PETROGRAPHY AND BIOSTRATIGRAPHY OF EOCENE ROCKS IN SOUTH SAMAWA AREA, SOUTHERN IRAQ

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ABSTRACT

The petrographic and biostratigraphic study of the Eocene rocks of South Samawa indicates the existence of the two Eocene formations: Rus and Dammam. Detailed petrographic examination of the carbonate rocks of the Rus Formation has led to the distinction of one microfacies (gypsiferous bioclastic miliolidic dolowackestone) and one lithotype (fine crystalline dolostone). In Dammam Formation, three main microfacies are recognized (mudstone, wackestone and floatstone), two lithotypes (crystalline dolostone and crystalline dedolostone) and one lithofacies (claystone). Each of the microfacies is subdivided into several submicrofacies depending on the components of the rock. The carbonate rocks of the Eocene are inferred to have undergone extensive diagenetic events including dolomitization that appear to have been widespread, dedolomitization, neomorphism, micritization, dissolution and porosity developments, cementation, physical compaction and silicification. These microfacies are interpreted as having been deposited in different environments (platform margin sand shoals, open marine, shallow restricted and evaporitic platform interior). Biostratigraphically, miliolids are the common fossils recognized within the Rus Formation and assigned to the Early Eocene age and restricted environment, while the *Nummulites gizahensis – Nummulites discorbinus* assemblage zone and other associated fossils represent the Middle Eocene age of the Middle Dammam Formation with Shoal environment.

صخارية وطباقية حياتية لصخور الإيوسين في منطقة جنوب السماوة، جنوب العراق

وفاء فيليب بشير، بسمة اسعد السامرائي و رشا طالب الدليمي

المستخلص

أثبتت الدراسة البتروغرافية والطباقية لصخور الايوسين في منطقة جنوب السماوة وجود تكوينين هما الرص والدمام. وبينت دراسة الوصف الصخاري الدقيق ان تكوين الرص يتضمن سحنة دقيقة واحدة (صخور الواكي المدملته الغنية بالمليولد والمتبخرات) وسحنة صخارية واحده (الدولومايت ناعم التبلور).

وتم تمييز ثلاثة أنواع من السحنات الدقيقة الرئيسية في تكوين الدمام (الحجر الجيري الطيني، الحجر الجيري الواكي والحجر الجيري الفلوتي)، وسحناتان صخارية (الحجر الدولوماتي المتبلور والحجر غير المدملت المتبلور) وسحنه ليثولوجيه واحده (الحجر الطيني). وقسمت كل من هذه السحنات الدقيقة الى عدة سحنات ثانوية دقيقة اعتمادا على مكونات الصخور. وقد تعرضت صخور الإيوسين الكاربوناتية لعدة عمليات تحويرية شديدة تضمنت الدلمتة وهي الأكثر شيوعا في منطقه الدراسه، إعادة الدلمتة، التشكل الجديد، المكرتة، الإذابة وظهور المسامية، السمنتة، التراص الفيزيائي والسلكته.

ترسب تكوين الرص في بيئه ضحله محصوره بينما ترسبت السحنات الدقيقة لتكوين الدمام في بيئات مختلفة (حافة الرصيف الرملي الضحل، البيئة الضحلة المفتوحه، البيئه الضحله المحصورة والمتبخرات).

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واعتمادا على دراسة الطباقية الحياتية فان الميليولد هو المتحجر الشائع في تكوين الرص الذي يدل على عمر الإيوسين المبكر الذي ترسب في البيئه المحصورة بينما يمثل نطاق التجمع *Nummulites gizahensis – Nummulites discorbinus* في تكوين الدمام على عمر الإيوسين الأوسط المترسب في البيئه الضحلة.

INTRODUCTION

Two formations of Eocene age are recorded in the study borehole. These are from bottom to top; Rus and Dammam Formations. The Rus Formation was first defined by Bramkamp (1964) in Bellen *et al*. (1959) from the type section on the SE flank of the Dammam dome in east Saudi Arabia. For Iraq, a supplementary type section was introduced by Owen and Nasr (1958) in the Zubair-3 well in the Mesopotamian Zone of southern Iraq where the formation consists predominantly of anhydrite with some unfossiliferous limestone, blue shale and marl. The distribution of the formation is relatively restricted. It is developed in subsurface sections and covers the area of the Stable Shelf.

The Dammam Formation was first described by Bramkamp (1941) from the Dammam dome in east Saudi Arabia (Bellen *et al*., 1959) where it comprises limestone (chalky, organoderital or dolomitic), dolomites, marls and shales. It was divided in outcrops into five informal mapable units. In the supplementary type section in well Zubair-3 of the Mesopotamian Zone (Owen and Nasr, 1958), the formation comprises whitish grey, porous, dolomitized and locally chalky limestone. A grey green waxy shale layer often occurs near the base of the formation in southern Iraq.

The Dammam formation consists mainly of neritic shoal limestone often recrystallized and/ or dolomitized, nummulitic in the lower part and miliolids-bearing in the upper part. According to Bellen *et al*. (1959), the nummulitic limestone encountered in well sections, corresponds to the upper two biozones of the surface section. The Dammam Formation near Samawa area is divided into two units by Al-Hashimi (1974): The Nummulitic limestone unit, at the lower part and the dolomitic limestone at the upper part.

The present study includes facies analysis, diagenetic changes, fossils, biozones, age and the depositional environments of the Rus and Dammam Formations. The studied borehole BH8 is located at south Samawa the Southern Desert, at (45° 06' 15") E and (31° 29' 16") N, (Fig.1).

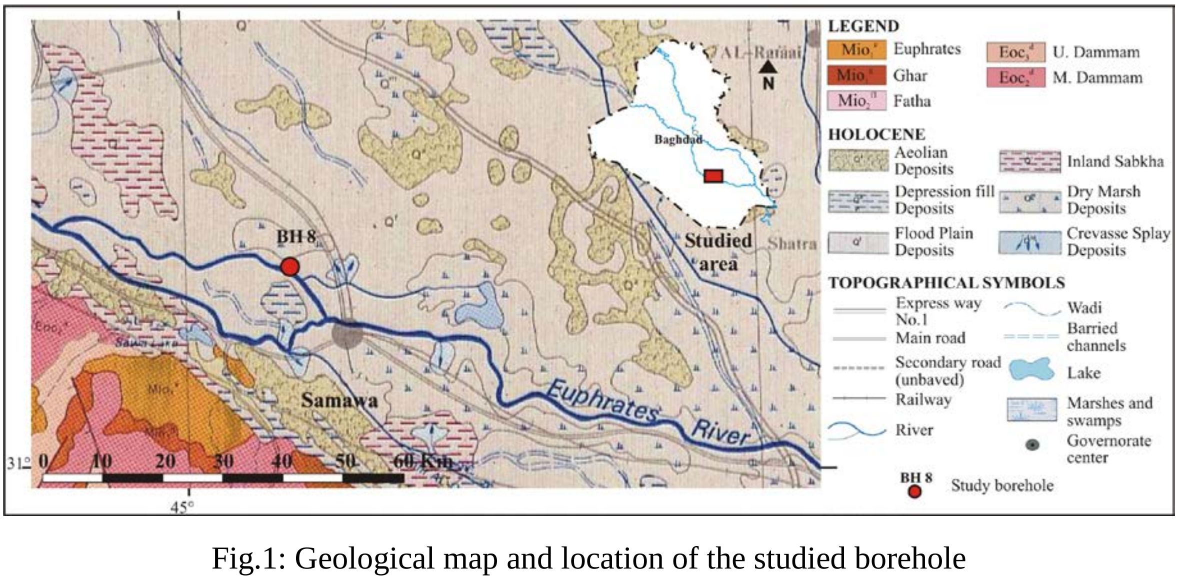

Fig.1: Geological map and location of the studied borehole
(after Sissakian, 2000)

- **Previous Work**

– Bellen *et al*. (1959) described the Dammam Formation in the type locality as shelly, chalky, recrystallized and dolomitized limestone, generally massive, with beds ranging in thickness from (1 – 2) m and found that the formation was deposited in shallow neritic environment.
– Powers *et al*. (1967, in Jassim, and Goff, 2006) assigned an Early Eocene (Ypresian) age to the Rus Formation.
– Al-Hashimi (1973) divided the Dammam Formation into 11 biostratigraphic units, comprising five larger foraminiferal assemblage zones, three planktonic foraminiferal concurrent range zones, and three benthonic foraminiferal local zones.
– Amer (1980) indicated that the sediments and the associated fauna of the Middle Dammam Formation were deposited in a neritic sublittoral forereef shoal zone of shallow warm water temperature.
– Jassim *et al*. (1984) confirmed that the Dammam Formation is partly of Late Eocene (Early Priabonian) age in SW Iraq depending on the work of Al-Hashimi (1973).
– Mazin Tamar-Agha (1984) divided the Dammam Formation in the Southern Desert into two microfacies (dolomitic clayey nummulitic biomicrudite and dolomitic clayey nummulitic micrudite), three lithotypes (fine to medium crystalline dolomite, aphanocrystalline and very fine crystalline biogenic and non biogenic dolomite and crystalline limestone) and three lithofacies (claystone, arenites and cherts).
– Al-Hashimi and Amer (1985) believed that the anhydritic rocks of the Rus Formation represent a platform evaporitic facies of a closed lagoon.

