Iraqi Bulletin of Geology and Mining *Vol.15, No.1, 2019* *p 15 – 30*

FACIES MODELING AND SEQUENCE STRATIGRAPHY OF AN EOCENE CARBONATE – PHOSPHORITE RAMP: DAMLOUK MEMBER, RATGA FORMATION, WESTERN DESERT, IRAQ

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Received: 29/ 07/ 2018, Accepted: 06/ 12/ 2018
Key words: Phosphorite; Facies modeling; Sequence stratigraphy; Ramp; Western Desert; Iraq

ABSTRACT

The Eocene phosphatic Ratga Formation of the Iraqi Western Desert consists of three members from bottom: Swab, Damlouk and Mugur Members. This study is focused on the Damlouk Member which is represented by 40 – 50 meters thick sequence of alternating shelf carbonates of mollusk-nummulites association, cherty phosphatic limestone horizons and basinal chalky limestone and marlstone. This member is an important part of a thick cyclic phosphorites-bearing sequence extends from the Upper Cretaceous to the Eocene. It is the aim of this paper to shade some lights on the basic characters, origin, and stratigraphic associations, through facies modeling and sequence stratigraphic analysis. This is done by examining the Damlouk Member sequence in three localities chosen from Wadi Al-Ratga and Wadi Akash around Akashat area at the Western Desert of Iraq. The Damlouk Member is deposited over a gently sloping ramp system. Sedimentary facies in seaward direction includes: coastal plain (not well represented in the study area), Nummulite shoals limestone, and the Oyster bank limestone, of the inner ramp. The middle ramp is represented by gray bioturbated and granular limestone-phosphate horizon. This facies is occasionally, punctuated by storm-derived shelly-nummulitic limestone lenses. The intercalation of the phosphatic facies with the basinal marlstone and chalk often occur in the seaward part forming the outer ramp facies. The latter facies opened up into the basinal marlstone and chalk of the Jaddala Formation or its equivalent. Both the middle and outer ramp facies are characteristically silicified and contain dark chert nodules and horizons. The Damlouk Member consists of two sedimentary sequences deposited during the Late Ypresian to Middle Lutetian (Middle Eocene), and developed by two fourth-order eustatic cycles. This is inferred from facies sequence as well as correlation with the regional and global eustatic curves of the sea level fluctuations. Both cycles have similar facies type, distribution and stratigraphic evolution. Each of the two sequences consists of well developed TST and HST which are separated by fingers of basinal marlstone from the adjacent Jaddala representing the MFS. Each of the two sequences is bounded by Type-2 sequence boundary which is characterized by sharp facies changes.

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النموذج السحني وطباقية التتابع لمنصة الايوسين الكلسية – الفوسفاتية لعضو الدملوق، تكوين الرطگة، الصحراء الغربية، العراق

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المستخلص

يتكون تكوين الرطگة (عمر الايوسين) من ثلاث أعضاء هي من الأسفل: صواب، دملوق و مكر. يتكون عضو الدملوق من 40 – 50 متر سمكا من طبقات متعاقبة من الصخور الجيرية المتحجراتية الرفية مع صخور الحجر الجيري الفوسفاتي المتعاقبة مع طبقات حوضية جيرية وصلصالية. تهدف الدراسه الى القاء الضوء على أصل وصفات العلاقات الطباقية عبر بناء النموذج السحني وتحليل الطبقات التتابعي من خلال دراسة عضوالدملوق في وادي عكاش ووادي الرطكه في منطقة الصحراء الغربيه في العراق. ترسب عضو الدملوق فوق منحدر معتدل وبسحنات من الساحل: السهل الساحلي، ضحضاح النيوميولايت والحافه الصدفيه لاعلى المنحدر، وسحنة الحجر الجيري الفوسفاتي البني اللون والمتعكر واللذي يظم احيانا رواسب العواصف البحريه ممثلا لسحنة أوسط المنحدر. اما سحنة اسفل المنحددر فتتمثل بتعاقب طبقات الحجر الجيري الفوسفاتي مع حجر الصلصال الحوضي، هذه السحنه تنفتح بدورها نحو الرواسب الحوضية الصلصالية لتكوين الجدالة وتتميز سحنات أوسط وأسفل المنحدر بوجود العقد والطبقات الصوانية. يتالف عضو الدملوق من تتابعين رسوبيين يمثلان دورتين رسوبيتين من المرتبة الرابعة امتدت من عهد البيراسي المتأخر الى اللوتياتي الأوسط تم استنباطهما من التتابع السحني والمقارنة مع المخطط العالمي لارتفاع وانخفاظ مستوى سطح البحر. يتكون كل من هذه الدورات من وجود كامل لحزمة TST و HST، يفصل بينهما امتدادات الرواسب الحوضية لتكوين الجدالة ممثلة لسطح الفيضان البحري الأقصى MFS. كلا التتابعين محاط بحدود من نوع Type-2 نتيجة التغير السحني الحاد.

INTRODUCTION

The Cretaceous – Paleogene stratigraphic succession of the Western Desert of Iraq is an interesting sequence for two reasons; it includes the economically attractive phosphorite deposits of Iraq. The second reason and due to the stable tectonic history of the area, it displays the strong eustatic control on stratigraphy in a better resolution as compared to the sequence of the NE active plate margin of Iraq. Thus, special attention has been always given to this sequence, and this work represents part of a continuous interest into the stratigraphic development of the area.

Geological studies on the Western Desert began as early as the thirties of the past century (Buday, 1980). The detailed work of Bellen *et al.* (1959) followed by the work of Al-Naqib (1967) established the early stratigraphic subdivisions of the area. Review of the stratigraphy of the Western Desert is conducted by teams from Iraq Geological Survey. Among these studies Hagopian (1979) which subdivided the Eocene Dammam Formation at the extreme western part of the Western Desert into five lithological units (from top A'naza, Al-Tinif, Ethna, Umm Chaimin, and Nhaidian). The results of the detailed geological survey of the Upper Cretaceous – Eocene phosphorite-bearing rock units of the Western Desert have highlighted more details on the stratigraphy of the sequence (Al-Bassam *et al*., 1990). The recognition of the Ratga Formation as an independent formal rock unit in the stratigraphy of Iraq, equivalent in age to the Dammam Formation, is justified by Karim and Al-Bassam (1997). Al-Hashimi and Al-Bassam (2006) studied the mineralogy, geochemistry and depositional environment of the Early Lutetian phosphorites of the Damlouk Member in Wadi Akash area.

GEOLOGICAL SETTING

The study area is located at the northwestern part of the Iraqi Western Desert, about 80 kilometers from Al-Rutba town in the Akashat area, between Longitude 40° 00' and 40° 45' N and Latitude 34° 00' and 33° 30' E (Fig.1). The area is part of the Stable Platform of the Arabian Plate which is characterized by subdued tectonic features including the Hail-Rutba

Uplift (Buday, 1980). This uplift and the succeeding erosion exposes Paleozoic strata at a sub-circular depression called the Ga'ara Depression. Strata at the shoulder of that depression belong to the Mesozoic era followed by the Cenozoic strata. To the north and northwest of this depression, the strata are dipping gently in that direction with dry valleys such as Al-Mana, Al-Ratga, and Akash, cutting into the Paleogene strata and draining into the Euphrates Valley (Fig.1). The examined sections of the Damlouk Member are exposed along these valleys and their tributaries.

