartz, chaclcedonic quartz and / or amorphous silica) and in some cases; it contains impurities of calcite and / or Fe-oxides.

Mode of occurrence of cherts in the studied rocks

Chert occurs as a banded and chert concretions. The banded cherts have been encountered in numerous horizons in both units of the Drunka Formation. They occur as thin beds within the limestones of its upper unit. The banded cherts in the present area are represented as thin bands up to 20 cm in thickness with no internal sedimentary structures and are usually parallel to the bedding planes. They range from regular to wavy forms with sharp contact with the surrounding carbonate rocks. The chert concretions are the most common form of chert within the carbonate host rocks where they are the product of the replacement process of these carbonate sediments by silica (Folk, 1959; Knauth and Epstein, 1976 and Maliva and Siever, 1989a). The chert concretions are recorded here in association with the carbonate facies of the lower unit and to greater extent with that of the upper unit of the Drunka Formation at several stratigraphic levels. Field description shows that these chert concretions are composed of small to large, hard, spherical, subspherical, elongate or ovoidal masses. These chert concretions are of diameter ranges from 10-20 cm and sometimes they exhibit a concentric internal structure. They may be dispersed throughout or may be concentrated with preferred orientation parallel to certain planes.

The cherts of the studied area are formed of quartz with few amount of lime mud that still unaffected by the silicification process. The quartz of these cherts takes the form of cryptocrystalline quartz, microquartz, spherulitic chalcedonic quartz and granular megaquratz. The cryptocrystalline quartz is recorded mainly in the banded cherts where it is either filling the pores of the fossils or replacing the lime mud matrix. The term microquartz refers to quartz crystals of <20 μm is diameter (Folk and Pittman, 1971). It is the main quartz type in the chert concretions in which it replaces both the matrix and the interior of the shell fragments (Pl.3D). The chalcedonic quartz is represented as spherulitic length-slow form that partially or completely replaces some skeletal shells. This replacement process begins in the center of the shells and proceeds outward towards the shell margin (Pl.3E). The granular megaquartz is defined as non-fibrous quartz with crystal diameter greater than 20 μm (Folk and Pittman, 1971). The granular megaquartz crystals in the present cherts are rarely recorded, they are found to fill in the pores within the matrix of some concretional cherts and hence they may be associated with the prismatic megaquartz. Also the granular megaquartz crystals sometimes fill the intrafossil cavities in the chert concretions.

B) Selective replacement of allochems: It is noticed from the microscopic analysis that some limestones can be so perfectly replaced by silica that the original texture is almost completely preserved. This type of silicification can be interpreted as “selective replacement” (term introduced by Hesse, 1989) because there is a part of the carbonate host rocks unaffected and the other part is riddled by the diagenetic silica.

The partially silicified limestones are recorded here in different horizons of the Drunka Formation and in the upper part of the Minia Formation. It is seemed that the selective replacement of the allochems in the studied rocks happened during the late diagenetic events as a result of the relative sea-level fall.

Fossils seem to be more readily replaced than the carbonate matrix due to the ability of the organic molecules to bind silica, which can be indicated by the frequent preservation of the internal structure of the shell during silicification (Blatt, 1992). In the studied microfacies, four groups of fossil taxa are observed to be replaced by silica. These are the bivalvia, echinoderms, foraminifera and algae.

The pelecypod shells from the pelecypod packstone, miliolidae packstone and fecal peloid packstone microfacies of the Drunka Formation are replaced by either chalcedony or megaquartz. Both microstructure-controlled and spherulitic chalcedony of Maliva and Siever (1989b) are observed in the present silicified pelecypods. The microstructure-controlled chalcedony is represented as fibers with a preferred orientation parallel to the shell microstructure (Pl.3F), while the spherulitic chalcedony is found as fibers, which are independently of shell microstructure (Pl.3G). The microquartz is the only variety of silica replacing the edinoderms.

