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A CONTRIBUTION TO THE LITHOSTRATIGRAPHY AND SEDIMENTOLOGY OF THE LOWER CRETACEOUS SUCCESSION AT GABAL MANZOUR, MAGHARA AREA, NORTH SINAI, EGYPT.

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Abstract

The Lower Cretaceous succession at Gabal Manzour, north Sinai, Egypt is studied for lithostratigraphy, microfacies, depositional environments and diagenesis. The lithostratigraphic study allowed differentiating two rock units; the Malha Formation at base, followed upward by the Risan Aneiza Formation. The Malha Formation is the oldest exposed rock unit and is essentially composed of siliciclastic rocks (sandstone, siltstone and claystone). The Risan Aneiza Formation is siliciclastic-carbonate rocks and conformably overlies the Malha Formation and underlies the Halal Formation. Moreover, the Risan Aneiza Formation is subdivided into two parts; the lower part (Part A) and the upper part (Part B) which are equivalent to the Ras Al Ahmer Member and the Hamret Salma Member of Hassan et al. (1992), respectively.

Different microfacies types have been recognized in the studied rocks and compared with the worldwide standard ones to deduce their depositional environments. As a result, the siliciclastic rocks of the Malha Formation were deposited in fluvial environment (meandering stream). The siliciclastic-carbonate rocks of the lower part of the Risan Aneiza Formation (Part A) were deposited in an intertidal zone under shallow agitated marine water conditions. The upper part of the Risan Aneiza Formation (Part B) which is carbonate-dominated with claystone interbeds was deposited under subtidal marine conditions. Thus, it is suggested that the deposition of the Risan Aneiza Formation was largely controlled by long term transgressive phase in which the Part A represents an early phase of marine transgression and Part B is the deeper phase of marine transgression. After their deposition, the studied rocks were subjected to various submarine and subaerial diagenetic environments. These are manifested by various diagenetic features such as micritization, aggrading neomorphism, cementation, compaction, dolomitization and dedolomitization.

Introduction

In North Sinai, many E-NE and NE oriented doubly plunging anticlines represent the conspiceous highs and form a distinctive tectonic province in the area (Moustafa and Khalil, 1990). These anticlines are a part of the Syrian Arc System (Said, 1962). Gabal Maghara anticline is one of the largest anticlines in the area. The Cretaceous rocks crop out at many areas in North Sinai making a good part of the northern Sinai folded belt (Issawi et al., 1999). At Maghara area, Lower Cretaceous rocks are exposed at Gabal Manzour, Gabal Maaza, Gabal Lagama, Gabal Mistan, Gabal Risan Aneiza, Gabal Al Amrar and Gabal Um Mitmam, etc. Gabal Manzour lies on the northeastern flank of Gabal Maghara anticline at Longitudes 33°23′-33°35′E and Latitudes 30°40′-30°55′N (Fig. 1).

Several geologic studies including stratigraphy, paleontology, facies analysis, paleoecology and geochemical characteristics of the Cretaceous sedimentary rocks around Gabal Maghara in North Sinai have been done. Among these studies are Hume et al. (1921); Moret and Mahmoud (1953); Farag and Shata (1954); Farag (1955); Barakat (1956); Said and Barakat (1957); Shata (1960); Said (1962; 1971); Mansour (1967); El Nozahi (1969); Ismail and Mansour (1969); Jenkins et al. (1982); Allam and Khalil (1988); Hegab et al. (1989); Said and El-Kelany (1990); Hassaan et al. (1992); Ibrahim (1992); Hamza et al. (1994); Ibrahim and El-Milahi (2000) and Hegab et al. (2001). At Gabal Manzour, few studies on the Lower Cretaceous rocks were done (e. g., Aly, 1988; Philip et al., 1988 and Ramadan et al., 1999).

The main purpose of the present study is to shed more light on the lithostratigraphy, facies, environments of deposition and diagenesis of the Lower Cretaceous succession at Gabal Manzour (Maghara Area, North Sinai) with emphasis on the lower clastic part of the section which, as far as the authors know, received no or little detailed stratigraphical and sedimentological studies by previous workers at this area. To achieve this goal, a lithostratigraphic section was measured, primary sedimentary structures were examined in the field, rock samples were collected and the sandstone and limestone samples were thin-sectioned and examined under the polarizing microscope.

Lithostratigraphy

Several lithostratigraphical studies on the Cretaceous sedimentary rocks around Gabal Maghara in North Sinai have been done. Said (1971) proposed the name Risan Aneiza Formation for the Aptian-Albian section on the northern flanks of the Maghara structure at Bir Lagama in North Sinai. Philip et al. (1988) studied the facies and environment of deposition of the Albian rocks exposed at Gabal Manzour. They reported 234 m of the Lower Cretaceous succession there. According to them, this succession consists mainly of clastic units (sand, sandstones and claystones) near the base with increasing limestone intercalations in the middle, and the upper part of the section is made up of alternations of dolomitic limestones, shales and claystones. They subdivided the Lower Cretaceous succession in Gabal Manzour into two main time-rock units on the basis of macrofaunal content. These units are (from base to top) the pre-Albian and Albian units. Philip et al. (1988) added that the pre-Albian unit comprises the lowermost 22 m clastic part which is made up mainly of sandstone with mudstone and kaolinitic clay intercalations. It is unfossiliferous except for few scattered plant remains and badly preserved palynomorphs. These pre-Albian sandstones are conformably overlain by the marine Albian strata. Furthermore, they divided the Albian section of Gabal Manzour into three informal divisions; lower, middle and upper Albian on the basis of fossil content and correlation with those at other localities. They did not assign any formational names to this Lower Cretaceous succession.

The Lower Cretaceous rocks at Arif El-Naqa area are represented by the Aptian-Albian Malha Formation which was described by Allam and Khalil (1988) as 160-180 m thick of white and variegated, cross-bedded, poorly sorted, ferruginous sandstone, with silt and shale intercalations. They added that the Malha Formation there unconformably overlies the Jurassic rocks (Shusha and Rajabiah formations) and conformably underlies the Cenomanian Halal Formation. The bottom of the formation is marked by a basal conglomerate bed (up to 15 m).

Hegab *et al.* (1989) divided the stratigraphic section at Gabal Um Mitmam into two conformable distinctive units on the basis of field observations, lithological characteristics and macrofaunal content. Their lower unit is made up of clastics with few carbonate interbeds and has been given an Aptian age. The upper unit is dominated by carbonates (limestones and dolomite) and has an Albian age. In addition, they correlated the lower unit with the Alamain Formation of North Sinai, Alamain and Dahab formations of the Western Desert and Alamain Formation of the Nile Delta and the upper unit with the Albian Kharita Formation. Furthermore, Hegab *et al.* (1989) suggested the names Um Mitmam Formation for the lower unit and Manzour Formation for the upper unit.

Jenkins (1990) and Kerdany and Cherif (1990) reported that the contact between the Jurassic and Cretaceous rocks is obscured by wadi fill at Gabal Maghara. They added that the lowermost exposure of the Cretaceous there consists of thin cross-bedded very fine- to coarse-grained sandstones and conglomerates which represent the last pulse of the Mesozoic land-derived sediments in north Sinai before the oncoming of the marine transgression of the Aptian.