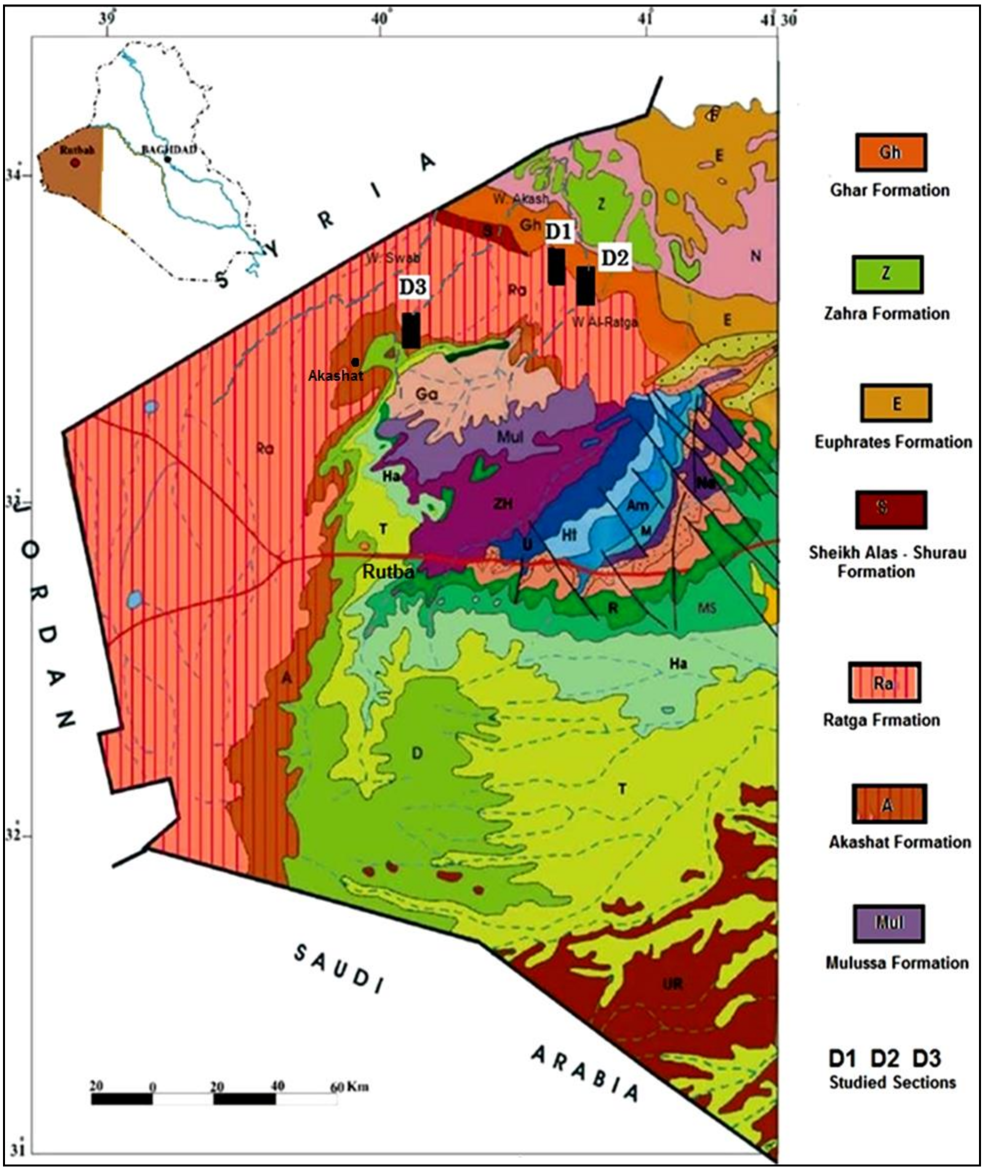

Fig.1: General geologic map of the Western Desert showing locations of the studied sections of the Damlouk Member. (Map from Sissakian and Mohammad, 2007)

The Eocene strata of the study area is considered now as part of the Ratga Formation which is introduced informally for the first time by Jassim *et al*. (1984), and Al-Bassam *et al*. (1986). Karim and Al-Bassam (1997) gave detailed and formal description of the formation and its members. The formation represents the phosphatic carbonate equivalent unit in part to the Dammam Formation of the Southern Desert (Al-Bassam, 2017). The Jaddala

Formation and partly the Aaliji Formation are its equivalent in Central Iraq. Further northeastwards, towards the northeastern margin, the basinal facies is replaced by the platform carbonates of the Pila Spi Formation (Fig.2).

The Ratga Formation of Lower – Upper Eocene age is widely distributed in the Western Desert with thickness ranges between 200 – 220 m. The Formation consists mainly of nummulitic limestone, phosphatic limestone, crystalline limestone with chert horizons and nodules. The Lower boundary is conformable with the Paleocene Akashat Formation. The upper boundary is also conformable with the Sheikh Alas/ Shurau Formations of Lower Oligocene (Karim and Al-Bassam, 1997). It is subdivided into three lithologic members from bottom: Swab, Damlouk, and Mugur Members. These members display cyclic alternations of similar lithologic association. Each cycle consists of two distinctive lithologic parts. The lower is of deep marine and consists of phosphatic limestone, and occasionally phosphorite, basinal marlstone, and chalky limestone (Fig.3). The upper part commonly consists of nummulitic limestone and/ or shelly bioclastic limestone. The Damlouk Member is usually recognized with two distinctive cycles oftenly called Damlouk (A) and Damlouk (B). The type locality of the Damlouk Member is selected from Wadi Akash for Damlouk (A) (28 m), and Wadi Halgum for Damlouk (B) (52 m) (Jassim *et al*., 1984; Al-Bassam *et al*., 1986; and Karim and Al-Bassam, 1997).