The foraminifera from several horizons of both the Drunka and Minia formations are subjected to silicification. In the orbitolites green algae packstone, nummulitic dasycladacean algae packstone and codiacean algae packstone microfacies of the Drunka Formation, the orbitolites, nummulites and miliolids particles are partially to completely silicified. Among the quartz types, the megaquartz is mainly replacing the orbitolites and nummulites and to less extend the miliolids, while the microgqurtz is replacing the miliolids (Pl.3H). In the Minia Formation, the silicified foraminifera are recorded in the orbitolites alveolinid dasycladacean algae grainstone and alveolina packstone microfacies at which the orbitolites and alveolines are replaced mainly by microquartz crystals and sometimes replaced by the cryptocrystalline silica (Pl.4A).

Algae are also subjected to silicification, this is well noticed in the codiacean algae packstone at the top of the Drunka Formation exposed at El-Zarabi section, orbitolites alveolinid dasycladaccan algae grainstone and alveolina bioclastic wackestone microfacies of the Minia Formation outcropping at Gebel Gibeil section. Under the effect of silicification, the details of the shell structure of the algal components are destroyed and then make them as ghosts masked with silica, so they are difficult to be defined. The microquartz is the main type of quartz replacing algae (Pl.4B), while the cryptocrystalline silica and megaquartz are also observed.

Maliva and Siever (1988) proposed a mechanism for the silicification process of the fossil. They suggested that this process occurs along a thin film at which calcite dissolves and silica precipitates thus silica precipitation is contemporaneous with the calcite dissolution. According to that the solution film must be supersaturated with silica and undersaturated with respect to shell carbonate.

The silicified non-skeletal particles are recorded in the oolitic grainstone and fecal peloid grainstone microfacies of the Drunka Formation. The quartz of the replaced oolites and fecal peloids takes the form of microquartz and granular megaquartz (Pl.4C). The microquartz crystals are represented as equigranular, subrounded to subangular, anhedral to subhedral crystals of <20 μ in size. The granular megaquartz crystals are composed of moderately to well-stored, euhedral to subhedral crystals with >20 μm in size. In some cases, the cryptocyrstalline quartz replaces the internal structure of oolites and fecal peloids.

It is observed in the uppermost part of the upper unit of the Drunka Formation at El-Zarabi section that the neormorphic spar that formed by the aggrading neomorphism of the lime mud in the recrystallized lime mudstone is replaced by silica from the outer margin and towards the center of the neomorphic spar. The quartz in this rock is found as megaquartz and spherulitic chalcedony. The spherulitic chalcedony crystals are occurred as radial arrangement of chalcedonic fibers, which slow radiating fans of crystals (Pl.4D).

Origin of cherts

The genesis of chert (both banded and concretional) has attracted many workers and it is still a subject of controversy among authors. Morse (1974) and Salyes (1979) proposed that the source of silica in cherts is due to the vertical flux of silica from the underlying sediments. The biogenic and submarine volcanic origins were suggested for the origin of cherts by Heath (1974) and Tucker (1981). Gao and Land (1991) proposed that the nodular chert was formed by the selective replacement of grainstones, burrow fillings, algal stromatolites and evaporative nodules.