- **Methods of Work**

This study is based on forty one core samples collected from borehole no.8 drilled by GEOSURV, during the execution of the detail geological mapping in South Samawa, the Southern Desert, in 2013 – 2014. The carbonate rocks of these formations are classified after Dunham (1962) with modification of Embry and Klovan (1971) depending on the depositional texture of the rocks. Grain types as bioclasts and intraclasts may qualify this classification. The modified Dunham classification (1962) by Raymond (1995) is also adopted in this work.

The identified carbonate microfacies of the formations is compared with Standard Microfacies Types (SMF) from well known environments (e.g. Wilson, 1975 and Flugel, 2004). Depositional environments of the carbonate microfacies are discussed mostly according to their petrographic characteristic (Flugel, 2004) and also according to Al-Hashimi and Amir (1985).

All thin sections made in this work are stained with Alizarin Red S using (Friedman, 1959) method in order to differentiate between calcite and dolomite and for estimating their percentages in thin sections.

MICROFACIES, LITHOTYPES AND LITHOFACIES ANALYSIS

Two formations are encountered in the studied borehole. These are:

- **Rus Formation**

Only one microfacies and one lithotype are identified. These are:

– Gypsiferous bioclastic miliolidic dolowackestone microfacies consists of bioclasts (30%) embedded in a micrite groundmass which are completely replaced by very fine crystalline dolomite. The recorded bioclasts are *Peneroplis* sp., *Elphidum* sp., *Textularia* sp., abundant miliolids, gastropods, common pelecypods and ostracods (Fig.2A and B). The other constituent present in this microfacies is gypsum (15%) occurring as a cementing material between dolomite crystals, as granular and as fine fibrous aggregates of crystals. Nodules of anhydrite crystals (2%) are present in this microfacies as clusters of subhedral to rhombohedral crystals of anhydrite (Fig.2C). The presence of such microfacies indicates deposition in restricted circulation on a marine platform.

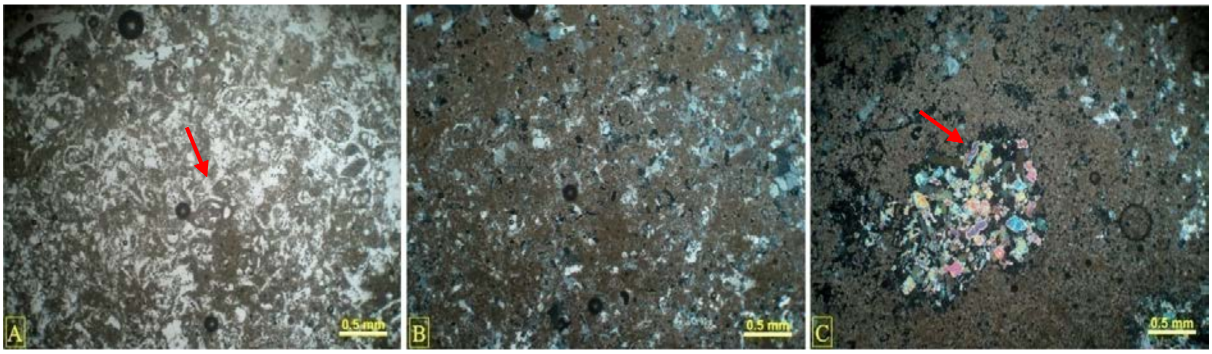

Fig.2: **A)** Gypsiferous bioclastic miliolidic dolowackestone in PPL, **B)** The same as (A) but in XPL, **C)** Nodules of anhydrite filling pores in XPL

─ Fine crystalline dolostone lithotype was originally dolomitized limestone and then replaced completely by fine crystalline dolostone. The dolomite crystals are mostly rhombohedral to slightly euhedral in shape (Fig.3). Some of the crystals show zoning. Ghosts of bioclasts are observed in this lithotype. This lithotype includes traces of pyrite and anhydrite occurring as inclusions within gypsum crystals. Gypsum crystals (1%) are present as radial, long euhedral to rhombohedral filling vugs and intercrystalline between dolomite and occurring as single and as grouped in clusters.

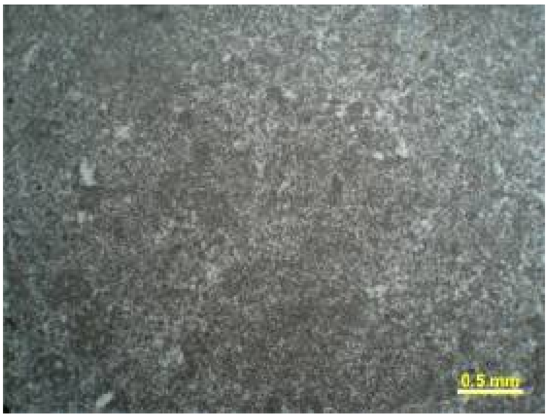

Fig.3: Fine crystalline dolostone

This lithotype is considered to be deposited in a shallow marine environment of relatively high salinity.

- **Dammam Formation**

The major identified microfacies of this formation are mudstone, wackestone and floatstone. Each type consists of several submicrofacies depending on their components.

─ **Mudstone microfacies:** It consists mainly of micrite as groundmass with fossils <10%. This microfacies is divided into the following submicrofacies:

- Dolomudstone. The groundmass consists of micrite, completely replaced by very fine to fine dolomite (Fig.4). The dolomite crystals are present as rhombohedral to slightly euhedral forms, some of which have inclusion of black materials and others with zoning. This submicrofacies are related to SMF23 which was deposited in tidal flat (FZ8) and evaporitic coasts (FZ9A) as categorized by Flugel (2004).

- Biomoldic dolomudstone. It consists of bioclasts (<10%) floating in a micritic groundmass completely replaced by very fine rhombic dolomite (Fig.5). The bioclasts are badly preserved as a result of severe dolomitization and remains as ghosts and biomolds. These molds are thought to represent the space left by most of the completely dissolved fossils (pelecypods and nummulites-shaped molds). Other bioclasts present in trace amount are ostracods, algae and echinoid spines. This submicrofacies is deposited in a restricted environment (FZ8).

- Intraclastic dolomudstone and gypsiferous intraclastic dolomudstone. It consists of intraclasts (2 – 3%) and traces of bioclasts embedded in a micritic groundmass completely replaced by very fine rhombic dolomite. The intraclasts are anhedral in shape (Figs.6A and B) consisting of aphanocrystalline dolomite and ranging in size from medium to coarse (0.25 – 0.95) mm.

The recorded bioclasts are miliolids, rotallids, algae and biomolds of pelecypods. This submicrofacies consists of subrounded to rounded quartz grains (2%) indicating eolian sediments. Their size ranges from silt to coarse sand (0.06 – 0.5) mm. This submicrofacies indicates deposition in restricted shallow marine environment. In few samples, secondary gypsum (10%) is found filling the pore space between dolomite crystals.

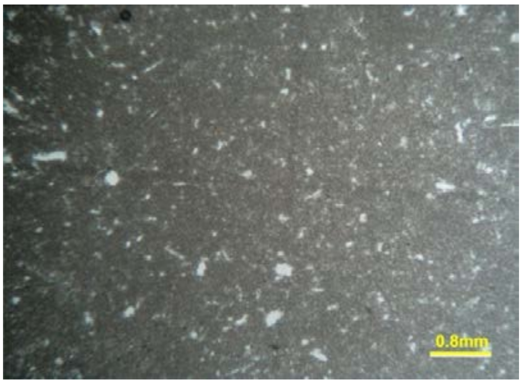

Fig.4: Dolomudstone

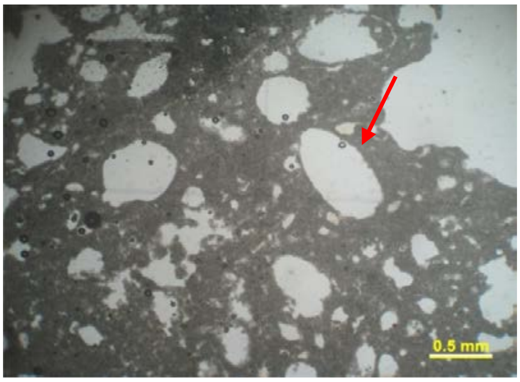

Fig.5: Biomoldic dolomudstone

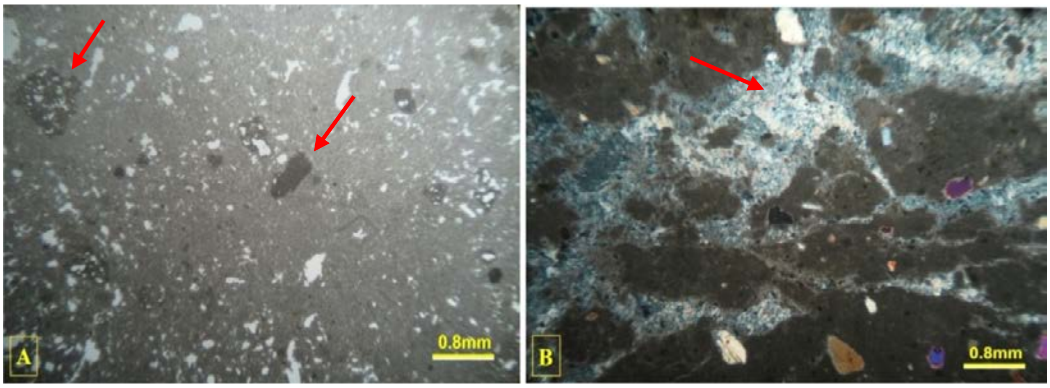

Fig.6: **A)** Intraclastic dolomudstone in PPL, **B)** Gypsiferous intraclastic dolomudstone in XPL

