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Lithostratigraphy and microfacies of the Lower Carboniferous (Viséan) Um Bogma Formation in Gabal Nukhul, west-central Sinai, Egypt

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Abstract

The Lower Carboniferous (Viséan) succession of the Um Bogma Formation at Gabal Nukhul, west-central Sinai is subdivided into lower, middle and upper members. Integrating field observations and microfacies analysis led to the recognition of six microfacies as follows: wackestone/packstone, packstone/grainstone, grainstone, bafflestone, calcareous quartz arenite and paleokarst breccia. The paleokarst breccia is the first record to indicate an Early Carboniferous karstification in the Gabal Nukhul area.

During the Early Carboniferous (Viséan) marine transgression, the lower member of Um Bogma Formation was deposited in intertidal to shallow subtidal environments. A marked drop in sea level and/or synsedimentary block faulting (uplifting) let to subaerial exposure of the lower member and followed by karstification process (paleokarst surface). The middle member was deposited in an open platform environment followed by shallow subtidal facies of the upper member. The uniform stacking pattern of the middle and upper member's facies implies a characteristically regressive trend throughout the studied area. The abundance of oolitic deposits together with chlorozoan assemblage within the Um Bogma Formation indicates that the Lower Carboniferous sediments of Sinai were deposited in the lower subtropics region.

Key-words : Lithostratigraphy, microfacies, Viséan, karstification, Sinai, Egypt

1. Introduction

The Carboniferous deposits of Egypt range from fully marine carbonates, shallow marine clastics, deltaic and continental fluviatile sandstones to lacustrine and fluvio-glacial deposits. The main reason for much differentiated appearances of Carboniferous strata beside eustatic changes is due to the structural and tectonic development (Fig. 1) during the Early Carboniferous time characteristic of Egypt (Klitzsch, 1990, p.399; Keeley, 1994). The post-Cambrian uplift of south-western Sinai was about 130 m in magnitude, while the pre-Viséan subsidence was greater than 40 m over a maximum of 150 m.y. The direction of Wadi Khaboba-Gabal Nukhul high is north-south, almost parallel with the Gulf of Suez rift (Beyth, 1981).

The Lower Carboniferous (Viséan) rocks in Sinai represent a short-lived marine flooding surface over non-marine clastic sediments and are limited to the Um Bogma area, west-central Sinai. These rocks constitute the Um Bogma Formation, which unconformably overlies the Cambro-Ordovician Adedia Formation (Kora, 1984) and conformably underlies the Late Viséan-Early Namurian Abu Thora Formation (Kora, 1998). Gabal Nukhul (latitude 29° 03′ 30″ N; longitude 33° 15′ 00″ E) represents the type section of the Um Bogma Formation (Figs. 2, 3),

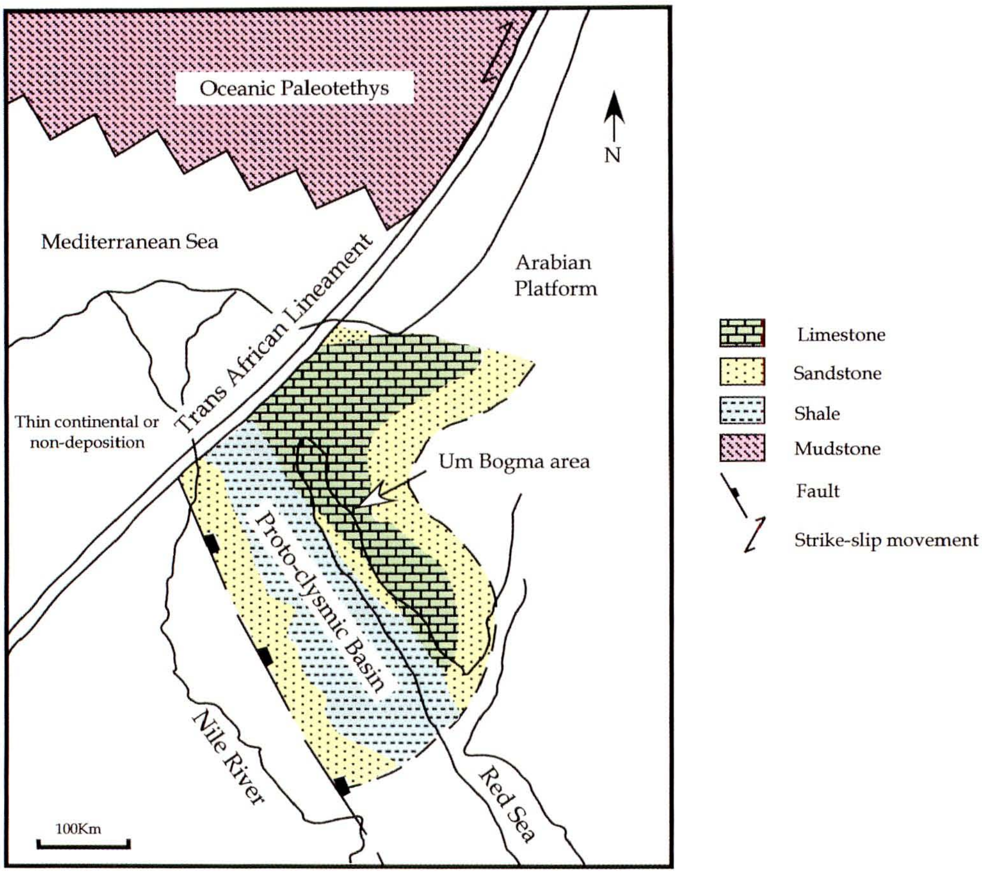

Fig. 1 Early Tournaisian-mid-Permian depositional phase in Northeast Egypt (after Keeley, 1994).

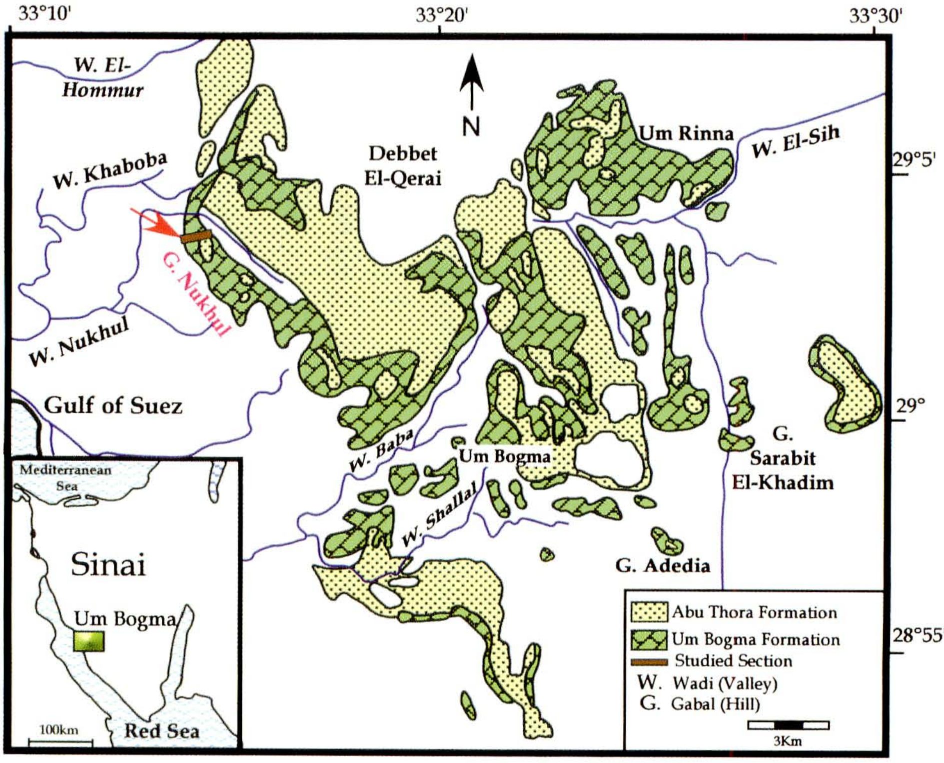

Fig. 2 Distribution map of the Lower Carboniferous in the Um Bogma area, west-central Sinai, Egypt (after Kora and Jux, 1986).