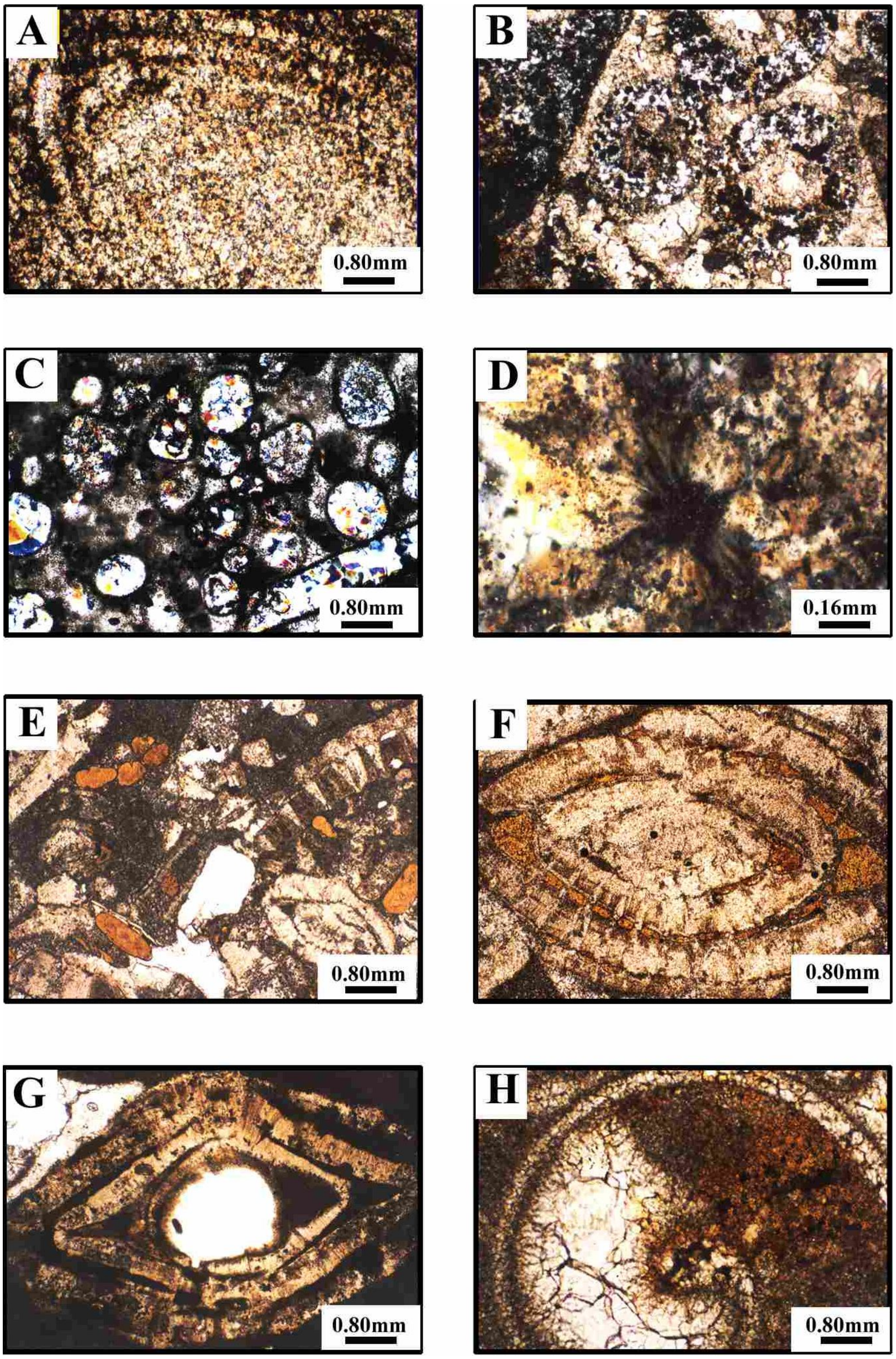

Plate (4)

(A) Photomicrograph showing an alveolinid grain replaced by microquartz and cryptocrystalline silica. Alveolinid packstone microfacies. Minia Formation. C.N. (B) Photomicrograph showing microquartz crystals replacing dasycladacean algal particles. Orbitolites alveolinid dasyeladacean algae grainstone microfacies. Minia Formation. C.N. (C) Photomicrograph showing the replacement of ooids by both the microquartz and megaquartz crystals. Oolitic grainstone microfacies. Lower unit, Drunka Formation, El-Zarabi section. C.N. (D) Photomicrograph showing the spherulitic chalcedony replaces neomorphic spar. Recrystallized lime mudstone. Upper unit, Drunka Formation, El-Zarabi section. C.N. (E) Spheroidal, ovoid, pellet-like detrital glauconite grains. Nummulitic packstone microfacies. Samalut Formation, Mallawi Section. (F) Photomicrograph showing the glauconite fossil mold of a nummulitic grain formed by filling the chambers of a nummulitic shell by glauconite clays. Nummulitic packstone. Samalut Formation, Mallawi Section.(G) Photomicrograph showing the staining of a nummulitic grain due to the ferrugination process. Nummulitic packstone microfacies. Samalut Formation, Mallawi Section. (H) Ferrugination stains the internal structure of a transrverse section of gastropod shell with yellowish red colour. Bioclatic packstone microfacies. Upper Unit, Drunka Formation.