− **Wackestone microfacies:** This microfacies consists of micrite as groundmass with fossils >10%. Only one submicrofacies is recognized. It is:

– Intraclastic dolowackestone which consists of intraclasts (15%) embedded in a micritic groundmass and completely replaced by very fine dolomite. The intraclasts are composed of aphanocrystalline dolomite, crystalline limestone and microsparite. They are anhedral in shape (Fig.7). Traces of miliolids are present in this submicrofacies. Such submicrofacies occurred in a restricted environment with high salinity.

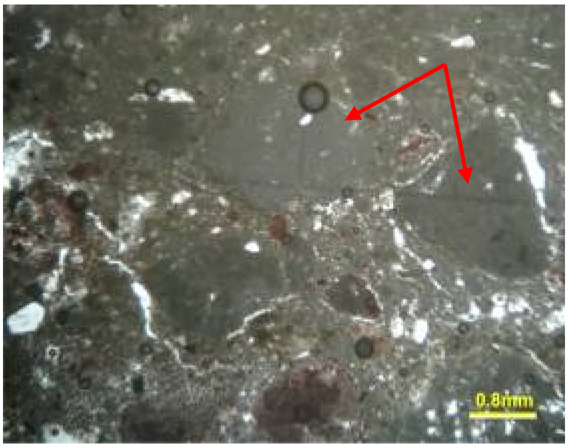

Fig.7: Intraclastic dolowackestone

− **Floatstone microfacies:** This microfacies consists of >10% grains of more than 2 mm in size embedded in a micritic groundmass (Embry and Klovan, 1971). Two submicrofacies are recognized depending on the percentages of the mineralogical and textural components. These are:

– Dolomitic nummulitic bioclastic floatstone. The groundmass of this submicrofacies consists of microsparite (4 – 10) µ, formed by the recrystallization of micrite (<4µ), admixed with clay materials (5%) and partially replaced by fine to medium rhombic dolomite (10% – 20%) and selectively by rhombic calcite (2%). Bioclasts (45%) are mostly calcitic in composition including *Nummulites bayhariensis*, *Nummulites gizehensis*, *Linderina* sp., *Rotalia* sp., *Coskinolina* sp., *Rhapydionina* sp., *Peneroplis* sp., echinoderm plates, algae, uniserial forams and shell fragments (Fig.8A and B). This submicrofacies is deposited in open marine environment (Flugel, 2004).

– Calcareous bioclastic nummulitic dolofloatstone. It is characterized by the presence of calcitic bioclasts (45%) embedded in a dolomite groundmass consisting of fine to medium crystals of dolomite (0.02 – 0.1) mm and mostly rhombohedral to slightly euhedral in shape. Few of the crystals have zoning and dark centers. The bioclasts consist of abundant *Nummulites gizehensis*, *Nummulites bayhariensis*, *Linderina* sp., *Coskinolina* sp., echinoid spines, shell fragments and bryozoa (Fig.9A and B).

This submicrofacies is deposited in shoal environment as indicated by the accumulation of large nummulites (Al-Hashimi, 1985) and (Flugel, 2004).

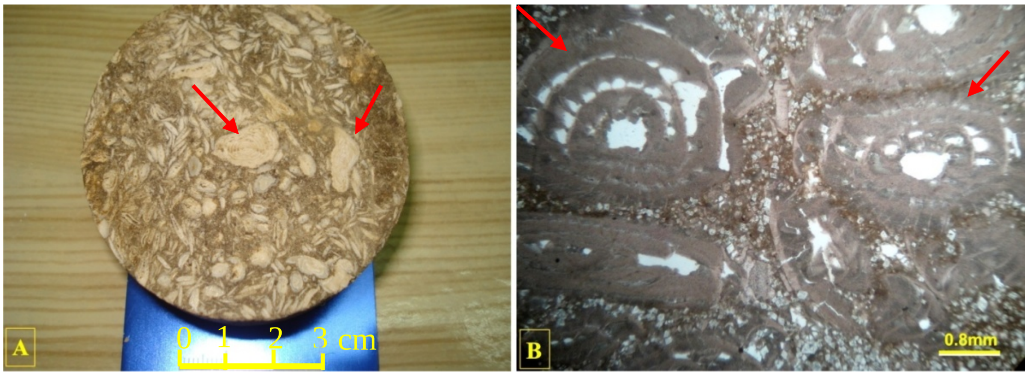

Fig.8: **A)** Core sample showing abundant nummulites, **B)** Dolomitic bioclastic nummulitic floatstone in PPL

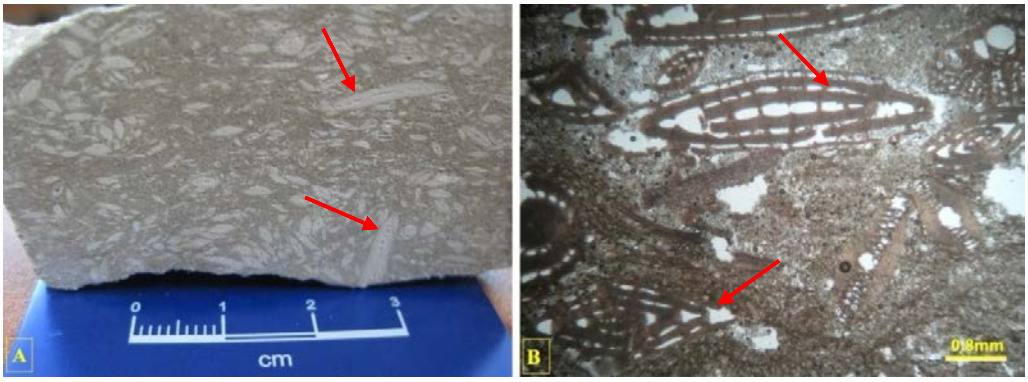

Fig.9: **A)** Core sample showing nummulites and shell fragments, **B)** Calcareous bioclastic nummulitic dolofloatstone in PPL

– **Crystalline dolostone lithotype:** This lithotype was originally bioclastic lime mudstone and then replaced completely by crystalline dolostone. The dolomite crystals are mostly rhombohedral to euhedral in shape and ranging in size from fine to medium (0.02 – 0.12) mm (Fig.10). Some of the dolomite crystals show zoning and others have inclusion of black materials. This lithotype contains relict allochems ghosts that are either completely dolomitized or leached to form moldic pores representing by biomolds of nummulites and pelecypods. Echinoid spines, algae and echinoderm plates are also observed in some rocks. Few samples contain traces of phosphoclasts including bioclasts and intraclasts and traces of clay as filling of the pore space between dolomite crystals. This lithotype is considered to be deposited in shallow restricted environment with relatively high salinity.

Fig.10: Crystalline dolostone

─ **Crystalline dedolostone lithotype:** Calcite forms the main constituents (90 – 100%) occurring as fine interlocking rhombohedral crystals (pseudomorphs after dolomite) and coarse to very coarse crystals poikilotopically enclosing finer crystals (0.03 mm) of rhombic calcite (Fig.11A). This lithotype was originally bioclastic dolomudstone and then replaced completely by crystalline limestone (dedolomitization). The textural criteria for reorganizing dedolomitization are the presence of relicts of dolomite within recrystallized calcite, rhombic calcite pseudomorphs after dolomite, the presence of poikiliotopic texture and the presence of biomolds and ghosts of fossils within recrystallized calcite (molds of nummulites and shell fragments) (Fig.11B). This lithotype may be indicative of subaerial exposure.