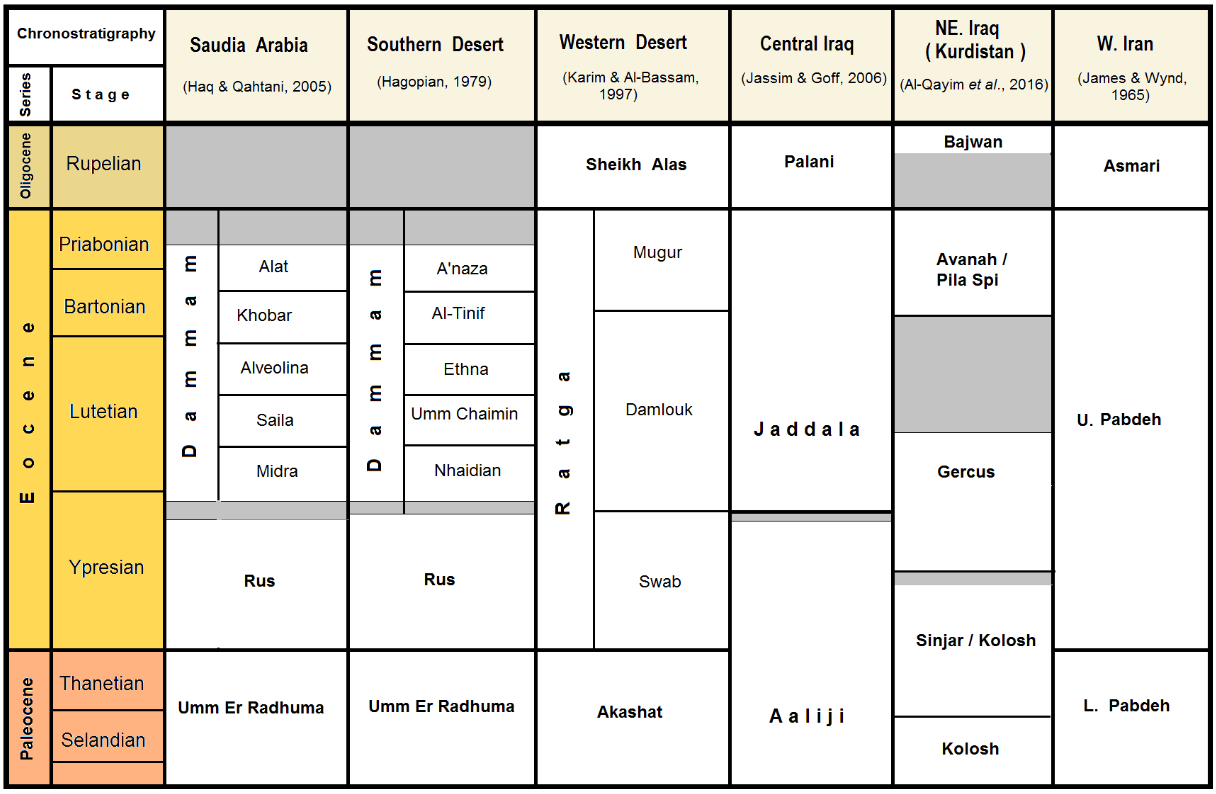

Fig.2: Stratigraphic chart of the Eocene stratigraphic units of the Western Desert and its equivalents. (Compiled from different sources)

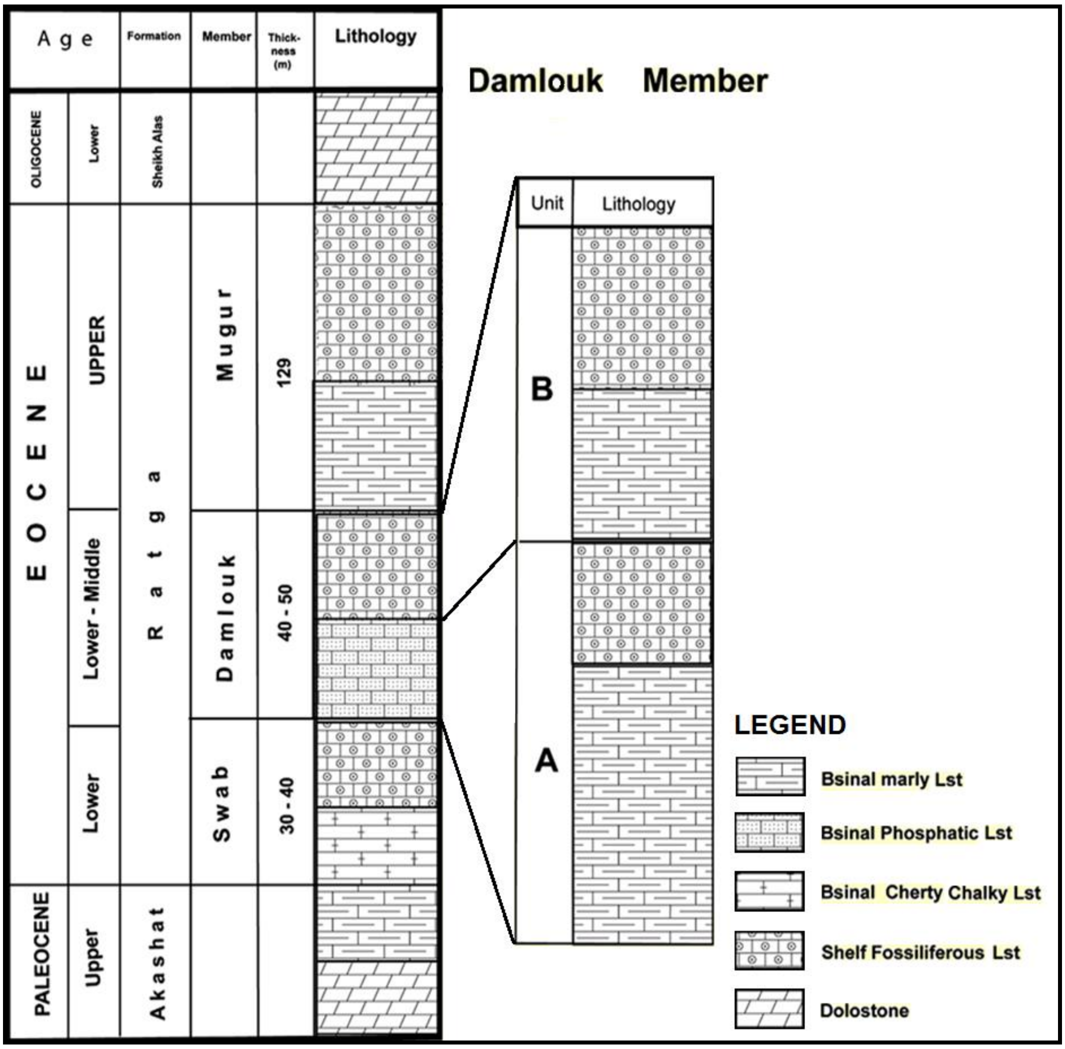

Fig.3: Stratigraphic column of Ratga Formation, showing lithologies of its members. (Compiled from Jassim *et al*., 1984; Al-Bassam *et al*., 1986 and Karim and Al-Bassam, 1997)

MATERIAL AND METHODS

In this study, three sections are selected for the study of the Damlouk Member, which are: D1 (at 60 Km NE Akashat), D2 (at 65 Km NE Akashat), and D3 (at 20 Km NE Akashat) (Fig.1). Field observations, such as measuring and description, as well as systematic sampling have been done in all sections. Sixty samples are collected from the different lithologies of each locality. The collected samples are examined under polarizing microscopes to identify petrographic components and microfacies types. Alkaline Alizarin red S staining method is used to differentiate carbonate minerals following Friedman (1959). Naming of microfacies is conducted after Wilson (1975) and Flugel (2010) standard microfacies system and following Dunham (1962) classification scheme. The microfacies are recognized and described following the presentation of Al-Qayim *et al*. (1988). Facies interpretation and modeling is attempted using field observation supported by microfacies identification and distribution. Sequence stratigraphic analysis is done following the guidelines of Emery and Myers (1996) and Catuneanu (2006) approach. Interpreted cycles are correlated with global third and fourth order cycles of Haq *et al*., chart of (1987), and regional eustatic cycles of the Arabian Platform as suggested by Haq and Al-Qahtani (2005).

RESULTS

- **Lithostratigraphy of the Studied Sections**

The three examined sections (D1, D2 and D3) displayed similar lithologic characters and association with variable thicknesses. These sections have 54, 34, and 32 meters thicknesses consequently (Fig.4). Both Damlouk Units (A) and (B) are represented at the three sections but with variable components and proportions.