Hassaan *et al.* (1992) studied the Cretaceous sedimentary rocks in Risan Aneiza-Gabal Al Amrar area stratigraphically, petrographically, mineralogically and geochemically. They differentiated the Lower Cretaceous rocks (Risan Aneiza Formation of Said, 1971) into two members. The lower member is the Ras Al Ahmar Member (Aptian) and the upper member is the Hamret Salma Member (Albian). The lower and upper members attain a thickness of 170 m and 42 m, respectively. The lower member is made up of purple to dark brown quartzitic, ferruginous, unfossiliferous sandstone with dolomitic limestone and clay beds followed upwards by dolostone and clays. The upper member is marl, limestone and dolostone with clay interbeds.

Ramadan *et al.* (1999) studied the geochemical characteristics of the Lower Cretaceous rocks in Gabal Manzour. In addition to the geochemical data, they used the microfacies to interpret the paleoenvironment and the diagenetic changes. They treated the whole Lower Cretaceous succession at Gabal Manzour as being the Risan Aneiza Formation of said (1971) which they differentiated into two members (following Hassaan *et al.*, 1992) on the basis of lithologic characteristics, sedimentary structures, microfacies types and fossil content. These two members are the Aptian Ras Al Ahmar Member and the Albian Hamret Salma Member.

In the present work, the Lower Cretaceous succession at Gabal Manzour attains a thickness of 214 m (Fig. 2). The contact between the Jurassic and Lower Cretaceous rocks is obscured by wadi fill and the contact between the Lower Cretaceous and the Cenomanian rocks is conformable. The Lower Cretaceous rocks in this area can be subdivided into two main conformable rock units; the lower unit (Malha Formation) and the upper unit (Risan Aneiza Formation) (Fig. 2).

Lower Unit (Malha Formation):

The Malha Formation represents the oldest exposed Lower Cretaceous rocks at Gabal Manzour (Figs. 2 & 3A). The name Malha Formation was applied by Abdallah *et al.* (1963) to the sandstone exposed at Wadi Malha in the northern Galala Plateau at the western side of the Gulf of Suez. This unit (74 m thick) is made up essentially of sandstones, siltstones and kaolinitic claystones. The sandstones are poorly to moderately sorted, fine- to coarse-grained, and varicoloured (white, gray, yellow, red, violet and brown). The sandstone beds are laterally continuous, in spite of thickening and thinning of some of them because of basal scours. They are pebbly (conglomeratic) and/ or silty. Pebbles are concentrated at the bases of beds in the lower part of this unit and decrease upwards in each bed and in the whole unit. The siltstones are variable in colour (white, gray, yellow and red). They are clayey and sometimes are intercalated with sandstones. The sandstones and siltstones are ferruginous, siliceous, calcareous or dolomitic. The claystones are creamy, gray and green. They are silty and/ or sandy. The claystones are either massive or fissile. The siltstones and claystones increase in the upper part of this unit. The succession of the lower unit consists of several fining upward sequences; each of which begins at its base by pebbly conglomeratic coarse-grained sandstone and ended at top by either siltstone or claystone. Iron bands of a thickness of 1-20 cm and iron oxide nodules are frequent at the top of sandstone beds especially in the upper half of the unit. The rocks of this unit are generally nonfossiliferous in spite of the occurrence of scattered hazy plant remains. Primary sedimentary structures in this unit include thinly bedding, flat bedding (Fig. 3B), planar cross bedding with gradded bedding within its sets (Fig. 3C), and convolute bedding (Fig. 3D). Channel features are dominant in this unit (Fig. 3E).

This unit includes the clastic Pre-Albian unit of Philip *et al.* (1988) which lies below the marine Albian strata. This rock unit is lithologically and stratigraphically similar to the Malha Formation of Abdallah *et al.* (1963). So, the authors propose the name Malha Formation for the lower clastic part of the Lower Cretaceous succession at Gabal Manzour. Some authors collected Aptian to Albian fossils from the Malha Formation while others believe that Barremian fossils are also present (Hume, 1962). In the present work, the Malha Formation is considered to be Barremian-Aptian in age since it underlies the Aptian-Albian Risan Aneiza Formation of Said (1971). The lower sandstone beds which may be Barremian in age were called Nubia Sandstone by Kerdany and Cherif (1990). The Barremian-Aptian Malha Formation at Gabal Manzour is time equivalent to the Alam El-Bueib Formation and Matruh Formation in north Western Desert and to the Six Hills Formation in south Wesetern Desert.

Upper Unit (Risan Aneiza Formation):

Several studies on the Risan Aneiza Formation in North Sinai have been done. This formation was introduced by Said (1971) for the Aptian-Albian section that overlies the Maghara structure at its type locality (Bir Lagama on the northern flanks of the structure) where it attains a thickness of 110 m. The lowest bed of the section contains *Orbitolina lenticularis* of Aptian age (Said and Barakat, 1957) and the upper part of the section contains *Knemiceras* sp. and *Douvilleceras mammilatum* which are, according to Mahmoud (1955), of Albian age. Ammar and Afifi (1992) recorded that the Risan Aneiza Formation is exposed in the whole area of North Sinai (Gabal El-Minsherah, Gabal Yelleg, Gabal El-Falik and Gabal El-Maaza) forming a distinctive slope below the Halal Formation. They assigned an Aptian-Albian age to this formation due to the occurrence of *Everticyclammina hedbergi* Maync, *Orbitolina* cf. *Discoidea* Gras and *Orbitolina kurdica* Hensen. Ramadan *et al.* (1999) considered the whole Lower Cretaceous succession at Gabal Manzour as being Risan aneiza Formation. They reported that this formation attains a thickness of 234.75 m and can be differentiated following Hassan *et al.* (1992) into two members: The Lower (Ras Al-Ahmar) Member of Aptian age and the Upper (Hamret Salma) Member of Albian age.

In the present work, the Risan Aneiza Formation can be lithologically differentiated into two conformable parts; part A and part B. Part A conformably overlies the Malha Formation (Fig. 3A). It is made up of 92 m thick of sandstone, claystone and limestone interbeds. Several thin iron oxide bands (up to 20 cm thick) and nodules occur frequently in the lower half of this part (Fig. 2). The sandstones are fine- to coarse-grained, yellow and brown, ferruginous, dolomitic, siliceous and gypsiferous. The siltstones are laminated and thinly bedded, white, gray, yellow and reddish. They are ferruginous and contain iron oxide nodules. The shales are fissile and yellow, gray and greenish. The limestones are yellowish, greenish and gray in colour, fossiliferous, oolitic, dolomitic, sandy, massive, blocky or fractured. The limestones are flat bedded and planar cross bedding also occurs in the fossiliferous oolitic limestone (Fig. 3F). Vertical burrows are common in the limestone beds. The dominant primary structures in part A include flat bedding and planar cross bedding in both sandstones and oolitic limestones and flaser- and lenticular bedding in the sandstone, siltstone and claystone interbeds. Part B conformably underlies the Cenomanian Halal Formation (Fig. 3A). It attains a thickness of 48 m and consists of sandstone, claystone and limestone interbeds with increasing of carbonate rocks upwards. The sandstone of part B is fine- to coarse-grained, calcareous or dolomitic. Some green glauconitic sandstone beds occur in this part. The claystone is either gray or greenish. Sometimes, it is fissile. The limestone is usually sandy, dolomitic and fossiliferous.

Risan Aneiza Formation in North Sinai is time equivalent to the Alamein, Dahab and Kharita formations in north Western Desert and to the Abu Ballas Formation and the lower part of the Sabaya Formation in south Western Desert (El-Azabi and El-Arabi, 1996).