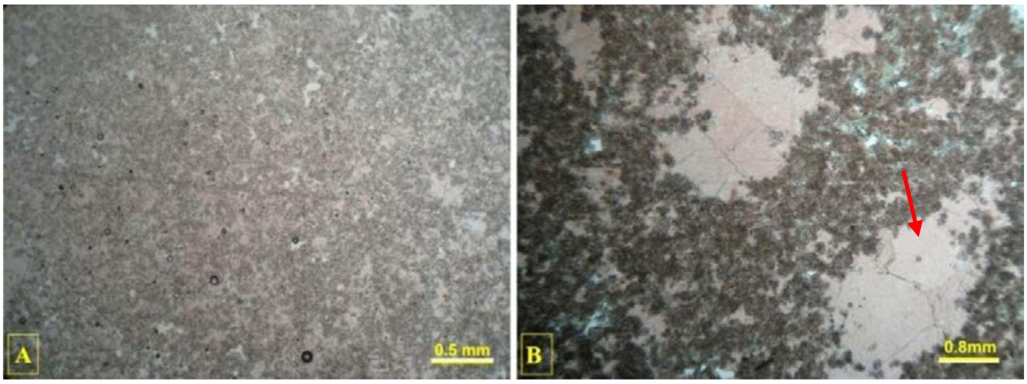

Fig.11: **A)** Crystalline dedolostone showing rhombic calcite in PPL, **B)** Crystalline dedolostone showing molds of nummulites in XPL

─ **Claystone and dolomitic claystone lithofacies:** This lithofacies represents the contacts between Rus and Dammam Formations at a depth of 107.4 m. It contains rhombic and fine crystals of dolomite (2 – 15%) floating in the clay matrix (85% – 99%) (Fig.12 A and B). Some of the crystals show zoning. Few of quartz grains of silt to very fine sand size and traces of pyrite are present within this lithofacies. Celestite crystals are observed in some samples as euhedral to rhombohedral and rarely subhedral in shape. This lithofacies indicated deposition in restricted environment (intertidal). The distribution of the microfacies, lithotypes and lithofacies within the examined lithological subsurface section is shown in figure (13).

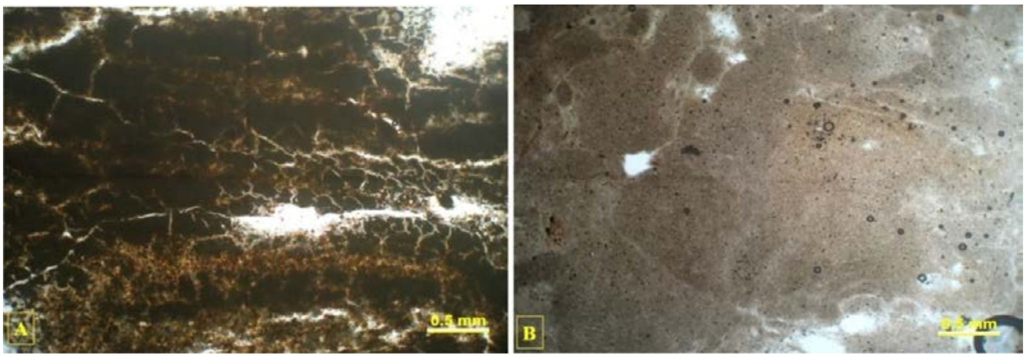

Fig.12: **A)** Claystone, **B)** Dolomitic claystone

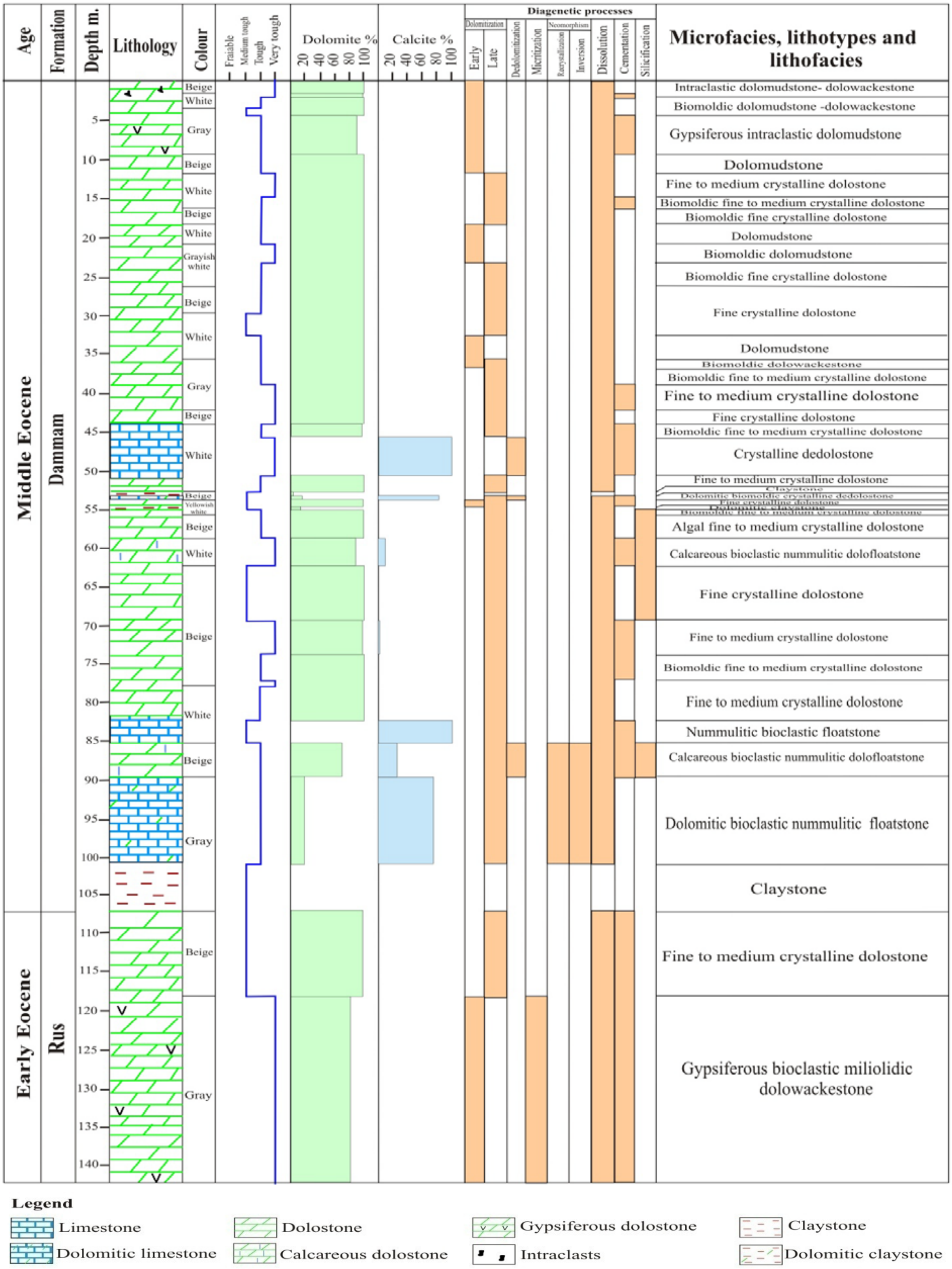

Fig.13: Lithological column of borehole no.8 illustrating the distribution of dolomite and calcite, diagenetic processes, microfacies, lithotypes and lithofacies

- **Diagenetic processes**

The diagenetic processes and products are distinguished by petrographic observations and staining of thin sections. The diagenetic processes encountered in the studied rocks include dolomitization, dedolomitization, neomorphism, micritization, dissolution and porosity developments, cementation, physical compaction and silicification reflecting different environments. Each process is discussed below:

- **Dolomitization**

Two types of dolomitization are observed:

— **Microdolomitization** (Early dolomitization)**:** This process is the dominant type and confirmed by the presence of very finely crystalline dolomite that is completely or partially replaced micritic matrix and fossils (Fig.14A).

— **Pervasive dolomitization** (Late dolomitization)**:** It is indicated by the presence of fine to medium (0.02 – 0.12 mm) crystalline dolomite. These crystals are anhedral to mostly rhombohedral and euhedral in shape, having inclusion of black materials and some of them show zoning (Fig.14B). The presence of subhedral to euhedral and zoned crystals of dolomite suggest a major, probably long- lasting dolomitization event during marine-meteoric mixing zone environment under low temperature and pressure (Chafetz, 1972).