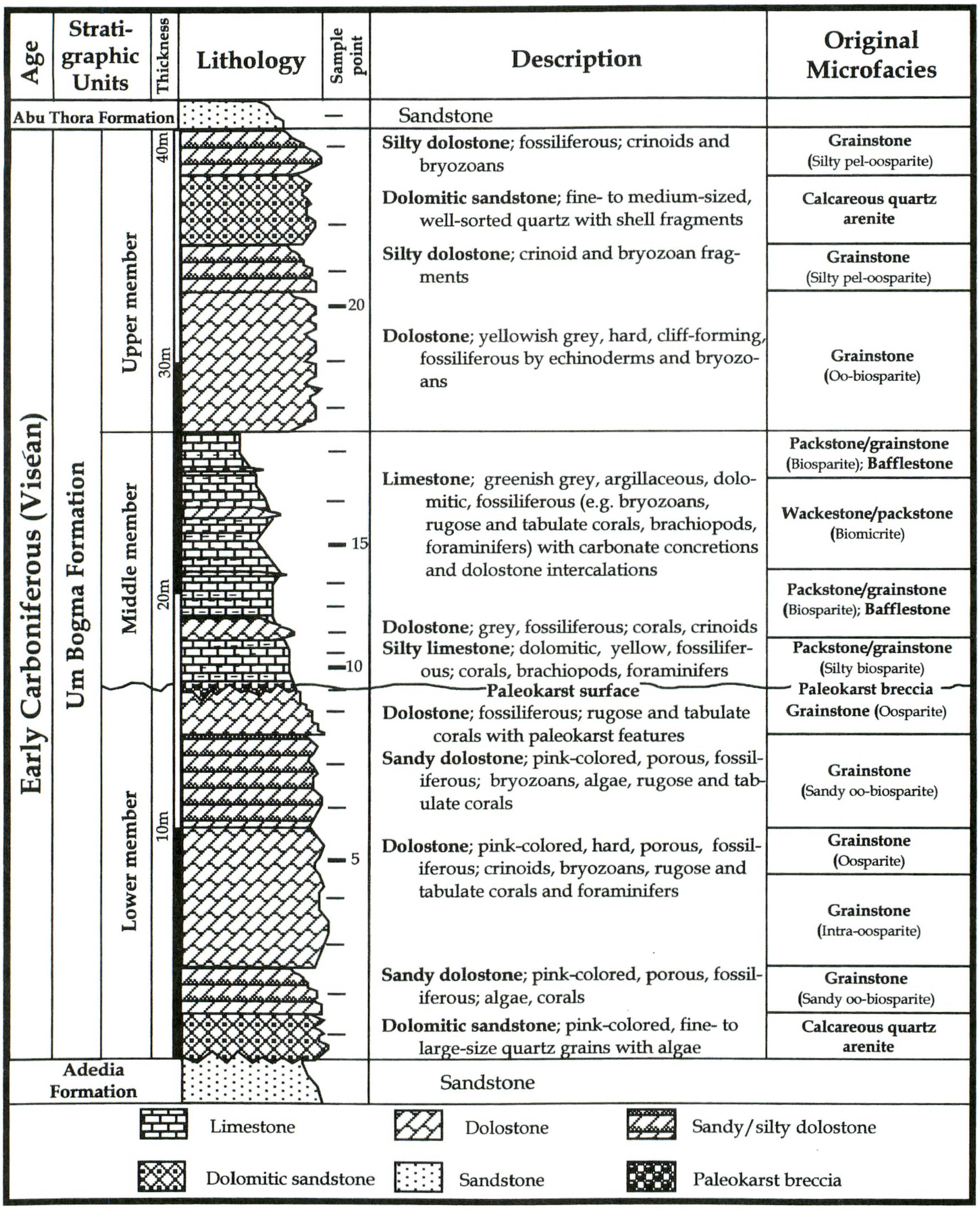

Fig. 3 Lithostratigraphy and microfacies associations of the Lower Carboniferous (Visêan) in Gabal Nukhul, west-central Sinai, Egypt.

which constitutes the maximum thickness (approximately 40 m)

The Um Bogma Formation is economically of further interest because it hosts ferro-manganese ore deposit in Egypt. From the beginning of the twentieth century, the Carboniferous rocks in the Um Bogma area have attracted the attention of many geologists (Barron 1907; Ball, 1916; Kostandi, 1959; Omara and Conil, 1965; Soliman and El-Fetouh, 1969; Weissbrod, 1969; Mart and Sass, 1972; Soliman, 1975; Kora, 1984, 1995; Brenckle and Marchant, 1987; El-Shahat and Kora, 1988; El-Sharkawi et al., 1990; Kora et al., 1994; Ahmed and Osman, 1999; El-Agami et al., 1999; El-Kelani, 2001 and others).

The Um Bogma Formation was first treated as Carboniferous Limestone Series by Barron (1907) and Ball (1916, p.143) or Dolomitic Formation by Omara (1965, p.416) and Omara and Conil (1965, p.223). Kostandi (1959) used the term Um Bogma Series for Lower

Carboniferous Sandstone and Carboniferous Limestone divisions of Ball (1916, p.151) in south-western Sinai. This name was emended by Weissbrod (1969, p.11) and Omara (1971, p.145) to Um Bogma Formation for the carbonate unit only of Viséan age. Subsequently, the term Um Bogma Formation has been accepted by most investigators. The Khaboba Formation of Soliman and El-Fetouh (1969, p.62) is a synonym of the Um Bogma Formation. The Um Bogma Formation is subdivided by most workers into three members. The common subdivisions from base to top are as follow: 1) lower dolomitic, middle dolomitic limestone and upper dolomitic members of Omara and Conil (1965); 2) lower, middle and upper members of Kora (1984); 3) lower dolostone, middle carbonate-clastic and upper dolostone members (Ahmed and Osman, 1994); and others as shown in Table (1). Generally, all suggested subdivisions of Um Bogma Formation by several workers are informally depending on criteria of lithology. Only Kora et al. (1994) established formal names for these members. They are the Ras Samra Member, El-Qor Member and Um Shebba Member from base to top.

Based on the occurrence of smaller foraminifers Omara and Conil (1965) suggested Viséan age for the Um Bogma Formation. This age estimation was accepted by most authors based on micro-and macrofaunal contents (e.g., Mamet and Omara, 1969; Brenckle and Marchant, 1987; Kora and Jux, 1986; Kora, 1992).

El-Sharkawi et al. (1990) noted that the lower member of the Um Bogma Formation in the eastern part of the Um Bogma area was subjected to a Carboniferous karstification process, in addition to Quaternary karstification which affected all the formation. They suggested that the manganese ore deposits of the Um Bogma Formation were accumulated during these karstification processes. This suggestion, however, has not been accepted by other workers (e.g., Kora et al., 1994; Saad et al., 1994; El-Agami et al., 1999).

Most of the previous works focused on the ferromanganese deposits and its host rocks of the Um Bogma Formation in the middle and eastern parts of the Um Bogma area. The present study aims to shed more light on the lithostratigraphy, Carboniferous karstification and microfacies analysis in order to elucidate the prevailed depositional environments during the Early Carboniferous time in Gabal Nukhul.

2. Lithostratigraphy

The Um Bogma Formation represents a short-lived, open marine incursion into the continental-paralic environments which were predominant in the Gulf of Suez region during the Paleozoic (Brenckle and Marchant, 1987).

The general lithostratigraphic subdivisions proposed by Kora (1984) for this formation at Wadi Khaboba (near the studied section) are the most suitable and will be followed herein.

The Um Bogma Formation

Author: Weissbrod (1969) and Omara (1971) emended from the Um Bogma Series of Kostandi (1959).

Type locality: Gabal Nukhul (latitude 29° 03′ 30″ N; longitude 33° 15′ 00″ E), west-central Sinai (Fig. 2). It consists approximately of 40 m thick succession of sandy dolostone which is pinkish, porous, hard and cliff-forming in the lower part; yellow, marly and fossiliferous in the middle part and gray, hard and cliff-forming in the upper part.

Boundaries: At Gabal Nukhul, the Um Bogma Formation unconformably overlies the clastics of the Cambro-Ordovician Adedia Formation (Kora, 1984) and conformably underlies the sandstones of the Late Viséan-Early Namurian Abu Thora Formation (Kora, 1998) (see Pl. 1, Figs. A, B).

Description and subdivisions: In the studied section the Um Bogma Formation is composed mainly of lower and upper sandy dolostone units separated by argillaceous, fossiliferous and dolomitic limestone unit with thin laminated siltstone and shale intercalations. To the southeast, the carbonates decrease while the siliciclastics increase to form calcareous clastics and clastic facies (Kora et al., 1994).

The maximum thickness (approximately 40 m) of this formation was recorded at the place between Wadi Khaboba and Gabal Nukhul sections in the northwestern part of the Um Bogma area. Its thickness tends to decrease gradually southeastwards although the isopach map established by Kora et al. (1994) indicates an abrupt thinning at several localities in the mined central part of the Um Bogma area.

Based on micro-and macro-faunal contents, the age of the Um Bogma Formation is fixed as Middle Viséan; V2a to V3a of the Belgian Viséan stages (Mamet and Omara, 1969; Brenckle and Marchant, 1987; Kora and Jux 1986; Kora, 1995). The Um Bogma Formation represents the oldest marine Carboniferous rock unit known in the Gulf of Suez region, Egypt (Kora, 1992).

In the field, it is easy to distinguish this formation into three parts at Gabal Nukhul. Kora (1984) subdivided the Um Bogma Formation in that area into lower, middle and upper members (Table 1).