Microfacies

Representative indurated sandstone and limestone samples of the Lower Cretaceous rocks (Malha and Risan Aneiza formations) at Gabal Manzour, Maghara area, North Sinai were thin sectioned and studied under the polarizing microscope. The following sandstone and limestone microfacies were identified:

A- Sandstone Facies:

1- Quartzarenite Facies (Facies A-1).
2- Sublitharenite Facies (Facies A-2).

B. Limestone Facies:

1- Wackestone Facies Association (B-1).
2- Grainstone Facies Association (B-2).
3- Packstone Facies Association (B-3).

A- Sandstone Facies:

The sandstone facies occur in both Malha and Risan Aneiza formations with their dominance in the first formation. The sandstone facies are classified following the classification of Pettijohn *et al.* (1973), and the results given by Tucker (1991). Under the microscope, two main kinds of sandstone facies are recognized including quartzarenite facies (Facies A-1) and sublitharenite facies (Facies A-2).

1- Quartzarenite Facies (Facies A-1):

The quartzarenite facies (Facies A-1) occurs in the whole Lower Cretaceous succession at Gabal Manzour although it is more dominant in the Malha Formation (Fig. 2). However, there are some differences between the quartzarenites of the Malha Formation and those of the Risan Aneiza Formation. Microscopically, facies A-1 is composed mainly of quartz grains (more than 95 %). These quartz grains are very fine- to coarse-grained sand size. They are poorly sorted to well sorted, subrounded to well rounded and most of them are monocrystalline (Fig. 4A). Most of the quartz grains show straight extinction and some grains exhibit strained or slightly undulose extinction. All types of grain to grain contacts are present in this facies with the majority of the point contacts. Incipient (partial) silica overgrowth occurs in some samples. Sometimes, the quartz grains are cracked; probably due to their subjection to pressure and the cracks are filled with iron oxides. In some samples (e.g., sample 34), the rock contain burrows that are filled by dolomite. Dedolomitization occurs also in the burrows. The cementing materials include one or more kind of the following: silica, iron oxide, dolomite, calcium carbonate and gypsum. Siliceous quartzarenites are dominant in the Malha Formation while ferruginous quartzarenites dominate in both Malha Formation and the lower part of the Risan Aneiza Formation. Calcareous and gypsiferous quartzarenites (Fig. 4B) occur dominantly in the Risan Aneiza Formation. Dolomitic quartzarenite facies (Fig. 4C) dominates in the Risan Aneiza Formation and in the uppermost part of the Malha Formation. In the gypsiferous quartzarenite facies (sample 33), the gypsum is partially glauconitized (altered and partially replaced by glauconite). The dolomite cement (samples 34 and 37) is composed of fine dolomite rhombs each of which has dark core of iron oxide and clear outer rims. The dolomite rhombs are stained with iron oxide. Glauconite grains (about 5 %) occur in the dolomitic quartzarenite facies in the Risan Aneiza Formation (sample 37).

2- Sublitharenite Facies (Facies A-2):

The sublitharenite facies (Facies A-2) occurs only in the Malha Formation (Fig. 2, e.g., samples 6, 8′, 10). In the field, this rock is white, creamy, gray, or greenish in colour. It is friable or slightly indurated and sometimes fractured. The rock of this facies is usually kaolinitic, very fine- to coarse-grained, and contains clay interbeds. Under the microscope, this facies is composed of quartz grains (40-45%) and sandstone lithoclasts (15-20%) embedded in iron oxide cement (Fig. 4D). Quartz grains are angular to rounded, monocrystalline, poorly to moderately sorted and cemented by iron oxide. Grain contacts are straight to point with the majority of the latter type. Lithoclasts of fine to very fine quartz grains cemented by iron oxide and dolomite occur in this facies (e.g., sample 8′). Some quartz grains of sand size are haphazardly distributed and in other places the sand grains are accumulated in groundmass of silt grains. Heavy minerals are common with clay particles. Glauconite pellets and patches and mica flakes are found in this facies.

B- Limestone Facies:

The limestone facies occur only in the Risan Aneiza Formation, in addition to the sandstone and shale interbeds. The limestone facies are compiled according to their depositional textures as adopted by Dunham (1962). The depositional environments of the limestone facies are interpreted in comparable with the Standard Microfacies Types (SMF) and Facies Zones (FZ) of Wilson (1975) and Flugel (1982).

Three main limestone facies associations are recognized in the Risan Aneiza Formation including; wackestone facies association (B-1), grainstone facies association (B-2), and packstone facies association (B-3).

1- Wackestone Facies Association (B-1):

This facies association occurs only in the Risan Aneiza Formation with its dominance at the bottom and top of part A and the upper half of part B of the formation (Fig. 2). There are different types of the wackestone facies that include foramineferal ostracode wackestone, skeletal pelloidal wackestone, foraminiferal bioclastic wackestone, sandy dolomitic molluscan wackestone and oolitic iron wackestone facies.

The foraminiferal ostracode wackestone facies consists of skeletal materials (ostracodes, foraminifera, pelecypods, echinoidal plates and spines) which are recrystallized to sparry calcite and microcrystalline to cryptocrystalline calcite.

The skeletal pelloidal wackestone facies consists of pellets, oolites, skeletal particles, microcrystalline calcite (micrite) matrix and microspar cement. The pellets are ovoid and micritic in composition.

Oolites are less frequent than pellets. The skeletal particles include pelecypods and echinoderm spines.

In the sandy dolomitic molluscan wackestone facies, the fossils include pelecypods and echinoids. The cementing materials are dolomite rhombs and sparry calcite. Other components include 5-10% quartz grains which are angular to subrounded, fine- to very fine sand size, monocrystalline with straight extinction. Few glauconite grains are also noticed.

Oolitic iron wackestone facies occur in several places in the whole Lower Cretaceous succession at Gabal Manzour (Fig. 2). It occurs in the field in the form of several thin iron oxide bands (up to 20 cm in thickness) in both Malha and Risan Aneiza formations at the top of both sandstone and limestone beds. Microscopically, in the oolitic iron wackestone facies, each oolite consists of quartz nucleus which is surrounded by layers of iron oxide. The oolites are cemented by microcrystalline calcite which is stained by iron oxide (Fig. E). Composite oolites are rare.

The foraminiferal bioclastic wackestone facies consists of fossils, lithoclasts and matrix. Fossils include pelecypod, gastropod, echinoid, ostracode and benthonic foraminiferal shell fragments. The lithoclasts are well rounded and brown sand grains and shell fragments. The matrix consists of microcrystalline calcite with some microspars (Fig. 4F).

2- Packstone Facies Association (B-3):

The packstone facies association (B-3) occurs only in the lowest half of part A of the Risan Aneiza Formation overlying and underlying claystone beds (Fig. 2). In the field, the rocks of this facies association are sandy and argillaceous; massive and bedded; vertical burrowed and highly fossiliferous limestones. Under the microscope, three different types of packstone facies are recognized. They are oolitic skeletal packstone facies, sandy molluscan packstone facies and oolitic packstone facies.

In the oolitic skeletal packstone facies, the oolites consist of nucleii of recrystallized shells that are surrounded by microcrystalline calcite and stained by iron oxide (Fig. 5A). The fossils include recrystallized pelecypod shells and echinoderm spines and plates. Some randomly scattered quartz grains are observed. Cement is both microsparry calcite and iron oxide.

In the sandy molluscan packstone facies, the allochems are mainly pelecypod fossils which are recrystallized. The borders of shell fragments are well rounded and stained by iron oxide. Fine, well- to subrounded quartz grains are abundant. The cementing material is iron oxide that fills the pores within shell fragments.