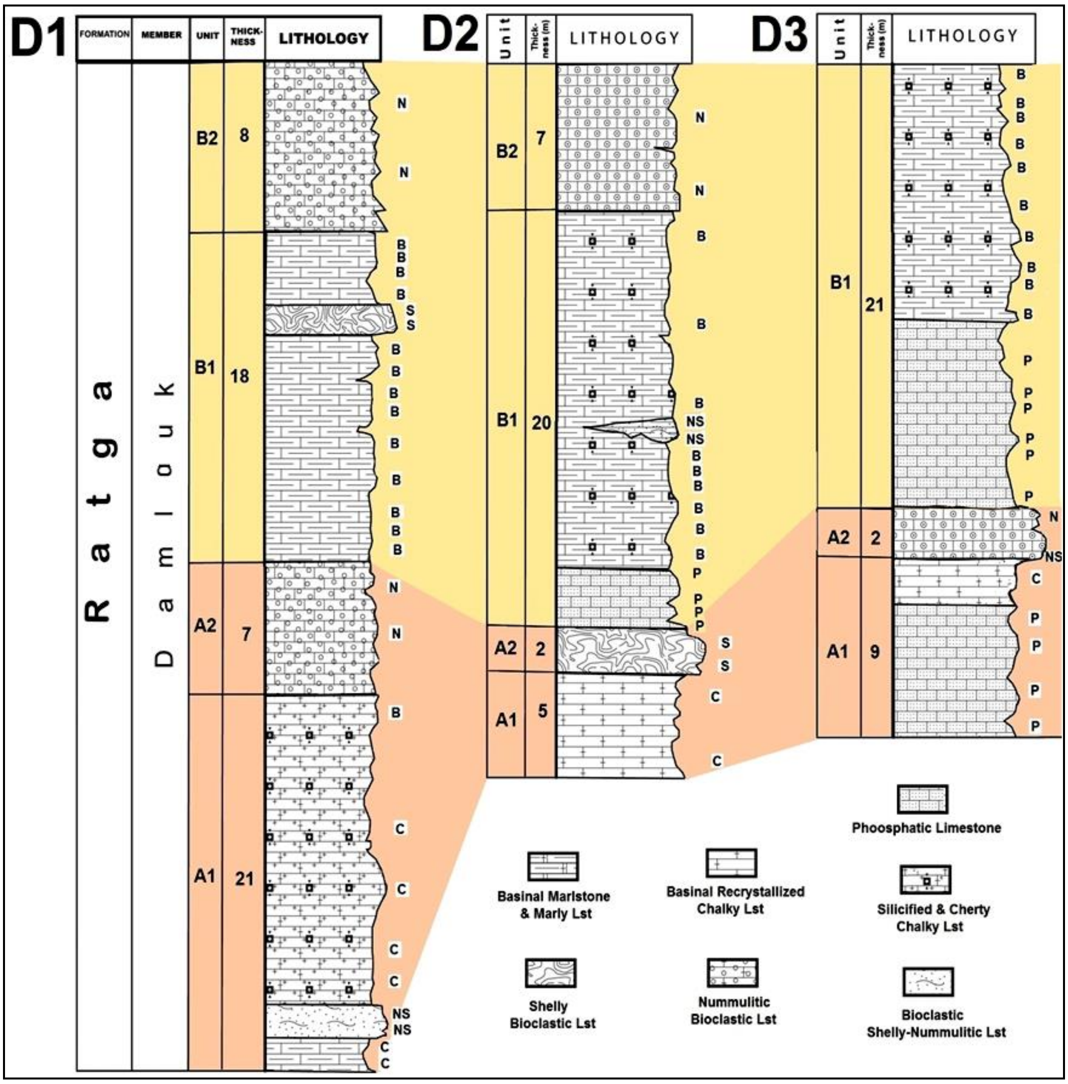

Fig.4: Stratigraphic columns of the studied sections of Damlouk Member showing lithologic variation and distribution of microfacies types (S, NS, P, B, N and C are microfacies notations; for nomenclature and description see text)

– **Lower Damlouk Sequence (Damlouk A):** This unit represents the lower cycle of the Damlouk Member. Based on lithology and sedimentary environment, it has two subunits (A1) which represents the deep marine part and (A2) for the shallow marine part.

- **Damlouk (A1) Unit:** This subunit is recognized from the three sections but with variable thicknesses (Fig.4). The lower part of this unit is represented by the granular, relatively soft phosphatic limestone horizon as in section (D3) (Fig.4 and 5a). It is occasionally punctuated by local lenses of bioclastic shelly limestone followed by deep marine basinal marly limestone or silicified white recrystallized chalky limestone as in section (D1). Not all these lithologies are recognized in the other examined sections such as (D2) and (D3).

- **Damlouk (A2) Unit:** This unit represents the shallow marine facies of the Damlouk lower cycle. It is recognized in section D1 and D3 by a hard well cemented limestone horizon rich in nummulites of *Nummulite gizehensis* ssp. At the bottom of these horizons, gastropods and pelecpods are concentrated in a characteristic association and often display extensive silicification as in section (D2 and D3). In section (D1) the horizon about 7 meters thick and characterized by white nummulitic limestone with concentration of shells of mollusks in a silicified matrix (Figs.4; 5a, 5b and 5c).

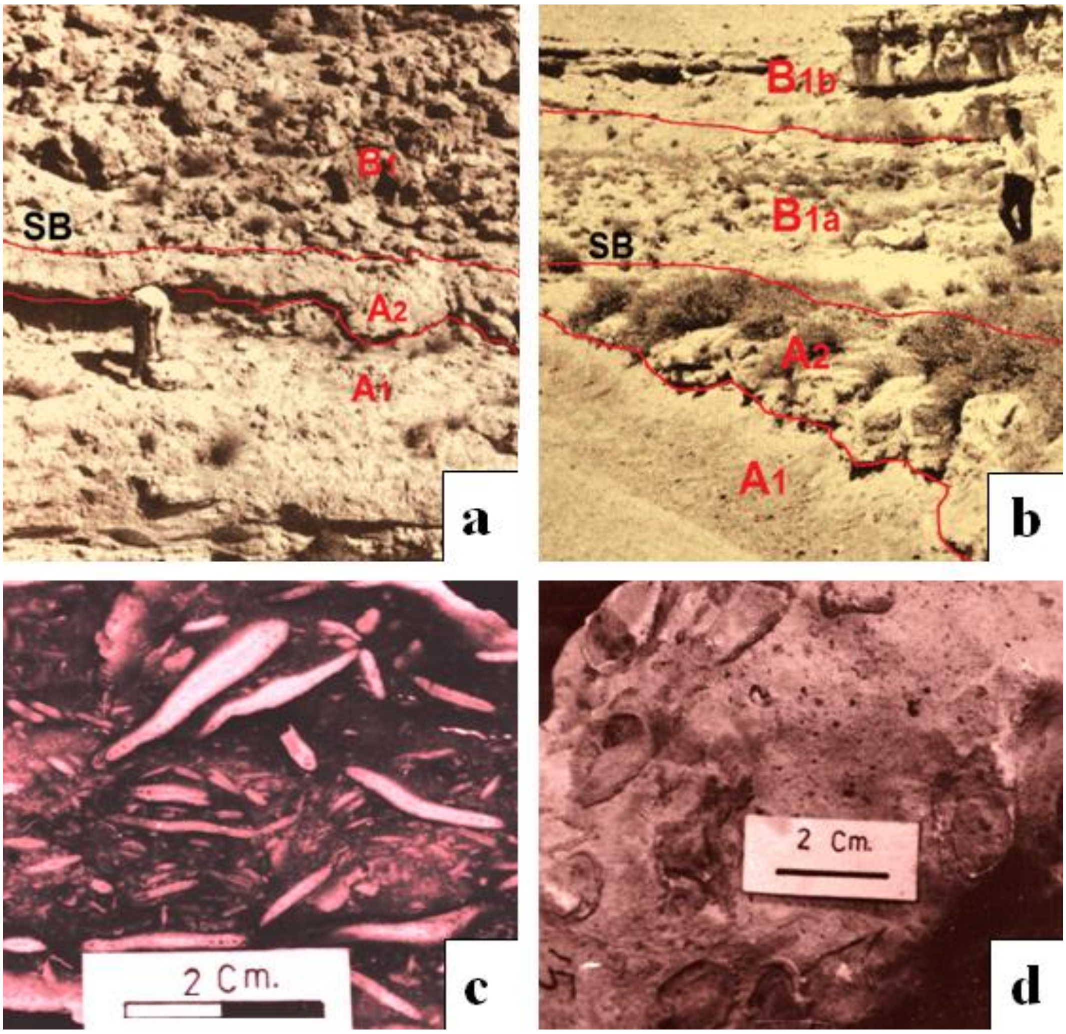

Fig.5: **a)** Field photo of section (D3) showing succession of Unit (A1) the phosphatic limestone with upper part showing cavernous vuggy chalky limestone, unit (A2) as a protruding ledge of nummulitic limestone of the Lower Damlouk cycle. The Upper Damlouk Cycle (B) is represented here by the lower part of unit (B1) the phosphatic Limestone. **b)** Another view of section D3 showing the succession of the different units. (B1a) is the lower part of (B1) the soft granular phosphatic limestone, and (B1b) represents the thick cavernous recrystallized chalky limestone. **c)** Well preserved nummulites in a chert nodule. **d)** Dense accumulation of Oyster shells forming hard shelly limestone, from section D1