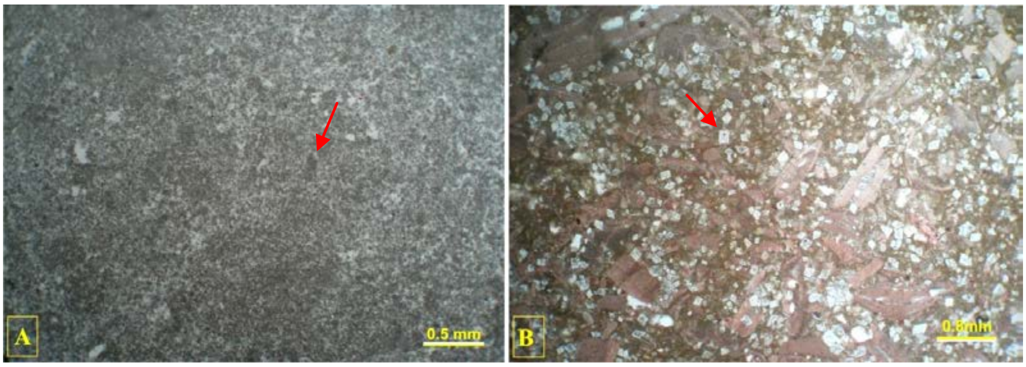

Fig.14: **A)** Early dolomitization, **B)** Late dolomitization affected groundmass

- **Dedolomitization**

This process is common in the rocks of this subsurface section. It is the diagenetic replacement of dolomite either partially or completely by calcite to produce a limestone again. The petrographic evidence for dedolomitization is the presence of rhombic calcite within groundmass as shown in figure (11A). Dedolomitization is widely accepted as a surface or near surface phenomenon resulting from the interaction between sulphate-rich solution and dolomite.

- **Neomorphism**

The effect of this process on the rocks of the studied borehole is limited. This process involves recrystallization (transformation of calcite to recrystalized calcite) and inversion (transformation of aragonite to calcite).

— Recrystallization processes in this study are mostly of aggrading type in which coarse crystals grow at the expense of the finer crystals (Fig.15A). This process is indicated by the presence of microsparite (4 – 10 µ). Longman (1977) suggested that the main factor affecting microsparite formation is the Mg ions when these are expelled from high Mg calcite and located around micritic matrix. He thought that if the Mg ions are removed by flushing with meteoric water, then the micritic matrix will become free to grow to microsparite and sparry calcite.

– Inversion is the gradual replacement of aragonite by calcite through solution and in-situ precipitation in an aqueous environment. It is indicated by the preservation of the original aragonitic fossils by radial calcite. In the Dammam Formation, this process has affected the floatstone microfacies (Fig.15B). This process may occur in freshwater phreatic environment (Longman, 1980).

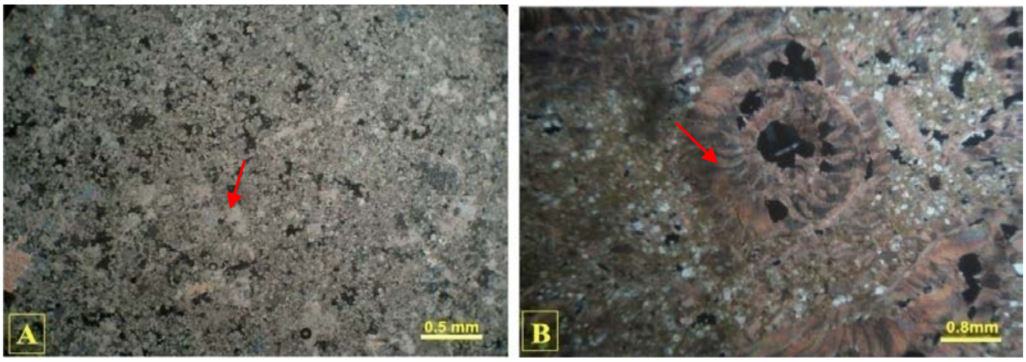

Fig.15: **A)** Recrystallization affected groundmass and fossils, **B)** Inversion affected nummulite

- **Micritization**

This process occurs in Rus Formation. It is the first diagenetic alteration producing a micritic envelope around skeletal grains that originally composed of aragonite and/ or high Mg calcite. *Peneroplis* sp. and miliolids are the most noticed fossils affected by this process (Fig.16).

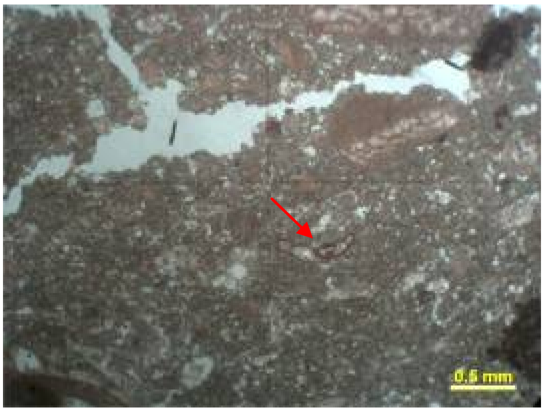

Fig.16: Micritization

- **Dissolution and porosity development**

This process is gained through solution and dolomitization and reduced through cementation. It is the most extensive and dominant diagenetic processes in the study subsurface section and is divided into two main groups according to Choquette and Pray (1970). These are fabric selective pores and non-fabric selective pores.

The Fabric-selective pores, is controlled by the components of the original rock. These pores are of several different types:

– **Intraparticle porosity:** This type of porosity is developed within individual particles or grains, particularly within the chambers of skeletal fragments (Fig.17A). This type of solution is formed under the influence of meteoric phreatic and meteoric vadose environments.

– **Moldic porosity:** This is caused by solution of whole fossils (biomoldic). Most of the shells in the studied borehole are dissolved forming moldic porosity as metastability of aragonite (Fig.17B). This type of porosity is widespread in shallow marine carbonate and commonly occurs in meteoric-phreatic environment (James and Choquette, 1983).

— **Intercrystalline porosity:** These pores are developed between dolomite crystals. The intercrystalline porosity has resulted most likely from dolomitization, which caused an increase of pore space when limestone changes to dolomite (Fig.17C).

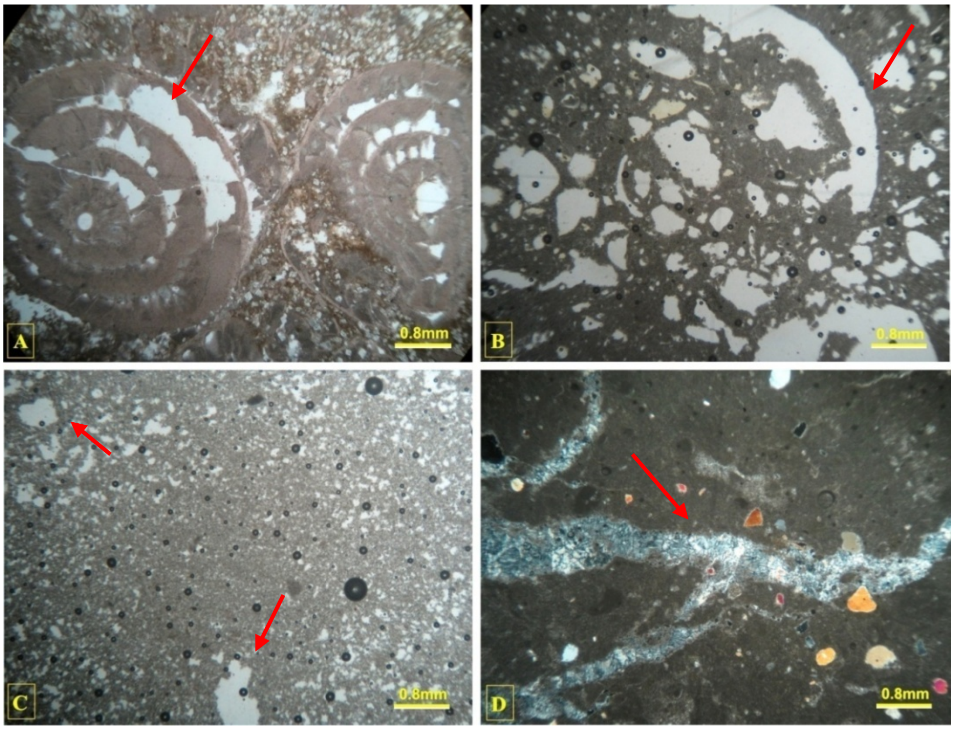

Fig.17: **A)** Intraparticle porosity, **B)** Moldic porosity, **C)** Intercrystalline porosity, **D)** Fractures filled with secondary fibrous gypsum cement

The non fabric selective pores occur where the pores are developed independent of original textures. Two types are recognized. These are:

— **Vuggy porosity:** These pores are extremely irregular with no definite shape. Most vugs represent solution enlargement of fabric selective pores.

— **Fractures and veins:** These types of porosity are mostly common in dolomudstone, gypsiferous intraclastic dolomudstone and biomoldic fine crystalline dolomite as shown in figure (17D). It may be formed through pressure solution.

- **Cementation**

The following types of cement are recognized calcite, dolomite and gypsum. The calcite cement is recognized in three types:

— **Granular sparry calcite:** It is the most common type of cement in the study subsurface section. Granular calcite cement occludes extensive pores, vugs and biomolds in different facies and characterized by the presence of clear subhedral to anhedral crystals without a distinct direction for their growth (Fig.18A). This type of cement can be precipitated in several diagenetic environments and over a long period, usually in meteoric vadose and meteoric phreatic.

— **Blocky calcite:** It consists of medium to coarse crystals without a preferred orientation (Fig.18B). It occurs inside molds and vugs. This process represents freshwater phreatic zone (Longman, 1980).