The oolitic packstone facies consists mainly of fossils and oolites. Fossils are echinoid plates and recrystallized pelecypod shells. The oolites are few and consist of microcrystalline calcite stained by iron oxide. The matrix is microcrystalline calcite which is stained by iron oxide.

3- Grainstone Facies Association (B-2):

This facies association occurs only in part A of the Risan Aneiza Formation. It overlies shales and underlies either shales or the quartzarenite facies (Fig. 2). In the field, the limestone of this facies association is oolitic, fossiliferous, glauconitic and planar cross-bedded. Under the microscope, this facies association includes two different grainstone facies; oolitic skeletal grainstone and intraclastic oolitic grainstone facies.

The oolitic skeletal grainstone facies consists of oolites, fossils, intraclasts in addition to the sparry calcite cements (Fig. 5B). The oolites consist mainly of cores of shell fragments surrounded by several layers of microcrystalline calcite. Some radial oolites occur. Composite oolites are observed. Fossils are represented by shell fragments of pelecypods and echinoderms. Benthonic foraminifers occur in the core of the oolites. The intraclasts are mainly aggregates of oolites, pellets, and shell fragments cemented by iron oxides.

The intraclastic oolitic grainstone facies consists of oolites, fossils, pellets, and lithoclasts and sparry calcite cement. The oolites are composed of cores of quartz grains or shell fragments and concentric outer layers of iron oxide. Fossils include pelecypods and echinoderms. The lithoclasts include very coarse quartz grains and shell fragments. Detrital glauconite pellets whose borders are oxidized and rounded and iron oxide pellets occur in this facies.

Diagenesis

The present Lower Cretaceous sandstones and limestones at Gabal Manzour were subjected to both physical and chemical diagenetic processes. Physical processes include mechanical compaction and chemical changes are represented by micritization, aggrading neomorphism, cementation, dolomitization and dedolomitization.

1- Micritization

Micritization is a process of sketetal particles diminution by the effect of boring endolithic algae at/or just below the sediment/water interface where the bioclasts and/ or shells are replaced by micrite (Tucker and Wright, 1990). In the present facies, micritization is noticed in the molluscan shells of the sandy dolomitic molluscan wackestone lithofacies of the Rizan Aneiza Formation. The micritization in this facies is observed partially enveloping the center of the shells (Fig.5C). Such micrite envelopes may indicate early stage of diagenesis at shallow marine depths (Bathurst, 1975).

2-Aggrading Neomorphism

Aggrading neomorphism is a process of crystal growth in a wet medium by which the cryptocrystalline crystals increase in size to form spary crystals of the same mineral through solution-repreciptation or solid state processes (Folk, 1965 and Bathurst, 1975). In the studied lithofacies, the aggrading neomorphism is mainly recorded in the molluscan skeletal pelloidal wackestones and sandy molluscan packstones of the Risan Aneiza Formation. It is represented by the replacement of aragonitic shell fragments by drusy calcite (Fig. 5D). This process may took place through solution – reprecepitation instead of recrystalization (i. e., the aragonite is dissolved and drusy calcite is subsequently precepitated). This is evidenced by the lack of original internal structure and organic matter inclusions within the shells (Tucker, 1991). This type of neomorphism indicates that the studied rocks were influenced by meteoric/phreatic water in the earliest stage of diagenesis (Longman, 1980).

3- Cementation

Cementation is a chemical process of diagenesis including precepitation of minerals that lead to binding of the sediments and/or particles (Tucker, 1991). In the studied rocks, cementation is mainly recorded in both the sandstone and limestone lithofacies.

In the sandstone lithofacies, the most encountered cements are iron oxide, calcite and dolomite. The iron oxide cement is common in the quartzarenite lithofacies of the Malha Formation. It is present as grain-coatings and pore fillings (Fig. 3A). Such cement is mainly hematite which may be supplied by an interstitial solution of detrital iron-bearing minerals (e. g., hornblende, biotite and chlorite) in oxidizing environment (Walker, 1976). Both calcite and dolomite cements are abundant in the sandstones of the Rizan Aneiza Formation. Apart from filling pores, calcite and dolomite cements replaced the quartz grains. This replacement is represented by corrosion and etching of the quartz grain margins (Figs. 3B &C). Such corrosion indicates that the studied calcareous and dolomitic quartzarenites were influenced by an interstitial solution of high pH and temperature at deep burial (Pettijohn *et al.*, 1973 and Tucker, 1991).

In the limestone lithofacies, two types of cement are noticed. The first type of cement occurs in the wackestone and packestone lithofacies of the Risan Aneiza Formation. It is represented by micrite (Figs. 3F and 4A). Such cement may represent an early formed shallow-marine cement associated with boring algae (Bathurst, 1975 and Morse and Mackenzie, 1990). The second type of cement occurs in the grainstone lithofacies of the Risan Aneiza Formation. It occurs as granular calcite spars (Fig. 5E). This cement may be formed by near-surface diagenesis during late stage of diagenesis and characterizes meteoric phreatic conditions (Longman, 1980 and Morse and Mackenzie, 1990).

4- Compaction

Compaction has been defined as one of the main diagenetic processes that results from an increase of the overburden and subsequently changes in both texture and fabric of the rock (McBride, 1987). Compaction is both mechanical and chemical. The mechanical compaction involves dewatering and closer packing of the grains, whereas the chemical compaction refers to solution of grains at points of their contact (Chilingarian, 1983). In the studied lithofacies, compaction is mainly noticed in the sandstones. Many of the studied sandstones exhibit features of the mechanical compaction, but the chemical type of compaction is not observed. This may be due to the primary effect of pre-existing cements at the early stage of diagenesis, which is capable of the stablization or freezing of detrital grain contacts at deep burial (Pittman and Larese, 1987). The observed features of mechanical compaction herein include point and straight grain contacts (Fig. 3A).

5- Dolomitization

Dolomitization process is noticed in the dolomitic quartzarenite lithofacies of the Risan Aneiza Formation. In this lithofacies, the dolomite occurs as cement and is made up of rhombs of cloudy cores surrounded by clear outer rims (inclusion-rich dolomite, Fig. 4C). The cloudy cores are dark brown in colour indicating concentration of iron oxides. The dominance of such inclusion-rich dolomites in the studied lithofacies may indicate that they were formed in the earliest stage of diagenesis by marine water of relatively high salinity (Khalifa and Abu El-Hassan, 1993). Such earlier dolomitization by marine water can be also supported by the constant stratigraphic position of the dolomitic sandstone at the base of the Risan Aneiza Formation and its complete absence in the underlying Malha Formation (El-Shishtawy *et al.*, 2003).

6- Dedolomitization

The term dedolomitization was introduced by Von Morlot (1848) and Katz (1968) to describe the replacement of dolomite by calcite. Dedolomitization is encountered at the tops of the dolomitic quartzarenite lithofacies of the Risan Anieza Formation. It is noticed by the occurrence of large calcite crystals enclosing relics of dolomite rhombs, and that calcites are surrounded by iron oxides (Fig. 5F). These iron oxides could be the dedolomitization by-products of the former ferraon dolomite. Such petrographic characters of the dedolostone lithofacies, and its stratigraphic position at the top of the dolomitic sandstone lithofacies may indicate that the recorded dedolostone was resulted from an influence of meteoric water during subaerial exposure (Al-Hashimi and Hemingway, 1973 and Khalifa and Abu El-Hassan, 1993).