Table 1 Comparison of subdivisions for the Um Bogma Formation in west-central Sinai, Egypt.

Present Work			Omara and Conil (1965)	Weiss-brod (1969)	Mart and Sass (1972)	Kora (1984)		Brenckle and Marchant (1987)	El-Sharkawi et al. (1990)			Kora et al. (1994); Kora (1995)	Ahmed and Osman (1999)	El-Agami et al. (1999)
						W. Khaboba	Um Bogma							
Lower Carboniferous (Viséan)	Um Bogma Formation	Upper member	Upper dolomitic member	Brown dolomitic member	Upper dolomite member	Upper member	Upper dolostone member	Upper dolomite member	Upper dolostone			Um Shebba Member	Upper dolostone member	Dolostone- sandstone member
		Middle member	Middle dolomitic limestone member	Yellow dolomitic member	Marly dolomite and silt member	Middle member	Marly dolostone -siltstone member	Carbonate- shale member	Marly dolostone -siltstone member	Topsoil horizon Subsoil horizon	Soil profile of a buried paleokarst	El-Qor Member	Middle carbonate- clastic member	Marly dolostone- siltstone member
		Lower member	Lower dolomitic member	Sandy dolomitic member Shaly-ore member	Silty shale member Dolomite and ore member	Lower member	Dolostone- ore member	Lower dolomite member	Lower dolostone member	Parent horizon		Ras Samra Member	Lower dolostone member	Shaly ore- sandy dolostone member

The lower member at Gabal Nukhul section is about 16 m thick. The basal part represents the first marine transgression throughout the area and consists of dolomitic sandstone. The clastic sediments gradually decrease upward while the carbonates become dominant to form sandy dolostones (Pl. 6, Figs. B, E). Generally, these dolostones are characterized by a pink-color and a fenestral fabric structure (Pl. 2, Fig. A). Some fossils are observed in the field and in the thin sections, including calcareous algae, rugose and tabulate corals, bryozoans and smaller foraminifers (*Endothyra* spp.) of Visêan age (Pl. 2, Fig. B).

Noteworthy is the paleokarst surface at the topmost part of the lower member. This surface is distinguished by paleokarst breccia filling the caves of the parent rocks followed by thin topsoil bed (Pl. 2, Figs. C-E).

The middle member attains a thickness of 11 m and consists essentially of greenish yellow, fossiliferous, dolomitic and argillaceous limestones. These limestones are generally intercalated with thin beds of fossiliferous, sometimes sandy, gray dolostones and partly with thin-laminated calcareous shales and siltstones (Pl. 3, Fig. E). The upper part of this member is characterized by carbonate concretions embedded in argillaceous limestones (Pl. 3, Fig. B)

The fossils in this member are diverse and well preserved, including bryozoans *(Tabulipora* sp., *Stenophragmidium* sp., *Fenestella* sp.), articulate brachiopods (spiriferids, productids, etc.), rugose and tabulate corals (Pl. 3, Figs. C, D), echinoderms, bivalves, gastropods, smaller foraminifers (*Endothyra* spp., *Omphalotis* spp., *Pseudoammodiscus* sp.; Pl. 4, Figs. C, D), ostracods and trilobites. *Hexaphyllia marginata* (FLEMING) of Heterocorallia (Pl. 4, Fig. D) was noted in thin sections for the first time in Egypt (Sobhy and Ezaki, in preparation).

The upper member consists mainly of thick-bedded, cliff-forming, massive and yellowish gray dolostones (Pl. 3, Fig. F). These dolostones are characterized by gray-colored, coarse-grained, sometimes sugary dolomite crystals, containing variable amounts of silt-and sand-sized quartz grains to form sandy/silty dolostones and dolomitic sandstones. Some Carboniferous marine fauna including bryozoans, tabulate corals, crinoids and bivalves are recognized in this member.

Throughout the Um Bogma area, the maximum thickness (17 m) of the upper member was recorded from the northwestern part near Um Shebba. It decreases gradually towards the east and southeast, and is completely absent in the easternmost localities (Kora et al., 1994). The thickness of this member is 13 m in the studied section.

3. Microfacies analysis

Petrographic examination and microfacies analysis together with field observations throughout lithology, sedimentary structures and fossil contents were carried out to shed more light on the depositional conditions during the Early Carboniferous in Gabal Nukhul. All thin sections made in this work have been etched and stained by dissolving Alizarin Red S and potassium ferricyanide in a weak hydrochloric acid according to the method described by Tucker (1991) who adopted from Dickson's technique (1965, 1966).

3.1 Carbonate microfacies

The studied Um Bogma Formation consists essentially of a carbonate facies which constitutes 87.5 % of the total thickness investigated (Table 2). The modified Dunham's (1962) classification by Embry and Klovan (1971) with Folk's (1959, 1962) classification for carbonate rocks are adopted in the present work. Moreover, the proposed classification of Mount (1985) for mixed siliciclastic and carbonate sediments has been applied when necessary.

The identified facies and subfacies are compared with the Standard Microfacies Types (SMF) and Facies Zones (FZ) of Wilson (1986), and their depositional environments are interpreted as categorized by Flügel (2004) and Steinhoff and Strohmenger (1996), especially for subfacies platform environments.

3.1.1 Wackestone/packstone microfacies

This microfacies is transitional in texture between wackestone and packstone, and is affected by bioturbation. The grain-size and packing of the bioclastics vary greatly. Biomicrite subfacies could be identified belonging to this microfacies.

3.1.1.1 Biomicrite

This microfacies constitutes 11.5 % of the carbonate microfacies in the studied section. It is restricted to the upper part of the middle member of Um *Bogma Formation*. Petrographically, it is composed mainly of bioclasts (bryozoans, brachiopods, rugose corals, gastropods, echinoderms, calcareous algae and foraminifers) in addition to peloids (Pl. 4, Figs. A, B). The bioclasts are floating in black micritic and muddy groundmass and constitute about 40 % of the bulk volume (in part attaining more than 60 %). This microfacies contains a small amount of angular silt-sized quartz grains (about 5 %). The rearrangement of bioclasts in a circular pattern and the different packing of particles are attributed to bioturbation processes. The bioclasts are poorly sorted in nature ranging from silt-size (smaller foraminifers and ostracods) to coarse sand-size (bryozoans and molluscans). The roundness of bioclasts ranges from angular to subrounded, where most fossils are well preserved suggesting less reworking on the substrate.

Following Wilson (1986) and Flügel (2004), this microfacies type is interpreted to have been formed in a shelf lagoon with an open circulation and low energy environment below wave base. Bioclast contents especially calcareous algae reflect that this subfacies corresponds to SMF 8 and FZ 7.

3.1.2 Packstone/grainstone microfacies

This packstone microfacies consists mainly of poorly sorted subangular to subrounded fine to large-sized bioclasts (up to 60 %) embedded in carbonate and argillaceous matrix. Partly, these bioclasts are densely packed with sparite cement to form grainstone microfacies. It represents about 20 % of total carbonate facies and is subdivided into the following two subfacies.

3.1.2.1 Poorly washed biosparite

This subfacies attains a thickness of about 5 m from the middle member of Um Bogma Formation. Microscopically, it consists of numerous, poorly sorted and angular to subangular bioclasts embedded in dark muddy micrite to sparite matrix. These bioclasts consist mainly of bryozoans, brachiopods, molluscans, rugose and tabulate corals, heterocorals, echinoderms, smaller foraminifers, ostracods and trilobites (Pl. 4, Figs. C, D).

The concentration of bioclasts in this subfacies suggests that it was deposited and accumulated in an open platform with normal salinity and good circulation of a

Table 2 Microfacies recognized in the Lower Carboniferous (Visêan) Um Bogma Formation in Gabal Nukhul, west-central Sinai, Egypt.

Carbonate Microfacies	**I- Limestone** (constitute 87.5% of the total thickness) @*	
	Facies	**Subfacies**
	1.Wackestone/packstone (11.5%)@ (Mud-supported, > 10% grains)	1.1. Biomicrite
	2. Packstone/grainstone (20%)@ (Grain supported, < 10% mud)	2.1. Poorly washed biosparite 2.2. Poorly washed silty biosparite
	3. Grainstone (68.5%)* (Grain-supported without mud)	3.1. Oosparite 3.2. Intra-oosparite 3.3. Oo-biosparite 3.4. Sandy oo-biosparite 3.5. Silty pel-oosparite
	4. Boundstone@	4.1. Bafflestone
Clastic Microfacies	**II- Sandstone*** (12.5% of the total thickness)	- Calcareous quartz arenite
	III- Paleokarst surface *	- Paleokarst breccia

@ Partially to completely dolomitized * Completely dolomitized

well oxygenated environment, comparable to SMF 12-S (coquina composed of different shell fragments) and FZ 7 of Wilson (1986) and Flügel (2004).