― **Poikilotopic calcite cement:** This cement develops after the pervasive dolomitization and development of intergranular cements. In this type of cement, coarse crystals enclose fine and rhombic crystals of calcite and dolomite (Fig.18B). It develops in phreatic environment commonly in burial diagenetic settings.

The dolomite cement is shown in two types in the studied borehole. These are:

― **Isopachous rim dolomite:** This type of cement is characterized by dolomite rim cement growing with equal thickness within the molds of dissolved fossils and consisting of microcrystalline dolomite. From the above observations, it is suggested that cementation accompanied dolomitization, with dissolution of the bioclasts taking place at an earlier stage (Fig.18C).

― **Granular dolomite cement:** Some vugs and biomolds are found to be filled with medium to coarse subhedral to rhombohedral clear dolomite crystals (Fig.18D).

The gypsum cement occurs as very fine fibrous aggregates (Fig.18E) and granular gypsum (Fig.18F) filling the pore space between dolomite crystals as in gypsiferous bioclastic miliolidic dolowackestone, intraclastic dolomudstone, gypsiferous intraclastic dolomudstone and intraclastic dolowackestone submicrofacies and fine crystalline dolostone lithotype.

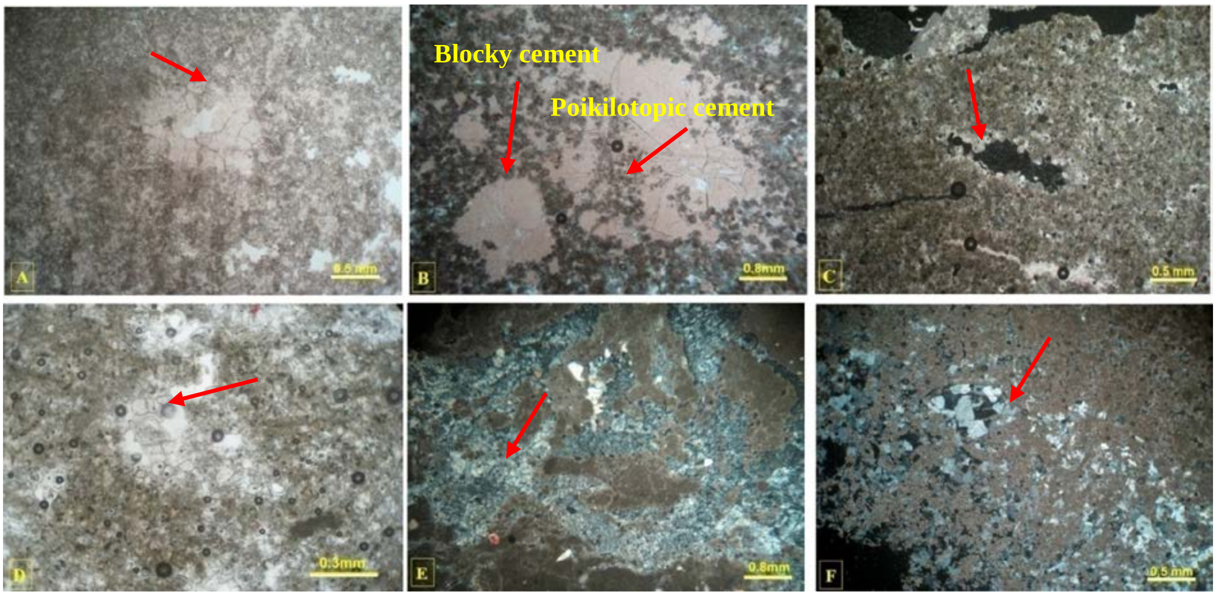

Fig.18: Common types of cementation occurring in different facies
A)Granular calcite cement, **B)** Blocky and poikilotopic calcite cement, **C)** Isopachous rim dolomite cement, **D)** Granular dolomite cement, **E)** Fine fibrous aggregates of gypsum, **F)** Granular gypsum filling pores

- **Silicification**

This process involves replacement of carbonate by silica. The silicification is minor and affected only few shell fragments in the Dammam Formation (Fig.19). The appropriate chemical conditions to dissolve calcite and precipitation of silica include supersaturation of pores solution by silica and decrease of pH and temperature (Blatt *et al*., 1972).

- **Physical compaction**

This process is very limited in the study borehole, noticed only in calcareous bioclastic nummulitic dolofloatstone and dolomitic bioclastic nummulitic floatstone submicrofacies. This process normally occurs after shallow burial in the subsurface. The evidence of physical compaction is observed in the presence of fossils oriented parallel to the bedding (Fig.20).

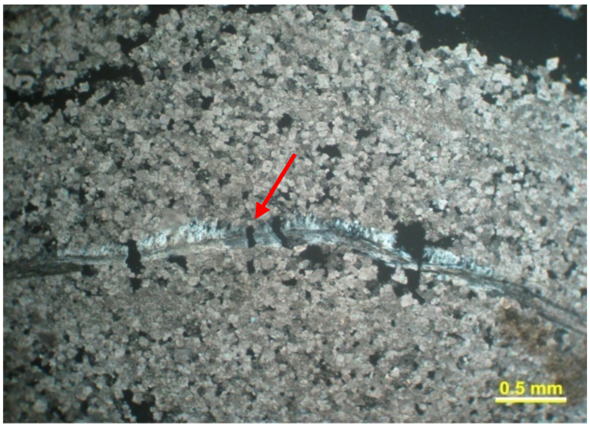

Fig.19: Silicification affected shell fragments

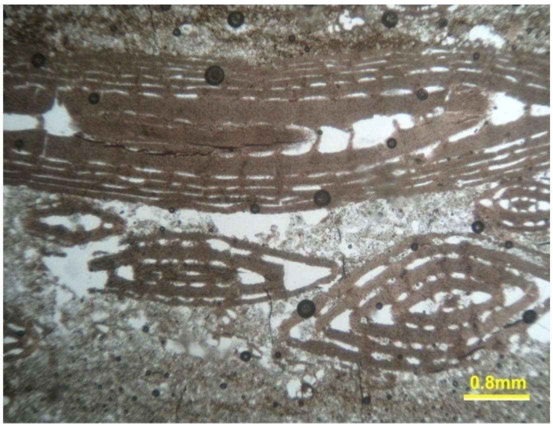

Fig.20: Physical compaction showing oriented fossils

BIOSTRATIGRAPHY

In this study, two formations are recognized.

- **Rus Formation**

The Rus Formation represents the oldest rock unit recognized in the studied borehole (Fig.23) with 23.4 m thickness and recorded at depth (141.7 – 118.3) m.

— **Fossils and Age:** Bellen *et al*., (1959) followed by Al-Hashimi (1972, 1973 and 1974) have correlated the Rus Formation with the Dammam surface units of Wagsa, Schbicha, Sharaf and Huweimi (chalky) Beds and confirmed that these formations are of Early Eocene age. In addition, Sander (1962) in Munien (1983) considered the age of the formation in its type locality at Saudi Arabia as Early Eocene. Munien (1983) recorded the formation from KH-2 at Umm Er Radhuma interfingers with lower part of Dammam Formation (Early Eocene). According to Al-Hashimi and Amer (1985), the age of the formation is Middle Paleocene – Early Eocene. In our study, miliolids are the common fossils recognized in the Rus Formation and as such assigned an Early Eocene age for this formation.

- **Dammam Formation**

In the studied borehole, the Middle Member of the Dammam Formation (106.4 m thick) is recorded from depth (107.4 – 1.8) m consisting of dolostone, limestone, dolomitic limestone, nummulitic limestone, calcareous dolostone and claystone (Fig.23).

— **Fossils:** The Middle Member of Dammam Formation is characterized by the presence of *Nummulites gizehensis – N. discorbinus* Zone, which is marked by the first appearance of excellent index fauna, *Nummulites gizehensis* DE LA HARPE (Fig.23); and other associated fauna like:

Nummulites gizehensis zeitteli DE LA HARPE (Fig.21A), *N. discorbinus* (SCHLOTHEIM) (Fig.21B), *N. perforatus* (MONTFORT) (Fig.21C), *N. elevata* (AL-HASHIMI AND AMER) (Fig.21D), *N. bayhariensis* CHECCHIA- RISPOLI (Fig.21E), *N. millicaput* BOUBEE

(Fig.21F), *N. planulatus* (LAMARCK) (Fig.21G), *N.* sp. (fragments), *Alveolina* sp. (Fig.22A), *Linderina chapmani* HALKYARD (Fig.22B), *Lockhartia alveolata* SILVESTRI (Fig.22C), *Textularia* sp. (Fig.22D) , *Coskinolina balsilliei* DAVIES (Fig.22E), *Rotalia trochideformis* (Fig.22F), *Linderina brugesi* SCHLUMBERGER (Fig.22G), echinoid plate (Fig.22H), echinoid spines, miliolids, ostracoda, algae, and shell fragments.