Depositional Environments

The exposed rocks of the Lower Cretaceous succession at Gabal Manzour could be differentiated into lower clastic-dominated facies (Malha Formation) and upper siliciclastic-carbonate facies (Risan Aneiza Formation). Each part of these facies exhibits different lithologic features, microfacies associations and primary structures which reflect different depositional environments. The following is a discussion of environmental interpretation of these facies:

The lower unit (Malha Formation). This unit is mainly composed of varicoloured coarse-to medium grained sandstones with fine-grained sandstones and mudstones interbeds in the form of several fining upward cycles. They are pebbly (conglomeritic) with the concentrating the pebbles at the bases of beds in the ower part. It is characterized by the occurrence of numerous ferruginous horions as well as scattered hay plant remains. The sandstones of the Malha Formation are mainly quartarenites and sublitharenites. The quartzarenites are mainly very fine-to coarse grained quartz grains which are poorly to well sorted. They are mainly siliceous and ferruginous. The sublitharenite facies is usually kaolinitic, very fine to coarse grained, and contains clay interbeds. The quartz grains are angular to subrounded, poorly to moderatly sorted and cemented by iron oxide.

The primary structures that occur in the Malha Formation include flat bedding, planar cross bedding, graded bedding, convolute bedding and channelling and scour features. Such facies sequence with its characters reflect a continental facies accumulating in a meandering fluvial system (Selley, 1996). Also, the red colouration of these rocks supports deposition in fluvial environment (Tremblay, 1972 and Wallace, 1972). The abundance of plane-bedding indicates upper flow regime conditions (Eriksson, 1978). In addition, planar and trough cross-stratification are produced from bedforms common in fluvial environments (Allen, 1963). Clanneling is one of the processes which are universal to fluvial sedimentation and rarely occur in other environments (Visher, 1972). In terms of their textures, sedimentary structures and vertical sequences, the sandstones of the Malha Formation are similar to channel sediments of modern stream (Harms and Fahnestock, 1965). Moreover, the rocks of the Malha Formation are mainly siliceous, and ferruginous quartzarenites that indicate deposition in continental fluvial environment (Tucker, 1982). Furthermore, gradual upward decreasing in both grain size and abundance of gravel reflect continous lowering of source area relief and decrease of discharge and transport capacity during aggradation of the stream (Mader, 1985), which in turn indicates a meandering type of fluvial system.

There are some negative evidences that support the fluvial origin of the Malha Formation. The absence of herringbone cross-stratification and flaser bedding (Reineck and Wunderlich, 1968), the absence of certain minerals such as glauconite which does not persist in fluvial, oxidizing environment (Visher, 1972), and the absence of marine fossils (Selley, 1996). In conclusion, The environment of deposition of the Malha Formation was mostly high energy agent fluvial system. The enclosing siltstones and claystones are similar to contemporary overbank flood plain deposits (Mckee *et al.*, 1967).

The lower part (Part A) of the Risan Aneiza Formation is made up of laminated and thin-bedded sandstones, siltstones, claystones and oolitic carbonate interbeds. The sandstones are fine- to coarse grained. The siltstones are laminated and thinly bedded. The shales are fissile and yellow, gray and greenish in colour. The limestones are fossiliferous, oolitic, dolomitic, massive, blocky and fractured. Flat bedding, planar cross-bedding and vertical burrows (skolithos) are common in both sandstones and limestones. Flaser and lenticular bedding are dominant in the sandstone, siltstone and claystone interbeds. The oolitic carbonates are represented by oolitic packstone in some beds and oolitic grainstone in others.

The dominance of oolitic nature in carbonate interbeds suggests deposition in intertidal zone of agitated water conditions (Flugel, 1982 and Wilson, 1975). The highly micritic cement in oolitic packstone and highly sparitic cement in oolitic grainstone indicate low and high energy level, respectively (Dunham, 1962). Therefore, the lower part of the Risan Aneiza Formation (Part A) was deposited in an intertidal zone of an interplay between high and low energy levels. In general, rocks of Part A of the Risan Aneiza Formation were deposited in an intertidal zone as revealed from the characteristics of its clastic and carbonate components. The relative richness of this part in clastic materials indicates that deposition of this part is not far from a neighbouring landmass that supplied the terrigenous materials.

The upper part (Part B) of the Risan Aneiza Formation is characterized by a relatively carbonate-dominated in comparison with Part A of the Risan Aneiza Formation. The carbonate rocks of Part B are represented by wackestone lithofacies with pellets, echinoids, benthonic foraminifera and some molluscan shell fragments which indicate subtidal marine conditions (Flugel, 1982 and Wilson, 1975). Also, the highly micritic cement of the wackestone lithofacies indicates low energy level (Dunham, 1962). Therefore, it is belived that the basal facies of the Risan Aneiza Formation (Part A) may represent an early phase of marine transgression, followed upward by deeper transgressive facies (Part B). In conclusion, the vertical distribution of the Risan Aneiza Formation in the studied area suggests a gradual upward deepening marine water conditions above the fluvial deposits of its underlying Malha Formation..

Conclusions

The Lower Cretaceous succcession of Gabal Manzour is differentiated into two rock units; the Malha Formation and the Risan Aneiza Formation. The Malha Formation is the oldest exposed rock unit and is made up of sandstone, siltstone and claystone. The Risan Aneiza Formation is siliciclastic-carbonate rocks and conformably overlies the Malha Formation and underlies the Halal Formation. This study allowed subdividing the Risan Aneiza Formation into two parts;

the lower part (Part A) and the upper part (Part B). Part A is equivalent to the Ras Al-Ahmer Member of Hassan *et al.* (1992), and is made up of sandstone and limestone interbeds. Part B is equivalent to the Hamret Salma Member of Hassan et al. (1992), and is made up of carbonate-dominated and claystone interbeds.

Petrographicaly, five microfacies have been identified and correlated with the worldwide standard microfacies associations of Wilson (1975) and Flugel (1982). Two facies have been recognized in the Malha Formation; quartzarenite and sublitharenite facies. Three microfacies associations have been indentified in the Risan Aneiza Formation; wackestone, packstone and grainstone facies associations.

On the basis of their lithological characteristics and microfacies associations, the Lower Cretaceous rocks at Gabal Manzour are of fluvial and marine origins. The fluvial environment (meandering stream) was prevailed during the deposition of the Malha Formation. The marine environment was dominated during the deposition of the Risan Aneiza Formation. The basal part of the Risan Aneiza Formation (Part A) was deposited in an intertidal zone, while the upper part of the Risan Aneiza Formation (Part B) was deposited in subtidal zone.

The main diagenetic features encountered in the studied rocks include micritization, aggrading neomorphism, cementation, compaction, dolomitization and dedolomitization. These diagenetic features revealed three stages of diagenesis; syn-(early stage), meso-(late stage), and telodiagenesis (diagenesis after uplift).