3.1.2.2 Poorly washed silty biosparite

This subfacies represents the basal part (2 m thick) of the middle member of Um Bogma Formation in Gabal Nukhul. It is composed mainly of silt-to sand-sized bioclasts, representing about 60 % of the bulk volume. Bryozoans are the most abundant kind of bioclasts (Pl. 4, Figs. E, F). Rugose and tabulate corals together with brachiopods are locally abundant. Molluscans and calcareous algae occur occasionally in varying amounts; they are ordinarily absent or inconspicuous. Smaller foraminifers and ostracods represent the micro-organisms in this facies and have a wide distribution. Moderately sorted silt-sized, angular to subrounded quartz grains constitute about 10 % of this subfacies. These bioclasts and quartz grains are embedded in muddy micrite to microsparite matrix.

This poorly washed silty biosparite subfacies is characteristic of the deposits at the slope of open platform edge, comparable to SMF 12-S (coquina composed of different shell fragments) and FZ 7 of Wilson (1986) and Flügel (2004). However, the presence of silt-sized quartz grains in this subfacies indicates near-shore piling up of the sediments, variations in sediment supplies and/or sea level changes.

3.1.3 Grainstone microfacies

This common microfacies represents 68.5 % of the carbonate microfacies in the studied area. It consists mainly of well-sorted allochems (>50 %) including ooids, bioclasts, peloids and aggregated grains with sparite cement. Locally, it is characterized by fenestral fabrics and trough and/or planar cross-beddings. The grainstone microfacies is classified into five different subfacies.

3.1.3.1 Oosparite

This subfacies type constitutes the middle and upper parts of the lower member of Um Bogma Formation. Ooids are the most dominant component of this subfacies, representing about 60 % of the allochems. The ooids (0.3 to 1 mm diameter) are generally well-sorted and exhibit few concentric laminae (Pl. 6, Fig. C). Their nuclei often consist of small bioclasts (algae) and occasionally of fine sand grains. Minor constituents of this facies type are algal bioclasts commonly with micritized rims, peloids and aggregated grains.

The present oosparite grainstone subfacies is equated to the ooid shoal subfacies of Steinhoff and Strohmenger (1996), which represents shallow subtidal deposits of a moderate to elevated-energy environment. This subfacies is equivalent to SMF 15 and FZ 6 of Flügel (2004).

3.1.3.2 Intra-oosparite

The intra-oosparite grainstone subfacies (4 m thick) is restricted to the basal part of the lower member of Um Bogma Formation. The dominant component of this facies is ooids, and the subordinates are intraclasts and peloids. The other components are algal bioclasts, aggregated grains and some smaller foraminiferal tests. The size of intraclasts ranges from fine silt-size to gravel-size. These intraclasts are composed mainly of oolitic carbonate rock fragments and characterize by angular to subrounded roundness (Pl. 5, Fig. E).

The studied intra-oosparite subfacies is similar to the grainy shoal subfacies of Steinhoff and Strohmenger (1996), which were deposited in a shallow subtidal environment of moderate to elevated-energy conditions. It corresponds to SMF 15 and FZ 6 of Wilson (1986) and Flügel (2004).

3.1.3.3 Oo-biosparite

Most of the carbonate rocks of the upper member of Um Bogma Formation consist of oo-biosparite subfacies. Microscopically, this subfacies consists essentially of subangular to subrounded and moderately-sorted bioclastic fragments. The bioclasts are mainly represented by bryozoans, crinoids, calcareous algae and some tabulate corals. Other allochems such as ooids and peloids are found in variable amounts, associated with a small amount of aggregated grains (Pl. 5, Figs. C, D).

Oo-biosparite grainstone subfacies can be compared with the grainy shoal subfacies of Steinhoff and Strohmenger (1996), which was deposited in a moderate to elevated-energy shallow subtidal environment (SMF 15 and FZ 6 of Wilson, 1986; Flügel, 2004).

3.1.3.4 Sandy oo-biosparite

This grainstone subfacies is recorded from the lower member of Um Bogma Formation in Gabal Nukhul section. It consists dominantly of bioclasts (up to 40 %) and sub-dominant allochems of ooids (>10 %), with subangular to subrounded and well sorted silt-and/or sand-sized quartz grains (>10 %). The bioclasts consist mainly of calcareous algae with a small amount of rugose and tabulate corals. Peloids and aggregated grains are randomly distributed in this facies (Pl. 6, Fig. B).

This subfacies contains rich calcareous algae and shows remarkable similarities to the algal-laminated subfacies of intertidal environment (Steinhoff and Strohmenger, 1996) and SMF 15 and FZ 6 of Wilson (1986) and Flügel (2004). The algal-laminated shoal is interpreted to be indicative of proximal (landward) setting equivalent to the grainy shoal subfacies where intensively agitated water regime is developed (Steinhoff and Strohmenger, 1996).

3.1.3.5 Silty pel-oosparite

This grainstone subfacies intercalates with the calcareous quartz arenite facies at the topmost part of the upper member of Um Bogma Formation in the studied section. Petrographically, it consists of ooids, peloids and bioclasts and a small amount of aggregated grains. The ooids range in diameter from 0.2 mm to 1 mm with nuclei of silt-sized grains. Bioclasts are represented by bryozoans, crinoids and calcareous algae with a small amount of tabulate corals (Pl. 5, Fig. F; Pl. 6, Fig. A).

This subfacies corresponds to SMF 15 and FZ 6 of Wilson (1986) and Flügel (2004). It is equal to the grainy shoal subfacies of Steinhoff and Strohmenger (1996), which represents shallow subtidal deposits in a moderate to elevated-energy environment.

3.1.4 Boundstone

According to the classification of Embry and Klovan (1971), this facies is represented in the studied area by bafflestone subfacies.

3.1.4.1 Bafflestone

Locally, the tabulate corals occur in small patches of bafflestone within the grainstones of the lower and upper members as well as the wackestone/packstone and packstone/grainstone microfacies of the middle member of Um Bogma Formation (Pl. 3, Figs. A, C). This autochthonous subfacies is composed of colonial organisms including corals of *Syringopora* and *Michelinia*, in association with some bivalves, solitary rugose corals, bryozoans, calcareous algae and smaller foraminifers. The interstices of all these components are embedded in micrites and/or sparite cements (Pl. 5, Figs. A, B). An association of *in situ* tabulate corals with benthic marine organisms indicates that the deposition had taken place in a well-oxygenated and moderately to high energy environment, near the platform margin.

3.2 Clastic microfacies

The calcareous siliciclastic rocks constitute 12.5 % of the total thickness of the Um Bogma Formation in Gabal Nukhul area. These sediments were recognized at the basal part of the lower member and the middle part of upper member of Um Bogma Formation.

3.2.1 Sandstone

3.2.1.1 Calcareous quartz arenite

It is the only facies which is made up essentially of non-carbonate sediments in the studied area. Microscopically, this sandstone microfacies consists of quartz grains, representing 55-60 % of the rock volume. The quartz grains are well-sorted, fine- to medium-grained, subangular to rounded, sometimes corroded and cracked. In some cases the quartz grains are coated by carbonate layers to form pseudo-ooids. Allochems represent about 15 % of the bulk volume as bioclasts of calcareous algae and rare rugose corals. All these components are embedded in dolomitic cement (Pl. 6, Figs. E, F).

The overlying of this facies unconformably above non-marine sediments of Adedia Formation reflects the first marine transgression of the Early Carboniferous sea throughout the Um Bogma area. The association of marine macrofossils such as calcareous algae and tabulate and rugose corals together with the clastic sediments is a good indicator for the predominance of shallow marine environments.

3.2.2 Paleokarst surface

Paleokarst is an ancient karst. Humid climate favors karstification of exposed carbonate platforms during sea-level low-stands (Flügel, 2004, p.730).

The present paleokarst surface represents an erosion surface in the topmost part of the lower member of Um Bogma Formation in Gabal Nukhul section (Pl. 2, Fig. C). The Carboniferous paleokarst was recorded in the east and middle parts of the Um Bogma area by El-Sharkawi et al. (1990). They subdivided the effect of karstification processes into 1) parent carbonate horizon, 2) subsoil horizon and 3) topsoil horizon (Table 1).

3.2.2.1 Paleokarst breccia

Paleokarst breccias caused by the collapse of cave rocks and speleothem carbonates are characterized by a disorganized fabric and clast-support angular limestone clasts ranging in diameter from a few millimeters up to boulders more than several tens of centimeters (Flügel, 2004, p.730). The present paleokarst breccia represents a part of the subsoil horizon of El-Sharkawi et al. (1990). Petrographically, it consists of sand to gravel-sized angular breccias (Pl. 2, Figs. D, E) from the parent rocks of oosparite grainstone. These carbonate clasts are closely packed and cemented by dolomite, silica, ferroan sparry calcite, and dark-colored manganese and iron oxides (Pl. 6, Fig. D).