– **Upper Damlouk Sequence (Damlouk B):** This unit represents the Upper Damlouk Cycle with thicker sequence (Fig.4). The two subunits (B1) and (B2) are recognized from section (D1) and (D2), however at section (D3) the upper shallow marine subunit (B2) is missing (Fig.4).

- **Damlouk (B1) Unit:** This unit is characterized by the occurrence of grey, soft, bioturbated, and phosphatic limestone (Fig.4). This layer is followed by fairly thick white recrystallized chalky limestone with thin chert beds or nodules layers as in section (D2) and (D3). At section (D1) this subunit is characterized by a thick section (18 m) of light grey relatively soft marly limestone and marlstone horizon. It is occasionally silicified, bioturbated, recrystallized. This unit occasionally includes local lenses of bioclastic shells of oysters as in section (D1) and (D2) (Fig.5d). The lower boundary of this unit is a sequence boundary of SB2 type which shows sharp lithologic contrast with no evidence of erosion (Figs.5a and 5b).

- **Damlouk (B2) Unit:** The shallow marine carbonate of the Upper Damlouk Cycle (B) is missing in section (D3) and well exposed in section (D1) and (D2) (Fig.4). It is characterized by white, hard, cliff-forming horizon of up to 8 meters thick nummulitic limestone. It is characterized by dense occurrence of large nummulites of *Nummulites gizehensis gizehensis.* At all the examined sections this unit has no overlaying unit and in section (D3) it is completely missing which suggest a possible occurrence of Type 1 sequence boundary with the overlaying Mugur Member.

▪ **Microfacies**

– **Nummulitic *Grainstone – Packstone (N)*:** It is characterized by dense occurrence of Nummulites including; *N. gizehensis gizehenses, N. discorbinus, N.beaument, in addition to N. planatus, N. globulus* and their fragments. These large foraminifera often recognized in dense accumulation and embedded in a partly recrystallized micritic matrix (Fig.6a). This microfacies are commonly associated with the nummulitic limestone horizons of both Damlouk units (Fig.4).

– ***Shelly Packstone to Wackestone (S)*:** This microfacies is characterized by the occurrence of whole shells of pelecypods and gastropods often embedded in a lime mud matrix (Fig.6b). Shells sometimes are fragmented forming bioclastic shelly microfacies ***(Sb)***. Pelecypods are common and in some cases dominated by dense occurrence of large *Oysters* ***(So)*** or dwarf *Nuculana* shells ***(Sn)***. This microfacies characterizes the shelly or Oyster beds recognized from the three sections (Fig.4).

– ***Nummulitic Shelly Bioclastoic Packstone (N – S)*:** Mixed Nummulites and shells and their fragments are the common components of this microfacies (Fig.6c). Other benthonic foraminifera are noticed, and all embedded in a bioclastic micritic matrix. This microfacies is commonly associated with both the shelly limestone and the nummulitic limestone horizons in addition to lenses of shelly nummulitic limestone within the basinal limestone facies of the Damlouk Member (Fig.4).

– ***Phosphatic Packstone to Wackestone (P)*:** This microfacies is associated with samples have phosphatic grains of different kinds and origin. The common type of phosphatic grains are oolites ***(Po)*** in addition to peloides, bone fragments, and phosphatic intraclasts. Matrix either lime mud or phosphatic mud (Fig.5d). In some cases, phosphatic grains are associated with bioclasts of different mollusk ***(Pb)***. This with the good sorting and sparry calcite cement indicates active agitation (Fig.6e). This microfacies is associated with the phosphatic horizons of the Damlouk Member (Fig.4).

– ***Basinal Foraminiferal Lime Wackestone (B)*:** Planktonic foraminifera including species of Globigerina, and Globorotalia in a bioclastic argillaceous lime mud are the characteristic features of this microfacies (Fig.6f). Other components includes silt-size fragments of plnktonic and benthonic foraminifera such as Bolivina, Bulimina, and Nodosaria (Al-Qayim *et al*., 1988). It is often associated with the basinal marly limestone horizons of both units (Damlouk A and B).