Meyers (1977) proposed the dissolution of detrital quartz as the main source of silica that forms the chert in the Mississippian Lake Valley Formation, sacrament Mountains, New Mexico. Snavely *et al.* (1979) and Ahmed (1983) believed in the chert nodules of the Thebes Formation in Upper Egypt are of diagenetic origin and they stated that the siliceous skeletal tests within the deeper pelagic carbonates of the Thebes Formation is the source of the silica. Maliva (2001) revealed that most of the Phanerozoic cherts are formed by the replacement of the carbonate rocks with silica derived from the dissolution and reprecipitation of the biogenic silica. Kidder and Keheila and El-Ayyat (1992) believed in that the volcanic activity may be the main source of silica in the cherts of the Lower Eocene rocks in the Eastern Desert between Sohag and Qena, Egypt. McBride *et al.* (1999) suggested that the chertification process in the Drunka Formation was achieved by the replacement of carbonate mud by the microcrystalline quartz, while the fossils are replaced by equant megaquartz crystals, this process was proceeded under conditions of low temperature meteoric water at shallow burial depths. This view is in harmony with that of Knauth (1994) who stated that the mixing zone between meteoric and marine pore waters in coastal areas represents a geochemical environment conductive to calcite dissolution and simultaneous silica precipitation as opal CT or quartz. Shaaban (2004) revealed that the banded cherts recorded from the Thebes Formation exposed at Gebel Rewagen (Red Sea region, Eastern Desert, Egypt) is formed syngenetically with the host carbonate rocks as a result of the eustatic sea-level changes. He stated that these chert bands were formed during the periods of sea-level rise with high levels of silica productivity. Shaaban (op.cit) proposed that the sea-level fall during the lowstand period at the end of the Early Eocene leads to formation of the chert concretions and the partial silicification of bioclats near the marine-meteoric mixing zone where the sulphate reducing bacteria plays an important role in this aspect.

In the present study, the authors agree with the view of Shaaban (op.cit) about that the banded cherts are formed for the same reasons suggested by him (i.e. alternating in a cyclic manner within the host limestone and the lack of carbonate dissolution in the limestone adjacent to these chert bands). Also the authors believe in that the concretional cherts are formed in the marine-meteoric zone by the replacement of limestones during the later diagenetic events as a result of the relative sea-level fall and establishment of a lowstand time. This can be evidenced by the presence of the original calcareous fossils preserved in detail as siliceous fossils in these chert concretions. Also finding of some patches of lime mud that still unaffected by the silicification process may be another evidence about these cherts are formed in late diagenetic stages. Hesse (1989) suggested that the source of silica is either due to biogenic silica of sponge spicules, dissolution of quartz and other silicates in hypersaline, marginal environment or migration of silica rich solutions.

In the present study, it is noticed that the detrital quartz is a very minor component of the sediments so the hypothesis that the dissolution of detrial quartz by alkaline ground water as the source of silica is excluded here. In the studied rocks, no remains of siliceous skeletons (radiolaria or sponge spicules) were observed within the chert concretions or bands. The authors suggest the migration of the biogenic silica-rich solutions from the surrounding limestones may be the source of silica even if there is no evidence about that (Maliva & Siever, 1988b and Abd El-Hameed et al., 1997). Abd El-Hameed et al. (op.cit) revealed that the dissolution of the siliceous shells (sponge spicules or radiolaria) leads to formation of moulds, which are collapsed under the influence of compaction unless they are filled by calcite.