This facies forms a transitional zone between the underlying parent oosparite grainstone bed and the overlying topsoil materials. It resulted from weathering effects during subaerial exposure of the platform carbonate rocks of the lower member of Um Bogma Formation in Gabal Nukhul area. The present paleokarst is contemporaneous with that previously recorded by El-Sharkawi et al. (1990) in eastern parts of Um Bogma area. It might have been developed when the carbonate platform was exposed to weathering due to a marked drop in sea-level and/or synsedimentary block faulting (uplifting) in the studied area.

4. Diagenetic processes

Diagenetic processes, products, and sequences have been distinguished by petrographic observations and staining (Alizarin Red S and potassium ferricyanide) with checking by cathodoluminescence (CL). The diagenetic processes encountered in the studied rocks include cementation, micritization, recrystallization, dolomitization, dissolution, silicification, dedolomitization and fracturing.

Most of the fossil fragments (smaller foraminifers, ostracods, calcareous algae, etc.) are subjected to micritization process, and the skeletons are filled with ferroan and/or non-ferroan sparry calcite (Pl. 4, Fig. D). Molluscan shells are filled with non-ferroan calcite and completely replaced by ferroan sparry calcite (Pl. 4, Fig. A). Bryozoans, brachiopods, echinoderms and corals, which are characterized by well preserved original skeletal structures, are filled with ferroan and non-ferroan calcite (Pl. 4, Figs. B, E, F; Pl. 5, Fig. 1).

Two generations of cementation are clearly visible in most microfacies. In addition to the difference in crystal morphology between the two cement generations, staining shows a compositional difference. The first generation cement is an isopachous radial-fibrous non-ferroan calcite and is likely to have been a marine precipitate. The second generation of coarse, mauvey-blue stained cement is ferroan and therefore was precipitated in reducing conditions during meteoric phreatic or burial diagenesis (Pl. 4, Figs. C, E).

Two basic dolomite crystal textures of planar and non-planar (dolomite classification scheme of Sibley and Gregg, 1987) frequently replace the Lower Carboniferous limestones in the studied Um Bogma area (Pl. 5, Fig. C; Pl. 6, Fig. A). Completely, the lower and upper members are replaced by dolomites, whereas the middle member is partially to completely dolomitized. Most of the dolomitization processes are recognized as mimic (Pl. 5, Fig. E) and non-mimic (Pl. 5, Fig. D) replacements. Mimic replacement refers to preservation of the external form and internal structure of allochems or cements, whereas non-mimic replacement may only preserve the external form but not the internal structure (Sibley, 1991).

Late diagenetic dolomite cement filling vugs, fractures (Pl. 5, Fig. E), channel and breccia pores (Pl. 6, Fig. D) ranges from coarse to very coarse (up to centimeter) in dolomite crystal size and varies in color from white to pink-orange. Locally, dedolomitization is frequently observed as partial replacement of the dolomite rhombs by calcite. In some cases, the carbonate rocks of the Um Bogma Formation are subjected to silicification process in the form of authigenetic quartz grains (Pl. 6, Figs. B, D).

5. Depositional environments

The Lower Carboniferous succession of Sinai was deposited during transgressive/regressive cycles of a subtropical epicontinental sea which might have covered the northern parts of the Eastern and Western Deserts of Egypt, Western Libya and greater areas in northwestern Africa (Kora, 1995). The Visêan paleogeographic map of Webb (2002, p.243) indicates that, Egypt was situated closely to the south of the paleoequator in the continental shelf environment. The paleomagnetic direction of the Lower Carboniferous (Visêan) manganese-iron ore confirmed that Um Bogma area, west-central Sinai was located at latitude 10° south the equator in a tropical climate condition (El-Agami et al., 1999).

According to the fossil contents (bryozoans, corals, calcareous algae, molluscans, forams), ooids, peloids and aggregated grains in addition to the oxygen isotope values (Kora, 1984), the organisms of the Um Bogma Formation can be classified into chlorozoan assemblage. The corrected $\delta^{18}O$ values derived from diagenetically less altered fossils (*Saharopteria sinaitica* and *Spirifer striatus*) suggest paleotemperature of bottom water of about 25-28℃ (Jux and Omara, 1983; El-Shahat and Kora, 1988). Oolitic deposits appear to be a good paleoclimatic indicator, concentrated in the tropics and lower subtropics, but not at or very near to the equator (Flügel, 2004, p.156). Accordingly, the abundance of oolitic deposits within the Um Bogma Formation indicates that the studied Lower Carboniferous sediments of Sinai were deposited in the lower subtropics region.

At Gabal Nukhul area, the first marine transgression led to gradational lithological changes from calcareous sandstone, via sandy limestone to limestone facies. Sea-level rise resulted in the reduction of siliciclastic influx and favored carbonate deposition (Khetani and Read, 2002).

Due to sea-level changes during carbonate production, vertical subfacies transitions can be observed. The intertidal sandy oo-biosparite subfacies is gradually intercalated with intra-oosparite and oosparite subfacies of a shallow subtidal environment. Generally, the lower member of Um Bogma Formation built up a carbonate platform that is characterized by intertidal to shallow subtidal settings of moderate to elevated-energy environments above wave base. Repetitive and rhythmic vertical facies successions correspond to the changes in sea-level and result from the lateral migration of facies zones (Noack and Schroeder, 2003).

A marked drop in sea level at Gabal Nukhul section led to siliciclastic sediment influx on oolitic grainstone facies which was subjected to a period of subaerial exposure followed by karstification to form paleokarst surface accompanied by paleokarst breccia and topsoil. This drop in seal level might have resulted from synsedimentary block faulting (uplifting) in the Um Bogma area, west-central Sinai during the Early Carboniferous (Visêan) time.

The middle member's wackestone/packstone and packstone/grainstone facies of open carbonate platform overlie the oolitic grainstone facies (intertidal to shallow subtidal) of lower member throughout unconformity (paleokarst) surface. These facies contain abundant open marine fauna (including bryozoans, brachiopods, rugose and tabulate corals, echinoderms, bivalves, gastropods, smaller foraminifers, ostracods and trilobites. The juxtaposition of normal marine deposits of middle member above the unconformity surface would suggest a base-level rise due to relative sea-level rise accompanied with tectonic subsidence to various degrees.

The open marine facies of the middle member gradually changed to grainstone platform facies of the upper member. The latter facies is characterized by variable amounts of allochems including ooids, bioclasts, peloids and aggregated grains. Carbonate facies of this member were deposited in a moderate to elevated-energy shallow subtidal environment. Moreover, El-Shahat et al. (1994) suggested that the oolitic facies of the upper member of Um Bogma Formation were deposited in warm and highly agitated shallow marine environments of oolite shoals, beaches and tidal bars. The uniform stacking pattern of normal marine facies of the middle member which is commonly overlain by shallow subtidal platform facies of the upper member implies a characteristically regressive trend throughout the studied area.

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Plate 1

Fig. A: General view of the Lower Carboniferous (Viséan) Um Bogma Formation unconformably overlying the Cambro-Ordovician Adedia Formation and the Pre-Cambrian basement rocks, NW side of the Gabal Nukhul, west-central Sinai, Egypt.

Fig. B: Normal fault contact between the Upper Cretaceous (Senonian) rocks and the Lower Carboniferous Um Bogma Formation, which unconformably overlies the Cambro-Ordovician Adedia Formation and conformably underlies the Upper Viséan-Lower Namurian Abu Thora Formation, SW side of Gabal Nukhul, west-central Sinai, Egypt.

Plate 2

Fig. A: Pink-colored dolostones characterized by a fenestral fabric of the lower member of Um Bogma Formation.

Fig. B: Rugose corals (white arrows) encountered in the dolostones of the lower member of Um Bogma Formation.

Figs. C-E: Paleokarst deposits in the topmost part of the lower member of Um Bogma Formation.

C: Paleokarst features in the topmost part of the lower member (Beds No. N-8, N-9).

D, E: Close-up view of the paleokarst breccia.

Plate 3

Figs. A-C: Topmost part of the middle member of Um Bogma Formation.

A: Arrow indicates a stylolitic structure in the packstone/grainstone microfacies.

B: Calcareous concretions in the basal part of Fig. A.

C: Close-up view of a tabulate coral (*Syringopora*) in Fig. A.

Fig. D: Close-up view of a solitary rugose coral found in an argillaceous limestone bed of the middle member of Um Bogma Formation.

Fig. E: Greenish gray argillaceous limestone with thin-laminated calcareous shales and gypsum intercalations of the middle member of Um Bogma Formation.

Fig. F: Middle/upper member contact of the Um Bogma Formation.

Plate 4

Figs. A, B: Wackestone/packstone microfacies

A: Biomicrite subfacies; bioclasts (smaller foraminifers, echinoderms, brachiopod and bivalve fragments) embedded in dark muddy calcareous matrices. Stained thin section of sample no. N-15, PPL, × 25; middle member of the Um Bogma Formation.