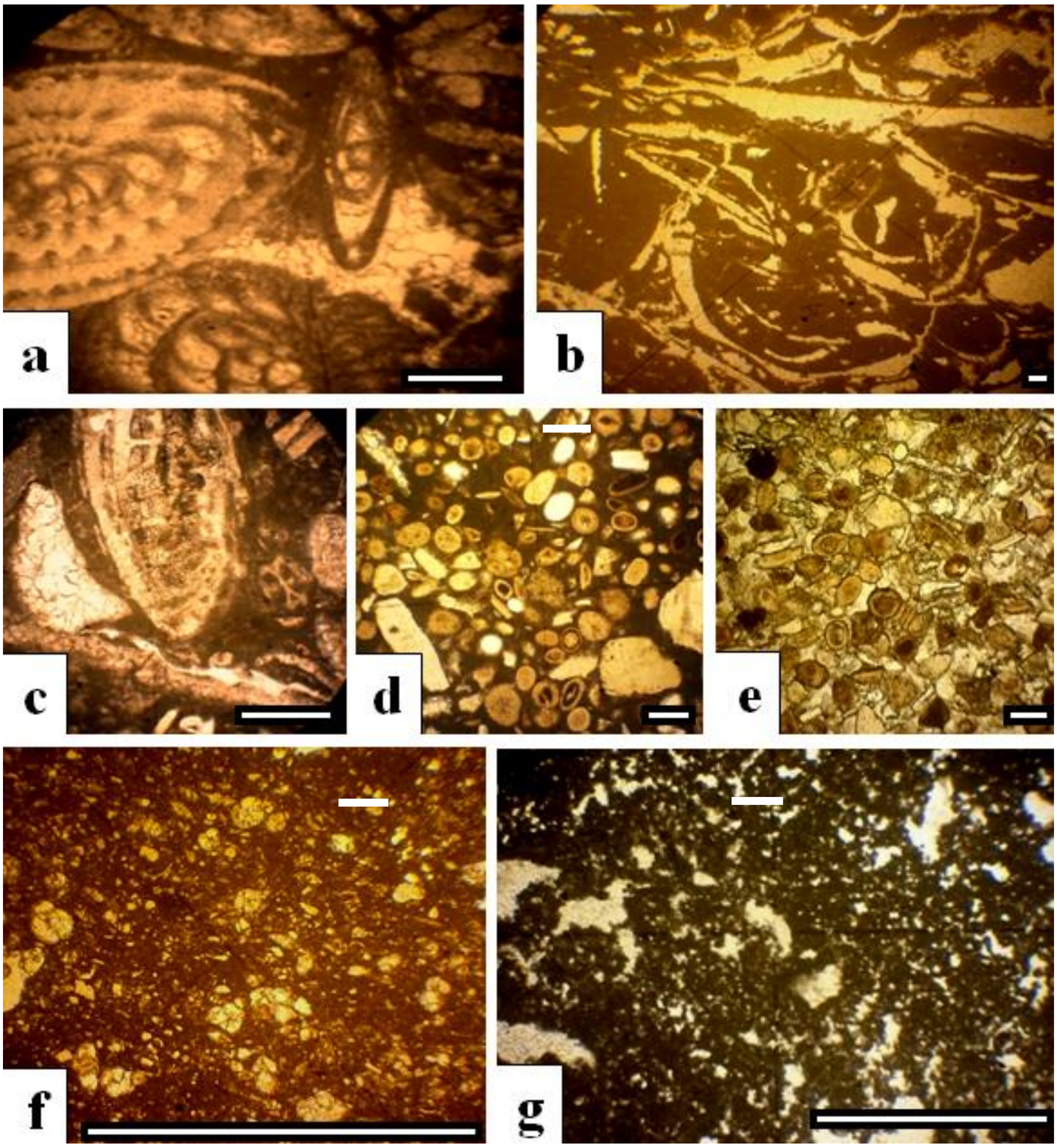

Fig.6: **a)** Nummulitic grainstone microfacies, section D_3, unit A_2. **b)** Shelly packstone microfacies of section D_3, unit A_2. **c)** Bioclasts of Nummulites and shells mixed together, section D_2, unit B_1. **d)** Oo-phosphatic packstone microfacies, section D_2, unit B_1. **e)** Oo-phosphatic grains and shell bioclasts of the phosphatic bioclastic microfacies, section D_3, unit B_1. **f)** Planktonic foraminiferain bioclastic matrix of the basinal lime wackestone, section D_3, unit B_1. **g)** Fenestral porosity of the crystalline chalky limestone microfacies, section D_2, unit A_1. (Bar is one mm long)

– ***Crystalline Chalky Limestone (C)*****:** It represents the white, porous, crystalline chalky limestone horizons (Fig.6g). coarse calcite crystals and fenestral porosity is the common type. This microfacies is seemingly influenced by diagenetic effect which is reflected on the variability of crystal size, different colorations (commonly red), and strong association with silicification. Secondary silica affect both matrix and grains and occur as partial silicification, chert nodules, and irregular thin cherty horizons. The effect of silicification went beyond this microfacies into other facies including the shallow marine nummulitic limestone (Fig.5c). This microfacies is recognized from the three studied sections.

- **Facies Modeling**

Identifying microfacies of each examined sample with their distribution within each studied section (Fig.4), in addition to correlation of lithologic associations among the studied sections help identifying sedimentary facies. Correlation of facies distribution and succession with similar phosphatic-carbonate setting from Egypt (Ahmed *et al*., 2014; and Hegab *et al*., 2016) suggests that the Damlouk Member sequence is deposited over a gently sloping ramp (Al-Bassam, 2017). Sedimentary facies model of a ramp is suggested by Ahr (1973) and detailed review of its sedimentary facies is given by Burchette and Wright (1992); and Wright and Burchette (1998).

This model seems to best fit the facies type and succession in the studied region (Fig.7). The **inner ramp** system is controlled by a belt of **oyster banks** and the associated shell bioclasts facies. This bank develops fore bank nummulitic shoal facies seawards, which is represented by the nummulitic limestone, and a back-bank foramol lagoonal facies. The latter is poorly represented in the study area. The middle ramp system is well developed within the studied sections (Fig.7). This part consists of two basic facies: The proximal bioturbated **phosphatic limestone** and the distal **bioclastic middle ramp facies** of the white chalky limestone. The latter is highly recrystallized and silicified to an extent where the original fabric is rarely preserved. Occasionally, these two units are punctuated with lenses of shelly-nummulitic limestone representing a ***storm shelly facies***. The outer ramp on the other hand represents the deep marine facies of the sequence and it consists of the ***basinal marlstone and marly limestone*** which is characteristically includes planktonic foraminifera and fine-grained bioclasts. This facies is often represents an offshoot of the basinal sediments of the Jaddala Formation. The vertical succession of the recognized facies at each section is shown in Figure (8).

- **Sequence Stratigraphy**

Facies type, succession, and vertical association are used to construct the sequence stratigraphic framework of each of the studied section. The procedures followed standard steps for identification of sequence boundaries (SB), transgressive surfaces (TS) and maximum flooding surfaces (MFS). The recognition of the different types of system tracks is made according to that demonstrated by Emery and Myers (1996), Catuneanu (2006) and Catuneanu *et al*. (2011).

Both cycles of the Damlouk Member have similar sequence architecture and thus repeated itself in similar fashion. Most of the cycles are incomplete, and each began with slow transgression followed by abrupt regression (Al-Bassam, 1992). Because of the position of the selected sections at a relatively at marginal part of the shelf area, the Low Stand System Tract (LST) is not well recognized. Similarly, sequence boundary of type one (SB1) was hard to find within the study area, and if any it must be located towards the southwest within the inner ramp part. Al-Bassam (1992) recognizes such type of boundaries (SB1), i.e. hardgrounds and omission surfaces within the shallower parts of the inner ramp domain.

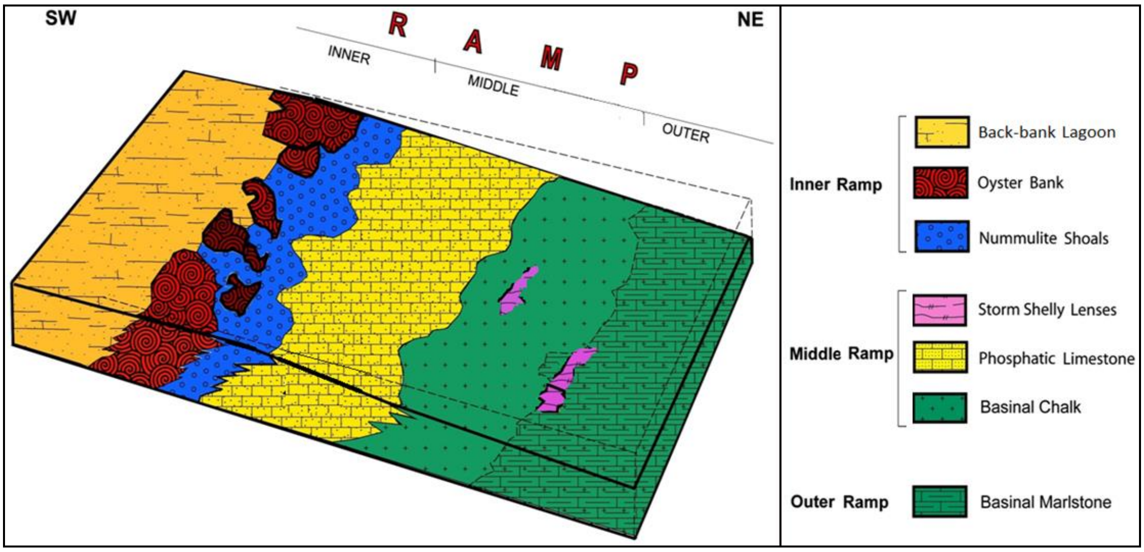

Fig.7: Facies model for the cyclic deposits of the Eocene, Damlouk Member of the Western Desert