Glauconitization:

The glauconitization is the process by which a mineral is replaced by glauconite under very slow rates of sedimentation and at depths of 100 to 300 m. Glauconite is not common in the studied rocks. It is recorded in most of the studied microfacies of the Samalut Formation, while they are completely absent in both the Drunka and Minia formations.

A. Mode of occurrence of glauconities:

Hein *et al.* (1974) used the term glauconitic pellets as a morphological term to describe any heterogenous green pellets that composed of the mineral glauconite. Glauconitc occur either as pellets and/ or Glauconitic clays replacing the fossils. In the present study, the term glaucanitic pellets is adopted to describe the subrounded to well-rounded, spherical to ovoidal glauconite grains occur scattered within the matrix in most microfacies associations of the Samalut Formation. These glauconitic pellets exhibit a green, pale green or greenish yellow colour with diameters ranging from 0.1 to 0.5mm (Pl.4E). Ojakangas and Keller (1964) observed that the glaucenite pellets replace the foraminiferal tests and hence these tests became common molds for the glauconite pellets. Boyer *et al.* (1977) studied the green sand fecal pellets from the Marshalltown Formation in New Jersey and found that glauconite pellets from this formation are sometimes represented as internal molds of the foraminiferids. The skeletal fragments that are replaced by glauconies are the most common variety of glauconies in the studied rocks. The glauconitization of these shells is represented by the infilling or replacement of their structures by the glauconies. The grains most affected by the glauconitiztion are the nummulites at which the glaucony is recognized as internal mold of nummulites that the combers of these nummulites are filled or replaced by the glauconies (Pl.4F). Also some fragments of bryzoans are replaced by glauconies. The glauconies that replace the shells are recorded as spots and irregular grains and are usually molded according to the morphology of the skeletal particle that replace.

B. Origin of glauconite

The origin of glauconite attracted the attention of several eminent workers long time ago. Galliher (1939) revealed that the glauconite is formed by the replacement of biotite. Light (1952) suggested that the Cretaceous and Cenozoic glauconite of New Jersey is formed by the replacement of illite. Wermund (1961) stated that the glauconite is formed by the replacement of quartz. Hein *et al.* (1974) argued that the glauconite is formed by the alteration of clay minerals that trapped within the microfossil tests. El Gindy *et al.* (1998) concluded that the glauconite of the carbonate facies of NW Minia, Egypt, is formed authigenically as an indirect effect of organisms on the Midawara sediments in pre-burial stages. Mesaed (1999) subdivided the Eocene glaucony of the northern part of the Western Desert of Egypt into the follwing types and subtypes: (1). allochthonous intrasequential glaucony (glauconitic pellets, glauconitic fossil molds and casts, glauconitic ooids, syndepositional glauconitic clay particles laminae and flacers and glauconitic clay coatings and flocculated aggregates. (2). Autochthonous (diagenetic) glaucony (accordion or vermicular grains and neoformed glauconite crystals).

In the present study, the authors suggest two origins of glaucony: allochthonous and autochthonous. **The first allochthonous glauconites** is represented here by the glauconitic pellets which can be considered as detrital or of extrasequential origin (Amorosi, 1995). The detrital glauconies include grains that have been reworked from an older sequence. This view is based on that the glauconite samples always contain less than 5% glauconite pellets and hence they could be consider detrital rather than authigenic according to Hein *et al.* (1974). The rarity of quartz and the complete absence of biotite, feldspars or other detrital minerals beside the lack of evidence about their replacement like recording gradation of this replacement process support the authors' opinion that these glaucony pellets are of detrital origin. **The second autochthonous glauconites** (diagenetic) is illustrated by the glauconies that fill the structures of the skeletal particles. These glauconies have not experienced significant transport from its place of formation. It is noticed from the petrographic investigation that these glauconies are formed by the replacement of the mud (clay minerals) that trapped within the fossil tests (chambers of nummulites and zoocia of bryzoans) that can interpret the selectivity in the replacement process that observed in all the skeletal parcticles that affected by the glauconitization process. This glauconitization process is achieved by the addition of iron to the clay minerals to form glauconite by iron exchange process favoured by slightly reducing conditions, free excess of seawater and Ph around 8. Iron is available in the sediments of the Samalut Formation as pyrite mineral (FeS_2).