B: Biomicrite subfacies; original wall structure of brachiopod and bryozoan skeletal fragments embedded in dark muddy calcareous matrices. Stained thin section of sample no. N-16, PPL, × 25; middle member of the Um Bogma Formation.

Figs. C-F: Packstone/grainstone microfacies

C: Poorly washed biosparite; smaller foraminifers (*Endothyra* sp.), shell fragments and peloids cemented by non-ferroan and ferroan sparry calcite. Stained thin section of sample no. N-17, PPL, × 25; middle member of the Um Bogma Formation.

D: Poorly washed biosparite; smaller foraminifers (*Endothyra* sp.), *Hexaphyllia* and shell fragments cemented by non-ferroan sparry calcite. Stained thin section of sample no. N-14, PPL, × 62.5; middle member of the Um Bogma Formation.

E: Poorly washed silty biosparite; bryozoans and silt-sized quartz grains cemented by non-ferroan and ferroan calcite. Stained thin section of sample no. N-10, PPL, × 25; middle member of the Um Bogma Formation.

F: Poorly washed silty biosparite; bryozoans, echinoderms and silt-sized quartz grains embedded in micro-sparry calcite cement. Stained thin section of sample no. N-11, PPL, × 25; middle member of the Um Bogma Formation.

Plate 5

Figs. A, B: Boundstone

A: Bafflestone; original wall structure of a tabulate coral (*Syringopora*) filled with ferroan calcite and dolomitic cement. Stained thin section of sample no. N-14, PPL, × 25; middle member of the Um Bogma Formation.

B: Bafflestone; dolomitized tabulate coral (*Syringopora*) filled with dolomite crystals. Stained thin section of sample no. N-10, PPL, × 12.5; middle member of the Um Bogma Formation.

Figs. C-F: Grainstone microfacies

C: Oo-biosparite; nonmimically replaced ooids and shell fragments cemented by planar dolomite crystals (complete dolomitization). Stained thin section of sample no. N-20, PPL, × 25; upper member of the Um Bogma Formation.

D: Oo-biosparite; mimically replaced ooids and shell fragments in mimically replaced cement (complete dolomitization). Stained thin section of sample no. N-18, PPL, × 12.5; upper member of the Um Bogma Formation.

E: Intra-oosparite; mimically replaced intraclasts and ooids in mimically replaced cement (complete dolomitization). Note the stylolitic structure in the lower part. Stained thin section of sample no. N-3, PPL, × 12.5; lower member of the Um Bogma Formation.

F: Silty pel-oosparite; silt-sized quartz grains and mimically and nonmimically replaced shell fragments, peloids and ooids in mimically replaced cement (complete dolomitization). Stained thin section of sample no. N-23, PPL, × 25; upper member of the Um Bogma Formation.

Plate 6

Figs. A-C: Grainstone microfacies (continued)

A: Silty pel-oosparite; silt-sized quartz grains and nonmimically replaced peloids and ooids in mimically replaced cement (complete dolomitization). Stained thin section of sample no. N-21, PPL, × 25, upper member of the Um Bogma Formation.

B: Sandy oo-biosparite; sand-sized quartz grains and nonmimically replaced algae and ooids in mimically replaced cement (complete dolomitization). Stained thin section of sample no. N-7, PPL, × 12.5; lower member of the Um Bogma Formation.

C: Oo-sparite; mimically replaced ooids and cement (complete dolomitization). Stained thin section of sample no. N-8, PPL, × 12.5; lower member of the Um Bogma Formation.

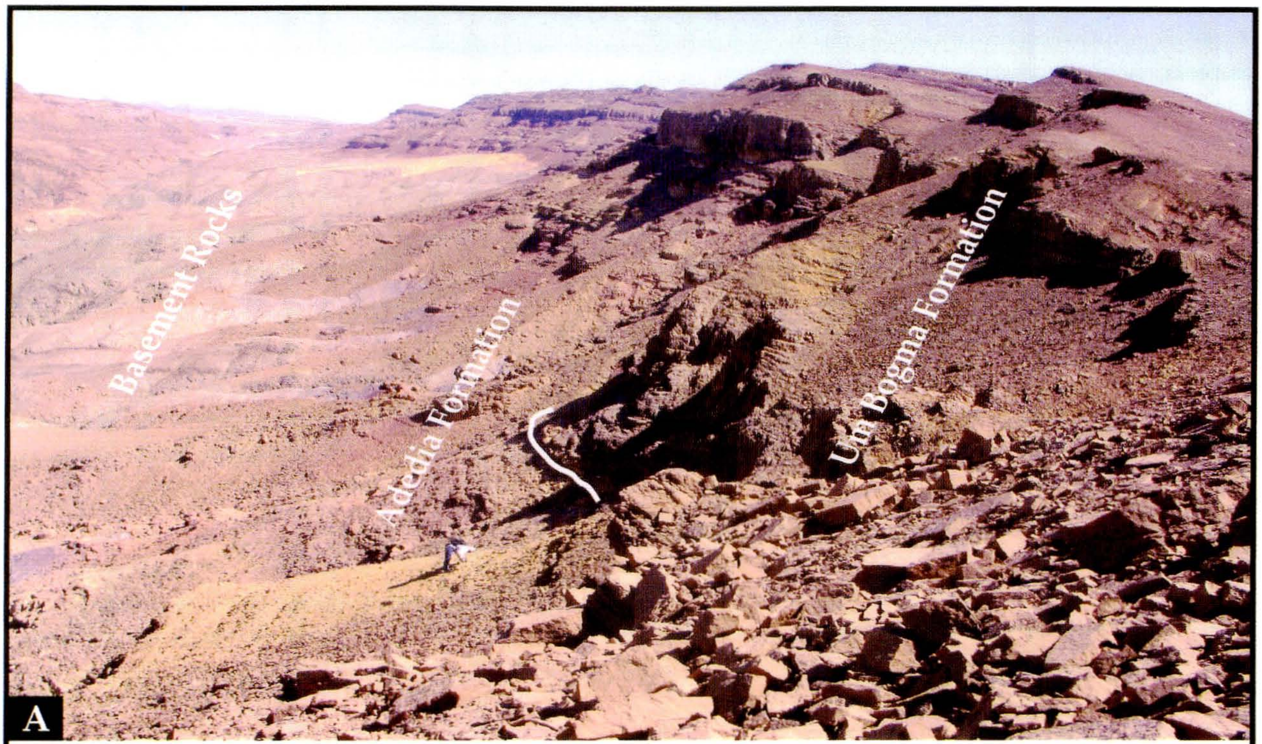
Fig. D: Paleokarst breccia; sand- to gravel-sized dolomitic breccias cemented by dolomite, silica and manganese-iron oxides. Stained thin section of sample no. N-9, PPL, × 25; topmost part of the lower member of Um Bogma Formation.

Figs. E, F: Sandstone microfacies

E: Calcareous quartz arenite; moderately sorted subangular to subrounded quartz grains with algal fragments embedded in dolomitic cement. Stained thin section of sample no. N-1, PPL, × 12.5; basal part of the lower member of Um Bogma Formation.

F: Calcareous quartz arenite; subangular medium- to fine-grained sand of quartz and ooids embedded in dolomitic cement. Some grains are coated by carbonate layers to form pseudo-ooids. Stained thin section of sample no. N-22, PPL, × 12.5; upper member of the Um Bogma Formation.