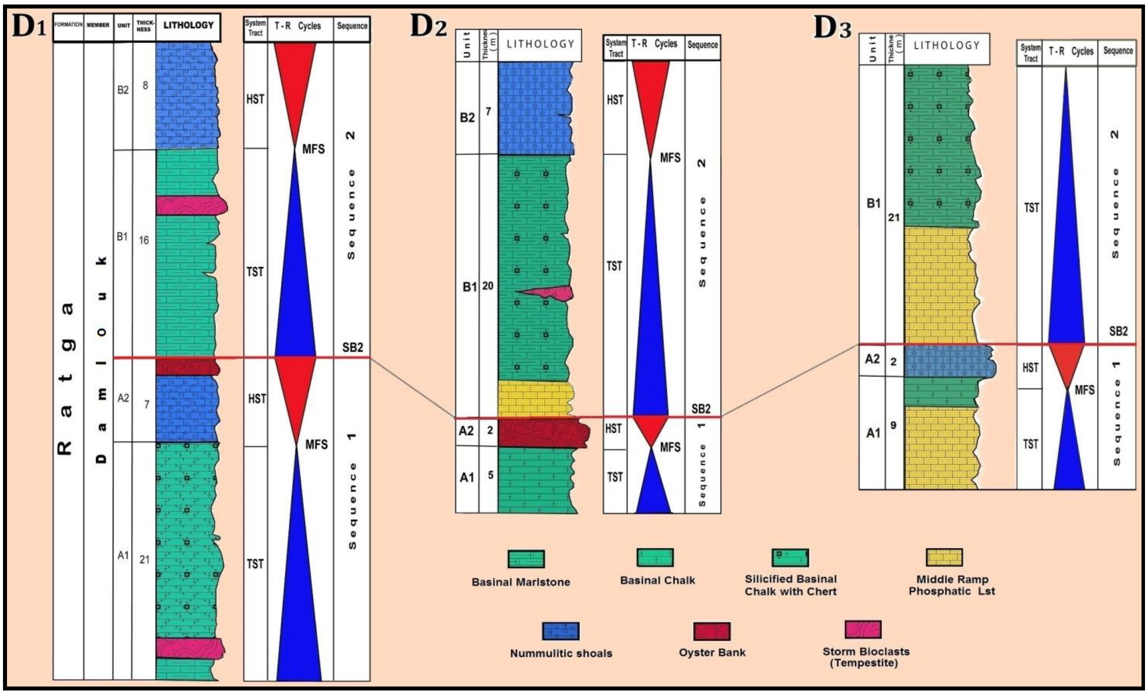

Fig.8: Facies type and distribution, and the sequence stratigraphic framework of the examined sections of the Damlouk Member of the Western Desert

The sequence of each cycle in the study area often recognized with a Transgressive System Tract (TST) at the bottom, which represents unit (A1, B1) in both cycles and consists of two parts. The lower and early TST part if exist is represented by the middle ramp deposits of phosphatic limestone and or phosphorite horizons. Phosphatic strata are related to mostly in situ concretions developed within transgressive and to reworked and winnowed lags associated with transgressive surfaces (Scasso and Castro, 1999). Phosphatic rock types depending on concentration of the phosphorous and/ or the phosphatic organic material within the deep marine upwelling currents (Al-Bassam, 1992). This part is recognized only from section (D1) and is missing from the other section. The Late TST part is of outer ramp facies and characteristically consists of basinal, globigerinal marlstone and marly limestone. This part exists in the three examimed sections (D1, D2, D3). Occasional lenses of accumulated nummulites and fragmented mollllusc shells are recognized within the TST indicating tempestite deposits of the middle ramp (Fig.8). Maximum Flooding Surfaces (MFS) are located within the upper part of the TST and represented by marlstone horizons rich in planktonic foraminifera. These horizons are considered as the maximum shoreward extension of the basinal Jaddala Formation fingers into the middle and inner ramp environment.

The following High Stand System tract (HST) is often thinner and rich in fossiliferous limestone. It consists of the Oyster shelly bank limestone followed by the fore-bank shoals of the nummulitic limestone. In some case both facies are recognized one section over each other in an aggradational stacking pattern as in section (D1), Unit (A2). In other cases either one can be recognized in one section reflecting progradational stacking pattern as in section (D1) Unit (B2) , section (D2) Unit (A2, B2) and section (D3), Unit (A2). The upper boundary of Member (B) (cycle 2) is often considered conformable with the overlaying cycle of the Mugur Member (Karim and Al-Bassam, 1997). However, Al-Bassam (1992) suggests that hardground surfaces were recognized in between the two members at a near-shore localities, might suggests a break in sedimentation between the two cycles.

Correlating the Damlouk cycles with the global eustatic curve of Haq *et al*., 1987), and the regional eustatic curve of the Arabian Platform of Haq and Al-Qahtani (2005) reveal interesting matching. Each of the two cycles of the Damlouk Member represents a fourth-order cycle, and both extend in age from Late Ypresian to the Late Lutetian in age (Fig.9).

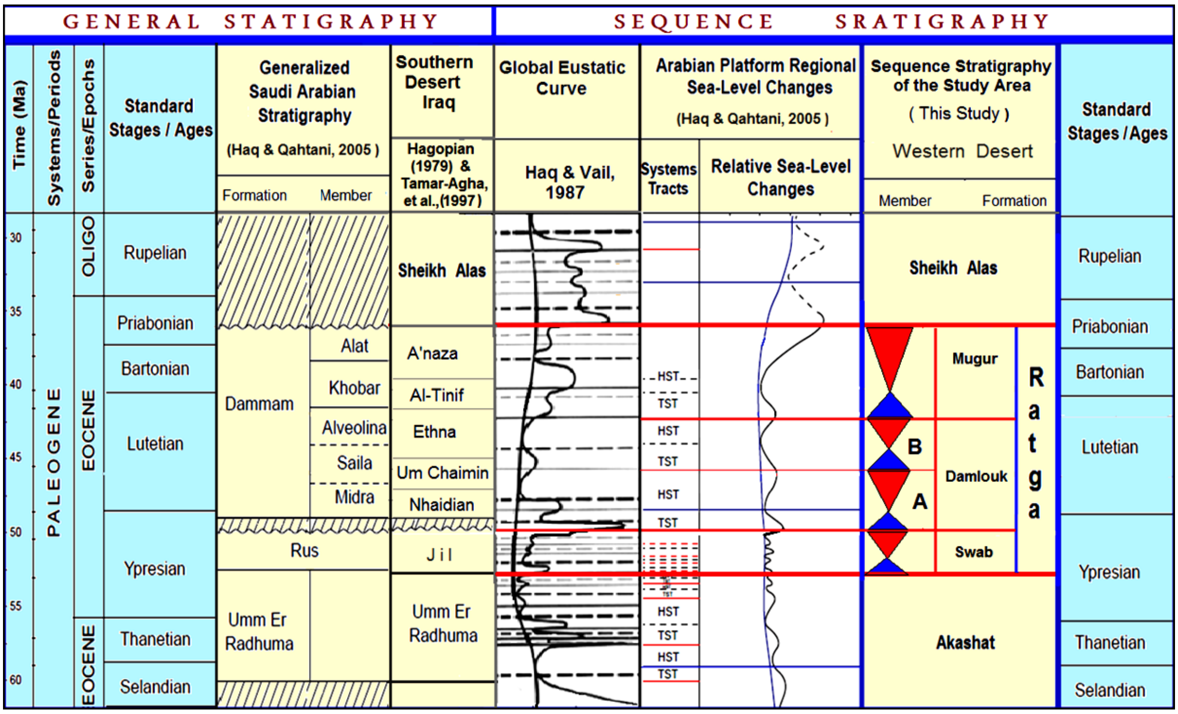

Fig.9: Stratigraphic chart and sequence stratigraphic analysis of the Eocene strata of the Western Desert of Iraq. (Sources of stratigraphic data are indicated)

DISCUSSION

The sequence stratigraphic subdivision of the Eocene strata of the Arabian Platform is discussed by Sharland *et al*. (2001) and Haq and Al-Qahtani (2005). They show that the Eocene in the Iraqi Southern Desert and in Saudi Arabia includes both Dammam and Rus formations. The Dammam Formation consists of five stratigraphic units: Mirda, Saila, Alveolina, Khobar, and Alat. These units corresponds to the five units of the Dammam Formation proposed by Hagopian (1979) and includes: Nhaidian, Um Chaimin, Ethna, Al-Tinif and A'naza (Fig.9). These five units, in addition to the Rus Formation sequence are well correlated with six fourth-order cycles of Haq and Al-Qahtani (2005). However the new classification of the Eocene stratigraphy for the Western Desert (Karim and Al-Bassam, 1997) suggests that the sequence is represented by the Eocene Ratga Formation, which includes three members. Using the sequence stratigraphic analysis of this study, these members represents three third-order cycles following the global eustatic curve of Haq *et al*., 1987).