– **Age:** The above fossil assemblage is more closely similar to the Middle Eocene fossils (Upper Lutetian) in the supplementary type sections in Iraq such as Al-Hajara section, SW Iraq, in well Zubair No.3 section (subsurface section) southern Iraq in Samawa area (Bellen *et al*., 1959; Al-Hashimi, 1972, 1973, 1974; and Jassim *et al*., 1984). The *Nummulites gizehensis* Zone is correlated with the Middle Eocene the *Nummulites gizehensis* Zone (in part) of Iran (Sampo, 1969). The age of the Middle Member of the Dammam Formation is Middle Eocene since it contains large foraminifera such as *Nummulites*, *Linderina* and *Coskinolina*.

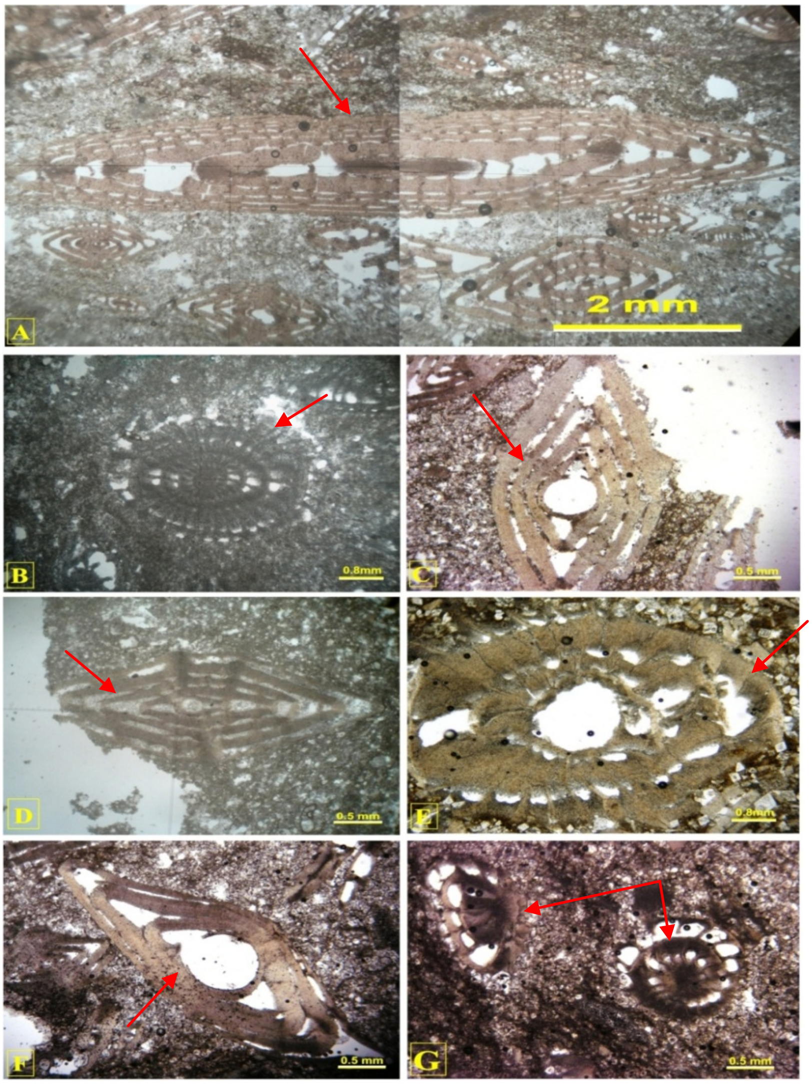

Fig.21: **A)** *Nummulites gizehensis zeitteli* DE LA HARPE, **B)** *Nummulites discorbinus* (SCHLOTHEIM), **C)** *Nummulites perforatus* (MONTFORT), **D)** *Nummulite s elevate* (AL- HASHIMI- AND AMER), **E)** *Nummulites bayhariensis* CHECCHIA- RISPOLI, **F)** *Nummulites millecaput* BOUBEE, **G)** *Nummulites planulatus* (LAMARCK)

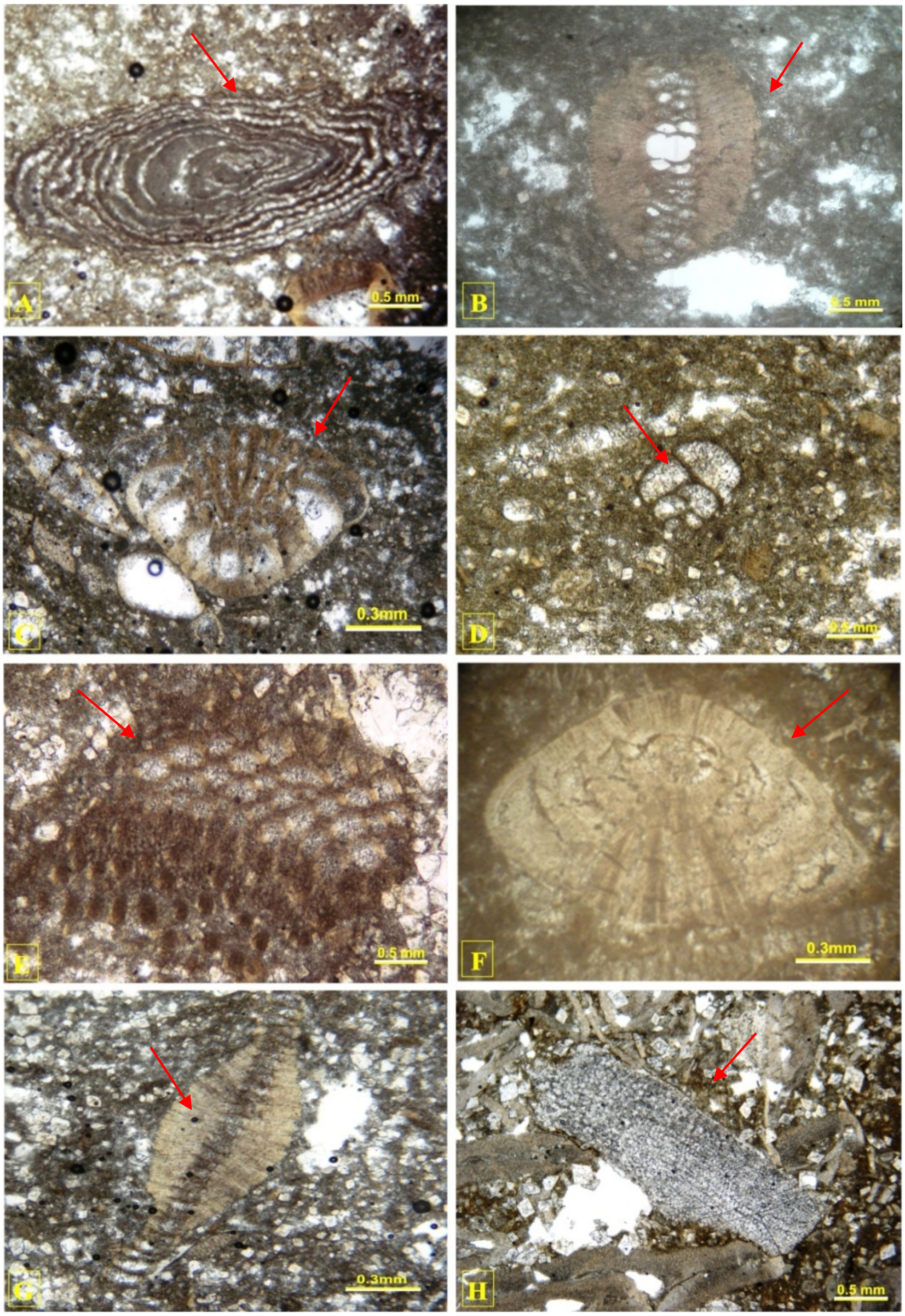

Fig.22: **A)** *Alveolina* D'ORBIGNY, **B)** *Linderina chapmani* HALKYARD, **C)** *Lockhartia alveolata SILVESTRI*, **D)** *Textularia sp.*, **E)** *Coskinolina* sp., **F)** *Rotalia trochideformis*, **G)** *Linderina brugesi* SCHLUMBERGER H) Echinoid plate