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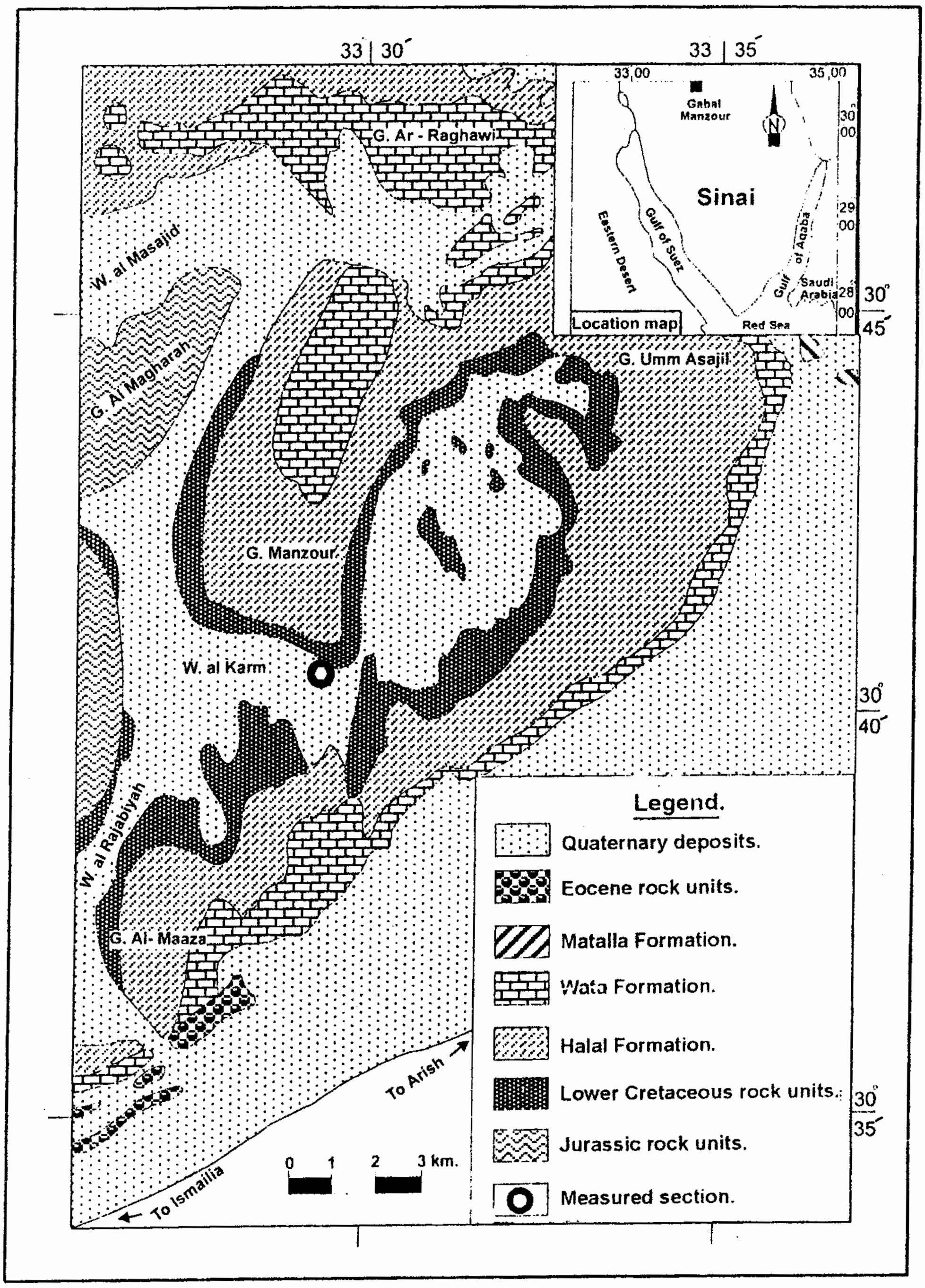

Fig.(1): Geological map of Gabal Manzour (modified after the Egyptian Geological Survey, 1993).

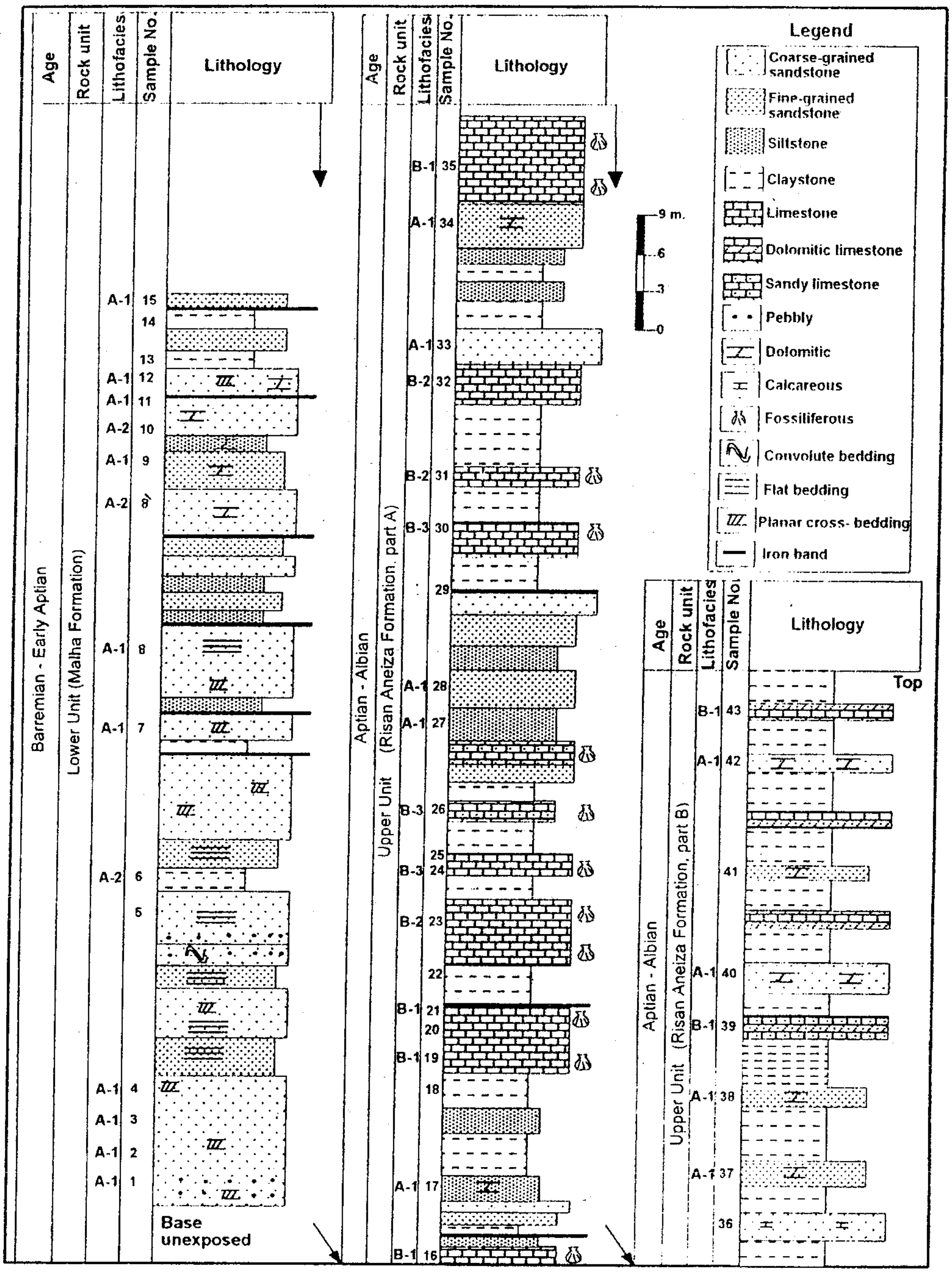

Fig. (2): Lithostratigraphic succession of the Lower Cretaceous rocks at Gabal Manzour,Sinai.