Ferrugination:

Illing (1954) reported that the iron-stained sediments that were recorded in the Bahamas are residual deposits that generated by the removal of $CaCo_3$ in solution by percolating rainwater. Maiklem (1967) revealed that the iron in the oxidizing environment usually forms a ferric hydroxide and / or oxide and hence it appears as brown stains. Mansour and Kenawy (1977) and El Gindy *et al.* (1998) stated that the ferrugination is achieved by the replacement of carbonates by iron oxides. In the present rocks, the ferrugination is clearly observed in the studied three rock units with varying degress. It is highly pronounced in Gebel Gibeil and Mallawi sections. In the field, the ferrugination process stains the limestones causing a pinkish violet, reddish brown or red colouration within the studied succession. Petrographically, the ferrugination is represented as patches and pockets of iron hydroxide and / or oxide with red and brown colours and all shades between them. The iron hydroxide and / or oxide replaces, coats or stains the skeletal particles which are the most common variety that affected by the ferrugination in the studied rocks. The grains most affected are the molluscan and foraminiferal shells but some fragments of bryozoans and echinoderms are also impregnated or replaced (Pl.4G). Iron matrix is also lining or filling of some of the internal skeletal microcavities (Pl.4H).

Different workers suggested many postulations in order to clarify the origin of iron. Ferruginated materials are suggested to be originated by the oxidation of iron-bearing minerals (pyrite and glauconite) during weathering and hence these minerals ar converted to iron hydroxide and / or oxide with red ferric state (Walker, 1967; Mansour and Kenway, 1977; Dabous and Mohammed, 1989; El Gindy *et al.* 1998 and Lee, 2000). Also, it is believed that the iron oxides material in limestones is produced by the effect of the hydrothermal solutions rich

in iron related to volcanic activity. These solutions take their way passing through the planes of weakness in the rocks and cause the development of new minerals by the replacement and precipitation process (Mansour and Kenway, 1977; Abd El Aal and El Gindy, 1989; Sturesson, 1992; Kamel *et al.* 1995 & 1998; Abdel Fattah, 1998 and Sturesson *et al.* 1999). Soliman *et al.* (2001) studied the ferruginous crusts in west El Bahnasa area, Minia Governerate, Egypt and proposed that these crusts are derived through subaerial weathering of neighbouring basalt, glauconitic calcareous shales, fossiliferous limetsones and iron bearing rocks. They revealed that this subaerial weathering leads to formation of goethite and hematite under the effect of oxidation.

In the studied area, the two origins of iron oxides are suggested. The first is attributed to the epigenetic replacement of the Lower Eocene sediments of the Drunka and Minia formations that exposed at Gebel Gibeil section. This replacement is proceeded by the hydrothermal solutions of the post volcanic eruptions, related to the nearby Oligocene basaltic activity. The second proposed origin is due to the oxidation of iron bearing minerals (pyrite and glauconite). This origin is represented in the rocks of the Samalut Formation. The oxidation of glauconite either found as detrital components or that replaces the skeletal particles common near surface oxidizing environments. This process results in forming of ferric hydroxide and / or oxide minerals with reddish brown or brown colour. Ferrugination is thus here considered as an epigenetic process, which occurred after the rock, is already consolidated.