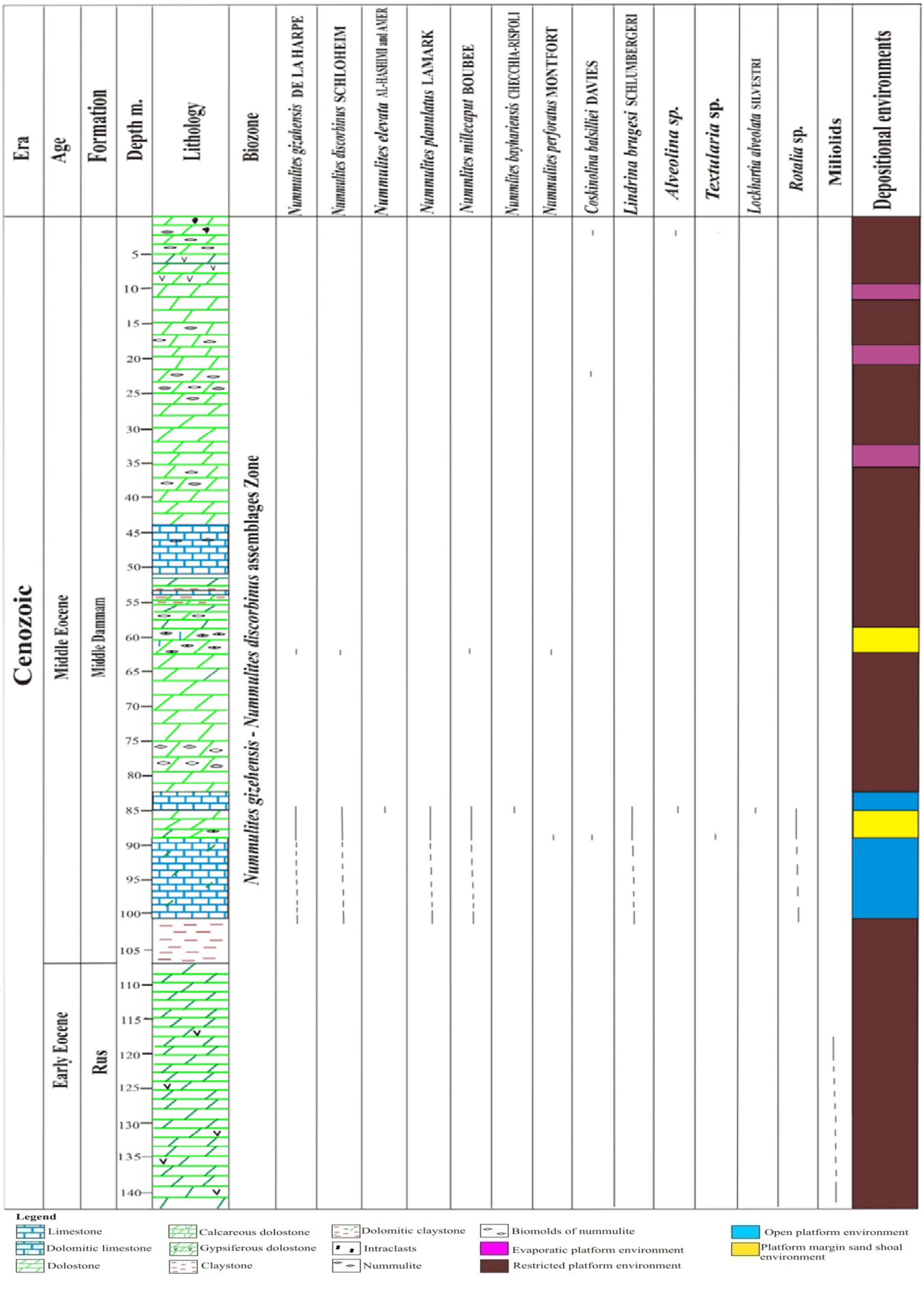

Fig.23: Vertical distribution of fossils and biozone of Rus and Dammam Formations

DEPOSITIONAL ENVIRONMENT

Depending on the description of microfacies, four major environments can be recognized within the formations of the studied subsurface section including marine evaporitic lagoons, restricted-marine platform, open platform interior and platform marginal sand shoal environment. The features of these depositional sites and their sediments are summarized below and as illustrated in figure (24) according to Flugel (2004).

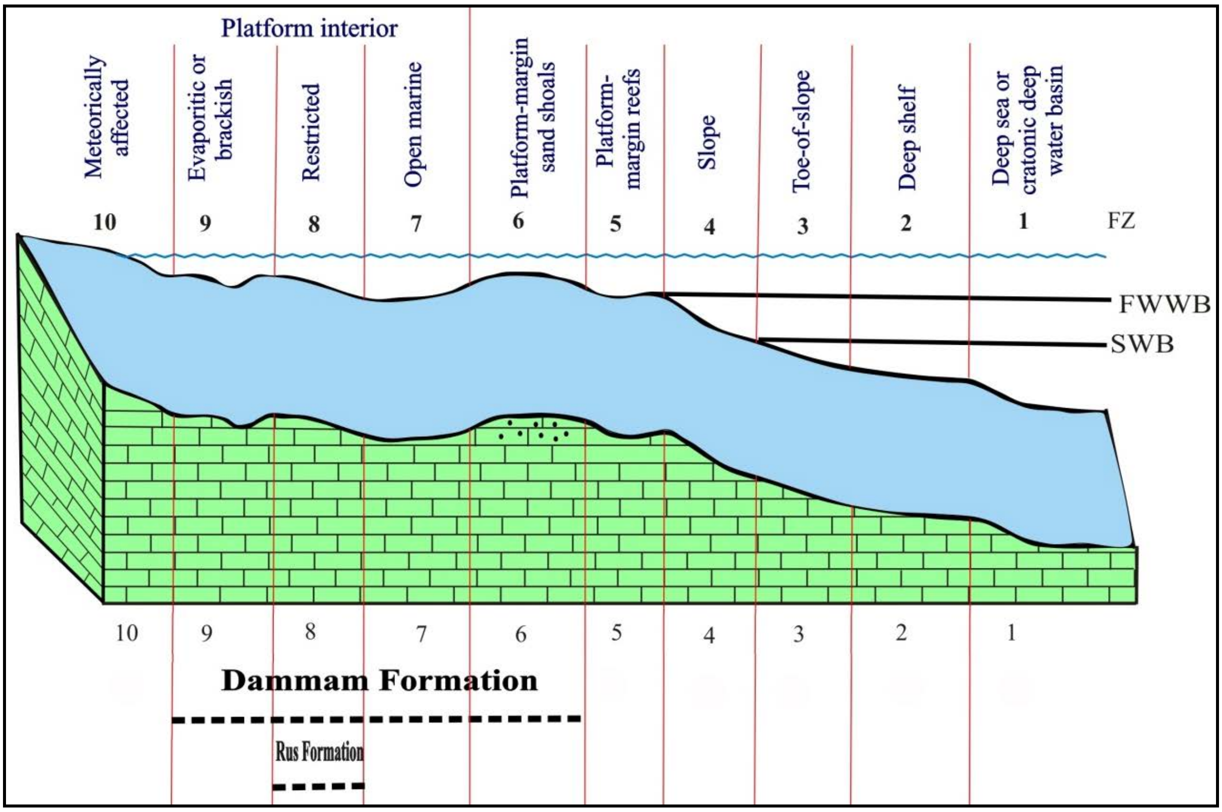

Fig.24: Depositional environments of the carbonate rocks of Rus and Dammam Formations according to Flugel (2004)

- **Rus Formation**

Only one environment is recognized in the studied borehole. It is:

─ Restricted platform interior environment, indicated by the presence of gypsiferous bioclastic miliolidic dolowackestone microfacies and fine crystalline dolostone lithotype.

- **Dammam Formation**

Four environments are distinguished in the studied borehole. These are:

─ Evaporatic platform interior environment**,** characterized by the presence of dolomudstone. This microfacies is also characterized by restricted marine platform.

─ Restricted platform interior environment is indicated by presence of biomoldic dolomudstone, intraclastic dolomudstone and gypsiferous intraclastic dolomudstone, biomoldic dolowackestone, intraclastic dolowackestone, claystone and dolomitic claystone lithofacies.

─ Open platform interior environment, indicated by the presence of nummulitic bioclastic floatstone and dolomitic bioclastic nummulitic floatstone submicrofacies including diverse fossils of *Nummulites bayhariensis*, *Nummulites gizehensis*, *Linderina* sp., *Rotalia* sp., *Coskinolina* sp., *Rhapydionina* sp., *peneroplis* sp., echinoderm plates, algae, uniserial forams and shell fragments.

– Platform margin sand shoals environments, characterized by the presence of abundant large types of foraminifera (*Nummulites gizehensis*) and other associated grains including shell fragments. Medium to coarse rhombic dolomite crystals are scattered randomly throughout the nummulites in calcareous bioclastic nummulitic dolofloatstone.

CONCLUSIONS

- Within the Rus Formation, one carbonate microfacies and one carbonate lithotype are recognized and within the Dammam Formation, three main microfacies, two lithotypes and one lithofacies have been recognized.
- Several diagenetic processes are observed in the rocks of the Eocene including dolomitization (which appears widespread), neomorphism, dedolomitization, micritization, dissolution and porosity developments, cementation, physical compaction and silicification.
- Depending on microfacies and biostratigraphy, the Rus Formation was deposited in shallow restricted environment while the Dammam Formation was deposited in different environments including evaporitic platform interior, restricted-marine platform, open interior platform and platform margin sand shoals.
- Based on biostratigraphical study, the age of Rus Formation is Early Eocene and Middle Eocene for the Middle Dammam Formation.

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