Plate 1


Basement Rocks
Adedia Formation
Um Bogma Formation
A

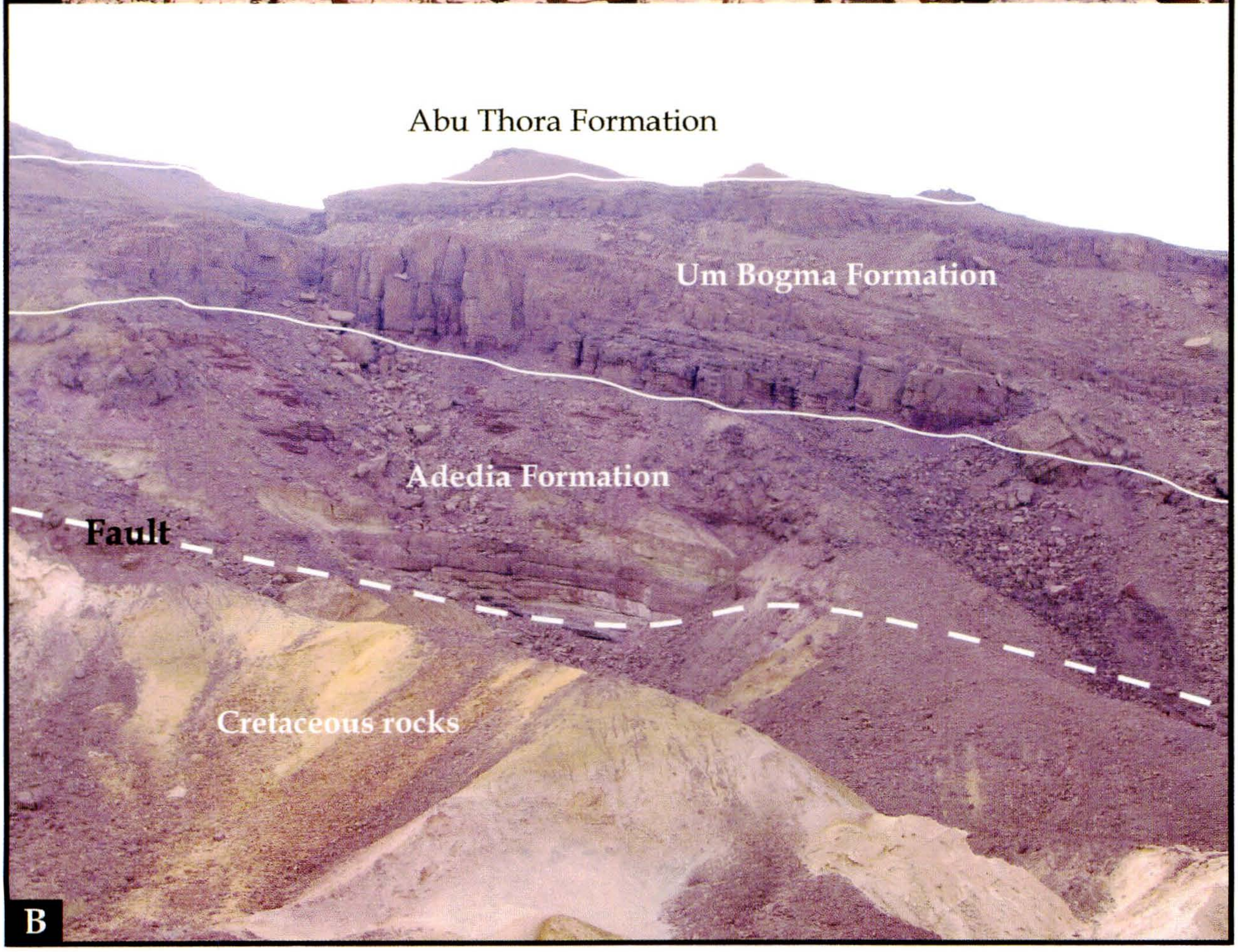

Abu Thora Formation
Um Bogma Formation
Adedia Formation
Fault
Cretaceous rocks
B

Plate 2