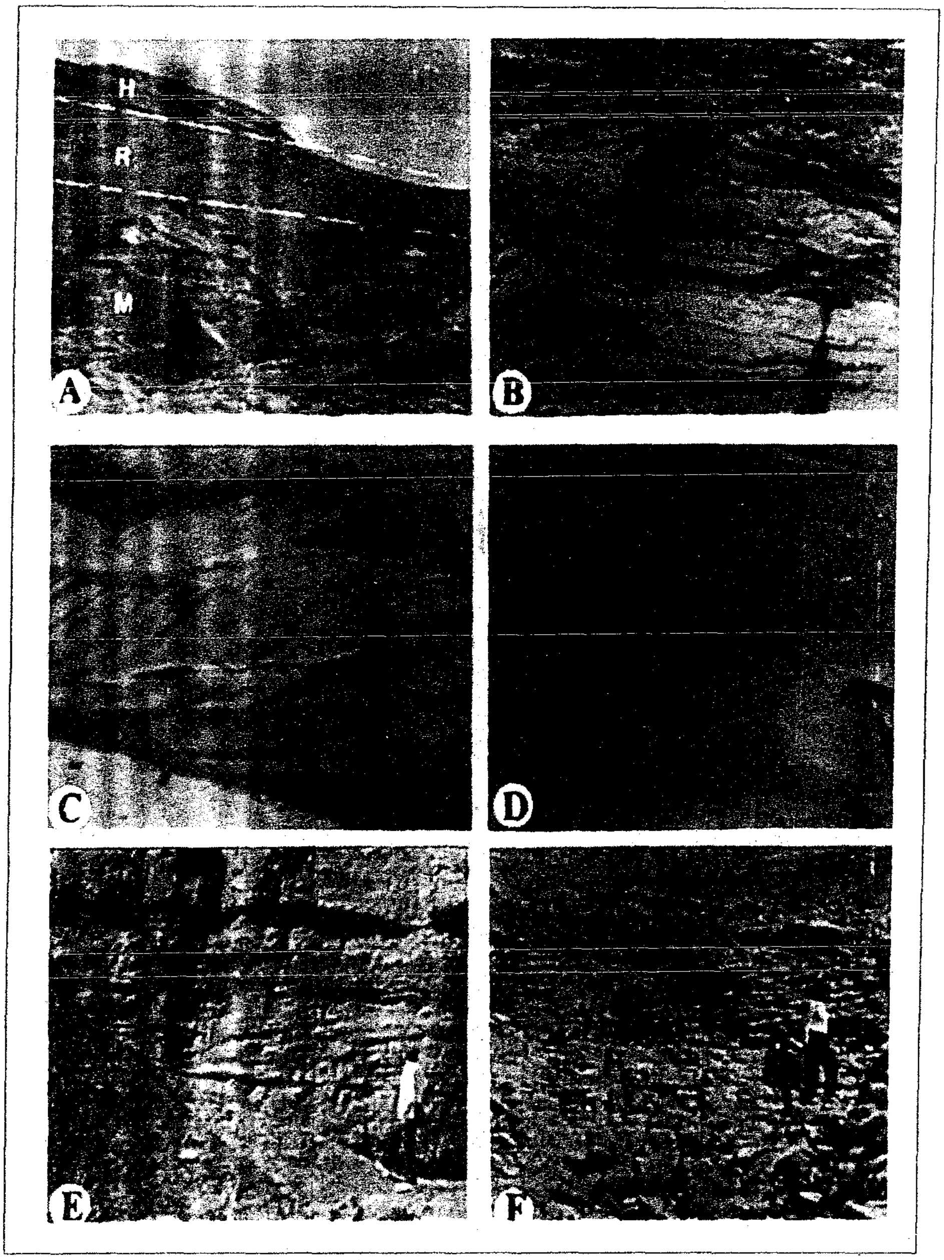

Fig. (3): Field Photographs showing A)- general view of the Cretaceous rock units at Gabal Manzour, the Malha Formation at base (M), the Risan Aneiza Formation (R) and Halal Formation (H). B)- thinly-bedded flat lying sandstone of the Malha Formation. C)- planar cross bedding in the sandstone of the Malha Formation. D) convolute bedding in the sandstone of the Malha Formation. E) fluvial channel in the Malha Formation, notice downcutting of channel sands into underlying rocks. F)- planar cross-bedded oolitic limestone of the Risan Aneiza Formation.