SUMMARY AND CONCLUSIONS

The Lower and Middle Eocene rocks in the area under study show remarkable six diagenetic features:- compaction, cementation, recrystallization, silicification, glauconitization and ferrugination.

The compaction process is represented by both the mechanical and chemical types. The mechanical process includes closer packing of the grains, squashing of the soft grains, reorientation of the grains to closer parallism to the bedding, fractures in the delicate shells, expulsion of intergranular fluids and the point contact between the adjacent grains. The chemical compaction process is mainly represented by the pressure solution (e.g. solution seams and stylolites). Three cement types (dark micrite, fibrous calcite and isopachous calcite cement) are interpreted to be of marine origin, while the granular (equant) spar and syntaxial overgrowth are interpreted to be formed in the phreatic meteoric diagenetic zone in a further diagenetic stage.

Both particles and matrix are affected by the recrystallization process. Matrix is subjected to aggrading neomorphism. Early recrystallization produces uniform equigranular microspars, while in further stages of aggrading neomorphism, the microspar crystals coalesced with one another to produce single coarser crystal of pseudospar which converts to blocky neomorphic calcite by further recrystalliztion. Skeletal particles are also influenced by the aggrading recrystalliztion (e.g. mollusks, foraminifera, algae and bryozoa).

The aggrading neomorphism process is controlled by the presence of freshwater, Mg ions and clay minerals. The general mechanism of this process is depending upon the removal of Mg ions which can be leached by the fresh meteoric water and absorbed on the surface of the clays and hence causing the enlargement of the high Mg-calcite crystals into coarser low Mg-calcite crystals. Particles represented by algae, foraminifera and echinoids have suffered from degrading recrystallization (micritization). It was found that the boring of organisms is not distinct, but it seems that the particles are replaced by micrite that produced by the disintegration of algal components or that of the matrix.

The silicification process is represented here by the formation of cherts and the selective replacement of the limestone components. Two modes of occurrence of chert are recorded in the rocks of the Drunka Formation; the syngenetic-banded chert and the diagenetic concretional chert. Some skeletal particles are replaced by silica (e.g. pelecypods, foraminifera and algae). Also the non-skeletal particles are replaced by silica through the silicification process (e.g. fecal peloids and oolites). The matrix, cement and neomorphic spars are also replaced by silica. The silica is represented by cryptocrystalline quartz, microquartz, spherulitic chalcedonic quartz and granular megaquratz. The source of silica in the present rocks may be the migration of silica-rich solutions of the mixed meteoric-marine coastal system and / or of the volcanic and hydrothermal activity.

Two modes of occurrence of glauconite are recorded in the rocks of the Samalut Formation, the glaucony pellets (detrital allochthonous glaucony) and the glauconitic clay replacing fossils (autochthonous glaucony (diagenetic)). Two origins of iron oxides responsible for the ferrugination process are proposed. The epigenetic replacement of the Lower Eocene sediments of the Drunka and Minia formations that exposed at Gebel Gibeil section. This replacement is proceeded by the hydrothermal solutions of the post volcanic eruptions, related to the nearby Oligocene basaltic activity and the second proposed origin is due to the oxidation of iron bearing minerals (pyrite and glauconite).

The diagenetic history of the above processes could be summarized as follows: during or after deposition and in marine environment, the grains are affected by the compaction process as a result of the overburden load and the high pressure. After that and also in the marine environment, the grains are cemented by micrite, fibrous calcite and isopachous calcite cements. Then these grains are influenced by the degrading neomorphism (micritization) process. After sea regression, the meteoric water caused the cementation of the carbonate particles by the equant sparry calcite crystals and the precipitation of the syntaxial overgrowth around the echinoidal particles in addition to the aggrading neomorphism of both matrix and skeletal particles into microspar, pseudospar and neomorphic blocky calcite. This is followed by the precipitation of silica in forms of cherts and silica-replacing the carbonate components. During subaerial exposure and weathering periods, the glauconitization and ferruginatioin processes were developed.

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