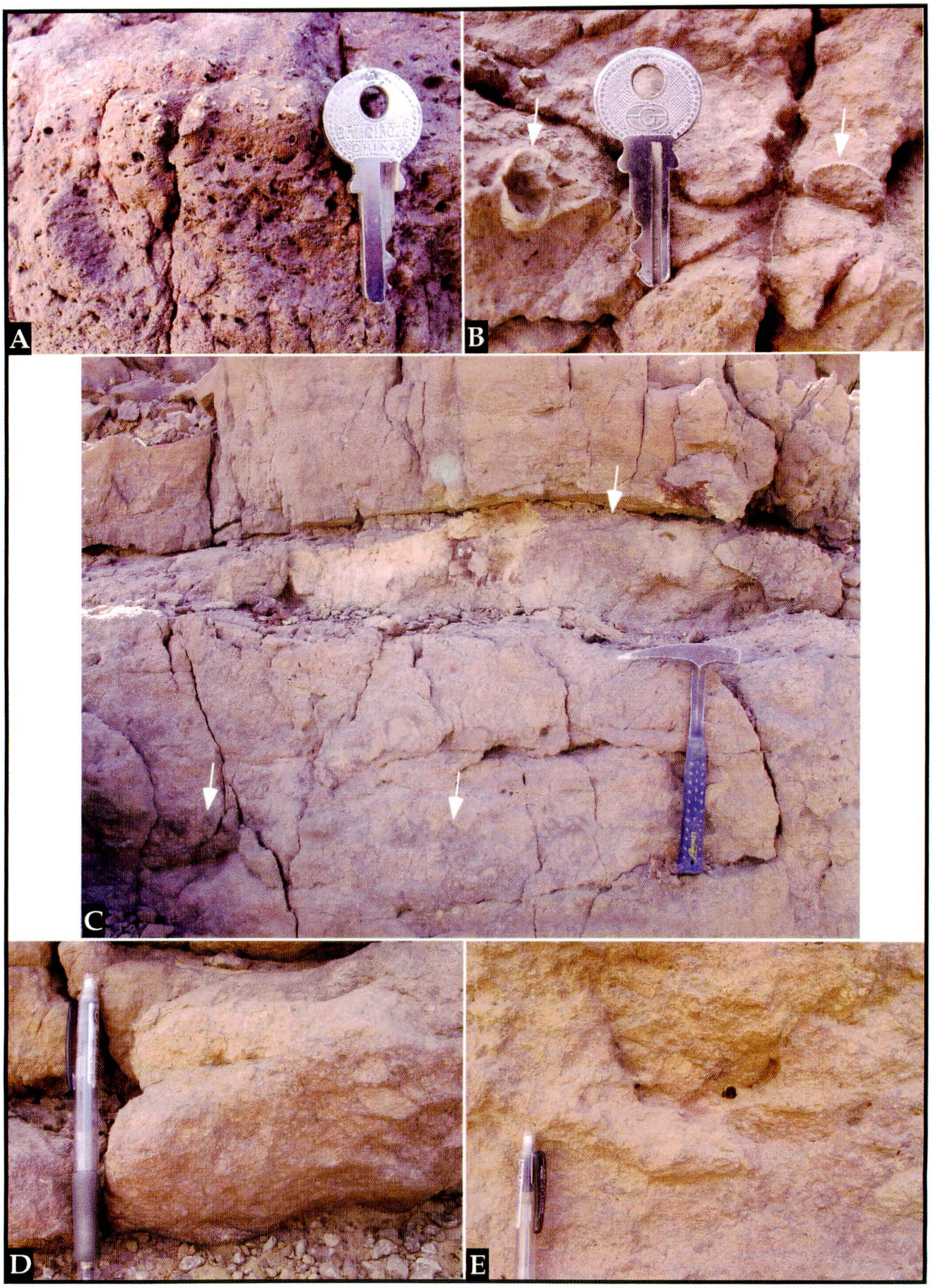


Plate 3

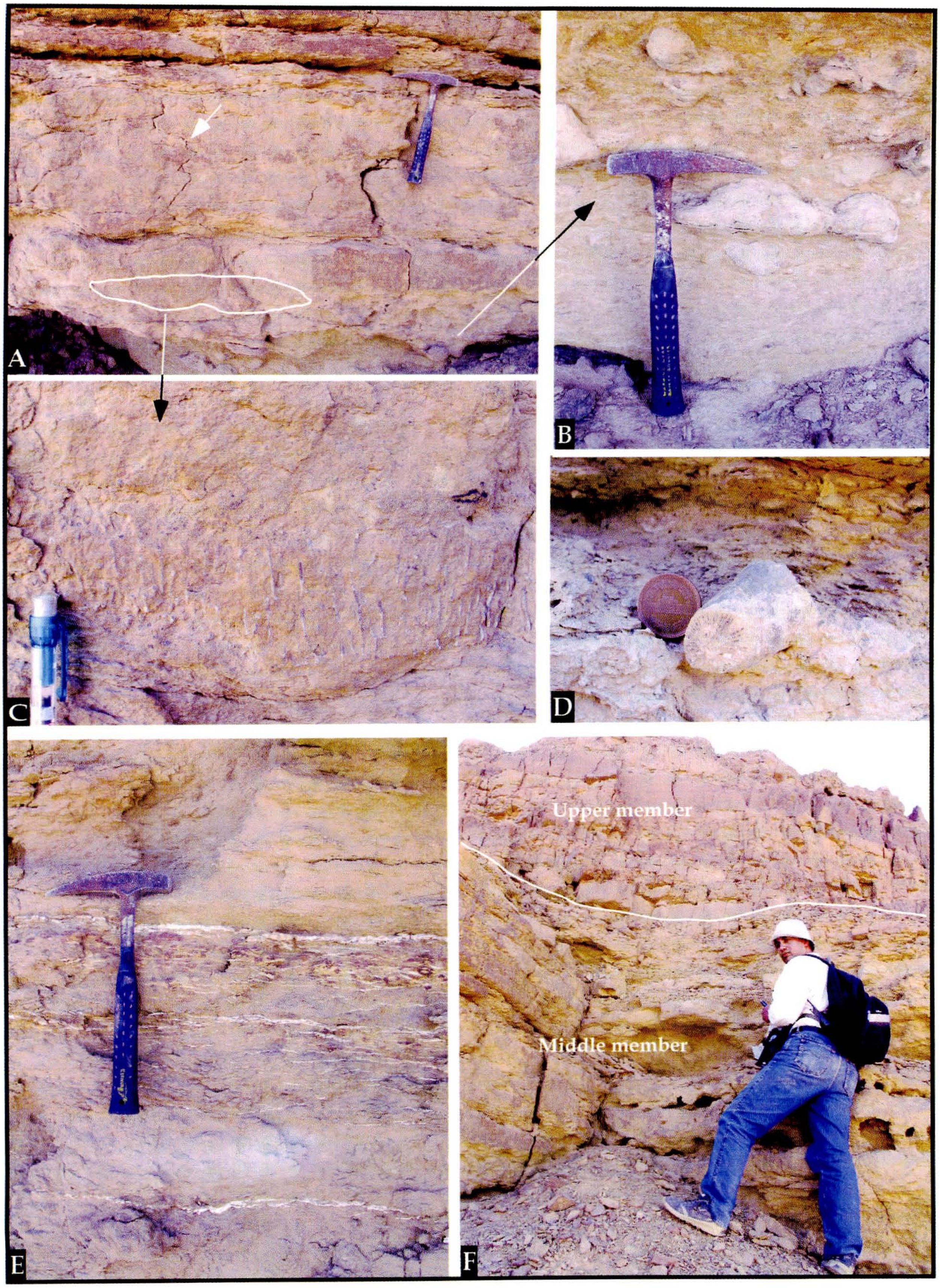


Plate 4

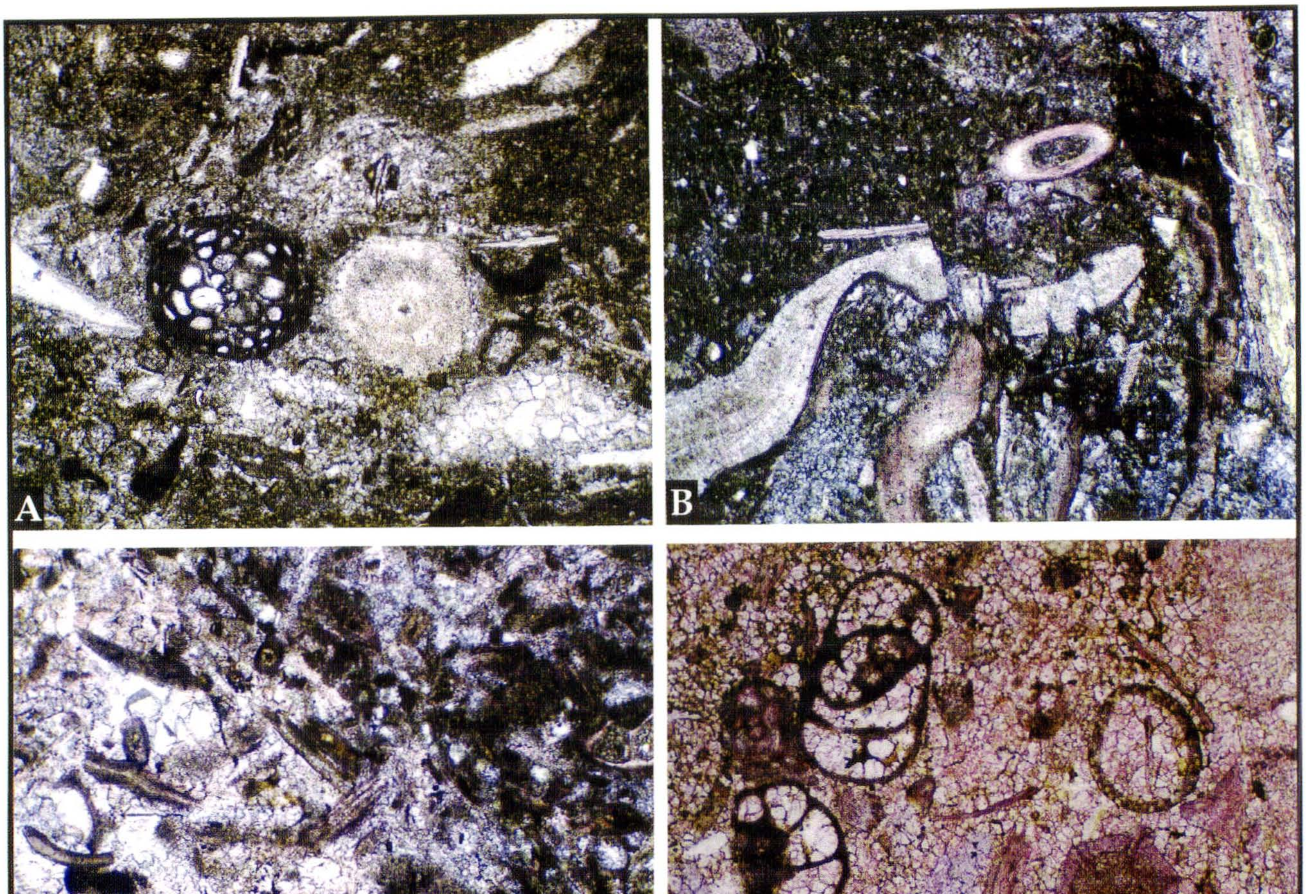


Plate 5

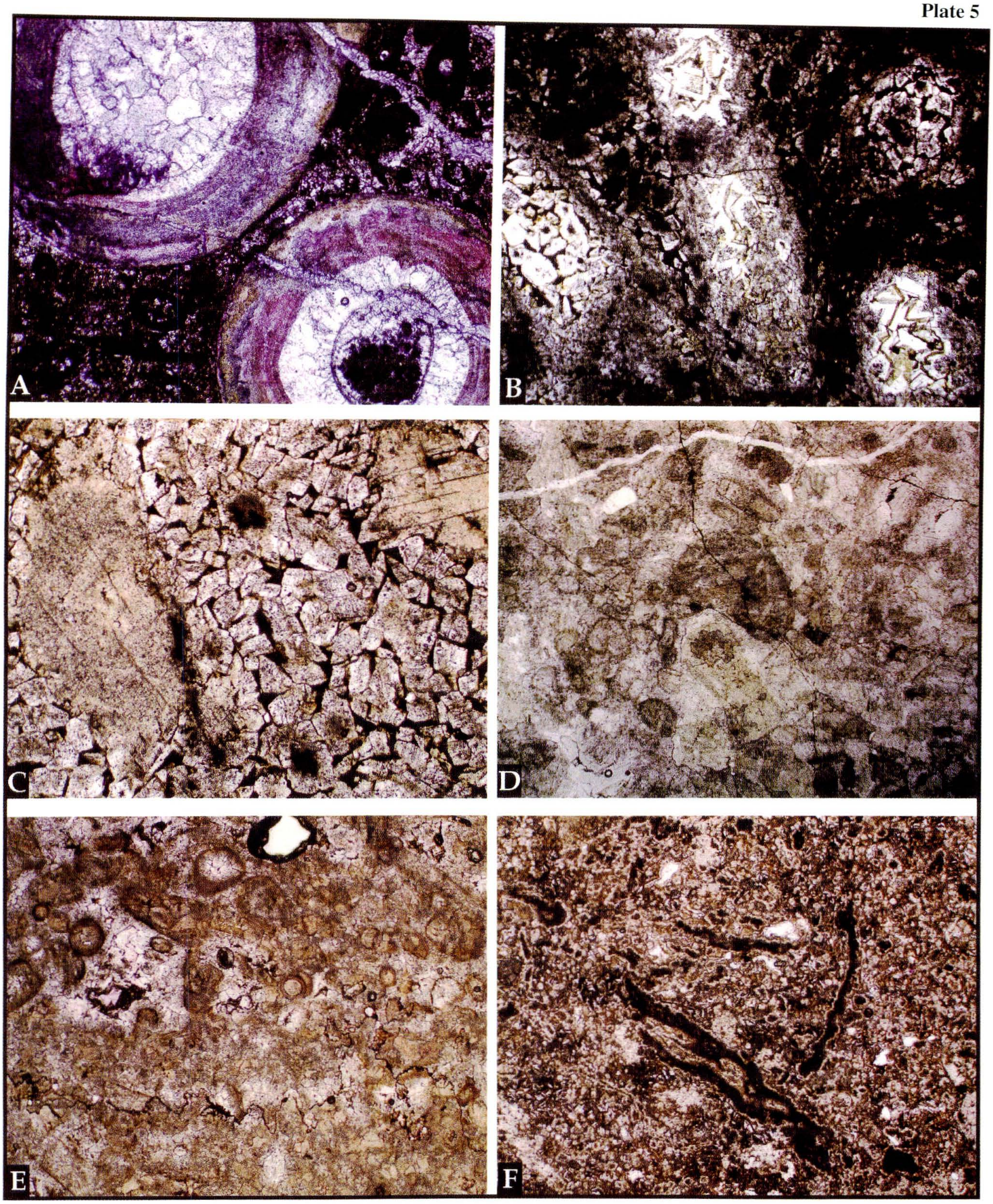


Plate 6