These cycles from bottom: the Swab Member (equivalent to the Rus or Jil Formation) of Middle to Late Ypresian, the Damlouk Member Late Ypresian – middle Late Lutetian, and the Mugur Member cycle of Late Lutetian – Early Priabonian (Fig.9). Based on these results, the age of the Ratga Formation is considered to extend from Middle Ypresian to Early Priabonian. Karim and Al-Kubaysi (2014) reports the occurrence of the Ratga Formation in subsurface wells nearby Nassyria. The formation here is intercalated with the carbonate rocks of the Dammam Formation. They found that the Damlouk Member is of Lutetian age.

However the Swab cycle seems to be individualized from the rest of the Eocene cycles. This cycle, which is well developed in the Western Desert, is correlated with the Rus Formation in Saudia Arabia (Haq and Al-Qahtani, 2005) and Basrah area of south Iraq (Bellen *et al.,* 1959) and by the Jil Formation at southwestern desert of Iraq (Tamar-Agha *et al.*, 1997). The upper boundary of this cycle is characterized by a major sea level drop on the eustatic curves (Fig.9). This boundary is marked by an unconformity relation with the rest of the overlaying sequence of the Eocene (Bellen, 1956; Bellen, *et al*., 1959; Tamar-Agha *et al*., 1997; Haq and Al-Qahtani, 2005; and Jassim and Goff, 2006). However in the Western Desert (the study area) this unconformity surface is not reported and may be overlooked by this and other previous studies. If this Late Ypressian major regression and unconformity is proven at the Western Desert area then, the Swab Member must belong to an older secondorder cycle (Paleocene – Early Eocene) rather than the rest of the Ratga Formation (Middle – Upper Eocene). The equivalent basinal unit of the Swab Member (Ypresian), therefore, belongs to the upper part of the Aaliji Formation, and the lagoonal equivalent would be the Jil Formation on the other side (Fig.10).

After the late Ypresian unconformity, a major transgression developed over most of central and west Iraq (Bellen, 1956 and Bellen *et al*., 1959), whereby, another second-order cycle (Lutetian – Priabonian) was developed within the (AP10) sequence of Sharland *et al.* (2001). This cycle represents the "remnant foreland" seaway (Ziegler, 2001) of an elongate, asymmetrical and dynamically fluctuated basin (Alavi, 2004). The basinal sediments of this cycle (the Jaddala Formation) were deposited in an open sea conditions. Towards the southwestern margin of the basin, the open sea conditions changed into a gently sloping ramp setting at which the Damlouk and Mugur Members were deposited. Further southwestwards, an extensive back-ramp lagoon is developed with lagoonal limestone of the Dammam Formation.

The Ramp sediments include phosphatic horizons with different (P) concentrations. These phosphates often developed at the bottom of the TST of each marine cycle in the area in an onlapping retrogradational stacking during early transgression stage. The Upper Cretaceous – Eocene section of the Western Desert includes around 20 cycles of this kind (Al-Bassam, 1992). Therefore, this association of the phosphatic sediments with the lower part of the TST of each cycle can be used as important tool to predict stratigraphic distribution of the phosphates, if sequence stratigraphic analysis applied to the whole section. This will enhance exploration strategy for this valuable resource.

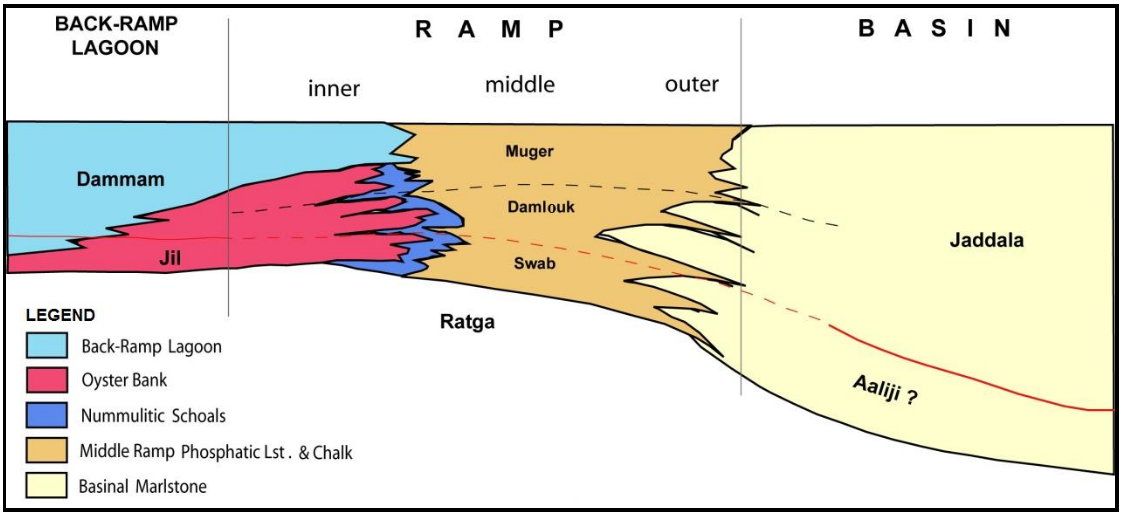

Fig.10: Schematic stratigraphic cross section showing depositional setting of the Eocene in part of the Western Desert, Iraq

CONCLUSIONS

- The Damlouk Member represents the middle part of the Ratga Formation, which is deposited in a cyclic phosphate-carbonate ramp setting.
- Inferred sedimentary facies includes:
  - Nummulitic Shoal, Oyster Shelly Bank, Coastal Lagoon (Inner Ramp),
  - Phosphatic Limestone and Storm Shelly lenses (Middle Ramp),
  - Basinal Marlstone and Basinal Chalk (Outer Ramp)
- Sequence Stratigraphic Analysis reveals that:
  - The Damlouk Member is a third-order cycle, includes two fourth order cycles: the Damlouk (A) and Damlouk (B).
  - Each of these cycles consists of a deep marine (TST), and shallow marine (HST) separated by a (MFS) marked by the marine marlstone of the Jaddala fingers.
  - Correlation with global and regional eustatic SL curves, shows that the Damlouk Member is of late Ypresian to late Lutetian age.
  - An important unconformity surface (SB1 Type) at late Ypresian separates the Swab Member from the rest of the Ratga Formation, and implying the occurrence of two different 2^{nd} order cycles for the Eocene of the area.
  - The association of the phosphatic deposits with the lower part of the (TST) provides important predictive tool for future survey and exploration strategy.

ACKNOWLEDGMENTS

The authors would like to thank Iraqi Geological Survey (GEOSURV-IRAQ) for assistance in field work and samples collection.

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