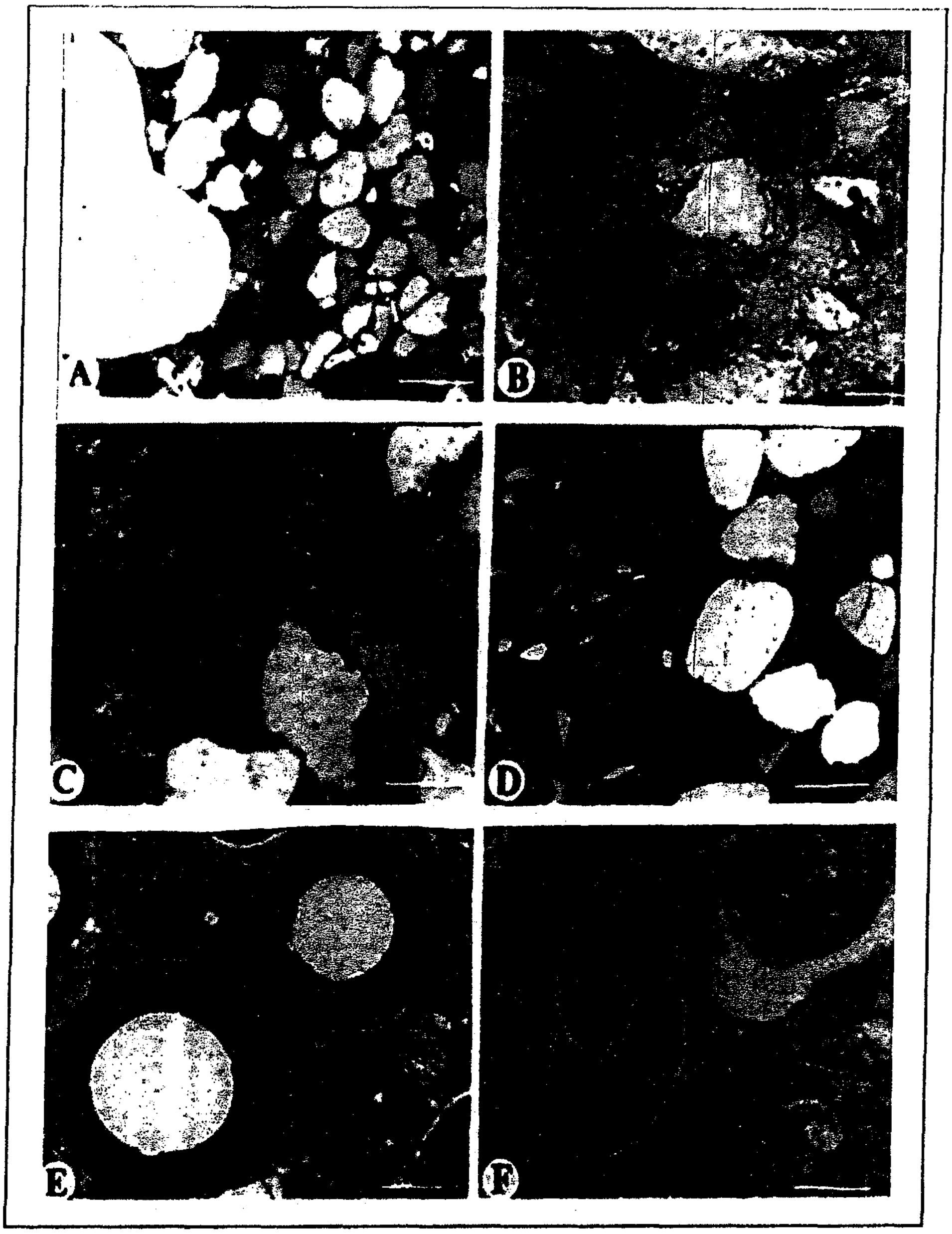

Fig. (4): Photomicrographs showing: **A)**- ferruginous quartzarenite facies (Malha Formation). It consists of subrounded, monocrystalline, very fine to coarse quartz grains in ferruginous cement. **B)**- calcareous quartzarenite facies (Risan Aneiza Formation), in which the quartz grains are corroded in their peripheries by the spary calcite cement. **C)**- dolomitic quartzarenite facies (Risan Aneiza Formation). It consists of subrounded quartz grains cemented by zoned dolomite rhombs. **D)** sublitharenite facies (Malha Formation). It is made up of sandstone lithoclast (left side of photo.) and quartz grains. **E)** oolitic iron wackestone facies (Risan Aneiza Formation). **F)**- foramineferal bioclastic wackestone facies (Risan Aneiza Formation). All photomicrographs are in crossed-nicols, except the photomicrgraph (F) which is in plane polarized light. All the scale bars are equivalent to 100 um, except that of photmicrograph B which is 50um.

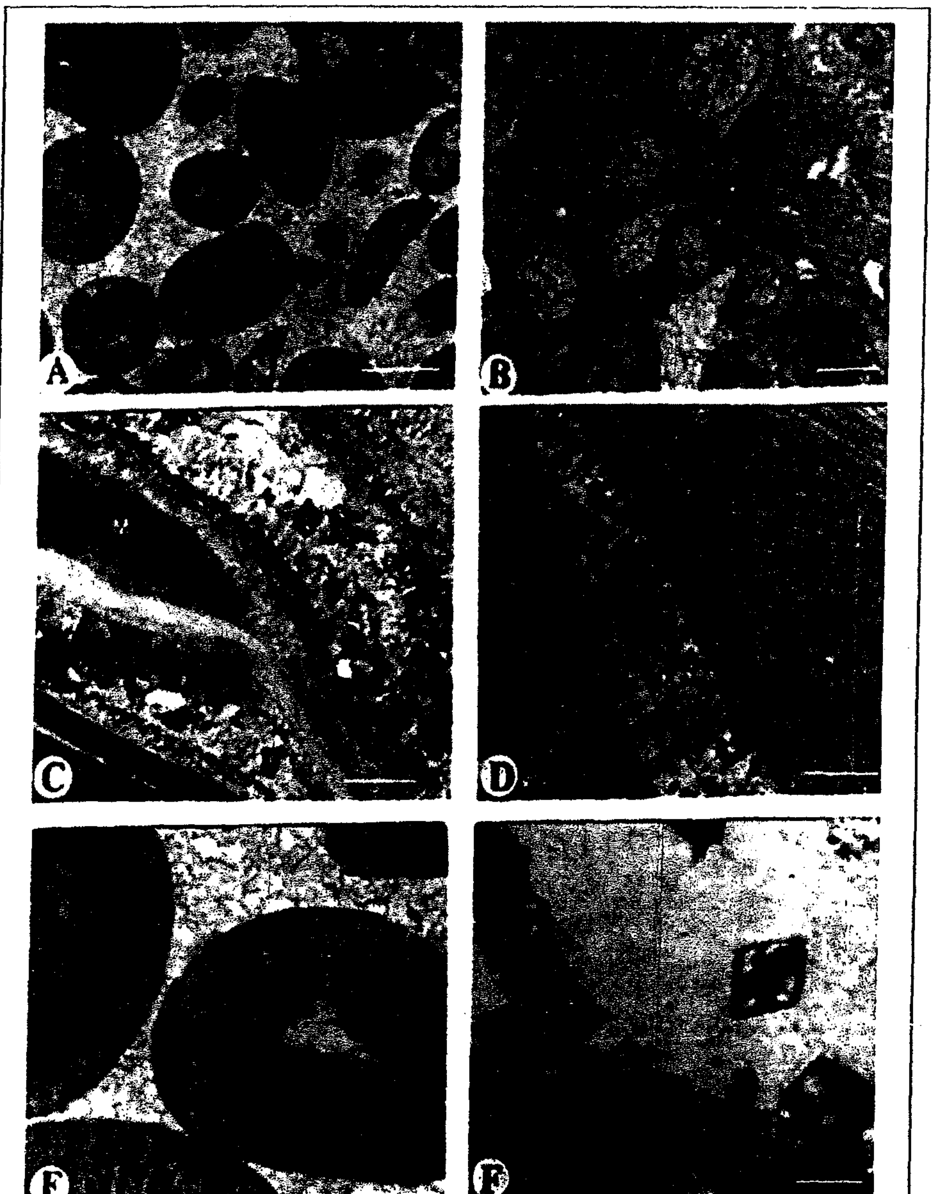

Fig. (5): Photomicrographs showing **A)**- oolitic skeletal grainstone facies consisting of oolitic carbonate and iron in a spary calcite cement. **B)**- oolitic skeletal packstone facies in which the oolites consist of recrystallized shells that are surrounded by microcrystalline calcite. **C)** molluscan bioclastic wackestone facies, in which the pelecypod shell fragments are with dark micrite envelope (M). **D)** molluscan bioclastic wackestone facies, in which the pelecypod shell fragments are subjected to aggrading neomorphism. **E)**- granular spary calcite cement in the grainstone facies. **F)** dedolomitization of dolomite to blocky calcite. This is noticed by the occurrence of dolomite rhombs relics within the blocky calcite, and the iron oxides are precipitated at the edges of the blocky calcite.The photomicrographs **A, B** and **E** are in plane polarized light, while the photomicrgraphs **C, D** and **F** are in crossed-nicols. All the scale bars are equivalent to 100 um, except those of photomicrographs E and F which are equivaent to 50 um.

إضافة إلى استراتجرافية وترسيب تتابع الطباشيرى السفلى في جبل منظور بمنطقة المغارة – شمال سيناء – مصر

حسنى الدسوقى سليمان و حمد الله عبد الجواد ونس

قسم الجيولوجيا – كلية العلوم – جامعة المنوفية – شبين الكوم – مصر

ملخص البحث :

تم تقسيم تتابع الطباشيرى السفلى في جبل منظور بشمال سيناء الى وحدتين صخريتين : الوحدة السفلى (متكون المالحه) والوحدة العليا (متكون ريسان عنيزه) ٠ وأمكن أيضاً تقسيم متكون ريسان عنيزه الى جزئين : الجزء السفلى يكافئ عضو راس الأحمر بينما الجزء العلوى يكافئ عضو حمرة سلما ٠

بدراسة الخواص الصخرية والسحنات الدقيقة أمكن الاستدلال على أن صخور متكون المالحه قد ترسب في بيئة نهرية وبالنسبة لصخور الجزء السفلى لمتكون ريسان عنيزه قد ترسب في منطقة المد والجزر بينما الجزء العلوى لنفس المتكون قد ترسب في بيئة بحرية ضحلة ٠

بدراسة عوامل مابعد الترسيب أمكن التعرف على أن الصخور المدروسة قد تأثرت بعد ترسيبها بعمليات التضاغط والتلاحم واعادة التبلور والدلمتة والمكرتة ٠